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THE ELECTRIC-LAMP INDUSTRY:

Technological Change and Economic Development from 1800 to 1947

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FOREWORD

THIS study of the economic development of the electric-lamp industry is the second volume in a series of studies on the economics of innovation, undertaken at the Massachusetts Institute of Technology.

The creative role played by science and technology in modern economic life is apparent to everyone. But we know relatively little about the human factors which condition the introduction of technological change into our environment. Are there barriers to innovation inherent in the increasing concentration of power in a few large concerns? Does the patent system, designed as an incentive to invention, act more often as a brake on new developments? What has been the role of key personalities in creating change? Are there lessons to be drawn from the past on how the innovating process can be more effective, not only from the standpoint of achieving a higher standard of material being but from the point of view of smoother human relations? Certainly, material progress at any price is not a satisfactory goal. On the other hand, freedom for creative action in initiating and carrying out new developments is a basic human drive for many individuals. I believe, personally, that a great society should strive toward a goal which will give to individuals and groups the maximum opportunities for creative expression; yet this means to me that the State must act to prevent the compulsive pressure of some particular group from overriding others to the destruction of human values.

But, although many of us could probably agree on the general goals for which we should strive in an industrial society, we know very little in detail about the operation of our industrial machine in relation to these goals. This is understandable enough when we realize that modern industry is only about 150 years old and that in this country at least we have been so busily engaged during that period in building business empires that there has been very little time out for reflection.

The Great Depression and the Second World War have jolted us out of our complacency. We are now ready to re-examine the values of industrial life in a more critical vein. There is much to admire and a good deal to criticize. Most American observers would probably agree that the weaknesses in the process of economic development can be corrected without any major reorganization. On the other hand, if we are to progress to a standard and a content of living as yet undreamed of in this country, the nature of the structural defects must be critically examined.

Arthur Bright's study of the electric-lamp industry represents a contribution to this objective. It offers a detailed analysis of the economic and technological evolution of electric lighting from the first scientific demonstrations shortly after 1800 to the end of World War II. Attention is focused upon the various forces affecting the direction and timing of technical advances in the lamp industry; and conclusions are drawn concerning the influence of the organization of the industry, the patent system, the international cartel and antitrust enforcement on the development of the industry.

Mr. Bright has given us an extremely thorough and penetrating analysis of the data, based on intimate study. He has visited all the major companies in the industry and digested a vast quantity of historical evidence. The result is a basic descriptive analysis of a major American industry which covers the period when America came of age industrially. This should prove an important document for the formulation of public policy. It should also contribute to one of our major scientific tasks—the formulation of an organized and systematic theory of economic development based on observation and experiment.

W. Rupert Maclaurin

PREFACE

Tremendous strides have been made in the application of technology to industry in the United States during the one hundred and seventy years of its existence as an independent nation. Most handicraft industries have been mechanized and placed on a mass-production basis; hundreds of new industries have come into existence; and even agriculture has been adopting more scientific methods. Enormous increases in the amounts of goods produced have accompanied the sweeping changes in methods of production and distribution.

Except for short pauses, the rising trends of productivity and output continued through the decade following World War I. The long and severe depression of the thirties raised serious doubts as to whether a fundamental change had not occurred in these trends. A theory of "secular stagnation" emerged, and even in the midst of the production and employment peaks of World War II, doubts persisted for the period of peace which lay ahead.

There are important unresolved questions regarding the future course of technological progress in American industry. Is the rate of advancement likely to slow down, or are we rather on the verge of a new era in which the application of science to industry is going to be far more rapid and economically significant than ever before? What are the principal environmental factors that affect technological progress? How can the rate of development and effectiveness of new industrial designs and techniques be stimulated? To provide partial answers to such questions it should be helpful to explore the process of technological change as manifested in particular American industries. By investigations of this sort we can learn how progress has taken place in the past, and what have been some of the limiting factors on the rate of change.

The present analysis of the electric-lamp industry is one in a series of studies in the economics of technological change undertaken by members of the Department of Economics and Social Science at the Massachusetts Institute of Technology. These studies are being carried out under the leadership of Professor

W. Rupert Maclaurin through a grant from the Rockefeller Foundation.

Empirical evidence is needed to answer the many questions involved in the economics of technological change. This work and its companion intensive industry studies are designed to add a new type of evidence to that which is already available through studies of industry as a whole, groups of industries, and specific problems such as the patent system. The emphasis throughout each study has been upon the underlying factors which have influenced the direction, extent, and timing of technological advances. Industrial technology cannot move forward more rapidly than the scientific knowledge which is fundamental to such advances, but the transition from basic research to practical applications in industry is materially affected by the incentives for change and by the capacities of business organizations to make changes.

The present analysis of technological developments in the electric-lamp industry covers the entire historical sweep of events from the earliest experiments in electric lighting to 1947. The original development and introduction of commercial electric lighting, both arc and incandescent, are treated in some detail. The principal emphasis, however, is on improvements in electric lamps and methods of production after electric lighting was first introduced. Since it became evident during the course of the study that the organization of the lamp industry and the operation of the patent system have been of outstanding importance in relation to technical progress in lighting, they have been given special attention, both in the historical portions of the book and in the conclusions.

Although the major developments in electric lighting are discussed more or less chronologically, I have tried to effect a compromise between a straightforward historical approach which would reserve all conclusions to the end, and a topical approach which would introduce the necessary data and evaluate the various factors as it went along. Accordingly, I have divided the history of electric lighting into four periods, each of which is discussed in considerable detail. Interpretations and minor conclusions are introduced into the historical presentation, and summaries collect the principal facts and conclusions at the end of each of the later groups of chapters. The final chapter brings together the data

and conclusions of the earlier chapters and treats topically the influence on innovation of industrial organization, the patent system, cartelization, tariffs, antitrust legislation, and other factors.

The conclusions of this study are primarily relevant to the electric-lamp industry only. At the same time, certain inferences may be drawn regarding other industries confronted by similar conditions. Companion studies may eventually permit us to generalize convincingly for a large segment of American industry.

Although the primary purpose of this study is to analyze the factors which influence technological progress, I hope that the story of the electric-lamp industry will also be of interest to the general student of industrial development and to those concerned with electric lighting itself. I do not know of any other analysis of the lamp industry with so broad a scope or such a long historical sweep.

Assistance and helpful criticism in the collection and presentation of material have been generously given by a great number of individuals and organizations. Thanks must first of all be given to the Rockefeller Foundation, which has provided the financial support for the entire program and at the same time has given us freedom to carry out the studies in the ways which seemed most productive and useful. Professor W. Rupert Maclaurin, who has been in charge of the program, has also directed the efforts of those of us who have been responsible for studies of particular industries with the utmost encouragement and generosity. He has provided us with considerable latitude in the techniques of collection and presentation of material to suit the peculiarities of our own industries and working habits, while ensuring that our attention was directed into the same broad lines of research. I have been deeply indebted to Professor Maclaurin for direction and for innumerable suggestions and criticisms throughout the entire study, which has stretched over a period of five years as a result of wartime delays.

Thanks are also due to many of my other former colleagues in the Department of Economics and Social Science at the Massachusetts Institute of Technology for fruitful discussions and suggestions and for reading portions or all of the manuscript. In particular, the assistance of Daniel C. Vandermeulen, Warren C. Scoville, and Robert L. Bishop has been most helpful.

Members of the industry have been exceptionally cooperative and helpful during the course of this analysis and have willingly provided much essential information. Without their assistance this study could not have been made. Although it is impossible to mention all of them by name, I should like in particular to cite the assistance of M. L. Sloan, T. W. Frech, the late Dr. W. L. Enfield, Dr. Clifton G. Found, W. A. D. Evans, and T. D. Foster of the General Electric Company; the late D. S. Youngholm, D. W. Atwater, E. W. Beggs, S. G. Hibben, Dr. H. C. Rentschler, Dr. J. W. Marden, D. S. Gustin, and J. W. Greenbowe of the Westinghouse Electric Corporation; E. J. Poor, John Wooldredge, John S. Learoyd, O. H. Biggs, R. G. Slauer, Harris Reinhardt, and Lawrence Burns of Sylvania Electric Products, Inc.; Louis Klein of the Incandescent Lamp Manufacturers Association; Preston S. Millar of the Electrical Testing Laboratories, Inc.; W. H. Simson of the Duro Test Corporation; James Cox of Duro Test, formerly of Sylvania; Lester Anderson of the Wabash Corporation; Gustav Herzberg of the Jewel Incandescent Lamp Company; Daniel R. Donovan of the Callite Tungsten Corporation; Charles S. Eisler of the Eisler Engineering Company; A. C. Lescarboura, formerly of the Fluorescent Lighting Association; and D. G. Trutner, formerly of Alfred Hofman & Company and now of Duro Test. Professor Colin G. Fink of Columbia University and Waldemar Kaempffert, Science Editor of the *New York Times*, have also given me valuable data during the course of the study.

I have also received valuable suggestions and criticisms from numerous individuals who have read all or portions of the manuscript. They include, in addition to my former colleagues in the Economics Department at the Massachusetts Institute of Technology, Professor Parry Moon, Professor John E. Burchard and Professor Emeritus Dugald C. Jackson of M.I.T.; Professors W. H. Nicholls, William F. Ogburn, E. H. Levi and Jacob Marschak of the University of Chicago; Louis Klein of the Incandescent Lamp Manufacturers Association; E. J. Poor of Sylvania; D. W. Atwater and others of Westinghouse; Dr. L. A. Hawkins of the General Electric Research Laboratory; and M. J. Hamner and others of the General Electric Lamp Department. Of course, the assistance of these individuals in providing data or reading the manuscript does not in any way imply approval by any one of them of the views or conclusions expressed in this study, which are my own. The sole responsibility for any errors which may remain is likewise mine.

I wish to thank Miss Beatrice A. Rogers for her splendid cooperation and assistance in seeing the manuscript through repeated drafts and in innumerable other matters during the course of the study. Finally, I owe much to the encouragement and patience of my wife during the years occupied by this study and to her editorial assistance.

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A. A. B., Jr.

Hanover, New Hampshire
August 4, 1947

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PART I

INTRODUCTION

Chapter 1: THE ECONOMIC POSITION OF ELECTRIC LIGHTING AND THE ELECTRIC-LAMP INDUSTRY

ELECTRIC lighting has become a "necessity" in all the leading industrial nations of the world. The production of goods and services for electric lighting in the United States totaled about $1,200,000,000 in 1939. The productive efforts of more than 500,000 individuals and a total investment of around $5,000,000,000 in plant, equipment, and working capital were required.[1] All other types of artificial illumination in this country have been relegated to minor or special applications.

1. The Growth of Electric Lighting

The conquest of darkness by means of artificial illumination has been a problem for inventive imagination ever since man learned to make fire. Progress was slow until the nineteenth century, however, when the development of illuminating gas, kerosene oil, and other new materials introduced flame sources of greatly increased efficiency. Yet with even the best flame sources most of the potential energy was converted into heat, and only a very tiny percentage was given off as visible light.

Although the electric-arc lamp and the incandescent electric lamp met with some passive public resistance and with active opposition by the gas interests when introduced commercially, their advantages were so great that within a few years they were well established in all leading industrial nations. After a few decades of practical experience, the incandescent lamp moved ahead of arc lighting in efficiency and became the standard for

[1] The expansion of the war years resulted in a rise in the value of electric lighting to $1,750,000,000 in 1944 and 1945. The immediate postwar years have produced further increases. Employment and investment were also greater. Since 1939 is the last peacetime year for which fairly complete data are available, that year will be used in most instances throughout this chapter for the evaluation of the economic importance of electric lighting.

almost all applications. Now a newer form of electric lighting, the vapor lamp, is rising as a potential replacement for much of incandescent lighting.

TABLE I: THE PRODUCTION OF LARGE INCANDESCENT LAMPS IN THE UNITED STATES

1879–1945

Year	*Production of Large Incandescent Lamps*	*Approximate Lumen-Hours Represented by Production of Large Incandescent Lamps*[a]	*Per Capita Production of Large Incandescent Lamps*[b]	*Per Capita Lumen-Hours Represented by Production of Large Incandescent Lamps*[b]
1879	NEGLIGIBLE	....	....	....
1891	7,500,000[c]	315,000	.1	4,900
1899	25,320,198	1,520,000	.3	20,400
1909	66,776,997[d]	7,875,000	.7	87,150
1919	224,713,466[d]	96,000,000	2.2	920,000
1929	354,542,107	282,000,000	2.9	2,330,000
1939	516,661,048[d]	470,000,000	4.0	3,590,000
1945	792,620,000	760,000,000	5.7	5,430,000

[a] 000,000's omitted. Estimated in part from data of the National Electric Light Association, *Report of the Lamp Committee*, New York, 1930. A lumen is the amount of light given off through a unit solid angle (steradian) from a uniform point light source of one candle.

[b] Based on census population data.

[c] Census data on lamp production were not collected in 1889. This figure for 1891 was estimated by J. E. Randall in *A Practical Treatise on the Incandescent Lamp*, Lynn, 1891.

[d] A small number of large lamps of special types are not included in this figure.

Sources for lamp production data: Census Office, U.S. Dept. of the Interior, *Census of Manufactures*, Washington, 1879–1899; Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures*, Washington, 1909–1939; and Bureau of the Census, U.S. Dept. of Commerce, *Facts for Industry: Electric Lamps, 1945*, Washington, Mar. 29, 1946.

The demand for improved lighting has been a necessary concomitant of increased urbanization, industrialization, and education. More activities have come to require artificial illumination, and changed seeing tasks have called for higher levels of illumination. Moreover, there has developed a demand for greater quantities of light for the same tasks. Where once 5 or 10 foot-candles were deemed adequate, from 50 to 75 foot-candles are not now considered excessive.

Table I shows the expansion since 1879 in the production of large incandescent lamps,[2] which for sixty-seven years have provided most general-purpose electric lighting. The increase in lamp production has been far more rapid than population growth,

TABLE II: STATISTICAL CHARACTERIZATION OF THE ELECTRIC-LAMP INDUSTRY IN THE UNITED STATES

1939

Number of establishments	55
Total employment	11,587
Salaried individuals	1,965
Wage earners	9,622
Total salaries and wages	$15,309,066
Salaries	4,620,047
Wages	10,689,019
Cost of materials, supplies, containers, fuel, purchased electric energy, and contract work	28,571,141
Value of products	84,827,985
Large tungsten incandescent lamps	58,378,740
Other electric lamps	20,295,340
Other products	6,153,905
Value added by manufacture	56,256,844
Expenditures for plant and equipment (this year)	2,646,550

Source: Bureau of the Census, U.S. Dept. of Commerce, *Sixteenth Census of the United States, Manufactures, 1939*, Washington, 1942, Vol. II, Pt. 2, pp. 386–387.

and the light output of these lamps has increased even more markedly as a result of greater efficiency, higher average wattage, and longer life. It is evident, however, that market saturation is far in the future. Continued expansion will in all probability raise lamp and lumen-hour output to levels that dwarf the 1939 and 1945 figures.

2. *The Economic Value of Electric Lighting*

Statistics for the American electric-lamp industry provide a preliminary measure of the economic importance of electric lighting. In 1939, as shown in Table II, there were fifty-five separate

[2] Large incandescent lamps include the ordinary electric-light bulbs for residential, commercial, and industrial use but exclude miniature lamps such as those for motor vehicles, flashlights, and Christmas trees.

lamp-manufacturing establishments[3] providing gainful employment for 11,587 persons, who received salaries and wages totaling $15,309,066. The products of the industry, of which all but about $6,000,000 consisted of various kinds of electric lamps, were valued at $84,827,985.[4] The value of large tungsten-filament incandescent lamps, which comprised the most important part of the output, was $58,378,740. The value contributions of wholesalers, retailers, and transportation organizations should be added to the value of lamps produced. These contributions amounted in 1939 to about $70,000,000 for large and miniature lamps combined,[5] and furnished additional employment and investment opportunities.

To reckon the economic importance of electric lighting only in terms of lamp production and distribution, however, would be to underestimate seriously its total influence. A 100-watt lamp, retailing for 15 cents, has an expected life of 750 hours. During that life it consumes about 75 kilowatt-hours of electric energy, which cost from $0.75 to $3.75, depending on the consumer's geographical location and his rate classification. The costs of purchasing and installing lamp fixtures and the necessary wiring constitute another important addition to the value of the lamp alone, even on a per-lamp basis.

By far the most expensive commodity consumed in lighting is electric energy. In 1939 current used for electric lighting amounted to about 31,000,000,000 kilowatt-hours with a value of nearly $690,000,000.[6] The electric-lighting portion of the power industry in 1939 afforded direct employment to about 86,000

[3] The 55 establishments were operated by about 45 companies. In 1939 General Electric operated 9 lamp assembly plants, and 2 other large producers operated 2 lamp plants each.

[4] Electric lamps made as secondary products in other industries were valued in 1939 at only $629,564, less than 1 per cent of the value of lamps produced within the industry. Most of these lamps were of miniature types.

[5] The retail value of electric lamps sold in this country in 1939 was $149,000,000, of which $108,000,000 consisted of large lamps (*Electrical Merchandising*, Jan., 1942, pp. 6–7).

[6] It is estimated that about 30 per cent of the total sale of electric energy to ultimate consumers in 1939 was for electric lighting. Total power sales in that year were 105,768,000,000 kilowatt-hours worth $2,290,000,000. In addition to the electric energy sold by the utilities, power is generated by thousands of establishments exclusively for their own use. The 30 per cent figure makes allowance for the portion used in lighting by the private concerns.

workers and paid them approximately $148,000,000 in salaries and wages (see Table III). Of that year's total of nearly $13,000,000,000 in public-utility investment, almost $4,000,000,000 was utilized in the provision of electric energy for lighting.[7]

In addition to electric lamps and energy, the value of electric-lighting fixtures and lamp shades produced in 1939 was over $120,000,000. These activities gave employment to more than 26,000 workers. About 12,700 persons were also employed by electrical contractors for the installation and alteration of electric-lighting systems valued at $66,800,000.[8] Miscellaneous other lighting products and activities added approximately $250,000,000 in value and 37,000 more jobs in 1939.[9] Table III summarizes these and other figures, showing the economic contribution of electric lighting. The last column of the table gives figures for the total employment provided by electric lighting; they take into consideration the employment in prior stages of manufacture and distribution as well as in the activities directly concerned.[10] The investment required for all activities other than the generation and transmission of electric energy for lighting added perhaps $1,000,000,000, to the $4,000,000,000 utility investment in lighting.

3. The Incandescent Lamp as the Heart of Electric Lighting

The manufacture of electric lamps contributes less than 10 per cent of the total value of electric lighting in this country and an even smaller percentage of its direct employment and investment; yet the lamp is obviously the foundation of the entire lighting industry. Since it has such a strategic position in reference to electric lighting as a whole and, as will be pointed out shortly, to the

[7] A wartime peak of 64,400,000,000 kilowatt-hours valued at $1,050,000,000 was reached for electric lighting in 1944.

[8] In addition to installations and alterations by contractors, a large volume of similar work is performed by industrial concerns for themselves.

[9] The miscellaneous category includes such items as flashlight batteries and cases, automotive lighting equipment other than lamps, installations by other than contractors, and the value added by distribution for all manufactured lighting products.

[10] The production of parts, supplying of power, construction of buildings, manufacture of machinery, etc., are represented in the value of lighting through their inclusion in the costs of the industries which participate directly.

entire groups of electrical industries, the electric-lamp industry is the principal subject for the later chapters of this analysis.

Although there have been many different commercial electric-light sources, including the arc lamp, a great range of incandescent sources, and a growing number of vapor types, up to the present time the filament lamp has been the most important of all. It was technically and commercially preceded by the arc lamp; but within a relatively few years the incandescent-lighting industry caught up with and passed arc lighting, absorbed it, and eventually squeezed it out almost completely. The later developments of vapor sources have been sponsored in large part by the incandescent-lamp manufacturers. In actuality, then, there has been one central lamp industry, and various small branches have been absorbed by it or have branched off from it. The incandescent lamp itself has not been a static thing since its commercial introduction, of course. It has evolved from the old Edisonian carbon-filament vacuum lamp through a number of intermediate steps to the modern coiled-coil gas-filled tungsten-filament lamp.

A further distinction should be made among the types of incandescent lamps. Large lamps are used for general lighting purposes, and they constitute by far the largest portion of incandescent-lamp production. Miniature lamps, used for motor vehicles, flashlights, Christmas trees, etc., are also made in large numbers. Their lower unit value results in a much smaller total value. Technologically, the miniature lamps have followed the large lamps to a great extent. Table IV shows the relative importance of the various types of electric lamps produced in 1939. Since that date, the expansion of fluorescent-lamp production has raised the value of vapor lamps produced to a much more significant total.

4. *The Stimulus of the Incandescent Lamp to the Electrical Industries as a Whole*

Besides holding a central position in electric lighting, the large incandescent lamp has had a profound effect on both technical and commercial developments in the entire group of electrical industries. Prior to the development and introduction of a practical incandescent lamp in 1880, the only important applications of electric energy were in the telephone and telegraph, in electro-

TABLE III: ESTIMATED ECONOMIC CONTRIBUTION OF ACTIVITIES ASSOCIATED WITH ELECTRIC LIGHTING IN THE UNITED STATES

1939

Activity	*Persons Employed*[a]	*Pay Roll*[a]	*Value of Activity*	*Value Added by Activity*[b]	*Est. Contributions to Value of Electric Lighting*[c]	*Estimated Contribution to Employment Provided by Electric Lighting*[c]
Production of electric lamps of all types (93.5% of electric-lamp industry)	10,800	$ 14,314,000	$ 79,303,644	$ 52,600,000	$ 79,303,644	38,500
Production of electric-lighting fixtures (90% of lighting-fixture industry)	23,000	32,180,000	113,207,082	58,250,000	113,207,082	53,400
Production of electric-lamp shades (100% of lamp-shade industry)	3,105	2,474,304	8,375,706	3,991,264	8,375,706	5,280
Generation, transmission, and distribution of electric energy to ultimate consumers for lighting (30% of electric-power industry)	86,000	148,000,000	690,000,000	585,000,000[e]	690,000,000	310,000
Electrical-contracting work in connection with electric-lighting installations and alterations (30% of the electrical-contracting industry)[d]	12,700	20,600,000	66,800,000	36,200,000	50,000,000[e]	21,100
All other related activities	37,000	60,000,000	250,000,000	190,000,000	250,000,000	113,000
Total (rounded figures)	172,600	$277,500,000	$1,207,700,000	$926,000,000	$1,190,000,000	541,000

[a] Includes executives of corporations and their salaries, but not firm members or proprietors of unincorporated businesses or their withdrawals.
[b] Total value of activity less cost of materials, supplies, purchased electric power, contract work, etc.
[c] See Appendix A for a discussion of the methods used in making these estimates.
[d] With the increase in fluorescent lighting after 1939, the lighting part of electrical contracting rose to about 50 per cent by 1945.
[e] Because a portion (estimated at roughly 50 per cent) of the materials used in electrical contracting consists of lighting fixtures, electric lamps and shades, the value contributed to electric lighting is not the whole of the value of electrical contracting work performed on lighting.

Sources: Based principally on data from Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures, 1939* and *Census of Electrical Industries, 1937*, Washington.

plating, and in arc lighting. These industries were all handicapped by the inefficiency of existing electric-generating devices and by the absence of an effective system of power distribution. One of the greatest contributions of the incandescent lamp was its stimulation of central-station generation and distribution of electric

TABLE IV: PRODUCTION OF ELECTRIC LAMPS IN THE UNITED STATES, BY TYPES
1939

Product	No. of Lamps	Total Value	Unit Value
Incandescent-filament lamps:			
Large tungsten	516,661,048	$58,379,740	$0.113
Miniature tungsten:			
Motor-vehicle	136,553,456	7,240,976	.053
Christmas tree, flash-light, etc.	[a]	7,105,175	[a]
Carbon	1,639,015	392,638	.240
Total incandescent	[a]	$73,118,529	[a]
Vapor and photoflash lamps	[a]	5,359,164	[a]
Photoflood lamps	1,885,793	340,440	.181
Other lamps	[a]	485,511	[a]
Total, all types	[a]	$79,303,644	[a]

[a] Not reported.
Source: Bureau of the Census, U.S. Dept. of Commerce, *Sixteenth Census of the United States, Manufactures, 1939*, Washington, Vol. II, Pt. 2, p. 387.

energy. Most of the earliest central stations were built to provide incandescent electric lighting. Once installed and operating, they encouraged the growth of electric traction, the use of electric motors for power, and the entire range of domestic and industrial electrical appliances of various kinds.

The rise of incandescent lighting attracted public and scientific interest to electricity more than any other application and served as the spark plug for the early development of allied elec-

trical industries. The rate of growth and the general expansionary influence of these industries were so great that they have been thought fundamental in the general upswing after about 1895 of a long wave of economic prosperity that lasted until World War I.[11] Table V presents a summary of the growth in value over the years of most of the principal activities associated with the electrical industries.

A particularly close relationship can be traced between the incandescent lamp and later developments such as radio. From a technical point of view, the radio tube is an offspring of the incandescent lamp. The famous "Edison effect," which forms the basis for the radio tube, was first noted during experimentation upon the incandescent lamp. Many techniques of tube design and manufacture were first developed in connection with the incandescent lamp. Other more complicated devices, such as X-ray and cathode-ray tubes and all other electronic devices, including radar, also stem in part from this chain of development.

5. *Plan of Organization*

Gas lighting was the first "modern" light source. It was followed by electric arc lighting, which reached a commercial stage around 1877. Technical interest in incandescent lighting reached a high level in that year. A group of independent inventors, rather than established companies, worked to develop the new lighting device. Although a great number of previous and contemporary workers made many important contributions to the development of practical incandescent lighting, Thomas A. Edison achieved the first real success. The background and nature of this development are treated in Chapters II and III.

Edison was the first to begin the manufacture of satisfactory incandescent lamps, but a rapid influx of competitors led to much early confusion in the industry. Technical, legal, and financial problems were numerous and complicated. The incandescent

[11] The existence of long cycles of economic activity was first proposed by the Russian economist N. D. Kondratieff around 1920. See his "Long Waves in Economic Life," in the *Review of Economic Statistics*, Vol. XVII, pp. 105–115 (Nov., 1935); and J. A. Schumpeter, *Business Cycles*, McGraw-Hill, New York, 1939, Vol. I, pp. 164–170.

lamp soon became just one among many products in the rapidly growing electrical-goods industry. Forces affecting the entire industry brought about widespread corporate consolidations, until by 1896 there were only two important full-line manufacturers of non-communication electrical equipment in the United States—the General Electric Company, successor to the Edison interests, and the Westinghouse Electric & Manufacturing Company. Having concentrated on the lighting field and having won important legal victories in connection with its patents, the General Electric Company emerged as dominant in that aspect of its business. The early commercial evolution of the electric-lamp industry and the technological developments which accompanied it are the subjects of Chapters IV and V.

A general patent-licensing arrangement between General Electric and Westinghouse in 1896 and subsequent specific licenses established a pattern in the lamp industry which was substantially maintained until 1945. General Electric was the senior member of a partnership between these two firms in the lamp business that retained its supremacy for fifty years. The technological changes and commercial developments since 1896 are treated in Chapters VI–XV. Part III (Chapters VI–VIII) includes a discussion of the development of the metallic filaments and the other improvements in electric lighting which took place during the eventful years from 1897 to 1912. The patent-licensing and quota system, which aided General Electric in retaining its superiority in the incandescent-lamp business to the present time, was based after 1912 principally on patents covering the tungsten-filament lamp. The fundamental Just and Hanaman patent was issued in 1912. The history of incandescent lighting from 1912 to 1947 is treated in Part IV (Chapters IX–XV), which also covers the same time span for gaseous-discharge lighting devices. It has seemed preferable to divide Part IV in this fashion rather than by time intervals, in order that the sweep of events in the development of each type of modern electric lighting may not be interrupted.

Chapter XVI presents some general conclusions regarding the direction and rate of technological progress in the electric-lamp industry, the various factors which have influenced it, and some

TABLE V: THE VALUE OF ACTIVITIES OF MAJOR ELECTRICITY-PRODUCING AND ELECTRICITY-USING INDUSTRIES IN THE UNITED STATES

1879—1939

Activity [a]	*1879*	*1899*	*1919*	*1929*	*1939*
Production of electrical apparatus and supplies of all kinds	$ 2,655,036	$ 94,680,709	$1,156,515,989	$2,397,764,620	$1,727,389,949
Operation of telegraph systems	16,696,623	40,930,038 [b]	106,990,000 [c]	196,280,000	128,214,000
Operation of telephone systems	3,098,081	86,825,536 [b]	382,830,000 [c]	1,023,574,000 [d]	1,180,028,000 [e]
Operation of electric light and power systems	458,400	84,187,000 [b]	502,060,000 [c]	1,802,655,493 [d]	2,289,583,000
Electroplating work done for others	1,975,700	2,719,961	10,389,617	23,727,916	28,168,051
Electrotyping and stereotyping carried on outside printing establishments [f]	724,689	3,772,025	15,919,014	35,617,297	29,045,159
Operation of electric railways, subways and trolley-busses	....	247,554,000 [b]	778,362,000 [c]	1,056,794,000 [d]	613,888,000 [e]
Production of electric-lighting fixtures [g]	....	19,821,334	80,366,870	144,965,706	124,581,725
Operation of radio broadcasting stations	....	....	....	h	147,146,717 [i]
Totals (to closest million)	$26,000,000	$580,000,000	$3,033,000,000	$6,681,000,000	$6,268,000,000

[a] Categories included cover only the major uses of electricity. Many minor additions would be required to make the list complete. Values given refer in most instances to the total value of goods or services produced by establishments in the industry or to total revenues of establishments. In a few cases operating income is used.

[b] Figure refers to the year 1902.

[c] Figure refers to the year 1917.

[d] Figure refers to the year 1927.

[e] Figure refers to the year 1937.

[f] Only the electrotyping portion of this figure is applicable to the electrical industries, but separate figures have not been reported.

[g] Figures given are for all lighting fixtures, of which an increasing proportion have been electric lighting fixtures.

[h] Data not reported.

[i] Figure refers to the years 1940.

Principal sources: Various publications of the Bureau of the Census, U.S. Dept. of Commerce, Washington, 1879–1941.

suggested modifications in the technological environment of the industry which would stimulate further progress and lead to greater consumer benefits.[12]

[12] Readers primarily interested in the commercial and economic development of the lamp industry will find most of the non-technical history in Chapters IV, VI, IX–XI, and XV. The portions devoted largely to technological developments include Chapters II–III, V, VII–VIII, and XII–XIV.

PART II

GENESIS OF THE LAMP INDUSTRY

Chapter II: THE RISE OF GAS LIGHTING AND ELECTRIC-ARC LIGHTING TO 1880

In 1880 illuminating gas, candles, and kerosene and other types of oil lamps were the most widely used artificial light sources in the United States. Only a beginning had been made in lighting with arc lamps, and the first incandescent lamp satisfactory for commercial use had just been developed. Before considering the early evolution and interrelations of gas, arc, and incandescent lighting,[1] however, it is desirable to discuss briefly the relationships between science and industry during the nineteenth century. It was the great spurt in science at that time which made electric lighting possible.

1. The Relationship of Science to Industry

The line of demarcation between scientists and practical inventors was even more pronounced during the nineteenth century than it is today. Scientific discoveries were made and announced by the professors or fellows of the great universities or organizations such as the French Academy of Sciences and the British Royal Institution. The study of physics and chemistry and the other sciences was an end in itself, and most of the scentists were not concerned with the application of their discoveries.

It was primarily in France, Germany, England, and to a lesser extent in Italy, that science throve during the nineteenth century.[2] After 1850 the increasing intercourse among nations destroyed many of the individual differences among the leading European countries and resulted in greater equalization of their methods

[1] For a brief history of oil, rush, candle, and other early forms of lighting see, for example, Leon Gaster and J. S. Dow, *Modern Illuminants and Illuminating Engineering*, Pitman, London, 2nd ed., 1919, pp. 1–30.

[2] See John Theodore Merz, *A History of European Thought in the Nineteenth Century*, Vol. I, Blackwood, London, 3rd ed., 1907.

and more even progress in building up all branches of science. Other nations can point only to the brilliant work of a small number of individuals, as Joseph Henry, J. Willard Gibbs, and a very few others in the United States. The scientific spirit did not bloom fully in America until the twentieth century, and there was relatively little governmental or public support for science. Most of our scientific knowledge was imported from Europe. Any American who wanted to obtain an extensive scientific education had to go to Europe, and particularly to Germany and France.

The situation with respect to the use of scientific knowledge in industry was somewhat different. Before the nineteenth century industry had moved more or less independently of the state of science or had even set the pace for science to follow and the problems for science to solve.[3] The great discoveries of the early nineteenth century opened up many important new fields for industry to exploit, and science quickly pushed far ahead of its applications. The scientific advances during the first half of the century were exploited during the next fifty years. After 1850 the interplay between invention and science became much greater. The time lag between fundamental advances in knowledge and their practical use gradually became shorter.

Important applications of science to industry were not made in each country in proportion to the fundamental advances made within its borders. England and France were the industrial leaders of the world, to be sure, but Germany in the 1870's had not yet started the rise which carried it to world prominence. The unification of Germany and the growth of the pan-Germanic spirit had important effects on German industry. Significant inventions were coming in small numbers out of the other western European nations, and America was just beginning its spectacular rise to world industrial leadership. The inventors of the United States lacked scientific and even engineering education, for the most part, yet they offset their educational deficiencies with practical experience, ingenuity, and experimental skill. They achieved their results more by intuitive insight than by theoretical knowledge, and they were less hampered by tradition.

While the early nineteenth-century advances in scientific

[3] Sir William C. Dampier (formerly Whetham), *A Shorter History of Science*, Cambridge University Press, Cambridge, 1944, p. 92.

knowledge had little effect on the feasibility of gas illumination, they were fundamental to successful electric-arc lighting and incandescent lighting. Indeed, all practical modern uses of electricity depend on the principles discovered by Volta, Davy, Oersted, Ampère, Faraday, Henry, Arago, Ohm, Weber, Gauss, Joule, von Helmholtz, Maxwell, and the other great scientists of that time. Of particular importance to commercial electric lighting were the discovery of the voltaic cell, electrically induced incandescence, the electric arc, the properties of electromagnetism, and electromagnetic induction.[4]

2. *Illuminating Gas*

Illuminating gas was the first in the series of "modern" centrally-supplied light sources which broke away from the candle and oil-lamp tradition. The early experimentation in this field was conducted primarily in Great Britain, France, and Germany shortly before 1800 and was based upon original discoveries made more than a hundred years previously.[5] William Murdoch and Philippe Le Bon were among the most important contributors to the development of illuminating gas. These men generated gas by the distillation of coal or wood and fed it through pipes to crude burners formed by flattening the ends of small tubes or by perforating metal caps with small holes. Early burners gave five times as much light as candles for the same cost. A few scattered applications of manufactured gas for illumination were made in England and France around 1800,[6] and in 1812 a company was chartered in London to light the streets with gas.

Within a few years after commercial gas lighting had been inaugurated in Europe, it was introduced into the United States. The first active company in this country was formed in Baltimore in 1816, and it was followed by companies in New York, Boston, and other large cities within a few years. The early history of those companies was marked by many failures, caused in part by

[4] These specific scientific contributions will be considered in greater detail in the pages that follow.

[5] The first recorded discovery of coal gas was made in Great Britain by Dr. John Clayton, a minister, around 1660.

[6] Natural gas had been employed for lighting by the Chinese as early as A.D. 900 (Jerome J. Morgan, *Manufactured Gas*, New York, 1926, Vol. I, p. 1).

financial and technical difficulties and also in part by widespread public opposition to the "health-menacing" new type of illumination. Gas lighting was also opposed by the dealers in oil and tallow lamps and candles, who feared its competition.

Once in use, gas lighting underwent rapid changes in technique which enabled it to secure widespread acceptance and broaden out from street and industrial illumination to residential use. Purer, enriched gases made less smoke and soot and gave more efficient light. More economical gas generation and distribution reduced costs. New types of burners also resulted in improved

TABLE VI: THE MANUFACTURED-GAS INDUSTRY IN THE UNITED STATES
1850–1870

	1850	*1860*	*1870*
Number of establishments	30	221	390
Capital	$6,674,000	$28,848,726	$71,773,694
Wage earners, average no.	952	5,730	8,723
Total wages	$ 390,684	$ 2,321,536	$ 6,546,734
Cost of materials used	503,074	3,667,630	10,869,373
Value of products	1,921,746	12,016,353	32,048,851

Source: U.S. Census Office, Dept. of the Interior, *Twelfth Census of the United States, 1900*, Washington, 1902, Vol. X, p. 705. Data for the industry were not collected during the 1880 census.

performance. The fishtail burner, in which two jets of gas came together to spread out into a thin flat flame, was introduced in 1820 and had many residential and other applications until the invention of the incandescent mantle. Oher improvements were made, such as the Argand burner [7] for large space lighting, the batwing burner for outdoor lighting and other purposes, and, much later, the regenerative burner, in which the gas and air were preheated before combustion.

Commercially, the illuminating-gas industry in the United States entered its period of important development after 1850. The data of Table VI show how rapidly its activities expanded, once gas had been generally accepted. Its $71,770,000 capital in-

[7] The Argand gas burner was adapted from the Argand oil lamp, which had been invented during the eighteenth century by the Swiss from whom it derives its name.

vestment of 1870 had about doubled by the time incandescent electric lighting became a competitor in 1880. Gas lighting was experiencing its most rapid expansion at the very time of the development of the electric-light sources.

Despite its initial advantages over competing light sources and subsequent improvements in efficiency and economy, gas lighting in the United States was continually confronted with serious competition from older types of lighting. The use of kerosene following the discovery of oil in Pennsylvania in 1859 resulted in improvements in both the design and the fuel of oil lamps. The cheapness and simplicity of lighting with kerosene made it desirable for many applications. The competition for illuminating gas provided by petroleum was offset, however, by the hydrocarbons conveniently derived from it to enrich the gas and raise its efficiency.

The gas interests were not research-minded in the modern sense. The companies, which varied in size approximately as the cities which they serviced, devoted most of their engineering attention to methods of generating and distributing their product. Such investigations in the fundamental nature of gas lighting as were conducted concerned primarily changes in the composition of the gas, in gas pressures, and in burner design.

The improvements in artificial illumination with flame sources from 1800 to 1880 were noteworthy, but none of the illuminants was wholly satisfactory for general purposes. The amount of light given off by each one was small; the light flickered; the products of combustion were undesirable, and the danger of fire was great. In gas lighting, there were the added dangers of asphyxiation and explosion. Moreover, efficiencies were still very low in terms of theoretical maxima, and there was room for a further substantial reduction in lighting costs. Under such circumstances it is evident that the potential market for improved light sources was very large.

3. *Electric-Arc Lighting*

EARLY ARC LAMPS

Electric-arc lighting attempted to meet the need for a better illuminant. The principle underlying the electric arc is relatively simple. Under favorable conditions, an electric current can pass through gases and vapors as well as through metallic and other solid or liquid conductors. When the current does pass through a gaseous medium, light is produced by the electric arc itself and by the incandescence of the heated ends of the interrupted conductors. Commercial application of the phenomenon required (1) the discovery of electrode materials which would have long lives and produce large quantities of light, (2) the construction of devices which would automatically maintain the proper distance between the electrodes, and (3) the discovery and exploitation of natural laws which would permit electric currents to be produced cheaply.

The phenomenon of the continuous electric arc was first discovered by Humphry Davy in 1802. He employed a pair of wood charcoal electrodes and drew the electric current from a voltaic cell, which was the first chemical battery known to the world. It had been invented only two years previously by Alessandro Volta, professor of natural philosophy at the University of Pavia in Italy.[8] At the time of his first electric-arc experiments, Davy was an assistant lecturer at the Royal Institution in London. He made a series of demonstrations of the arc, including one before the members of the Institution in 1810. Davy's soft rods of porous charcoal were rapidly consumed, however, and his source of current was expensive. These defects discouraged private inventors from adapting his scientific discovery to a practical purpose, and for thirty-four years no further progress was made in arc lighting.

The invention of the Daniell battery in 1836, the Grove battery in 1839, the Bunsen battery in 1842, and several other varieties within a few years raised hopes that economical sources of current had been found. There was a sudden rush of attention to the electric arc. The inventors included manufacturers, doctors, craftsmen, engineers, university professors, and representatives of various other professions. Their goals were clear-cut—the construction of automatic electrode regulators and the determina-

[8] The voltaic cell was the first source of continuous electric current available to experimenters, although static electricity had been known for many hundreds of years before 1800.

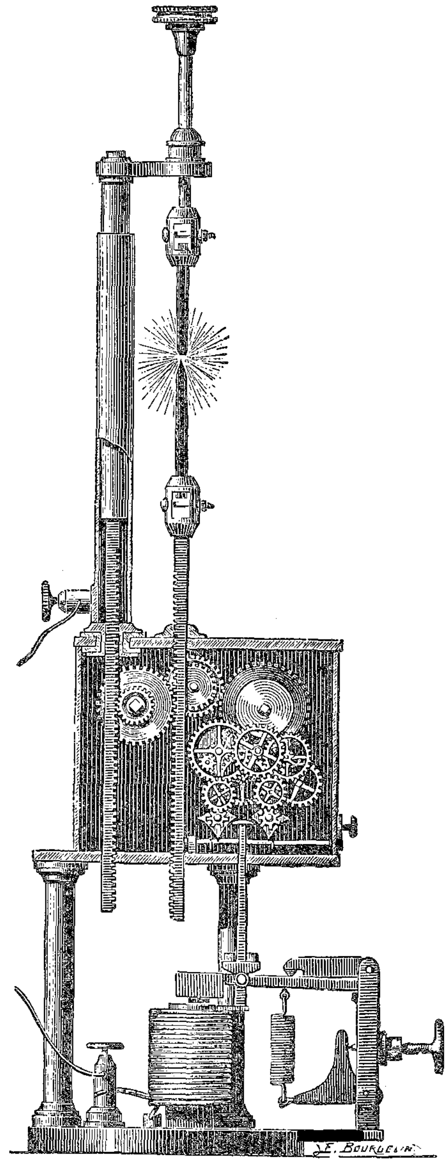

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Fig. 1. Dubosq Arc Lamp, 1858
One of the earliest practical arc lamps.

tion of optimum electrode composition. While the relative success of the individual inventors varied considerably, commercial electric lighting would probably have resulted within a few years, had the new battery sources of electric energy been sufficiently inexpensive. Unfortunately, the limitations were still very great. French and English inventors were the most active in the arc-lamp developments from 1844 to 1859, as is indicated in Table VII, although American, German, Russian, and other experimenters made many later contributions.

Léon Foucault effectively pointed the way to the proper composition of the electrodes in 1844 by using hard retort carbon in place of Davy's soft charcoal. The retort carbon was better, even though it was not pure or homogeneous. Most other experimenters after 1844 used retort carbon or mixtures of powdered carbon with various other substances. Significant progress was made in 1876 by the French inventor, F. P. E. Carré, who mixed powdered coke or lampblack with syrup or tar and molded the mass into rods. Great ingenuity was used in developing automatic regulators, which were of many types but usually employed clockwork with electromagnetic adjusters. The most practicable lamps developed during that period were those of Serrin and Dubosq, which were used in most of the scattered installations from 1858 to the early 1870's.

Despite the measure of success attained by the practical experimenters, the early arc lamps were costly, complicated, and cumbersome. The limitations of energy sources were so great that most workers had abandoned the field of arc lighting by 1860. For a dozen years no improvements on existing lamps were patented. Voltaic batteries, even with the improvements of Daniell, Grove, and the others, were not sufficiently economical to permit widespread use of electric-arc lighting.

IMPROVED SOURCES OF ELECTRIC ENERGY

The development of better sources of electric energy continued, however, based upon the discovery of electromagnetic induction.[9] This significant advance was made independently in 1831

[9] An electric current is generated in a wire when it is moved in a strong magnetic field in such a way that the wire cuts across the lines of force.

TABLE VII: EARLY HISTORICAL EVOLUTION OF THE ARC LAMP 1844–1859[a]

Date	Experimenter	Nationality	Type of Electrode	Type of Regulator
1844	Léon Foucault	French	Rods of retort carbon	Hand regulator
1845	Thomas Wright[b]	English	Discs of carbon	Clockwork
1846	W. E. Staite	English	Cones, rings, or plates of carbon (mixture of pulverized coke and sugar)	(1) Solenoid magnetic device with clock work, (2) spring regulator
1848	W. E. Staite	English	Rods or discs of carbon (mixture of pulverized coke and sugar)	Solenoid and counterweight with clock work
1848	F. Allman	English	Rods of carbon	Electromagnets or solenoids or fixed magnets or other device
1848	Archereau	French	Rods of carbon mixed with magnesia	Solenoid magnetic device
1848	A. E. Le Molt	French	Discs of retort carbon, or mixture of retort carbon, wood charcoal or coke, and tar	Clockwork
1849	W. E. Staite and W. Petrie	English	Rods of carbon (mixture of pulverized coke and sugar)	Solenoid, counterweight and clockwork
1849	L. Foucault	French	Rods of carbon	Electromagnetic device with clockwork[c]
1849	C. T. Pearce	English	Pencils of carbon or disc and bar of carbon	Electromagnetic device with clockwork
1852	M. J. Roberts	English	Rods of carbon	Electromagnetic device and gravity with clockwork
1852	T. Slater and J. J. W. Watson	English	Rods of carbon (powdered coke, charcoal, gas pitch, coal dust, and china clay)	Electromagnetic device and gravity
1853	Christopher Binks	English	Discs, rods, or wheels of carbon, carbon coating on metal, or mercury	Mechanical devices and gravity, or float device

Date	Experimenter	Nationality	Type of Electrode	Type of Regulator
1853	W. E. Staite	English	Rods or plates of carbon soaked in oil	Float device with solenoid
1853	P. Armand Le Comte de Fontaine Moreau	French	Rods of carbon	Electromagnet with springs and clockwork
1855	Henry Chapman	English	Rods of carbon	Electromagnet and gravity
1856	Joseph Lacassagne & Rudolph Thiers	French	Rods of purified retort carbon	Magnetic mercury-float device with electromagnets
1856	J. T. Way	English	Stream of mercury and pool of mercury or steel point, or two streams of mercury	None required except to control flow
1857	V. L. M. Serrin	French	Rods of carbon	Electromagnetic device with springs, clockwork and gravity[d]
1857	C. W. Harrison	English	Rods of metals and metallic salts, carbon rods or mercury or other liquid	Electromagnet with clockwork or other device
1857	J. B. Pascal	French	Rods of carbon	Electromagnet and float or other device
1858	E. C. Shepard	American	Rods of carbon	Float device
1859	W. Clark	English	Rods of carbon	Electromagnetic device with clockwork and gravity

[a] Although this is not an exhaustive list of all who experimented on arc lamps during these years, it includes most of the important developments.

[b] Received first patent (British) granted on an arc lamp.

[c] Improved in 1858 by J. Dubosq.

[d] Later improved by Lontin.

Sources: Alglave and Boulard, *The Electric Light*, 1884; Commissioner of Patents (British), *Patents for Inventions: Abridgements of Specifications Relating to Electricity and Magnetism, Their Generation and Applications*, Part I, 1859, Part II, 1874; Dredge (ed.), *Electric Illumination*, Vol. I, 1882; Fontaine, *Electric Lighting*, 1878; and others.

by two eminent scientists, English and American. Michael Faraday was Davy's successor at the Royal Institution, and Joseph Henry was at the time a professor of mathematics and physics at the Albany Academy. Although Henry preceded Faraday by a short time in his discovery, the English scientist was the first to publish his results and made greater later contributions; the credit for the advance is commonly divided between the two men.[10] Each man built his work upon three recent discoveries in electromagnetism. H. C. Oersted of Copenhagen had discovered in 1820 that a magnetic field is created about a wire when current flows through it; A. M. Ampère of Paris had discovered a year or so later that current flowing through a coil of wire gives it magnetic properties; and in 1825 William Sturgeon had made the first electromagnet by placing a bar of iron in the coil.[11] It was a momentous step to reverse the process and create electricity from magnetism.[12]

The principle of electromagnetic induction was rapidly adopted by the practical inventors who were trying to improve the sources of electric currents. As early as 1832 the Frenchman Hippolyte Pixii made a "magneto-electric machine," in which a permanent horseshoe magnet revolved before two wire bobbins

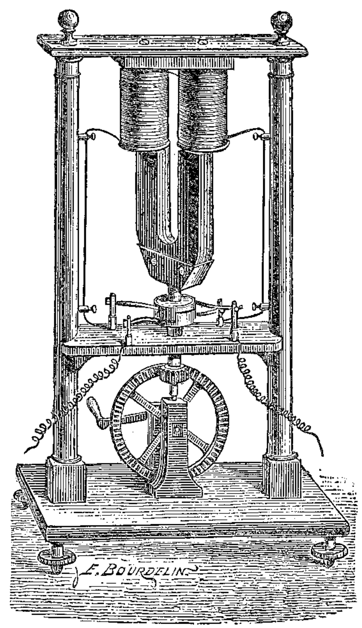

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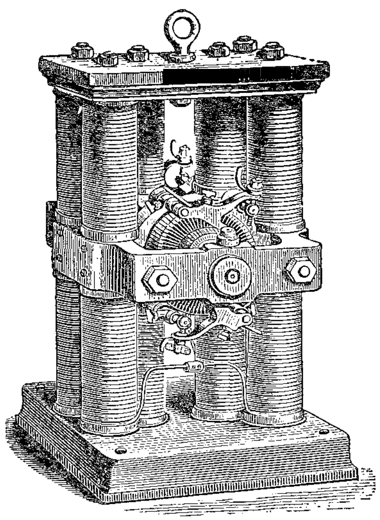
FIG. 2. Pixii Dynamo, 1832

First experimental dynamo based upon the Faraday-Henry discovery of electromagnetic induction.

[10] See Bernard Jaffe, *Men of Science in America*, Simon & Schuster, New York, 1944, pp. 188–192.

[11] The electromagnet was considerably improved later by Henry, by the British engineer, J. P. Joule, and by others. See J. A. Fleming, *Fifty Years of Electricity*, Iliffe, London, 1921, pp. 1–6.

[12] Faraday went further than Henry and built a small machine to demonstrate his discovery. It consisted of a copper disc which rotated between the poles of a permanent magnet. Current was drawn by a copper brush from the edge of the disc as it rotated.



Urquhart

FIG. 3. Large Gramme Dynamo, 1870's

Commercial model of ring-wound dynamo which greatly increased the efficiency of electric power production.

mounted on a soft iron core. A great number of other generating machines were built by inventors in many countries during the following years.[13]

Three major advances up to 1873 made possible great increases in electrical output and efficiency. The first two were the replacement of the original permanent magnet by an electromagnet and the use of the "self-excited field." Charles Wheatstone's dynamo of 1845 was the first to employ an electromagnetic field, and the idea was soon adopted by almost all other experimenters. Around 1867 S. Alfred Varley, Charles Wheatstone, and Werner and Carl Wilhelm Siemens almost simultaneously suggested using some of the output of the dynamo to energize the electromagnetic field. A few earlier workers had had the same idea, but no actual change in practice resulted until after 1867.[14] The third important advance in dynamo design was the improvement in armature winding. During the early seventies the Belgian electrician Z. T. Gramme developed a series of dynamos,

[13] Among the most noteworthy devices built before 1870 were those of Saxton (1833), Clarke (1836), Stöhrer (1836), Nollet (1850), Page (1850), Holmes (1853), C. W. Siemens (1856), Pacinotti (1860), Wilde (1861–1866) and Varley (1866). See Hippolyte Fontaine, *Electric Lighting* (trans. by Paget Higgs), Spon, London, 1878; John W. Urquhart, *Electric Light*, Lockwood, Crosby, London, 1890; Ém. Alglave and J. Boulard, *The Electric Light* (trans. by T. O. Sloane), Appleton, New York, 1884; and James Dredge, ed., *Electric Illumination*, Vol. I, Offices of "Engineering," London, 1882.

[14] The first recorded mention of self-excitation was in 1848 by Brett. Other references were made by Sinsteden in 1851, by Soren Hjorth (Danish) in 1855, and by the American, Moses G. Farmer, in 1865. See Dredge, *op. cit.*, Vol I, pp. 115–120, 140–141; Adam G. Whyte, *The Electrical Industry*, Methuen, London, 1904, pp. 4–9; and Henry Schroeder, *History of Electric Light*, Smithsonian Institution, Washington, 1923, pp. 24–25, 27.

using a new, highly efficient ring winding.[15] A similar but simpler drum winding was developed in 1873 by von Hefner-Alteneck and used by the Siemens brothers in their dynamos.

The more efficient and more uniform currents obtainable after 1870 restored interest in arc lighting, with renewed vigor. In view of the previous history of experimental lamps, it was natural for commercial electric lighting to follow almost immediately the development of a satisfactory source of electric energy.

COMMERCIALIZATION OF THE ARC LAMP

Within a short time dozens of new varieties of arc lamps were developed by experimenters in all industrialized countries of Europe and the United States. One particularly important innovation was the "electric candle" of Paul Jablochkoff, a Russian army officer, in which parallel electrodes separated by a nonconducting volatile substance made unnecessary the use of complicated regulators in the lamp. The first use of this startling new device in France and in England in 1877 and 1878 aroused tremendous interest and assisted materially in establishing arc lighting as a new commercial type of artificial illumination. Other inventors later produced electric candles of various sorts in an attempt to overcome the numerous defects of the Jablochkoff candle, which wasted a great deal of light upward, could not be relighted after being extinguished, was noisy, required alternating current, and gave a fluctuating light output. The expensive electric candle was soon displaced in most installations by more economical though more complicated arc lamps of the traditional type.[16]

The first practical application of the arc lamp was in lighthouse illumination, even though it had been used for temporary exhibition and experimental lighting in France, England and other countries on a few occasions early in its history. Installations in England in 1858 and 1862 and in France in 1863 were the first of

[15] The ring-wound armature was essentially an iron ring with insulated wire wound upon it all around the circle. It was first devised by Antonio Pacinotti in 1860 but was not used commercially until after Gramme's rediscovery.

[16] Besides the Serrin and Dubosq lamps used in the earliest European installations, a number of other types were used commercially in Europe. Among the outstanding ones were those developed by Archereau, Gaiffe, von Hefner-Alteneck, Lontin, Carré, and Rapieff.

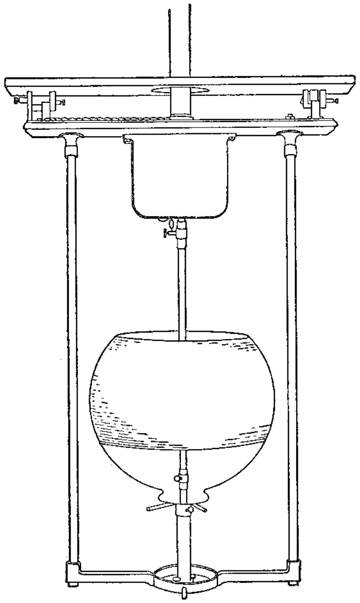


FIG. 4. Brush Arc Lamp
Series-wired arc lamp with automatic shunt to minimize system failure.

this sort.[17] The first permanent installation for general lighting purposes evidently occurred in 1873 in the Gramme workshop at Paris, where electrical apparatus was produced.[18] By 1877, when the practicability of arc lighting had been conclusively demonstrated, its period of real commercial expansion in Europe was under way. It gradually came into widespread use in Europe in street and other outdoor lighting and in illuminating some large interiors such as factories, as well as in various special applications.

American inventors had shared very little in the development of the arc lamp and relatively little in the development of the dynamo up to 1877, in large part because few Americans had participated significantly in the fundamental electrical discoveries of the early nineteenth century. By that year successful work abroad had encouraged many individuals to undertake experimentation, however, and soon American technical and commercial progress in arc lighting equaled or surpassed that of Europe. The work of Brush, Thomson and Houston, Wallace, Farmer, Weston, Wood, Maxim, and Van Depoele was particularly noteworthy in the expansion of arc lighting in the United States. Each inventor normally designed a new dynamo as well as a lamp, and the variety of equipment available grew rapidly.

The great simplicity and reliability of the arc lamp and dynamo system of Charles F. Brush made it of particular importance, both in this country and in Europe. Brush, a graduate of the University

[17] T. Commerford Martin, "Central Electric Light and Power Stations," *Electrical Industries, 1902*, Bureau of the Census, U.S. Dept. of Commerce and Labor, Washington, 1906, pp. 87–89.

[18] Fontaine, *op. cit.*, p. 105.

of Michigan, built his first dynamo while engaged in the iron business in 1876. After 1877 he devoted his entire attention to electrical invention. In that year he contracted with the Telegraph Supply Company of Cleveland to give it exclusive rights to produce and sell equipment patented by him in exchange for a royalty. The first Brush arc lamp was made in 1877, and within a short time he had produced a series-wired arc-lighting system with an automatic shunt about each lamp. If a single lamp went out, the rest were unaffected. This device was a very real contribution to arc lighting, which had been plagued by the lack of independence of series-wired lamps. Among the other important Brush arc-lighting inventions were an improved regulator, copper-plated carbons, multiple-carbon arc lamps for all-night burning, a series-shunt winding for dynamos, and an improved storage battery.

The inventions of Elihu Thomson and Edwin J. Houston were also noteworthy. They were teachers at the Boys' Central High School of Philadelphia; they became interested in arc lighting in 1878 when some Brush lamps were installed in a Philadelphia store window. Thomson and Houston designed an improved dynamo and arc lamp of their own and made a few small installations with the aid of a local backer. In 1880 Thomson accepted the offer of a group of individuals in New Britain, Connecticut, to finance the manufacture of arc lamps, dynamos, and other apparatus under Thomson and Houston patents. Thomson moved to New Britain, and Houston remained at his teaching. Beside his inventions in arc-lamp and dynamo design, Thomson later made notable contributions in electric welding, transformers, motors, meters, and many other fields.

Most of the American arc-lamp experimenters were young men, in their twenties or early thirties. This was true for all the electrical industries in the United States from 1875 to 1890, for it was a new and rapidly expanding field and drew its engineering personnel primarily from among the technically minded young men who had no previous ties—or only weak ones—with other occupations or industries. Although some of the inventors working before 1880 were university-trained, the majority were not. All, however, were enthusiastic about the possibilities of the practical application of electricity.

The only well established applications of electricity in 1875 were telegraphy and electroplating. Telegraphy in the United States had had its practical beginnings in 1844 with a message sent from Washington to Baltimore by Samuel F. B. Morse,[19] and it had expanded rapidly thereafter. Electroplating was still older, for it had been introduced when chemical batteries were the only source of electric current. Electrical-goods manufacturers largely confined their attention to the construction of the necessary apparatus for those two uses. The improvement in dynamos was a great stimulus to electroplating, as it was to all the other applications of electricity.

The telephone passed to a commercial stage in the United States in 1877, shortly in advance of its European introduction. Alexander Graham Bell was the single most important inventor of the telephone, although others, including Thomas A. Edison, made noteworthy contributions. Rapid commercial success by 1879 raised the telephone to a position in the electrical industries second only to the telegraph. In that year electric lighting, electric traction, and other uses of electric motors were still in experimental or very early commercial stages. Table VIII gives a statistical characterization of the size and operations of the American electrical industries in 1879.

Since electric lighting was based on quite different principles and was still in an experimental stage, the gas companies paid the new light source little or no attention. Their indifference lasted until about 1880, when the potentialities of commercial electric lighting began to be apparent.

In the United States each arc-lamp inventor typically aroused the interest of local capitalists and formed a company to manufacture the necessary apparatus and make installations. These manufacturing companies then encouraged the formation of local electric-light companies, which they licensed under their patents and supplied with equipment. The first central electric-generating station in America was installed in 1879 by the Brush-licensed California Electric Light Company of San Francisco.[20] Arc lighting was making commercial as well as technical progress in this

[19] The first European successes came a few years earlier.
[20] Martin, *op. cit.*, p. 90.

TABLE VIII: THE LEADING ELECTRICAL INDUSTRIES IN THE UNITED STATES 1879

Industry	*Establishments*	*Capital*	*Average Employment*	*Wages Paid*	*Value of Materials*	*Value of Products*
Operation of telegraph systems	77	$93,062,922	14,928	$4,886,128	[a]	$16,696,623
Operation of telephone systems	148	15,702,135[b]	3,338	[a]	[a]	3,098,081[c]
Electroplating work done for others	221	865,898	1,441	620,848	$663,588	1,975,700
Production of telephone and telegraph apparatus	40	636,458	893	458,406	755,891	1,580,648
Production of other electrical apparatus and supplies	36	873,300	378	224,758	360,579	1,074,388
Electrotyping and stereotyping carried on outside printing establishments	45	536,000	642	312,208	200,491	724,689
Operation of electric light and power systems	3	425,000	229	117,500	150,650	458,400
Totals	570	$112,101,713[b]	21,849	[d]	[d]	$25,608,529[c]

[a] Not reported. [b] Does not include 74 telephone systems. [c] Does not include 16 telephone systems. [d] Incomplete.

Principal Source: U.S. Census Office, Dept. of the Interior *Tenth Census of the United States*, 1880, Government Printing Office, Washington, 1883, Vol. II.

country by the time incandescent electric lighting appeared on the scene in 1880.

The arc lamp gave more light for a given cost than any of the other illuminants in use when it appeared. However, it was only partially successful in meeting the need for better lighting. It gave off light of great strength and brilliance, effectively lighting large areas, but it could not be used with satisfaction in the confined space of a private home. Even the smaller sizes were very brilliant and dazzling.[21] Other characteristics—the high system voltages required, the large amounts of current needed, the wiring in series which made it difficult to turn individual lamps on or off without affecting the rest of the system, the peculiar color of the light, and the necessity for frequent adjustment—made it unsatisfactory for ordinary indoor lighting. Despite its disadvantages, arc lighting was strongly pushed by its promoters and found ready acceptance in street lighting and many other outdoor applications.

The problem of obtaining a satisfactory general-purpose illuminant had not been solved, however, and it was redefined in terms of "subdividing the electric light." What was required was a smaller light of equal or greater efficiency, which could be turned on or off without affecting the other lamps in its circuit and which could be used safely and easily in private houses.[22] The incentives for the development of a new and more generally satisfactory light source were great for both inventors and capitalists. The possible financial reward for a successul lamp was enormous. Moreover, the prospective glory of being the victorious inventor was in itself an ample reward for some.

[21] Arc lamps were usually furnished in sizes of 500, 800, 1,200, 2,000, or 3,000 candlepower. Still larger sizes were supplied for special uses.

[22] Strictly speaking, "subdivision of the electric light" required a subdivision of the current from a generator among a number of small arc lamps which could be controlled individually and which retained the characteristics and economy of the original lamp. (The earliest dynamos were able to operate only a single arc lamp.) Since arc lighting in parallel had not yet been worked out, and since the efficiency of the arc lamp diminished materially with a decrease in its size, many practical inventors turned to incandescent lighting as offering a greater chance of success. At a later date arc lighting in multiple became feasible, though very small individual arc lamps were never successfully developed.

Chapter III: THE DEVELOPMENT OF INCANDESCENT ELECTRIC LIGHTING TO 1880

THE passage of sixty-seven years since the first commercial incandescent lighting has almost obliterated from the American mind the memory of the work of all inventors other than Edison. There had been a long line of experimenters prior to 1877, however, and many of them had aided in limiting the number of variables with which their successors had to deal. Several inventors besides Edison deserves a share of the credit in the great burst of activity from 1877 to 1880, which finally brought forth a marketable incandescent lamp. Pope writes in his history of the incandescent lamp:

> The outcome of a race of diligence between two independent but equally meritorious inventors, is perhaps as often as otherwise determined by chance or accident. In this respect, it may not inaptly be compared to the result of a horse race in which the fortunate winner carries off, not only all the honors, but the purse as well, although his nose may have passed under the wire barely an inch in advance of some of his less deserving competitors. . . . The critical student of affairs perceives that, however wonderful or however unexpected an invention may appear, it is seldom that it is not found to be a necessary sequence of a long series of other discoveries and inventions which have preceded it. . . . But it has always been the way of the world to consider every such invention . . . as the work of some particular individual, who . . . is regarded as its sole originator and contriver, and upon him fame, honor and wealth are lavished without stint.[1]

A consideration of the technical background and the economic environment of the incandescent lamp indicates that by 1877 the time was ripe for the development of this type of electric lighting.

[1] Franklin L. Pope, *Evolution of the Electric Incandescent Lamp,* Elizabeth, N.J., 1889, p. iii.

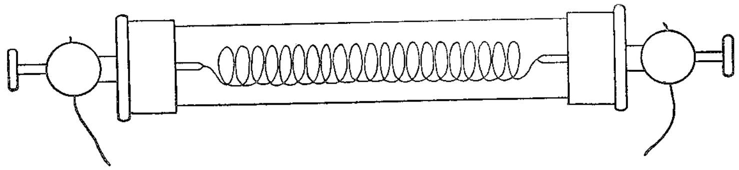


Fig. 5. De La Rue Lamp, 1820
First recorded incandescent lamp, using platinum illuminant.

Intense activity followed, and the first successful commercial installations were made three years later.

1. *The Technical Background of Incandescent Lighting in 1877*

One of the first demonstrations of electrically induced incandescence was made in 1802 by Humphry Davy while he was a lecturer at the Royal Institution.[2] As in the case of the electric arc, Davy did not make a lamp using the principle of incandescence which he had discovered. He merely passed an electric current through a platinum wire or through a slender carbon rod and observed that they glowed until consumed by oxidation. Many decades elapsed before practical use was made of this principle. The arc lamp and the incandescent lamp thus had their roots in the scientific experiments of the same man in the same year and depended fundamentally upon the voltaic cell, which was the first reliable source of a continuous electric current.

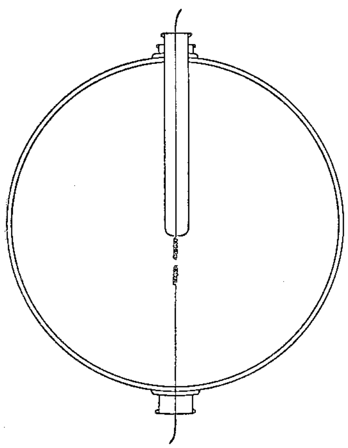


Fig. 6. De Moleyns Lamp, 1841
First patented incandescent lamp, using powdered charcoal falling from glass tube through interrupted coils of platinum wire.

As with the arc lamp, there was a sudden burst of experimentation with lighting by incandescence following the development of the

[2] Jean Escard claims in *Les Lampes Électriques* (Dunod & Pinet, Paris, 1912, p. 267) that the original discovery of electrical incandescence was made in 1801 by Thénard. No further details are offered, and the claim is not substantiated by other sources.

Daniell, Grove, Bunsen, and other batteries around 1840. An even earlier incandescent lamp has been credited to the English experimenter De la Rue, who in 1809 is said to have enclosed a coil of platinum wire in glass tubing from which part of the air had been exhausted to prevent too rapid oxidation of the platinum.[3] The Belgian, Jobard, repeated Davy's experiment with carbon in an exhausted glass container in 1838, and seven years later he tried platiniridium. Frederick De Moleyns, an Englishman, was granted the first patent on an incandescent lamp by the British government in 1841. His lamp consisted of a spherical glass globe, exhausted of air, containing two coils of platinum wire connected by powdered charcoal, which became incandescent as current was passed through the wires. The British government granted another patent in 1845 on the invention of J. W. Starr, a young American from Cincinnati, who made an incandescent lamp composed of a carbon rod in a vacuum above a column of mercury. This represented the first patent on a lamp using a solid carbon conductor, although it was not much like the attenuated high-resistance carbon filament of Edison's final lamp. The Göbel lamp of 1854 was said to have contained a fine carbon thread glowing in a vacuum.[4]

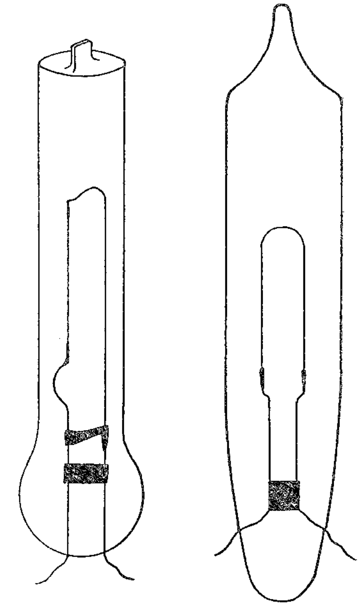


Fig. 7. Unauthenticated Göbel Lamp, 1854
Litigation over the basic Edison incandescent-lamp patent produced claims of priority by Heinrich Göbel. Only weak evidence supported the claims.

[3] Association of Edison Illuminating Companies, *Development of the Incandescent Electric Lamp Up to 1879* (Appendix B from Report of the Lamp Committee), New York, 1929, p. 4.

[4] While this design purportedly anticipated the later commercial lamp in some respects, its authenticity has remained doubtful. Göbel took out no patents and published no papers; his claims were not made public until the time of the litigation over the Edison patent.

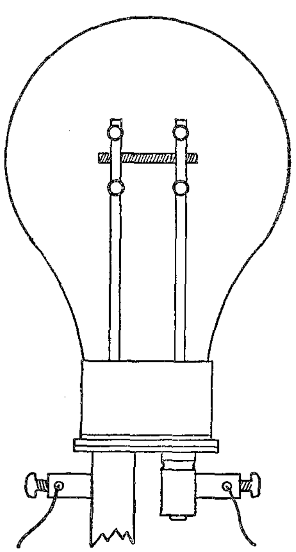


FIG. 8. Roberts Lamp, 1852
Vacuum lamp with graphite illuminant in a pear-shaped glass bulb.

Incandescent lamps[5] of varied nature were made by many other experimenters up to 1860, as is indicated in Table IX. The early lamps generally contained platinum, iridium, or carbon conductors. Of all the metals which could be made into wires or thin strips at that time, platinum and iridium were the best for incandescent lighting because of their relatively high melting points.[6] Carbon was widely used because its melting point is higher than that of any metal, and because it has a high—but not too high—resistance to electric current. Its great disadvantage was its tendency to vaporize or combine with atmospheric gases. The many better illuminants were not known, not available in the proper form, or not thought of at that time.

The early incandescent lamps "burned" in air, in a vacuum, or in atmospheres of nitrogen or some other gas, with or without protective globes and with all manner of special devices. The incandescent materials in lamps with atmospheres of air generally burned for only a short time before they were consumed by oxidation, particularly if the conductor was made of carbon. To se-

[5] The incandescent-arc lamp also received some attention during this period. It was an intermediate type between the arc lamp and the incandescent lamp proper. In this device an electric current was passed through a rod of carbon of small diameter pressing against a disc or block of carbon and usually burning in the open air. The end of the carbon rod became incandescent. It was more efficient than the enclosed incandescent lamp at that time, but it had other defects which made it impractical. Greener and Staite, working around 1846, seem to have been the first to develop such a lamp, and many later workers were interested in this line of development. The experiments reached their peak in the work of Reynier and Werdermann in 1878. They had little commercial significance. See Dredge, *op. cit.*, Vol. I, pp. 542–571.

[6] Other things being equal, the higher the temperature, the greater the incandescence.

TABLE IX: HISTORICAL EVOLUTION OF THE INCANDESCENT LAMP 1809–1878 [a]

Date	*Experimenter*	*Nationality*	*Illuminant*	*Atmosphere*	*Container*
1809	De la Rue	English	Coiled platinum wire	Partial vacuum	Glass tubing with brass caps
1838	Jobard	Belgian	Carbon rod	Vacuum	Glass
1840	W. R. Grove	English	Coiled platinum wire	Air	Inverted tumbler in dish of water
1841	F. De Moleyns [b]	English	Powdered charcoal between two coils of platinum wire	Vacuum	Stoppered spherical glass globe
1845	J. W. Starr [c]	American	(1) Platinum strip (2) Graphite rod	(1) Air (2) Vacuum	(1) Stoppered glass globe (2) Stoppered glass tube above mercury column
1848	W. E. Staite	English	Arched platinum and iridium rod	Air	Stoppered glass globe
1849	W. Petrie	English	Iridium or iridium alloy rod	Air	None
1850	E. C. Shepard	American	Charcoal cylinder pressing against charcoal cone	Vacuum	Stoppered glass globe
1852	M. J. Roberts	English	Graphite rod	Vacuum	Stoppered glass bulb
1854	H. Göbel (?)	German	Carbon thread	Vacuum	Sealed glass bulb
1856	C. de Changy	French	(1) Coiled platinum wire (2) Carbon rods	(1) Air (2) Vacuum	(1) Glass tube (2) Sealed glass bulb
1858	Gardiner and Blossom [d]	American	Coiled platinum wire	Vacuum	Signal lamp with reflector
1859	M. G. Farmer	American	Platinum strip	Air	None

Date	Experimenter	Nationality	Illuminant	Atmosphere	Container
1860	J. W. Swan[e]	English	Carbonized strips and spirals of paper and cardboard	Vacuum	Bottle or bell jar on brass plate
1865	Isaac Adams	American	Carbon strip	Vacuum	Sealed glass bulb
1872	A. M. Lodyguine	Russian	(1) Carbon rod (2) V-shaped graphite block	(1) Vacuum (2) Nitrogen	(1) Sealed glass globe (2) Stoppered glass globe
1875	S. A. Kosloff	Russian	Graphite rods	Nitrogen	Sealed glass tube
1875	S. W. Konn	Russian	Graphite rods	Vacuum	Sealed glass tube
1876	Bouliguine	Russian	Graphite rods	Vacuum	Sealed glass tube
1878	H. Fontaine	French	Carbon pencils	Vacuum	Stoppered glass globe

[a] This list includes the principal incandescent lamps made during the precommercial period. Most of the later workers had begun their experiments by 1878, but their work after 1877 belongs to the second phase of the lamp's technical development and must be considered separately.

[b] Received first patent (British) granted on an incandescent lamp.

[c] Received first patent (British) granted on a carbon incandescent lamp.

[d] Received first American patent granted on an incandescent lamp.

[e] Made first lamp using carbonized paper strips.

Sources: Association of Edison Illuminating Companies, *The Development of the Incandescent Electric Lamp Up to 1879*, 1929; J. W. Howell and H. Schroeder, *The History of the Incandescent Lamp*, 1927; Sawyer, *Electric Lighting*, 1881; Dredge (ed.), *Electric Illumination*, Vol. I, 1882; Fontaine, *Electric Lighting*, 1878; Commissioner of Patents (British), *Patents for Inventions: Abridgements of Specifications Relating to Electricity and Magnetism, Their Generation and Applications*, Pt. I, 1859, Pt. II, 1874, Pts. I–II (n.s.), 1880; and others.

cure longer life, experimenters usually attempted to obtain a vacuum in the globe or bulb and reduce the rate of chemical reaction. A few lamps contained nitrogen or a similar gas which would not combine chemically with the filament. Both schemes aided in lengthening lamp life and in improving lamp performance, particularly the vacuum method. Nevertheless, lamp design and the techniques of assembly were not yet sufficiently developed to produce lamps suitable for commercial use.

The limited practicability with existing energy sources led to almost universal abandonment of incandescent lighting by 1860, and this was true for arc lighting. Although a cheaper source of electric energy might have enabled some of the early lamps to operate moderately well with only small modifications, there were other difficulties. The forms of the carbon and metallic materials then in use as illuminants were not adequate for commercial use, and the existing mechanical pumps could not produce a vacuum sufficiently complete to give long lamp life.

The year 1870 marked an important turning-point in the struggle for an adequate source of electric energy. By the time the "subdivision of the electric light" was attacked in earnest in the United States and in England, inventors could assume an economical power source. Although the dynamo had to be adapted to their particular needs and there was considerable room for its improvement, they were able to devote a much larger share of their attention to the lamp itself than would otherwise have been possible.

The air-exhaust problem was practicably solved with the invention in 1865 of a superior mercury vacuum pump by Herman Sprengel, a German chemist in England, and with the perfection of methods for using this pump to exhaust glass bulbs in 1875 by the British scientist Sir William Crookes, during his experiments with the radiometer. After 1875 the problem of lighting by incandescence was again considered seriously. The work of Lodyguine, Kosloff, Konn, and their European contemporaries marked the resumption of interest in an important problem. Since an adequate source of energy and an adequate vacuum pump were available, the most satisfactory composition and form of the illuminant were the only important unknowns blocking commercial incandescent lighting. From that time on, the ultimate success of incandescent lighting seems to have been assured, although a great deal of arduous experimental work remained to be done.

Thomas A. Edison was the first inventor to discover a substance in a form which could satisfactorily be used in a commercial incandescent lamp.[7] He was, therefore, the person who successfully solved the last major unknown in a long series of unknown variables. His illuminant consisted of a high-resistance carbon conductor in filamentary form. The distinction between a carbon rod and a carbon filament was a real one and provided the basis for Edison's patent victory as well as for his commercial success.

Of the principal features of the successful Edison lamp of 1880, only the form of the conductor had not appeared in previous lamps, except for the questionable Göbel lamp of 1854. The vacuum-sealed glass globe, the material of the illuminant, the platinum lead-in wires and the other major characteristics were all well known. Starr, De Moleyns, Roberts, and several others had made vacuum lamps. The first Edison lamps sold commercially contained filaments made from carbonized paper, a material which Swan had utilized in his experimental lamps by 1860. Sawyer and Man had also used carbonized paper before Edison began his experiments. Other types of carbon had commonly been used as illuminants. Platinum wires had frequently been used both as lead-in wires and as illuminants. Sealed glass globes were likewise no novelty, although the stoppered type was more widely employed.

2. *Inventors Interested in Incandescent Lighting in 1877*

Individual inventors carried on most of the work during the early period of incandescent-lamp development. They were a heterogeneous group, and many of them conducted their experiments as sidelines to their regular professions. It is doubtful whether any had more than a small room, limited equipment, and meager funds. Neither established industrial concerns nor university facilities

[7] Even if Göbel did use a carbon thread, which is not certain, he abandoned his experiments at an early stage and did not exploit or publicize them in any way. This necessitated the rediscovery of whatever he had learned, as well as the development to a commercial stage.

were of much direct importance before 1877.[8] Large-scale financial support was forthcoming only after a measure of technical success had been realized and economic conditions presaged substantial financial return.

The illuminating-gas companies in the United States numbered well over five hundred by the time the incandescent lamp appeared on the market, and the companies in the leading cities were large and well financed. Nevertheless, they made no contribution to the development of the new type of lighting. In fact, the gas companies feared and opposed all electric lighting as a threat to their investment, which by 1880 amounted to about $150,000,000 in this country. The arc lamp soon became a dangerous competitor in the outdoor market, but that constituted only 10 per cent of the illuminating business. The sudden success of the incandescent lamp after 1880 threatened to take over the other 90 per cent as well. For the most part, the gas industry reacted by pushing its own product and opposing doggedly the expansion of all electric lighting. The gas industry as a whole did not have the vision to enter into and go along with the new development. Its opposition took such forms as belittling the advantages of electric lighting, exaggerating its disadvantages, attempting to influence municipal bodies against franchises to electric companies or ordinances to permit electric lighting, and attempting to influence safety standards established by insurance companies.[9] Despite all their efforts, the gas interests could not check the growth of the new light sources. In partial explanation of the obstructive tactics of the gas companies, it must be stated that the gas industry was undergoing its most rapid expansion at that time and was much too preoccupied with its own problems to understand fully the revolution in lighting technique which was taking place. Any research or development by the gas companies was confined to their own product.

Although the early histories of incandescent lighting and arc lighting had many experimenters in common, by 1877 the pro-

[8] By 1877 electrical engineering began to be recognized as a profession, although educational institutions had not yet accepted it as a field of specialization.

[9] See, for example, A. Hickenlooper, *Edison's Incandescent Electric Lights for Street Illumination* (report of an argument by A. Hickenlooper before the Committee on Light of the Municipal Council, City of Cincinnati, July 22, 1886), Cincinnati, 1886.

ponents of arc lighting seem to have become so attached to their own development that they had little or no time for incandescent lighting. The situation parallels that with respect to gas illumination. The rush of technical developments in connection with the arc lamp, the dynamo, and the other elements of an arc-lighting system, which had already reached the stage of practicability, did not encourage work on a device as yet no more than promising. Here again the experimenters did not envision the great future of incandescent lighting and, with one exception that will be pointed out later, made no direct contributions to the original development of the incandescent lamp.

Since neither the gas industry nor the arc-lighting industry was seriously interested in incandescent electric lighting, the field at first was left almost entirely to electrical inventors not tied to any previously established method of illumination. Most of these men had had experience with the telegraph or other electrical apparatus, or were mechanically talented and had turned their attention to this promising new field as a further step in their varied inventive careers. Many individuals were interested in the problem, but four inventors in this country and two in England were particularly concerned with "subdividing the electric light." Besides Edison, there were William E. Sawyer and Albon Man, working as a team, Hiram S. Maxim, Moses G. Farmer, Joseph W. Swan, and St. George Lane-Fox.[10] Swan and Lane-Fox were English; the rest were American. The work and contributions of each of these six inventors will be considered in turn in what seems to be an ascending order of their relative success.

MOSES G. FARMER

Moses G. Farmer was one of the two early pioneers in incandescent electric lighting whose interest and life span carried them over to the period of intensive development after 1877. His plati-

[10] Many other experimenters had lesser degrees of success. For example, the Englishman James Gordon developed an incandescent lamp in 1879 which used a platinum-iridium alloy in the illuminant. The superiority of the carbon-filament lamp of 1880 quickly superseded it. ("The Electrician," *Electrical Trades' Directory and Handbook for 1891*, London, 1891, p. xxxv.) Also, Edward Weston, who was born in England and emigrated to the United States in 1870, did some early experimenting with incandescent lamps. His attention was directed more to arc lighting, however, and it was not until after 1880 that he made his most important contributions to the incandescent lamp.

num lamps of 1858 and 1859 were crude devices in which specially shaped strips of the metal were heated to incandescence in the open air by electric current from a set of batteries. The light from this source was powerful enough for a partial lighting of his home in Salem, Massachusetts. Although his earliest experiments were abandoned before reaching commercial fruition, he accumulated considerable knowledge of the problems of incandescent lighting.

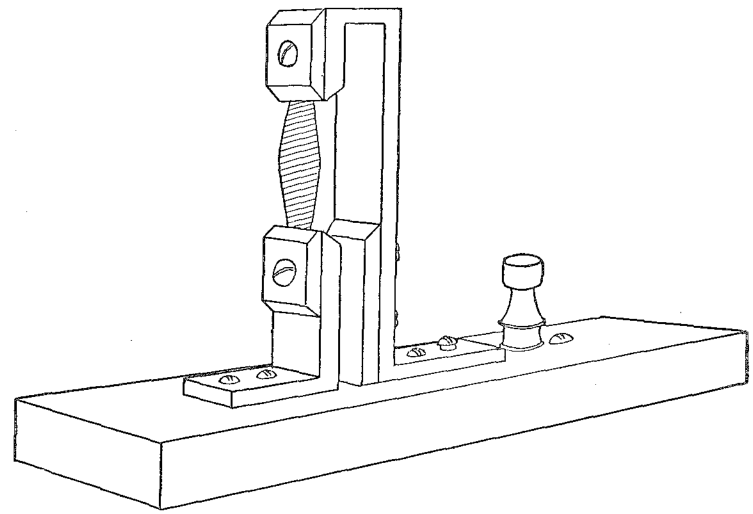


FIG. 9. Farmer Lamp, 1859
Platinum-strip lamp operated in the open air.

Farmer had been educated at Phillips Andover Academy and Dartmouth College, where ill health kept him from graduating. He began to teach but devoted his spare time to scientific experiments and became so interested in this work that in 1847, at the age of twenty-seven, he gave up teaching. The rest of his life was spent in the development of a wide variety of electrical and other devices. In 1847 he designed an electric locomotive powered by Grove batteries; the inefficient source of energy made it impractical. Later interests included the quadruplex telegraph, the printing telegraph, electric signaling systems, the dynamo, and the incandescent lamp. Farmer designed Boston's first fire-alarm telegraph system and manufactured telegraphic instruments for many

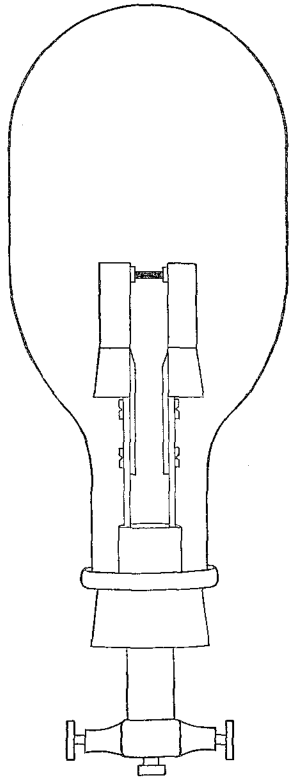


Fig. 10. Farmer Lamp, 1879
A graphite rod was used as the illuminant in an exhausted or nitrogen-filled glass bulb.

years. His suggestion of self-excitation of the dynamo has already been mentioned. His greatest financial success was in the field of telegraphy; he was ahead of his time to some extent in his early experiments on electric traction and electric lighting, and made no profit from them. From 1872 to 1881 he was employed as electrician by the United States naval torpedo station at Newport, and there he made his more important experiments in incandescent lighting. His interest later moved from lighting to the telephone and aviation and back to electric traction.

The first incandescent lamp made by Farmer after he resumed work in this field in 1877 did not carry him much closer to success than his earlier lamps of 1858 and 1859. The new device consisted of a graphite rod in an atmosphere of nitrogen. Around 1878, when series-wired arc lighting was proving successful, he proposed connecting incandescent lamps in parallel rather than in series, in order that each individual lamp might be controlled without affecting the others. He also favored a voltage regulation at the dynamo. Further efforts produced a lamp patented on March 25, 1879, which contained a horizontal carbon rod between two large carbon blocks in an exhausted or nitrogen-filled glass globe. The sealing did not remain permanent, and this lamp also was unsuccessful. The Farmer patents shortly came under the control of the United States Electric Lighting Company, discussed below. This company became an important factor in the early history of the electric-lighting industry, but the Farmer patents proved to be of only minor commercial value.

HIRAM S. MAXIM

Another versatile experimenter, who did not, however, arrive at a practical incandescent lamp until Edison had shown the way, was Hiram S. Maxim. After a pioneer boyhood in Maine, he worked for several manufacturing companies before he became interested in electric lighting. He had experience in the production of coaches, machinery, scientific instruments, ironwork, and ships. His inventions up to that time had been limited to steam engines and automatic gas machines, but he had learned a great deal about all phases of practical engineering in spite of his lack of formal education.

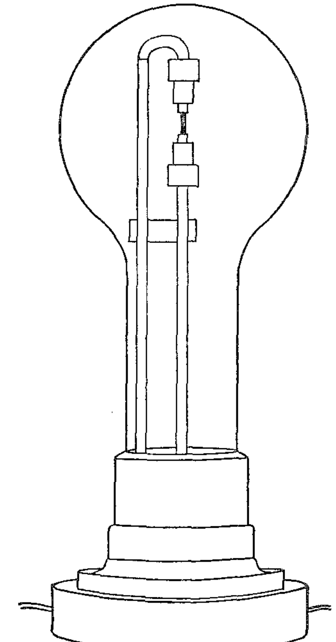


Fig. 11. Maxim Lamp, 1878
The illuminant was a graphite rod brought to incandescence in hydrocarbon vapor.

Maxim's interest in electricity started around 1877. He became chief engineer for the newly formed United States Electric Lighting Company, which he founded along with Messrs. Schuyler and Williamson. Although the company was primarily interested in arc lighting, he conducted incandescent-lighting experiments in its laboratories for a number of years. This was evidently the only arc-lighting company which actively tried to develop incandescent lighting to a commercial stage. Maxim's first incandescent lamp consisted of the old sheet platinum burner in air, not much different from Farmer's lamp of 1859. The main original feature of Maxim's lamp was an automatic short-circuiting device which permitted the platinum to cool for an instant when it became too hot. Another lamp, for which a patent application was made in 1878 and granted in 1880, was composed of a graphite rod in a glass globe. The rod became incandescent when it was heated by an electric current in rarefied hydrocarbon vapor. It, also, was protected from excess current by an electromagnetic device which short-circuited the graphite burner when it became too hot.

In 1878, after carrying out the experiments mentioned above, Maxim for a while devoted an increased proportion of his time to arc lighting and to problems of electrical generation, distribution, and control. He had turned back to incandescent lighting with renewed vigor by 1879, however, when activity by his competitors and public interest had been raised to a new high pitch.

Maxim's commercial lamp of 1880, which he used in a successful installation only a few months after Edison's first installation, differed from the Edison lamp in no essential particular. His high-resistance filament was cut from cardboard, carbonized, and sealed into an exhausted glass bulb. At first the filament resembled a Maltese cross, but in later lamps it took the shape of an **M**. It is claimed by Jehl,[11] one of Edison's original helpers, that Maxim was able to make a satisfactory lamp only after Edison had personally explained to him the entire process, and after he had enticed away one of Edison's best assistants. The great similarity of the two types of lamp indicates that this may well have been true. The production of the Maxim lamp began in the summer of 1880, and installations of the Maxim incandescent-lighting system were made by the United States Electric Lighting Company for a number of years.

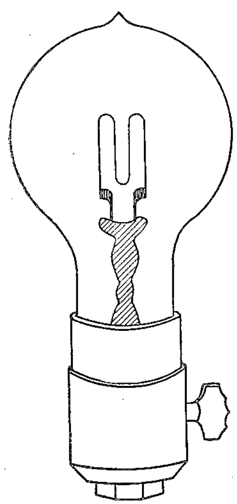


FIG. 12. Maxim's Commercial Lamp

A vacuum lamp employing a high-resistance carbon filament.

In one respect the Maxim lamp was superior to the Edison lamp. It employed a filament treated with hydrocarbon vapor to equalize and standardize its resistance. Maxim was able to patent his method of treatment in October, 1880, despite an earlier patent by Sawyer and Man covering the same process. Although the processes were similar, the disclosure of Sawyer and Man was more restricted and enabled Maxim to make his specific claims. Maxim concurred with Edison, Sawyer, and others in employing a self-regulating generator to maintain an even flow of current and in operating his lamps in parallel.

[11] Francis Jehl, *Menlo Park Reminiscences*, 2 vols., Edison Institute, Dearborn, Mich., 1936–1939, Vol. II, pp. 611–613.

After a few years' concern with electric lighting, Maxim moved on to new fields. He won particular renown for his inventions on guns, starting around 1883.[12] In later years he became interested in other problems, such as aerial navigation.

ST. GEORGE LANE-FOX

A third inventor actively engaged in developing a commercial incandescent-lamp was the Englishman, St. George Lane-Fox. In 1878 he patented his first lamp consisting of loops of high-resistance platinum-iridium wire in an atmosphere of nitrogen or air in a stoppered glass tube. He made another lamp about the same time with a "burner" of asbestos impregnated with carbon and placed in a nitrogen-filled glass bulb. The nitrogen was introduced, as in some earlier lamps, to prevent oxidation of the illuminant. Neither lamp proved satisfactory.[13]

When the success of other inventors pointed the way in 1880, Lane-Fox rapidly redesigned his lamp, using a carbon filament in a vacuum glass globe. He carbonized a French grass fiber, removed its hard outer surface, and then treated it with hydrocarbon vapor to obtain a filament of uniform resistance. Lane-Fox received a British patent on this treating process on March 10, 1879. The process had been discovered in the United States by Sawyer and Man, however, before its apparently independent development by Lane-Fox.

[12] Maxim went to England in 1881 after serving as the representative of the United States Electric Lighting Company at the Paris Exposition. He became an English subject and was later knighted for his inventive accomplishments.

[13] One great difficulty in the use of nitrogen or other chemically inactive gases instead of vacua in incandescent lamps is that the gases conduct heat away from the illuminant and reduce its efficiency. A counteracting factor, the tendency of the gas to reduce the rate of vaporization of the illuminant, is utilized in modern filament lamps to increase operating temperatures and lamp efficiency. With carbon lamps, especially those of the small sizes used before 1880, the negative effects of using nitrogen are greater than the positive effects, and a vacuum lamp is more satisfactory.

Lane-Fox developed a distribution system different from that which had previously been outlined or was subsequently adopted by other important inventors. He accepted the generators of other inventors without significant change but used a single-wire circuit with both the lamps and the generator grounded so that the earth acted as the return conductor. The flow of current was regulated by a battery arrangement. The system was ingenious but not wholly satisfactory. For the measurement of current consumption he devised three different types of electric meter. Despite the breadth of his experiments, the most important advance made by Lane-Fox over the work of his predecessors was his early employment of a high-resistance illuminant.

The Lane-Fox system finally decided upon after 1880 was introduced commercially in England by the Anglo-American Brush Electric Light Corporation, Ltd., which was organized in that year. This concern bought the British dynamo and arc-lamp patents of Brush as well as the incandescent-lamp patents of Lane-Fox. As a consequence, it was able to license operating companies and supply equipment for either type of electric lighting.

WILLIAM E. SAWYER AND ALBON MAN

William E. Sawyer first took an active interest in incandescent lighting in 1875, after some desultory work in this field. He had developed his interest while working as a telegraph operator in New England and later as a reporter and journalist in Washington, D.C. By 1877 he was devoting his entire attention to electrical experimentation, and he had developed several lamps which employed graphite burners in atmospheres of nitrogen and at least one other which used a platinum illuminant. His glass globes were cemented to metal holders and could be opened to renew the graphite in the carbon lamps. Current was distributed by a wiring arrangement with the lamps in parallel. The most that could be said for these lamps was that they held a promise for the future.

Sawyer was hampered in his work by his meager financial resources. Early in 1878 he met Albon Man, a middle-aged Brooklyn lawyer, who became interested in the work and undertook to assist him ostensibly as a financial partner. Man's interest in scien-

tific matters grew so rapidly, however, that he soon became an active partner in the experimental work. The joint efforts of the two men produced a number of lamps employing a great variety of carbon burners in nitrogen or in a vacuum. The first lamp which was exhibited utilized a carbon pencil held by carbon blocks. A pencil held so rigidly did not allow for expansion and contraction of the carbon and frequently broke. To allow for this, the carbon was formed into an arch or horseshoe. First, the arch was fashioned from a rod of retort carbon, and later twigs of live willow and many other substances were tried. Among these materials was carbonized paper cut into a horseshoe shape. Although at the time, during 1878, the paper illuminant did not seem to hold much promise, it nevertheless represented the closest that Sawyer and Man came to the eventual solution. Their use of this material anticipated Edison's first commercially produced incandescent lamp, yet the thickness of the Sawyer and Man illuminant was much greater than that of the successful filament of Edison.

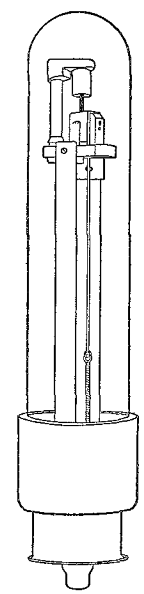


Fig. 13. Sawyer's Final Lamp, 1879

A nitrogen-filled lamp employing a carbon rod as the illuminant.

In the midst of these experiments, on July 8, 1878, the Electro-Dynamic Light Company of New York was incorporated to manufacture lamps according to the Sawyer-Man system and to carry on further development. It was formed with the aid of a group of New York capitalists who had hopes for large profits from this new type of lighting. In the same year Sawyer and Man added to the completeness of their electric-lighting system with the invention and patenting of a mechanical meter for the measurement of current consumption.

Further experimentation indicated that to renew the carbon in the horseshoe-type lamp took too long and was too expensive; and the lamp was redesigned in 1879. The new model contained a long carbon pencil which fed upward as it was consumed, and was designed for cheap carbon renewal with easy sealing and exhausting. Nitrogen was used within the glass globe to reduce the rate of oxidation of the carbon. This lamp seems to have represented the final choice of Sawyer and Man. Although more efficient than their previous lamps and offering more apparent likelihood of commercial success, it took them a step backward to the complicated and uneconomical lamps of Konn, Bouliguine, and other predecessors.

Sawyer and Man confined their attention almost exclusively to nitrogen-filled lamps after the few experiments which they made with vacuum lamps seemed to prove them failures. They realized that no vacuum could be perfect, and that there would always be some molecules of oxygen to carry on chemical action. From this they reasoned incorrectly that chemical action alone was responsible for decay of the illuminant. They did not believe that vaporization of the carbon could be responsible, since the temperature of the carbon was below its melting point. Actually, vaporization is almost as great a threat to incandescent lamp conductors as chemical action. The gas-filling of the lamps of Sawyer and Man served to reduce vaporization without their knowing it; but at the same time it resulted in excessive cooling of the filament, and the lamps were not successful.

All the carbon illuminants used by Sawyer and Man were comparatively stubby as compared with Edison's long, slender illuminants. Although Man was sympathetic to the idea of trying longer and thinner carbons of higher resistance, Sawyer's insistence that the resistance must be kept as low as possible confined their attention for the most part to short, thick carbons.[14] Even after Edison's disclosure, Sawyer expressed the belief that only a low-resistance illuminant was feasible. Several years passed before he admitted the superiority of the Edison-type lamp.

An outstanding contribution of Sawyer and Man seems to have been their first discovery of the method of preparing carbons by "flashing" them in an atmosphere of hydrocarbon gas. As the carbon was heated by the gradually increasing strength of an electric current flowing through it, those portions of greater resist-

[14] Pope, *op cit.*, p. 74.

ance were heated most rapidly. The hydrocarbon vapor in contact with these hotter portions decomposed, depositing a layer of pure carbon on the horseshoe or pencil. In this manner carbon was precipitated where the resistance was highest, and the process could be controlled to produce any desired resistance uniformly along the entire length of the illuminant. Lamps with treated carbons were more efficient than those containing untreated carbons.

The process was patented by Sawyer and Man in the United States on January 7, 1879, and by their agent in England somewhat earlier. Its importance was not appreciated until after the incandescent lamp had come into commercial production, however. By then Lane-Fox in England and Maxim in the United States had each patented similar processes for use in connection with their own lamps, and Edward Weston had carried out experiments along the same line. Most other leading manufacturers, except Edison, subsequently gained the right to use the process through mergers, licenses, or the outright purchase of a patent.

JOSEPH W. SWAN

Joseph W. Swan[15] was the second individual who played a part in both early periods of the technical development of the incandescent lamp. Swan was originally a chemist; but long before he turned his entire attention to electric lighting he had made a brief investigation of the problems of lighting by incandescence. As early as 1860 he had made various experimental incandescent lamps in England, employing horseshoe-shaped carbonized strips of paper and cardboard of low resistance as his incandescent material. These early lamps, operating in a vacuum inside a bottle or bell jar, broke down quickly because of air leaks. Discouraged by the meager results of this work, Swan discontinued his experiments on lighting for a number of years.

As laboratory assistant to a firm of manufacturing chemists, Swan made his early technical contributions primarily in the field of photography. He developed a dry plate, a practical carbon printing process and bromide printing paper, among other things.

[15] He later was knighted in recognition of his scientific achievements, particularly with respect to incandescent lighting.

He also later designed an improved cellular-surfaced lead-plate storage battery.

Stimulated in large part by Crookes' success in obtaining a vacuum in his radiometer with the aid of a Sprengel mercury pump, Swan in 1877 resumed his attempts to make a practical incandescent lamp.[16] With the assistance of Charles H. Stearn, who was skilled in the use of vacuum pumps, he repeated his experiments with carbonized paper and cardboard. Higher vacua brought more encouraging results. Nevertheless, the lamps deteriorated rapidly in operation, as water vapor and gases were given off by the hot glass and the incandescent carbon. Early in 1879 Swan found that he could overcome this difficulty by heating the bulb in a flame, and by passing a strong current through the carbon while it was still connected to the exhaust pump. In this manner, the occluded vapors and gases were driven off and a better vacuum could be maintained throughout the life of the lamp. At about the same time, Edison made the same discovery during his experiments with platinum and platinum alloy illuminants for the incandescent lamp.[17]

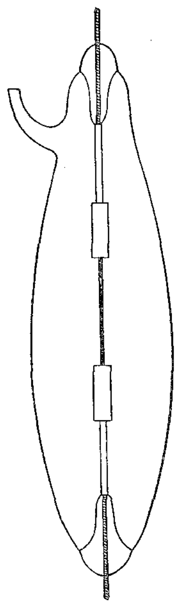


FIG. 14. Swan Lamp, 1878

A vacuum lamp employing a slender carbon rod enclosed in a sealed glass bulb.

The progress of Swan and Edison in their search for a practical incandescent lamp seems to have been fairly comparable during most of 1879. Swan recognized that low-resistance carbon lamps were not adequate and worked in the direction of higher resistances; Edison realized that he could not obtain the desired results with platinum and swung over to carbon. The Swan lamp, which by that time was employing a very slender carbon rod in a vacuum-sealed glass bulb, was the closest competitor to Edison's

[16] The work was done independently by Swan and not for the chemical company.

[17] Alglave and Boulard (*op. cit.*, p. 172) claim that Edison preceded Swan in this discovery, and that Swan merely applied Edison's results in platinum to his own problems in carbon. Other contemporary writers do not support this claim.

commercial lamp of 1880, even though Swan had not yet progressed to the use of carbon in filamentary form. It was claimed that Swan anticipated Edison by making successful demonstrations with his lamps in December, 1878, and the summer of 1879; but it seems clear that those lamps deteriorated rapidly and were otherwise not suitable for commercial application. Swan shifted from his slender rods to a carbon filament similar to that of Edison some time after the announcement of Edison's real success.[18] Moreover, Swan's results were not released to the public until June, 1880, and he was relatively slower in taking out patents on his inventions.

Another respect in which Swan notably lagged behind Edison was his lack of provision for the distribution of current to his lamps and for other elements of a complete lighting system. He contributed nothing to the development of the dynamo and advocated the use of series wiring for the transmission of current. Even after the advantages of wiring lamps in parallel had been pointed out by other inventors, he did not immediately admit the superiority of this method of energy distribution.

British patents were granted to Swan in 1880 on his developments, and in the same year a company was formed to manufacture incandescent lamps of his design. The Swan lamp was introduced to the public soon after its technical development.

Continuing his attempts to improve the texture of the illuminant, Swan discovered a process of "parchmentizing" cotton thread with dilute sulphuric acid before carbonization, for which he was granted a British patent late in 1880. Although he had patented

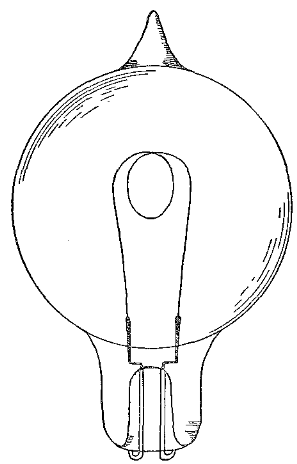


FIG. 15. Swan's Commercial Lamp

A high-resistance carbon lamp operating in a vacuum.

[18] Some English writers never admitted the priority of Edison in developing the first practicable incandescent lamp; and even at the present time there remains some slight difference of opinion on the matter. The verifiable facts all point to the conclusions given above.

the same process earlier in the year in connection with paper filaments, he soon found that the thread produced more efficient illuminants. "Parchmentized" filaments were structureless, unlike the Edison filament, and hence more uniform and more efficient than untreated fibers.

3. The Work of Thomas A. Edison

Thomas A. Edison was the last of the six leading inventors to undertake the "subdivision of the electric light." He made his first experiments with electric lighting in 1877, and he became seriously interested in the new field only in the summer of 1878, when he inspected the electrical-goods factory of William Wallace at Ansonia, Connecticut, and was greatly excited by the dynamo and arc-lighting system which Wallace showed him. Although Edison secured one of the dynamos[19] for use in his own laboratory, he felt that the solution to the electric-lighting problem lay in the incandescent lamp rather than the arc lamp.

In 1878, at the age of thirty-one, Edison had already made many important inventions and was known as the "Wizard of Menlo Park." He had not attended school, but under the tutelage of his mother he had read history and science voraciously. At a very early age he went to work as a newsboy on a railroad. He quickly expanded his activities to include publishing a paper, running a news stand, and other profitable ventures. While engaged in all these endeavors, he undertook chemical experimentation and learned telegraphy. As a telegraph operator he acquired experience in electricity and devoted most of his income to experimentation on whatever attracted his attention. When hardly out of his teens, he went to Boston as a telegraph operator and opened a small workshop for experimentation. He ran into debt while perfecting a chemical vote-recorder. Even though the recorder worked satisfactorily, he could find no purchaser for it. This experience is said to have made him determine never again to work on an invention unless he was sure it would be useful.

Edison's inventive career flowered rapidly after he went to New York in 1869 at the age of twenty-two. He was fortunate

[19] This dynamo was a product of the joint efforts of Wallace and Farmer, who had had a long-standing interest in generating machines.

in selling at good prices several inventions in the telegraphic field, such as his stock-ticker and gold-ticker, which freed him from debt and provided funds for further work. Improvements in the multiplex telegraph, printing telegraph, and other devices further established him as a leading inventor, and in 1870 he set up shop as a successful manufacturer of stock-tickers and telegraphic instruments in Newark, New Jersey. While there he also invented the mimeograph and the electric pen; but he found the conflict between manufacturing and inventing to be irreconcilable. To gain the freedom he wished, he gave up manufacturing in 1876 and with his own money established a laboratory at Menlo Park, New Jersey, where he could devote all his time to experimentation. It was there that his greatest technical contributions were made; for, besides the incandescent lamp and all its related devices, he developed the carbon telephone transmitter, microphone, phonograph, magnetic ore separator, and many other devices. After about 1885 he moved on from the incandescent lamp, as most of his fellow inventors had done, and devoted his efforts to a whole new series of interests, including the Ediphone, the motion-picture camera, an alkaline storage battery, talking motion pictures, and improved methods of producing carbolic acid and other chemicals. He took out over one thousand patents on the inventions made during his lifetime.

FIRST EXPERIMENTS ON INCANDESCENT LIGHTING

During the last few months of 1877 Edison had experimented with incandescent lamps employing carbon, platinum, boron, chromium, and other substances as illuminants. However, the development of the phonograph was claiming most of his attention, and the lamp experiments received only secondary notice. They were laid aside for more than half a year when the pressure of other work became greater and his health was temporarily impaired.

When he saw the Wallace-Farmer dynamo and arc light in 1878, Edison was struck forcibly by the possibilities of electric illumination. Despite his familiarity with electricity and his incandescent-lighting experiments of the year before, he had not given much thought to this field. Now, however, he attacked the development of an incandescent lamp with great enthusiasm and vigor, and problems of the lamp and the lighting system occupied most of his attention for six or seven years.

Before initiating actual experimentation on incandescent lighting, Edison made a very intensive study of all phases of gas illumination and reasoned out carefully what he wished to accomplish. He strove to duplicate gas lighting with electricity, retaining the good features while eliminating the bad ones. He proposed to make lamps of about the same candlepower as gas jets and to distribute energy to them in an analogous manner, so that each lamp could be operated independently of all other lamps on its circuit.

One of the first public statements which Edison made about his new interest and his intentions appeared in a newspaper interview. Edison said to the reporter:

> I have let the other inventors get the start of me in his matter, somewhat, because I have not given much attention to electric lights; but I believe I can catch up to them now. I have an idea that I can make the electric light available for all common uses, and supply it at a trifling cost, compared with that of gas. There is no difficulty about dividing up the electric currents and using small quantities at different points. The trouble is in finding a candle that will give a pleasant light, not too intense, which can be turned on or off as easily as gas. Such a candle cannot be made from carbon points, which waste away and must be readjusted constantly while they do last. Some composition must be discovered which will be luminous when charged with electricity, and that will not waste away. A platinum wire gives a good light when a certain quantity of electricity is passed through it. If the current is made too strong, however, the wire will melt. I want to get something better.[20]

Edison was aware of the long technical history of incandescent lighting and the progress toward fulfilling the public need for the "subdivision of the electric light." He was also aware of the nature of the work which was currently being performed by Sawyer and Man, Maxim, and the others. He knew that he was entering the development late, but hoped to be the first to invent a commercially satisfactory incandescent lamp. The most difficult aspect of the problem was the composition and form of the incandescent material.

[20] *New York Tribune*, Sept. 28, 1878, p. 4.

There were elements both of financial reward and of personal glory in being the inventor of the first successful incandescent lamp. Edison was far from oblivious of the possible financial returns, but he had what is commonly thought of as the inventive spirit to such a degree that for him pecuniary reward seems to have been secondary. When the reporter suggested that he might "easily make a great fortune," Edison replied, "I don't care so much for fortune as I do for getting ahead of the other fellows."

He had a far more elaborate and fully staffed laboratory than any competing inventor, and he was well aware of this advantage. In the same interview, he commented on his acquisition of the Wallace dynamo: "Now that I have a machine to make the electricity, I can experiment as much as I please. I think . . . there is where I can beat the other inventors, as I have so many facilities here for trying experiments." The laboratory was one of the earliest industrial laboratories of significance in the United States. Its facilities and staff were small by present standards but very large by those of the time. It is evident that this organized invention was a major factor in Edison's eventual triumph over his competitors, equal in importance to his own innate genius and ability. Pope's statement, that the outcome of a race between two inventors is perhaps as often as otherwise determined by chance or accident,[21] was not correct in this instance. Under the circumstances, the probability of success was greater for Edison than for any of his rivals.

Many of Edison's chief assistants went with him from Newark to Menlo Park, and their continuity of experience with him on a variety of problems was helpful in developing an incandescent lamp. The number of workers in the new laboratory and surrounding buildings grew as the years went by, particularly after 1879, although in 1878 the nucleus of the force totaled scarcely a score of men, among whom Francis R. Upton, Edison's mathematician, was one of the few college graduates. Besides the central group, there were many less highly skilled laborers, however. The laboratory was entirely devoted to practical engineering development, with a financial return expected from every project.

Despite his optimistic statements to the *Tribune* and other re-

[21] See above, p. 35.

porters,[22] which aroused widespread public interest and precipitated a brief crisis in gas-company stocks, Edison's first idea for an incandescent lamp resulted in complete failure. The experiments were performed with carbonized paper and other carbon conductors, and their lack of success seemed to prove the impracticability of carbon. Edison went so far as to state on November 25, 1878, that he had tried carbon and carbon would not do,[23] whereas two days previously Sawyer had said publicly that he had cast platinum aside as worthless a year before.[24] Both Sawyer and Maxim were devoting almost their entire attention to carbon even as Edison temporarily abandoned it.

Grosvenor P. Lowrey, a leading New York lawyer and friend of Edison, had become interested in electric lighting shortly before that time and had urged Edison to speed his work on the incandescent lamp. Because Edison felt that he could not carry all the expense of the development himself, the two, with the assistance of a number of Lowrey's capitalist clients, including J. P. Morgan, organized the Edison Electric Light Company on October 17, 1878, with a capital of $300,000. The funds enabled Edison to expand his facilities and continue the work. This company was the first in the series of Edison development and manufacturing companies which were eventually brought together under the Edison General Electric Company, a forerunner of the present General Electric Company. The young electric-light company also later became the parent patent-holding company in the hierarchy of Edison central-station illuminating companies.

Edison's long record of success with previous inventions had gained for him the almost unlimited financial support of his backers. Nevertheless, he was required to give evidence of commercial promise for all inventions supported by their funds. The coupling of the inventor's energy, perseverance, and creative genius with the shrewdness of his financial supporters provided a most effective leadership for Edison's commercial laboratory.

22 See, for example, articles printed by the *New York Sun*, Sept. 16 and Nov. 25, 1878, and by the *New York Herald*, Oct. 12, 1878.

23 Article in *New York Sun*, Nov. 25, 1878.

24 Letter in *New York Commercial Advertiser*, Nov. 23, 1878. (See Pope, *op. cit.*, p. 23.)

UNSUCCESSFUL EXPERIMENTS WITH PLATINUM

Having temporarily given up on carbon, Edison turned to platinum and other metals and for nine or ten months repeated the experiments of his predecessors, trying vainly to develop a practical incandescent lamp of this type. Some initial success in these new experiments roused Edison's enthusiasm for further public statements that he had the problem almost solved. Again there was a sharpening of public interest and a flurry in gas shares. The lamps with platinum "burners" in air or in a vacuum did not merit the claims Edison made for them, but they taught him many

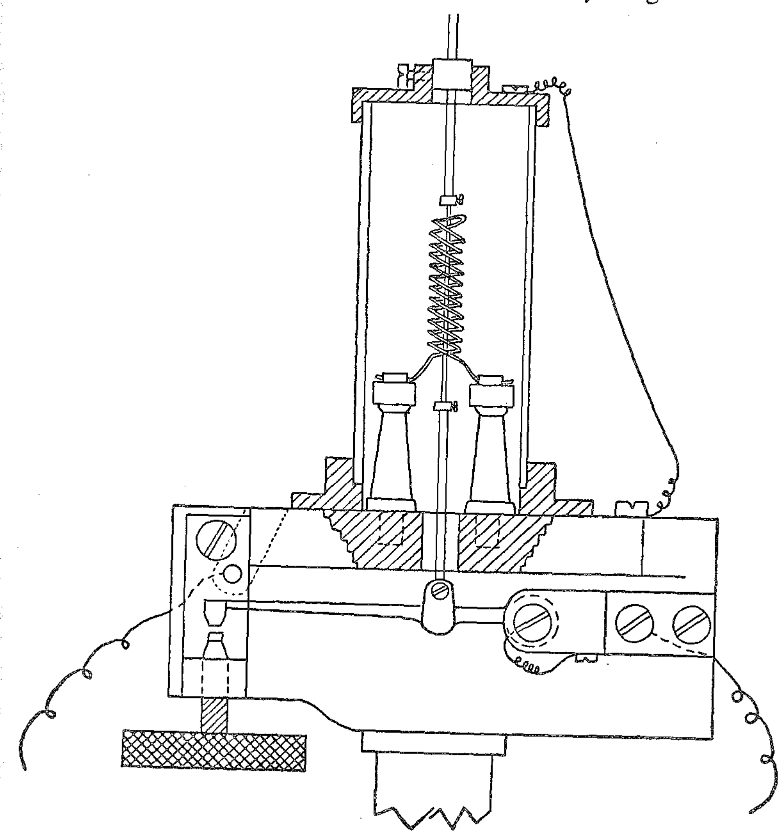


Fig. 16. Edison Platinum Lamp, 1878
A platinum-wire lamp employing a thermostat to protect the wire from excessive currents.

things which helped considerably in making a successful lamp when he turned back to carbon.

The first two platinum lamps developed had thermostatic devices for short-circuiting the platinum wire when it became too hot. A momentary interruption in the current prevented the wire from melting and destroying the lamp. This idea was not new, however, for Maxim and others had already developed similar current regulating devices. The complexity and unsatisfactory operation of this sort of regulator later encouraged Edison to work out a method of regulation at the generator, a scheme which Sawyer and Man had favored even before Edison's first lamps were made.

Many other lamps were developed during that period. One was of platinum foil, similar to Farmer's lamp of 1859. Another was similar in some respects to Jablochkoff's "electric candle," employing a composition of a finely ground metal, usually platinum or iridium, with a non-conducting material like clay. All these lamps contained illuminants of low resistance, and none was practical.

Edison was the first inventor to consider the cost of wiring a city for electric lighting, and he discovered that with low-resistance "burners" the electric mains carrying the current would have to be of such great cross section that the cost would be prohibitive. He became convinced, contrary to almost all other leading electricians, that the solution to practical incandescent lighting lay in a high-resistance illuminant of small radiating surface which would require only a small flow of current.[25] Among several lamps devised upon this premise one employed a carbon rod pressing upon one of platinum. The poor electrical contact caused the carbon rod to glow brightly. Although this was not satisfactory, it led to a series of attempts in the spring of 1879 which were more successful. High-resistance lamps were made of thin platinum wire in sealed vacuum bulbs. The platinum wire was wound on small spools of clay, coated with zirconium oxide to retard evaporation of the platinum, and connected to larger

[25] The success of Edison's experimentation and invention is a great tribute to his reasoning ability as well as to his ingenuity and perseverance, for the knowledge of electrical mathematics was still very limited at that time.

platinum lead-in wires which brought the electric current through the glass.

The high-resistance platinum lamps were much more satisfactory than anything Edison had tried before, and he came closer than any previous experimenter to making a practical platinum lamp. Nevertheless, his results were not all that could be desired for commercial use. A fundamental difficulty lay in the conflict between the temperature required for the incandescence of platinum and its melting point. Even though the melting point of platinum is higher than that of most metals, it proved to be too low for an incandescent lamp of satisfactory efficiency. Moreover, in platinum lamps which used coatings of zirconium oxide, the oxide became a conductor when heated during operation and short-circuited the platinum. The elimination of the thermostatic devices from the platinum lamp left a lamp looking almost exactly like the carbon lamp of six months later, except for the illuminant.

Other metals and nonmetals, such as boron, silicon, iridium, rhodium, chromium, zirconium, zirconium oxide, titanium oxide, and osmium, were tried as illuminants without any greater success. Some of them were used much later by other experimenters in the attempt to improve incandescent lighting, and some, when used in the proper form, are actually superior to carbon. Nevertheless, the state of chemical science and the tools with which Edison had to work were not adequate for successful application to incandescent lamps at that time. If tantalum, osmium, and tungsten, with their higher melting points, had been available to Edison in the form of slender wires, it is almost certain that a practical lamp would have been made then. These elements were known, and osmium was tried, but twenty to thirty years went by before they were successfully made into fine wires. Their ultimate employment was the work of trained chemists far more than that of electricians.

Edison decided quickly that a vacuum in the bulb was preferable to an inactive gas. Almost all his later experiments were made with vacuum lamps. He reasoned that, even though a gas did not combine chemically with the illuminant, it gradually destroyed it by "air-washing," which he described as "the attrition produced by the rapid passage of the gas over the slightly-coherent highly-heated surface of the carbon."[26] His reasoning was not correct, yet his conclusion that vacuum lamps were preferable to gas-filled lamps was correct for his time and was substantiated by several decades of commercial experience. It was not until after the introduction of the tungsten filament that gas-filled incandescent lamps were used on a large scale.

In the course of his attempts to obtain vacua in the glass bulbs of the platinum lamps, Edison made a discovery very important to the later success of his carbon lamp. He found that vapors and gases were occluded in the glass bulb and stem and in the metal filament. When the lamp was operated, the gases were given off and impaired the vacuum. The same discovery with respect to carbon filaments was made about the same time by Swan, as has already been stated. Each man learned how to maintain a satisfactory vacuum in his lamp by heating the filament and bulb as the lamp was being exhausted. The heating and cooling of the filament not only drove out the occluded gases but also made the surface of the illuminant hard and dense, decreasing its brittleness and increasing the temperature at which it could be operated.

SUCCESS WITH CARBON

Despite the much improved results with platinum, it became evident that a platinum lamp of sufficient efficiency could not be made cheaply enough to compete successfully with other forms of illumination. In the fall of 1879 Edison once again turned to carbon. Although the illuminant was still a most troublesome problem, great progress had been made in the decision to employ a high-resistance conductor. Edison's task was to discover a material of the proper resistance with a high enough melting point to be heated to efficient incandescence without destruction. It was said that the renewed interest in carbon came one night as the inventor absent-mindedly rolled between his fingers some of the lampblack and tar which were lying on the table. The thought presented itself that a filament of such material might solve his problem.[27]

In September and October, 1879, Edison and his men performed a large number of experiments with carbon conductors.

[26] From specifications of Edison patent No. 223,898, dated Jan. 27, 1880.
[27] Jehl, *op cit.*, Vol. I, 1936, p. 331.

They tried hundreds of different forms of carbon in rapid succession, taking advantage of their excellent facilities for speedy development. The experiment which finally led to success started on October 19. A piece of cotton sewing thread was carbonized by heating it to a very high temperature out of the presence of oxygen. This thread, bent into a hairpin shape, was then fastened to two platinum wires mounted on a glass stem. The wires led through the stem and out of the exhausted glass bulb containing the carbon filament and were inserted in an electric circuit. When tested, this filament burned for almost two days.

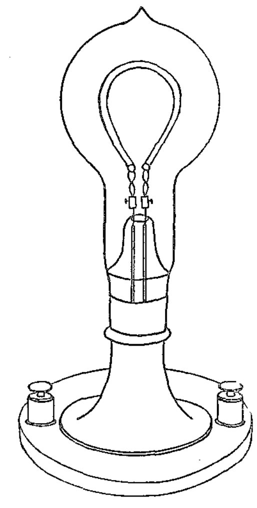


FIG. 17. Edison Paper-Filament Lamp, 1880
A vacuum lamp employing a horseshoe-shaped Bristol-board filament.

Feeling confident that some form of carbon would give him what he was looking for because its melting point was so high,[28] Edison continued his search for the best possible material. The carbonized cotton thread was very fragile, and a more serviceable illuminant was desired. Paper provided a tentative answer. It had been used as the material in illuminants by previous experimenters, although never as a high-resistance filament. Some of the first Edison lamps made with narrow horseshoe-shaped pieces of carbonized Bristol board lasted as long as 170 hours. Bristol-board filaments were used in the initial public demonstration of the lamp on New Year's Eve and in the first commercial lamps made by the newly formed Edison Lamp Company late in 1880. Widespread public skepticism at this third announcement of Edison's success gradually gave way to enthusiasm after his demonstration and trial installation had been reviewed.

The paper filament was not wholly satisfactory, even though Edison put it into commercial production, and thousands of ex-

[28] The melting point of carbon is about 3500°C., but it volatilizes rapidly at temperatures above 1700°C. Even at the temperatures between 1500° and 1600°C. which were eventually used in most carbon lamps, the vacuum had to be very good to protect the carbon from rapid oxidation.

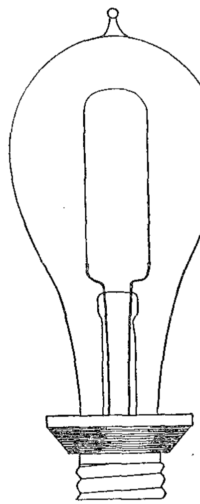


FIG. 18. Edison Bamboo-Filament Lamp, 1881
A vacuum lamp employing a special Japanese bamboo as the filament material.

periments were performed with other substances. One day he saw a palmetto fan lying on a table and had one of his men make a filament from the bamboo strip which held it together. The efficiency of the lamp made from it was so much greater than the efficiency of those using paper that bamboo became the standard filament material in the Edison works until 1894. Taking advantage of his financial resources, Edison sent several expeditions to China, Japan, the Amazon Valley, India, and other remote places to find still better fibrous materials. A particular type of Japanese bamboo was found to be most satisfactory, and for many years it was cultivated especially for him by a Japanese farmer.

Edison attempted to protect all his important developments by patents in foreign countries as well as in the United States. On or about November 4, 1879, he applied for American, British, Canadian, French, and other patents to cover his cotton-thread filament lamp. The British patent was granted November 10, and the Canadian patent November 17. The American patent was not issued until the following January 27. Even though paper illuminants quickly replaced the cotton thread, the bamboo filament represented a return to the use of structural vegetable fibers, which were prominently mentioned in the first patent.[29] That patent, No. 223,898, proved to be the basic patent in the early American incandescent-lamp industry.

Edison applied for a second patent December 11, 1879, to cover a similar lamp using an illuminant of carbonized paper, preferably Bristol board. That application ran into unexpected difficulties in the United States Patent Office, although the British application was granted within a few days. For more than five

[29] Another patent specifically pertaining to the use of bamboo was granted Dec. 27, 1881.

years Edison fought to secure the American patent, only to lose in the end.

It will be remembered that Sawyer and Man had made incandescent lamps using low-resistance paper conductors early in 1878. They did not apply for a patent on their development, however, until after Edison. Papers had been drawn up and given to their patent representative for the purpose of obtaining a patent, but Sawyer had refused to sign the application. Soon after the organization of the Electro-Dynamic Light Company friction had developed as a result of Sawyer's disreputable personal habits, and he was discharged. He organized the Eastern Electric Manufacturing Company in 1879, and for a time seems to have been interested primarily in breaking down the first company which he had helped to establish.[30] As might be expected, technical progress by both Sawyer and Man was seriously impaired. When Edison made his disclosure on the paper filament, Sawyer recognized the importance of his own previous work with Albon Man, and on January 9, 1880, he signed the application. The two applications promptly went into interference in the patent office, and they were locked in a long struggle to obtain legal supremacy. Despite Edison's priority of application, Sawyer and Man were able to prove priority of reduction to practice and were finally granted their patent on May 12, 1885.

THE EDISON LIGHTING SYSTEM

Edison saw the necessity of perfecting a complete incandescent-lighting system rather than simply an incandescent lamp, and he improved on the work of his predecessors and contemporaries in virtually every phase. He was one of the first strong supporters of central-station generation and distribution of electric energy. He believed in supplying as large an area as possible from a single generating station to obviate the necessity of each home or building having its own generator. The lamp itself was the heart of the system; nevertheless, commercial success or failure depended in addition upon the efficiency of the generating source, the method of distributing energy, and the method of obtaining a constant flow of current. Each of these, as well as a meter to measure current consumption, was intensively studied.

[30] Pope, *op cit.*, p. 33.

It has already been seen how important the dynamo was to all electric lighting. Though practical dynamos were being made commercially, the best arc-lighting generators available for use by Edison were only about 50 per cent efficient, and most of them gave a constant flow of current rather than the constant voltage desirable for incandescent lighting. Edison felt that he should have something better and decided that a dynamo of low internal resistance with a high-resistance field would provide a more efficient and more satisfactory conversion of mechanical energy into electrical energy. The validity of this idea, which ran counter to prevailing accepted principles, was confirmed by his development of a dynamo with an efficiency of close to 90 per cent.

The method of distributing electric current to its users provided another major problem. An arrangement of lamps in parallel was no novelty, and Edison adopted that as his starting point. He was successful in improving this type of distribution beyond the achievements of his competitors, however. On January 28, 1880, he applied for a patent on a system of multiple distribution from a number of generators. The patent was not granted until August 30, 1887, but it proved to be a legal advantage to the Edison illuminating companies in competing with other systems of incandescent lighting.

Further improvements on the original system of energy distribution were developed continually. One innovation was Edison's use of "feeder" wires to carry the current from the generators to the larger "mains" which ran under the street. This innovation, which was patterned after the methods of the gas industry, prevented an undesirable voltage drop in the lamps and motors most distant from the generators. In 1883 Edison was granted another patent for a three-wire distribution system.[31] With the two larger wires acting as the conducting mains and the smaller third wire serving as a neutral wire, lamps were connected in parallel between either of the outer wires and the third wire.[32] This development resulted in a saving of over 60 per cent in the weight of copper required for a given current capacity in energy distribution.

[31] The three-wire system was also worked out at about the same time by John Hopkinson, an English consulting engineer, who in 1883 and 1884 redesigned and improved the Edison dynamo.

[32] Such a system is feasible only for direct-current distribution. Satisfactory alternating-current systems had not yet been developed in 1883.

The flow of current was regulated at the generator in the final Edison system. In this Edison concurred with the judgment of Sawyer and Man, Swan, and others. He was probably ahead of many of them, however, in his selection of about 110 volts as the proper potential to use in his system instead of the considerably lower voltages used by most others. He calculated that this voltage would reduce the amount of copper needed for wiring to the minimum compatible with optimum lamp performance. The selection was wise for the times, since the cost of mains is one of the largest capital items in central-station electric lighting. The majority of his competitors made lamps adapted to potentials of 40 to 70 volts for several years. The lower-voltage lamps were evidently brought out primarily because they were easier to make, for thicker and stronger filaments of lower resistance were used in them.[33] As the economies of higher potentials became more widely known and as the skill of lamp makers increased, the tendency toward 110 volts became universal.

One further element of a commercial incandescent-lighting system is the meter with which to measure the energy consumption of each individual consumer. A mechanical meter had been made and patented in 1872 by Samuel Gardiner; and Sawyer, Lane-Fox, and many others had developed meters for their own purposes. When the need for a measuring device confronted him, Edison evolved a number of alternative types of meter. Of these the electrolytic or chemical meter proved most successful, requiring only the weighing of zinc or copper plates to determine how much metal had been transferred and consequently how much current had been used. Its simplicity and accuracy when correctly handled were so great that it remained in use for a number of years; then it was replaced by improved mechanical types.

[33] The Edison plant also made some 55-volt lamps, and a few other early producers made lamps with higher voltages.

Chapter IV: COMMERCIAL DEVELOPMENTS DURING THE FORMATIVE PERIOD OF THE ELECTRIC-LAMP INDUSTRY: 1880–1896

1. Early Commercial Experience and Expansion in the American Electric-Lamp Industry, 1880–1884

FIRST INSTALLATIONS

THE first commercial installation of incandescent lighting was made by Edison in May, 1880, on the steamship *Columbia.*[1] Henry Villard, president of the Oregon Railroad & Navigation Company, had seen Edison's first public demonstration of the lamp and had determined to use it in his newest ship. Even with the crude equipment of that date, the resulting lighting system with 115 lamps operated satisfactorily for fifteen years before it was replaced by more modern equipment.

The second commercial installation was made in the autumn of 1880 by Maxim and the United States Electric Lighting Company. They lighted the basement reading rooms of New York's Safe Deposit Company. The installation included about 50 lamps, which performed satisfactorily and may even have surpassed those of Edison in some respects.[2] Maxim possessed an advantage in his use of the filament-flashing process, which was not available to Edison.

The second land installation of an incandescent-lighting plant was made by Edison in January, 1881, in a New York lithographer's shop. Rapid expansion in the number of installations began several months later, when the various parts of the lighting system had been more nearly perfected. Small, complete generating plants were placed in stores, hotels, residences, and factories to provide current for incandescent lighting. Early in 1882 an Edison subsidiary company, the Edison Company for Isolated Light-

[1] During most of 1880 the streets and houses of Menlo Park, N.J., where the Edison laboratory was located were lighted at night by an experimental installation.

[2] Pope, *op cit.*, pp. 80–81.

ing, was organized to promote and carry out incandescent lighting installations. On June 27, 1882, there were sixty-seven Edison plants of 10,424 lamps in operation or in process of installation in the United States. The number had more than doubled by the end of the year. By the middle of 1886, Edison isolated installations in the United States had increased to seven hundred and two plants of 181,463 lamps.[3]

PIONEER MANUFACTURERS

Edison and his associates were naturally the first to undertake the commercial production of carbon-filament lamps and related equipment. The lamps for the *Columbia* were made in the Menlo Park laboratory by the Edison Electric Light Company. The directors seem to have been unwilling to commit themselves to manufacturing lamps and equipment on a large scale, however. They considered the company to be a development and patent-licensing concern only. Accordingly, Edison himself organized a new company, the Edison Lamp Company, in which he held an 80 per cent interest, to occupy itself solely with the manufacture of lamps under the patents of the Edison Electric Light Company. The lamp works first went into production in a small factory near the laboratory at Menlo Park in November, 1880, and were shifted to a much larger plant at Harrison, New Jersey, in 1882. Because Edison felt that it was unwise to buy the other equipment needed for lighting installations from existing manufacturers, he engineered the organization of three more Edison companies to make dynamos, underground conduits, wire, and other components. Fixtures, sockets and similar auxiliary appliances were made for Edison by Sigmund Bergmann & Company.[4]

Two other concerns had been interested in incandescent lighting before 1880. The United States Electric Lighting Company

[3] From a folder of the Edison United Manufacturing Company, New York, 1886. Annual growth in the use of incandescent lighting during that interval is illustrated by the following data for the Edison isolated plants: 1881, 5,122 lamps; 1882, 153 plants and 29,192 lamps; 1883, 64,856 lamps; 1884, 98,020 lamps; 1885, 520 plants and 132,875 lamps; 1885, 520 plants and 132,875 lamps; 1886, 702 plants and 181,463 lamps. See also *Bulletin of the Edison Electric Light Company*, New York: No. 11, June 27, 1882, p. 7; No. 14, Oct. 14, 1882, pp. 19–21; No. 15, Dec. 20, 1882, pp. 30–31; No. 18, May 31, 1883, pp. 30–38; and No. 22, Apr. 9, 1884, pp. 5–8.

[4] Bergmann, a former Edison employee, had gone into business for himself and became a most successful manufacturer.

had been organized in 1878 and had title to the incandescent lamp patents of Maxim and Farmer.[5] It had concentrated its production on arc lighting until the Safe Deposit Company installation of 1880. Sawyer and Man had also initiated their manufacturing operations in 1878. They had specialized in incandescent lighting from the first, but their low-resistance carbon rods were not successful. After internal tension had broken up their first company and Sawyer had started a new one, the old Electro-Dynamic Light Company failed. Following Edison's success in 1881, Sawyer's Eastern Electric Manufacturing Company bought up the property and patents held by Electro-Dynamic and expanded its operations. In 1882 it was reorganized as the Consolidated Electric Light Company, which adopted the Edison-type filament and became one of the largest producers of incandescent lamps (see Table X).

When the success of Edison and his very able group of assistants became known, several more lighting and electrical-goods manufacturers took up this new line.[6] The Weston Electric Light Company, an arc-lighting company established in 1877 to exploit the technical developments of Edward Weston, expanded its operations to include both types of electric illumination in 1881. Its merger with the United States Electric Lighting Company in 1882 brought the patents of Farmer, Maxim, and Weston together under the control of a single company. In the summer of 1883 the Brush Electric Company, which had succeeded the Telegraph Supply Company in 1880, acquired the American rights to the Lane-Fox incandescent-lamp patents and added incandescent lighting to its dynamo and arc-lighting business. When the Lane-Fox lamp did not work out well in practice, the Brush interests shifted to a Swan-type filament with somewhat greater success. The Swan Lamp Manufacturing Company was incorporated in 1885, and it manufactured incandescent lamps in Cleveland under license from the Swan Incandescent Electric

[5] Farmer himself later became the president of the Farmer Electric Manufacturing Company of Portland and had no particular further importance in the technical and commercial evolution of electric lighting.

[6] Figure 19 on page 85 presents a graphic representation of most of the important changes in the corporate organization of the electric-lighting industry from 1877 to 1896. Although this chart has been drawn up primarily to assist in the comprehension of later developments, the reader may find it of aid in fixing in mind the early relationships of the pioneer electric-lamp manufacturers.

TABLE X: PRINCIPAL PIONEER MANUFACTURERS OF CARBON-FILAMENT LAMPS IN THE UNITED STATES

1880–1885

Company	*Began Production*
Edison Lamp Company	1880
United States Electric Lighting Company	1880
Weston Electric Light Company	1881
Consolidated Electric Light Company	1882[a]
Brush Electric Company	1883
Union Switch & Signal Company	1883
Bernstein Electric Light Manufacturing Company	By 1884
American Electric Manufacturing Company	By 1884
Thomson-Houston Electric Company	1884
Swan Lamp Manufacturing Company	1885

[a] The predecessors of this company had started to make low-resistance incandescent lamps in 1878.

Light Company of New York, which had been formed in 1882 to introduce the Swan system into the United States.

Also in 1883, George Westinghouse, who had expanded his interests from railroad equipment to include electric generators the year before, began manufacturing incandescent lamps at his Union Switch & Signal Company. One year later, in 1884, the Thomson-Houston Electric Company placed its incandescent lamp on the market. This company had been formed in 1883 to succeed the American Electric Company, a pioneer in the dynamo and arc-lighting field, which had been organized in 1880. Both companies were built upon the work of Elihu Thomson and Edwin J. Houston, who had been colleagues at Philadelphia's Central High School. The Thomson-Houston company adopted the "Edisonized" version of the Sawyer-Man lamp, which it produced under a license from the Consolidated Electric Light Company, in which Thomson-Houston at that time owned a controlling block of stock. Two other early producers of incandescent lamps were the Bernstein Electric Light Manufacturing Company [7] and the American Electric Manufacturing Company.

[7] The Bernstein company chose two novel illuminant materials. At first it used a cylindrical carbon of high resistance, made of an infusible and insulating material covered with carbon. Within a short time it changed to a hollow carbon cylinder to obtain a larger illuminating surface with lower resistance; a narrow and hollow ribbon of white silk produced lamps of relatively high efficiency.

CENTRAL-STATION DEVELOPMENT

The early arc-lighting companies had started their installation activities before the incandescent-lighting companies, and their method of operation was followed for the newer light source. Most early installations had their own generators and were completely self-sufficient. For urban areas it was soon recognized that it would be more efficient to generate electric energy centrally and distribute it to a large number of consumers in the vicinity. The first central station in the United States was installed in San Francisco in 1879 and employed the Brush arc-lighting system. It was soon followed by others, including the Brush Electric Light & Power Company of New York, which lighted Broadway with electric arcs in 1880. Each operating company was typically given an exclusive license under the patents of a manufacturing company for a particular territory. In return, it paid a block of stock and a sum in cash to the parent patent-holding company. In addition, the operating company bought most needed equipment from the parent company or its affiliates.

Although the development of arc lighting was gradually leading in the same direction, within a few years the incandescent lamp gave a tremendous stimulus to central-station expansion. The New York Edison Electric Illuminating Company was incorporated in 1880 for the purpose of introducing incandescent lighting on a large scale into New York City. The company was granted an exclusive license under the patents of the Edison Electric Light Company for the New York area in return for stock and cash, in accordance with the already accepted practice. Two years were required before technical and manufacturing problems were satisfactorily solved, however, and the formal opening of the Pearl Street station, the first full-fledged central station in the United States for incandescent lighting, was not held until September 4, 1882.[8] It serviced a substantial portion of lower Manhattan and was completely successful.

During the two-year period while the New York company was being equipped, the parent patent-holding company discour-

[8] A small public-service station, not much larger than the usual isolated installation, had been placed in operation by the Edison interests in 1881 in Appleton, Wis.

aged the formation of local Edison companies in other communities. It desired to wait until the "practicability, economy and profitableness" of central-station incandescent lighting had been fully established before initiating active promotion.[9] The success of the New York undertaking led to the formation of a dozen more local Edison companies by the end of 1883, and within three more years fifty-eight Edison central stations providing current for 149,900 incandescent lamps were in operation in this country.

During the years from 1880 to 1886 Edison's competitors were similarly expanding their operations in isolated and central-station incandescent lighting, and arc lighting was continuing to grow rapidly. Scores of illuminating companies came into existence in a short time to take advantage of the attractive opportunities for profit which confronted them. Nevertheless, according to the Edison Company, all its competitors combined had placed only 84,600 incandescent lamps in isolated plants and central stations by October 1, 1886.[10] This was only about one-fourth the Edison total of over 330,000 lamps installed by the same time.

Arc and incandescent lighting were customarily operated on different types of circuits and with different voltages. Since transformers for stepping up or stepping down electric potentials had not yet been satisfactorily developed, the two types of lamps could not at that time be operated from the same central generator. At an early date the idea of using storage batteries to compromise the difference in voltages between the two types of lamp occurred to a number of individuals.[11] To serve both arc lamps and incandescent lamps from the same dynamo, storage batteries were charged in the daytime and used to power incandescent lamps at night, while the dynamo supplied high-potential current directly to the arc lamps at night.

Among the American companies attempting to put this scheme

[9] *Bulletin of the Edison Electric Light Company* (New York), No. 20, Oct. 31, 1883, p. 47.

[10] Edison Electric Light Company, *The Edison Electric Light: The Legal and Commercial Status*, New York, 1886, p. 3.

[11] The first storage battery made of lead in dilute sulphuric acid had been invented by Gaston Planté in 1860. The battery was much improved in 1881 by Camille Fauré, and a number of other inventors both in Europe and in America made further advances. It will be recalled that Lane-Fox had used batteries to regulate the current flow in his earliest incandescent-lighting system.

to commercial use was the Brush Electric Company. A subsidiary company was organized in 1883 to produce storage batteries for use with Brush dynamos and arc lamps and Swan incandescent lamps. Despite vigorous promotion, battery costs and conversion losses made the scheme unsatisfactory in practice, and it enjoyed only temporary success. Similar attempts by other producers, both in this country and abroad, and particularly with the Fauré "accumulator," likewise met with only transitory success for the same reason. Batteries employed to even out widely varying power loads were sometimes more satisfactory.

COMPETITIVE SITUATION AND CONDUCT OF THE BUSINESS

The principal reason for the initial commercial leadership of the Edison interests in incandescent lighting was, of course, the technical leadership of Edison himself. His vigor, thoroughness, and vision carried incandescent lighting along during its first few years of life. He made the first satisfactory incandescent lamp, and, equally important, he developed a complete lighting system with generators, cabling, fuses, sockets, fixtures, junction-boxes, meters, and all the other necessary items. Many of the competing concerns did not at first have complete systems and were forced to take time to develop, copy, or purchase rights to the missing items.

The lamps most widely employed in the United States during the early years of incandescent lighting were of about 16 candlepower. This was the standard Edison size.[12] Some 8-candlepower lamps were produced, and small numbers of other sizes up to 150 candlepower were made for special purposes. One dollar was the standard price for the 16-candlepower lamp for several years. Improved manufacturing techniques, expanding sales, and production economies of scale resulted in a gradual decline in costs while prices remained unchanged. Large profits encouraged the entrance of new producers, yet it was not until after 1886 that there was any general reduction in lamp prices. The lamps were not sold to individuals or companies by retailers or wholesalers, as is common at

[12] The most popular sizes of incandescent lamps put out by other American and European producers ranged from 15 to 20 candlepower. They also made both larger and smaller lamps for special purposes.

the present time, but rather to the central-station companies and directly to the owners of isolated installations. It was the obligation of each illuminating company to supply lamps and other equipment for the use of its customers. This method of selling persisted for many decades.

The first incandescent-lamp production was conducted largely by laborious hand operations; there were some two hundred stages in the manufacture of Edison lamps in 1883.[13] Despite the increasing number of installations, output was small for a few years. Total sales for the industry were only 70,000 lamps in 1883 and 125,000 lamps in 1884, according to Hammond.[14] The new Edison plant at Harrison employed 150 workmen and had a daily capacity of 1,200 lamps when it was opened in 1882.[15]

International trade in incandescent lamps was negligible during the early years. The American market was well protected by tariff rates only slightly lower than those established during the Civil War, and even the most efficient foreign manufacturers were not able to compete successfully. While lamps were not specifically mentioned in the tariff laws of the nineteenth century, the applicable rates under more general classifications were about 30 per cent during the early eighties and went even higher during the nineties. In addition, expanding domestic markets in all countries kept most manufacturers busy at home and reduced the incentive to export lamps.

By 1885 all those American manufacturers who could be called pioneers in the field of incandescent illumination had initiated their operations. Throughout the remainder of the 1880's about twenty additional concerns began to produce filamentary electric lamps. Although a few of these later entrants were arc-lighting or other electrical-goods manufacturers who were interested in expanding their lines, most of them were small concerns organized for the primary purpose of making incandescent lamps. They were the imitator firms which typically spring up when it is possible to exploit a new discovery or invention. They did not produce complete lighting systems, only lamps for use with systems

[13] *Bulletin of the Edison Electric Light Company*, No. 16 (Feb. 2, 1883), p. 17

[14] John Winthrop Hammond, *Men and Volts*, Lippincott, Philadelphia, 1941, p. 92. Copyright, 1941, by General Electric Company.

[15] *Bulletin of the Edison Electric Light Company*, No. 11 (June 27, 1882), p. 3.

sponsored by other producers. Their entry was encouraged by the expanding market, the favorable profit prospects, and the fact that only a few thousand dollars were required for establishing a new company. Despite the fact that lamp production was arduous and required meticulously careful work, one good engineer could bring to a company almost all the necessary technical knowledge for setting up in business.

The basic characteristics of almost all the early commercial lamps were similar to those of the Edison lamp. The older firms, whether originally specialists in incandescent or arc lighting, typically owned or had rights to incandescent-lamp patents under which they purportedly operated, while very few of the entrants of the late 1880's had any significant patent rights whatsoever. Delay on the part of the Edison interests in establishing the validity of their basic patents permitted this multiplication of competition throughout the entire decade. The rivalry became very keen, despite the initial advantage of the Edison interests.

The introduction of electric lighting during the eighties was a significant event in the progress of the nation, and it attracted considerable attention. The public and the press showed great interest in the progress and relative merits of the various schemes of incandescent lighting, as well as in the older gas lighting and arc lighting. Attacks on rival companies or systems and rebuttals of attacks were frequently quoted in the news columns, and editorial comment was often lengthy and generally fairly well informed.

While incandescent lighting had many advantages over the older light sources, it was not so superior at first that it could ignore its competitors. The struggle among them went on for over twenty years before the superiority of incandescent lighting became definitely established. The gas companies quickly became alarmed at the improving cost position of electric lighting and its greater safety, quality, and convenience, particularly with incandescent lamps. They were definitely on the defensive by 1882. For several years, however, the gas industry continued to have nothing to do with either incandescent or arc lighting other than to resist their advance in every possible way and to make some belated attempts to improve the quality and reduce the cost of its own product. Finally, around 1887, the gas industry began to realize that the progress of electric lighting was inevitable, and many gas companies added electric lighting and power supply to their business. The American Electric Manufacturing Company was the pioneer promoter of the union of gas and electricity, particularly for outdoor arc lighting. The basic rivalry continued, nevertheless, and was largely responsible for the substantial improvement in gas lighting during the decade of the eighties.

2. *Incandescent Lighting and Consolidations in the American Electrical-Goods Industry, 1885–1896*

Electric illumination, both arc and incandescent, provided a great stimulus to the expansion of electrical-goods production after 1880, even though the telephone and telegraph had been largely responsible for the initial growth of the industry. Communications and lighting soon became just two of many important applications of electricity, however. The development of electric motors for street railways, electrified steam railroads, elevators, factory machinery, and many other uses greatly expanded the scope of the industry within a few years. When first organized, each of the manufacturing companies typically specialized in a single field. Those which entered the field of electric lighting, particularly incandescent lighting, have already been listed in some detail. There were as many or more concerns in most of the other branches of the industry.

In all other electrical fields, as well as in lighting, there was much early confusion over the diversity of systems and their relative efficiencies, over the continual changes and improvements in design, and over the relative strengths of patent rights. Companies grew so rapidly that they had difficulty in financing their expanded business without constantly bringing in new money. At the same time, many of the concerns desired to expand into new lines of production. The pressure of all these factors, particularly financial needs and patent conflicts, coupled with the natural competitive urge to expand and the spirit of trustification then prevalent in American industry, precipitated most of the corporate mergers and reorganizations in the electrical-goods industry between 1882 and 1896.[16] While the telegraph and telephone were somewhat in advance of the remainder of the electrical-goods industry, they had very little effect upon electric lighting once the latter was on the market; nor were they significantly affected by electric lighting. For that reason, the consolidations and activity in those branches of the industry are not considered here. This account is limited to those companies in the non-communication fields of electrical-goods production which had an important connection with the history of electric lighting.

FINANCIAL CONSOLIDATIONS

At the beginning of 1886, the manufacture and sale of Edison electrical equipment was being conducted by five separate companies. Although their ownership and control were interlocking, the arrangement was cumbersome. In 1883 the Edison Machine Works had absorbed the Edison Shafting Company and the Edison Tube Company. In 1886 two further changes were made. The parent Edison Electric Light Company absorbed the Edison Company for Isolated Lighting, which had been operating as a subsidiary for four years to promote the installation of isolated incandescent-lighting plants. In addition, the Edison United Manufacturing Company was formed to consolidate the work formerly done separately by the Edison Lamp Company, the Edison Machine Works and Sigmund Bergmann & Company and to act as selling agent for all the Edison manufacturing plants.[17]

[16] Besides the very few mergers of electric-lighting companies discussed previously in this chapter, there was one additional early move toward consolidation of interests that should be noted. In 1881 the Gramme Electrical Company was founded in the United States, based upon the basic Gramme dynamo patent of 1871. It was a union of electrical companies, primarily producers of arc-lighting systems, "for mutual convenience in transacting business and protecting the public." The companies tried to set uniform prices, minimize patent litigation, and prevent the rise of new competitors. The idea of a central organization to do work "of mutual interest" to all lighting companies was the first indication of collaboration among the various producers. Among the members were the Edison, Brush, Weston, United States, and American companies. The Gramme company fell apart quickly and had little later significance, however. See *Bulletin of Edison Electric Light Company*, No. 9 (May 15, 1882), pp. 3-5, and No. 15 (Dec. 20, 1882), p. 38; and *Electrical World*, Vol. C, p. 424 (Oct. 1, 1932).

[17] According to the Edison Electric Light Company, a large number of other electric-lighting companies made overtures to it for consolidation during the early eighties. Offers were made for the sale of patents, for patent licensing and for amalgamation. All such proposals were declined. The Edison company felt that in the field of incandescent lighting its patents entitled it to a legal monopoly. Also, it felt that its commercial progress was so much greater than that of its competitors that it had nothing to gain by consolidation with any of them. See *Bulletin of the Edison Electric Light Company*, No. 15 (Dec. 20, 1882), p. 38, and No. 20 (Oct. 31, 1883), p. 45.

The individual Edison factories expanded very rapidly during the eighties as product lines and output grew to fill the spreading market. Financial and administrative matters became problems of great magnitude, with which the technical personnel were entirely unable to cope. Edison himself started in 1884 to withdraw from active participation in the businesses which bore his name. Lawyers, financiers, and promoters became the guiding spirits in the management of the growing companies. The same was true in competing concerns. By 1886, most of the pioneer companies in the electrical-goods industry were out of the control of the inventors whose work had made them possible. The original inventors had either withdrawn to investigate new lines or had continued as salaried employees or consultants who took little part in actual management.

The final step in the transition of the Edison companies from domination by Thomas A. Edison to domination by financiers took place in 1889 with the merger of all the remaining separate Edison development and manufacturing companies into the Edison General Electric Company. Besides the Edison Electric Light Company and the Edison United Manufacturing Company, the Canadian Edison Manufacturing Company,[18] the Sprague Electric Railway & Motor Company [19] and Leonard & Izard Company [20] were brought into the consolidation.[21] The new company had a capitalization of $12,000,000, over half of which was controlled by Henry Villard of New York and Werner Siemens of the German Siemens & Halske Company. Villard, who had ordered the first installation of incandescent lighting for his steam-

[18] The Canadian Edison Manufacturing Company was organized in 1882 to produce and sell Edison electrical equipment in Canada.

[19] The Sprague Electric Railway & Motor Company was organized in 1884 by Frank J. Sprague, a former Edison employee, who was a pioneer in electric traction. Its president was Edward H. Johnson, who also headed the Edison Electric Light Company.

[20] The partnership of Leonard & Izard was founded early in 1889 by H. Ward Leonard, who had worked for Edison as an engineer until that time.

[21] The Edison Electric Light Company retained its separate corporate identity for many years after the consolidation.

ship *Columbia*, became the president of the new Edison General Electric Company. Edison and his associates sold their manufacturing interests to the financial syndicate headed by these two men. Even though he remained a director, Edison devoted almost all his time to new technical interests and ended his personal participation in the enormous enterprises which had grown out of his work in less than ten years.

While the Edison companies were growing and merging, the Thomson-Houston Electric Company of Lynn, Massachusetts, was rising in the industry in a quite different manner. It had concentrated upon arc-lighting systems at the time of its organization in 1883, and within eight years it became one of the largest concerns in the electrical-goods industry. Its astute leader, Charles A. Coffin, a former shoe manufacturer, was a shrewd and ambitious administrator and financier. He was not content to see his company expand in the electric-lighting business solely by the gradual accretion of business. In addition to that method, with the aid of influential Boston bankers, he engineered the purchase of all the stock or of controlling interests in several competing concerns during the late eighties. The Van Depoele Electric Manufacturing Company was an early promoter of arc lighting and electric traction. It had been established in 1880 and reorganized in 1882 to produce electrical equipment invented by Charles J. Van Depoele, a Belgian who had come to America at an early age and developed an interest in electricity while working as a furniture maker. In 1888 the Thomson-Houston company bought the business and patents of the Van Depoele company when the latter was in a straitened financial condition. Similarly, financial difficulties made the owners of two other arc-lighting companies, the Fort Wayne Electric Light Company and the Schuyler Electric Company, willing to sell controlling interests to the Thomson-Houston company in 1888 and 1889.[22] None of these arc-lighting concerns was at the time of purchase a producer of incandescent lamps.

From 1884 to about 1888 Thomson-Houston also controlled

[22] The Fort Wayne company had been formed in 1881 around the arc-lighting inventions of James and Charles Jenney. The Schuyler company also dated from 1881 and was founded on the arc-lighting inventions of D. A. Schuyler and A. G. Waterhouse.

the Consolidated Electric Light Company. In 1886 the two companies formed the Sawyer-Man Electric Company in which Thomson-Houston retained a 90 per cent stock interest. A license was then granted to Thomson-Houston to make incandescent lamps under the Sawyer-Man patents. In 1887, however, Thomson-Houston sold all its stock in the Sawyer-Man Electric Company to Consolidated, and in December, 1888, it sold its controlling stock interest in Consolidated to Westinghouse. At the same time Thomson-Houston executed a mutual patent-licensing agreement with Westinghouse and Consolidated whereby it could continue after the stock sale to produce and sell the Sawyer-Man lamp in certain areas.

Besides the companies mentioned above, Thomson-Houston bought out the Bentley-Knight Electric Railway Company and the Brush Electric Company in 1889. The Bentley-Knight company had been one of the first in the field of electric traction when it was organized in 1884. Ownership of both the Bentley-Knight and the Van Depoele companies gave Thomson-Houston great strength in electric traction, even though it had made few important original contributions to the field itself. The Brush Electric Company, one of the oldest promoters of electric lighting, was purchased by Thomson-Houston for about $3,000,000 when a prolonged struggle over arc-lighting patents loomed dangerously ahead. Finally, in 1890, another smaller arc-lighting competitor, the Excelsior Electric Company, was acquired. With the acquisition of control over all these concerns, Thomson-Houston enormously increased its size and strength in the electrical-goods industry, particularly in arc lighting and electric traction. To carry on its ambitious plan of expansion, Thomson-Houston had increased its capitalization to over $10,000,000 by 1891, rivaling that of the Edison General Electric Company.

Figure 19 sketches the corporate development of the General Electric and Westinghouse Electric companies to the year 1896 and shows the most important consolidations which took place during the early years, including all those mentioned above. There were, of course, many other small firms in all branches of the electrical-goods industry at that time which are not represented on the chart. Their role in the development of electric lighting—particularly incandescent electric lighting—will be discussed shortly.

PATENT CONFLICTS

The problem of conflicting patent rights in the electrical-goods industry became acute around the middle of the eighties. Each inventor had patented his own developments but usually found that the patents conflicted with those of someone else or covered only a few aspects of a large system, thereby making it difficult to construct the most efficient apparatus. Patent litigation inevitably arose as the legal rights of some companies were intentionally or unconsciously infringed by others.

Up to 1885, most inventors and companies seem to have been so busy taking out new patents and getting into production that they had neither the opportunity nor the inclination to defend their rights vigorously under the patents which they had already obtained. Although some patent litigation went on during those years, in general a live and let-live policy was practiced. Only the most flagrant infringements which threatened established commercial positions were taken to court.[23] About that time, however, the electrical-goods industry as a whole and the incandescent-lamp industry in particular became moderately well established, and the situation could be considered more broadly.

There were in 1885 approximately a dozen manufacturers of filament lamps in the United States. Most of them owned or had rights under patents which purportedly covered their products. Despite the entry of new producers and the growth of old competitors, the Edison Electric Light Company was still supplying around three-fourths of all filament lamps produced in this country. Total production at that time was at the rate of about 300,000 lamps a year. As the pioneer, the Edison company also had the strongest patent position. At the end of 1883 it had title to 215 patents on various features of the lighting system and 307 addi-

[23] Among the few important patent trials of the early eighties was the suit of the Brush Electric Company against the United States Electric Lighting Company for alleged infringement of two of its arc-lighting patents. The suit was instituted in 1880 and ended in 1884 in a complete triumph for the United States company. One of the patents under suit was withdrawn by the plaintiff during the trial, and the other patent was declared invalid and void.

Because of its age and state of development, arc lighting was not as subject to basic patent control as incandescent lighting. Although alternative techniques and apparatus were patentable, the industry was fairly open.

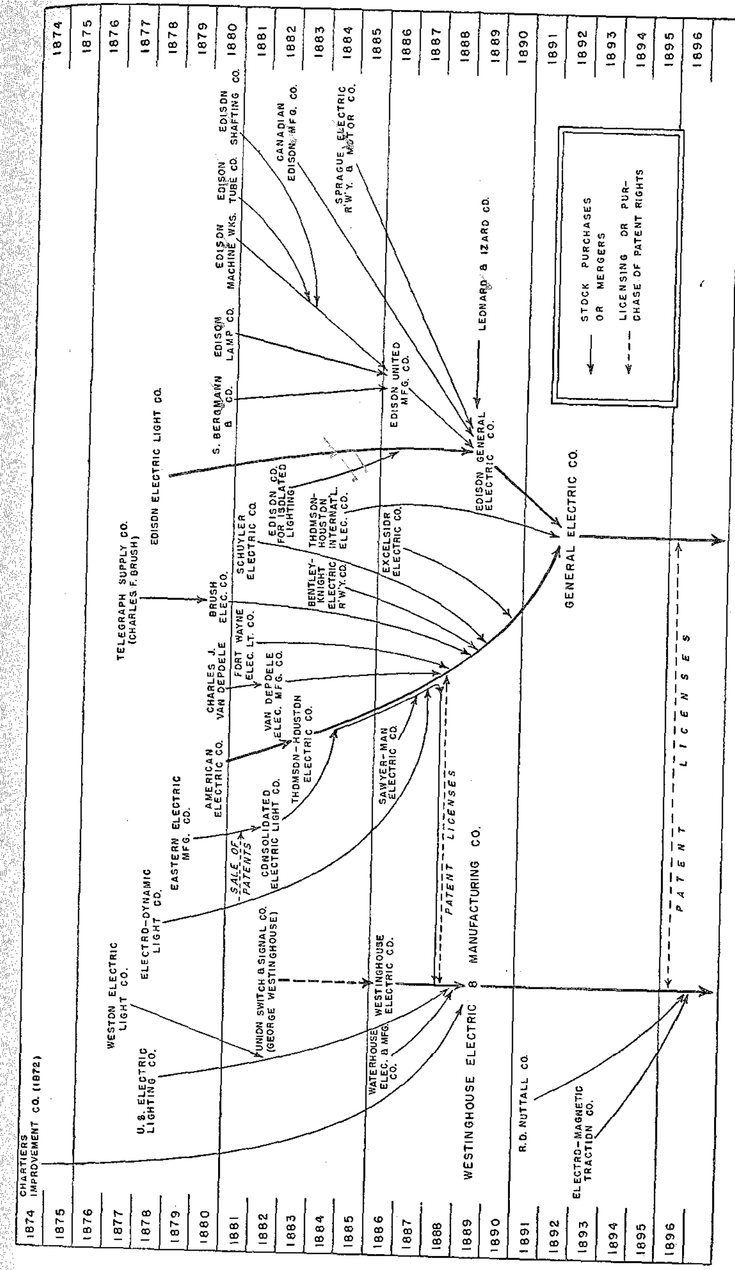


FIG. 19. The Development of the General Electric and Westinghouse Companies, 1872–1896
Sources: Hammond, *Men and Volts*, 1941; Jehl, *Menlo Park Reminiscences*, Vol. II, 1939; Pope, *Evolution of the Electric Incandescent Lamp*, 1889; U.S. Tariff Commission, *Incandescent Electric Lamps*, 1939; and others.

tional applications were pending.[24] The number of patents under Edison control had increased to 345 by the middle of 1887, and numerous others were subsequently issued. The validity of the patents granted in 1880 had not yet been tested, however, and many of the lamps produced by competitors were substantially like those patented and produced by the Edison companies. Moreover, the number of competitors and their total output were increasing. The Edison Electric Light Company felt that the time had come to clarify the situation.[25]

Once the patent struggle was taken up, it proved to be long and costly. Between 1885 and 1901 the Edison company and its successors spent about $2,000,000 on well over two hundred infringement suits under its lamp and lighting patents. Defendants of the suits probably had to spend nearly the same amount. These prosecutions resulted in a striking legal victory for the Edison interests.

Besides the fundamental incandescent-lamp patent, many other electrical patents were involved in litigation during the late eighties and early nineties. In 1887 the Edison Electric Light Company sued Westinghouse, Church, Kerr & Company, a construction firm which installed equipment made by the Westinghouse Electric Company, for alleged infringement of eleven of its patents on the distribution of electric energy. After six years, the New Jersey Circuit Court upheld the Edison feeder-and-main patent, which was one of the eleven patents in suit, and decided that Westinghouse was infringing it. The decision was reversed in 1894 upon appeal by Westinghouse, effectively opening that method of energy distribution to all users.

In 1888 the Thomson-Houston company was successful in its suits against the Citizens Electric Light Company *et al.*, over the alleged infringement of an 1881 patent covering improvements in current regulation for dynamos. Later, in 1895, the courts

[24] *Bulletin of the Edison Electric Light Company*, No. 20 (Oct. 31, 1883), p. 49.

[25] In their annual report dated Oct. 23, 1883, the directors of the Edison Electric Light Company stated that the company's few competitors in incandescent-lamp production had so far failed to make themselves sufficiently felt to render it worth while to go to the expense of infringement suits. The company thought that it could maintain its position and practical business monopoly without the expense of litigation, while keeping its patents in reserve in the event that their protection might be needed. See *Bulletin of the Edison Electric Light Company*, No. 20 (Oct. 31, 1883), pp. 45–46.

found the Thomson-Houston arc-regulator patent invalid, after Thomson-Houston had instituted an infringement suit against the Western Electric Company, the manufacturing subsidiary of the Bell telephone interests. There were other cases relating to arc lighting, such as the unsuccessful attempt of the Brush Electric Company to prove infringement by the Western Electric Company of a Brush patent covering a device for throwing into action a new set of electrodes when the first ones had been consumed. Extensive litigation was also carried on over patents covering various phases of electric traction.

Even though several patents for which broad claims were made were invalidated or limited in their coverage, others were upheld or clarified and gave greater strength to the largest firms in the industry—the Edison and Thomson-Houston companies and their successor, the General Electric Company, and Westinghouse. The costs of litigation sapped the strength of the smaller companies, even where they were successful in defending themselves. Many small independents were forced to liquidate or sell out.

SUIT OVER BASIC EDISON FILAMENT PATENT

The key to Edison's legal victory was the suit against the United States Electric Lighting Company, which started in 1885 for alleged infringement of the basic carbon-filament patent No. 223,898 of January 27, 1880.[26] The United States Electric Lighting Company, at that time Edison's largest competitor in incandescent lighting, had title to the patents of Maxim, Farmer, and Weston, yet it was producing incandescent lamps substantially like those made by Edison. Although other patents could have been brought into the case, the Edison company desired to make this a test case of the validity of the basic patent, and the legal issue was narrowed to whether the slender high-resistance carbonized filament, in combination with an exhausted and sealed glass bulb with platinum lead-in wires, was or was not a patentable innovation, and whether the United States Electric Lighting Company was infringing its claims.

[26] At the same time the Edison company brought infringement suits against Consolidated, the Swan Incandescent Electric Light Company, and a number of other lamp producers, as well as against some users of competing products. The suit against the United States company was the one pushed to a conclusion as a test case.

The Edison prosecution had a stormy career in the courts. The patent under suit was threatened with invalidation even before the trial was completed. The United States patent laws at that time contained a provision that an American patent was valid only as long as the shortest-lived patent on the same innovation in a foreign country, if the foreign patent had been issued first. The Canadian patent was declared invalid by the Canadian Deputy Commissioner of Patents, on February 26, 1889, for non-compliance with Canadian statutes regarding manufacture and importation. If that decision had been allowed to stand, the American patent would probably have become void also, since the Canadian patent had been granted before the American patent. Fortunately for the Edison interests, it was decided that the Deputy Commissioner of Patents had not had proper jurisdiction over the matter, and the case was retried by the Minister of Agriculture. The new decision held that the statutes regarding manufacture and importation had been satisfied, and that the patent remained valid.

Even though the suit against the United States Electric Lighting Company had been initiated in 1885, it did not finally come to a hearing until 1889. After a long and involved trial, a judgment in favor of Edison was handed down by Judge William Wallace on July 14, 1891, in the Circuit Court of the United States for the Southern District of New York. The defendant had contended that the Edison patent No. 223,898 was invalid because its description of the invention was not adequate, and because other inventors had anticipated the invention. Both of these defenses and the claim of non-infringement were denied. Judge Wallace held that Edison had been the first to make a satisfactory high-resistance illuminant out of carbon for an incandescent lamp and, in so doing, had made commercial incandescent electric lighting possible. An appeal by the defendant was of no avail. The decision of the lower court was sustained by the Circuit Court of Appeals on October 4, 1892, on virtually the same grounds.

By the time the patent was upheld and the Edison company and its successors were guaranteed a legal monopoly of the production of incandescent lamps using this type of filament in exhausted and sealed bulbs, the patent had only a few more years of life. Its seventeen-year term was scheduled to expire in January of 1897.

At first the Edison interests declared that they did not intend to raise lamp prices, and it was expected that competitors would be licensed to make lamps under the Edison patent in return for royalty payments. This attitude did not prevail for long; the General Electric officials soon decided that they could greatly increase their share of domestic lamp production, which by that time was down to 40 per cent, by taking full advantage of their patent victory. The Edison interests expected to have about four years to consolidate their position and to regain their commercial monopoly. They immediately set about obtaining injunctions against the producers and users of competing and infringing lamps, the number of which had increased rapidly during the preceding five years. They did not wish to allow competitors to continue in business even as licensees. Within a short time injunctions had closed the lamp plants of the Sawyer-Man Electric Company, the Perkins Electric Lamp Company, the Mather Electric Company, and the Sunbeam Electric Lamp Company.

The infringing producers of incandescent lamps were much angered by the tardiness of the Edison company in bringing this legal action and by the vigor with which its successor, the General Electric Company, was attempting to put all competitors out of the lamp business and secure a complete monopoly. For twelve years competition had been possible; it suddenly became impossible. The Beacon Vacuum Pump & Electrical Company of Boston attempted to avoid an injunction early in 1893 by claiming priority of invention for Heinrich Göbel, a German-American watchmaker from New York, who was said to have built several carbon-filament lamps from 1854 to 1872 which anticipated Edison's later developments. Göbel had taken out no patents on his developments, however, and the evidence to prove his priority of invention was questionable.[27] Judge Colt of the United States Circuit Court at Boston ruled that the evidence presented was

[27] Göbel had tried unsuccessfully to sell his inventions to the Edison Electric Light Company in 1882, and other companies had considered but had not used his claims in previous litigation. His work is not mentioned in the histories of electric illumination written before 1885. Although some German writers have referred to him as a contender for the title of inventor of the incandescent lamp, it seems clear that his work had no commercial significance and did not even enter the body of scientific knowledge on the subject for the benefit of future experimenters.

not sufficient to invalidate Edison's patent, and he granted the injunction against the Beacon company on February 18, 1893.

Injunctions were shortly granted against several additional producers of incandescent lamps; and others closed down their plants without waiting for legal action against them. Some of the independent manufacturers put up a vigorous defense to the attempts by the Edison interests to close them down, however. Even after the first use of the Göbel defense had failed, it was used in other cases. In the United States Circuit Court at St. Louis, Judge Hallett ruled that the probability of anticipation by Göbel was sufficiently great for him to refuse to grant an injunction requested by the Edison interests against the Columbia Incandescent Lamp Company. Although that decision was later reversed on appeal, it kept Columbia in production while the life of the patent was slipping away.

A few other companies remained in production or reopened their plants by redesigning their lamps and claiming that the newer types did not infringe the Edison patent. Although the courts issued new injunctions against some of the redesigned lamps, a few were sufficiently different to be able to remain on the market. In addition, many new companies were formed after 1892 to produce "non-infringing" lamps. From 1892 till the expiration of the patent, there were probably ten or more competing producers making lamps at all times, despite the vigorous efforts of the General Electric Company to close them down.

By far the most important of the non-infringers was the Westinghouse Electric & Manufacturing Company. It had been given the contract for lighting the Chicago World's Fair of 1893, and its ability to supply enough lamps to satisfy its contract was seriously threatened by the Edison lamp-patent victory of 1892. Upon the defeat of its subsidiary, the United States Electric Lighting Company, Westinghouse had shifted all its lamp-making activities to the Sawyer-Man company; but the latter was also closed down promptly by a court injunction requested by General Electric. Westinghouse then speeded its efforts to develop and manufacture a non-infringing lamp, and it was able to resume production very shortly after the initial injunction against it had been granted. The new lamp employed the old stoppered base instead of a hermetically sealed glass globe and used a type of fila-

ment covered by a Weston patent controlled by Westinghouse. The early patents of Sawyer and Man, Farmer, and Maxim on stoppered lamps proved valuable in this connection. The stoppered lamp was produced by Westinghouse until the Edison patent expired; thereafter, production was resumed on the sealed-bulb lamp, which maintained the vacuum more satisfactorily.

Even though some competitors were successful in remaining in production after 1892, the Edison lamp temporarily gained a much larger proportion of the domestic market, rising for a time from a little less than half to around three-fourths of all lamps sold. Continued injunction proceedings against central stations and other users of competing and infringing lamps added to the commercial strength of the Edison lamp. Injunctions were even granted against companies which repaired incandescent lamps by replacing broken filaments, an activity which was just beginning in both the United States and Europe.

Patent protection for the Edison lamp was cut short on November 17, 1894, because of the expiration of the Canadian patent.[28] The expiration provision of the American patent system reduced the life of the basic patent by more than two years, despite a strenuous attempt by General Electric to show that the provision was intended to refer to dates of application rather than issuance of a patent, and hence was not applicable.[29]

Besides the litigation over the fundamental Edison patent, there was one other noteworthy set of legal proceedings on the incandescent lamp. The Consolidated Electric Light Company was aggressive in its use of the Sawyer and Man lamp patents. When the patent covering the paper illuminant was finally granted to

[28] Although the British patent had expired Nov. 10, 1893, the American limitation provision was not applicable in that instance because of legal technicalities. It was decided that the date applicable to the British patent was not Nov. 10, 1879, the day on which it was granted, but was rather either the date of the filing of final specifications or the date on which the great seal was attached. Both of those dates were subsequent to the Jan. 27, 1880, date of the American patent.

[29] The American patent laws were revised as of Jan. 1, 1898, to include a provision that domestic applications for patents might be filed any time within seven months of the earliest foreign application without prejudicing the full seventeen-year term of the American patent, regardless of its date of issue. The revision resulted in large part from agitation created during the early nineties when the Edison patent and a few fundamental patents in other industries were cut short before their full terms. The modification had an important bearing on the length of patent protection in incandescent lighting after that date.

Sawyer and Man in 1885, Consolidated immediately undertook to assert its rights. It instituted proceedings against the Edison company and other alleged infringers. The test case on the Sawyer and Man patent was the prosecution of Consolidated against the McKeesport Light Company, an operating affiliate of the Edison company. The circuit court held in 1889 that the broad claims of the Sawyer and Man patent were invalid because of lack of reduction to practice. Their low-resistance illuminants were based upon the wrong principle for success. Westinghouse and Consolidated appealed the case to the United States Supreme Court, where on November 11, 1895, the decision of the lower court was upheld and the Sawyer and Man patent was finally invalidated. By that time the fundamental Edison patent had expired, and control over the paper filament would not have given Westinghouse any important commercial advantage.

The introduction of non-infringing lamps before the end of 1894, plus the resumption of production by old firms and the entry of a few new producers after expiration of the basic patent, resulted in a new increase in the proportion of incandescent-lamp business conducted by the competitors of the Edison lamp. Table XI shows the entries into the American lamp industry and the

TABLE XI: ENTRIES AND DEPARTURES FROM THE AMERICAN INCANDESCENT-LAMP INDUSTRY

1889–1896

	1889	*1890*	*1891*	*1892*	*1893*	*1894*	*1895*	*1896*
Number of companies at beginning of year [a]	26	35	32	34	57	58	44	35
New entries during year	12	5	10	26	15	8	2	6
Withdrawals or mergers during year	3	8	8	3	14	22	11	8
Number of companies at end of year [a]	35	32	34	57	58	44	35	33

[a] From 1892 to 1894 a great many lamp manufacturers were temporarily closed down as a result of injunction proceedings brought by the Edison interests.

Source: The Electrician, *Electrical Trades' Directory and Handbook*, Vols VII–XVI, London, 1889–1897.

withdrawals from it for the period 1889 to 1896. Although some of the independents had been seriously weakened, competition became very keen and prices were forced down to levels far below previous figures. The following figures show the approximate course of list prices per lamp for standard 16-candlepower lamps from 1880 to 1896:[30] 1880–1886, $1.00; 1888, 80 cents; 1891, 50 cents; 1892, 44 cents; 1893, 50 cents; 1894, 25 cents; 1895, 18 to 25 cents; 1896, 12 to 18 cents. The prices follow closely what one would expect, based on the number of lamp producers, the vigor of competition, the legal situation and the impact of the panic of 1893. There was some dispersion about these averages, however; for example, the Westinghouse stopper lamp in 1893 had a list price of only thirty cents in the 16-candlepower size.

It should be remembered that lamp prices represent only a very small proportion of the total cost of electric lighting. Because lamp manufacturers at that time sold most of their output to central stations, which supplied them to their customers, there was at first relatively little downward pressure on prices from lamp users. The downward trend which started after 1888 resulted almost entirely from the situation among lamp suppliers. It was retarded by the upholding of the Edison patent in 1891 and was renewed after the panic of 1893 and the expiration of the basic patent.

FORMATION OF GENERAL ELECTRIC

Even as the courts were passing on the Edison lamp patent in 1891, the Edison General Electric Company foresaw the probability of difficult years ahead. It had been gradually slipping backward in its commercial position, particularly since 1886, even in the incandescent-lamp business. The Thomson-Houston Electric Company and the Westinghouse Electric & Manufacturing Company, especially, were rising rapidly. Although the Edison company was still the largest electrical-goods producer in the country, it needed new life, leadership, and capital. Its technological contributions were becoming relatively smaller than they had been during the early eighties. With the withdrawal of Thomas Edison from active participation in the technical and commercial affairs of the company, especially after control had passed to a financial

[30] These prices are based largely on advertisements and articles in various electrical journals during the period.

syndicate in 1889, the relative decline was hastened. Morever, continued patent conflicts were in prospect as long as the largest firms in the industry battled together.

Early in 1891 the Edison company proposed consolidation with its chief rival, the Thomson-Houston Electric Company. There were several advantages to Thomson-Houston in such a consolidation, for it was faced by somewhat the same problems as the Edison company. Patent conflicts were a great problem to all companies. By bringing together the patents of the Edison company and those amassed by Thomson-Houston, it appeared that a tremendously powerful patent position could be established. Moreover, Charles A. Coffin, who headed Thomson-Houston, had expansionary ambitions and was receptive to the idea of increasing his company's control over the industry. The trust movement was at that time current in many American industries, and conditions in the electrical-goods industry were favorable to "trustification."

There were also financial advantages in the consolidation for Thomson-Houston. It had promoted the sale of its goods widely by accepting large blocks of stocks and bonds in local electric operating companies in lieu of cash.[31] Although the Edison company and other producers had used the same technique to some extent, none of the others had relied upon it so heavily. As a result, Thomson-Houston had a great deal of its assets tied up in securities and did not have a strong working capital position, particularly after acquiring so many of its competitors prior to 1890. After a year of negotiations, the General Electric Company was formed on April 15, 1892, bringing together the two largest electrical-goods manufacturers in America.

The two companies may be statistically compared for the year 1891:[32]

	Edison Gen'l Electric	*Thomson-Houston*	*Total*
Capitalization	$15,000,000	$10,400,000	$25,400,000
Gross business	10,940,000	10,304,500	21,244,500
Profits	2,098,000	2,700,000	4,798,000
Number of employees	6,000	4,000	10,000

31 The United Electrical Securities Company had been organized as a Thomson-Houston subsidiary in 1890 to deal in the securities of operating companies.

32 Hammond, *op cit.*, p. 404.

	Edison Gen'l Electric	*Thomson-Houston*	*Total*
Factory space (sq. ft.)	400,000	340,000	740,000
Customers	3–4,000	3–4,000	6,000
Central stations	375	870	1,245
Isolated installations	2,300	very few	over 2,300
Street railways equipped	180	204	384
Street railway cars	2,230	2,760	4,990

The new General Electric Company had a capital stock of $35,000,000, which was distributed to the shareholders of the Edison General Electric Company, the Thomson-Houston Electric Company, and the Thomson-Houston International Electric Company[33] in exchange for their holdings.[34] The three underlying companies and many of their twenty-one subsidiaries[35] retained their corporate identities for several years before complete transfers of assets, activities, and accounts could be effected.[36] In addition to its capital stock, the General Electric Company sold for cash $10,000,000 in debentures. During its first eight months, the company maintained sales at about the 1891 level indicated above for the two major predecessor companies. Similarly, profits remained close to their former level.

The Thomson-Houston influence in the General Electric Company was considerably greater than that of the Edison interests. The two organizations were consolidated, but the principal executives and methods employed in the new company came from Thomson-Houston. Charles A. Coffin became the first president and provided much of the leadership which brought General Elec-

33 The Thomson-Houston International Electric Company had been organized in 1884 to handle the foreign business of the parent Thomson-Houston company.

34 See *First Annual Report of the General Electric Company*, Schenectady, Jan. 31, 1893.

35 Among the subsidiaries taken over from Thomson-Houston was the Swan Lamp Manufacturing Company, which continued the manufacture of incandescent lamps until 1895 under license from the Swan Incandescent Electric Light Company. The latter concern also went out of business in 1897.

36 The use of the holding-company device in industrial combination, including the electrical-goods industry, was greatly stimulated in 1888, when the state of New Jersey amended its general corporation laws to permit corporate charters to contain the specific power of holding stock in other companies. Other states soon modified their laws correspondingly. Before that time, the corporate right to hold stock had been granted only by special legislative act.

tric to unquestioned superiority in the American electrical-goods industry. A number of prominent New York and Boston bankers, including J. Pierpont Morgan and Henry L. Higginson, became members of the first board of directors and provided important financial strength. Elihu Thomson went along with the new company as consulting engineer and head of the Lynn research laboratory. He was the only one of the leading early inventors who was active in the new company; he declined a proffered directorship in order to continue his laboratory work unimpeded. Thomas Edison remained inactive, although he continued as a director. All the other pioneer inventors who had been affiliated with the numerous predecessor companies by that time had retired or had become interested in other activities. The first technical director of the General Electric Company was Edwin W. Rice, Jr., a former pupil of Elihu Thomson, who had been with the Thomson-Houston company, and who later succeeded Coffin as president of General Electric.

One aspect of General Electric's business, the manufacture of incandescent lamps, remained temporarily under the leadership of Edison men. When the two companies consolidated, it was felt desirable to conduct lamp making in a single plant. The plant which made the better lamps was to continue, while the other was to shut down. Although Thomson-Houston lamps had previously been superior in efficiency, the expiration of the patent on the filament-flashing process in 1893 soon after the consolidation permitted the Edison Works at Harrison to use the process. With that improvement the Harrison plant could make better lamps than those made in the Thomson-Houston plant at Lynn, and all lamp production was shortly concentrated at Harrison. John W. Howell was electrician at the Harrison works, which were for a few years in the charge of Francis Upton, formerly one of Edison's most brilliant assistants.

Despite the profitability of its first year's operations, the new General Electric Company was hit hard by the financial panic of 1893 and the years of reduced business activity which followed. Sales shrank to twelve or thirteen million dollars a year, with annual net profits ranging from only $400,000 to $900,000. Far more serious than that, however, was the effect of the financial recession upon the assets and capitalization of the company. The

declared assets of the new company included patents valued at $8,000,000 as well as large quantities of stocks and bonds received initially in partial payment for patent licenses and equipment. The value of those securities fell precipitously during 1893 and 1894, and reduced the credit balance of $1,025,000 in General Electric's surplus account as of January 31, 1893, to a debit balance of $14,800,000 by the beginning of 1895. Large blocks of securities had to be liquidated at substantial losses to provide working capital during those years. The financial support of Drexel, Morgan, and other New York and Boston bankers was necessary to sustain the big company, the common stock of which fell from 115 in 1892 to below 30 by early 1895. General Electric tottered perilously close to receivership for a time. The financial difficulties of its early life were not resolved until 1898, when its capital stock was reduced to $20,827,200 and a small credit surplus was restored.[37]

The panic of 1893 brought about a major readjustment in all the electrical industries. Many central-station companies and street railways, as well as manufacturers of electrical equipment, passed through receivership or were liquidated. The leading producers found that they could no longer afford to accept securities of only speculative value as payment for their equipment. Prices for all types of equipment fell to one-third or one-half of what they had been before. Activity remained depressed until about 1898, when sales began to increase. Within a short time all the electrical industries were booming again.

It was during the years of greatest financial stress, from 1893 to 1896, that the struggle for commercial superiority in the incandescent-lamp business was going on. Similar struggles were taking place in the fields of electric traction, alternating-current generation and distribution, and arc lighting. In all fields General Electric adopted an aggressive patent policy. It wanted to control as large a portion of the American electrical-goods business as possible. While many competing companies put up a vigorous defense, General Electric was able to establish itself firmly as the dominant firm in the industry, supplying more than half the

[37] See *Annual Report of the General Electric Company*, Schenectady, Nos. 2–7, Jan. 31, 1894, to Jan. 31, 1899.

domestic market for almost all non-communications electrical items. Even though a number of individual companies survived, they found it extremely difficult to do more than maintain their positions with respect to the leader. The aggressive policies employed by General Electric during the nineties resulted in some popular reaction against the big company, however. Public anti-trust agitation was directed against it as early as 1893, based upon its attempts to use the Edison patent to regain absolute control of the incandescent-lamp market and to broaden its control in other branches of the industry. Similar attacks were made later, and around 1910 they resulted in a prosecution by the federal government under the Sherman Anti-Trust Act of 1890.

EXPANSION OF WESTINGHOUSE

The importance of George Westinghouse in the electrical-goods industry had also been growing at a rapid rate during the eighties and early nineties, primarily because of his pioneering promotion of alternating current. Westinghouse himself was a prolific inventor, rivaling Edison in his breadth of interests. During his lifetime he took out more than four hundred patents. While he attended college for only three months, he acquired a wealth of practical experience in his father's machine shop in Schenectady. At the age of twenty-two he invented a practical railroad air-brake; and a year later, in 1869, the Westinghouse Air Brake Company began manufacturing the new device. Westinghouse then turned to electric signaling and combined his own inventions with purchased patents in the Union Switch & Signal Company.[38]

From signaling, Westinghouse expanded to other electrical apparatus. He began to manufacture direct-current generators in 1882; and in 1883 he started producing incandescent lamps and alternating-current generators at the Union Switch & Signal Company. In the former year the French inventor, Lucien Gaulard, and his English backer and co-worker, John D. Gibbs, brought out and patented in Europe a transformer whereby the high-voltage current of an alternating-current generator could

[38] The other interests of Westinghouse included the use of natural gas, manufactured gas, electric traction, steam and gas engines, and the steam turbine, to each of which he made important contributions.

be delivered at any desired lower voltage to local circuits.[39] This system was designed to provide the economies of high-voltage transmission of energy and also make possible the supplying of current for arc and incandescent lighting from the same machine. George Westinghouse acquired the American patent rights on the Gaulard-Gibbs system for $50,000. Although some experimental installations were made with the system in 1883 in Europe, it was not ready for universal commercial application.

The Hungarians Charles Zipernowsky, Max Déri, and Otto T. Bláthy, engineers of Messrs. Ganz & Company in Budapest, recognized the weakness of the series wiring employed in the Gaulard-Gibbs system, for such a scheme made it difficult to maintain a constant voltage. By August of 1884 they had developed a commercially practicable transformer system in multiple which permitted the extensive application of alternating current. Word of this discovery traveled to the Edison Electric Light Company through its widespread system of agents. The Edison company concluded an arrangement in 1887 with Ganz & Company to give the Edison organization exclusive rights in North America to use all Zipernowsky patents relating to the distribution of electricity by alternating currents of high tension with transformers.[40] In addition, the Edison company reserved an option to purchase the patents and their improvements for $20,000, as soon as a broad controlling United States patent should be granted. The Edison company did not comprehend the technical and commercial importance of the innovation, however. Edison himself opposed the use of alternating current, and the Edison company never took up its $20,000 option. With this decision, the Edison company lost an excellent opportunity to gain a powerful position in what

[39] The transformer was based on the principle of electromagnetic induction, discovered by Faraday and Henry in 1831. It was found that, when a current in a primary circuit was started or stopped, a secondary circuit showed a momentary current flow. Since the secondary circuit is induced only when the voltage is changing, induction is possible only with alternating current or fluctuating direct current. While the idea of an induction transformer was not new, no feasible system had been developed before the work of Gaulard and Gibbs. The first suggestion had appeared in C. W. Harrison's English patent No. 588 of 1857. The next mention did not appear until 1877, when Paul Jablochkoff made experiments in this connection. Other investigators before 1882 were C. T. Bright, Fuller, Varley, and Enuma. See article by Charles Zipernowsky in *Modern Light and Heat,* Vol. II, p. 140c (June, 1887).

[40] *Ibid.,* Vol. II, p. 84 (Apr., 1887).

was to become a tremendously important aspect of electric utilization, for the transformer was the key to economical long-distance power transmission. The Edison company's opposition to alternating current made it blind to the advantages of such a system.

The same mistake was not made by George Westinghouse, who became the principal sponsor of this method of power distribution in the United States. The Hungarian system itself was not introduced into this country on any great scale, although it found extensive use in Europe. Westinghouse relied principally upon the American transformer patents of Gaulard and Gibbs and of William Stanley. Stanley had started working on much the same problem in 1883, and he succeeded in developing for Westinghouse a practical scheme of step-up and step-down transformers in parallel. The system was first placed in operation at Great Barrington, Massachusetts, in 1886. Westinghouse acquired the patents on it and immediately put it into successful service in Buffalo. Within three years, 150 alternating-current stations supplying 300,000 lamps had been installed under Westinghouse auspices. Besides sponsoring Stanley's work, Westinghouse encouraged the alternating-current experiments of other inventors and carried the new system to success in the United States.[41] The work of European-born Nikola Tesla on the polyphase motor was of particular importance in increasing the usefulness of alternating current. Tesla's alternating-current patents were acquired by Westinghouse for $1,000,000 plus a royalty of $1 per horsepower, and Tesla himself was employed by Westinghouse as a consultant for a few years after about 1888.

All work in this country in connection with alternating current was not sponsored by Westinghouse, nevertheless. Among the experimenters was Elihu Thomson of the Thomson-Houston Electric Company. His progress on transformers later proved to be of value to the General Electric Company.

The electrical business conducted by the Union Switch & Signal Company grew so rapidly after 1882 that on January 8, 1886, the Westinghouse Electric Company was incorporated to take over

[41] The development of practical transformer systems ended most serious attempts to use storage batteries to reconcile the voltage differential between arc lighting and incandescent lighting.

that activity. George Westinghouse retained a majority of the stock of the new company. Besides its own normal growth, the company adopted the Thomson-Houston technique of acquiring competing companies. Within a few years it had purchased controlling interests in the United States Electric Lighting Company and the Consolidated Electric Light Company, as well as the Waterhouse Electric & Manufacturing Company, an arc-lighting concern. Consolidated had acquired the old Electro-Dynamic Light Company and the Sawyer-Man Electric Company just prior to its own acquisition by Westinghouse. In addition, a cross-licensing agreement was negotiated with the Thomson-Houston company, and other companies were acquired later.

By 1890 the Westinghouse Electric & Manufacturing Company[42] had total declared assets of about $12,000,000, although book values were somewhat inflated. Its billed sales were around $5,000,000, and its issued capital stock was approximately $6,000,000. Sales had increased somewhat by 1892, but after the panic of 1893 they fell again to $5,000,000 and remained near that level for a number of years. The company narrowly escaped receivership during the depression. Because of the company's rapid physical growth and the drain of costly patent litigation, franchises, and patent rights, it was necessary to bring in new money to maintain working capital. Capital stock issued was increased to $12,000,000 by 1896. Net profits were small during almost all the nineties, averaging about $200,000 a year.

AGREEMENT BETWEEN GENERAL ELECTRIC AND WESTINGHOUSE

The net result of all the corporate purchases, consolidations, mergers, and reorganizations discussed above was the concentration of most of the non-communication electrical-goods production of the United States into the hands of two large rival organizations by 1896. The General Electric Company and the Westinghouse Electric & Manufacturing Company handled between them more than 75 per cent of the total business. Although there were a few other "full-line" producers, such as the Siemens

[42] A financial reorganization in 1889 resulted in the adoption of the expanded name. The Chartiers Improvement Company, an early pioneer in the production of electrical machinery and appliances dating from 1872, was acquired in that year and used as the vehicle of the reorganization.

& Halske Company of America [43] and the Stanley Electric Manufacturing Company,[44] and a great number of small specialty companies producing incandescent lamps, arc lamps, dynamos, or other single products, they were completely overshadowed by the two leaders. Perhaps the outstanding competitor in the production of arc lamps, dynamos, and other heavy electrical equipment was the Western Electric Company.

Even though control over the electrical-goods industry had been concentrated largely in two companies, the problem of conflicting patents still existed in 1896. Westinghouse had title to the patents of Maxim, Sawyer and Man, Farmer, Weston, Tesla, Stanley, and others, as well as those of Westinghouse himself. General Electric had title to the patents of Edison, Thomson, Brush, Sprague, Van Depoele, Bradley, and others. It seemed inevitable that new patent struggles would occur if something were not done to avoid them. The conflict was particularly acute in connection with alternating current and electric lighting, for they belonged together. Alternating current simplified and unified electric illumination, power transmission, and other aspects of the use of electric energy, and by that time its advantages were universally recognized. Its reconciliation of the differences between the circuit voltages of arc and incandescent lighting was of particular importance. Despite the expiration on November 17, 1894, of the basic Edison lamp patent No. 223,898, the accumulation of hundreds of minor patents on the lamp and associated equipment gave General Electric continued domestic patent leadership in this field. General Electric also controlled many important patents on electric traction, including the Van Depoele trolley patent, which had recently been sustained in the lower courts.[45] Westinghouse similarly led in the alternating-current field, although General Electric owned the Thomson alternating-current patents.

[43] The Siemens & Halske Company of America was organized in 1892. At first it appears to have operated primarily as selling agent for the German Siemens & Halske Company. In 1895 its capital was increased to $2,000,000, and its plant was considerably expanded so that it could supply all types of electrical equipment.

[44] The Stanley Electric Manufacturing Company was organized in 1891.

[45] The 1895 upholding of the Van Depoele trolley patent, which was a factor leading to the 1896 patent-licensing agreement between General Electric and Westinghouse, was later reversed in large part by the higher courts. Most of the claims of the patent eventually either were held to be invalid or were so narrowed as to offer little protection.

This time the impasse was not solved by consolidation but by the interchange of patent rights. An agreement was evolved whereby each company recognized the patents of the other "and the right, subject to certain exclusions, to a joint use thereof." [46] Royalties were to be paid on the basis of use of the patents by the other company. It was agreed that General Electric had contributed 62½ per cent and Westinghouse 37½ per cent of the value of the combined patents; and the business handled by the two companies in the covered fields was to be divided in that proportion without royalty payments. If either company exceeded its share, royalties were required. This significant agreement became effective March 31, 1896, and was to continue for a period of fifteen years. The companies felt that the arrangement had "many advantages, particularly in eliminating much costly patent litigation." [47] The patent-licensing agreement between General Electric and Westinghouse specifically excluded lamp patents. Nevertheless, the two companies suspended a large number of patent infringement suits against each other, including some over the incandescent lamp.

Competition in the incandescent-lamp industry was keen for a time following the expiration of the Edison patent. Lamp prices were forced down to a point where profits were small or nonexistent for many companies, and some companies even found themselves selling below cost. With their greater resources and staying power, General Electric and Westinghouse were able to meet the cutthroat pricing more easily than the smaller producers. Although some new companies continued to enter the business, many more older ones were forced out, and the total number of firms declined rapidly (see Table XI on page 92).

Following the patent agreement with Westinghouse, General Electric undertook to stabilize the entire incandescent-lamp industry. In August of 1896 "the General Electric Company, together with six other companies, organized an association known as The Incandescent Lamp Manufacturers, which had for its purpose the fixing of lamp prices and the allotment of business and customers to each. Soon after its organization, 10 other lamp

[46] *Fourth Annual Report of the General Electric Company*, Schenectady, Jan. 31, 1896, p. 7.

[47] *Ibid.*

companies joined the association and later still others were brought under its control. Agreements were made between the members of the association and the Westinghouse Company, whereby the latter, through its subsidiary, agreed to maintain prices fixed and established by the association."[48] A pool price of about twenty cents a lamp was established for the 8- to 25-candlepower sizes to succeed the prices of twelve to eighteen cents a lamp which had previously prevailed. Larger lamps were priced higher according to candlepower. It was agreed that for lamps supplied with bases other than the Edison and Westinghouse designs a premium would be charged.[49]

These steps in the early evolution of the incandescent-lamp industry completed the development of a pattern of organization which was maintained in many of its general characteristics for almost fifty years. The lamp division of General Electric itself handled about half the domestic lamp business, which amounted in 1896 to around twelve million lamps. Although it no longer had a fundamental lamp patent, it owned a very large number of minor patents on the lamp and on methods of manufacture. Westinghouse supplied about 10 or 12 per cent of the incandescent lamps sold in this country. Most of the lesser competitors operated under restrictive agreements which permitted a continuation of General Electric's supremacy. Only a few minor concerns remained outside its immediate sphere of influence.

3. The European Electric-Lamp Industry, 1880–1896

Although the most significant early technical and commercial developments in arc lighting had been conducted in Europe,

[48] U.S. Tariff Commission, *Incandescent Electric Lamps,* Report No. 133, 2nd Ser., Government Printing Office, Washington, 1938, p. 32. The original source for these statements is given by the Tariff Commission as Transcript of record—*United States v. General Electric Company et al.*—U.S. Supreme Court, October term, 1926, No. 113, pp. 807–809.

[49] Among the members of the new association were several of the companies which had resisted most strongly the injunctions brought by General Electric only a few years before. The Columbia Incandescent Lamp Company of St. Louis, the Buckeye Electric Company of Cleveland, the Sunbeam Incandescent Lamp Company of Chicago, the Perkins Electric Switch Manufacturing Company of Hartford, the Bryan-Marsh Company of Marlboro, Massachusetts, and the Adams-Bagnall Electric Company of Cleveland were the first to enter the association.

American inventors and companies led the world in getting incandescent lighting into commercial production. British experimenters were concurrently working toward the same goal, however; and they were able to follow the American lead very rapidly. In continental Europe only a little more time was required. Within a few years a growing incandescent-lamp industry had arisen in virtually every industrialized nation in Europe to supplement arc lighting, which was already making rapid progress.

Following the early period of confusion and rapid change, there generally emerged in each country one firm or a small group of firms which dominated the lamp business for many years thereafter, even if the number of producers continued to grow. Patent monopolies and patent conflicts were important, though only in Great Britain to the same extent as in the United States. The leading companies usually either were or became "full-line" electrical-goods producers who led in several fields in addition to lamps.

ELECTRIC LIGHTING IN GREAT BRITAIN

In England, both the Swan and the Lane-Fox incandescent lamps were put into production in 1880, with the organization of what later became the Swan United Electric Light Company, Ltd., and the Anglo-American Brush Electric Light Corporation, Ltd., respectively. The Brush company had rights under the dynamo and arc-lamp patents of Charles F. Brush, as well as under the filament-lamp patents of Lane-Fox; and it was able to make both arc and incandescent installations. Swan was slower in getting started with actual installations because of his early concentration upon the incandescent lamp alone and his failure to develop simultaneously all the other parts of a complete incandescent-lighting system.

The Edison lighting system was introduced into England in 1882, with the organization of the Edison Electric Light Company, Ltd. The first central station for incandescent lighting in Europe, and indeed in the world, was the Edison plant at 57 Holborn Viaduct in London, which operated for about two years after January 12, 1882, as an exhibition station.

The three companies mentioned above were the most important producers of incandescent lamps in England for several years. Other concerns included the partnership of Woodhouse & Rawson; the Maxim-Weston Electric Company; the Duplex Electric Light, Power, & Storage Company; Siemens Brothers & Company; the Pilsen, Joel, & General Electric Light Company; and the British Electric Light Company. The last two concerns were primarily arc-lighting companies; they added incandescent lighting to round out their lines. A large number of other concerns, such as the Jablochkoff Electric Light & Power Company, confined their attention to arc lighting.

Although the British incandescent-lighting industry got off to a rapid start, progress was subsequently retarded by the Electric-Lighting Act of August 18, 1882, passed by Parliament to govern the terms whereby the streets could be opened for the laying of cables for central-station distribution of electric energy.[50] For three years prior to the passage of this act, there had been a violent boom in operating companies, particularly those licensed by the Anglo-American Brush Company. Public enthusiasm had been roused to a feverish pitch after the Paris and London electrical exhibitions of 1881 and 1882. Inflation of security values and extravagant commercial ventures in both types of electric lighting were the rule rather than the exception. Exhaustive hearings were held by Parliament, and a law was passed which was intended to provide the greatest public protection in the development of central-station electric lighting. It was designed to avoid the monopoly evil in electric lighting that had plagued gas lighting and to keep proponents of electric lighting from rushing ahead heedlessly in an untested field. The strongest provisions of the act represented a reaction against the abuses of the gas companies. They had been granted perpetual monopolies for their local areas and customarily sold poor gas at high prices, with no attempt at improvement in quality or economy of service.

The key provisions of the law were (1) that licenses might be granted to companies or to local authorities for the establishment of central-station electric lighting, and (2) that the local govern-

[50] See Arthur P. Poley and Frank Dethridge, *A Handbook on the Electric Lighting Act, 1882*, Simpkins, Marshall & Co., London, 1882; George Spencer Bowes and Walter Webb, *The Law Relating to Electricity, Being the Electric Lighting Act, 1882*, Sampson Low, Marston Searle, & Rivington, London, 1882; and Whyte, *The Electric Industry*, pp. 19–25.

ments might purchase all properties and rights of the lighting companies at fair market value within six months after twenty-one years from the date of the license. If the option to purchase were not taken up then, it could be exercised within six months of the expiration of each subsequent seven-year period. Market value, moreover, was stated explicitly as excluding goodwill, accumulated profits, and similar items. Local authorities were in that way protected from being obliged to continue indefinitely with the new method of illumination, should it be found to be unsatisfactory.

The Electric-Lighting Act had effects not foreseen by Parliament. Instead of provoking caution in central-station electric lighting, it stifled commercial development. Investors were unwilling to risk their capital in facilities which could be taken over at much reduced prices by the local communities after twenty-one years. The speculative Brush and similar companies collapsed and were liquidated, one after another. Very few central-station companies of any sort were able to survive. Until the law was amended in 1888 the only progress in electric lighting was in isolated incandescent and arc-lamp installations, which were common,[51] but did not stimulate the British electrical-goods industry as did the central-station development in America. The amended law extended the life of illuminating companies to forty-two years; and, with this greater inducement to venture capital, central-station electric lighting became commercially possible. Electric lighting expanded rapidly thereafter, yet all branches of the British electrical industry had inevitably been held back. Unhampered during those six years, the American industry had far outdistanced the achievements of the British; and the German industry was rapidly rising in relative importance.

As early as 1882 the Swan and Edison electric-light companies collided over patent rights. Each company accused the other of infringing its "basic" incandescent-lamp patents. The ensuing cross-suits were settled out of court by a merger of the two interests through the creation of the Edison & Swan United Electric

[51] In Apr., 1883, there were 28 complete Edison isolated plants of 7,493 lamps in operation or in process of installation in England. Additional plants followed rapidly, and several other companies were also making installations. See *Bulletin of the Edison Electric Light Company*, No. 17 (Apr. 6, 1883), pp. 20–21.

Light Company, Ltd., in 1883.[52] The Edison & Swan company purchased Sawyer's English patent on the "filament-flashing" process and in 1886 was successful in defending it, as well as its lamp-design patents, in litigation against the British firm of Woodhouse & Rawson. The most important aspect of this case was the upholding of the basic Edison carbon-filament patent over the patents of Swan and all others. Because both Swan and Edison patents were owned by the same company, it made little commercial difference in England which were upheld; yet the decision for Edison created an important precedent for the American case against the United States Electric Lighting Company which has already been discussed.

After its victory over Woodhouse & Rawson, the "Ediswan" company attacked the users of lamps made by the Anglo-American Brush Company, its other large competitor. The courts again upheld the Edison patent and found that the Brush company was infringing both the "flashing" process and the basic Edison lamp patent. The Brush company agreed to give up the production of incandescent lamps until the Edison patent expired.

All the electric-lamp companies had had a difficult time from 1882 to 1888 under the Electric Lighting Act. Of the pioneers the only important survivors were the Ediswan, Brush, and Woodhouse & Rawson companies, and they all had found it hard to remain solvent. After the amendment of the act in 1888, the entire industry grew much more rapidly. New lamp producers entered the business, and the market expanded. Nevertheless, in 1890 there were only twelve producers of incandescent lamps in Great Britain, as compared with thirty-five in the United States.

The Ediswan company's legal victories gave it a practical monopoly of incandescent-lamp production, and after 1891 competition melted away. Some companies were stopped by injunction proceedings; some accepted licenses. Others voluntarily suspended operations, and others became insolvent and were liquidated. By 1893, the number of producers even nominally

52 Other early patent clashes were settled by the offering of licenses. For example, early in 1883 the Edison Electric Light Company, Ltd., withdrew its proposed infringement suit against the British Electric Light Company, Ltd., and granted it a license under the Edison lamp patents in return for a lump sum in cash and a royalty for each lamp produced thereafter by the British company. See *Bulletin of the Edison Electric Light Company*, No. 16 (Feb. 2, 1883), p. 7.

in the lamp business in Great Britain had dropped to seven, and a few of those were temporarily closed (see Appendix B).

As the monopolist, the Ediswan company was able to charge high prices for its product. The 16-candlepower lamp was priced at 3 shillings 9 pence, and larger sizes were sold for proportionately higher sums. Those prices were maintained almost to the expiration of the patent, while at the same time the 16-candlepower lamp was selling on the continent for only about a shilling.

It was not until the middle of 1893 that many new manufacturers became seriously interested in producing incandescent lamps. The patent ran out in November, and within three years close to fifty new brands were introduced in the British market. Many of the new lamps were made by foreign producers, who began exporting to Great Britain on a much larger scale than formerly. Despite the increased number of competitors and the reduction of prices to about a shilling for the standard 8- to 32-candlepower lamps, the Ediswan company had the advantage of a high-quality lamp and a well established commercial position and continued to lead the industry. It also still had important patents on lamp holders and lamp fittings. A great many of the newer firms soon failed, and only about thirty domestic and foreign brands remained on the market at the end of 1896.

Dynamos, arc lamps, and all other types of electrical equipment were produced in quantity in Great Britain during the years 1880 to 1896, particularly after the amendment of the Electric Lighting Act in 1888. Although total output was considerably less than American production in most of these fields, there were at least as many British manufacturers of electrical apparatus; and they far outnumbered producers in other European countries. For example, there were twenty-seven manufacturers of arc lamps in Great Britain in 1889 and but fifteen in the United States. By 1896 the numbers of arc-lamp producers had increased everywhere, yet Great Britain still led the United States, fifty-four to forty-four (see Appendix C). Nevertheless, the slow growth of central-station lighting until 1888 held back the British somewhat, and not much of importance to the American lamp industry took place in England in these other fields after 1880 and before 1896.

ELECTRIC LIGHTING IN CONTINENTAL EUROPE

Even though the most successful inventors of the incandescent lamp had been Americans or Englishmen, after the International Exposition of Electricity at Paris in 1881 continental interest in incandescent lighting was greatly stimulated. That exhibition marked the first extensive publicity which the Edison lamp had received in Europe, and it was given a more enthusiastic reception than any that its competitors had yet won. A number of European experts who had been very critical of Edison were entirely converted to the completeness and excellence of his system. He was awarded the diploma of honor for the best incandescent electric-lighting system and was decorated by the French government.[53]

The first permanent central station for incandescent lighting in Europe was the Edison station in Milan, which was put into operation soon after the New York Pearl Street installation. The Italian concern was organized and financed by Italians, and held a license under the Edison patents according to the arrangement employed with American illuminating companies. The Italian development, although quick to get under way, did not result in an important electrical industry. Isolated plants and other central-station installations were made, and the Milan plant was one of the most progressive in the world; but most equipment continued to be imported, and relatively few significant technological advances were made by the Italians.

The first central station in Germany was erected in Berlin by an Edison-licensed company in 1884. Isolated plants were common in Germany, however; the first one was an Edison plant installed in the Strassburg railroad station in 1881, and 550 were in operation by 1885.[54] Arc lighting was also common by the time the first incandescent station was put into operation.

After the Paris Exposition of 1881, Basch writes, Edison had offered to license the German Siemens & Halske Company under his patents for the manufacture of incandescent lamps. Werner

[53] Similar recognition and honors were won by Edison's light at the Crystal Palace Exposition in London during 1882.

[54] Carl Basch, *Die Entwicklung der elektrischen Beleuchtung und der Industrie elektrischer Glühlampen in Deutschland*, Siemenroth, Berlin, 1910, pp. 11, 13.

Siemens declined the offer because he was too proud of his reputation to accept a license under some other company's patents, and because at that time he thought that the arc lamp would force the incandescent lamp off the market within a short time. The Edison patents for continental Europe were then assigned to the Compagnie Continentale Edison in Paris, and the German Emil Rathenau acquired the German rights from it and organized a research company. From this company there followed in 1883 the German Edison Company (Deutsche Edison Gesellschaft für angewandte Elektrizität), which produced lamps itself and licensed others to produce them under its patent rights. The Siemens & Halske Company was active in the organization and control of the new concern, despite its earlier rejection of Edison's proposal. In Germany, also, numerous inventors and engineers soon undertook to produce lamps of their own design.

In France the situation was somewhat like that in Germany. French laws required patented articles to be manufactured in France to maintain patent validity. For that reason, and since no Frenchmen had participated in any important way in the technical development of the incandescent lamp from 1877 to 1881, electric lighting installations of that type were delayed until foreign plants could be established for the manufacture of the necessary apparatus. In 1881, a lamp factory was established in Paris by Swan.[55] The Edison interests were not far behind Swan in their establishment of the Société Electrique Edison and the Compagnie Continentale Edison. By 1882, installations of isolated incandescent lighting plants were common, and central-station lighting followed within a short time. Many domestic manufacturers similarly went into production soon afterward, and by the end of the eighties there were more producers of incandescent lamps in France than in England.

In other parts of the world, such as Central and South America, lighting activity was at first confined largely to the installation of isolated plants produced by the larger American or European

[55] When the Swan United Electric Light Company, Ltd., was formed in 1882, Swan's continental business, which by that time included factories at Lille and Cologne as well as in Paris, was consolidated with the English business under a single company.

manufacturers. In those areas also the American Edison Company was at first more active than its competitors.

Despite the slower start of incandescent-lamp production in continental Europe, by the beginning of 1891 there were more than fifty producers in operation in nine countries (see Appendix B). France and Germany led the continent, with more than half of the companies located within their borders. Among the other countries with growing lamp industries were Belgium, Holland, Austria, Italy, and Hungary. As a rough approximation, it may be said that total output of the rest of the world was at that time a little greater than production by American incandescent-lamp manufacturers.

The French lamp industry increased in size at first more rapidly than any other in continental Europe. As in other countries, the interests of the opposing Swan and Edison companies soon clashed, and a compromise similar to the British solution was reached in 1888 with the formation of the Compagnie Générale des Lampes Incandescentes. Patent conflicts and litigation continue in France, however, between the Compagnie Générale and the increasing number of competitors. By 1891 there were at least eighteen producers in operation. Court decisions did not give the French Edison patents the sweeping victory which they gained in England and the United States, even though some infringement prosecutions were successful. Lacking a conclusive decision, competition in France continued very keen, and the market was fairly open. The standard lamps sold for about 25 cents each.

In Germany the Edison and Swan lamps supplied most of the market for a few years.[56] When the inevitable patent conflict arose, the Germans did not resolve the problem by consolidation, as the British and French had done. The German Edison Company sued the Swan United company for infringement. In 1891, after several years of litigation, the Supreme Court at Leipzig decided that the Edison patent was valid, but that the Swan lamp did not infringe.

The German patent monopoly was weakened even before the

[56] The Swan United Electric Light Company operated a lamp plant at Cologne until 1894, when the company was merged with the Edison & Swan United company.

final court decision, for as early as 1887 the German Edison Company terminated its obligations to the Compagnie Continentale Edison and agreed with Siemens & Halske to the same rights and duties for the German industry. At the same time it changed its name to Allgemeine Elektrizitäts-Gesellschaft[57] to make known its independent position.[58]

The influx of new lamp producers in Germany was greatest during the year 1889. Competition became intense, and prices were forced to levels well below a shilling for the standard lamp. According to one German writer,[59] it was neither lawsuits nor patent-precipitated consolidations which held down the number of firms in the industry, but rather the inability of many producers to keep up with the others in productive efficiency. This seems also to have been true in Austria, Italy, Hungary, Holland, Belgium, and other countries. The European product suffered seriously in quality as a result of the violent price competition. Representatives of the German electrical-goods companies met in 1894 to study the problem, and they concluded that the complaints about low lamp quality were justified. Poor manufacturing techniques produced uneconomical lamps of short life, and imperfect sorting and false marking were common.

Faced by that situation, and in the absence of a patent monopoly such as existed in England and America, the Germans turned to another device. The representatives of the electrical-goods companies worked out an agreement for raising and standardizing the quality of incandescent lamps and for reducing competition. A retail price equivalent to about one shilling was established, as well as wholesale and manufacturers' prices. The organization of German incandescent-lamp producers had for its purpose "removing economic losses by common agreement."[60] That association was the predecessor of the lamp cartel that has controlled the bulk of European lamp production since 1903. Originating in Germany, it soon spread to the other Euro-

[57] It is frequently called A.E.G., Allgemeine, or the German General Electric Company.
[58] Basch, *op. cit.*, p. 56.
[59] E. A. Krüger, *Die Herstellung der elektrischen Glühlampe*, Oskar Leiner, Leipzig, 1894, pp. 3–4.
[60] Basch, *op. cit.*, pp. 66–68.

pean nations. Siemens & Halske and Allgemeine were the leaders in the movement to end "ruinous price competition."

While the incandescent-lamp industry was expanding, arc lighting and other applications of electricity also continued to flourish in Europe (see Appendix C). Arc lighting had had a vigorous start in Great Britain, and the number of producers of arc lamps in that country led all other nations through 1896. The American industry expanded rapidly during the eighties and early nineties, however, and the smaller number of producers evidently exceeded British production by a considerable margin. France was for a short time the third largest producer of arc lamps, as well as of other electrical goods. With the growth of Siemens & Halske and Allgemeine after 1890, continental leadership soon passed to Germany.

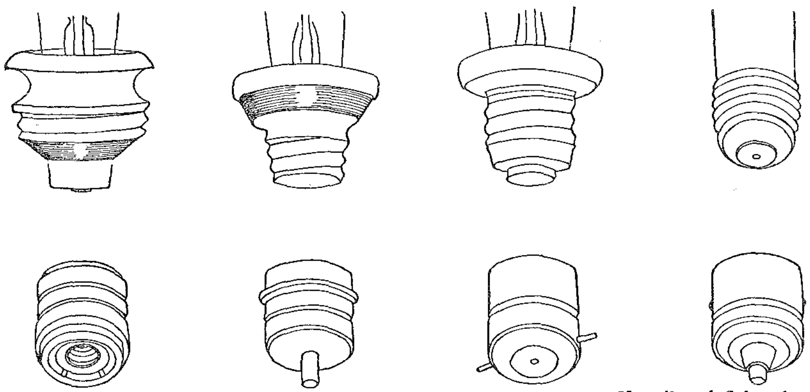
Chapter V: TECHNOLOGICAL DEVELOPMENTS DURING THE FORMATIVE PERIOD OF THE ELECTRIC-LAMP INDUSTRY: 1880–1896

1. *Technological Developments in Incandescent Lighting, 1880–1893*

FREEZING OF DESIGN

ONCE a practical incandescent lamp had been developed and placed on the market, engineering attention was shifted largely from the basic characteristics of the lamp and the filament to other aspects of the lighting system. For commercial success it was necessary to establish satisfactory designs for bases, sockets, fuses, fixtures, meters, and similar features. The distribution system and generating equipment also required a great deal of attention. Efficient methods of production had to be devised for lamps and all other apparatus. This does not mean that the lamp filament was completely ignored, for Edison's Bristol-board filament was quickly displaced by bamboo, by Swan's parchmentized cotton thread, and by other materials that will be mentioned shortly. It does mean that the nature of the technical problems changed radically with the new commercial status of the industry, and for some years the illuminant received relatively less attention than formerly. In the lamp, the emphasis passed from the improvement of basic characteristics to the improvement of details.

The evolution of the Edison lamp base and socket was typical of the rapid change through which many such features of the lighting system passed. The first Edison base was a round wooden plug which slipped into a wooden socket containing a hole of the same size. Strips of metal on the base in contact with similar strips in the socket permitted the current to flow through the lamp. This type of base required the lamp to stand upright, for otherwise it would have fallen out. Early in 1880 the screw cap on a kerosene can provided the inspiration for a new screw-type base. A wooden base supported and insulated the metal screw-shell and ring terminals and was attached to the bulb with plaster of Paris. The following year the size of the base was reduced, although it retained the same general features. Shortly thereafter, the wood was superseded by plaster of Paris, and the metal ring above the shell was replaced by a metal button on the end of the base. Subsequent changes were more gradual and were made



Howell and Schroeder

Fig. 20. Base Varieties Used During the Early Commercial Years
Top row: Edison base evolution (left to right); original wooden screw base with metal ring, 1880; plaster base with metal ring, 1881; plaster base with metal button, 1881; porcelain base, 1900. Bottom row (left to right): Thomson-Houston base; Westinghouse base; "Ediswan" base; United States Electric Lighting Company base.

only in minor features. Other lamp manufacturers, in this country and abroad, after similar evolutionary developments, also adopted particular types of bases and sockets. Since each producer had his own design, the lamps of one would not normally fit into the sockets of another. At first, it was only by using special adapters that lamps could be used interchangeably. Later, many manufacturers undertook to provide customers with lamps having any type of base required.

IMPROVEMENTS IN CARBON FILAMENTS

The success of the carbon lamp in 1879 and 1880 ended for a time almost all attempts to make metal filaments. It was thought by many that carbon was the best of all possible materials, and attempts at betterment were confined largely to carbon. By 1884, however, the greatest progress had been made, and no further important improvements in carbon resulted for twenty years.

For a dozen years after 1884 relatively little attention was paid to filament development. Lamp manufacturers were busy with manufacturing and promotion, and carbon seemed to have reached its peak. The type of competition within the lamp industry at that time was not conducive to extensive filament experimentation by men of top-notch ability; nor had competition from gas and arc lighting assumed dangerous proportions. Also, numerous scientific advances, which soon opened up many new channels of investigation, were not available to lamp engineers during the eighties and early nineties.

The development of homogeneous, non-structural carbon filaments was the great advance from 1880 to 1884. British inventors were outstanding in that work. In 1882, Desmond G. Fitzgerald of the School of Telegraphy and Electrical Engineering in London invented a new structureless filament. He soaked paper in zinc chloride to make it homogeneous, washed it in baths of dilute hydrochloric acid and water, and then dried it. The resulting sheet was hard, transparent, and tenacious. It was cut into strips, carbonized, and used in incandescent lamps.[1] The lamp was produced in England in 1882 by the school, which was the first electrical engineering school in England, if not the world. This seems to have been the first non-fibrous material successfully employed for incandescent-lamp filaments. Swan's parchmentized filaments of 1880 had represented a partial abandonment of Edison's natural vegetable fibers, but not to the extent of the Fitzgerald and later developments.

Other methods of preparing structureless filaments were devised within a few years. Swan discovered a process in 1883 for squirting a viscous solution of nitrocellulose through a die into a coagulating bath of alcohol. The thread was washed and deni-

[1] *Electric Light*, Vol. I, pp. 83–84, 87 (Oct. 2, 1882).

trated before carbonizing.[2] It was used in European lamp production for many years. In 1884 Edward Weston, who had concentrated primarily upon arc lighting, developed a modification of the Swan process that was used by the United States Electric Lighting Company in some of its lamps.[3] "Gun-cotton in the form of flat sheets was treated chemically to separate the nitryl from the cellulose. The resulting cellulose product is a tough, firm translucent substance from which the strips are cut in a sinuous form and carbonized."[4] The Weston product was called the "tamadine" filament and was used in the Westinghouse stopper lamp of 1893.

After 1884 further refinements were made in non-structural carbon filaments, although there were no radical changes. Alexander Bernstein obtained a new kind of carbon filament in 1886 by suspending a fine metallic wire in a liquid hydrocarbon or some other carbon compound. When an electric current was passed through the liquid from the wire to a copper plate on the bottom of the container, a hard and dense deposit was formed on the end of the wire. By varying the current and the rate at which the wire was withdrawn, a filament of any desired size could be obtained.[5] In 1888, Leigh S. Powell, another Englishman, combined the earlier Fitzgerald and Swan methods. He dissolved cotton in a hot zinc chloride solution, squirted this mass through a die into alcohol or water to harden it, washed out the zinc chloride and then shaped and carbonized the filament.[6] Other unique processes were developed by inventors in many nations.

The structureless filaments were improvements over the bamboo, grass, cotton, silk, woolen, and other structural-fiber filaments used by Edison and many other manufacturers. Greater homogeneity in composition and uniformity in cross-section could be obtained with the chemical processes, particularly when

[2] G. Basil Barham, *The Development of the Incandescent Electric Lamp,* Scott, Greenwood & Son, London, 1912, p. 26.

[3] Weston became the electrician and guiding technical force of the United States Electric Lighting Company in the place of Maxim, who had gone to Europe.

[4] Franklin Institute, *Efficiency and Duration of Incandescent Electric Lamps,* Philadelphia, 1885, p. 7.

[5] *Electrical Engineer,* Vol. V, p. 213 (Sept., 1886).

[6] John W. Howell and Henry Schroeder, *The History of the Incandescent Lamp,* Maqua, Schenectady, N.Y., 1927, p. 82.

they were followed by "flashing" the filaments in a hydrocarbon atmosphere. Although each manufacturer generally made his filaments by a unique process, most of the filaments were the same in essential nature.

Further attempts at improvement involved the use of additional substances in efforts to raise the operating temperature above the 1600°C. or so normally used or to add strength to the carbon. The German-made Seel lamp, for example, used threads of silk or wool impregnated with a mixture of sodium silicate and gum arabic. A Hungarian lamp company used threads impregnated with potassium silicate and other substances. Alexander Lodyguine toughened his carbon filaments by treatment with boron fluoride and impregnation with sugar. Even when successful, however, all the proposed replacements for vegetable fibers marked only a small step forward in terms of potential improvements. Only 1 or 2 per cent of the electric energy used by any carbon lamp was given off as light; the rest was wasted as heat.[7]

NEW NON-CARBON FILAMENTS

The eventual downfall of the carbon filament was foreshadowed by a number of other developments which had occurred by 1893. When experimenters found after 1884 that they could not increase the efficiency of carbon filaments, they gradually turned back to metals and to metallic oxides and salts. The first attempts made were to combine with carbon other substances as in the impregnated threads mentioned above. Other more complicated composite carbon filaments were also tried, as well as a great many containing no carbon at all.

Even though none of the metallic or composite filaments made by 1893 represented any real improvement over carbon, they did indicate the growing interest in finding a new and better filament material. In the United States this interest in large part repre-

[7] Carbon has a relatively high electrical resistance as compared with the metals, and cellulose filaments of all types for use on circuits of 110 volts averaged only about six inches in length. Because of the great elasticity of the carbon, the filaments needed no further support, and carbon lamps could burn in any position. Since the shape of the filament largely determines the distribution pattern of light output, many variations were adopted by the lamp manufacturers for the different sizes and types of lamp. Some were straight U's; some were wavy loops; some were shaped like the figure 8; others had loose coils of one or two turns; and there were still other types.

sented attempts by competitors to get around the basic Edison patent. In England the stringent monopoly choked out almost all attempts at betterment, particularly after 1888. On the continent, where there was not a tight monopoly, interest in new materials was aroused more quickly and more keenly, although with no greater initial results.

One of the first to turn away from pure carbon after 1880 was F. G. Ansell, an Englishman, who in 1883 tried the electrodeposition and oxidation of calcium, aluminum, and magnesium on carbon filaments. Filament operating temperatures were no higher than those of pure carbon, however. Ansell also attempted unsuccessfully to give strength to wires of calcium and similar metals by oxidizing their surfaces.[8] In 1886 a German patent was issued to Max Neuthel for a filament of magnesia and porcelain clay saturated with "platin-iridium" salts and then heated to reduce the salts to a metallic state. It was strengthened by a covering of chromium and was burned in air.[9] Although coatings of metallic oxides on platinum or carbon wires were later tried by many other individuals, the differences in coefficients of expansion always destroyed such filaments when they were heated.

In 1887 the American, Turner D. Bottome, applied for a patent which was granted in 1889 on a process for making a composite carbon and tungsten filament. The tungsten was designed to add hardness to the carbon. The process did not permit a much higher operating temperature, however, and it was not successful. Bottome took out another patent in 1889 on a composite filament of carbon and molybdenum. In 1890 Lawrence Poland was granted an American patent, for which application had been made in 1887, on a special type of iridium-filament lamp. A few years later, after the validity of the basic Edison patent had been sustained, the Westinghouse company undertook to develop a non-infringing lamp. As part of this effort, the Russian inventor, Alexander Lodyguine, whose experiments in incandescent lighting had started as early as 1872, was hired by Westinghouse. Lodyguine attempted to coat carbon, platinum, or other metallic cores with various metals, including tungsten, osmium, molybdenum, and chromium. Unfortunately, he was not able to get rid

[8] *Electrical Engineer*, Vol. X, p. 353 (Oct. 7, 1892).
[9] *Ibid.*, Vol. V, p. 175 (June, 1886).

of the cores and obtain pure metals; his filaments could not stand high temperatures any better than those of Bottome or the others. The American, F. M. F. Cazin, received the first of a long series of patents on the incandescent lamp in 1892. He tried at first to cover carbon filaments with copper or other metals, which were then coated with metallic oxides. Other schemes were developed later.

One of the most notable early developments in new filament materials was the attempt by the German, Rudolf Langhans, in 1888 to make a composite filament consisting of an "inner mineral core of great light-giving power which was in itself a conductor, together with an outer coating of carbon, silicon or boron which conducted the current to the mineral vein or core when the latter had passed to the radiating condition." [10] Langhans was brought to America in 1889 by the Thomson-Houston Electric Company, which encouraged and financed his efforts to develop a substitute for carbon. Although he obtained an American patent in 1894 for his process of chemically combining carbon, silicon, and boron in varying combinations, he was not able to develop his ideas to a commercial stage in this country. After his return to Europe, however, the Langhans lamp was made and sold there for some years. Many other materials were also tried by a great number of inventors in efforts to obtain filaments which could stand higher operating temperatures. Though unsuccessful, the work up to 1893 broke new ground for later experiments by individual workers and by the lamp companies.

It is significant that most of the attempts up to 1893 to replace carbon by other substances were made by private inventors. Established lamp manufacturers did not participate notably, except in the two instances in the United States where the primary goal was to avoid the Edison patent. Fundamental scientific advances were being made continually, yet the lamp industry was not at that time receptive to new approaches to its problems. Moreover, there had not as yet been a specific scientific discovery that impinged so closely on incandescent lighting that it could not be ignored. Such advances came a few years later, along with great increases in incentives for filament improvement.

[10] Barham, *op. cit.*, p. 29.

DECLINE OF EDISON LEADERSHIP

During the first few years of commercial incandescent electric lighting, the Edison lamp excelled in almost all respects. It won first place at the Paris Exposition over the lamps of Swan, Maxim, and Lane-Fox. By the beginning of 1884 it had also received awards at the London Crystal Palace and at expositions in Cincinnati and Louisville. Supplementary tests at the Paris Exposition showed that the lamp compared very favorably in efficiency with all its rivals at that time.

After the original introduction of the incandescent lamp and its first rapid changes, however, the Edison Electric Light Company did not introduce many important new developments. Edison himself turned to other problems, and the company's technical leadership in incandescent lighting was not revived until after the merger with Thomson-Houston. It made no significant contribution to the filament advances mentioned above. To be sure, after 1888 the Edison lamp was somewhat improved in efficiency by a thin coating of asphalt on the filament; but it was not until 1894 that General Electric replaced bamboo with the squirted filament. After the merger, the Edison lamp works were also able to use the "flashing" process on lamp filaments and catch up with competitors who had previously been using the process.[11]

The first commercial Edison lamps were rated at 1.68 lumens per watt when new.[12] Improvements in the untreated bamboo filament increased its initial rating to 2.25 lumens per watt in 1881. The asphalt-treated filament of 1888 was rated at 3 lumens per watt, and the rating rose to 3.3 lumens per watt with the use of the "filament-flashing" process in 1893.

Despite the improvements in the Edison lamp, a number of its competitors had improved their lamps even more rapidly. As early as 1885 the lamps of several manufacturers were tested by a committee of the Franklin Institute, and, although the Edison lamps were found still to excel in certain respects, particularly in length of life and uniformity of performance, they consumed more energy than any other make tested for an equal amount of light output. The tests showed the average efficiency of the standard Edison lamp at that time to be 4.47 watts per spherical candle (2.8 lumens per watt), and that of the competing lamps tested to range down to 3.45 watts per spherical candle (3.65 lumens per watt).[13] Efficiency advantages permitted many of the other American concerns to compete very successfully with the Edison lamp after 1885 and to improve their positions steadily until the corporate reorganizations and the establishment of patent supremacy regained for the Edison lamp commercial supremacy as well.

[11] "Flashed" lamps gave on the average about one-third more light for the same energy consumption than those in which the process was not employed.

[12] Edison's experimental lamps of 1879 are estimated to have had an efficiency of 1.4 lumens per watt.

Initial efficiency is not the only measure of a lamp's value; its life and its maintenance of candlepower throughout life are equally important. There is an inverse relationship between incandescent lamp efficiency and life. A lamp can be made which will provide a very high candlepower for a few seconds, a very low candlepower for tens of thousands of hours, or a candlepower anywhere between. The candlepower of an incandescent lamp falls off with use, and for carbon lamps the decline was often found to be the greatest for those with the highest initial efficiencies. After very long use of 2,000 or 3,000 hours, lamps which had not yet burned out frequently gave less than one lumen per watt. It became clear that since electric-lighting costs consist largely of current consumption, the optimum balance of lamp efficiency and life required replacement after from about 600 to 1,000 hours. The lower efficiency of the Edison lamp made it less economical than many competing lamps, despite its long actual life of up to 2,000 hours. The declining candlepower which accompanies long life and which usually makes lamp replacement desirable before filament failure began to be recognized as important only around 1890. Methods of reducing bulb blackening as one means of maintaining light output were not explored seriously until after that date.

The economy of American lamps in general surpassed that of lamps of British and continental European manufacture throughout the entire period from 1880 to 1896. The slower start of continental producers and the obstacles to expansion of the British industry gave the Americans an initial advantage which they were able to maintain. American superiority resulted primarily from greater manufacturing precision and care. Although many con-

[13] Franklin Institute, *op. cit.*

tinental European lamps had very high initial efficiencies, American lamps tended to be more efficient at optimum lives, more uniform, and more reliable. There were still considerable differences among manufacturers in the United States as well as in all other countries, however, and even among lots made by the same manufacturer. As long as manual methods of production were employed, quality could not be completely standardized.

IMPROVEMENTS IN MANUFACTURING METHODS

During the eighties incandescent lamps were made almost wholly by hand. Only a few simple machines were employed in either filament making or lamp assembly. Processing the various parts took a long time, and high skills were needed by the glass blowers [14] and other workmen, both in making the parts and in assembling the lamp. Most workers at that time were men. Although gradual improvements were made in almost all phases of manufacture, the methods remained almost exclusively manual for many years. Facilities had to expand tremendously as production increased from about 70,000 lamps in 1883 to 7,500,000 lamps in 1891; but techniques did not change rapidly. One of the most important early advances in manufacturing technique was the improvement in the Sprengel mercury pump, which by 1885 had reduced exhaust time from five hours to thirty minutes.[15] The first recorded glass-working machine used in lamp manufacture was a crude sealing-in machine introduced into the Edison lamp works around 1889, which joined the glass stem and filament support to the neck of the bulb in an airtight seal. Its use lowered the skill necessary for the operation but did not increase the number of lamps an operator could process in a day. This and similar simple machines had the important effect of displacing men by women in many lamp-assembly operations.

One of the major problems which confronted the early lamp

[14] Lamp bulbs were blown "off hand" at first, but hand blowing into molds was soon adopted to achieve uniformity and to reduce costs. Glass tubing and cane were made completely by hand.

[15] Since the life of the lamp depended in large part upon the quality of the vacuum, it was essential to remove as much of the air and occluded water vapor as possible. To drive the moisture out of the glass bulb and other parts, the lamp had to be heated during exhaust to a higher temperature than it would experience in actual operation.

manufacturers was reducing the amount of platinum used in the lamp. Because it was a good conductor of electricity, because its coefficient of expansion was very nearly the same as that of glass and because it adhered well to glass, platinum had been used commercially since 1880 to conduct electric energy from the lamp base through the bulb to the filament. The increasing demand for platinum drove up its price, and by 1890 it represented about one-third the cost of the entire lamp. Various attempts were made to find a satisfactory substitute. As early as 1881 Sir William Crookes had suggested a copper, silver, or gold wire encased by a sheath of platinum; that constituted only a slight improvement. Attempts to embed iron or copper wires in a cement which would adhere to both the glass and the wire were unsuccessful. In 1891 a tin-copper alloy was tried by a Viennese inventor, and in the same year the American, R. A. Fessenden, devised an alloy of iron, nickel, cobalt, silicon, and gold or silver. Nevertheless, in 1893 the most satisfactory method of reducing the amount of platinum consisted simply of using a very short length of pure platinum to pass through the glass and welding to it a copper wire to carry the current from the base and a nickel, copper, or other type of wire to carry the current to the filament. This was known as the "Siemens seal."

None of the early producers of incandescent lamps conducted basic research in the general field of incandescent lighting. Their laboratories, such as they were, concerned themselves primarily with specific problems of improving parts of the product or its processes of manufacture. For example, Barham [16] cites two improvements in methods which he attributes to the Edison & Swan United Electric Company, Ltd.: (1) welding the ends of the filaments to the lead-in wires by local electric heating in a hydrocarbon liquid, and (2) finishing the filaments by heating in an electric furnace. The conclusion of almost all writers on the subject has been that there was relatively little improvement in the carbon-filament lamp after the early eighties. The attention of producers was devoted to details of product and process, particularly the latter, and the design of the commercial lamp remained relatively stable.

Besides the progress in lamp design and production methods,

[16] *Op. cit.*, p. 28.

there were, of course, important advances in the fundamental problems of electric power generation and distribution which broadened the market and lowered the costs of both arc and incandescent lighting. Some of the advances have been mentioned in the preceding chapter—notably the development of practical transformers and alternating current systems. In addition, improvements were made in dynamos and steam engines, culminating in 1885 in the direct coupling of the dynamo and high-speed steam engine. The use of water power and turbines to generate electricity next received attention, and larger, steadier, and more efficient generating systems followed one another in rapid succession. Better mechanical meters for the measurement of current consumption and many other improved types of supplementary equipment were also built during the eighties.

2. *Increased Competition from Gas and Arc Lighting After 1893*

During the eighties and early nineties incandescent lighting forged ahead of gas illumination and arc lighting, both in this country and abroad, despite gradual improvements in quality, reliability, and cheapness by its competitors. Arc lighting, in particular, benefited from cheaper and more reliable current generation, from better electrode materials, and from simpler and steadier arc lamps. Although the use of both competing light sources continued to expand, American incandescent lighting manufacturers felt increasingly sure of their position. They were much disturbed around 1893 by the rapid spread in use of the Welsbach gas mantle, invented by the Austrian, Carl Auer von Welsbach. The mantle had been invented in 1883, but technical problems in its development and consumer resistance had been so great that it did not become widely accepted until the early and middle nineties. By that time, the cost of mantles had been reduced, their efficiency and life had been increased, and the higher gas pressures needed for best results were more readily available.

It had long been known that the oxides of certain elements such as calcium, thorium, and cerium glow brightly when they are heated; the higher the temperature, the greater the amount of light produced. The "limelight," invented in 1826 by Thomas

Drummond, made use of this principle; a hot gas flame played on a button of calcium oxide, and the resulting light was projected in a beam. Welsbach adapted the same principle to gas illumination by constructing a cotton mantle impregnated with a mixture of 99 per cent thorium oxide and 1 per cent cerium oxide.[17] By using a different mixture of gas from the high-hydrocarbon type customarily employed to produce a bright flame, and by adding more air to the mixture, a much hotter flame was obtained. The successful introduction of the gas mantle reduced the cost of gas lighting by about two-thirds and materially increased its cost advantage over electric lighting. For a number of years the potential superiority of the incandescent electric lamp remained in doubt, and even its survival was sometimes questioned.

Improvements in arc lighting as well as in gas lighting made the position of the incandescent electric lamp more precarious. Use of the arc lamp had been expanding rapidly alongside incandescent lighting throughout the eighties and early nineties, with its greatest application in street and other outdoor lighting. Despite the large number of producers, arc-lamp output in 1893 was concentrated in the United States within the plants of General Electric and its subsidiaries, Westinghouse and its subsidiaries, and the Western Electric Company. The reliability and efficiency of arc lighting had increased gradually during the years with the development of better carbons and more precise regulators, and in 1893 a fundamental improvement in arc-lamp design was introduced by an independent inventor.

As early as 1846 Staite had discovered that enclosing the arc and restricting the entrance of air by means of a glass globe resulted in a less rapid consumption of the carbons. Other inventors later experimented with the same idea. At first the enclosed arc was not practicable because of the rapid blackening of the globe

[17] Other inventors had attempted before Welsbach to improve gas lighting in the same way. In 1839 Alexander Cruikshanks had made a platinum-basket mantle covered with lime. In 1853 J. J. W. Watson had patented a lamp in which water was decomposed by a voltaic battery. The hydrogen and oxygen were then ignited in contact with an incombustible substance such as spongy platinum or a mixture of lime, graphite, and pipe clay. The light from the radiator could be increased by surrounding it with a coil of fine platinum wire. Colored light could be produced by steeping spongy platinum in strontium nitrate or similar substances. In 1867 Tessie du Motay tried to increase the light output by using zirconia instead of lime.

from impurities in the carbons. It was not until much purer carbons for open arcs were made toward the end of the eighties and until a new type of regulator was developed that could strike and maintain a long arc that the idea became commercially feasible. The progress in carbon purity had its origin in Germany, although engineers in other countries soon showed increasing interest in electrode development.

In 1886 William Jandus of Cleveland applied for his first patent on an arc lamp with an enclosed chamber. This patent, issued in 1891, and several later patents formed the basis for the commercialization of the enclosed arc starting around 1893. Louis B. Marks of New York also contributed significantly to the development of a satisfactory enclosed arc lamp and took out a number of patents starting in 1894. The Jandus Electric Company and the Electric Arc Light Company were established to exploit the patents of the two inventors in the United States, and other companies were formed abroad.

Both inventors found that when the arc was surrounded by a globe having a restricted air inlet a longer arc could be maintained with a small current. The carbons lasted around 150 hours, as compared with perhaps 10 hours for the open arc. Less attention was required for trimming; the lamp gave a steadier light; the fire hazard was lessened; and still other advantages were obtained. The efficiency of the enclosed arc was somewhat less than that of the open arc, however, ranging from eight to about twelve lumens per watt with the size of the lamp, the kinds of globes used, and the type of electrical circuit employed.[18]

With this improvement, the arc lamp was better suited for indoor application, as well as for the street and other outdoor lighting to which its characteristics were originally most appropriate. Its continued higher efficiency and improved performance made it a more serious competitor of incandescent-electric lighting than before. After 1894 an increasing proportion of new arc lighting in America used the enclosed arc, and the old open arc with its coarse carbon electrodes gradually declined in use. The initial

18 As with the open arc, direct current lamps were more satisfactory than those which operated on alternating current. On direct current the single electrode crater, from which most of the light was obtained, radiated almost all the light downward, whereas one of the two craters in an alternating-current arc wasted much of the light upward. The d.-c. arc was also more reliable and less noisy.

conservatism of the central-station men and the active resistance of the arc-lamp trimmers, who feared they would lose their jobs because of the less frequent trimming of enclosed arcs, faded after a few years before the unquestionable superiority of the new design. In Europe, where labor costs were lower and electrical rates were higher, the incentives for replacing open arcs by enclosed ones were lower, and the resistance to change was greater. Nevertheless, even in Europe the enclosed arc forged ahead a few years after its American triumph. The environmental factors which led to greater use of enclosed arc lamps in the United States than in Europe seem also to have been instrumental in the original development by American inventors.

Another development which made arc lighting a stronger competitor with both indoor and outdoor incandescent lighting was the production after 1890 of "midget" arc lamps. Small arcs of 250 candlepower were frequently more desirable than a single large incandescent bulb or a group of small ones, because of the efficiency advantages of the arc.

3. Technological Developments in Incandescent Lighting, 1894–1896

The expiration of the basic Edison lamp patents in England and in the United States, and the improvements in gas lighting and arc lighting, resulted in a changed attitude toward technological progress in the incandescent-lamp industry after 1894. Without the legal protection of fundamental patents the General Electric Company and the Ediswan company faced the prospect of more intense competition and made greater efforts to improve their lamps. Competitors tried to better their competitive positions, and more persons outside the industry undertook experimentation in lamp development. A British writer, thinking primarily of his own country, stated the case in a way that applies in large part to conditions in the United States:

> . . . the attention of electric light engineers as well as all those who use the light, is once more directed to the consideration of the lamp itself, to the possibility of obtaining better lamps, and to the probable reduction in price which will naturally follow. Owing to the long prevailing monopoly in the sale and manufacture, there has

been little inducement for those interested to experiment and to study the problems connected with the incandescent lamp.[19]

It was not until the successful introduction of metallic filaments early in the twentieth century that the incandescent lamp pushed permanently ahead of gas lighting and arc lighting. The competition of other light sources was a powerful stimulus to technological progress in incandescent lighting between 1894 and 1910, just as the development and introduction of electric lighting of both types had increased the speed of technological progress in gas lighting during the eighties.

IMPROVEMENTS IN MANUFACTURING METHODS AND DESIGN

Despite the renewed vigor with which the problems of incandescent lighting were attacked after 1894, the immediate improvements were still concentrated largely in manufacturing methods rather than in any basic change in the lamp. For example, in 1895 Spiller and Massey of the Buckeye Incandescent Lamp Company of Cleveland brought out a much improved sealing-in machine. John W. Howell, electrician at General Electric's Edison Lamp Works, adopted the idea and developed it still further. This was the first modern-type machine used in the manufacture of incandescent lamps. Even with the simpler machines in use before that time, however, production efficiencies had been increasing, and necessary skills had been declining. Nimbleness of fingers replaced special knowledge, and lower-paid girls and women were performing almost all assembly work by 1896. Mechanization and the replacement of men by women were greatly encouraged by the competition which forced prices down after 1893, since costs had to be reduced for a manufacturer to remain in business.

One of the most important advances in production technique during those years was the invention in 1894 of a new and much more efficient method of producing a vacuum in the lamp bulb. The inventor of the process was an Italian engineer named Arturo Malignani, who had set up an electric-lighting plant in his home town of Udine and was producing his own incandescent lamps. A high vacuum was produced when a small amount of red-phosphorus vapor was placed in the exhaust tube while the filament

[19] Gilbert S. Ram, *The Incandescent Lamp and Its Manufacture*, Electrician Printing & Publishing Co., London, 1894, p. ix.

was heated above normal operating temperature. When news of the discovery reached the General Electric Company it dispatched a representative immediately to buy the American rights to the process. The phosphorus-exhaust method was introduced to America in 1896. The process was similarly adopted by many lamp producers throughout Europe. General Electric lamp engineers improved the technique and were able to reduce exhaust time to less than a minute.

The Malignani exhaust process represented a considerable step forward in the technique of lamp assembly, yet somewhat the same principle had been employed as early as 1882 in the Fitzgerald lamp. In that lamp a third terminal was connected to one of the two regular terminals by a short piece of iron wire wrapped with magnesium ribbon. When the filament was heated during the exhaust process, the wire became hot and the magnesium combined with the residual oxygen.[20] This was probably one of the first commercial lamps to use what is now called a "getter"—that is, an agent used inside the bulb to assist in obtaining a vacuum, to reduce bulb discoloration, or to improve the quality of the lamp in some other way. Getters are used in almost all modern incandescent lamps.

A further inkling of the future use of getters had been given in 1886 with the introduction of hydrogen gas at low pressure into filament lamps by the Siemens brothers in Germany. After the insertion of the gas, the glass bulb and filament were heated above normal operating temperatures. Bulb discoloration was said to be prevented while longer lamp life was obtained. Although the attempt to use hydrogen was no more successful than earlier experiments with nitrogen and other gases, the journal *Electrical Engineer* in reporting the news made the prophetic statement:

> It is thought that many evils which are found in the vacuus glow lamp now in use will disappear when the carbon filament is in an atmosphere of a gas exerting considerable pressure, but not acting chemically upon it.[21]

By 1893 interest in gas-filled lamps had risen to a new high level. Early gas-filled lamps had failed because the gases conducted heat

[20] *Electric Light*, Vol. I, p. 87 (Oct. 2, 1882).
[21] *Op. cit.*, Vol. V, p. 175 (June, 1886).

away from the filament to a greater extent than they reduced filament evaporation. The legal triumph of the Edison vacuum-lamp patent encouraged some lamp producers to turn back from the vacuum lamp to the gas-filled lamp. The Star Electric Lamp Company and the Waring Electric Company each brought out such lamps by 1894. The former evidently employed a heavy hydrocarbon gas in its "New Sunbeam" lamp. The "Novak" lamp of the Waring Electric Company used a filling of low-pressure bromine vapor to prevent too great a loss of heat while reducing filament evaporation. The bromine was used up by combination with carbon molecules thrown off by the filament, and eventually a high vacuum was produced. The principal advantage of the bromine lamp was that it reduced bulb discoloration. The Waring Electric Company was not able to continue production for long, for the General Electric Company brought injunction proceedings against it, and the court ruled that the "Novak" lamp infringed the Edison vacuum-lamp patent in spite of its initial bromine filling.

Experimentation with gas-filled lamps and discussions of their properties continued after the "Novak" lamp had been withdrawn from the market. Professor William A. Anthony of Cooper Union made an intensive study of the problem and reported his conclusions before the American Institute of Electrical Engineers in 1894.[22] There was general agreement with Anthony's conclusion that bulb blackening and filament destruction were caused by vaporizing of the filament at temperatures below its melting point, and that the insertion of inert gases of great molecular weight would slow down bulb blackening, in part by redepositing vaporized molecules of carbon on the filament.

Both the advantages and the disadvantages of the gas-filled lamp were, therefore, well known before 1896. Widespread use of gas fillings had to wait for two things, however. In the first place, the volatility of carbon is so great that no gas has ever been found that can be used economically to produce a gas-filled carbon lamp more satisfactory than a vacuum lamp. Even at the present time, the few carbon lamps made are vacuum lamps. In the

[22] See William A. Anthony, "On the Effect of Heavy Gases in the Chamber of an Incandescent Lamp," *Electricity*, Vol. VI, pp. 139–141, 153, 189–191 (Mar. 28, Apr. 4, and Apr. 25, 1894).

second place, the inert atmospheric gas argon, which is best suited for low-cost use in gas-filled lamps, was unknown in the eighties and did not become commercially available until the end of the First World War. The improvement of incandescent lamps by means of gas fillings had to wait for the development of metallic filaments and also to some extent for the availability of the inert gases. Nitrogen can be used advantageously with metallic filaments, but it is not so satisfactory as argon or the rarer and much more expensive krypton and xenon.

Although work on new filament materials continued during the years 1893 to 1896, particularly in Germany, no successful replacement for carbon had been developed by the latter year. Among the new proposals was the complicated German suggestion to use strips of asbestos paste covered with layers of spongy platinum, magnesium oxide, and cerium nitrate. Another inventor, the American J. W. Aylsworth, tried a new method of coating carbon cores with refractory metals like tantalum, molybdenum, titanium, and zirconium.

A final development affecting the incandescent lamp which should be mentioned here was the invention in 1894 by Michael J. Owens of the Libbey Glass Company of a semiautomatic paste-mold blowing machine for making lamp bulbs. Most bulbs for lamps had been hand-blown into molds by the Corning Glass Works up to 1890.[23] With the interruption of Corning's production in that year by labor difficulties, Libbey expanded into this new field of glassmaking on a large scale. The improved process was introduced in 1895; and, along with other minor improvements in glass production technique, it resulted in reduced costs for finished lamps as well as for the bulbs themselves. Experiments with semiautomatic bulb-blowing were also made in Germany at about the same time.

STATE OF INCANDESCENT LIGHTING PRACTICE IN 1896

The improvements in manufacturing methods from 1894 to 1896, when added to the advances of the preceding fourteen years, produced a lamp considerably cheaper and better than that of 1880,

[23] Corning made the bulbs for Edison's first lighting experiments and continued to supply the Edison Lamp Company, its successors and many other manufacturers with glass bulbs, tubing and rod for lamp assembly.

even though it was essentially the same in design. In the Edison plant costs had dropped from seventy cents in 1881 to twenty-two cents a lamp by 1884,[24] and they fell considerably farther by 1896. The cost of production for German lamps in 1895 was given as about eleven cents.[25] The decline of lamp prices from about a dollar each in 1880 to twelve to eighteen cents each in 1896 has been discussed previously, as well as the increase in efficiency from 1.68 to about 3.5 lumens per watt during the same period. Most of the efficiency advances occurred prior to 1885. With those advances there was a net improvement in useful lamp life. In 1896 a dollar could buy approximately six standard carbon-filament lamps which would give more than twelve times as many lumen-hours of light as a single lamp of the same candlepower costing a dollar in 1880.

The expected life of the Edison lamp was about 500 hours when incandescent lighting first went on the market. Actual life soon proved to range from 2,000 to 3,000 hours, although light output fell below 80 per cent of its initial rating very early in life. To improve lamp efficiency, lamp life was reduced in 1881 to about 1,000 hours, a duration which was made standard until the introduction of the gas mantle. Life to 80 per cent of initial efficiency rose gradually from 200 hours in 1881 to about 400 hours in 1896. Prior to the introduction of the gas mantle, some special high-efficiency lamps had been made with average lives of 800 hours, and the competition of improved gas lighting led to a wider use of the more efficient though shorter-lived lamp. New high-efficiency gas mantles later made their appearance, and still more efficient incandescent lamps of 600 hours average life were brought out.[26]

Until the revived competiton from gas lighting resulted in lamps of greater efficiency and shorter life, the bulbs used in lamp making had usually been made of clear glass. The brilliance of

24 Hammond, *op. cit.*, p. 43.

25 *Electrical Engineer*, Vol. XVI, p. 337 (Sept. 20, 1895).

26 Both high- and low-efficiency lamps had advantages in particular applications. The high-efficiency lamps were much more sensitive to voltage fluctuations and were most desirable where regulation of pressure was good and current costs were high. The low-efficiency lamps were advantageous where current regulation was poor and current costs were low. In selecting lamps it was necessary to balance the factors of price, initial efficiency, maintenance of light output, and life with the cost of electric current.

the filament had been noted from the beginning, but the brightness of the more efficient lamps stimulated a more widespread use of special types of bulbs.[27] In some the bulb was frosted by dipping it into a hydrofluoric acid solution to diffuse the light. In others opal glass was used. Clear glass was also employed in conjunction with shields, reflectors or diffusing shades; or part of the bulb was silvered, etched or painted. Another technique was to cover the bulb with a thin film of collodion or varnish. Most of these methods were employed for improving the efficiency of the lamp in use as well as for decreasing lamp brightness. Even though they absorbed some of the output, they usually produced more efficient direction of the light. Despite the growth of these methods for light diffusion, however, the clear glass bulb continued in use for the great bulk of incandescent lighting.

Many varieties of lamps for special purposes were also developed during those early years; and, although they received only limited acceptance at the time, they anticipated many types which have attained a wide sale only recently. William J. Hammer cites a number of lamps made as early as 1880 in which two or more filaments were operated in series or parallel or separately by turning a switch.[28] The same idea was employed in the featured lamps of the Duplex Electric Light, Power & Storage Company of London in 1882.[29] These lamps were forerunners of the "three-light" lamps of today.

The tipless lamps of the twentieth century also did not constitute a new idea. Several early workers, including Lane-Fox, had made tipless lamps by exhausting and sealing off the lamp at its side or bottom. Tipless lamps were desirable because they eliminated the bothersome and wasteful shadow created by the tip and also because they were less subject to breakage. The methods proposed for making tipless lamps prior to 1896 were not commercially feasible, however, unless the lamps were of the stoppered type.

Miniature lamps were used for medical and dental purposes before 1890. Other applications followed quickly, particularly

27 The need for diffusion of light was, of course, always much greater for arc lighting.

28 William J. Hammer, *The William J. Hammer Historical Collection of Incandescent Lamps* (Transactions of the New York Electrical Society, 1913), p. 23.

29 *Electric Light*, Vol. I, p. 119 (Dec. 1, 1882).

after the development of the dry cell and the invention of the automobile. Incandescent lamps in sizes of 200 to 1,500 candle-power, as large as many arc lamps, were also introduced as early as 1888. By 1896 the large sizes began to find wider use in street lighting, sometimes replacing arcs. More and more special styles were introduced for decorative purposes, too, including many with flame-shaped and other fancy bulbs.

The multiplication of sizes and styles of incandescent lamps was accompanied by a trend toward standardization of lighting equipment. Some progress had been made by 1896 in the virtual elimination of 50- and 60-volt circuits and lamps, although at the same time there was a great increase in the use of 200- to 220-volt lamps on direct-current circuits.[30] The general increase from 55 to 110 volts resulted largely from the increased manufacturing ability of lamp producers, who learned how to make the longer and thinner carbon filaments necessary for the higher-voltage lamps. Filaments for 200- to 220-volt lamps were even harder and more expensive to make, and it was not until the 1890's that the use of such lamps began to increase appreciably.[31]

The continuation of the variety of voltages within a given range resulted from the inability of lamp manufacturers to standardize their output completely. If but a single voltage had been used in a given range, a large part of the output of each lamp plant would have been unsalable, for many of the lamps would have been above or below the desired voltage.

4. *Summary of Electric Lighting from 1880 to 1896*

All the electrical industries expanded tremendously during the eighties and early nineties, stimulated to a great extent by the growth of central-station incandescent lighting; and inventors and promoters flocked into the various fields. Financial difficulties and conflicts over patent rights in incandescent lighting, arc light-

[30] The principal advantage of the higher voltage was in reducing the amount of copper needed for conducting mains. The efficiency of both 220-volt and 50- to 60-volt lamps was less than that of lamps operating on 110 volts.

[31] The high-voltage lamps were best received in England, where 220-volt direct current became standard for central stations. In the United States, alternating current and transformers solved the problem of low-cost transmission, and little need was found for increasing lamp voltages above the range of 100 to 120 volts.

ing, and other electrical-goods production led directly to a series of consolidations which in 1892 culminated in the organization of the General Electric Company. Except for the Westinghouse Electric & Manufacturing Company, with which General Electric signed a mutual patent-licensing agreement in 1896, this consolidation brought almost all important lamp manufacturers into one organization. Besides Westinghouse, only a number of small lamp companies were left as competitors, and in 1896 a price and market-sharing agreement was signed by General Electric and several of these concerns. The Edison patent No. 223,898 was eventually upheld by the courts. The combination of patent victory, consolidations, and patent and marketing agreements resulted in the acceptance of General Electric as the unquestioned leader of the American incandescent-lamp industry. It also became the leader in most other non-communication fields of the electrical-goods industry.

In England the combined Edison and Swan interests similarly dominated the production of incandescent lamps until expiration of the basic Edison patent. The British industry was somewhat held back until 1888, however, by the restrictive terms of the Electric Lighting Act of 1882. In continental Europe lamp making started within a few years of the founding of the American and British industries. Although patents were of less competitive significance on the continent, within a relatively short time one or a small group of lamp-producing companies became dominant in most of the industrialized countries through consolidation, cartelization, or competition.

During its formative years the incandescent-lamp industry was preoccupied with problems of production and marketing more than with product improvement. During the first few years, rapid changes were made by all manufacturers in details of product design and manufacturing methods. Once design standards had become established, each manufacturer concentrated on producing the lamp rather than on improving it. There were continued incentives, however, for bettering production methods and reducing costs.

When the Edison patent was upheld and injunction proceedings were brought against infringing producers, a number of competitors attempted to develop non-infringing lamps, some with filaments made of materials other than carbon. None of the attempts resulted in an improved lamp of commercial practicability, however. In England, filament improvement was almost entirely halted during the period of Edison patent monopoly from 1886 to 1893. In continental Europe and particularly in Germany, where early patent control was less absolute and where fundamental advances in chemistry were more rapid, there was an earlier interest in improving the lamp itself as well as manufacturing methods.

In the United States and Great Britain, improvements in manufacturing techniques were encouraged by price reductions after 1893, when the controlling patents had expired or were about to expire. The end of the patent monopoly and increased competition from the Welsbach gas mantle and the enclosed arc lamp after 1893 or 1894 also stimulated interest in the basic technology of the incandescent lamp. Nevertheless, even though the carbon lamp was better and cheaper in 1896 than in 1880, it was still extremely inefficient in converting electric energy into light. No outstanding advancements over the carbon filament had been made anywhere by 1896.

Although the carbon lamp was the best that the engineers were able to make up to 1896, they had learned a great deal about it and about problems of incandescence. The theory of lighting by incandescence was far advanced, the characteristics of carbon lamps were becoming well known, and most desired types and styles of incandescent lamps could easily be made.

Contributions to technological advancement in the incandescent-lamp industry emanated from many sources during the early commercial period. Many of the most significant innovations were made by Europeans, both as individuals and as engineers for the lamp producers. Private inventors in the United States also did much of the invention. Manufacturers in this country were to varying extents alert to the need for continued technological advance. The early technical leadership of the Edison Electric Light Company diminished as Edison himself moved on to other fields of experimentation and the company devoted itself increasingly to promotion, production, and litigation. The lengthy and expensive patent struggle in the lamp industry from 1885 to 1894 was a serious damper on progress in lamp design, although process

improvement continued. The Edison interests concentrated on eliminating competition rather than outstripping it. Although the patent monopoly stimulated some competitors to develop non-infringing lamps, their efforts did not lead to significant results. After 1894, when it was no longer protected by a basic lamp patent, General Electric devoted more attention to lamp improvement to maintain its market superiority. One substantial advantage enjoyed by General Electric was that its large resources and established European relations assisted it in buying the American rights to most significant foreign developments in the incandescent-lamp field.

The universities made no important direct contributions to technological advancement in incandescent lighting during the period, with the one exception of the Fitzgerald lamp. Lamp development was carried on only by commercial organizations and by private inventors who had commercial ambitions; very few of these men were college-trained. Indirectly, the universities made a great contribution to later advancements in lighting technology through their fundamental discoveries in chemistry and physics.

PART III

ADOLESCENCE OF THE LAMP INDUSTRY

Chapter VI: GROWTH AND FURTHER CONCENTRATION IN THE INCANDESCENT LAMP INDUSTRY: 1897–1912

THE years from 1897 to 1912 were the period of greatest change in the history of the electric-lighting industry. Both commercial and technological developments in incandescent lighting were raised to a high pitch not rivaled before or since. The unusual rate of activity was characteristic of the industry in all nations, not merely in the United States. During those years lamp production grew into a mass-production industry, turning out an ever increasing variety and number of electric lamps of ever increasing value. New filament materials, including tungsten, were introduced to the market, broadening the applications of incandescent lighting. Although electric arc lighting was also greatly improved during the same period, the incandescent lamp finally outstripped both arc lighting and gas lighting. Yet at the same time new electric-light sources were coming into existence that foreshadowed further competition for the glowing filaments.

The early twentieth century was a time of rapid progress in all the electrical industries. The tremendous expansion of electric traction and other types of electric power utilization drew some attention away from electric lighting, and the many other great new inventions captured the popular imagination still further. The X-ray, the radio, the automobile, the growth of the chemical industries—these and many more striking innovations occurred within a short time. Electric lighting came to be taken for granted, and only the most important new developments aroused general interest in it again from time to time.

Through all the rapid technological progress the General Electric Company maintained its supremacy in the American electric-lamp industry and, indeed, in the greater part of the American electrical-goods industry. General Electric's hold on the incandescent-lamp market was even stronger in 1912 than in 1897. The concentration of lamp production in most foreign countries also continued during that interval.

1. *Commercial Developments in the American Electric-Lamp Industry, 1897–1912*

THE INCANDESCENT LAMP MANUFACTURERS ASSOCIATION

In 1897 the General Electric Company was unquestionably the leader of the American electric-lamp industry. It had recently entered into a general cross-licensing arrangement with the Westinghouse Electric & Manufacturing Company, its largest competitor; and it had a special pricing agreement with Westinghouse for incandescent lamps. General Electric had also organized the Incandescent Lamp Manufacturers Association, thereby obtaining the cooperation of a large proportion of the rest of the industry in marketing incandescent lamps. Six formerly bitter competitors joined General Electric in the initial organization to avoid intense price competition. The members of the association agreed among themselves to fix lamp prices, both wholesale and retail, to divide business and customers, and to set terms of sale. The agreement was for a three-year term with provisions for extension. To make the combination effective, fines were levied for the violation of regulations.

Between 1896 and January 4, 1901, ten more lamp producers were induced to join the association; three of them and two earlier members went out of business in that time. Only Westinghouse and five small producers of incandescent lamps remained outside the association in 1901; and Westinghouse had made agreements with General Electric and other members to maintain agreed prices.[1] During those years General Electric produced approximately half the incandescent lamps made in this country, while Westinghouse made about 12 per cent and the rest were supplied by the smaller companies. Only a few were handled by companies not affiliated with the pool in any way.

1 All Westinghouse lamp production had by that time been concentrated in its subsidiary, the Sawyer-Man Electric Company.

The existence and operation of the association were clearly to the advantage of General Electric. Basic patents on the carbon lamp no longer gave the big company firm control over the incandescent-lamp industry, although it owned or had rights under numerous improvement patents, which were of value as competitive weapons. Outstanding among these were two patents on the Malignani chemical-exhaust process, already described. Westinghouse also held a number of incandescent-lamp patents, the most important of which was the Weston patent covering the "tamadine" structureless cellulose filament of 1882. General Electric and Westinghouse were able to produce better lamps than the other members of the association or the small firms outside the association. In addition, the members of the association were bound by price agreements and were unable to compete with the industry leaders by price-cutting even if they wanted to. Since the greatest inducement to join the pool initially had been avoidance of disastrous price competition, it is evident that few small companies wished to return to open competition.

THE NATIONAL ELECTRIC LAMP COMPANY

A proposed solution for the problems confronting the small firms was evolved in 1901. None of them by itself was powerful enough to compete successfully with the aggressive General Electric organization, and none by itself could make the technological advances necessary to keep up with General Electric. As a group, however, the small companies roughly equaled General Electric in volume of lamp production. Led by Franklin S. Terry, who had organized the Sunbeam Incandescent Lamp Company of Chicago in 1889 and still headed it, and B. G. Tremaine, several of the independents proposed consolidation. While General Electric would undoubtedly have resisted federation of the small companies to increase competition in the lamp industry, it saw in the move an opportunity to increase its own control and reduce still further the degree of competition. Arrangements were worked out with Terry, Tremaine, and the other promoters whereby General Electric obtained control over the combination in return for providing it with some new working capital. Accordingly, with the blessing and assistance of General Electric, the

National Electric Lamp Company [2] was incorporated on May 3, 1901. It was set up as a holding company and was intended to combine as many as possible of the small independent lamp producers as well as the eleven surviving members of the Incandescent Lamp Manufacturers Association.

The initial capitalization of National consisted of $500,000 of common stock, $150,000 of preferred stock and $2,000,000 of bonds. Of the common stock, $360,000 went to General Electric in return for $120,000 in cash. Most of the remaining common stock and all the preferred stock were issued to the stockholders of the Sunbeam Incandescent Lamp Company, the Fostoria Incandescent Lamp Company, and the Fostoria Bulb & Bottle Company (an important producer of glass bulbs and tubing for incandescent lamps), as part payment for all their stock. Bonds for $1,314,000 were issued in exchange for the stock of the Bryan-Marsh Company, the Buckeye Electric Company, the Columbia Incandescent Lamp Company, and the General Incandescent Lamp Company, as well as in part payment for the stock of the two Fostoria companies and Sunbeam. The remaining five members of the earlier combination and seven other previous or newly formed competitors came into the National organization between 1902 and 1909 by exchanging their stock for bonds, notes, or cash. The new organization made its headquarters at Cleveland, and the constituent companies operated as semiautonomous divisions. The organization was completed and went into full operation about 1904.

The capitalization of National was expanded gradually to take care of its increasing financial commitments and to reflect its successful growth. In 1910 General Electric owned 75 per cent of

[2] This company should not be confused with the National Electric Light Association, which was organized in 1885 to increase the effectiveness of the service furnished by central-station electric companies and to promote their mutual interests. Although the National Electric Light Association was at first primarily an association of arc-lighting interests, its scope was soon expanded to incandescent lighting and all other uses of electricity. Franklin S. Terry was an organizer of this early association also.

Other electrical associations had been formed by 1885. The oldest was the New York Electrical Society, organized Feb. 23, 1881, and it was followed by the American Institute of Electrical Engineers (1884) and the Association of Edison Illuminating Companies (1885).

the $5,000,000 common stock [3] of National and retained its original option to purchase the remaining 25 per cent, which was owned by the officers of National. The bond issue was increased to $4,000,000, while the preferred stock was retired.

Despite its controlling stock ownership in National, General Electric took no open part in the management. The company was nominally run by its own officers, all of whom were former competitors of General Electric, and it was publicly represented to be a competing association of lamp producers. General Electric continued to operate its own lamp works at Harrison, New Jersey. The price and market-sharing agreements which General Electric had signed with the members of the 1896 association were continued. General Electric and National acted in harmony on the pricing and marketing of lamps, and continued the agreements with Westinghouse and made new ones with five small lamp-making firms which did not become part of National.

Besides the commercial agreements between General Electric and other lamp producers, agreements were also made for the interchange of patent licenses. Licenses were first given to National and its lamp-making subsidiaries, as well as to some companies not yet part of the National organization, after General Electric had initiated thirty lawsuits in 1904 for alleged infringement of the Malignani lamp-exhaust patent of 1895, Howell's 1903 patent for improvement of the Malignani process, and an Edison patent of 1891 covering the sealing of lead-in wires. Most of the suits were discontinued when the companies agreed to take licenses and pay royalties of about one-fourth cent for each lamp produced. The patent licenses became the vehicle of the agreement not to sell below established prices, and to divide the market.[4] Later, when National had established a central engineering department for all its subsidiary companies, the two-way license system was established. Nevertheless, despite provisions for the mutual interchange of patent licenses and technical information,

[3] The $4,500,000 of common-stock expansion was distributed to stockholders in a series of stock dividends.

[4] It is difficult to comprehend why General Electric undertook infringement prosecutions against companies in which it had controlling stock interests unless it wished to give the appearance of dealing with competing companies with which it had no affiliation.

the flow of technical information continued to be preponderantly from General Electric to National and its subsidiaries.

As a result of the formation of the National Electric Lamp Company and the reorganization of the industry, most of the small lamp producers were brought together in a federation and became subsidiaries of the industry leader. General Electric acquired about two-fifths of the industry for an initial cash outlay of $120,000. Sales competition between the two organizations was restricted, and General Electric received about three-fourths of the cash dividends of more than $600,000 paid by National between 1904 and 1910. It also benefited enormously from the increased stock value of the concern. General Electric and National, together with Westinghouse, controlled more than 90 per cent of the domestic market for incandescent lamps. The price and license agreements consummated with other domestic producers not part of National left only 3 per cent of United States lamp production outside General Electric control.

THE RELATIONSHIP BETWEEN GENERAL ELECTRIC AND WESTINGHOUSE

Despite the rapid progress made by General Electric in consolidating the American lamp business in its own hands, the industry was not in perfect harmony. The few dissidents who remained outside the trust continued to fight it, for the most part, and many of the lamp makers who sold out to National undoubtedly did so with great reluctance and only after strong pressure had been brought to bear on them. The principal source of difficulty, however, was in unsettled relations between General Electric and Westinghouse. A great deal of jealousy and rivalry existed between the two concerns; and the 1896 agreement over lamp prices was not maintained without interruption. Westinghouse never joined the Incandescent Lamp Manufacturers Association, and it refused to take a license under General Electric lamp patents in 1904 along with the smaller companies. After 1897 Westinghouse had itself licensed most lamp producers in the country, including General Electric, under its own lamp patents in return for small royalty payments. However, the introduction of metallic filaments around 1906 made Westinghouse far more willing to accept a patent license from General Electric, which held most

of the American patent rights to the new lamps. Also, Westinghouse went through receivership during the panic of 1907 and emerged on December 5, 1908, in a considerably weakened condition.[5] Cooperation in incandescent-lamp production and distribution was virtually industry-wide during the last few years of the decade.

Both the General Electric Company and the Westinghouse Electric & Manufacturing Company expanded rapidly in the entire field of electrical-equipment production during most of the years from 1897 to 1912. By 1900 each company had recovered from the difficult middle nineties and was increasing its assets and sales every year. In 1902 General Electric restored the 40 per cent common-stock impairment of 1898. For the year ending January 30, 1900, it reported total sales of $22,379,000 with a profit on sales of $3,806,000. Total net profits, which included income from investments, royalties, and similar items, were $5,479,000, and total assets were $29,533,000. For the year ending December 31, 1910, sales of $71,479,000 were reported, with a profit on sales of $8,579,000. Total net profits were $10,856,000, and total assets were $107,767,000. The Westinghouse company reported similar growth, except for a somewhat more severe setback during the panic of 1907. Its sales mounted from $11,963,000 in 1900 to $38,119,000 for the year ending March 31, 1911, and its assets similarly increased from around $30,000,000 to $82,395,000. Net annual profits rose from about $2,000,000 to $4,881,000. Although separate profit figures are not publicly available for the early lamp business of the two companies, it is well known that lamp sales provided General Electric, at least, with one of its most substantial and most reliable sources of profit.

The production of incandescent lamps in the United States increased far more rapidly between 1897 and 1912 than the output of all other electrical goods combined. For example, the value of output rose from $3,515,118 in 1899 to $15,714,809 in 1909, an increase of 350 per cent in ten years.[6] The 1899 production consisted almost entirely of about 25,000,000 carbon-filament

[5] George Westinghouse lost control of the Westinghouse Electric & Manufacturing Company during the receivership and never fully regained it.

[6] Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures, 1909*, Washington, 1913. Separate statistics for incandescent-lamp production were first collected by the Bureau of the Census for the year 1899.

lamps. In 1909 more than 55,000,000 carbon-filament lamps were made, as well as 11,700,000 tungsten-filament lamps and many more of a wide variety of other types.[7] The achievement of General Electric in building up its hold on the incandescent-lamp industry is all the more remarkable in view of the tremendous expansion of the lighting market during that period.

The activities of the other departments of the industry leaders were of great assistance to their lamp departments,[8] since central stations and other contractors tended to favor suppliers who could furnish entire installations, from generators to lamps. General Electric and Westinghouse were virtually the only companies in the United States that were in a position to do this. They were able to maintain or strengthen their leadership in most branches of the production of electrical equipment.

Both General Electric and Westinghouse continued to acquire competing electrical-goods producers. In 1898 Westinghouse bought most of the stock and bonds of the Walker Electric Company, a leading manufacturer of street-railway equipment with which Westinghouse had been waging a bitter patent struggle. In 1902 Westinghouse acquired the Bryant Electric Company and the Perkins Electric Switch Manufacturing Company. General Electric acquired the Fort Wayne Electric Corporation at a receiver's sale in 1899, and in 1900 it purchased the patents and goodwill of the Siemens & Halske Company of America and Marks' Electric Arc Lamp Company. The properties of the Siemens & Halske Company had been sold the preceding year to an American syndicate for the production of electric vehicles. In addition, General Electric obtained a controlling interest in the Sprague Electric Company in 1902 and in the Stanley Electric Manufacturing Company in 1903. All these acquisitions strengthened the broad competitive position of the two large companies. One further step was made in 1910 when the Western Electric Company announced its withdrawal from the manufacture of heavy electrical equipment to specialize in telephone and

[7] Appendix D presents detailed census data for the production of incandescent lamps in the United States for those two years as well as for 1904 and all subsequent census years to 1939.

[8] In 1907 the Sawyer-Man Electric Company, the wholly owned lamp-making subsidiary of Westinghouse, was renamed the Westinghouse Lamp Company and was given a large new plant at Bloomfield, N.J.

small electrical apparatus. General Electric bought its tools and plant.[9]

Although most of these corporate acquisitions were indirectly of some importance to electric lighting, it is evident that after 1900 the lamp departments of General Electric and Westinghouse can be considered with less direct reference to other parts of the companies' operations than formerly. Commercial developments outside the lamp departments became less significant to incandescent lighting. Technological developments which affected the cost of electric current continued to be extremely important, however.

OTHER RELATIONSHIPS IN THE AMERICAN ELECTRIC-LAMP INDUSTRY

In the year 1910 American incandescent-lamp production was divided as follows:[10]

General Electric Company	42 per cent
National Electric Lamp Company	38
Westinghouse Electric & Manufacturing Company	13
All others	7
Total	100

Lamps were sold at uniform prices by the three large producers and by those others with whom agreements had been signed, and wholesale and retail prices were maintained by contracts with the distributors. The standard 16-candlepower carbon lamp was generally sold for about seventeen cents, only one cent below the 1896 price.[11] Although any firm was free to compete in the selling of carbon lamps, and although some of the independents charged only eleven cents for their 16-candlepower lamps,[12] the General

[9] *Electrical Engineer*, Vol. XLV, p. 46 (Jan. 14, 1910).

[10] U.S. Tariff Commission, *Incandescent Electric Lamps*, Report No. 133, 2nd Ser., Government Printing Office, Washington, 1939, p. 33.

[11] Slight fluctuations in lamp prices have relatively little effect on total lamp sales, since the cost of electric lighting is made up largely of charges for electric current. Even though, under the General Electric monopoly, prices were somewhat above the competitive level, total industry sales were not greatly affected. The growth in lamp sales was primarily the result of population growth, lighting education, and increasing lamp efficiency.

[12] Local price discrimination by the General Electric group met the lower prices charged by some independents and aided in hindering their growth.

Electric group retained an advantage even for those products by tying them in distribution to the new and more efficient GEM, tantalum, and tungsten lamps, for which General Electric held basic patent rights. Dealers and central stations were required to make their entire purchases of carbon lamps from companies in the pool in order to obtain the needed lamps of the newer types. These other lamps were developed and commercially introduced from 1903 to 1910 and were priced considerably above the carbon lamps.

Established relations with the central-station companies gave General Electric, and Westinghouse to a lesser extent, continuing markets for electric lamps as well as generating, transmission, and other types of apparatus. General Electric's extensive holdings of utility stocks and bonds gave it a particularly strong bargaining position. For example, to handle its bond investments in local power companies, General Electric set up the Electrical Securities Corporation in 1904, and in 1905 Electric Bond & Share was organized as a holding company to deal in utility stocks. Under the guidance of the General Electric Company, the latter rose to great power in the utility field and expanded the preferential market for General Electric equipment.

The General Electric Company was also favored by its relations with the firms supplying the lamp industry with parts and equipment. The industry leader was large and powerful and was an important customer of those suppliers. It was able to obtain competitively favorable price terms from the Providence Gas Burner Company, a subsidiary of National, and the principal lamp-base manufacturer in the country, in return for licenses under some of the General Electric patents. Advantageous terms were similarly obtained by the General Electric group in contracts with the two important outside manufacturers of lamp-making machinery—the York Electric Machine Company and the Dwyer Machine Company. Licenses were exchanged for patents covering lamp-manufacturing machinery. Under the licenses received by them, York and Dwyer sold machinery covered by General Electric patents only to approved companies.

In the purchase of glass bulbs, tubing, and cane, which were among the most important materials for lamp assembly, General Electric, National, and Westinghouse were also favorably situated. When the Libbey Glass Company had entered into bulb production in 1894, it had pooled its patents with the Corning Glass Works and had agreed upon prices at which lamp bulbs should be sold. The following year General Electric signed agreements with Corning, Libbey, and the Phoenix Glass Company, agreeing to buy its entire supply of glass from the three companies and to divide its purchases in ratios of 2 : 2 : 1, respectively. No other lamp producer was to buy its bulbs and other lamp-glass requirements from those manufacturers more cheaply than General Electric, and in addition the lamp producer reserved the right to start its own glass production should it see fit.

Other agreements were later signed by General Electric with the glass manufacturers, including a 1910 contract which bound General Electric and its subsidiary National to buy 85 per cent of their glass requirements from Libbey and Corning (42½ per cent from each) and to make the balance themselves. Prices were established, and the glass producers agreed not to engage in the manufacture of electric lamps. After 1911 the quotas of the lamp producers were to be increased to 25 per cent.

Westinghouse also made agreements with Corning and Libbey whereby it was to purchase all its needs from Corning at prices as low as those paid by General Electric. Under certain conditions purchases could be made from Libbey or other producers. There were a few other bulb producers, but the amount of business available to them was small, and they were unable to grow in the industry. The independent lamp producers thus had to buy bulbs from the large producers at higher prices than were paid by General Electric, Westinghouse, or National, buy them from the smaller and less efficient producers, or import them.

There was relatively little patent litigation in the American incandescent-lamp industry from 1897 to 1912. The patents for the new developments were not granted by the Patent Office in time to be tested by litigation before 1912, and only a few of the older detail patents on the carbon-filament lamp were sufficiently important to merit litigation. Westinghouse threatened infringement suits in 1897 against producers who did not take licenses under its lamp patents. Similarly, General Electric in 1904 used lawsuits as leverage in inducing lamp producers to accept licenses under its patents. Although most companies took licenses, a few did not, and some suits were continued. General Electric was successful in upholding the validity of the Howell lamp-exhaust patent in 1910 and the Edison patent covering the seal for lead-in wires in 1909 in separate suits, although each suit had to be carried to the Circuit Court of Appeals. The interchange of patent licenses among the principal lamp producers and the leading part and machinery suppliers avoided other patent conflicts in this country.

The competition of foreign producers in the American incandescent-lamp market was not great between 1897 and 1912, except briefly after the introduction of the metal filaments. Mechanization of parts production and assembly processes was more rapid in the United States, particularly in the General Electric group, than elsewhere in the world; and American lamps were in general of higher and more uniform quality. Besides the German and English producers, firms in Austria, Holland, Switzerland, Italy, France, and Japan were of particular international importance. Except for Japanese lamps and special types of European-made lamps, there has been no successful price competition by foreign companies in the American market over any considerable period of time.

The price of imported lamps was greatly increased by the American protective tariff. Between 1897 and 1909 the rate on lamps was 35 per cent of value. Under the Tariff Act of 1909 glass bulbs were subject to ad valorem duties of 60 per cent. The duties on electric lamps were also raised to 45 or 60 per cent, according to whether their chief value was in their metal or blown glass, respectively.[13] The increase in tariff rates was in part a reaction to the priority of European producers in the introduction of the metal-filament lamps.

It does not seem likely that the European producers would have constituted a serious threat to the American lamp market, however, even if they could have met domestic prices. A cartel philosophy quickly took hold in the world incandescent-lamp industry. Although the American General Electric Company did not formally join the cartel, patent licensing agreements were established by General Electric with some of the largest European companies. Relations between General Electric and the leading

[13] U.S. Tariff Commission, *op. cit.*, p. 4.

European producers were friendly, and there appears to have been no desire on either hand to invade the other's market, so long as its own market was not invaded.

One of the most important early international agreements announced by General Electric was with the Allgemeine Elektrizitäts-Gesellschaft in 1904.[14] The two companies exchanged exclusive licenses under many of their electrical patents. The agreement was directed initially toward a joint exploitation of the Curtis and Riedler-Stumpf steam-turbine patents, for lamp patents were not at that time of great importance. Technological progress in lamp design and manufacture during the next few years soon made that understanding of considerable importance to the American lamp industry, however. Between 1906 and 1909 General Electric signed additional agreements with other leading German lamp producers for the purchase of exclusive patent rights to technical developments of the German companies in incandescent lighting. Although the granting of exclusive licenses effectively narrowed international competition in lamp making and marketing, such agreements affected principally the large producers of lamps and did not entirely eliminate international competition.

One important immediate result of the concentration of the American lamp industry and the increasing international exchange of technical data was General Electric's adoption in 1909 of the trademark "Mazda." The name was taken from the Persian god of light, Ahura Mazda. It was applied to lamps constructed on the basis of "the latest" technical developments at home and abroad. The General Electric Research Laboratory had been established in 1901,[15] and the National Electric Lamp Company set up a central lamp-development laboratory a few years later. The General Electric lamp works also had a development laboratory. These three laboratories contributed most of the important

[14] Other early patent agreements were executed by 1905 with the British Thomson-Houston Company, the French Thomson-Houston Company, and the Tokyo Electric Company, in all of which General Electric held controlling or large minority stock interests (George W. Stocking and Myron W. Watkins, *Cartels in Action*, Twentieth Century Fund, New York, 1946, pp. 321–322).

[15] The founding of the General Electric Research Laboratory is discussed on pp. 179–181.

American developments in incandescent lighting during the period.

Both General Electric and National used the Mazda trademark for the new ductile-tungsten filament lamps and for later types, belying their claimed independence. Westinghouse was not at that time permitted to use the mark. In England, the British Thomson-Houston Company, which was controlled by General Electric, was a party to the arrangement and used the Mazda trademark. The trade name was intended to be a mark of research and laboratory service. It has played a significant role in the American electric-lamp industry to the present time.

THE ANTITRUST SUIT OF 1911

The domination of General Electric in the American electric-lamp industry had grown to such an extent that on March 3, 1911, the Department of Justice brought equity proceedings under the Sherman Anti-Trust Act in the Northern Ohio Circuit Court against General Electric and thirty-four other companies. The principal defendants included National and its lamp-making and part-producing subsidiaries, Westinghouse and its lamp-making subsidiary, and the Corning Glass Works. Other defendants were a few small lamp makers not part of the National organization, the York Electric Machine Company, the Dwyer Machine Company, the Libbey Glass Company and the Phoenix Glass Company.

The charges piled up by the federal government in its complaint were impressive. The subsidiary relation of National to General Electric, notwithstanding which it was represented to the public as a competing organization, was impugned by the government. The price-fixing and market-sharing agreements with Westinghouse, with National, with the members of the Incandescent Lamp Manufacturers Association, and with other lamp producers were attacked as restraining trade. The pyramiding of patents on improvements in machinery and production processes as well as on detail improvements in lamp design and on improvements in filament materials was alleged to maintain for General Electric and its group a substantial monopoly of the carbon-filament lamp after the basic patent on it had expired. It was also charged that the acquisition of patents by General

Electric and National was illegally suppressing competition in tantalum and tungsten lamps. In addition, the dealer contracts tying the distribution of carbon lamps to the new metallic-filament lamps were attacked. The practice of requiring prices fixed by General Electric to be maintained to the retail level for both carbon and metal-filament lamps was also complained of as a restraint of trade, as were the preferential agreements which had been made with the glass, base, and machinery manufacturers.

The government suit brought to a head two issues of paramount importance to all American industry as well as to incandescent-lamp producers. Those were the extent to which the monopoly awarded by a patent might be extended in various directions and the extent to which a manufacturer might be free to fortify his interests through the purchase of patents. The outcome of the federal suit promised to answer both quesions.

The General Electric Company and its associates intended at first to fight the charges, and answers to the complaint were filed on June 5. That decision was reconsidered in time to permit withdrawal of the answers and acceptance of a consent decree on October 12, 1911. The other defendants followed the lead of General Electric in admitting the facts cited in the government's complaint but denying that they constituted any violation or attempt at violation of the law. Accordingly, Judge John M. Killits of the Circuit Court entered a decree finding that most of the actions and practices complained of were violations of the Sherman Act and ordering certain changes to be made in the organization and conduct of the industry.

During the interval between the filing of the government complaint and the handing down of the court decree, General Electric took up its option to purchase the remaining 25 per cent of the common stock of National. That action made National a wholly owned subsidiary of General Electric and for the first time took active management out of the hands of the minority stockholders. The Westinghouse and General Electric cross-licensing agreement of 1896 also expired during that interval, on April 30, 1911. Each company still retained specific patent licenses, however, including the license granted by General Electric under patents covering the new metal-filament lamps.

Among the most important provisions of the decree was the order that the General Electric Company take over and operate under its own name the business done by National and its subsidiaries and completely dissolve the latter. The Cleveland properties of National were called the National Lamp Works of General Electric and later became the headquarters of General Electric's lamp department. The 38 per cent of domestic business controlled by National passed directly into the General Electric Company, giving it 80 per cent of the lamp business of the country in its own name. In addition, the dissolution of National gave to General Electric one of the principal lamp-glass suppliers in the country and the only lamp-base producer.[16]

The decree specified that price and market-sharing agreements with Westinghouse and other lamp manufacturers should be discontinued, and it stated that no further agreements should be made with manufacturers of lamp-making machinery and glassware which would prohibit them from making similar agreements with other lamp makers. Another significant provision prohibited the fixing of resale prices, the imposing of conditions bearing on resale, or discriminating against purchasers who did not buy carbon lamps from the manufacturers of other patented lamps.

What the decree did not require was of equal importance. No restriction was placed upon a manufacturer's right to acquire patents to fortify his interests. Moreover, the decree expressly stated that patent licenses might specify any prices, terms, and conditions of sale desired, although they could not fix resale prices. That permission left an enormous opening for continued control over the incandescent-lamp industry by General Electric, and the industry leader took full advantage of it in later years. Since the GEM, tantalum, and tungsten lamps were rapidly replacing the ordinary carbon lamp, an open market for carbon lamps was not of much importance. General Electric's control over prices charged by its licensees was not seriously affected, and it retained its patent monopoly over the new types of lamps. By developing a new method of distribution which will be discussed in a later chapter, the prohibition against resale price fixing was avoided. The 1911 antitrust action did not significantly change the situation in the American lamp industry.

16 Until a few years before the consent decree, the Providence Gas Burner Company, which was owned by National, had been the principal but not the only manufacturer of bases for incandescent lamps.

2. *The European Incandescent-Lamp Industry, 1897–1912*

THE GERMAN INDUSTRY

While American incandescent-lamp production was increasing rapidly and was being concentrated largely in the hands of the General Electric Company, German lamp production was going through a similar tremendous growth and consolidation. Along with the rest of the electrical-goods industry, lamp production in Germany forged far ahead of that of all other European nations and drew up to a temporary equality with American output.

The electrical industries of Germany went through a gradual and conservative expansion during the 1890's. Besides the Allgemeine Elektrizitäts-Gesellschaft and Siemens & Halske, a great many smaller firms grew up to important positions in the industry. The years 1899 and 1900 were boom years during which all electrical-goods manufacturers expanded greatly. A sudden panic in 1901, which lasted until 1903, took the young electrical industry by surprise. The commercial crisis paralleled the 1893 depression in the United States. Most companies found themselves far overexpanded. A number of small concerns were forced to liquidate and even some of the larger ones had to draw on their reserves.

The German electrical-goods producers turned to consolidation as a solution for their problems. A number of amalgamations ensued which concentrated most German electrical-goods production in A.E.G.,[17] the Siemens-Schuckert group,[18] the Felten-

17 In 1904 A.E.G. took over the Vereinigte Elektrizitäts Gesellschaft of Berlin, which had previously been affiliated with the American Thomson-Houston Company. This acquisition by A.E.G. was part of the amalgamation of interests between the German company and the American General Electric Company which also resulted in an interchange of patents and a limitation of markets. A further result of the arrangement was an A.E.G. agreement with the British Thomson-Houston Company regarding the limitation of export trade.

18 The heavy manufacturing of Siemens & Halske was merged in 1903 with the Schuckert company to form the Siemens-Schuckert works. The light manufacturing of Siemens was not affected by the combination.

Guilleaume-Lahmeyer Werke, A.G.,[19] and the Bergmann Elektrizitäts-Werke. As in the United States and other countries, the full-line producers were favored in the sale of incandescent lamps. In general, they were able to maintain prices for all electrical goods and prevent "injurious" competition through working agreements; their profits were substantial.

There were still many German producers of incandescent lamps, however. A number of them had joined in 1894 to raise lamp quality and to maintain prices. Out of that organization grew the Verkaufsstelle vereinigter Glühlampenfabriken Gesellschaft, or the International Incandescent Lamp Cartel of 1903,[20] which was formed under the leadership of A.E.G. and Siemens & Halske. At the time of organization the cartel included eleven lamp producers in Germany, Austria, Hungary, Holland, Switzerland, and Italy. The cartel began operations in 1904 and remained more or less in force until World War I. Its principal tasks were to fix lamp prices, establish quotas for the various members, and divide the profits. It was concerned only with carbon-filament lamps, on which there were no basic patents; at that time carbon-filament lamps were virtually the only type of incandescent lamp made. The cartel members produced about 30,000,000 lamps each year and included most of the principal lamp producers of continental Europe.

The development and introduction of a number of new types of patented lamps during the first decade of the twentieth century weakened the carbon-lamp cartel somewhat after about 1905. The A.E.G. introduced and pushed the Nernst lamp; the Deutsche Gasglühlicht Aktien-Gesellschaft introduced the osmium lamp; Siemens & Halske developed the tantalum lamp; and a number of concerns developed and introduced various types of tungsten lamps. The competition of these lamps, all of which were far more efficient than the carbon lamp, kept the sales of carbon lamps from rising. Members of the cartel continued to sell about 30,000,000 carbon lamps each year, but profits fell by two-thirds as the increased market pressure forced prices down. Besides the metal-filament lamps and price reductions, the competition of new firms outside the cartel and the depressing

19 The Felten-Guilleaume-Lahmeyer company was absorbed in 1910 by A.E.G.

20 See Basch, *op. cit.*, pp. 68–72.

effect of taxation on lamps were important factors in the declining profitability of carbon-lamp production.[21]

Despite its technical and commercial leadership in metal-filament lamps, the German industry by 1910 found itself in the situation which had confronted it in 1894 for carbon-filament lamps. There was an alarming tendency toward careless manufacture and poor lamp quality as a result of efforts to reduce costs and compete on a price basis. The seriousness of the problem was intensified early in 1910 by the sudden announcement by A.E.G. of a reduction in the prices of metal-filament lamps. It appeared that either the carbon-filament cartel would be so weakened as to fall apart or metal-filament lamps would have to be brought into the cartel.[22] In 1911 the three producers who held the most important European patents for metal-filament lamps, A.E.G., Siemens & Halske, and the Deutsche Gasglühlicht Aktien-Gesellschaft, formed the Drahtkonzern, or Filament Trust, through which they pooled their patent rights.[23] Although output and sales were not strictly controlled, the companies did make agreements for the maintenance of prices.

THE BRITISH INDUSTRY

The British manufacturers of incandescent lamps had dropped far behind the Germans by 1900, as indeed had all the British electrical industries. The great legal obstacle to electrical expansion was removed in 1888. The obstacles which remained, and which largely persisted from 1897 to 1912, were apathy, limited ability, and a lack of specialization. The British made no technical contribution to the development of metal-filament lamps. There

21 In 1910 German manufacturers produced 26,000,000 carbon-filament lamps, 42,000,000 metal-filament lamps, and 249,000 Nernst lamps. Although total production was not quite as great as American output at that time, the proportion of metal-filament lamps to the total was considerably larger in Germany. See *Electrical World*, Vol. LXIII, p. 54 (Jan. 3, 1914).

22 In 1910 eighteen companies in Germany, Austria, Hungary, Sweden, Holland, Italy, and Switzerland were members of the cartel. The few French concerns which had joined did not remain members. British producers had not joined at all.

23 Under German patent law and the interpretation of the German courts it was much harder to obtain a complete patent monopoly than it was in the United States or Great Britain. Under those circumstances, it was natural for the owners of the German patents covering all important ways of making tungsten filaments to pool their patents and obtain basic protection in that fashion.

was not a single lamp-research laboratory in Great Britain during all that time, and all important innovations were imported from Germany, Austria, and the United States.

The make-up of the British incandescent-lamp industry reflected its technological reliance upon America and Germany. The large lamp producers abroad had subsidiaries or affiliates in England which held the British patent rights of the parents, imported and marketed goods made by the parents, or conducted actual manufacturing operations under the patents of the parents. General Electric and Westinghouse were represented in Great Britain principally by the British Thomson-Houston Company, Ltd.,[24] and the British Westinghouse Electric & Manufacturing Company, Ltd.[25] The German and other continental leaders also had their affiliates or agents.

There were still, of course, many exclusively British producers in the lamp industry, and they carried on the bulk of production. The General Electric Company, Ltd., became the industry leader after the turn of the century.[26] It was a more aggressive firm than the others and was the first to secure British rights for the German-developed Nernst lamp and the Austrian-developed osmium and tungsten lamps. Its ownership of the basic British tungsten-lamp patent was probably the principal single factor in its preeminence in British lamp making to the present.[27] As was true in other countries, the fact that it was a full-line electrical-goods manufacturer gave it an additional advantage in the sale of lamps. The two pioneer lamp makers still in business were the Edison &

[24] General Electric gained a controlling interest in the British Thomson-Houston Company in 1901 by buying out the French and German holdings in the company. The British company had originally been a licensee of the American Thomson-Houston company.

[25] Westinghouse formed three electrical subsidiaries in Great Britain in all. The Westinghouse Electric Company, Ltd., was organized in 1889 to handle patent rights. The Westinghouse Electric & Manufacturing Company, Ltd., was established in 1899 as a manufacturing concern. The Westinghouse Metal-Filament Lamp Company, Ltd., was formed in 1906 to work with an Austrian Westinghouse company in the marketing of tungsten-filament lamps.

[26] The British General Electric company, which has had no financial connection with the American General Electric company except from 1928 to 1934, began to produce incandescent lamps after the controlling Edison patent expired in 1893.

[27] The G.E.C. carried on its lamp production through subsidiaries, the Robertson Lamp Company for carbon lamps and the Osram Lamp Company for tungsten-filament lamps.

Swan Electric Light Company, Ltd., and the Sunbeam Lamp Company, Ltd. There were also many newer companies of varying size and importance.

Competition in carbon-lamp production and sale was very keen in Great Britain. Since there were no longer any important patents on carbon lamps, the industry was open to all who wished to enter. By 1910 prices had been pushed down to about ten cents for the standard sixteen-candlepower lamp. Despite the keen competition, however, the quality of production did not fall to the extent true for Germany. The larger and better established producers in England generally managed to keep quality fairly uniform, although they tended to prefer low-efficiency lamps of long life rather than lamps of high efficiency and shorter life.

The technology of the new metal-filament lamps was imported into England from Germany and Austria, and later from the United States, between 1900 and 1910. Besides the effect of the metal-filament lamps on the old carbon lamps, there was an important effect upon the organization of the entire British lamp industry. The G.E.C. owned what proved to be the basic tungsten-filament patent, which was granted in 1904 on the work of Alexander Just and Franz Hanaman, even before the commercial lamp appeared on the market.

When domestic competitors introduced their own brands of tungsten lamps and foreign manufacturers commenced exporting tungsten lamps to Great Britain on a large scale, the G.E.C. and its Osram Lamp Works initiated a series of lawsuits to test their patents. The first important infringement suit was instituted in 1910 against G. M. Boddy & Company, an importer and distributor of lamps made in Holland by the Dutch N. V. Philips' Gloeilampenfabrieken (Philips' Metallic Glow Lamp Works) of Eindhoven. Before the lawsuit was completed the litigants came to an agreement out of court. Philips and Boddy took licenses under the G.E.C. patents and agreed to pay royalties on all lamps exported to Great Britain as well as to limit total exports. Prices and discounts were also to follow those set by the G.E.C. Other infringement proceedings by the G.E.C. were similarly successful. The British General Electric Company adopted a policy of requiring other manufacturers to take patent licenses and pay royalties rather than of trying to force them to withdraw from the business altogether, as the Ediswan company had done some twenty years earlier.

Two other British companies also had important holdings of tungsten-filament patents. The British Thomson-Houston Company owned several patents based largely on the work of the American General Electric Company and of A.E.G. The Siemens Brothers Dynamo Works owned patents based on the work of Siemens & Halske in Germany. In 1912 the three companies—G.E.C., B.T.-H. and Siemens Brothers—formed the Tungsten Lamp Association. They pooled their patents on tungsten-filament lamps and licensed a number of other companies, including Philips, Ediswan, and the British Westinghouse company. The companies agreed to maintain selling prices, and those which were only licensees were required to pay royalties and to remain within established production quotas. The association was indirectly affiliated with the German Drahtkonzern through the British subsidiaries of the German companies which were members.

THE INDUSTRY IN OTHER COUNTRIES

The lamp industries of the other industrialized European nations were much smaller than the German and British industries. France had faded relative to the two European leaders. The Austrian industry, though of considerable importance technologically, was not large. The producers in Holland, Belgium, Sweden, Switzerland, Italy, and Hungary were not at that time of very great importance to the world industry, except through their association with the international cartel.

The French market for carbon-filament lamps was quite open. Competition was keen, and prices were forced to very low levels. Carbon lamps of the ordinary sizes sold for as little as eight cents apiece in 1906. At that price only inferior lamps could be made, yet purchasers demanded cheap lamps rather than economical lamps. The leading American, German, and British lamp producers had subsidiaries or affiliates in France, and they were of great commercial as well as technological importance. There were fewer consolidations at that time in the French lamp industry than in the American and German industries. The failure of French lamp manufacturers to retain their memberships in the international cartel was probably caused by the insistence of French buyers on low prices, even if that also meant low lamp quality. All important technological advances in incandescent lighting continued to be imported; French producers did not make any real contributions.

Total output in each of the smaller countries reached no more than a few million lamps per year, and it was much smaller in most instances. European tariff rates on lamps were relatively low, however, generally ranging from 5 to 10 per cent of value, and international trade in lamps was very extensive in Europe. Most countries relied on Germany as their principal source of imports. They also relied largely on Germany for their advancements in lamp design and manufacturing technique. Moreover, prices generally followed the cartel, which was under German control.

Chapter VII: THE DEVELOPMENT AND INTRODUCTION OF NEW FILAMENT MATERIALS: 1897–1912

ALTHOUGH the General Electric Company had emerged as the unquestioned leader of the American electric-lamp industry by 1897, and other leaders were similarly emerging in most other lamp-producing countries of the world, the technical superiority of incandescent electric lighting over other light sources had not yet been permanently established. High-efficiency gas lighting was competing keenly for interior illumination, while the enclosed arc had strengthened the grip of the electric arc lamp upon street and other outdoor lighting as well as on certain indoor applications. The competitive interplay of gas lighting and incandescent electric lighting, which had produced the incandescent gas mantle in 1885, was of especial importance in encouraging improvement of the incandescent lamp.

1. *The Problem of Filament Improvement*

The old carbon-filament lamp had apparently reached its limits; for no fundamental improvement had been made in it since 1884. Experimenters seeking to improve the efficiency of the incandescent lamp directed their efforts principally to finding new and better filament materials. Although carbon has the unusually high melting point of 3500°C. or more its rate of evaporation, even at the considerably lower temperatures around 1600°C. at which it operated, was too great to permit economical operation except at efficiencies of about 3.4 lumens per watt or less.[1] At

[1] Operating efficiencies for different types of incandescent lamps can be assigned only roughly, for variables other than the filament material also affect efficiency. Lamps designed for voltages around 110 are generally more efficient than those of higher or lower potentials, for example, and lamps of greater light output are normally more efficient than those of lower candlepower. Likewise, efficiencies diminish with the age of the lamp as the bulb blackens and the resistance of the filament rises. References to efficiencies in this and following paragraphs should be considered to refer to those sizes and voltages most commonly used and to initial values, unless otherwise specified.

higher filament temperatures the initial lamp efficiency was greater, but lamp life was greatly shortened and the rate of decline in candlepower was increased.

The problem in 1897 was to discover an illuminant which could be heated to temperatures well above 1600°C., and which would be durable at such temperatures, for the operating temperature of a non-selective or only slightly selective radiator[2] like most incandescent filaments is the most critical factor in its efficiency. Hot filaments give off radiation over a very wide range of wave lengths, of which only a narrow band is visible to the human eye. At relatively low temperatures a greater proportion of total radiation is given off in the infrared region. As the temperature of a non-selective radiator increases, the peak of the light output shifts to higher frequencies until it would be in the middle of the visible range at about 6200°C. The whiteness of the light output increases as the temperature rises. At 6200°C. light output would be a maximum, and an incandescent-lamp filament would have a luminous efficiency of 85 lumens per watt. That would represent a conversion of electric energy into visible light of about 14 per cent of the theoretical maximum of 621 lumens per watt of monochromatic light by an "ideal" selective radiator.[3] Although efficiencies approaching 85 lumens per watt are unobtainable unless amazing new substances with very high melting points are discovered, a considerable range for improvement was available to experimenters in 1897. Many materials have melting points well in excess of 1600°C.

An additional possibility for improving incandescent illuminants lay in the use of selective radiators. If less energy could be wasted in the invisible portions of the spectrum, it appeared possible to devise a lamp with greater over-all efficiency even at relatively low operating temperatures. The rare earths[4] are selec-

[2] A non-selective radiator emits light in a "normal" curve over a very broad spectrum and includes both ultraviolet and infrared radiation. A selective radiator emits a larger proportion of its total radiation in some particular range of wave lengths, visible or non-visible.

[3] See Parry Moon, *The Scientific Basis of Illuminating Engineering*, McGraw-Hill, New York, 1936, pp. 135–139.

[4] The family of chemical elements which includes scandium, cerium, yttrium, lanthanum, illinium, samarium, and europium is known as the rare earths. The name was applied because of their scarcity when first discovered in various minerals.

tive radiators, and they attracted considerable attention along with other materials. Here the Welsbach gas mantle offered assistance to its rival. The rare earths occur mixed in nature. To prepare the cerium oxide required for gas mantles, the other earths found with it had to be separated. Since they had no important commercial uses before 1900, large amounts were cheaply available for those who wished to experiment. At about the same time important new deposits of rare earth minerals were discovered, and their prices fell even more. The combination of the two factors led to a tremendous advance in the chemistry of the rare earths during the next twenty years. That fundamental advance was of great importance to lamp designers.

Besides the advances in the chemistry of the rare earths, there were significant advances in other branches of inorganic chemistry. The development of the electric-arc furnace in 1892 by the French chemist Henri Moissan opened up an entirely new avenue of study. The electric furnace made it practical to obtain temperatures with controlled atmospheres at readings far higher than those of the old gas furnaces. The knowledge of metals made enormous forward strides within a few years, and by the turn of the century the experimental possibilities open to lamp engineers had expanded greatly. Almost all the fundamental advances in electrochemistry between 1885 and 1900 were made by scientists in Germany, France, and England.

The combination of increased competition with gas lighting and fundamental progress in scientific knowledge led to a period of most rapid advancement in incandescent-lamp design from 1897 to 1912. It is significant, however, that established lamp manufacturers did not produce the first important innovations. Individuals outside the industry were quicker to seize the opportunity for filament improvement. Neither the concentration which existed at that time in the American and German carbon-lamp industries nor the intense commercial competition of the British and French industries provided a stimulating environment for the prompt initiation of lamp research and fundamental development. After a few years of progress by outsiders, however, certain leading lamp producers started to work seriously on lamp improvement and made important contributions.

Within about a dozen years a great number of substitutes for

carbon were proposed. As might be expected, the greatest attention was directed to metals with high melting points, although many non-metallic substances with desirable properties were also considered. The concentration upon filament materials lasted until about 1912; by that time the ductile-tungsten filament,

TABLE XII: THE IMPROVED PERFORMANCE OF INCANDESCENT LAMPS

1881–1910

Year	*Type of filament*	*Initial efficiency per watt* [a]	*Approximate useful life*
1881	Carbonized bamboo	1.68 lumens	600 hr.
1884	"Flashed" squirted cellulose	3.4	400
1888	Asphalt-surfaced carbonized bamboo	3.0	600
1897	Nernst (refractory oxides)	5.0	300 or 800 [b]
1898	Osmium	5.5	1,000
1902	Tantalum	5.0	250 or 700 [c]
1904	GEM (metallized-carbon)	4.0	600
1904	Non-ductile tungsten	7.85	800
1910	Ductile tungsten	10.0	1,000

[a] Efficiencies apply to the sizes most commonly used for general illumination, 16-candlepower for the carbon lamps and 50- or 40-watt for the GEM and later metal-filament lamps.

[b] The smaller figure applied when the lamp was used with direct current, the larger when it was used with alternating current.

[c] The smaller figure applied when the lamp was used with alternating current, the larger when it was used with direct current.

Sources: Franklin Institute, *Incandescent Electric Lamps*, 1885; Howell and Schroeder, *The History of the Incandescent Lamp*, 1927; Schroeder, *History of Electric Light*, 1923; and others.

which is still in use today, had been developed and introduced. Table XII summarizes the life and efficiency characteristics of the most important improvements made in the composition of incandescent-lamp filaments after 1897 as compared with the earlier carbon filaments. Each of these new types will be considered in turn, along with certain other similar experiments of importance.

2. *The Nernst Lamp*

The first in the series of new commercial incandescent lamps was developed in 1897 in Germany by Dr. Walther Nernst, a professor of electrochemistry at the University of Göttingen. In his lamp a small rod of refractory metallic oxides was used as the illuminant. Although they are non-conductors at ordinary temperatures, these materials become conductors at higher temperatures and emit a strong white light. Moreover, the oxides are selective radiators and waste less energy in the infrared region.

The idea of using the rare earths and other metallic oxides for incandescent-lamp illuminants was not new. Many individuals had failed before Nernst succeeded. The earliest recorded use of refractory materials which became incandescent at high temperatures was in the electric candle devised by Paul Jablochkoff around 1876. Jablochkoff used a kaolin slab between his two conductors. When the arc was started, the kaolin was heated and became incandescent. During consumption of the candle, the kaolin vaporized and also made the flame of the arc more luminous.

The early patents of Lane-Fox and Edison made more specific reference to the use of oxides for incandescent illuminants. An 1878 patent of Lane-Fox stated that coating the surface of carbon illuminants with various materials, including lime and magnesia, produced greater luminosity. Edison suggested the oxides of titanium and zirconium as possible filament materials. All such ideas were brushed aside by the great success of carbon in 1879 and 1880, however, and attention was focused on carbon for the next five years or more until it reached its peak. Then, little by little, scattered attempts were made by inventors to develop new materials for use in incandescent lamps. Most experimenters tried to coat carbon with other substances. The experiments of Ansell in 1883 and Neuthel in 1886, which have been mentioned in Chapter V, were the first to return to the refractory oxides.

After the successful development and commercial introduction of the incandescent gas mantle its Austrian inventor, Carl Auer von Welsbach, attempted to apply the same old "limelight" principle to incandescent filaments for electric lamps. It seemed that if oxides of elements such as calcium, thorium, and cerium could be raised to high temperatures in a gas flame to give off light, the same or similar oxides might be formed into filaments. Welsbach tried to coat platinum and other metal wires with thorium oxide to increase their luminosity. His efforts were unsuccessful. Other inventors, including Rudolf Langhans, failed in similar attempts. Differences in coefficients of expansion and other difficulties made the coated filaments break down quickly. No really successful composite filament for an incandescent lamp has ever been made.

Nernst set out in a new direction. He did not try to retain carbon, nor did he try to make a filament. His interest in the problem started in 1897 while he was investigating the theory of light emission from the Welsbach mantle. By the end of that year he had decided that a mixture of metallic oxides in the form of a short rod would produce the best illuminant for an incandescent lamp. His first patent application was filed in 1897, and a series of patents was issued in 1899 to disclose the nature of the invention to the public for the first time.

The Nernst burner was a small rod about an inch long and one thirty-second of an inch in diameter. It was a mixture of oxides of metals such as magnesium, calcium, and the rare earths. Many combinations were possible. One early mixture was composed of 85 per cent zirconia and 15 per cent yttria. These materials were powdered, made into a paste with an organic binder, squirted through dies, and dried. Later a mixture of the oxides of thorium, zirconium, yttrium, and cerium was used.

The earliest Nernst lamp used external non-electrical sources of heat to raise the illuminant to its conducting temperature of 950°C. or more. A match or alcohol burner was employed. This was, of course, a great nuisance and handicap, and numerous suggestions were made by many inventors for automatic heating devices. The most successful was a heater coil of platinum or other wire which was automatically cut out of the circuit when its task was accomplished. Since the resistance of the Nernst burner declined with rising temperature, it was necessary to add in series a ballast resistance of iron wire to maintain the proper current flow.

Although the Nernst burner operated at a temperature of about 2350°C. and was a selective radiator, its over-all efficiency was only about 50 per cent higher than that of the ordinary carbon-filament lamp. The ballast wasted a considerable amount of energy. Initial efficiencies were about 5.0 lumens per watt, though that efficiency was not well maintained throughout life in the early commercial lamps. Light output during life was considerably improved in later lamps.

A burner life of about 800 hours was obtained when the Nernst lamp was used with alternating current, and of approximately 300 hours when it was used on direct current. The heater coil had a life of around 2,500 hours. Direct current had a deleterious effect on burner life because of its electrolytic action. It was not necessary to burn the glowers in a vacuum, because they were already oxidized. However, it was customary to cover them with diffusing globes. For use on direct current it was important that air should have access to the burner to counteract the electrolytic action at least partially.

The Nernst lamp was generally made in sizes from 25 to 2,000 candlepower. The smaller units had but a single burner, while the larger ones contained up to thirty glowers. Most lamps were made for use on 110 or 220 volts. The smaller lamps, up to 50 candlepower, sold at first for about $1.25 complete, and the larger ones were priced appropriately higher. Despite cheap glower renewal and definite efficiency advantages over the old carbon-filament type, the Nernst lamp was rather expensive and complicated. This was the only incandescent lamp ever to reach quantity production which deviated materially from the traditional carbon-filament lamp in design.

Nernst applied for German, British, and other patents on his invention in 1897, but it took much more work to develop the lamp to a commercial stage. Nernst himself withdrew from active participation in the final development and commercialization of his invention. Patent rights for the leading markets were divided among a small number of companies. The Allgemeine Elektrizitäts-Gesellschaft acquired the patents from Nernst initially and retained for itself sole selling rights for Germany, Great Britain, and most other European countries. George Westinghouse obtained the rights for the United States and Canada and set up the Nernst Lamp Company to make the new lamp.[5] This was the only major new incandescent lamp introduced in the United

[5] The Nernst Lamp Company was not connected with the Westinghouse Electric & Manufacturing Company except through common ownership and control.

States between 1897 and 1912 that was not controlled by General Electric. Ganz & Company secured the rights for Austria, Hungary, and Italy. The Nernst Electric Light Company, Ltd., was formed in England to acquire the rights for Australia, Africa, Asia, South America, and Central America. The validity of the Nernst patents was upheld in Germany and appears not to have been seriously challenged in any other country.

Each of the four concerns undertook to develop the basic Nernst invention to a commercial stage in its own way. The final lamps were quite similar, although they varied in many minor details. The lamp was used commercially for the first time in 1900 in Germany. A satisfactory automatic starter had not yet been devised, however, and it was not until early in 1902 that it was employed on a large scale in Germany and successfully introduced in the United States and other countries.

The efficiency advantage of the Nernst lamp over carbon lamps led to its fairly extensive use in Europe and the United States until about 1912. As an indication of its market, Basch quotes a figure of 7,500,000 lamps produced by A.E.G. alone by 1907.[6] The Nernst lamp stood between the arc lamp and the ordinary incandescent lamp and could perform certain lighting tasks more effectively than either. When the Nernst lamp was first introduced and pushed commercially, central-station operators were uneasy about its effect on their revenues. They feared that their customers would replace carbon lamps completely by Nernst lamps to produce the same light output, and that the sale of energy would decline. Such fears proved to be totally unfounded. For one thing, the Nernst lamp was merely a useful new light source and could not satisfactorily replace all carbon lamps. For another, the greater efficiency and economy of the Nernst lamp led to better electric lighting at higher levels of illumination rather than to reductions in lighting expenditures. As long as lighting was not ideal, most persons were willing to pay the same amount of money for better light. By 1912, however, other new illuminants had been developed, and their efficiency improvements in turn were too great for the Nernst lamp to survive.

[6] *Op. cit.*, p. 87.

3. *The Osmium Lamp*

The second successful new lamp and the first to employ a metallic filament was the osmium lamp developed by the Austrian, Carl Auer von Welsbach, the inventor of the gas mantle. Although he did not succeed in his original attempt to develop an incandescent-lamp filament employing metallic oxides, his experiments led to the production of a filament even more efficient than the Nernst lamp.

Welsbach's experiments on incandescent lighting were carried on about the same time as those of Nernst, and they extended over a longer period of time. The Austrian started by trying to coat metallic wires of the platinum family with thoria or other refractory materials and thus add to the emissivity of the filament and prevent the metallic core from breaking when it was heated above its melting point. Besides platinum, with its melting point of 1770°C., Welsbach tried iridium, which had been used unsuccessfully by a number of early experimenters, and osmium. Iridium has a melting point of 2260°C., and osmium, the heaviest member of the family, has a melting point of 2700°C. In fact, at the time osmium was thought by some to be the most infusible of all metals.

The high melting point of osmium was attractive and led to a number of experiments for forming it into thin wires. Moreover, osmium is a selective radiator and has greater luminosity than carbon at the same temperature. Osmium as it was then known could not be made into a wire like most other metals. It existed commercially only as a powder, a spongy mass, or a brittle hard metal. The powder could not be pressed into a wire of adequate strength, nor could the metal be drawn. New techniques of treatment had to be devised.

The most satisfactory technique devised by Welsbach made use of the squirting process that had been employed in making carbon filaments for a dozen years or more.[7] Powdered osmium was mixed into a paste with a cellulose binder, squirted through dies and sintered at a high temperature to fuse the separate particles of the metal. The binder was volatilized out, and the porous and brittle wire was formed into a looped coil, attached to platinum lead-in wires, and enclosed in an exhausted glass bulb. The application of the squirting process to metals was a revolutionary idea and was the principal element in Welsbach's success.

[7] One of Welsbach's first methods was the deposition of osmium or osmium compounds on platinum or other cores, the reduction of the compounds, and the volatilization of the cores.

This successful technique for making osmium filaments was devised in 1898, and a few lamps were made commercially in 1899. Regular commercial sale was not initiated until 1902, however. The metal osmium was very rare and expensive, and only limited numbers of lamps could be made. Welsbach applied for American as well as European patents on his lamp and the process for making it. The American patent applications were made on August 9, 1898, and after many delays in the Patent Office were finally granted on November 22, 1910. By that time further improvements in incandescent lighting had made the osmium lamp obsolete. The osmium lamp was produced and marketed by the Austrian Gasglühlicht und Elektrizitäts Gesellschaft (the Austrian Welsbach Company) and by its German licensee, the Deutsche Gasglühlicht Aktien-Gesellschaft (the German Welsbach Company or Auergesellschaft). Despite the American patent applications, the lamp was sold only in Europe because of the limited production. The General Electric Company, Ltd., secured exclusive selling rights for Great Britain.

Owing to its high melting point, selective radiation, and high operating temperature, the osmium lamp had an initial efficiency of 5.5 lumens per watt or more. It maintained its light output extremely well through an actual life of as long as 2,000 hours. Rated average life ranged up to 1,000 hours. Moreover, the filament was able to stand variations in voltage quite well.

Despite the great improvement in efficiency, osmium lamps had disadvantages which limited their usefulness. The rarity and expensiveness of the metal have been mentioned. New lamps were priced at from $1.25 to $2.00, and because of the scarcity of the metal it was necessary to reclaim used filaments from burned-out lamps. The brittleness of the sintered osmium filament resulted in a very fragile lamp. In addition, osmium was of such low electrical resistance that unusually long filaments were required. It was necessary to burn the lamps base up in order to prevent sagging of the softened filaments during operation. A thread of refractory oxides attached to the inside of the rounded end of the bulb was used to support the middle of the fine osmium spiral. The brittleness of the metal presented another serious handicap in that it was very difficult to make the extremely slender wires necessary for high-voltage lamps. The first commercial lamps could not be used at potentials greater than 44 volts. On higher circuit voltages it was necessary to employ a group of lamps in series. Later advances produced satisfactory lamps for 55 and 73 volts and finally for 110 volts.

Although some millions of osmium lamps were produced and sold in Europe, their primary significance was technological rather than commercial. The osmium lamp contained the first practical metal filament and opened up a new avenue for lamp designers. It was more economical than the best carbon lamp, though less economical than the Nernst lamp, despite its higher efficiency. Osmium was superseded by the osram lamp in 1906, the filament for which was at first an alloy of osmium and tungsten, and by other metal-filament lamps of greater efficiency and suitability. The osram type will be discussed presently along with the other varieties of tungsten lamp. Osmium was better suited for low-voltage use than some of its successors, however.

4. The Tantalum Lamp

A third new type of incandescent lamp was developed by the Siemens & Halske Company, the first of the leading lamp producers to achieve results in the search for better filament materials. Dr. Werner von Bolton, head of the company's chemistry laboratory, and Dr. O. Feuerlein developed a lamp in 1902 and 1903 with a tantalum filament. Their work had begun in 1901 with a study of vanadium, niobium, tantalum, and other rare metals.

Tantalum is a hard and heavy metal with a very high melting point, about 2850°C., and seemed to possess the desired properties for incandescent lighting to a greater extent than the other metals tried. The material as then known was very brittle, however, and it could not immediately be drawn into slender wires. It had been fused for the first time only a few years previously by Henri Moissan in his electric furnace through the reduction of tantalic

acid with powdered carbon. The Siemens & Halske chemists found that Moissan's method did not produce pure tantalum, and they developed other techniques for purifying it. One method was the reduction of potassium tantalofluoride in powder form. The resulting tantalum was melted in a vacuum and was very pure. The reduction of the brown oxide of tantalum also produced a metal of great purity. It was found that tantalum was ductile and could easily be drawn into fine wire unless impurities of carbon, hydrogen, or metallic oxides were present.

Von Bolton and Feuerlein applied for German and other patents in 1902 to cover the process of making pure and ductile tantalum and its use in incandescent lamps. The German patents were granted in 1903 and 1904, and the American patents in April, 1906.

After further development, the new Siemens & Halske lamp was placed on the market in Europe in 1905. At that time tantalum was a very scarce metal costing about $5,000 a pound. Siemens & Halske gained control of all possible world sources of supply and retained the sole manufacture of tantalum filaments during the entire period that the lamp was marketed. Nevertheless, the company did license certain affiliated European lamp manufacturers to assemble tantalum lamps with filaments bought from the German company for sale in prescribed areas.

In the United States, where there was no longer a Siemens affiliate, the General Electric Company and the National Electric Lamp Company acquired exclusive rights to manufacture and sell tantalum lamps on February 10, 1906. The purchase of the rights cost the two companies $250,000, of which General Electric contributed 60 per cent, and in addition they paid royalties on all tantalum lamps sold. The lamps were marketed in this country from 1906 to 1913.

The tantalum lamp was a very successful new product, even though it was not quite so efficient as the osmium lamp which preceded it. Its initial value of about 5.0 lumens per watt declined to an average of about 4.25 lumens per watt throughout its useful life of 600 to 800 hours. Total life was normally about 1,000 hours. Those values applied only for direct current, however, because on alternating current the tantalum crystallized rapidly

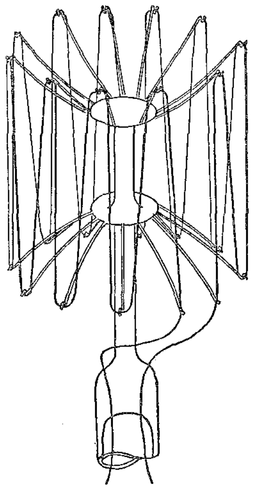


FIG. 21. Filament Arrangement of the Tantalum Lamp
The long tantalum filament was strung back and forth between two sets of radial wire supports set into a glass rod.

and became brittle. On alternating current, lamp life was normally only 200 or 300 hours.

Despite the lower efficiency and shorter life of tantalum as compared with osmium and its weakness on a.-c. circuits, the tantalum lamp had several important advantages which might well have made it the standard incandescent lamp had not tungsten displaced it. The ductility and strength of tantalum were great advantages, for it could stand considerable vibration. Because of its low electrical resistance, very slender filaments from two to three feet in length were required. Siemens & Halske engineers devised a new filament arrangement on which they obtained broad master patents. The glass stem of the lamp was extended up into the bulb and small wire hooks were placed radially around two spots on the stem. The filament was then strung securely back and forth between the two levels of hooks. The expansion and softening of the wire in use at its most economical operating temperature of about 1900° C. had no serious effect, and the lamp could be burned in any position.

The lower cost of tantalum lamps was another important advantage over the osmium type. Even when they were first introduced, the standard 16-, 25-, and 32-candlepower sizes were priced at only about a dollar. Not many other sizes were made. Prices, which were very nearly the same in all leading countries, were reduced to approximately sixty cents in 1907, and some further reductions were made later. Most tantalum lamps were made for operation on circuits of 110 volts. The resistance of the tantalum filament, as well as other metal filaments, increases as the temperature rises, so that it stands variations in voltage quite well.

5. The General Electric Research Laboratory and the GEM Lamp

Although most of the new filament materials were metallic, one final attempt was made to improve carbon. The researches which led to the development of the GEM lamp were conducted in the General Electric Research Laboratory, which was established at Schenectady in 1900. Before discussing the GEM lamp specifically, it is desirable to consider in some detail the factors underlying the establishment of the research laboratory, and its significance.

At the beginning of the year 1900 there was no laboratory in the American electrical-goods industry that was capable of conducting real research in the field of incandescent lighting. The small producers of incandescent lamps had nothing to offer, for their staffs included no more than a few design and production engineers. The industry leaders, General Electric and Westinghouse, had larger engineering staffs which included many very capable individuals. They were not research-minded, however, nor were they trained in research techniques; and their work continued in the traditional pattern of trying to make a better carbon-filament lamp of the same general type more cheaply. American universities at that time were also not strongly research-minded, although there were some faint stirrings of a desire to achieve scientific equality with the leading European nations.

By 1900, however, conditions in the American electrical-goods industry had advanced to a point where there were incentives to establish laboratories which could make definite scientific advances and at the same time produce definite commercial results. The electrical industries had run beyond the discoveries of Davy, Faraday, and the other great early nineteenth-century scientists. New discoveries in Europe were opening up new avenues of electrical application. To retain international leadership, it was desirable for American electrical-goods producers to conduct fundamental investigations of their own.

Other factors were important, too. General Electric had solidified its position in the industry. The principal consolidations had been completed. The early absorption in commercial expansion, financial problems, and patent litigation was over. The situation could be viewed more broadly. Almost all the patents of the early and middle eighties, on which the industry had been built, had expired. It became evident that important new patents were necessary to General Electric if it was to retain its place at the head of the American industry. Moreover, the European electrical industries, the German in particular, were making rapid technological strides which threatened American leadership in the commercial applications of electricity.

The new General Electric Research Laboratory was established with the endorsement of Charles A. Coffin, president of the company, and upon the initiative of Edwin W. Rice, technical director and his successor as president. Dr. Willis R. Whitney, an assistant professor of chemistry at the Massachusetts Institute of Technology, was hired as the first director of the laboratory. It started operations with a staff consisting of Whitney and an assistant. It was set apart from routine manufacturing and sales and was to be devoted to pure and applied research in fields of importance to the electrical-goods industry. The engineering and testing laboratories of the various departments of the company were to be unaffected by the innovation. The research men were to have broad latitude in the selection of problems for study. The philosophy of the new organization was in marked contrast to that of the usual American commercial laboratories of the time, which expected immediate financial returns from almost every development.[8]

Although the G.E. Research Laboratory was set up as part of a long-range plan, there were some important immediate reasons for the move. The situation in the incandescent-lamp business was particularly critical. The expiration of the basic Edison patent, the progress of gas illumination, and the increasing volume and success of European and domestic experiments with new filament materials and new light sources, all spurred General Electric to action. The acquisition by George Westinghouse of American rights to the Nernst lamp was particularly disturbing. For several years the laboratory focused its attention upon the improvement of incandescent and arc lighting. Much of the work

[8] The Westinghouse Research Laboratory was founded in 1916. Until that time the Westinghouse company relied largely on Europe and on General Electric for fundamental advances in its field. A separate lamp research laboratory was established in 1917.

at first was advanced engineering rather than research. The staff was built up gradually over the years as expanding work required.

Dr. Whitney himself undertook the study of incandescent filaments. Despite the fact that virtually all other experimenters were abandoning carbon, he directed his efforts to improving the traditional carbon as well as to investigating the metals with high melting points. During his study he developed a new type of electric resistance furnace to produce high temperatures. The changes produced by the furnace in ordinary carbon filaments were quite remarkable. He heated an untreated filament in an atmosphere saturated with carbon to a temperature of about 3500°C., then treated it with the "flashing" process and reheated it in the furnace. In that way he drove off impurities found in the carbon and changed the nature of the graphite coating of the "flashed" filament. The final product had a hard and tough shell of purer graphite around the base filament as a core. A very important change took place in its electrical resistance, which rose with increases in temperature like that of the metals, instead of falling like that of ordinary carbon filaments.

The Whitney heating treatment was a successor to heat treatments at much lower temperatures used during the 1880's and 1890's to harden the surface of carbon filaments after they had been flashed. J. W. Howell of the General Electric Company in 1893 had discovered that, above a certain temperature, ordinary flashed filaments had rising electrical resistances although unflashed carbon continued to fall in resistance, and that the more the treatment, the greater the rise in the resistance of flashed filaments.[9] At that time, however, the very high temperatures of the electric furnace were not available, and the new knowledge could not be developed and put to commercial use.

The filament which resulted in 1904 from Whitney's work was the greatest improvement made in the carbon lamp since 1884, and no further important advance has been made. Because in its resistance pattern the new filament followed the metals rather than ordinary carbon, the lamp in which it was used was

[9] See John W. Howell, "Conductivity of Incandescent Carbon Filaments, and of the Space Surrounding Them," paper presented at Feb. 17, 1897, meeting of American Institute of Electrical Engineers and reprinted in *Electricity*, Vol. XII, pp. 117–118 (Mar. 3, 1897).

called the GEM (General Electric Metallized) lamp. The GEM filament could be heated about 200°C. above the temperature of the usual carbon lamp without shortening lamp life. With a useful life of about 600 hours the lamp had an initial efficiency of approximately 4.0 lumens per watt. Its efficiency fell off gradually

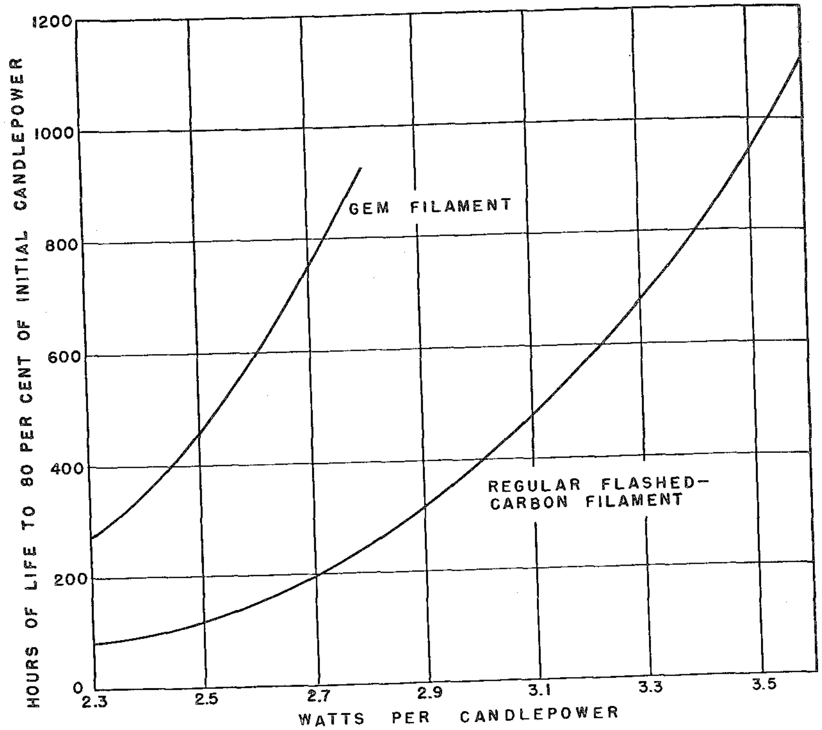


FIG. 22. Life-Efficiency Curves of GEM and Regular Flashed-Carbon Filaments

Source: *Electrical Review,* Vol. XLVII, p. 344 (Sept. 2, 1905).

throughout life, however, as did that of lamps with ordinary carbon filaments.

The superiority of the GEM lamp over ordinary carbon lamps is indicated in Fig. 22. Although it was considerably less efficient than the new Nernst, osmium, and tantalum lamps developed by German and Austrian chemists, it had the advantages of great similarity to the established standard and low cost. The 20-candle-

power lamps were priced at first at only about twenty-five cents each, and some reductions were made later. In addition, with the strength and simplicity of its filament, the GEM had advantages over the fragile osmium and the complicated Nernst lamps. Because of its rising temperature coefficient, the GEM could stand variations in voltage far better than ordinary carbon lamps. The GEM filament with its lower resistance had to be slightly longer than the filaments used in ordinary carbon lamps, but that did not prove to be a great obstacle in lamp design.

The new filament and the process for making it were patented by Dr. Whitney and the General Electric Company. Their application of February 8, 1904, was granted on March 30, 1909. GEM lamps were commercially introduced in the United States in 1905. Many millions in various sizes were sold by General Electric and its licensees until 1918, although their popularity began to decline after the introduction of tungsten-filament lamps in 1907. The GEM lamp was introduced in Great Britain by General Electric's affiliate, the British Thomson-Houston Company, a few years after its American debut. Despite its popularity in the United States, where it was strongly promoted by the General Electric group, it did not achieve great success in England or in continental Europe. The metal-filament lamps had had their origins in Europe, and their commercial use abroad was ahead of that in the United States. Most consumers in Europe jumped directly from the old carbon to the metal filaments, without stopping at the intermediary GEM type.[10]

6. The Non-Ductile Tungsten Lamp

Concurrently with the development of the tantalum and GEM lamps and the commercial expansion of the osmium and Nernst lamps, a fifth new lamp using tungsten was making progress. The

[10] Efforts to improve the carbon lamp further were continued by a number of workers for several years without success. In one attempt to produce a filament made entirely of pure graphite, powdered graphite mixed with an organic binder was squirted or otherwise worked into a filament, after which the binder was removed. General Electric developed and patented a process whereby a cadmium-mercury or other amalgam was used with powdered graphite to form a filament from which the amalgam was subsequently removed. Other attempts to coat carbon with oxides, nitrides, silicides, and similar materials were also continued and for a short time gave some promise of success.

revival of widespread interest in incandescent lighting around the turn of the century had resulted in an examination of all conceivable materials which might be used for filaments. Among them all, tungsten attracted most interest. It will be remembered that Bottome and Lodyguine had worked with tungsten several years earlier without success. Tungsten is a very hard and heavy metal, whose melting point of about 3380°C. exceeds that of any other metal and rivals that of carbon. It had been known to science for over a hundred years, and after about 1890 it became available in various ores in relatively large quantities at moderate prices. Despite its apparent attractiveness, however, its extreme brittleness and other difficulties in forming it into filaments were not overcome until around 1904, when a number of alternative chemical methods of preparation were devised.

TECHNICAL DEVELOPMENT

By 1904 several different individuals and groups were attempting independently to make tungsten filaments for incandescent lamps, and many more soon became interested in the problem.[11] In Europe, the Austrians, Dr. Alexander Just and Franz Hanaman and Dr. Hans Kuzel, were attempting on their own to develop tungsten lamps, while Dr. Werner von Bolton and others employed by the German Siemens & Halske Company had included it among the additional metals which they were studying even as they were developing the tantalum lamp. The Austrian Welsbach Company was working on the use of tungsten in incandescent-lamp filaments. The American General Electric Company was also among the first to conduct research on tungsten. Once initial success had been obtained, the number of experimenters increased rapidly, particularly among the German lamp companies and German and American private inventors.

[11] Besides the patents of Bottome and Lodyguine, the prior art in tungsten filaments included a British patent of no commercial value but of historical interest which was granted to Carl Kellner of Vienna in 1898. He proposed making filaments of thorium, titanium or titanium nitride, chromium, tungsten, or alloys of the various metals by pressing powders of the substances and oxidizing the surfaces of the resulting filaments. He also proposed mixing the powders with cellulose binders before forming and heating the filaments in a vacuum or in hydrogen until the carbon was converted into graphite. See *Electrical Engineering*, Vol. V, p. 797 (Sept. 9, 1909).

Dr. Alexander Just and Franz Hanaman were laboratory chemistry assistants at the Technische Hochschule in Vienna. They began serious work in 1902 on boron and tungsten filaments for incandescent lamps, and for two years they devoted their spare time and meager resources to filament experimentation. Even before 1902, however, Just had done some work on the problem, for he had been granted a patent in 1900 on a composite filament of carbon and a refractory nitride of a metalloid such as boron or silicon. Mixed powders of the substances were held together by a binder such as tar, formed into filaments, and carbonized.

The first results of the renewed experiments were not completely successful. Although filaments of boronitrate showed improved efficiencies over carbon, they had a very short life. Greater success was achieved with tungsten, and the priority of Just and Hanaman in the development of a satisfactory tungsten filament represented the most important single advance in lamp efficiency in the history of incandescent lighting. By the end of 1904, Just and Hanaman had devised two successful chemical processes for making tungsten into fine wire.

In the first process tungsten was deposited on a very slender carbon filament. Just and Hanaman used an atmosphere of tungsten oxychloride in the presence of a small amount of hydrogen. Pure tungsten was deposited on the carbon, and the carbon was dissolved and oxidized out. At the end of the process a tube of pure tungsten remained. The substitution idea was by no means new, for a number of earlier experimenters had attempted to employ it with various metals and other substances. Welsbach and his co-workers had worked with it in their experiments with osmium only a few years previously. Just and Hanaman were the first to apply it successfully to any material, however; they obtained virtually pure tungsten by the method.

The second process developed by the Austrian chemists was an adaptation of the sintering process which Welsbach had devised for the osmium filament. Powdered tungsten was mixed into a paste with an organic binder. It was then squirted through a die, baked and sintered in an atmosphere of hydrogen, nitrogen, and water vapor. The binder was removed during the heating.

Both of the Just and Hanaman processes produced very fragile filaments; yet they gave initial efficiencies of about 7.85 lumens per watt which were fairly well maintained through a useful life of around 800 hours. This was far better than the best carbon or any other incandescent lamp which had yet been made. The efficiency of carbon was less than half as great, and its light output fell off considerably over a life of about 600 hours. Like the other metals, tungsten had a rising resistance with increasing temperature and withstood variations in voltage well. Its low resistance made long filaments necessary, however, and the lamps had to be burned base up until later improvements kept the heated wire from softening and sagging disastrously. Either alternating or direct current could be used, although somewhat longer life was obtained on direct current; and it was possible to make lamps for potentials up to 220 volts.

Dr. Hans Kuzel of Vienna developed a process somewhat similar to the Just and Hanaman sintering method by which filaments could be made from a great variety of metals, including tungsten. He omitted the organic binder, using only water to hold together his paste of colloidal tungsten. He formed the colloidal mass by striking an arc between electrodes of tungsten under water. The paste was pressed or squirted through dies to form the filament, dried and sintered, and there was no binder other than water to be removed. His principal work was also done by 1904, although his processes were subsequently improved. Lamps made from his filaments had roughly the same characteristics as the Just and Hanaman lamps.

The third successful method of making non-ductile tungsten filaments was developed by Fritz Blau and Hermann Remané of the Austrian Welsbach Company. Auer von Welsbach himself had nothing to do with this improvement over osmium. The Welsbach Company continued its experiments after the osmium lamp had been perfected and studied other metals with high melting points, including molybdenum, tantalum, and tungsten. The engineers found that osmium filaments could be increased in efficiency by adding a percentage of tungsten. Accordingly, modifications of the osmium lamp which were called "osram" and "osmin" lamps were placed on the market. At first they contained a small percentage of osmium and a fairly large percentage of tungsten. It is apparent, however, that the superior characteristics and lower cost of tungsten made the greatest improvement in osmium when the osmium was displaced entirely. The osram lamp soon was composed of pure tungsten. The Welsbach Company used the sintering process for making its tungsten filaments. In one method tungsten trioxide was treated with an excess of ammonia to form a paste. Another method was the sintering of pressed metallic powder. The osram lamp also had the general characteristics of the Just and Hanaman tungsten lamp.

Siemens & Halske also experimented with tungsten. Von Bolton had made the metal tantalum ductile by purifying it. It seemed that other metals might make even better filaments, if formed into wires. Moreover, it seemed possible that some of these metals might be made as ductile as tantalum if they could be purified. Accordingly, von Bolton applied for a patent in 1904 to cover the use in incandescent lamps of purified ductile wires of a large number of metals, including tungsten. He did not, however, give a process by which this might satisfactorily be done. He merely claimed that tungsten, thorium, titanium, zirconium, or their alloys might be drawn into wires from sintered rods or compressed powder. Later patents of Siemens & Halske suggested the addition of small proportions of iron, cobalt, or nickel to increase the metals' ductility during drawing, after which the undesired metals were to be removed before use in lamps.

INTRODUCTION IN EUROPE

All the inventors applied for patents covering their inventions in various countries, and within a few years the competition among the alternative methods of making tungsten filaments became intense. Just and Hanaman made the first applications. They were granted European patents on their deposition method, but they were not successful in patenting their adaptation of the Welsbach paste and sintering process in Germany, Austria, and other countries which required considerable novelty for patentability. To obtain patent protection, Just and Hanaman used the deposition technique in their commercial lamps. They persuaded the Vereinigte Glühlampen und Elektrizitäts Aktien-Gesellschaft of Ujpest, Hungary, an established manufacturer of carbon lamps, to produce it, and their tungsten-filament lamp appeared on the European market in September, 1906.[12]

The osram lamp developed by the Austrian Welsbach Company was introduced to the European market even earlier than the Just and Hanaman lamp; it appeared during the summer of 1906. The German Welsbach Company acquired the osram patents, as well as the patents for the original osmium lamp, and manufactured and promoted the new product in Germany; it licensed other producers abroad. The Austrian company itself continued to make the osmin lamp.

For a short time the Just and Hanaman and the Welsbach lamps were the principal ones on the market, although the Kuzel lamp also had been introduced in 1906 by the Gebrüder Pintsch of Berlin. After about 1908 there was a great increase in the variety of tungsten lamps on the European market, particularly in Germany. One outstanding development was the "Z" lamp of the Germans Hollefreund and Zernig. Dr. Hollefreund had introduced a zirconium lamp in 1906 which employed a filament of carbon coated with zirconium.[13] When it did not prove to be satisfactory, Dr. Zernig showed how to improve it by the addition of tungsten. The new lamp, with a filament made by the squirted paste and sintering process, was called the zircon or "Z" lamp and was made by the Zircon Syndicate, an amalgamation of the original Hollefreund Company with Dr. Zernig. Like the osram lamp, it was soon greatly improved by leaving out the zirconium altogether and using pure tungsten.

The American Westinghouse Electric & Manufacturing Company entered the European tungsten-lamp field through the purchase of the Austrian Welsbach Company in 1906 and the acquisition of rights for the manufacture of the osmin lamp. It also set up companies to make tungsten lamps in other countries

[12] The Hungarian company owned licenses for Austria, Hungary, Russia, Belgium, Italy, Spain, and Portugal. Other producers were licensed in the remaining European countries. In Germany the patent rights were bought by a group of Augsburg financiers, and the lamp was manufactured by Georg Lüdecke & Company.

[13] The coated filament was shortly replaced by zirconium carbide.

and conducted a profitable European business for a number of years.[14]

Dozens of alternative chemical processes were developed in Europe for making non-ductile tungsten filaments, and many were used commercially. They all fitted into one or another of four major types, however: (a) substitution, (b) paste with organic binder, (c) colloidal paste, and (d) alloy or amalgam binder. In the last process, the powdered tungsten was mixed with other metals or amalgams during the formation of the filament. The great number of competing patents and the reluctance of German and other continental courts to uphold broad basic patent claims prevented the growth of an early patent monopoly on the tungsten filament in Europe.

Progress in lighting with tungsten-filament lamps was rapid in Europe. For one thing, electric current was more expensive than in the United States, and there was a greater inducement to use lamps of high efficiency. For another, competition among the various makers of tungsten lamps as well as among tungsten and the other metallic-filament lamps was more active on the continent. Prices were held to relatively low levels. Low prices had a deleterious effect on quality, however, as in the case of the carbon lamp. Metal-filament lamp production in Germany was not stabilized until the formation of the Drahtkonzern in 1911.

French and British producers made no important contributions to the tungsten lamp. The French market was exploited for years by foreign firms or their French affiliates. In Great Britain the General Electric Company, Ltd., purchased the osram and Just and Hanaman patent rights and eventually secured a strong patent monopoly in tungsten-lamp production. Other British producers also employed imported techniques of filament preparation until the Just and Hanaman patent was upheld.[15]

[14] Although Westinghouse owned the osmin patent rights for the United States, they were of little value against the controlling tungsten-filament patents acquired by General Electric.

[15] Although it appeared that the Just and Hanaman patent had been fully litigated when the Tungsten Lamp Association was formed in 1912, the situation was thrown open again in 1915 when the British House of Lords heard an appeal from a decision of the lower courts. It was held that the Just and Hanaman patent disclosed a process and not a product, and the tungsten filament could henceforth be made by anyone.

INTRODUCTION IN THE UNITED STATES

The General Electric Company introduced its tungsten-filament lamps into the United States late in 1907, under exclusive patent rights for the United States purchased in 1906 for $100,000 from the German Welsbach Company. It sold a 40 per cent interest in its option to the National Electric Lamp Company, which also began to sell tungsten-filament lamps through its subsidiaries. More than 500,000 tungsten lamps were sold during their first year on the American market. Some German-made tungsten lamps were sold in the United States for a few months before any lamps were made in this country, however.

As in Europe, the new tungsten lamps were originally produced in only a few sizes. The 40-watt and 60-watt sizes were the first made.[16] The carbon, Nernst, GEM, and tantalum lamps were gradually displaced. The prices of tungsten lamps established by General Electric upon introduction and for some time thereafter were very high. The 60-watt lamp was sold initially at a list price of $1.75, and the 40-watt lamp at $1.50. These were substantially above the prices prevailing in Germany and England. For example, as early as 1906 the German Welsbach Company was selling 34-candlepower lamps for 75 cents, 52-candlepower lamps for 81 cents, and 100-candlepower lamps for $1.25.[17]

Domestic competition in the American market for tungsten-filament lamps was even less than in the sale of carbon-filament lamps. General Electric, as the industry leader, along with its subsidiaries, carried on most of the business. Westinghouse also made tungsten lamps as a General Electric licensee. The few remaining competitors did not at first expand to the production of lamps with metallic filaments. Conditions were those of virtual monopoly, despite the slight threat from foreign producers. The Electrical Accessories Company of New York sold lamps made in

16 In 1905 the rating of incandescent lamps in the United States began to be changed from a candlepower to a wattage basis. Prior to that year the 16- and 20-candlepower lamps were used most commonly. The 16-candlepower carbon lamp took 50 watts, and the 20-candlepower GEM lamp took 50 watts. These sizes continued to be used widely until they were superseded by 40-watt and 60-watt tungsten lamps. In Europe, the change in rating to watts came a few years later. See Schroeder, *op cit.*, p. 83.

17 See Table XX on p. 269 for a complete American price history of selected sizes of tungsten-filament lamps from 1907 to 1947.

Germany under the Just and Hanaman patents. The American "Z" Electric Lamp Company, the Bergmann Elektrizitäts-Werke and other German producers also sold some foreign-made lamps in the United States for a few years. The potential foreign competition seems to have been at least partly responsible for the increase in tariff rates for electric lamps in 1909 from 35 to 45 and 60 per cent of value.

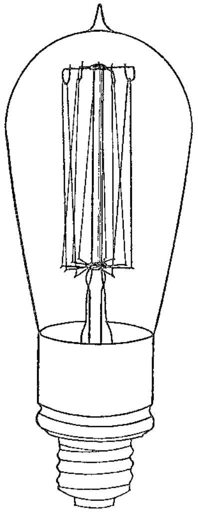


FIG. 23. Tungsten-Filament Lamp, 1907
This early tungsten lamp contained a sintered filament operating in a vacuum.

In the United States both the squirting process and the colloidal process of making non-ductile tungsten were used commercially, as well as an amalgam process developed in 1906 by Dr. William D. Coolidge of the General Electric Research Laboratory.[18] This was an adaptation of the amalgam process developed for use with carbon. In the Coolidge process a mixture of powdered tungsten and a cadmium-mercury amalgam were squirted through a die, and the amalgam was removed by volatilization at a high temperature to leave virtually pure tungsten.

The patent situation in the United States was highly complicated. Just and Hanaman had applied for British and French patents on November 4, 1904. At that time they had not sufficient funds to apply for patents in the United States and certain other European countries. Before July 6, 1905, when they were able to make their American application, both von Bolton and Kuzel had made American applications, von Bolton on November 10, 1904, and Kuzel on January 4, 1905.

A fourth party, the independent American inventor John Allen Heany, of York, Pennsylvania, had also made conflicting claims for the tungsten filament. He had been working for many years

18 Coolidge was an assistant professor of physicochemical research at the Massachusetts Institute of Technology when he was prevailed upon by Whitney to join the General Electric research staff in 1905. He became assistant director of the G.E. Research Laboratory in 1908.

with tungsten, titanium, chromium, molybdenum, and various other metals, with metallic oxides, nitrides, and still other materials in his efforts to improve the incandescent lamp. His first patent application had been made on December 29, 1904, and a few patents had been granted to him by 1907 on divisions of the original application. In 1908 it was discovered, however, that Heany's patent attorney and a Patent Office examiner had altered Patent Office records to show Heany's priority in the development of processes covered by the Just and Hanaman, Kuzel, and other applications. All three men were indicted. The attorney and the Patent Office examiner were convicted of conspiracy, forgery, and the destruction of official records. Heany himself was acquitted, although it was established that the criminal acts of the others had been done with his knowledge. The patents which had been issued to Heany were subsequently annulled, and all his pending applications were rejected in 1911 because of the fraud.

The rejection of Heany's applications dissolved the interference with other pending applications and permitted the Patent Office to resume its regular procedure in connection with them. Von Bolton's application gave no satisfactory method for producing a ductile tungsten wire, which he claimed, and it was held by the Patent Office to be inoperative. Despite their later date of application, Just and Hanaman were able to prove priority of invention with the date of their British and French applications. They were finally granted their fundamental American patent on February 27, 1912, while the applications of Kuzel and von Bolton were denied.

Although the General Electric Company had set up its own research laboratory and had initiated work on tungsten filaments too late to make any fundamental contributions on the non-ductile tungsten filament, it had been alert to the importance of the foreign developments. It had been eager to secure the exclusive American rights for the production and sale of tungsten-filament lamps. Not knowing which of the applications would be granted and not desiring to delay action until the legal status had been ascertained, General Electric started in 1906 to buy the American patent applications of all the contending European inventors, in order to be sure to have the victorious one. As already mentioned, $100,000 was paid to the German Welsbach Company for rights on its tungsten-filament inventions. In 1909 General Electric paid $170,000 to the Bergmann Elektrizitäts-Werke of Berlin for an option which it later exercised on the American rights for all the company's inventions and applications covering incandescent lamps and their methods of production. After the sale of its American rights, Bergmann stopped selling incandescent lamps in the United States.

General Electric also bought the patent applications and inventions of Just and Hanaman and of Kuzel in 1909. It paid $250,000 for the former and $240,000 for the latter. In its attempt to gain control of the tungsten-filament lamp, General Electric had even secured in 1904 an option on the work of Heany, which it dropped on satisfying itself that he had produced nothing of value. The total cash consideration paid out by General Electric for the patent applications mentioned was $760,000. Subsequent events proved it to be an extremely profitable investment.

The change-over from carbon lamps to tungsten-filament lamps was slower in the United States than in continental Europe. Some reasons have already been given—the later introduction, lack of competition, higher lamp prices, and lower cost of electric current. There was one additional factor of great importance. The American policy of free lamp renewal by the central-electric stations was an obstacle, for the central stations were afraid of the effects of the more efficient lamp on their revenues. For some years they were reluctant to encourage use of the new lamps, and consumers accustomed to free carbon lamps were unwilling to buy tungsten lamps. Eventually the electric companies discovered that tungsten lamps, as well as tantalum and other more efficient varieties, had no real downward effect on lighting load, for consumers took the opportunity to improve their lighting rather than decrease their bills. In fact, through education to higher levels of illumination, tungsten lamps became load builders. The same discovery was made in Great Britain, where central-station executives had been even more upset over possible load losses.

The substitution of tungsten for carbon did have a significant effect on the method of distribution of electric lamps in the United States, however. Central stations generally charged for the tungsten lamps while continuing for a number of years to supply free carbon lamps. Since customers had to pay for the newer type, normal wholesale and retail selling of tungsten lamps was encouraged.

Finally, it should be pointed out that the lack of competition and the high prices charged for tungsten-filament lamps in the United States did not constitute an unmitigated evil. Profits were high, to be sure, and the public paid more for lamps than it would have paid under more nearly perfect competition. Nevertheless, the public was buying electric lighting, not lamps alone; and the absence of competition and price cutting removed the great incentives for cost reduction which resulted in low lamp quality in Germany and other European countries. Where lamp costs represented less than 10 per cent of the total lighting bill, as they usually did, high quality was of even greater importance than the prices charged for lamps.

7. *The Ductile Tungsten Lamp*

Notwithstanding all the attention lavished upon tungsten from 1900 to 1908, the processes described above for making it into filaments left it brittle and fragile. In spite of its high efficiency, it was not able to stand rough usage. Even though the metal seemed to be pure, it could not be drawn into a wire or otherwise formed into a strong flexible filament.[19] This problem continued to hold the attention of experimenters trying to improve the incandescent lamp.

Successful production of ductile tungsten wire was achieved in the General Electric Research Laboratory. It was the first outstanding technical triumph of the laboratory. It will be recalled that Dr. William D. Coolidge had by 1906 devised an amalgam process for making non-ductile tungsten. The early experimentation had also produced a sintered tungsten-thorium filament, in which thorium oxide was used to increase the electrical resistance. Still other processes were studied, including the use of colloidal pastes and of various metal binders such as copper or nickel. Some metallic binders, as well as certain amalgams, increased the ductility of tungsten and permitted it to be drawn into filaments.

[19] In addition, the non-ductile tungsten filament was hard to make to voltage specifications, and the filament could not be coiled to produce a concentrated light source.

After the associated metals were removed, however, for use as a lamp filament, the tungsten was as brittle and fragile as before.

It became evident that a new avenue of approach was necessary if ductile tungsten was ever to be obtained. A General Electric group under Dr. Coolidge's direction tried an entirely new idea. With the assistance of Dr. Colin G. Fink, Coolidge discovered in 1908 that molybdenum could be made ductile by hammering, rolling, drawing, and otherwise mechanically working the pure metal while it was hot. Molybdenum has a melting point of 2500°C. and is similar to tungsten. It had not been used in commercial incandescent lamps, although early experimenters had frequently worked with it. It seemed logical that a method which would make it ductile would work for tungsten. That was found to be true.

Dr. Coolidge devoted two more years to finding a method of making ductile tungsten which could be used commercially. The essence of the final method was the repeated heating and hot swaging of the metal to increase its malleability and strength until very fine and flexible wires could be drawn through heated dies. Coolidge applied for an American patent covering the specific process June 19, 1912, and it was granted December 30, 1913.[20] Over a period of years patents were also obtained in other countries.

The effort devoted to producing ductile tungsten between 1906 and 1911 is well indicated by an annual breakdown of the total of $116,856 spent by General Electric on this development:

1906	$ 5,720
1907	14,323
1908	5,017
1909	29,920
1910	54,084
1911	7,792

During the year 1910 the outlay was one-third of the total expenditures of the entire General Electric Research Laboratory. It is noteworthy that this highly important research, conducted in its own laboratories, cost the General Electric Company only

[20] The 1912 application was in part an extension of four earlier applications dating from 1906.

about one-seventh as much as it spent in securing the American patent rights for the non-ductile tungsten filament.

Perhaps the most significant discovery made by the General Electric workers in their investigation was that tungsten and molybdenum behave quite differently from most other metals in regard to working temperatures. Most metals can be worked best when heated above their annealing points. Their ductility is reduced when worked at lower temperatures. Tungsten, on the contrary, becomes more ductile when it is worked below its annealing temperature. When worked above that point, it becomes brittle upon cooling. It was found that the best initial temperature, which was just below the annealing temperature, could be reduced as working progressed and ductility was increased. Ductile tungsten is fibrous, whereas brittle tungsten is crystalline. Ordinary ductile metals may be drawn in a crystalline state, and when their workability decreases they may be made ductile again by being heated to their annealing temperatures and recrystallized. Heating tungsten to its annealing point recrystallizes it and also makes it brittle. It was because of these facts that the drawing of tungsten wire presented such a difficult problem for so many years.

Werner von Bolton of the Siemens & Halske Company seems to have been the closest of all the earlier workers to making ductile tungsten. He had recognized that pure tungsten was necessary for ductility, but he had failed to realize that mechanical working and heat treatment were also required. In the continued search for ductility, the Siemens & Halske chemists and engineers had tried a number of schemes. They had used metallic binders for tungsten which made the mixture ductile during the drawing process, after which the binder was removed. Although lamps using those filaments were advertised as "drawn-tungsten" lamps, the wire was not truly ductile. Another "drawn filament" used by Siemens & Halske employed a tube of a ductile metal into which tungsten was packed. The filled tube was then drawn and rolled after which the outer shell was dissolved off to leave pure tungsten. Many other workers had also attempted to overcome the brittleness of tungsten, for the utility and desirability of ductile tungsten wire were apparent. None of the others had been successful.

The first public announcement of ductile tungsten wire was made by General Electric in 1910. The process developed by the research laboratory was turned over to the company's lamp department for commercial use; and in 1911 incandescent lamps using the flexible wire were placed on the market. They replaced those using the non-ductile tungsten filament. They were called Mazda B lamps, which meant that they were the product of the latest technical discoveries of American lamp-research laboratories.[21] By 1911 tungsten lamps of 25, 40, 60, 100, and 150 watts were available, and other sizes followed shortly.

The new tungsten lamps were strong and durable, and in addition they gave increased initial efficiencies of around 10.0 lumens per watt which were fairly well maintained over a useful life of about 1,000 hours. Lamps with drawn-wire tungsten were found to blacken more quickly than those with pressed filaments, however. The filaments were mounted on hooks radiating about the stem as in tantalum lamps, and the lamps could be burned in any position. It was possible to coil the ductile wire, and very shortly automobile headlight lamps and other focusing lamps were placed on the market. Miniature lamps for flashlights and similar purposes received a great boost. Drawn-wire filaments were also cheaper to make than the non-ductile type, and tungsten-lamp prices were reduced (see Table XX on page 269). A further advantage lay in the fact that the wire could be drawn to the desired diameters so accurately that control over lamp voltages was greatly improved.[22]

The drawn-tungsten filament was introduced in Europe only a short time after commercialization began in the United States. The British Thomson-Houston Company held the British patent rights, and it was those holdings which permitted it to join with the British General Electric Company and the Siemens Brothers

[21] If General Electric or one of its affiliates had been the original inventor of the non-ductile tungsten lamp, that lamp would probably have been known as the Mazda A lamp.

[22] It will be recalled that carbon filaments were not subject to close control in manufacture, so that each lamp had to be tested to determine its proper voltage. Because of the variations in lamps, there was a great diversity of voltages in general use and an uneconomical multiplication of varieties of lamps and other equipment. After the development of the drawn-tungsten filament, the number of voltages in use was largely reduced to 110, 115, and 120 as standards.

Dynamo Works in organizing and licensing the other producers of tungsten lamps in England. Similarly, in Germany, A.E.G. obtained the primary rights to the ductile tungsten filament under the terms of its 1904 license agreement with the American General Electric Company. The German Welsbach Company and Siemens & Halske were also permitted to make ductile tungsten lamps by the 1911 agreements among the founders of the Drahtkonzern. The German companies and General Electric pooled their patents so that each of them could make the best possible lamp with ductile tungsten wire and with the Siemens & Halske mounting method, which had originally been developed for the tantalum lamp.

8. Other Lamps

The introduction of the drawn-tungsten filament in 1911 is the last important change which has taken place in filament materials. Nevertheless, experiments on a number of other metallic and nonmetallic materials were continued during its development and for some years afterwards. In the words of Barham written in 1912: [23]

> It will be remembered that there are many electrochemists and engineers who are still firmly convinced that the metallic filament lamp is merely a stop-gap, as it were, and that before many years, possibly even before many months, lamp-makers will be at work again on carbon, either graphitized in connection with silicon, or combined with some other element which shall render it more refractory, and so able to withstand a higher temperature, without volatilizing or being unduly weakened, than that at which lamps with tantalum or tungsten filaments can be operated.

Two developments in the direction Barham mentions are of importance and should be discussed briefly.

Reference has already been made to the experiments of Rudolf Langhans begun around 1888 in combining carbon, silicon, and boron in varying proportions to produce incandescent-lamp filaments. His work in the United States for the Thomson-Houston Electric Company did not lead to a marketable lamp. Upon returning to Europe, he was successful in making further improvements which led in 1899 to the introduction in England of the Langhans silicon-carbide lamp by the Premier Electric Lamp Syndicate. The silicon carbide was made into a filament by the squirting process and then was coated with silicon and carbon by the flashing process. The lamp was sold on a limited basis for a short time.

[23] *Op. cit.*, p. 184.

The ideas of Langhans were further pursued by the Americans Herschel C. Parker and Walter G. Clark. Parker was a professor at Columbia University, and Clark was an electrical engineer. In 1907 the two men studied all likely filament materials and decided that a composite material having "the high efficiency of the metal and the durability of the carbon filaments" was what was required. They produced a composite filament with a carbon base coated with silicon or silicon carbide by the flashing technique. Such filaments were used in the "Helion" lamp, which was put out in small

TABLE XIII: OTHER PROPOSED FILAMENT MATERIALS 1898–1910 [a]

Date	*Inventor*	*Country*	*Filament Material*
1898	H. S. Maxim	England	Carbon impregnated with various minerals
1899	O. M. Thowless	United States	Carbon coated with metallic oxides
1899	T. A. Edison	United States	Mixture of carbon and metallic oxides
1899	F. M. F. Cazin	United States	Carbon covered with copper and oxide coatings
1899	————	Germany	Metal coated with nitrates of rare earths
1899	W. L. Voelker	England	Uranium carbide and thorium carbide
1900	G. Alefeld	Germany	Platinum group metals coated with rare earth oxides
1900	S. B. Husselman	United States	Asbestos coated with compound of aluminum and iodine
1900	C. Kellner	Austria	Thorium with oxidized surface
1902	W. L. Voelker	England	Titanium carbide
1902	F. de Mare	Belgium	Core of magnesia flashed in hydrocarbon
1908	O. M. Thowless	United States	Tube of tantalum or similar metal containing powdered thoria, etc.
1909	C. Trenzen and F. R. Pope	England	Metallic titanium
1910	H. Malachowski	Germany	Carbon coated with antimony or arsenic

[a] This tabulation includes only a few examples of the many proposed filament materials which did not achieve the commercial success of the Nernst, osmium, tantalum, GEM, and tungsten lamps.

quantities in the United States for a few years by the Parker-Clark Electric Company.

The great variety of other materials suggested for incandescent filaments is indicated by a partial list of the patents granted during that period (Table XIII). Most of the suggestions were made by independent inventors not associated with an established lamp manufacturer, and most were complete failures. The titanium carbide filament invented by W. L. Voelker in 1902 seems to have been the only one that found any commercial use, and it did not remain on the market for long. The clustering of suggestions by independents around 1900 was another characteristic of the period. That was before the large lamp companies had begun active work on filament improvement. The influence on other inventors of the success of the Nernst and osmium lamps is very noticeable.

After the large companies had become active and had taken over the commercialization of the Nernst and other new lamps, the private inventors were gradually squeezed out. Once aroused, the large producers, with their greater resources and man power, considered systematically all likely filament materials and took out scores of patents. Besides the lesser abilities of the individual inventors, their incentives to work on incandescent lighting gradually declined as the lamp was improved. By 1910 very little private work was being done. The field of incandescent lighting was left to the lamp manufacturers.

Chapter VIII: OTHER TECHNOLOGICAL DEVELOPMENTS IN ELECTRIC LIGHTING: 1897–1912

1. Design and Methods Improvements in Incandescent-Lamp Making

The period from 1897 to 1912 was of importance in the technical evolution of incandescent electric lighting primarily because of the rapid improvement in filament materials which took place. Nevertheless, significant progress was made in other aspects of lamp design and in manufacturing processes. Changes were made which reduced premature lamp failures, permitted more extensive lamp use, lowered lamp costs, and otherwise improved lamp performance. New lamp styles were developed for special uses, and advances in electrical generation and transmission greatly reduced lighting costs.

SOURCES OF DESIGN AND METHODS IMPROVEMENTS

Relative progress among lamp-producing countries was somewhat different in the various phases of lamp design and process improvement. Moreover, the introduction of new filament materials, new lamp designs, new lamp parts, and new processes of parts manufacture and lamp assembly did not take place at exactly the same time in all firms of the incandescent-lamp industry, either domestically or internationally. As was indicated in the preceding chapter, inventors outside the electric-lighting industry in Germany and Austria made the first advances in new filament materials. Large companies in Germany and the United States took over the burden of filament development a few years later. No other country made an important contribution in that direction. Lamp producers and independent inventors in Germany and the United States were also the leaders in the progress of such phases of lamp design as the composition of lead-in wires and the use of getters. The American lamp industry led the world in lamp standardization and the mechanization of lamp assembly. A genuine interest in illuminating engineering also grew up in the United States more rapidly than in any other country.

Since the General Electric Company dominated the American lamp industry, and since it far surpassed the smaller companies in lamp research and engineering activities, it naturally was responsible for most of the technological advances in this country between 1897 and 1912. The General Electric Research Laboratory contributed several innovations of importance concerning lead-in wires and getters as well as lamp filaments; and the engineers of the company's lamp department were active in improving lamp-making machinery and assembly methods.

Westinghouse, National and its subsidiaries, and the smaller firms with which General Electric had patent-licensing agreements were able to take advantage of the advances in lamp technology made by the industry leader. Their own development laboratories did not make any advances of great significance. Technological improvements made abroad were normally channeled into this country through General Electric. The few small American lamp producers outside the General Electric group, who controlled only a small percentage of the domestic market, were forced either to rely upon designs and processes of patents that had expired or to circumvent valid patents controlled by the General Electric group through slight redesigning or outright infringement. Their limited financial resources and laboratory facilities made it very difficult for them to develop important new products or processes or to secure important developments coming out of Europe. Where the small concerns were legally able to make the lamps produced and made standard by the General Electric group, their methods and parts were usually not sufficiently developed and standardized for their lamps to equal those of General Electric in reliability and all-round performance. Many of the American innovations which were not made by General Electric were made by independent inventors.

German technological competition and the competition of gas and arc lighting stimulated much of the domestic activity. Strong market competition within the American industry was lacking. Nevertheless, the record of American technological achievement in incandescent lighting as compared with the French record, for example, indicates that competition alone is no guarantee of progress. In fact, too keen competition may well discourage innovation through a cutting off of funds for research and advanced engineering. Both incentives for innovation and the ability to produce results are necessary. Despite the lightness of pressure on lamp costs through market competition, the General Electric Company was encouraged to mechanize and improve lamp assembly processes by the high wage rates paid in relation to European wage rates, by the company's well developed profit urge, and by the potential threat of greater market competition if it did not retain its technological leadership.

STANDARDIZATION IN INCANDESCENT LIGHTING

One of the first problems which confronted the American incandescent-lamp industry in 1897 was the diversity of lamp bases and sockets. Each producer had originally developed his own design, and the lamps of the various manufacturers were not interchangeable without special adapters. That was unquestionably wasteful, requiring uneconomically large inventories and inconveniencing the consumer.

There were over a dozen different base styles in use during the nineties. By 1900, however, about 70 per cent of lamps sold employed the Edison screw base, about 15 per cent used the Westinghouse base, 10 per cent used the Thomson-Houston base, and the remaining 5 per cent employed the various other types still in use. It seemed desirable to accept the Edison base as standard, because of its greater use and its simplicity. Industry-wide cooperation and a vigorous campaign for replacing some sockets and using adapters with the rest made it possible to eliminate all other styles within a very few years. The more rapid concentration of the American lamp industry permitted it to standardize bases before the European nations. That was one important benefit from coordinated industry action. Later, the lamp producers in most other countries got together and standardized one or a very few types of base. The Edison screw base was adopted in many nations.

In 1900 the Edison base was improved by replacing the plaster of Paris binder which had been employed since 1881 to hold the base to the bulb and give insulation. The tendency of plaster of Paris to absorb moisture and pull loose from the bulb made its elimination desirable. A new base was developed in which the screw shell and tip were fastened together and insulated by porcelain, while a waterproof cement held the base to the lamp. The following year, 1901, saw the final important change in lamp bases, as glass replaced porcelain. Further minor improvements have been made in the cement employed, and of course special bases of various kinds have been developed. With the waterproof base outdoor illumination and sign lighting were greatly encouraged.

The standardization movement in the United States was ahead of the European movement in more than lamp bases. There were calls for the standardization of lamp styles and dimensions, of central-station voltages and of electrical equipment of all other kinds. Considerable progress was made in the United States toward standardizing the physical measurements of incandescent lamps. Under the leadership of General Electric, cooperation was not difficult to secure. Until the development of the ductile tungsten lamp, however, there was less that could be done about the standardization of central-station voltages. Carbon lamps could not be made with sufficient voltage accuracy to merit reducing the number of potentials to two or three. Progress in that direction was slow until after 1912.

MECHANIZATION OF LAMP ASSEMBLY

After the year 1896 there followed about ten years of rapid mechanization in the United States in the processes for assembling incandescent lamps. Much effort was devoted to the reduction of production costs and to the standardization and improvement of lamp quality, principally by the General Electric Company and particularly between 1900 and 1906, when the old carbon-filament lamp was pressed so hard by a variety of new developments. Except for a very few simple machines, hand processes of assembly had been used almost exclusively until the wave of mechanization took place. The sealing-in machine built by J. W. Howell of General Electric permitted an unskilled worker to double the output of a skilled person working without it. It sealed the neck of the bulb upon the glass stem which supported the filament. Howell collaborated with W. R. Burrows to develop a stem-making machine in 1901, and Burrows developed a tubulating machine

in 1903. The stem-making machine assembled the glass stem, lead-in wires, and filament supports. The tubulating machine made a small hole in the round end of the bulb about which a glass tube was attached for exhausting the air from the bulb when the filament had been sealed in. Other machines were also constructed, including one for flaring the glass tubing used in stem making. Greatly improved mechanical vacuum pumps, developed by companies outside the lamp industry, became available around 1900.[1]

There is no evidence of resistance by American workers to the original introduction of labor-saving machinery in the lamp industry. At that time output was expanding so rapidly that productivity would have had to increase tremendously to keep up with production. Around 3,800 workers were employed by the General Electric lamp works alone in 1904, and there seems to have been little if any actual displacement of workers by machines. The employment of women for most assembly work was also a favorable factor in speeding mechanization. Turnover was rapid; the workers were unorganized; and the low skills required for machine operation permitted rapid training and the payment of low wage rates.

LEAD-IN WIRES, GETTERS, AND ELIMINATION OF THE TIP[2]

One essential part of the incandescent lamp, the lead-in wire, was considerably improved early in the twentieth century. Platinum was still being used by most lamp makers in 1897, for it was still the only material known which was a good conductor of electricity, adhered well to glass, and had essentially the same coefficient of expansion as that of glass. Producers in some countries where lamp prices were very low, like Germany and France, had reduced the amount of platinum required by using the three-part "Siemens" lead-in wire with only a very short piece of platinum in the center to pass through the glass. Other producers, including

[1] Hand or semiautomatic mold-blowing of lead-glass bulbs for incandescent lamps continued in the United States throughout the entire period 1897 to 1912. Nevertheless, minor improvements in glass making and handling resulted in some further cost reductions for incandescent lamps.

[2] There were, of course, other improvements in the details of lamp design, such as the use of molybdenum wires to support the tungsten filament and improved methods of attaching the filament to the lead-in wires. The changes discussed here are only those of greatest significance.

the British, were somewhat slower in reducing platinum requirements.

After 1897 somewhat greater success was achieved with platinum substitutes, and the degree of success increased up to 1912. The first important new proposal was contained in an 1899 patent to Guilleaume and Dumas of the German Felten-Guilleaume-Lahmeyer company. Guilleaume suggested using a nickel-iron alloy which had the same coefficient of expansion as platinum. It was not a very good conductor of electricity, however, and did not adhere well to glass; and the larger sizes of wire required did not retain the vacuum well. In 1901, the German A.E.G. also eliminated platinum entirely from lead-in wires for all its carbon lamps and lowered production costs by using iron wires which led in the current to filaments sealed in atmospheres of carbon monoxide. These lamps gave out quickly because of the poor seal. The nickel-iron wire was used commercially only in cheap lamps of low quality and only in continental Europe.

A partially satisfactory low-cost lead-in wire of copper was developed in 1905 by John H. Guest of Brooklyn. Copper adheres well to glass, even better than platinum, and it is a fine conductor of electricity, although its coefficient of expansion is greater than that of glass. Guest flattened the wire and formed it into an attenuated ring in that portion which was sealed into the glass. The required diameter of the copper wire was only one-sixth that of platinum, and the seal normally held a vacuum quite well. The different rates of expansion and contraction usually did not pull the thin copper away from the glass. Later improvements made this sort of lead-in wire even more reliable. Nevertheless, in 1910 most American lamps still employed small quantities of platinum for the portion of the lead-in wire which passed through the glass.

Another partial substitute for platinum in lead-in wires was the composite wire developed in 1911 by Dr. Byron E. Eldred, a New York consulting engineer. His lead-in wire consisted of a nickel-iron core, to which was added a thin coating of copper, a silver plating, and finally a platinum sheath. The intermediate coatings were used to join the core and the platinum, for the two could not be joined directly. A specific patent on this lead-in wire

and the method of making it was applied for in October, 1911, and granted in December, 1913, based on previous broader patents. Eldred sold his patents to General Electric, although he reserved limited license rights for himself. The commercial use of the wire in incandescent lamps extended from 1911 to 1913.

The ideas of Crookes, Eldred, and others regarding the use of a composite wire were improved upon by Dr. Colin G. Fink of General Electric's Schenectady Laboratory, who developed the first complete and fully satisfactory substitute for platinum in 1912. He covered a nickel-iron core with a thin copper coating, a sheath of brass, and then a sheath of copper. This composite wire conducts electricity well, has the same longitudinal coefficient of expansion as glass, and adheres well to glass. Even though the sheath stretches and contracts slightly, the seal remains unbroken. A British patent was granted August 21, 1913, on an October, 1912, application for this "dumet" wire. An American patent applied for earlier in 1912 was granted June 24, 1924, after lengthy Patent Office delays as a result of an interference with the Eldred patents and with another inventor's application. The wire came into use for lamps in 1913, and it has been widely employed ever since. Platinum has been completely eliminated. A further improvement was made soon after by coating the dumet wire with a borate, which made an even firmer seal.

The Malignani chemical-exhaust process was also improved between 1897 and 1912. In that process, as has been stated, vaporized phosphorus was driven into the bulb during the later stages of exhaust to clean up the residual gases and produce a good vacuum.[3] Around 1909 the technique was improved and simplified by John T. Marshall of the General Electric Company. He coated the filament by dipping it into a mixture of phosphorus and water, and the phosphorus was vaporized after exhaust by running a strong electric current through the lamp.

Since that time phosphorus has been supplemented by other getters, for different types of lamps require different getters to produce the desired conditions within the bulb. The introduction

[3] The process was physical rather than chemical, for the molecules of the gases were driven to the bulb and firmly held there unless the phosphorus was again vaporized.

of the tungsten-filament lamp created an increased need for new getters, since bulb blackening was greater with the tungsten than with the carbon and other lamps. The first special getter for tungsten-filament lamps was the compound of phosphorus, nitrogen, and hydrogen (phospham) employed in 1906 by the German "Z" company for decarbonizing metal filaments. It was soon discovered that phospham left in the bulb would combine with other residual and destructive substances to reduce bulb blackening.[4]

A new type of getter was invented by the Austrian chemist Franz Skaupy in 1910. He suggested placing halogen compounds of a metal in a hollow of the glass filament support, where they broke up as the lamp was heated in use. The liberated gas combined with the tungsten given off by the filament and produced a much lighter deposit on the bulb and a smaller decrease in effective light output. Skaupy's potassium-thallic-chloride was so active that in smaller-sized lamps it attacked the filament; consequently it was used only with lamps of 100 watts or more. Other chemical compounds were also used as getters. In 1912 Dr. Fink of General Electric adapted potassium iodide for use with lamps of from 15 to 40 watts, and he simplified the method of mounting it on the glass support. In the same year Harry H. Needham, also of General Electric, adapted cryolite for use as a getter in lamps of from 25 to 60 watts.

The introduction of inert-gas fillings into lamp bulbs also had the important gettering effect of decreasing filament decomposition and bulb blackening. The A.E.G. used low-pressure carbon monoxide in its carbon lamps in 1901. Attempts to employ gas fillings were renewed after the commercialization of the tungsten-filament lamp. Nitrogen filling was mentioned again in a 1908 patent by a French lamp manufacturer, and mercury vapor was used to exert pressure upon the carbon filament in a lamp developed in 1908 by the German, R. Hopfelt.

The suggestions before 1912 for filling lamps with gases were scattered and haphazard. Although some of the inventors who tried inert gases had the right idea about their value, they did not

[4] Around 1910 the Felten-Guilleaume-Lahmeyer company developed a similar getter. A nitrogen compound free of hydrogen, such as phosphorus nitride, was used to decrease filament disintegration. The hydrogen was omitted because it tended to become ionized and short-circuit the lamp filament during operation.

study the problem systematically, and their achievements were not great. The development of the successful gas-filled tungsten lamp, which eventually superseded the vacuum lamp in most of the important sizes, was completed by Dr. Irving Langmuir of the General Electric Research Laboratory in 1912. Inasmuch as the gas-filled lamp did not make its commercial apperance until 1913 and had a great significance for later years, a detailed discussion of Langmuir's work will be deferred until Chapter XII.

Another development which occurred around the turn of the century was an increasing preoccupation with eliminating the tip on the round end of the bulb. Most early commercial lamps were sealed before being pumped free of air, and the exhaust was made through the round end. When the exhaust tube was removed, a tip remained which interfered with an even distribution of light and rendered the lamp more fragile. Stoppered lamps had long been made without tips, but they could not hold the vacuum as well as sealed bulbs. A number of experiments had also been conducted at an early stage in many countries for exhausting the lamp through its side or bottom.

Although processes of making tipless lamps were developed and patents were taken out, for many years the processes were too expensive to result in extensive commercial production. Exhaust tubes were attached to the side of the seal at the base of the lamp or were run up through the stem. The Meridian lamp, which used the GEM filament, was one of many tipless lamps. It was made by General Electric from 1906 to 1910 for decorative purposes and to compete with the Nernst and other new lamps. It was exhausted through a tube in the stem, utilizing complicated processes patented by General Electric workers in 1894 and 1906.

A simpler method of achieving the same end was patented in 1903 by Herman J.

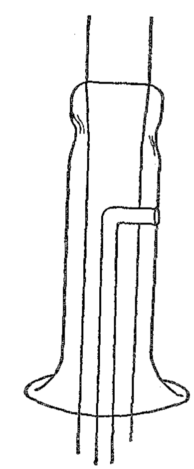


FIG. 24. Jaeger Stem, 1903

The L-shaped exhaust tube inserted in the stem permitted the construction of tipless lamps.

Jaeger, and his lamp was produced for a number of years by the Jaeger Tungsten Lamp Company and distributed by the Tipless Lamp Company. Jaeger used a small exhaust tube with a bend at one end. The tube was inserted into the stem, and the curved end was fused to the inside surface of the stem. Air was then blown through the tube and a hole was formed in the softened glass through which the bulb could later be exhausted.

General Electric as the industry leader was willing to buy the Jaeger patent, but it was unwilling to take a license under it. The big company preferred to postpone the general production of tipless lamps until it had devised an improved process of its own. Except for simplifications, however, the Jaeger method was essentially like the one developed by General Electric workers sixteen years later and used at the present time.

NEW STYLES OF INCANDESCENT LAMPS

Besides the general changes and improvements mentioned above, which applied to many or all varieties of incandescent lamps, there were numerous developments in connection with specific styles of lamps. In 1900, before the introduction of metal filaments in the United States, the journal *Electricity* reported that there were then in use 147,000 varieties of incandescent lamps of all forms.[5] The standardization of bases reduced the number of types substantially; the introduction of metal-filament lamps increased it again somewhat. In addition, there was a continuous multiplication in the sizes and varieties of both large and miniature lamps for all sorts of special purposes.

Decorative types in particular increased in number. Lamps with round, flame-shaped, or candle-shaped bulbs became very popular. The idea of a line of light was first introduced with the sale of straight tubular lamps about nine inches long which could be mounted end to end. The use of colored-glass or coated bulbs to produce colored light was expanded. The coloring filtered out the light of undesirable color but resulted in a much less efficient production of light. Silvered, opal, and frosted lamps to reduce glare and diffuse the light became more common. Acid etching and sandblast were the two most commonly employed methods

[5] *Electricity*, Vol. XVIII, p. 18 (Jan. 17, 1900).

of frosting the outsides of bulbs. Frosting reduced the initial light output of a lamp by about 5 per cent and reduced useful lamp life by around 40 per cent. High-efficiency but short-lived lamps for photographers also became more common, as did the multiple-filament lamps, which permitted one to adjust the amount of light given off by a single lamp. One of the most popular multi-filament lamps was a turndown night light which had one normal 8- or 16-candlepower filament and one small filament of but a single candlepower.

Apart from the new styles mentioned above, the unmetallized carbon lamp was little changed during the entire period here under consideration. Efficiency remained unchanged, and lamp life was increased by but a small amount. Prices declined only slightly. The principal advance was in manufacturing precision and in average lamp quality. The American manufacturers, led by General Electric, surpassed the producers of England, Germany, and all other countries in the quality of their output.

A final major source of improvement in incandescent lighting during that period was the great reduction in electric-energy rates. Residential rates per kilowatt-hour were reduced from twenty cents or more in 1897 to about nine cents in 1912. Industrial and commercial rates similarly declined. That reduction alone more than halved lighting costs. Rate reductions resulted from continued progress in the generation and distribution of electric energy. The steam turbine was developed around the turn of the century, and steam engines and water turbines were improved considerably. The larger and more efficient generators also produced a steadier voltage, which was important in incandescent lighting.

2. *The Triumph of Incandescent Electric Lighting over Gas and Arc Lighting*

With the commercial introduction of tungsten and the other metallic filaments, incandescent electric lighting finally achieved a definite superiority over gas illumination and arc lighting for general indoor lighting purposes. Before the final victory, the three light sources had waged a seesaw struggle for about thirty years. Gas had been supreme until the two electric-light sources had reached commercial use around 1880. It had continued to lead in economy, while arc lighting and incandescent lighting were favored among other things by cleanliness, safety, and incandescent by convenience and simplicity. Even though the incandescent lamp had been the least economical of the three, its use had expanded rapidly, particularly for indoor applications, and costs had been reduced. Arc lighting had displaced gas lamps for much street lighting and in other outdoor applications.

THE DECLINE OF GAS LIGHTING

The vigorous competition from electric-light sources made gas wake up. Gas quality and service were improved, and even more important, the Welsbach incandescent mantle was developed. Particularly when it was used with low hydrocarbon gas at high pressure after the turn of the century, the gas mantle provided a much improved quality of light at a far higher efficiency than ever before.[6] The mantles, though fragile, lasted a few hundred hours and cost only about ten cents each. Efficiencies were from 60 to 70 candlepower per cubic foot of gas per hour. They had been only 4 to 6 candlepower with the very early gas and gas burners.

After the introduction of the mantle, gas lighting competed more keenly with electric lighting and for a time threatened the existence of its newer rivals. However, after about 1909 the proponents of gas lighting could make no further major improvements.[7] With the development of ductile tungsten filaments and improved arc lamps, and with the reduction in electrical rates, the cost advantage of gas lighting was gradually overcome. The other advantages of the electric-light sources pushed them ahead of gas in all-round desirability, and gas was eventually displaced. The decline of gas lighting was more rapid in the United States than in England and continental Europe, for in this country there

6 An important difference between gas and incandescent lighting should be pointed out. In gas burners the quality of the light depends primarily upon the quality of the gas; the burner controls the quantity of light. In electric lighting both the quality and the quantity of light depend mainly on the burner; the central station simply maintains a constant voltage in its lines.

7 Among the major improvements in gas lighting between 1897 and 1909 were the use of artificial silk in mantles, the introduction of inverted burners and the broader use of high gas pressures.

was a greater willingness to change, to take advantage of new inventions and to commercialize and spread them. While gas lighting is still used in a few places, it has been reduced to a vestige of its former importance.[8]

Despite the declining importance of gas in lighting, the manufactured-gas industry as a whole has grown continually. The competition of the carbon lamp and the old open arc during the 1880's had encouraged the gas industry to spread its field to heating, and it was that use which permitted the industry to continue expanding when its lighting market was destroyed. Cooking, space heating, water heating, and later refrigeration resulted in a steady growth in the value of products of the industry from $56,987,290 in 1889 to $512,652,595 in 1929.[9] Over 90 per cent of that value consisted of gas; the rest was the value of various by-products. The actual volume of gas produced for sale during those forty years increased from 36,519,512,000 cubic feet to 408,401,395,000 cubic feet. The rate of physical increase was only slightly greater than that of the dollar value because prices declined very little during that time.

THE FADING GLORY OF ARC LIGHTING

The competition of gas and glowing filaments also had a stimulating effect upon arc-lamp technology. The development of the enclosed arc has already been mentioned. Although it was lower in efficiency than the old open arc, it had a number of advantageous features which led to a rapid expansion of its use in the United States.[10] The opposition of lamp trimmers, who feared they would lose their jobs because of the longer life of enclosed-arc carbons, soon declined. The inertia of conservative central-station men also was gradually overcome. By 1899, 85

8 Other light sources, such as acetylene, alcohol, and paraffin lamps, were greatly improved around the turn of the century through the use of incandescent mantles. While useful in many specific lighting applications, they have never become major light sources.

9 Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures*, Washington, 1889–1929.

10 The enclosed arc made slower headway in Great Britain and the rest of Europe than in this country. The relatively lower European labor costs and higher costs of current, which at least partially accounted for the original development of the enclosed arc in the United States, slowed the introduction of the longer-lived but less efficient lamp.

per cent of the arc lamps made in the United States were of the enclosed type. Besides replacing open arcs, the new type displaced many gas and incandescent lamps in interior lighting.

The American arc-lamp industry entered a new phase during the last years of the nineteenth century. Upon the advent of the enclosed arc, many small producers went out of business within a very few years. The number of manufacturers declined from the peak of forty-eight in 1894 to about fifteen in 1902. At first the Electric Arc Light Company and the Jandus Electric Company benefited most greatly by the change. Within a few years, however, the Electric Arc Light Company was absorbed by the General Incandescent Arc Lamp Company,[11] which was controlled by the General Electric Company. General Electric, as the largest producer of arc lamps in the country, had been interested in the development of the enclosed arc, and soon after Marks' success had brought out its own design of enclosed lamp. During the dispute which subsequently arose over patent rights, the big company became convinced that the Marks patents were valid and bought them.[12] Besides General Electric, Jandus, Westinghouse, and Western Electric, the industry soon consisted of only a few small producers, most of whom remained in business for only a few years.

The arc lamp, even with the improved performance of its enclosing globe,[13] might soon have gone the way of the gas mantle upon the introduction of the metallic-filament lamps had it not been for the development, around the turn of the century, of the flaming arc and of the magnetite arc. In consequence, its use for street lighting, where its closest competitor had been the gas lamp, continued a few more decades before further improvements in incandescent lighting reduced its application even there.

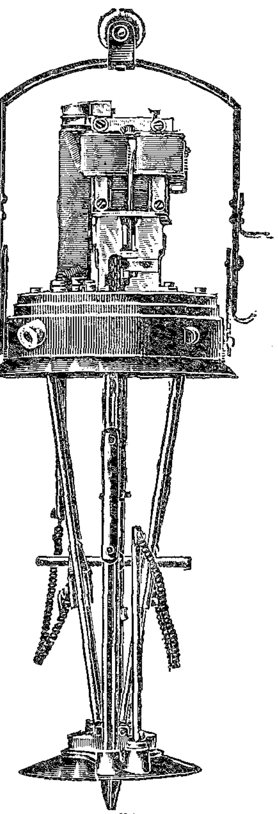
The flaming arc, first described in 1900 by Hugo Bremer of

11 The General Incandescent Arc Lamp Company had been founded by Sigmund Bergmann, Edison's former associate.

12 A similar clash over patents took place in England, where the Jandus Arc Lamp & Electric Company, Ltd., and the Electric Arc Light Company, Ltd., had been formed to exploit the American inventions. Litigation was avoided there by the purchase of the Marks patents by the Jandus company, which then licensed other producers under all the patents.

13 The efficiency of the enclosed arc was later raised somewhat by the use of a single outer airtight globe and the elimination of the inner globe.

Neheim, Germany, employed carbons treated with non-conducting salts which evaporated into the arc and produced streams of high luminosity. It had common ancestry with the Nernst lamp in the old Jablochkoff electric candle of 1876, in which the kaolin between the two conductors melted and gave off vapors, making the arc flame brighter. Other inventors before Bremer had attempted without success to introduce metallic salts into arc-lamp carbons for an economical flaming arc. In fact, the attempts to impregnate carbons for arc lamps paralleled the experiments on impregnating carbon filaments referred to earlier. One great difficulty was that scoria, or crust, formed on the ends of the electrodes and interfered with the arc and the distribution of light. Bremer conquered that problem by introducing into the electrode a flux of boron or fluorine which would keep the scoria from hardening and permit it to drip off the carbons. Bremer used various salts mixed with carbon to produce different-colored light, including calcium for yellow and magnesium for white.[14]



Birrenbach

FIG. 25. The Works of a Flaming-Arc Lamp

In operation the arc was covered by a glass globe, and the rest of the mechanism was encased in a metal shell.

The flaming arc, with its light output of 15.5 to 18 lumens per watt for white light and 30 to 35 lumens per watt for yellow

14 Further work by Bremer and others resulted in the use of pure carbons with the flame-producing materials in the cores only. The progress in the chemistry of the rare earths permitted a great deal of experimentation with salts of those metals and resulted in the commercial use of cerium fluoride and other related substances as well as calcium and magnesium compounds.

light,[15] was far more efficient than all previous arc lamps. Color quality was improved, and the arc was of lower intrinsic brilliancy. Instead of being placed one over the other, as in the previous arc lamps, the electrodes came together in a V at the bottom of the lamp and were fed by gravity in a new type of mechanism. An electromagnet pulled the arc down to produce a long broad flame with most of the light radiated downward where it was most useful. Most of the light came from the flaming materials in the arc, which were selective radiators, rather than from the electrode craters, as was true for the ordinary carbon arc.

Despite its many advantages, the flaming arc had weaknesses. Its light was less steady than that of the enclosed arc, it gave off noxious fumes, and its carbons were consumed in about ten hours.[16] In the United States, where labor costs for trimming were high, the short carbon life was a serious drawback. In Europe, where labor costs were low and electric current was expensive, it was not so important. This difference in economic environment was undoubtedly an important factor in directing European efforts into developing and rapidly commercializing the more efficient flame arc, just as it had been in the American precedence in developing and exploiting the long-lived enclosed arc. Germany, France, and Great Britain, all were ahead of the United States in commercializing the flame arc and in working to improve it.

The difficulty of short life was fairly well overcome in time by enclosing the arc, as had been done previously with the old-type carbon. That was not an easy matter, nevertheless, for the fumes tended to condense on the inside of the glass globe and obscure the light. The problem was solved with a chamber above the arc, where the vapors were collected and condensed to prevent their settling on the glass. Efficiencies in enclosed flaming arcs were fairly close to those of the open type, and electrodes lasted around 100 hours. The unsteadiness of the flame arc was also largely overcome.

Just as the incandescent mantle had given a new impetus to gas lighting, the flame arc stimulated all arc lighting. Its very high efficiency and improved quality of light pushed the arc in front

15 Schroeder, *op cit.*, p. 67.

16 The open-flame arc could be used only out of doors because of the fumes.

of gas again. The flame arc had the same effect on arc-lamp designers as the Nernst lamp had had on incandescent-lamp designers. A great flood of patents was issued during the next dozen years on a wide variety of proposed new arc lamps. Designers in the United States, Germany, France, and England were the most active.

The most important of the further improvements in arc lighting was the magnetite or luminous arc lamp developed principally by Dr. Charles P. Steinmetz of the General Electric Company, with help from Dr. Willis R. Whitney, C. A. B. Halvorson, Jr., and others. The magnetite arc, developed in 1902 and placed on the American market in 1903, was General Electric's principal contribution to technological advancement in arc lighting.

The magnetite arc was based on slightly different principles from the flaming arc. The Steinmetz lamp used an upper positive electrode of a non-consuming copper block encased in an iron shell. The lower negative electrode consisted principally of the oxide of iron called magnetite, packed in an iron tube. The magnetite provided the luminous material for the inch-long arc.[17] Titanium oxide was added to the magnetite to increase light output, and chromium oxide was added to increase life. In this lamp also a chimney was required to carry off and condense the fumes, and a new type of feeding system was necessary. The light given off was of a good white color, and the lamp was reliable and operated with low cost. The magnetite electrodes were eventually made in two types, those with very long life at efficiencies of 11 to 18 lumens per watt and those with shorter lives of around 150 hours at efficiencies of 17 to 25 lumens per watt.

The flame arc and the magnetite arc were the last fundamental advances of broad commercial importance in arc-lighting technique.[18] They assisted in driving out gas lighting, and for a time

17 The lamp operated only on direct current and required a mercury-arc rectifier for use on an alternating-current circuit.

18 Many other less successful proposals for new arc lamps were made between 1897 and 1912. Electrodes of platinum, aluminum, thorium oxide and other rare earth oxides, molybdenum, tungsten, chromium, titanium, and many other materials were tried. A mixture of titanium and titanium carbide gave encouraging results because of its superior light emissivity; but high costs and other difficulties prevented the titanium arc from achieving important commercial success. The more recent experiments with tungsten arcs, some of which have been contained in evacuated glass bulbs, have also not had any broad commercial significance, al-

they even held their own against improved incandescent lighting. Eventually, however, the greater convenience and over-all economy of the filament lamp won for it dominance even in most outdoor lighting. Arc lighting slowly declined after about 1910, and relatively little is still in use at the present time for space lighting.[19]

3. The Beginning of Electric-Discharge Lighting

The commercial introduction of the drawn-tungsten filament in 1911 and the development of successful gas-filled lamps a few years later permitted the incandescent lamp to become the standard source of artificial illumination throughout the industrialized world; yet even before it had gained ascendancy over gas and arc lighting a new competitor was coming into being in the form of the electric-discharge tube. The growing dissatisfaction with the carbon-filament lamp from about 1885 to 1900 served to turn men's attention to alternative light sources, as well as to alternative filament materials. Attempts were made to put to commercial use the increasing scientific knowledge of the effects of electric discharges through gases and vapors. Within a few years after the turn of the century, some strikingly novel types of electric illumination reached the market. Discharge tubes and vapor lamps of a great number of types have since come into extensive use and have replaced incandescent lamps in numerous special applications. Some of them are replacing it for general lighting.

THE SCIENTIFIC AND EXPERIMENTAL BACKGROUND IN 1897

The scientific principles underlying electric-discharge lighting went far back, even farther than the discovery of the voltaic cell. In 1683 Otto von Guericke of Magdeburg obtained light from

though a few have proved valuable in special applications. One of the most recent arcs produces a pinpoint of very high intensity light valuable in optical experiments, radio-photo transmission, photographic work, motion-picture projection, and similar uses. The arc is struck between a metallic plate and a tube of tantalum filled with zirconium oxide in a vacuum bulb.

19 The production of arc lamps in the United States fell from 158,187 units valued at $1,827,771 in 1899 to 123,985 units worth $1,706,959 in 1909. Output fell farther to $742,142 in 1914 and $606,771 in 1919. See Appendix E.

the discharge of a primitive static-electricity machine. Around 1700 Newton and Hawksbee found that if "exhausted" glass spheres were used in frictional electric machines the interiors of the globes would glow as charges were built up. The early scientists also knew that if electricity from such a machine was passed through a "vacuum" tube,[20] the same luminous effect was produced.

The first genuine progress beyond the simple observation of glowing gases was made in 1856 by Geissler, a German artist and glassblower, who originated the electric-discharge tube. He discovered that, when a high-voltage alternating current was passed through a sealed tube containing air at low pressure, the tube gave off light of very low luminosity for a few moments until the vacuum deteriorated. Further experiments by Geissler, Faraday, Crookes, and others indicated that all individual gases or vapors would carry a current, and some of them would give off a fairly strong light. Methods of creating alternating current of satisfactory character and of purifying gases and pumping out glass containers were crude; however, with certain gases the efficiencies of light emission realized were considerably higher than those of incandescent lamps. Nitrogen and carbon dioxide gave the best results. Mercury, sodium, sulphur, chlorides, bromides, and other vapors also produced light of various colors.

There were a number of attempts to apply electric discharges to illumination between 1860 and 1896. The first patents issued on the subject were granted in 1862 in Great Britain to Timothy Morris, Robert Weare, and Edward Monckton, who proposed to use colored light from Geissler tubes filled with various gases or vapors in signaling and in lighting buoys. In 1866 Adolphe Miroude also received a British patent on a battery-operated nitrogen-filled Geissler tube for buoy lighting. Scattered experiments were conducted by numerous individuals in European nations up to 1890 or so without any further real progress. Those made in 1879 by Crookes gave disappointing results because of the extremely low pressures employed in his tubes; he did not realize that there was a minimum desirable pressure.

20 The "exhausted" glass spheres and "vacuum" tubes of the early scientists contained atmospheric gas at low pressures. The equipment they worked with could not produce a high vacuum.

Enthusiasm for discharge lighting was increased around 1890. Thomas A. Edison experimented in the field and patented a Crookes vacuum tube containing calcium tungstate, which fluoresced when the discharge was passed. Other workers also considered the use of fluorescent substances in Geissler-type tubes. Roentgen's discovery of X rays in 1895 aroused even more interest in the various related fields of cathode rays, vacuum tubes, gaseous discharge, and fluorescence. Although no marked success was achieved with any single device proposed up to 1896, the Geissler tube gave great promise for the future. As an American electrical journal reported in 1893, "these tubes now are receiving the earnest attention of electrical experimenters with the fond and not chimerical hope that in the illumination of the tubes lies the desired secret of practical lighting by glowworm or phosphorescent light—light without heat."[21]

The operating principles of a discharge tube are quite different from those of incandescent and arc lamps, and far more complicated. When the gas pressure inside a sealed tube is low, an electric current can be passed through the tube between electrodes placed at either end, even though gases are normally good electric insulators. The electric discharge fills the tube and gives off light. Fairly high voltages are required, even with low gas pressures, and below some minimum pressure the voltage required rises again. Voltage applied at the electrodes accelerates the flow of free electrons, which bombard the atoms of the gas and displace electrons from their normal atomic positions. As the displaced electrons fall back to their normal positions, energy is radiated. The radiation may be visible, infrared, or ultraviolet light, depending on the nature of the gas and the degree of electronic displacement. Once the initial arc has been struck, a lower voltage is sufficient to maintain the discharge. Since the resistance tends to decrease as excitation increases, it is necessary to have a ballast in the circuit to prevent the current flow from rising too high and melting a fuse or destroying the tube. Ballasts are required with all electric-discharge devices, just as with arc lamps and the Nernst lamp.[22]

Most of the voltage across the lamp is employed in overcoming the resistance of the gas between the electrodes. A portion of the potential is required to extract electrons from the cathode, however, and a very small quantity is needed to overcome the surface resistance of the anode to the receiving of electrons. The resistance of the gas depends upon its type and pressure, the amount of electric current flowing, and the diameter of the tube. The larger the diameter, the less the resistance. For best results in illumination, both low resistance and high luminosity of a gas are required.

21 *Electricity*, Vol. IV, p. 142 (Mar. 29, 1893).

22 The usual ballast is a coil of wire wound on a soft iron core.

The greatest difficulty with electric-discharge tubes up to 1896 was their very short life, which made commercial utilization impracticable regardless of efficiency. The only useful applications of Geissler tubes for many years were in spectral analysis, in scientific lectures, and in obtaining special theatrical effects. Short life was caused largely by the tendency of the gases and vapors to combine chemically with the electrodes. As the gas combined, the pressure within the tube gradually dropped until the discharge could no longer be carried. Even if the gas and the electrode did not combine chemically, the gas pressure tended to decrease as positive ions bombarded the cathodes.[23]

THE MOORE TUBE

The first practical commercial application of the Geissler tube was made around the turn of the century by D. McFarlan Moore, a former Edison employee, who had become interested in electric-discharge tubes in 1891. Moore thought that the incandescent lamp was "too small, too hot and too red." He wanted a lamp that would give a cool, efficient, balanced white light like daylight, not a hot, inefficient light too strong in the reds and too weak in the blues, such as that produced by the carbon-filament lamp and by even the best later tungsten-filament lamps.

In 1894 Moore left General Electric, obtained outside financial backing, and organized the Moore Electric Company and the Moore Light Company to develop and commercialize his ideas. Demonstrations of the Moore tube were made in 1895. The inventor at first used tubes seven to nine feet long and two or two and one-half inches in diameter, which operated on 110-volt

23 Disintegration of the cathode as a result of ion bombardment is called "sputtering."

direct current. The quality of the light was good, and efficiencies seemed to be fairly high, yet Moore was plagued by the same short life that had handicapped his predecessors. Work was continued for several years before commercial success was achieved.

The essence of Moore's eventual triumph was his ability to overcome the problem of short tube life. He devised an automatic valve which permitted gas to flow into the tube when the pressure became too low. As the gas pressure inside the tube dropped below the standard of one-thousandth of an atmosphere, the current flow was increased. This strengthened the field of an electromagnet, which lifted some iron wires mounted in a glass tube floating in mercury. As the iron rose, the mercury level was lowered, exposing a piece of carbon through which the desired gas could seep until the correct pressure and current flow were restored.

The gases which Moore used in his early tubes were nitrogen, which gives a soft golden yellow light, and carbon dioxide, which produces a very white light much like daylight. In his first commercial installation, however, which was made in a Newark, New Jersey, hardware store in 1904 following earlier trial installations, Moore used tubes containing air. Air is a mixture of about 78 per cent nitrogen, 21 per cent oxygen, and 1 per cent argon, neon, and other inert gases. The tube pressure was about one-thousandth that of the atmosphere. Later installations used air from which the oxygen had been removed by passing it over phosphorus. Since nitrogen and carbon dioxide have high resistances, Moore had to use glass tubes of large diameter (one and three-quarters inches) and a high potential of about 16,000 volts to maintain the discharge through the continuous tube one hundred eighty feet long. Alternating current was employed, and a step-up transformer had to be used to convert the circuit voltage to the desired potential, despite the wattage loss which necessarily accompanied it. Since the wattage loss was fixed for both the transformer and the carbon electrodes which Moore employed, long continuous tubes were more efficient than short ones.

The Moore tube had very good prospects when it was first put on the market, for its efficiency exceeded that of the best incandescent lamp then available. Nitrogen installations with long

tubes gave efficiencies of about 10 lumens per watt; and about half that efficiency was obtainable with carbon dioxide. Despite the fact that the tube was expensive to install, complicated, and required very high voltages, its operating advantages were great enough for it to find restricted use in stores, offices, and similar general lighting uses as well as in photography and some advertising and decorative applications.

The potential threat of Moore's lamp to the established business and heavy investment of General Electric in incandescent lighting provided an extra inducement for the big company to hasten its efforts to improve the filament material. As Hammond[24] says, "Although Coffin and Rice negotiated for Moore's patent rights, they also implored Whitney to add an able man to his staff to study the elements which had promise of yielding better filaments." This resulted in the addition of Dr. William D. Coolidge to the staff of the General Electric Research Laboratory in 1905 and the subsequent developments which have already been discussed. With the development and introduction of tungsten-filament lamps, the efficiencies of Moore's long tubes were no longer great enough to overcome their disadvantages. They gradually disappeared from the market, leaving only short carbon-dioxide tubes in use for color matching, in which they excelled because of their daylight color. The General Electric Company absorbed the two Moore companies and Moore's patents in 1912. Moore himself rejoined General Electric's laboratory force.

Moore's own tubes, although not surviving in any important way, formed the basis for the development of neon tubing and had a considerable value in the much later development of fluorescent lighting as well as in other applications of electric-discharge tubes. In his work Moore was unfortunately limited by the fact that only the common atmospheric and chemical gases were available to him. Argon, helium, neon, krypton, and xenon, the inert gases found in small quantities in the atmosphere, were not discovered until late in the nineteenth century. Helium was found in the mineral cleveite in 1894 by the English scientist, Sir William Ramsay, and Ramsay and Lord Rayleigh succeeded in isolating all five of the inert gases from the air—argon in 1893, and neon,

[24] *Op. cit.*, p. 332.

helium, krypton, and xenon in 1898. The expense of extracting these gases from the air was so great that they could not be used commercially until 1907, however. In that year the French inventor Georges Claude perfected a method which had been developed independently over a period of years by both himself and Carl von Linde, a German, for liquefying air and separating its various ingredients.

With the rare gases at his disposal, Claude took up Moore's developments where the latter had left off. By filling a Moore nitrogen or carbon-dioxide tube with neon, he converted it from a complicated general light source which was finding it difficult to compete with improved incandescent sources into a glowing red tube of high luminosity which was readily adaptable to use in advertising. Despite its high resistance, neon's color and great efficiency of light production found ready acceptance in sign and other advertising lighting. Claude also experimented with the other rare gases, with mixtures of these gases and other gases and vapors, and with their use in colored glass tubes. He was able to produce light of many different colors at practical efficiencies. Within a short time industrial interests bearing his name began operating in France, and gradually the new development spread to other countries. The commercial and subsequent technical developments of the Claude tube will be treated in Chapter XIV.

THE COOPER-HEWITT AND OTHER MERCURY-VAPOR LAMPS

Another new electric-light source closely related to the Moore-Claude gaseous discharge tube, but somewhat different from it, was the mercury-vapor lamp invented in 1901 by Peter Cooper Hewitt, a young independent American inventor. This device, like the Moore tube, had a long previous history of experimentation.

The mercury arc had had its beginning in the work of the Englishman J. T. Way, who in 1856 and 1857 patented an arc lamp using a stream of mercury instead of the usual carbon electrodes. Arcs were formed between the drops of mercury, and a strong greenish light was obtained. Mercury vapor was used for the first time in 1879 by Rapieff, who filled the columns of an inverted U-shaped glass tube with liquid mercury, some of which was

vaporized by the passage of an electric current. Experiments with mercury in U-shaped tubes were later conducted by many other inventors. The Arons mercury-arc lamp of 1892 was the most promising of all up to 1900, yet it was limited in practicability to special polarimetric and other optical experiments. Building his work upon this prior art, Hewitt was the first to achieve notable success.

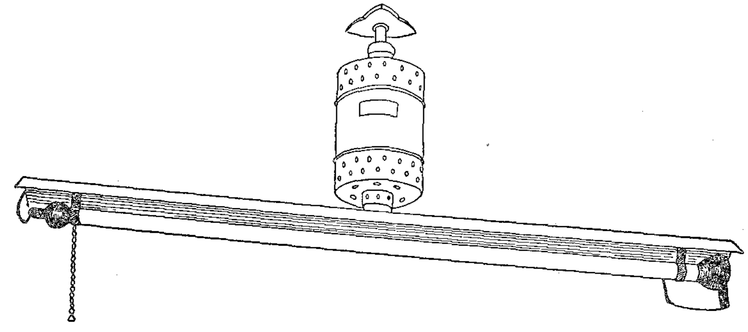


FIG. 26. Cooper-Hewitt Mercury-Vapor Arc Lamp, 1901
The larger bulb contained a pool of mercury. When the lamp was tilted a continuous stream of mercury bridged the electrodes; interruption of the stream broke the circuit and started an arc discharge.

The successful Cooper-Hewitt lamp consisted of a tightly sealed glass tube about four feet long and one inch in diameter from which all possible air had been exhausted. The tube was inclined at a fifteen-degree angle, and both ends were slightly enlarged. The lower end contained a pool of mercury. The mercury acted as the negative electrode, or cathode, while at the upper end an iron electrode similar to the one used by Arons served as the anode. When the electrodes were connected to a proper electrical circuit containing the necessary auxiliary equipment, the tube could be operated to produce a strong greenish blue light. To start the lamp it was tilted so that a stream of mercury bridged the two electrodes. The current flowing through this stream heated it and vaporized some of the mercury. When the stream was broken, the current was strong enough to leap the small gap and strike an arc. The small arc heated and ionized the vapor sufficiently for the arc to extend the length of the tube and to operate continuously.[25] Ionization of the vapor and the flow of electrons and positive ions in the tube produced light in the same way as in the Geissler-type tube developed by Moore.

While Moore's gases were already in the correct physical state, Hewitt's mercury required vaporization before ionization was possible. It was for that reason that the starting problem was different. Those Moore or Claude tubes which did employ mercury used it in combination with some gas. The gas started the discharge; that heated the mercury, which vaporized and entered into or completely took over the discharge. Some time after its introduction, the Cooper-Hewitt lamp was improved so that it did not have to be tilted by hand for starting.[26] Electromagnetic tilting devices, heating coils, or electric sparks were introduced to vaporize the mercury and start the arc, or a gas was added to start the arc and carry the discharge until the mercury vaporized sufficiently for it to take over the flow of current.

Like all other discharge lamps and tubes, the Cooper-Hewitt lamp required a ballast to maintain a constant current flow. On a 110-volt circuit the lamp took 385 watts and operated with an efficiency of 12.5 lumens per watt or more. Despite that efficiency, the color quality of the light was poor. It was strong in blue and green and almost wholly lacking in red. The Cooper-Hewitt lamp lasted for about 2,000 hours, and it found its greatest use in photography, drafting, and certain other industrial applications. The Cooper-Hewitt lamp did not require a high voltage, nor was the voltage drop at the electrodes great enough to make longer lengths of tubing desirable. For those reasons the lamp was a standardized unit, easily installed and replaced, and not a cumbersome specially designed and specially fitted piece of continuous tubing, such as the Moore tube. Besides the size mentioned above, lamps were made which ranged from one-eighth inch by three inches to three inches by twelve feet.

The color disadvantage of the Cooper-Hewitt lamp was partially overcome in several ways. Some lamps were used in combination with incandescent lamps, which gave off light of excessive redness to balance the unnatural blueness of the mercury discharge. A second technique was the addition of other gases or vapors in the tube to supply the missing red rays. A final method was the employment of fluorescent reflectors to supply red light.

25 The greater diameters of Hewitt's tubes permitted the use of lower voltages and made unnecessary the water-cooling devices employed by some of his predecessors.

26 The precommercial Cooper-Hewitt lamps had been started without tilting by a very high initial voltage built up in an inductance coil. In those first lamps the electrodes were placed vertically one over the other.

George Westinghouse financed the early experiments of Hewitt, and in 1902 the Cooper-Hewitt Electric Company was organized with the inventor and his backer as the principal stockholders. Hewitt applied for a number of patents to protect his inventions, covering the lamp itself and its various auxiliaries. Among the latter was the mercury-arc rectifier which he had developed for converting alternating to direct current. A similar rectifier had been invented by Dr. Ezechiel Weintraub of General Electric for use with another type of mercury-arc lamp made by Dr. Charles P. Steinmetz. The two patent applications covering mercury-vapor rectifiers went into interference in the Patent Office. Other patent conflicts arose over the vapor lamps themselves.

The patent controversies between General Electric and the Cooper-Hewitt Company continued until 1913, when licenses were exchanged covering rectifiers and mercury-vapor lamps. Westinghouse was also licensed under the Cooper-Hewitt patents. In 1919, after the death of George Westinghouse, General Electric bought out the Cooper-Hewitt Electric Company, which it operated as a subsidiary. The name was changed to the General Electric Vapor Lamp Company, and some twenty years later it was merged with the parent company's lamp department.

After the Cooper-Hewitt lamp had appeared and while it was being perfected, a number of other experimenters sought to improve the mercury-arc lamp. The modification proposed in England by Bastian and Salisbury in 1904 was one of the most outstanding of the new proposals. It returned to the inverted U-shaped tube employed by Arons and other early workers and contained an automatic tilting device for starting. The lamp was more compact than Hewitt's, and when used with an incandescent lamp to provide red rays its color quality was superior, although its efficiency was less. It was produced in England by Bastian Mercury Vapour Lamp, Ltd.

Another proposal, which was of particular importance to technological development in later years, was the high-pressure quartz lamp first made by Küch in 1906. Küch was an engineer for a German platinum firm and did some work on fused quartz. He reasoned that if quartz were used to contain the mercury arc instead of glass, the higher temperatures and pressures which it could withstand might permit the efficiency of light output to be increased. This was found to be true. In mercury-vapor lamps luminous efficiency increases with temperature up to a certain point and then falls. As temperature is further increased above the melting point of glass, however, efficiency rises again.

The Küch lamp consisted of a small, horizontal, transparent quartz tube from three to six inches long which contained a mercury electrode at either end. The vaporized mercury rose to atmospheric pressure during operation of the lamp. Fan-shaped copper coolers were employed for radiation of heat, and the lamp required the usual auxiliaries for starting and voltage regulation. At the relatively high pressure employed, the mercury discharge did not fill the tube but was constricted into a narrow arc. In other respects its operation was similar to that of the Cooper-Hewitt and other lamps of the same general type. The efficiency of the lamp was as high as 26 lumens per watt,[27] which was far above that obtainable with most other light sources, and life was around 1,000 hours. Although the light was whiter than that of the Cooper-Hewitt lamp, a deficiency of red and a predominance of blue and violet resulted in a color quality which was still unsatisfactory for general illumination.

A great deal of ultraviolet radiation was produced by the high-pressure quartz mercury lamp. Although ultraviolet light is useful for bacteriological and sterilizing purposes and is beneficial to humans in small quantities, continued exposure to it may produce severe burns. To make the Küch lamp safe for use as an illuminant, it was necessary to enclose it in an additional glass globe, through which the ultraviolet light could not pass.

The quartz lamp was manufactured in Germany by A.E.G. and supplied through its subsidiaries. General Electric acquired the American patent rights. The lamp did not become important as an illuminant in the United States at that time, although a few were made in this country for special purposes beginning around

[27] Schroeder, *op cit.*, p. 89.

1910.[28] The high-pressure mercury lamp was the forerunner of a number of later devices used for illumination, sterilization, and other purposes.

4. Summary of Electric Lighting from 1897 to 1912

Between 1897 and 1912 the General Electric Company maintained and strengthened its leadership, until in 1912 it conducted about 80 per cent of the American lamp business in its own name and licensed most of the remainder under its patents. In that period, a time of tremendously rapid growth in the industry, without the benefit of a basic patent except in the last few years, and in spite of an antitrust prosecution in which it was forced to accept a consent decree, General Electric almost doubled its share of the domestic lamp industry, acquired important properties for the production of essential lamp parts, and gained control of most important lighting patents in the United States.

The increase in General Electric's share of the lamp business resulted primarily from the acquisition of competing companies. Together with a number of small concerns, General Electric in 1896 formed the Incandescent Lamp Manufacturers Association and made a series of agreements that included its principal competitor, the Westinghouse Electric & Manufacturing Company, to maintain established prices and to divide the market. When the association proved to be insufficient protection for the small producers in the industry, most of them banded together under a holding company, the National Electric Lamp Company. General Electric acquired a controlling interest in National and took it over completely in 1911 in carrying out the terms of a consent decree entered in a federal antitrust prosecution. This decree also ordered a discontinuation of resale price maintenance and made other stipulations designed to end the domination of the industry by General Electric. Although certain prior practices of the industry were outlawed, the big company was able to continue its supremacy much as before.

Consolidation also took place in the leading European lamp-

[28] Litigation between General Electric and the Cooper-Hewitt Electric Company in 1918 resulted in a partial invalidation and a partial upholding of the Küch patents, which were not included in the 1913 license agreement.

producing nations. There was a difference abroad, however, in that no one company in any nation secured all the most important domestic patent rights covering electric lighting, and consequently no one company could dominate the industry. Control was exercised through the formation of patent pools, chiefly in Germany and England, which were the most important European lamp producers. Competition was keener, at least until the formation of the pools, and prices were lower than in the United States. The competition and pressure on costs also had a deleterious effect upon lamp quality.

During the fifteen years, the manufacture of lamps emerged as a mass-production industry. Production expanded tremendously in number and in value, and the number of varieties of lamps for special applications grew rapidly. Methods of production and lamp design were considerably improved, and costs fell. New filament materials of greater efficiency, principally tungsten, were developed and introduced; and they made secure the future of incandescent electric lighting. Gas lighting was unable to advance beyond the high-pressure Welsbach mantle and began to fade in relative importance. Arc lighting kept up for a time with the aid of the flaming arc and the magnetite arc, but it too began to be displaced more and more rapidly by the simpler and improved incandescent lamp. The new electric-discharge light sources which made their appearance by 1912 were not yet able to compete successfully for the general lighting market.[29]

The sources of the technological advances in lighting from 1897 to 1912 represent one of the most interesting and significant phases of the industry's development. Until around the turn of the century, most of the leading electric-lamp producers, in the United States and abroad, made no genuine effort to achieve fundamental improvements in incandescent lamps or to develop entirely new and superior light sources. The big companies, particularly in this country, were lulled into a feeling of security by the continuing supremacy of carbon filaments and the carbon arc and by their own financial supremacy. In the United States

29 Despite their inability to equal incandescent sources at the time, electric-discharge devices were considered by many contemporary observers to be the lighting of the future. It was concluded that in tungsten the glowing filament had about reached its limit, and that further efficiency increases were to be found in gas and vapor tubes.

the lack of competition within the industry retarded new product development. In Europe market competition was keener; yet even there the big companies were not responsible for the first important innovations.

The stimulation of activity in the lamp industry came from at least three different outside sources. Competition from the enclosed arc lamp and the Welsbach mantle was of primary importance. The increased fund of scientific knowledge opened up new experimental channels which hitherto had been closed; of particular importance were the chemical and metallurgical advances resulting from the use of the newly developed electric furnace and from increased knowledge of the rare earths after commercialization of the Welsbach mantle. "Cut and try" invention was largely outmoded; it had become necessary to have a strong background in science; and scientific knowledge was an essential raw material for lighting progress. Finally, private inventors and inventors in companies outside the lamp industry were quicker to see and grasp the technological opportunities than the established companies. Their vigor was a prime factor in stirring the big companies to action.

In the United States, General Electric began to make serious efforts to improve electric-light sources with the establishment of the General Electric Research Laboratory in 1900. It is greatly to the credit of General Electric that, despite its relatively slow start in lamp improvement, it moved rapidly and made two of the six most important filament developments during that period, the GEM filament and the ductile tungsten filament. The other four came from Germany and Austria. The Nernst lamp was made by a university professor, the osmium filament by the inventor of the gas mantle, the tantalum filament by Siemens & Halske and the non-ductile tungsten filament by two Austrian schoolteachers, the Welsbach Company, and others. No British or French inventors were of importance in that connection, and the large A.E.G. shared importantly in the activity only by taking over the engineering development of the Nernst lamp.

Fundamental progress in arc lighting and electric-discharge lighting was also effected primarily by persons not employed by lamp manufacturers. The only outstanding device produced by a lamp maker was the magnetite arc lamp of General Electric. The flaming arc, the Moore tube, the Cooper-Hewitt lamp, and the Küch lamp, all were developed by independent inventors or engineers associated with companies outside the lighting industry. With its tremendous financial resources and aggressive leadership, the General Electric Company was able to buy up the American rights to most of the advancements in the field of electric lighting which it did not make itself and to promote them vigorously, whether such advancements originated at home or abroad.

Differing scientific and economic environments were at least partially responsible for the different directions and speeds of technological advance in lighting in the various nations. Although this country lacked a rich scientific background, it was very receptive to new ideas. The extensive growth of the nation and its rapid industrialization led to tremendous expansion of output and mechanization. The relative scarcity of labor encouraged the improvement of production methods, in which General Electric and its associates surpassed their European competitors. The same factors stimulated improvements in electrical generation and distribution and resulted in lower energy costs in the United States than abroad. Low labor costs and high energy costs provided somewhat different stimulants abroad. The effect of this condition is particularly notable in the advance of arc lighting.

The European nations, particularly Germany, France, and England, had far richer scientific backgrounds than the United States. It was only in Germany that this underlying knowledge was turned to advantage in developing new light sources, however. The German industry and individual German inventors were vigorous; they also had an economic environment that stimulated them to progress. The French and English lamp industries were less alert to their opportunities, as were individual inventors in those nations. Their scientific advances were put to greater use abroad than at home. It appears that the keen market competition which reduced lamp prices and profit margins also weakened the ability of lamp producers to make important innovations, as well as the incentives of persons outside the industry to develop new light sources. The American monopoly, although not conducive to startling innovations without outside stimulation, worked more rapidly and more fruitfully once the proper incentives had been given.

PART IV

THE MATURE LAMP INDUSTRY

Chapter IX: MONOPOLISTIC CONTROL IN THE AMERICAN INCANDESCENT-LAMP INDUSTRY: 1912–1926

THE General Electric Company remained supreme in the American incandescent-lighting industry throughout the entire period from 1912 to 1947, despite continued challenges from several directions. The industry leader strengthened its patent position and established a more rigid licensing system. Although the controlling patents expired around 1930, the license structure continued in force until 1945. The end of licensing and the outcome of a federal antitrust prosecution now threaten the degree, although not the fact, of continued General Electric leadership in incandescent lighting.

The commercial superiority of General Electric and its former collaborator, Westinghouse, depended in large part upon their patent position and their technical superiority in incandescent-lamp design and production; in addition, it depended upon aggressive competitive tactics and the strict organization of the industry under General Electric control. As a result of the increase in demand for electric lighting and the much improved performance and reduced costs of incandescent lighting, manufacturers' sales of large incandescent lamps in the United States increased from about 85,000,000 units worth around $15,000,000 in 1912 to 830,300,000 units valued at $91,800,000 in 1947. Retail value was almost double the manufacturers' value. The sale of miniature lamps and other varieties also expanded enormously.

This and the following four chapters treat the extensive commercial and technological developments in incandescent lighting since 1912. The progress in electric-discharge lighting after 1912 will be discussed separately.

1. New General Electric and Westinghouse Licensing and Distribution System

The 1911 consent decree had partially disrupted established relationships in the incandescent-lamp industry, and General Electric took rapid steps to preserve the organization which it had built up. A new licensing system was set up in 1912, based primarily on the GEM and tungsten-filament patents. The GEM patent had been granted in 1909; the Just and Hanaman patent was issued on February 27, 1912; and the Coolidge application for the ductile tungsten filament had been made. Early in March, Westinghouse was granted a new A license to sell up to 15 per cent of the combined net sales of patented lamps made by the two companies [1] at a royalty of 2 per cent.[2] The royalty rate rose to 10 per cent on the value of all sales exceeding the quota. Westinghouse was also bound to follow the prices, terms, and conditions of sale established by General Electric, although it was granted permission to use General Electric's "Mazda" trademark. Further, Westinghouse was required to grant royalty-free licenses to General Electric under all its present and future incandescent-lamp patents for the duration of the license. General Electric did not grant a general license to Westinghouse under foreign lamp patents controlled by the licensor, although Westinghouse was licensed under the patents of certain countries. If Westinghouse had exported patented lamps to other countries, to which General Electric also could not export under its international agreements, it would have invited infringement actions under patents which Westinghouse had admitted in its A license were valid.

By 1912 it had become evident that the tungsten-filament lamp was far superior to all other incandescent lamps for general lighting and would eventually drive them off the market. Westinghouse realized that the patents held or applied for by General Electric would give it a legal monopoly of tungsten-filament lamp production if they were upheld in the courts. It was clearly to the advantage of Westinghouse to continue as a licensee in the lamp business, even under the rigorous terms of the new license agree-

[1] The Westinghouse quota represented 17.6 per cent of the sales of General Electric alone.

[2] The royalty rate was reduced to 1 per cent in 1919.

ment. When the licensee's share of the market was added to the 80 per cent controlled by General Electric as a result of its absorption of the former National Electric Lamp Company,[3] there remained only 6 or 7 per cent of the domestic market for other firms.

Despite the court order in the 1911 antitrust suit forbidding the establishment of resale prices, General Electric was unwilling to permit local market forces to govern the prices at which its products should sell.

> To meet this situation the officials of the Company worked out the present agency plan of selling lamps by which local dealers became agents under contract of General Electric. Stocks of lamps were not sold to them outright but taken on consignment, the company retaining ownership in the lamps while they were in the agents' hands, and relinquishing ownership only when the agent sold the lamps. Thus the sale by an agent to a consumer was a first sale rather than a resale, as formerly, and General Electric could therefore legally control the price of its product to the consumer.[4]

This plan, which covered only patented lamps and did not apply to those lamps sold directly to utility companies and other users, was put into operation by General Electric and Westinghouse in 1912. Initially it was intended to include all lamps, whether patented or unpatented; when such a plan was presented by Westinghouse to the United States Attorney General for approval, the latter stated that it was doubtful whether the plan was consistent with the consent decree, and that the companies would have to take full responsibility for whatever plan was employed. Accordingly, unpatented lamps were eliminated from the scheme, and other minor changes were made. When Westinghouse requested approval for the new plan, which it was induced to adopt by the terms of its patent license, the Attorney General declined to make a definite statement but expressed his confidence in the good faith of the two companies. He stated that

> if any question involving the right to sell through agents under the plan suggested should hereafter arise, I should regard it as the duty

[3] See pp. 156–159, for a discussion of the consent decree entered by General Electric in the antitrust prosecution of 1911, which led to that consolidation.

[4] Hammond, *op. cit.*, p. 343. Quoted by permission of The General Electric Company.

of the Department to test the matter civilly and upon the assumption that, if the arrangements were not in conformity with the decree, the variance was made in good faith, believing it to be authorized by the decree.[5]

Prior to the antitrust prosecution of 1911, General Electric had had patent-licensing and price agreements with five smaller companies as well as with Westinghouse and National. After the issue of the Just and Hanaman patent and the new agreement with Westinghouse, a license was granted to one of those small companies—the Franklin Electric Manufacturing Company. The license covered large tungsten-filament lamps only and fixed a quota of 2.7 per cent of the combined net sales of General Electric and the licensee. Within a few years the Franklin Company acquired three of the other concerns which had previously been licensed by General Electric, and the fourth went out of business. In 1918 Franklin was acquired in turn by Westinghouse, thereby increasing the sales quota of Westinghouse for patented lamps to 20.4 per cent of the net sales of General Electric.

2. *Upholding of the Just and Hanaman Patent and Expansion of Licensing*

Many other small companies were quick to bring the tungsten-filament lamp into production even without licenses, because it was much more efficient than the carbon-filament or any other previous incandescent lamp, and because the high prices set by General Electric held out the prospect of good profits. From 1912 to 1914 General Electric's share in the domestic large-lamp market dropped from 81.5 per cent to 64.2 per cent. Shortly after the Just and Hanaman patent was granted and assigned to General Electric, the industry leader moved to protect its position by taking action under it in the Southern New York District Court against the Laco-Philips Company, which at that time was believed by General Electric "to be the largest infringing seller of

[5] District Court of the U.S. for the District of New Jersey, *United States of America* v. *General Electric Company et al.*, Civil Action No. 1364, *Complaint*, Jan. 27, 1941, pp. 30–32, and *Answer of Defendant General Electric Company*, May 15, 1941, pp. 9–10.

incandescent lamps in this country." [6] The Laco-Philips Company was affiliated with the Dutch N. V. Philips' Gloeilampenfabrieken.[7] It sold lamps made in Holland and exported to this country.

General Electric was successful in its suit; the patent was sustained by the district court on February 15, 1916, and that decision was confirmed by the Second Circuit Court of Appeals on June 7, 1916.[8] The decision of Judge Mayer of the district court, with which the circuit court agreed, held that the patent covered a product, not merely a process, even though Just and Hanaman had not recognized all the alternative methods which could be employed for making tungsten filaments.[9] The court held that both squirted and drawn-wire filaments infringed the Just and Hanaman patent. Claims by the Laco-Philips Company of anticipation by Lodyguine and Welsbach were denied. That decision gave to General Electric, and such companies as it chose to license, the exclusive legal rights in the United States to the tungsten-filament lamp. Although the Just and Hanaman patent was challenged by a number of other independent concerns in later years, it was consistently upheld by the courts.[10]

By the year 1916, when the tungsten-filament patent was sustained, there were more than twenty concerns in this country making tungsten-filament lamps. Some of them had switched from carbon lamp production, and many others had recently entered the industry. General Electric decided to offer licenses under the Just and Hanaman patent to all firms which had been producing

[6] Statement of Albert K. Davis, vice president of General Electric Company in charge of patents, to Senate Committee on Patents, reported in *United States Daily*, Mar. 9, 1928, p. 2.

[7] N. V. Philips' Gloeilampenfabrieken was incorporated in 1912 in Holland as the successor to Philips & Company. It dominated the Dutch market for electric lamps and became very important in the international market.

[8] *General Electric Company* v. *Laco-Philips Company*, 233 Fed. 96 (1916), 147 C.C.A. 166 (1916).

[9] It will be recalled that the British Just and Hanaman patent was declared in 1915 not to cover a product.

[10] General Electric used the Just and Hanaman patent in successful infringement actions against the following individuals and companies, among others: F. A. Alexander in 1921, Save Electric Corporation and P. R. Mallory & Company, Inc., in 1923, the Minneapolis Electric Lamp Company in 1924, and the Desmond Incandescent Lamp Company, Atlas Specialty Company, Sunray Lamp Company, Inc., and Republic Electric Company, Inc., in 1928.

tungsten-filament lamps in 1915,[11] under a quota system "which permitted their business to grow in the same proportion as the incandescent lamp business of the General Company grew." [12] Patent licenses were not offered to those producers who had initiated operations after the patent had been adjudicated. Infringement proceedings and injunctions were brought against them, and a number of companies were forced to close down. The assets of some of them were purchased by General Electric. Four importers of infringing lamps, including Laco-Philips, were licensed temporarily to dispose of their stocks. After all lamps on hand had been sold, no further importation was permitted.

The difference between the policy of General Electric in 1916 over the Just and Hanaman patent and its policy in 1892 over the Edison patent is notable. In the earlier instance, General Electric had tried through the courts to force all its competitors out of the lamp business. The attempt had been only partially successful, and its apparent ruthlessness had injured the company's public relations. The attitude of General Electric in 1916 was considerably softened. Undoubtedly, the fact that it had been under antitrust attack was a contributory factor; the evolution of business ethics may also have had an influence.

The new licenses that were granted to the smaller companies differed somewhat from the one granted to Westinghouse and were called B licenses. They permitted each firm upon payment of a 3 per cent royalty to make and sell a specified small quota of incandescent lamps, based on the ratio between the 1915 sales of tungsten-filament lamps by the company and by General Electric. Whereas Westinghouse could make both large and miniature lamps, almost all the lesser companies were licensed only for one or the other,[13] and they were not licensed for export at all. As was true for Westinghouse, the smaller licensees agreed to extend royalty-free licenses to General Electric under all patents or rights relevant to electric lamps owned or controlled by the licensee dur-

[11] The only exception to that policy was the Independent Lamp & Wire Company, with which General Electric was then in litigation over the Coolidge patent.

[12] *United States Daily*, Mar. 9, 1928, p. 2.

[13] Two small manufacturers, the United States Incandescent Lamp Company and H. J. Jaeger Company, were licensed in 1916 and 1918, respectively, to make both large and miniature lamps. They soon withdrew from the industry.

ing the term of the principal license. Such licenses were to continue for the full life of each patent, however. The licensees were permitted to establish their own prices, terms, and conditions of sale, but they were not allowed to use the "Mazda" trademark.

Of the eight companies licensed by General Electric in 1916, not one was still in production in 1947 under the same name and ownership. One, the Kentucky Electric Lamp Company, was later acquired, and its quota was taken over by the Ken-Rad Tube & Lamp Company, which continued in the lamp business until 1945, when it was absorbed by Westinghouse.[14] All the others have completely discontinued operations. Of the thirteen additional concerns licensed in 1917, only the Hygrade Lamp Corporation still survives. It has expanded steadily with various changes in name and is now known as Sylvania Electric Products Inc.[15] Licenses were granted by General Electric to two more companies in 1918, two in 1919, two in 1920, two in 1921, one in 1922, and two in 1925. Only three of those eleven companies are still producing lamps. The Consolidated Electric Lamp Company makes large lamps, while the Chicago Miniature Lamp Company and Tung-Sol Lamp Works make miniature lamps. No new companies have been licensed for the production of incandescent lamps since 1925.

[14] The Ken-Rad Tube & Lamp Company was incorporated in 1929 to acquire the stock of and merge the Kentucky Electric Lamp Company and the Ken-Rad Corporation. Both of these companies were dissolved in 1936, and their assets were transferred to the Ken-Rad Tube & Lamp Company. In December of 1944 General Electric acquired all the assets of Ken-Rad which were used in the manufacture and sale of radio tubes, while Westinghouse some months later acquired the company's lamp business, which has since been conducted as a wholly owned subsidiary.

[15] The Hygrade Lamp Corporation was incorporated in 1917 to succeed a lamp business established in 1901. During its early years the business had specialized in the renewal of burned-out carbon lamps and the production of unpatented carbon lamps. When the tungsten filament was developed, the firm added this type of lamp to its line. Between 1917 and 1930, Hygrade acquired several other lamp firms: the F. V. Rooney Lamp Company and the Dexter Lamp Company in 1917; the Alpha Lamp Company in 1918; the Lux Manufacturing Company, a General Electric Company licensee, in 1922; the Triumph Lamp Company, another licensee, in 1927; and the Vosburgh Miniature Lamp Company, a third licensee, in 1928. Other companies were acquired later. In 1931 Hygrade merged with the Novelty Incandescent Lamp Company (Nilco), another licensee, and Sylvania Products Company to form the Hygrade Sylvania Corporation. The name was changed to Sylvania Electric Products Inc., on Aug. 12, 1942.

The number of licensed firms producing incandescent lamps declined rapidly after 1917. By 1921 only thirteen licensees were still in production, and but eleven of the original thirty-two survived until 1927. Owing to the tiny quotas to which they were restricted and to their limited experience and ability in the lamp business, many of the small licensees were unable to compete effectively. A large number of concerns sold their license rights or failed. Since the quota arrangement led to an equal rate of growth for all firms in the General Electric group, in order to expand more rapidly than the group it was necessary for a licensee to purchase the quota rights of another licensee. An outstanding example of licensee expansion is the former Hygrade Lamp Corporation, a brief history of which has been sketched in footnote 15. The Tung-Sol Lamp Works also grew rapidly by acquiring the rights of other licensees. The smallness of the quotas granted is indicated by the number of licensees, which has been given above, and by the following figures cited by the United States Tariff Commission for the distribution of total domestic lamp production during the period 1921 to 1923:[16]

	Percentage		
	1921	*1922*	*1923*
General Electric	69	62	61
Westinghouse	16	15	16
All other licensees	8	10	9
Unlicensed manufacturers, including imports	7	13	14

These figures also indicate that, although General Electric still controlled a very large portion of the domestic market for incandescent lamps, the number and size of domestic unlicensed concerns increased after 1921 at the expense of the industry leader. From 1914 to 1921 General Electric had maintained its share of the large-lamp market at about 66 per cent of total sales.[17]

16 *Incandescent Electric Lamps*, p. 34. (Original source, transcript of records, *United States* v. *General Electric Co. et al.*, U.S. Supreme Court, Oct. term, 1926, No. 113, p. 33.)

17 In the manufacture of miniature lamps, General Electric's position fell from 90 per cent in 1912 to 52 per cent in 1914. After the Just and Hanaman litigation and initiation of the licensing system, its share rose to 64 per cent and remained there until 1922, when it fell to 50 per cent. (*United States of America* v. *General Electric Company et al.*, Civil Action No. 1364, Ex. GE-238.)

Continued high profits in lamp making drew a new group of unlicensed firms into the industry. A few of the unlicensed companies were producing carbon-filament lamps, for which there was still a small market; General Electric and Westinghouse no longer produced such lamps. Most of the unlicensed producers, however, were recently formed companies engaged in the production of tungsten-filament lamps and were infringing the basic Just and Hanaman patent.

3. *General Electric Patent Litigation with Independents*

Inasmuch as its Just and Hanaman patent had been sustained by the courts and supposedly gave to General Electric a legal monopoly in the production, use, and sale of tungsten-filament lamps, the big company attempted to limit the activities of the unlicensed concerns. Around 1923 a new series of infringement and injunction actions was brought under this and other patents. In addition, since users of infringing products are themselves legally guilty of contributory infringement, some large purchasers of lamps made by unlicensed firms were also faced with prosecution. Most of the independent establishments producing tungsten-filament lamps ignored General Electric's patent claims.[18] Quick profits were their principal concern. They made little attempt to improve their products other than by copying changes made by the industry leaders. When successfully sued by General Electric under a basic patent, a few of the unlicensed producers sold out to the big company or otherwise liquidated and started business soon afterward under another name. Such a situation led to continual conflict. By 1927 the output of the independents had been forced down to 2 or 3 per cent of the domestic incandescent-lamp business, while that of the General Electric group had risen commensurately. General Electric's policy of eliminating the independents by legal action and/or purchase was cheaper and more effective than driving them out of business by competitive price reductions.

Besides the Just and Hanaman patent on the tungsten filament,

18 The unlicensed manufacturers sometimes shipped their lamps secretly by night to make it difficult for General Electric to gather evidence for initiating infringement proceedings against themselves and their customers.

General Electric owned two other basic patents on the incandescent lamp. One was the Coolidge patent of 1913 on the ductile tungsten filament, and the other was the Langmuir patent of 1916 on the gas-filled lamp.[19] Each of these patents was used to protect its position in the lamp industry. The Langmuir patent was first tested and fully sustained by the Southern New York District Court on October 27, 1919, and by the Second Circuit Court of Appeals on June 2, 1920, in infringement proceedings brought against the Nitro-Tungsten Lamp Company.[20] The Langmuir patent was later involved in much other litigation with allegedly infringing independent manufacturers, often in conjunction with the Just and Hanaman patent, and it was consistently upheld.[21] In each case the court declared that Langmuir's work on the introduction of inert gases was original and patentable and represented a definite advancement in lamp technology.[22]

The status of the Coolidge patent was not clarified as rapidly as that of the other fundamental patents. In its first court test, against the Independent Lamp & Wire Company, the patent was sustained.[23] Judge Morris of the New Jersey District Court held on June 29, 1920, that ductile tungsten was commercially new and important, and that the Coolidge patent was valid and infringed. The Independent Lamp & Wire Company, which was unwilling to take the financial risk of an appeal, sold out to General Electric in 1921.

The 1920 interpretation remained in force for seven years. On

19 The drawn-tungsten filament has been discussed in Chapter VII. See the opening pages of Chapter XII for a consideration of the gas-filled lamp.

20 *General Electric Company* v. *Nitro-Tungsten Lamp Company*, 261 Fed. 606 (1919), 266 Fed. 994 (C.C.A., 1920).

21 Among the other unsuccessful defendants to infringement actions initiated by General Electric in which the Langmuir patent was upheld were the following: F. A. Alexander in 1921, the Continental Lamp Works, United Lamp Manufacturers' Corporation, and Incandescent Products, Inc., in 1922; the Save Electric Corporation, Nitrogen Electric Company, Brite-Lite Lamp Company, Inc., and P. R. Mallory & Company, Inc., in 1923; the Minneapolis Electric Lamp Company in 1924; and the Desmond Incandescent Lamp Company, Sunray Lamp Company, Inc., and Republic Electric Company, Inc., in 1928.

22 The corresponding British patent of Langmuir was upheld by the House of Lords in 1921, reversing the decision of the lower courts in the case of the British Thomson-Houston Company, Ltd., against the Corona Lamp Works, Ltd.

23 *General Electric Company* v. *Independent Lamp & Wire Company, Inc.*, 267 Fed. 824 (1920).

January 15, 1927, a General Electric suit against the De Forest Radio Company and the Robelen Piano Company was decided in the Delaware District Court. The defendants were charged with infringement of the Coolidge patent in the manufacture and sale of radio tubes containing ductile tungsten filaments. The same Judge Morris, sitting in a different district, found this time that the discovery of the cold ductility of tungsten did not constitute invention, and that both the product and the process claims of the patent were void. The facts and arguments presented in the second court action were quite different from those in the Independent Lamp & Wire Company case and formed the basis for that surprising about-face. Judge Morris' decision was reversed in part on September 18, 1928, by the Third Circuit Court of Appeals at Philadelphia, which held that the process claims of Coolidge were valid, although it was agreed that the product claims, which covered the use of ductile tungsten wire in incandescent lamps and related devices, were invalid.

Since the ductility of pure tungsten is a natural phenomenon, it was held that a valid patent could not be granted which claimed exclusive use for any product made of ductile tungsten, no matter how important the innovation which had led to the technical advance. Claims had to be restricted to the process for achieving ductility. The United States Supreme Court refused to reconsider the decision of the Philadelphia appeals court on January 7, 1929.[24] The process claims, which covered the Coolidge method for preparing ductile tungsten wire, were thus finally upheld less than two years before the expiration of the patent; at the same time the product claims were entirely invalidated.[25]

24 See *General Electric Company* v. *De Forest Radio Company*, 17 F(2d.) 90 (1927), 28 F(2d.) 641 (C.C.A. 1928), 278 U.S. 656 (1929).

25 Two British patents covering the Coolidge ductile tungsten innovation also had stormy court careers before their final invalidation. A 1906 patent covered a process and apparatus for the treatment of tungsten to make ductile tungsten. A 1909 patent covered improvements in the technique for treating tungsten. The 1906 patent, which was the subject of litigation in the British Thomson-Houston Company, Ltd., against Duram, Ltd., was invalidated in 1917 by the High Court of Justice for making too broad claims and for want of invention; and that decision was sustained through all appeals. The second patent was invalidated in 1925 by the House of Lords, after appeal, on the ground of anticipation by the 1906 patent. In announcing their decision, the House of Lords stressed the rigid and narrow rules of validity to which a patent must conform before it may be granted a monopoly.

Since the basic Just and Hanaman and Langmuir patents were still in force, the partial invalidation of the Coolidge patent two years before its expiration date did not seriously weaken General Electric's patent position. Chief Justice Taft had said in the Supreme Court decision of the 1926 antitrust prosecution against General Electric and Westinghouse, "These three patents cover completely the making of the modern electric light with the tungsten filament and secure to the electric company a monopoly of their making, using and vending."[26] Although Taft was not correct in stating that the patents completely covered the lamp, it was certainly true that they covered its most outstanding features.

4. American Lamp Production and Trade

In the eleven years ending with 1925 the production of incandescent lamps in this country had increased enormously. In 1914 the value of electric lamps produced was $17,350,000. The principal component of that total was 74,434,000 large tungsten-filament lamps worth $11,886,000. Eleven years later the value of lamps produced was $73,558,000, and 266,462,000 large tungsten-filament lamps made up $54,892,000 of the total.[27] With the development of the automotive industry, the production and sale of miniature lamps had grown even more rapidly. There had been a steady increase from fewer than 15,000,000 units in 1914 to close to 200,000,000 units in 1925. Table XIV shows the numerical sales of large and miniature incandescent lamps, not classified by filament types, from 1912 to 1926. The figures include imports as well as domestic production.

The character of domestic lamp production also changed radically between 1912 and 1926. Carbon-filament and GEM lamps declined in number from nearly 60 per cent of total output and sales to only 1 or 2 per cent of domestic production and to less than 6 per cent of all lamp sales. The tantalum lamp disappeared in 1913, and tungsten reigned supreme. The larger tungsten-filament lamps were gas-filled, while the smaller ones were of the vacuum type.

[26] *United States of America* v. *General Electric Company, Westinghouse Electric and Manufacturing Company, and Westinghouse Lamp Company*, 272 U.S. 476 (1926).

[27] See Appendix D for complete census reports on lamp production during that interval.

TABLE XIV: LARGE AND MINIATURE INCANDESCENT-LAMP SALES IN THE UNITED STATES

1912–1926

(in thousands)

Year	*Large Lamps*	*Miniature Lamps*	*Total*
1912	85,469	5,379	90,848
1913	105,066	12,442	117,509
1914	112,951	14,582	127,533
1915	116,127	23,713	139,840
1916	150,491	50,194	200,685
1917	179,326	74,890	254,216
1918	181,020	72,556	253,577
1919	180,675	85,657	266,332
1920	204,829	118,146	322,975
1921	168,589	99,708	268,297
1922	210,209	129,470	339,679
1923	245,874	174,574	420,448
1924	262,636	188,329	450,965
1925	279,231	199,641	478,872
1926[a]	311,000	220,000	531,000

[a] Estimated from data for first ten months.
Source: *Electrical World*, Vol. LXXXIX, p. 78 (Jan. 1, 1927).

American foreign trade in electric lamps during the twenties amounted to only a very small proportion of total domestic production. In 1925, imports totaled 35,631,000 lamps valued at $1,464,000. In the same year exports totaled 7,935,000 lamps valued at $1,494,000. That situation was typical of most other years during the same period. As is indicated in Table XV, the imports consisted largely of carbon-filament lamps of low unit value, whereas the exports consisted primarily of metal-filament and vapor lamps of high unit value. The principal foreign supplier during the twenties was Germany. Exports were for the most part to Latin American countries.

A number of factors tended to hold foreign trade in electric lamps to a minimum during that period. The most important check was the international patent and patent-licensing situation.[28] General Electric exchanged exclusive patent licenses with the principal lamp-producing companies in many other important countries, with the stipulation that such technological advances must not be used in competition against the licensing firm in specified areas. Imports of lamps into this country came mostly from unlicensed firms and consisted largely of lamps upon which the patents had

TABLE XV: UNITED STATES IMPORTS AND EXPORTS OF ELECTRIC LAMPS

1925

Imports			Exports		
Type of Lamp	*Number*	*Value*	*Type of Lamp*	*Number*	*Value*
Metal-filament	7,144,000	$ 374,000	Metal-filament	7,239,000	$1,250,000
Carbon-filament	28,477,000	1,082,000	All other	696,000	244,000
Vapor	10,000	8,000			
Total	35,631,000	$1,464,000	Total	7,935,000	$1,494,000

Source: U.S. Tariff Commission, *Incandescent Electric Lamps*, Report No. 133, 2nd Ser., Washington, 1939, pp. 50, 54, 90, 95, 97.

expired; exports consisted primarily of patented lamps to non-industrial countries. The Central and South American markets were the most suitable for American exports, although certain colonial and other industrially undeveloped areas of the world were available for open sales competition.

Another important reason for the smallness of lamp imports was that independent producers in most of the other nations could not make lamps of American standards as cheaply as American producers. American methods for both parts production and the assembly of lamps were farther advanced and resulted in lower

28 The international situation will be discussed in some detail in Chapter XI.

unit costs for the high-quality mass-production items. It was partly for this reason that the lamps which were imported were mostly low-quality carbon lamps.

A final factor in limiting American lamp imports was the continued presence of tariff barriers, although at a somewhat lower level than formerly. The 1913 Tariff Act, which was the first law to provide specifically for electric lamps, reduced the 45 per cent and 60 per cent duties which had been applicable since 1909 under a more general classification to a uniform 30 per cent duty for glass bulbs, metal-filament lamps, carbon-filament lamps, and lamps without filaments. The duty was further reduced to 20 per cent for all categories by the Act of 1922, and it has remained at that level with minor exceptions ever since. The reductions of 1913 and 1922 reflected the declining need of the American industry for protection, as well as the current national reaction against excessively high tariffs.

Exports of lamps were small even though the leading producers in the United States were low-cost producers. License agreements again presented the chief obstacle, although tariffs in most other countries were higher than they had been at the end of the nineteenth century. Few developed markets were available to the two largest American producers, who were restricted by international patent licenses. The smaller licensees were prevented from exporting patented lamps by the terms of their licenses; the exportation of patented lamps would have constituted infringement of patents which they admitted were valid. The unlicensed companies were not sufficiently well established or stable to conduct much export business.

General Electric maintained its share of the domestic lamp business at a very high level between 1912 and 1926. The actual figure varied somewhat from year to year, depending on the current situation with respect to the independents. The position of the big company made it the price leader in the industry. Westinghouse was obliged by the terms of its license to follow whatever prices the licensor established on lamps patented by General Electric. The other licensees and the independents were free to determine their own prices; but inasmuch as General Electric's costs of production were typically much lower than those of the smaller producers—primarily because of cheaper parts and materials, better machinery, and superior methods of production—the small companies did not initiate price reductions. They tended to follow changes in General Electric's list prices, in which they were encouraged by the licensor, although they usually shaded the leader's discounted prices somewhat to stimulate their own sales.

The list prices established by General Electric were assertedly fixed in relation to production costs;[29] and the history of incandescent lamp prices from 1912 to 1926 does reflect the changes in production costs fairly closely. The policy was not unalterable, however, for General Electric used prices to encourage the sale of those lamps which it wished to make standard and to discourage the sale of those which it wished to eliminate. Such a procedure was employed to hasten the replacement of various clear-glass types after the inside-frosted lamp had been introduced. In addition, General Electric attempted to price its lamps so as to maintain its share of the total American lamp market. Competitive threats were recognized by cuts in the prices of particular lamps and in the general price level.

The price of the 40-watt tungsten lamp fell from 55 cents in March, 1912, to 27 cents by April 1, 1915, as the unlicensed manufacturers increased their output. During World War I, rising costs and declining competition led to increases in price, with the final increase to 40 cents occurring in 1920. Reductions followed when the market share of the independents began to rise in 1922, and the 27-cent price of 1915 was reached again in 1924. In 1926 the price was lowered to 25 cents. Prices for the other sizes of tungsten-filament lamp fluctuated similarly, as is indicated by the data of Table XX on page 269. The normal relationship was for production costs to amount to from 25 to 30 per cent of list prices, although profit margins were greater for lamps of high wattage, which the small manufacturers did not typically produce. The independents in general could meet the General Electric prices only by accepting smaller profit margins. It is evident that General Electric's profit margins were very wide, for even where discounts amounted to 50 per cent of list

29 "In the belief of General Electric only one basis existed for raising or lowering lamp prices. That basis was the rise or fall of costs." (Hammond, *op cit.*, p. 342.)

price the big company had a working margin of from 50 to 100 per cent of cost. The independents could have shaded that percentage considerably and still have made a good living, had it not been for General Electric's impregnable patent position up to about 1930.

5. *Supply of Lamp Parts and Machinery*

General Electric's position with respect to lamp parts and machinery became stronger than ever after 1912. Following its acquisition of the Providence Gas Burner Company as a result of the 1911 consent decree, it was the only manufacturer of a full line of lamp bases in the United States until 1923, when for $25,000 it sold to Westinghouse its trade secrets for the production of lamp bases.[30] After that date Westinghouse manufactured bases for its own use, while General Electric continued to supply other producers, both licensed and unlicensed. Unlicensed firms also satisfied some of their requirements through imports.[31] Prior to 1927, the Providence Base Works allowed special discounts to General Electric lamp factories and to Westinghouse. In addition, General Electric was able to keep track of lamp output by the unlicensed firms through its sale of bases to them.

In the production of glass bulbs General Electric similarly became increasingly important. The Fostoria Bulb & Bottle Company had been acquired by General Electric as a result of the 1911 consent decree. General Electric then produced bulbs for lamps until 1918, along with the Corning Glass Works, the Libbey Glass Company, and two smaller glass plants. On December 12, 1918, General Electric leased Libbey's bulb and tubing facilities and acquired an exclusive license under Libbey's associated patent rights. General Electric's glass production was considerably increased thereafter. An option to buy accompanied the lease, which expired in 1928. In 1932 Corning purchased Libbey's lamp-glass business—plants, equipment, and good will. Shortly after 1918 the two smaller bulb-making companies

30 United States of America *v.* General Electric Company et al., *Complaint*, Jan. 27, 1941, p. 34, and *Answer of Defendant General Electric*, May 15, 1941 p. 11.

31 "Brass bases for electric lamps are dutiable at 45 per cent ad valorem." (U.S. Tariff Commission, *op. cit.*, p. 40.)

went out of business, and General Electric and Corning were left in control of almost all domestic production of glass parts for electric lamps. Since 1913 the two companies have licensed each other under most of their patents which refer to electric-lamp glass. The licenses have not permitted General Electric to sell glass bulbs, tubing, and cane made on most of the patented machinery, nor has Corning been licensed to make or sell lamps. General Electric produced almost all its own glass requirements after the lease of Libbey's properties, although it continued to purchase a small percentage of its annual needs from Corning. The other domestic producers of lamps, both licensed and unlicensed, obtained their glass parts largely from Corning, although some bulbs were imported.[32] In pricing its glass bulbs, Corning appears to have favored General Electric over the latter's licensees, which were in turn favored over the unlicensed companies.

General Electric and Westinghouse typically made their own wire for filaments and lead-in wire, whereas the other licensees generally purchased their requirements from General Electric. The unlicensed firms were unable to buy this wire from General Electric. For the most part, they obtained a lower-quality, higher-cost product from outside domestic suppliers and from imports. One independent lamp producer, the Save Electric Corporation of Toledo, Ohio, did make its own wire, and prior to 1920 some of the concerns which later became licensees of General Electric also drew their own wire. They were required to abandon the manufacture of wire when the licenses were signed.

A number of minor parts and supplies were required for the production of incandescent lamps. There were generally greater numbers of suppliers for them than for the principal parts mentioned above, and prices were approximately the same for all buyers.

In lamp-making machinery, General Electric also held a very favorable position. It was the principal developer and producer of such equipment, which was made for its own use and for lease

[32] Imports of glass bulbs during the twenties amounted to only 2 or 3 per cent of domestic production. For example, 17,140,000 bulbs, valued at $180,000, were imported in 1925. Most of those imports were supplied by the Dutch N. V. Philips' Gloeilampenfabrieken. The tariff on bulbs was reduced from 60 per cent to 30 per cent in 1913 and to 20 per cent in 1922. (*Ibid.*, pp. 16–17.)

or sale to its licensees. Westinghouse did some of its own machinery development and production, while the other licensees normally purchased or leased all their equipment from General Electric or other suppliers licensed under General Electric patents. Two of the three leading outside producers of lamp-making machinery—the York Electric & Machine Company and Alfred Hofmann & Company—were licensed under the machinery patents of General Electric. They were permitted to sell the patented machinery only to lamp licensees of General Electric.

The Eisler Engineering Company was the third leading outside supplier of lamp-making machinery. It was not licensed by General Electric, and the unlicensed lamp manufacturers obtained most of their lamp-making equipment from it. The Eisler equipment was less automatic and of considerably less speed than the machinery used by the General Electric group. However, it was considerably lower in price.[33]

All in all, General Electric was quite successful in tying up the major sources of the principal lamp parts and of lamp-making machinery. The licensee group moved along smoothly under the protection of the licensor. The unlicensed firms had to make the best of their difficulties with lower-quality or higher-cost materials and machinery.

6. Antitrust Action of 1924

There was a pause in the normal evolution of the electric-lamp industry during the middle of the twenties. Early in 1922 the Lockwood Committee of the New York State legislature investigated the incandescent-lamp business among other alleged combinations of manufacturers in violation of the state antitrust laws. Extensive hearings produced a number of complaints against the methods employed by General Electric in the lamp business. Independent manufacturers charged legal harassment, exorbitant profits, and unfair tactics. General Electric defended its actions as fair and legal in view of its admitted patent monopoly.

[33] Eisler was sued four times during the twenties for alleged infringement of General Electric machinery patents. Each of the patents was declared invalid or was withdrawn by General Electric. (See *General Electric Company* v. *Eisler Engineering Company*, 20 F(2d.) 33 (C.C.A., 1927), 26 F(2d.) 12 (C.C.A., 1928), and 43 F(2d.) 319 (C.C.A., 1930).

In an effort to vindicate itself publicly and to clarify the matter, particularly with regard to its patent license and distribution systems, General Electric requested the United States Department of Justice to investigate the situation and bring charges if there were any doubts about the legality of General Electric practices.[34] The Department of Justice did investigate, using the testimony gathered by the Lockwood Committee, and on March 20, 1924, the government brought an antitrust suit in the Cleveland District Court against General Electric and Westinghouse.

The complaint charged that the license agreement between the two companies and their agency system of distributing lamps were illegal. Those were the only things complained of, and no other concerns were party to the suit. The principal issue raised by the government was whether or not the agency method of distribution and price determination employed by General Electric and Westinghouse was a mere evasion of the decree of 1911. The defendants felt confident of their position, inasmuch as the Federal Trade Commission had investigated the agency system in 1919 and had declined to take any action. In accordance with the statements made by the Attorney General in 1912, the matter was tried as a civil rather than criminal action under the Sherman Act.

After presentation of the evidence, the district court dismissed the government's case on April 3, 1925, for want of equity. The federal government then appealed directly to the United States Supreme Court.[35] The facts in the case, which consisted in large part of the contents of the license and agency contracts and other documents, were not in dispute. The conflict lay in their interpretation. The case was argued on October 13 and decided on November 23, 1926. The court upheld the district court in sustaining the legality of the license granted by General Electric to Westinghouse.

Chief Justice Taft, in writing the opinion of the court, stated that a patent holder had the right to include restrictive terms in

[34] *Electrical World*, Vol. LXXXIII, p. 637 (Mar. 29, 1924).

[35] The expedition of Sherman Act cases by skipping the Circuit Court of Appeals is in direct contrast to the slowness of patent litigation. In patent cases appeals can be taken to the U.S. Supreme Court only after conflicting decisions as to validity have been handed down by two circuit courts of appeal on appeals from district courts.

licenses granted to other producers. Since the patentee possessed a legal monopoly over the production, sale, and use of the patented article, he could legally exclude all others from such activities. The granting of any licenses at all, even with quantity, price, and other limitations, was thus declared to be legal. Moreover, the court found that the method of distribution whereby thousands of merchants became selling agents for the large producers of electric lamps was a true agency relationship and did not violate the antitrust laws.[36]

[36] The decision was important to the development of the electric-lamp industry, and it was also important to patent law in general. Because of that fact, summaries of the statements of law made by Chief Justice Taft in the decision are given below:

"*Monopoly—Appointing Agents for Sale of Goods at Fixed Prices—Validity*

"1. An arrangement between a manufacturer of a patented article and merchants by which the latter become agents for the sale of his goods at prices fixed by him, under which the title is retained by him until the goods are sold and the sales are under his control, is not invalid under the Anti-trust Acts, notwithstanding the system of distribution extends over the entire country, embraces a large number of agents who are required to guarantee the accounts when sales are made, are made responsible for all stock lost, missing or damaged, and agree to pay the expenses of shortage, cartage, local distribution, handling, sale and distribution.

"*Monopoly—Fixing Price to Consumer*

"2. A manufacturer does not violate the common law or the Anti-trust Acts by seeking to dispose of his product directly to the consumer and fixing the price by which his agents transfer the title from him directly to such consumer.

"*Patent—Scope of Assignment*

"3. The owner of a patent may assign it to another and convey the exclusive right to make, use, and vend the invention throughout the United States, or any other divided part or share of that exclusive right, or the exclusive right under the patent within and through a specified part of the United States.

"*Patents—Licenses—Construction*

"4. Conveying less than title to the patent, or part of it, a patentee may grant a license to make, use, and vend articles under the specifications of the patent, for any royalty or upon any condition, the performance of which is reasonably within the reward which the patentee, by grant of the patent, is entitled to secure.

"*Patent—Right to Exercise Control over Purchaser*

"5. After a patentee sells the patented article he can exercise no further control over what the purchaser may wish to do with the article.

"*Patent—Right to Limit Sales by Licensee*

"6. A patentee in granting a license to another to make and sell the patented article may limit the method of sale and the price, provided the conditions of sale are normally and reasonably adapted to secure pecuniary reward for the patentee's monopoly."

(*United States of America* v. *General Electric Company, Westinghouse Electric and Manufacturing Company, and Westinghouse Lamp Company*, 272 U.S. 476 [1926].)

Chapter X: INCREASING COMPETITION IN THE AMERICAN INCANDESCENT-LAMP INDUSTRY: 1927–1947

1. *Competition and Growth, 1927–1941*

REVISED LICENSE STRUCTURE

THE Supreme Court decision of November 23, 1926, seemed to give assurance that the methods of control exercised by General Electric could be continued. The licensor's principal lamp patents were about to expire, however. The Just and Hanaman patent was to run out in 1929, and the Coolidge and Langmuir patents were to lapse in 1930 and 1933, respectively.[1] Those three patents were the strongest elements in the patent-licensing structure, and in their absence the structure could not so easily be maintained. In addition, the 1912 license granted to Westinghouse was to expire within a few years, and the licenses granted to the smaller companies were to terminate soon thereafter.

It was particularly important for General Electric to hold the share of the lamp business conducted by Westinghouse to a fixed percentage, for Westinghouse was the second largest producer in this country and was potentially able to provide more vigorous domestic sales competition. Moreover, a continued control over exports would prevent a possible increase in competition for world markets and avoid a retaliatory increase in imports of lamps, lamp parts, and lamp-making machinery.

Although the three basic patents were expiring, General Electric owned many lesser ones covering incandescent lamps and lamp-making machinery which were to continue in force for many years. They were collectively of great importance to the licensed manufacturers, and they provided a strong inducement to extend the licenses.

[1] The final invalidation of the product claims of the Coolidge patent did not occur until 1929, after the revision and extension of the Westinghouse lamp-patent license had taken place.

Westinghouse wished to continue receiving favored treatment from General Electric and to continue operating in a well organized market; but it insisted on a larger percentage of the domestic market. Accordingly, on June 15, 1928, the two large companies signed a new "A-type" license agreement dated as of January 1, 1927, to supersede the agreement of 1912. The new agreement licensed Westinghouse to make vapor lamps covered by General Electric patents as well as the large and miniature incandescent lamps which it had formerly produced. Its quota was increased to 22.4421 per cent of the aggregate net domestic sales of electric lamps by General Electric and Westinghouse. The quota was to be increased 1 per cent each year until 1930, when it was to become fixed at a level of 25.4421 per cent. Those percentages corresponded to 28.94 and 34.12 per cent of the net sales of General Electric alone. The royalty was fixed at a flat rate of 1 per cent, although the penalty for exceeding the quota was increased from 10 per cent to 30 per cent. Other terms in the new license agreement similarly eased certain provisions of the former license while tightening others. The effect was to give Westinghouse a somewhat larger share of the industry and greater financial returns while imposing more rigid terms upon it to prevent uncontrolled competition. The most important provisions of the license, which remained in force until the middle of 1945 in essentially unchanged form, are included in Table XVI.

There were eleven small licensees of General Electric making incandescent lamps in 1927. New licenses for those firms to replace the ones originally granted between 1916 and 1922 were offered in 1933 and 1934, when the old ones were about to expire. By that time the licenses and quotas of five of the licensees had been transferred to other licensees, or their licenses had been canceled by General Electric. The remaining six concerns were given new licenses with unchanged quotas to supersede the former arrangements.[2] Those concerns, the locations of their plants, the type of lamp for which each was licensed, and the

[2] The B licensees had been given minimum sales quotas, regardless of their percentage quotas of General Electric's sales. The minimum was increased from $50,000 in 1916 to $75,000 in 1922, $150,000 in 1924 and $350,000 in 1925.

TABLE XVI: SUMMARY OF PRINCIPAL PROVISIONS OF A AND B LICENSES GRANTED BY GENERAL ELECTRIC FOR THE DOMESTIC MANUFACTURE OF ELECTRIC LAMPS

1927–1945

Topic	*Provision for A Licensee*	*Provision for B Licensees*
1. Types of lamps included in license	All types (large and miniature incandescent, vapor, etc.)	Large incandescent only to Hygrade, Consolidated, Kentucky, and Economic; miniature incandescent only to Tung-Sol and Chicago Miniature
2. Sales quota (as percentage of net sales of licensor)	28.94% in 1927 increasing in three steps to 34.12% in 1930 and thereafter [a]	Large incandescent only—to Hygrade 8.2242%, to Consolidated 3.89093%, to Kentucky 1.7584%, to Economic 0.8998% Miniature incandescent only—to Tung-Sol 26.71956%, to Chicago Miniature 2.975% (Shortage from preceding year to be added to quota in an amount up to 10 per cent of the quota for the year in which the shortage occurred)
3. Determination of prices, terms, and conditions of sale	Must follow licensor (must not interfere with consignment plan of licensor by offering better terms to agents than licensor, or in other specified ways)	Self-determined
4. Royalty rate on quota	1%	3% (based on prices of licensor)
5. Royalty rate on sales in excess of quota	30% (deficiency from previous year up to 3% of quota to be added to quota in figuring excess)	20% (on that portion of the excess which is greater than 5% of the quota, after allowed deficiency from previous year has been added to quota)
6. Amount of excess of sales over quota constituting breach of agreement	5%	10%
7. License for export	Granted for export to countries to which licensor itself may export under the terms of its international agreements	Not granted
8. Use of special trade name "Mazda"	Granted, except in connection with export sales	Not granted
9. Access to technical improvements made by licensor in fields covered by license	Complete information	No provision
10. Exchange of cost data	Complete exchange	No provision
11. License to make bulbs, tubing, or cane	Granted for miniature bulbs made from tubing (in amendment to original agreement executed June 15, 1928, as of Jan. 1, 1927)	Not granted
12. License to make lamp bases	Granted	Not granted
13. License to sell machinery, filaments, or other parts	Not granted	Not granted
14. License under licensor's foreign patents	Not granted	Not granted
15. Validity of patents involved	Admitted over life of license	Admitted over life of license
16. Duration of royalty-free license, with right to sublicense, granted to licensor on patents of licensee in fields of principal license	Duration of principal license only, if principal license canceled	Life of patent
17. Term of principal license	Jan. 1, 1927, till expiration date of patents issued or applied for to that date	Varying dates in 1933 and 1934 to Dec. 31, 1944 (unless extended)
18. Termination by licensor	If licensee willfully violates terms, upon sixty days' written notice	If licensee willfully violates terms, upon thirty days' written notice
19. Termination by licensee	On two years' written notice (only after Jan., 1935)	On six months' written notice

[a] These percentages appear in the license agreement as 22.4421 and 25.4421 per cent of the combined net domestic sales of General Electric and Westinghouse.

Source: U.S. Tariff Commission, *Incandescent Electric Lamps,* Report No. 133, 2nd Ser., Washington, 1939, pp. 111–135.

percentage of General Electric's net domestic sales which each was permitted to sell were as follows:

Company	*Plant*	*Lamp*	*Percentage*
Hygrade Sylvania Corp.	Salem, Mass., and St. Mary's, Pa.	Large incandescent	8.2242
Consolidated Electric Lamp Co.	Lynn, Mass.	Large incandescent	3.89093
Kentucky Electric Lamp Co.	Owensboro, Ky.	Large incandescent	1.7584
Economic Lamp Co.	Malden, Mass.	Large incandescent	0.8998
Tung-Sol Lamp Works, Inc.	Newark, N.J.	Miniature incandescent	26.71956
Chicago Miniature Lamp Works	Chicago, Ill.	Miniature incandescent	2.975

The provisions of the old "B-type" licenses were carried over in essentially the same form to the new licenses. With much smaller quotas, the B licensees were required to pay a higher royalty rate of 3 per cent[3] and were otherwise given less favorable terms than Westinghouse (see Table XVI). The B licensees and Westinghouse also exchanged licenses through General Electric, which had the right to grant sublicenses under the patents of its licensees. Westinghouse received licenses under patents owned by the B licensees for the life of each patent, while the B licensees were licensed under Westinghouse patents only as long as they remained licensees of General Electric and stayed within their quotas.

Except for a few minor changes the B-license structure continued unaltered to the end of 1944. In 1936 the Ken-Rad Tube & Lamp Company took over the assets and selling quota of its subsidiary, the Kentucky Electric Lamp Company, which was then dissolved. In the same year Hygrade acquired the assets and quota of the Economic Lamp Company, thereby increasing its quota to 9.124 per cent of General Electric's net domestic sales. The assets and license rights of the Vosburgh Miniature Lamp Company, which had been purchased by Hygrade in 1928, had

[3] The royalty rate was 3⅓ per cent of net sales, based on the prices of the licensor, but the discount of 10 per cent for prompt payment and proper reporting reduced the effective rate to 3 per cent.

been sold in 1929 to the Tung-Sol Lamp Works, Inc. The only other important change was the extension of Consolidated's license in 1939 to cover the production of fluorescent lamps. From 1936 to 1944 there were only three licensed producers of large incandescent lamps and two licensed producers of miniature incandescent lamps in addition to Westinghouse, which made all types of electric lamps.[4]

THE RISE OF JAPANESE COMPETITION

The distribution by value of the domestic market for incandescent lamps in 1927 was approximately as follows: General Electric, 65.3 per cent; Westinghouse, 17.7 per cent; other licensees, 11.9 per cent; and other producers (including imports), 5.1 per cent.[5] That situation continued until after the expiration of the controlling Just and Hanaman patent. The Langmuir patent was still in force, but, since gas filling of tungsten-filament lamps adds materially to efficiency only in sizes larger than 60 watts, it did not hinder the unlicensed sale of large tungsten-filament lamps of low wattage. The principal remaining obstacles were General Electric's Pacz improvement patent on tungsten wire and its Pipkin patent on inside-frosted bulbs,[6] which caused most unlicensed domestic concerns to move cautiously for a few years.

While the domestic independents increased their operations slowly at first, lamp imports rose rapidly after the expiration of the Just and Hanaman patent. In 1930 imported metal-filament lamps leaped from their 1929 level of 947,000 large tungsten-filament lamps worth $41,000 to 11,651,000 lamps valued at $391,000.[7] That quantity was doubled in 1931 and tripled in 1932. Imports then fell to an annual average of about 25,000,000 lamps, which was maintained until 1937. They dropped to 10,000,000 for the period from 1938 to 1940, and then ceased abruptly because of

[4] As of 1938, General Electric operated six plants in Ohio for the production of incandescent lamps, lamp bases and glass bulbs, tubing and cane; a lamp-base plant in Rhode Island; and one lamp plant each in Massachusetts, New Jersey, New York, Missouri, and California. Westinghouse operated a lamp-base plant in Belleville, N.J., and lamp plants in Bloomfield and Trenton, N.J.

[5] United States of America *v.* General Electric Company, et al., *Complaint*, Jan. 27, 1941, p. 49, and *Answer of Defendant General Electric*, May 15, 1941, p. 14.

[6] These developments will be treated in Chapter XII.

[7] U.S. Tariff Commission, *op cit.*, p. 50.

the war. During the early thirties imports of miniature tungsten-filament lamps increased even more rapidly, rising from about 3,500,000 lamps worth $86,000 in 1929 to more than 100,000,000 valued at over $500,000 in 1936 and 1937. Those imports were also ended by the war.

Before 1930 the imports of incandescent lamps had consisted primarily of carbon lamps from Germany; after 1930 they were chiefly tungsten-filament lamps from Japan.[8] Independent Japanese manufacturers were virtually the only producers in the world outside the cartel who were able to make tungsten-filament lamps cheaply enough to compete in the American market on a price basis.[9] Their lamps were far below the domestic output in quality, however. In 1938 the American-made 60-watt lamp sold for 15 cents in this country, whereas at the then prevailing rates of exchange foreign-made lamps of the same wattage were sold in their respective countries as follows: Japan, 7 cents; Canada, 20 cents; France, 22 cents; Switzerland, 30 cents; Sweden, 33 cents; Belgium, 34 cents; Czechoslovakia, 36 cents; United Kingdom, 39 cents; Hungary, 46 cents; Germany, 48 cents; and the Netherlands, 70 cents.[10] The differentials were somewhat smaller for lamps of lower wattage. This comparison does not represent relative costs accurately, of course, for varying degrees of monopolistic control over domestic prices and fluctuating exchange rates distorted the international cost picture. It is indicative, however, of the higher costs in most of the principal lamp-producing countries. An important reason for the very low price of Japanese lamps was the devaluation of the Japanese yen from an average of 48.851 cents in 1931 to an average of 28.111 cents in 1932 and 25.646 cents in 1933. Despite American devaluation of the dollar in 1933, the value of the yen remained below 30 cents through the 1930's.

The combination of patent expiration, currency devalution, and low labor costs made possible the enormous increase in the sale of Japanese tungsten-filament lamps in this country during

8 The Tariff Act of 1930 raised the duty on carbon-filament lamps from 20 per cent to 30 per cent, while leaving unchanged at 20 per cent the duties on all other types of electric lamps and glass bulbs (*ibid.*, p. 4).

9 The leading Japanese producers were members of the international lamp cartel.

10 *Ibid.*, p. 49.

the thirties.[11] Even with the tariff rate of 20 per cent, the large Japanese lamps retailed for about 10 cents during the early thirties and later sold for as little as 5 cents. With large lamps produced by the General Electric group selling from 1930 to 1935 at prices of 20 cents for sizes of 60 watts or less, the Japanese lamps found a ready market. Despite their lower price, they were in almost all instances no bargain, owing to their lower efficiency, shorter life, and much greater variability in performance.

To counter the increased imports without reducing the prices of standard lamps, General Electric and its large-lamp licensees brought out in 1932 a new line of 7½-, 15-, 30-, and 60-watt incandescent lamps. These, called Type D to distinguish them from the standard line, and priced at 10 cents, were not sold under the trademark "Mazda," even by General Electric and Westinghouse. They were designed to have fairly high efficiencies and short lives. The two larger sizes were rated at lives of only 500 hours as compared with 1,000 hours for the standard lamp at that time.[12] The 15-watt lamp was rated at 750 hours and the 7½-watt lamp at 1,400 hours. They were economical only for consumers whose electric rates were high. The increased imports of miniature lamps, including Christmas-tree lamps, precipitated selective price reductions in the regular miniature line.

In addition to the direct action taken by the General Electric group to counter the threat of Japanese imports, lamp producers sought governmental assistance in excluding the foreign product. An appeal was made to the United States Tariff Commission to raise the duties on incandescent lamps. In 1933 the Treasury Department ordered the imposition of dumping duties against Japanese lamps on the ground that they were likely to be sold at less than fair value and injure the domestic industry.[13] Customs officials also refused to admit Japanese lamps with markings similar to those of General Electric's lamps. In addition, the courts were used by General Electric to bar the lamps of certain

11 Exports of incandescent lamps from this country remained at substantially the same level as during the twenties, averaging annually about 10,000,000 large and miniature lamps combined. Their average total value was around $1,000,000 (*ibid.*, pp. 54, 97).

12 A few years later the rated lives of the 75-watt to 200-watt sizes of the standard lamp were reduced to 750 hours in order to obtain greater lumen output.

13 *Electrical World*, Vol. CII, p. 425 (Sept. 30, 1933).

Japanese distributors, who were charged with violating patent rights in the sale at "ruinously low prices" of short-lived and inefficient lamps. In combination, these defensive measures plus the normal preference of American buyers for lamps produced in this country held Japanese lamps in check during the rest of the decade.

INCREASING DOMESTIC COMPETITION

The introduction of the Type-D lamp by the General Electric group was also a defensive move against the unlicensed domestic manufacturers. With the expiration of the Just and Hanaman and other basic patents, many new firms entered the industry and older firms gradually began to expand. Where the independents had been small and insecure concerns before 1930, there emerged a growing number of responsible producers after that date.[14] The number and market share of the unlicensed firms in the production of large incandescent lamps rose gradually at first, and more rapidly after 1933, from a few small firms supplying 2 per cent of the domestic demand in 1929 to pre-World War II peaks of about twenty firms in 1937 and 14 per cent of the industry in 1941 (see Table XVII). During those years the total market for incandescent lamps continued to expand, except for a brief pause from 1930 to 1933.[15] Around the middle of the thirties the production of the independents numerically surpassed that of General Electric's B licensees. Table XVIII lists twenty-five firms which in 1938 were making various types of incandescent lamps without license from General Electric. Most of them made large lamps with tungsten filaments, but several produced miniature tungsten-filament lamps, and a number still made lamps with carbon filaments. Despite the growing share of the unlicensed domestic producers, however, General Electric and Westinghouse maintained their proportions of the market virtually unchanged. The relative losses were suffered by the B licensees and foreign imports.

The domestic market for miniature incandescent lamps was

14 The independents abandoned their secrecy of production and shipments to take their chances with General Electric infringement suits.

15 See Appendix D for census data on the production of incandescent lamps during that interval.

TABLE XVII: ESTIMATED ANNUAL SALES OF LARGE TUNGSTEN-FILAMENT LAMPS FOR GENERAL LIGHTING PURPOSES

1928–1941

YEAR	GEN'L ELECTRIC AND WESTINGHOUSE		B LICENSEES		*Unlicensed Domestic Firms*	*Imported Lamps*	*Total*
	Mazda Lamps	*Type-D Lamps*	*Standard Lamps*	*10-Cent Lamps*			
1928	261,636,000 82.7%	....	41,977,000 13.3%	....	7,152,000 2.3%	5,367,000 1.7%	316,132,000 100%
1929	289,958,000 84.3%	....	42,167,000 12.3%	....	6,057,000 1.8%	5,552,000 1.6%	343,734,000 100%
1930	281,992,000 82.7%	....	40,888,000 12.1%	....	7,298,000 2.1%	10,582,000 3.1%	340,760,000 100%
1931	268,269,000 78.0%	....	43,901,000 12.7%	....	12,108,000 3.5%	20,018,000 5.8%	344,296,000 100%
1932	210,105,000 62.8%	40,830,000 12.2%	36,173,000 10.8%	3,145,000 0.9%	12,200,000 4.0%	31,137,000 9.3%	334,590,000 100%
1933	210,438,000 62.0%	51,441,000 15.2%	33,050,000 9.7%	4,938,000 1.4%	17,203,000 5.1%	22,331,000 6.6%	339,401,000 100%
1934	233,132,000 61.4%	61,346,000 16.2%	30,409,000 8.0%	5,680,000 1.5%	24,484,000 6.4%	24,633,000 6.5%	379,684,000 100%
1935	263,563,000 63.8%	57,077,000 13.8%	29,670,000 7.2%	3,600,000 0.9%	34,800,000 8.4%	24,329,000 5.9%	413,039,000 100%
1936	304,649,000 65.9%	60,127,000 13.0%	39,104,000 8.4%	2,740,000 0.6%	35,684,000 7.7%	20,147,000 4.4%	462,451,000 100%
1937	335,436,000 66.2%	61,255,000 12.1%	40,063,000 7.9%	2,086,000 0.4%	44,551,000 8.8%	23,275,000 4.6%	506,666,000 100%
1938	331,023,000 68.0%	57,010,000 11.7%	40,639,000 8.3%	2,301,000 0.5%	46,330,000 9.5%	9,832,000 2.0%	487,135,000 100%
1939	355,048,000 66.5%	59,569,000 11.2%	46,707,000 8.7%	2,510,000 0.5%	59,056,000 11.1%	10,797,000 2.0%	533,687,000 100%
1940	416,284,000 70.1%	41,574,000 7.0%	53,307,000 8.9%	1,774,000 0.3%	69,366,000 11.7%	11,658,000 2.0%	593,963,000 100%
1941	514,253,000 70.8%	38,492,000 5.3%	65,675,000 9.0%	1,500,000 0.2%	103,199,000 14.2%	3,484,000 0.5%	726,603,000 100%

Source: Members of the industry.

Table XVIII: unlicensed producers of incandescent lamps in the united states

1938

Company	Plant	Types of Lamps Made: Tungsten-Filament, Large	Tungsten-Filament, Miniature	Carbon-Filament, Large	Carbon-Filament, Miniature
American Lamp Co.	N. Bergen, N. J.	x			
Atlas Lamp Corporation	Newark, N. J.	x			
Birdseye Electric Co.	Gloucester, Mass.	x			
Carlton Electric Lamp Co.	Newark, N. J.		x		
Dura Electric Lamp Co.	Newark, N. J.		x		
Duro Test Corporation	N. Bergen, N. J.	x			
Eastern Lamp Co.[a]	Newark, N. J.	x	x		
Elram Lamp Works	Hoboken, N. J.	x			
Everbest Engineering Corp.	New York, N. Y.	x			
Herzog Miniature Lamp Works, Inc.	Long Island City, N. Y.	x	x		x
Imperial Miniature Lamp Works	Newark, N. J.		x		
Jewel Incandescent Lamp Co.	E. Newark, N. J.	x			
Lightmore Appliance Corp.	New York, N. Y.	x			
Marvel Lamp Co.	Hoboken, N. J.	x			
Munder Electrical Co.	Springfield, Mass.			x	
North American Electric Lamp Co.	St. Louis, Mo.			x	x
Pennsylvania Illuminating Corp.	Scranton, Pa.	x			
Radiant Lamp Corp.[b]	Newark, N. J.	x			
Safety Electric Co.	Chicago, Ill.			x	x
Save Electric Corp.	Toledo, Ohio	x			
Slater Electric & Mfg. Co., Inc.	Brooklyn, N. Y.	x			
Vulcan Lamp Works, Inc.	Harrison, N. J.		x		
Wabash Appliance Corp.[c]	Brooklyn, N. Y.	x			
Warren Lamp Co.	Warren, Pa.	x			
Wonderlite Co.	W. Orange, N. J.	x			

[a] Also known as Sterling Products Co. and Cosmo Manufacturing Co.
[b] Also known as King Manufacturing Co.
[c] Also known by the name of its subsidiary, the Sun Glo Lamp Works.
Source: Adapted from U.S. Tariff Commission, *Incandescent Electric Lamps*, Report No. 133, 2nd Ser., Washington, 1939, pp. 100–101.

divided during the thirties in essentially the same manner as that for large lamps, although there were some differences (see Table XIX). The large quota of Tung-Sol increased the B-licensee category for miniature lamps other than Christmas-tree lamps to a total greater than that of Westinghouse, and General Electric itself had a slightly weaker position in that branch of its lamp

Table XIX: distribution (percentage) of the incandescent-lamp market in the united states

1939

	Large Lamps: $ Value	Large Lamps: Quantity	Miniature Lamps: $ Value	Miniature Lamps: Quantity	Christmas-Tree Lamps: $ Value	Christmas-Tree Lamps: Quantity
General Electric	59.3	58.7	52.5	49.9	67.0	53.7
Westinghouse	20.8	19.0	18.0	16.4	10.3	8.5
B Licensees	9.5	9.2	20.5	21.2	....	....
Unlicensed domestic firms	9.8	11.1	7.8	8.6	1.1	1.1
Imported lamps	0.6	2.0	1.2	3.9	21.6	36.7

Source: U.S. District Court for the District of New Jersey, Civil Action No. 1364, United States of America *v.* General Electric Company et al., *Complaint*, Jan. 27, 1941, p. 50, and *Answer of Defendant General Electric*, May 15, 1941, p. 14.

business. In the sale of Christmas-tree lamps, imports bulked much larger, while the independents and B licensees sold few or none. For all categories, the lower average unit value of lamps imported or made by the unlicensed domestic producers gave those groups a smaller percentage of the dollar value than of the number of lamps sold.

Another defensive tactic of General Electric during the thirties was its extensive promotional campaign for Mazda lamps in co-operation with the utilities with the slogan "Better Light, Better

Sight." Great effort was made to raise the lighting standards of the country and to sell more 60-watt and later 100-watt lamps, instead of the smaller sizes. The campaign, which was continued for several years, was designed to combat the general business depression and stimulate electric-power sales as well as to meet the increasing threat of independent lamp producers. Although total lamp sales by General Electric and Westinghouse did decline slightly from 1929 to 1932, the decrease was very small, and recovery after 1932 was rapid. The total business of the independent lamp manufacturers increased steadily, nevertheless, during even the worst of the depression years.

The course of large tungsten-lamp prices from 1927 to 1941 is indicated in Table XX, along with the rest of the tungsten-lamp price history. Substantial reductions were announced for all lamp sizes during those fifteen years. On average the cuts amounted to about 60 per cent of 1926 list prices on lamps up to 200 watts; the reductions were much smaller for those of higher wattage, which were not made in large quantity by the independents. General Electric continued to be the price leader for the industry. The stated policy of adjusting prices to changes in production costs was also continued, but there were some important deviations from that policy to achieve the goal of maintaining General Electric's percentage of the business. No reductions in price were initiated between 1929 and 1933, although costs declined. Substantial unit profits tended to maintain total profits for the General Electric group despite slightly reduced sales. Price reductions were made belatedly in 1933 and 1935, partly as a defense against the increasing sales of unlicensed domestic and foreign producers. The reductions of 1940, and the ones which followed in 1942, seem also to have been defensive moves by General Electric to counter rising competition, for the wartime increases in production costs were getting under way in those years. This conclusion seems justified particularly because the reductions were concentrated among the lamps of relatively low wattage, which are the principal types made by unlicensed producers. The 1940 and 1942 reductions lowered the prices of lamps from 15 watts to 60 watts by one-third; the prices of lamps from 75 watts to 150 watts remained unchanged; and

TABLE XX: LIST PRICES [a] FOR SELECTED SIZES OF LARGE TUNGSTEN–FILAMENT LAMPS FOR GENERAL LIGHTING 1907–1947

Date of List Price Changes	*15–W*	*25–W*	*40–W*	*60–W*	*75–W*	*100–W*	*150–W*	*200–W*	*500–W*	*1000–W*
Nov. 16, 1907			$1.50	$1.75						
May 12, 1908			....	....		$2.00				
Oct. 1, 1908		$0.85	1.10	1.40		1.75				
Nov. 13, 1908		....	1.00	....		....				
July 12, 1909		....	....	....		....	$2.50			
Sept. 1, 1909		.80	.90	1.25		1.60	2.25			
Jan. 1, 1910		.70	.80	1.10		1.45	2.10			
July 1, 1910		....	....	....		1.35	....			
Apr. 1, 1911		.65	.70	1.00		....	2.00			
Dec. 19, 1911	$0.65	....	....	....		....	....			
Mar. 1, 1912	.50	.50	.55	.75		1.10	1.65			
Oct. 1, 1912	.40	.40	.45	.60		.90	1.35			
July 1, 1913	.35	.35	.35	.45		.80	1.20			
Apr. 1, 1914	.30	.30	.30	.40		.70	1.10			$8.00
July 1, 1914	....	....	....	....		....	....		$6.00	....
Oct. 1, 1914	....	....	....	....		....	....	$3.00	....	....
Apr. 1, 1915	.27	.27	.27	.36		1.00	1.05	2.00	4.50	7.00
July 1, 1916	....	....	....	....	$0.65	....	....	....	....	....
Jan. 1, 1918	.30	.30	.30	.35	.70	1.10	1.20	2.20	4.70	7.50
Oct. 1, 1918	.35	.35	.35	.40	....	....	1.50	....	....	....
Apr. 1, 1920	.40	.40	.40	.45	.75	....	1.55	2.10	4.60	....
Oct. 1, 1921	....	....	....	....	.70	1.00	1.40	1.90	4.15	6.70
Apr. 1, 1922	.35	.35	.35	.40	....	.95	1.30	1.80	3.75	6.00
Oct. 1, 1922	....	....	....	....	.60	.75	1.00	1.30	2.75	4.50
May 1, 1923	.32	.32	.32	.37	.55	.70	.90	1.15	2.50	4.25
Feb. 1, 1924	.30	.30	.30	.35	.50	.60	.75	1.00	2.35	4.00
July 1, 1924	.27	.27	.27	.32	.45	.55	.70	.95	2.25	....
Jan. 1, 1925	....	....	....	....	....	.50	.65	.80	2.00	3.75
Feb. 1, 1926	....	....	....	....	....	.45	.60	....	....	....
Sept. 1, 1926	.25	.25	.25	.30	....	.43	....	....	....	....
Feb. 1, 1927	....	....	....	....	....	....	....	....	....	4.00
Apr. 1, 1927	.23	.23	.23	.25	....	.40	....	....	....	....
July 1, 1928	.20	.20	.20	.22	.35	.35	....	....	....	....
Mar. 1, 1929	....	....	....	.20	....	....	....	....	....	....
Apr. 1, 1933	....	....	....	....	.20	.25	....	....	....	....
July 1, 1934	....	....	....	....	....	....	.50	.70	1.75	....
Apr. 1, 1935	.15	.15	.15	.15	....	.20	.40	.55	1.55	....
Jan. 1, 1936	....	....	....	....	....	....	.35	....	....	....
May 1, 1936	....	....	....	....	....	....	.25	.45	1.40	....
June 1, 1937	....	....	....	....	....	....	....	.35	....	....
Apr. 1, 1938	....	....	....	....	.15	.15	.20	.30	1.20	....
June 1, 1940	.10	.10	.13	.13	....	....	....	.27	1.10	3.50
Sept. 1, 1942	....	....	.10	.10	....	....	....	....	....	....
July 1, 1946	.11	.11	.11	.11	....	....	....	....	....	....
June 1, 1947	....	....	....	....	....	....	....	....	.95	3.10

[a] Quotations are for the cheapest standard lamps in each size, except for the Type D lamps. For lamps of 100 watts or less, the quotations apply to clear lamps up to 1926 and for inside-frosted lamps subsequently, except that the shift for the 75-watt size was made in 1930. For the 150-watt size, prices up to 1936 are for clear lamps, and those after 1936 are for either clear or inside-frosted lamps. Similarly, for the 200-watt lamp, prices up to 1938 are for clear lamps, and those after 1938 are for either clear or inside-frosted lamps. For the 500- and 1000-watt lamps, prices refer to clear lamps.

Sources: National Electric Light Association, *Lamp Committee Report, 1928–29*, New York, 1929, p. 4; Sylvania Electric Products, Inc.; General Electric Company; Westinghouse Electric Corporation.

the prices of lamps of 200 watts and more were reduced by about 10 per cent.[16]

The most effective pressures leading to lower lamp prices from 1927 to 1945, as well as during earlier years, came largely from the supply side of the market. Since lamp costs are but a small fraction of lighting costs, lamp demand as a whole at any one time is very inflexible, within fairly broad price limits.[17] When a residential consumer needs a lamp, he is not greatly concerned whether it costs him 10, 13, or 15 cents. Even commercial and industrial users, with their much larger purchases, are more interested in electric-energy rates and lamp efficiency and life. Where major consumers did press for price reductions, they possessed only limited bargaining power with the solidly organized General Electric group. The small-scale but constant competition or threat of competition by the independents provided the chief downward pressure on lamp prices.

Profits in lamp making continued high for the leading concerns. In incandescent lamps alone from 1935 to 1939 General Electric made average net profits of between $16,000,000 and $21,000,000 on net sales which averaged around $45,000,000. These figures represented profits of 64 to 88 per cent on costs, 39 to 47 per cent on net sales, and 20 to 30 per cent on invested capital.[18] Since total net profits of the General Electric Company ranged only from $28,000,000 to $63,000,000 during the same years, it is evident that far greater profits on sales were achieved in lamp making than in the other phases of the company's business. In fact, the lamp department of General Electric contributed from one-third to two-thirds of total profit while adding only about one-sixth of total sales. The profit rate of Westinghouse on its average lamp sales of about $15,000,000 from 1935 to 1939 was

[16] Profit margins represent a larger percentage of list price for high-wattage lamps.

[17] In economic terminology, the price elasticity of demand for incandescent lamps at a given time is less than one. A reduction in lamp prices does not result in a great enough addition to the number of lamps sold to increase the total value of sales. Even over time, taking into consideration the increase in population, declining power costs, and extensive advertising and promotion, price elasticity is only about one. (See Appendix F.)

[18] United States of America *v.* General Electric et al., *Complaint*, Jan. 27, 1941, pp. 154–155; *Answer of Defendant General Electric Company*, May 15, 1941, p. 62; and *Brief for the United States of America*, Aug. 30, 1946, pp. 117–119.

also high, although not quite so high as that of General Electric, and the earnings of the B licensees were above average.

It is clear that the lamp prices which yielded the dominant concern and its licensees such high profits were above a truly competitive level. Despite the price reductions precipitated by the growth of the independent manufacturers during the thirties, General Electric and its licensees were able to maintain their profit position by continual reductions in costs. The presence of the independents could not prevent profits from exceeding a "normal" return; it could only prevent prices from being set at maximum monopolistic levels for the most widely used types of lamps. Actually, since 1938 the prices announced by General Electric for large lamps of 100 watts and less have put considerable pressure on the independent manufacturers, who must normally undercut General Electric's prices to maintain their sales, and whose operating handicaps have made it difficult for them to achieve commensurate cost reductions.

THE PATENT SITUATION AFTER 1927

Although the invalidation or expiration of the Just and Hanaman, Coolidge, and Langmuir patents removed General Electric's strongest controls over the incandescent-lamp industry, the leader still owned a great many lesser patents covering various features of the incandescent lamp and its manufacture. While they were not of enough importance to prevent the rise of the unlicensed manufacturers, they added considerably to the difficulty of competing with the General Electric group. Three of the remaining General Electric patents were of particular importance: (1) the Pacz patent of March 21, 1922, on non-sag tungsten wire; (2) the Mitchell and White patent of July 25, 1922, on the tipless lamp; and (3) the Pipkin patent of October 16, 1928, on the inside-frosted lamp. The essential data for each are summarized in Table XXI, along with corresponding information for the Just and Hanaman, Coolidge, and Langmuir patents. The features covered by the three secondary patents were introduced commercially by General Electric and its licensees and were made standard in this country. To keep up with the industry leaders and to secure acceptance for their lamps, the unlicensed concerns found it necessary to introduce similar changes.

TABLE XXI: PRINCIPAL PATENTS COVERING INCANDESCENT LAMPS OWNED BY GENERAL ELECTRIC 1912–1947

Patent No.	*Application*	*Issue Date*	*Inventor*	*Source*	*Subject*	*Normal Expiration*	*Court Record*
1,018,502	July 6, 1905	Feb. 27, 1912	Just and Hanaman	Purchased from Austrians	Tungsten filament	Feb. 27, 1929	Upheld
1,082,933	June 19, 1912	Dec. 30, 1913	Coolidge	General Electric employee	Ductile tungsten	Dec. 30, 1930	Partly invalidated, 1929
1,180,159	Apr. 19, 1913	Apr. 18, 1916	Langmuir	General Electric employee	Gas-filled lamp	Apr. 18, 1933	Upheld
1,410,499	Feb. 20, 1917	Mar. 21, 1922	Pacz	General Electric employee	Non-sag tungsten	Mar. 21, 1939	Invalidated, 1938
1,423,956	Mar. 20, 1919	July 25, 1922	Mitchell and White	General Electric employees	Tipless bulb	July 25, 1939	Upheld
1,687,510	June 29, 1925	Oct. 16, 1928	Pipkin	General Electric employee	Inside-frosted bulb	Oct. 16, 1945	Invalidated, 1945

Principal source: *Official Gazette of the Patent Office*, Washington, 1912–1928.

In following the product leadership of General Electric, the small concerns laid themselves open to patent-infringement prosecutions. Wherever possible they used non-infringing designs or methods which would achieve the same purpose; but such designs or methods were not always available. The situation resulted in extensive patent litigation and a continual testing of the validity of the General Electric patents. The court record of the Pacz non-sag tungsten patent was quite similar to that of the Coolidge ductile tungsten patent.[19] One of the first judicial considerations of the patent was in May, 1935, in a prosecution by General Electric against the importer T. Anraku and a number of companies run by him.[20] The Southern California District Court found the patent valid and infringed by the Japanese-made lamps sold by Anraku, and the Ninth Circuit Court of Appeals upheld the lower court on December 20, 1935.[21] A few years later General Electric sued the Wabash Appliance Corporation of Brooklyn for infringement of the Pacz patent on the ground that it was using non-sag tungsten filaments produced without license by the Callite-Tungsten Corporation. The Eastern New York District Court on January 16, 1937, held the patent valid and infringed. Upon appeal by Wabash, the Second Circuit Court of Appeals in the same year found that the product claims of the patent, three of which were involved in the litigation, were invalid because of anticipation by the Coolidge ductile tungsten patent. A further appeal to the Supreme Court, based on the conflicting opinions of the two appeal courts, affirmed the invalidation of the product claims on May 16, 1938,[22] but for another reason, the lack of adequate definition of the invention. The court did not even consider the matter of anticipation. Once again, therefore, the product claims of a General Electric patent were invalidated a very short time prior to the patent's normal expiration date. Although the process claims were not directly involved

19 See pp. 324–325 for a discussion of the Pacz development.

20 In all, General Electric brought twenty suits for infringement under the Pacz patent during its life.

21 *General Electric Company* v. *T. Anraku et al.*, 10 F. Supp. 935 (1935), 80 F(2d.) 958 (C.C.A., 1935).

22 *General Electric Company* v. *Wabash Appliance Corp. et al.*, 17 F. Supp. 901 (1937), 91 F(2d.) 904 (C.C.A., 1937), 304 U.S. 364 (1938).

in the litigation, the Supreme Court decision made it clear that those claims also were invalid.

The Mitchell and White tipless-lamp patent had a somewhat simpler, though longer, court record.[23] The patent, which covered a particular method of constructing tipless lamps, was initially infringed by the unlicensed companies. After a number of suits had been brought under it and the case against the Save Electric Corporation of Toledo, Ohio, had been pushed through successfully by General Electric,[24] the independents switched to the use of the old Jaeger technique, the patent for which had expired in 1920. The Jaeger method was more costly, but it permitted the independents to make tipless lamps freely without legal complications. Although the Mitchell and White patent for the General Electric construction was again held valid in a prosecution against the Eisler Engineering Company in 1927,[25] it was held not infringed by lamps made by the independent manufacturers with the Jaeger technique.[26] At the same time a companion Mitchell and White patent covering the machine for producing stems for the General Electric tipless lamp was declared invalid for want of invention.

The Pipkin inside-frosting patent, which was the last of the important patents, had a long and eventful court record.[27] It covered a double-dip acid process for the inside frosting of lamp bulbs and made broad product claims. Around 1932 the sales subsidiary of the Save Electric Corporation was sued by General Electric for infringement, and the patent was declared invalid by the Northern Ohio District Court in 1934. On March 6, 1936, after an appeal by General Electric to the Sixth Circuit Court of Appeals, the patent was upheld.[28] Other cases initiated at about the same time were settled out of court.[29] Another infringement action under the Pipkin patent was brought in 1937 against the Wabash Appliance Corporation in the Eastern New York District Court at Brooklyn. Again the patent was declared invalid in the district court and upheld on appeal to the Second Circuit Court of Appeals.[30] Wabash then frosted bulbs by a single-dip acid process which it claimed was a non-infringing process. General Electric brought suit in the Brooklyn District Court in 1940 in an attempt to prove that all inside frosting was covered by the Pipkin patent. The motion to punish for contempt was denied. Although General Electric later moved, and was granted permission, to reopen the contempt case, no further court action was taken. The final infringement suit under the Pipkin patent was instituted by General Electric against the Jewel Incandescent Lamp Company of East Newark, New Jersey.[31] In that case the New Jersey District Court declared the patent invalid on December 9, 1942. General Electric's appeal was denied by the Third Circuit Court of Appeals in December, 1944. That decision, which for the first time invalidated the patent in an appeals court, was taken to the Supreme Court by General Electric. The high court declared the patent invalid on November 5, 1945,[32] just twenty days after it had expired.[33] The principal issue throughout all the cases was that of anticipation by the prior art.

The situations with respect to the Pacz and Pipkin patents, as well as the Coolidge and other patents, were indicative of the difficulties faced by both General Electric and the independents in determining and protecting their rights.[34] Since the validity of a patent cannot be decided except by the courts, the unlicensed firms were not able to conduct their business with certainty until final decisions had been made, and were prompted to infringe unlitigated patent claims. The cumbersome mechanism of the

23 See pp. 325–326 for a discussion of the Mitchell and White development.

24 *General Electric Company* v. *Save Electric Corporation*, 4 F(2d.) 584 (1924).

25 *General Electric Company* v. *Eisler Engineering Company*, 20 F(2d.) 33 (C.C.A., 1927).

26 Sixty-eight suits were brought under the Mitchell and White tipless-lamp patent during its life, although only two were pushed through to a decision.

27 See pp. 326–328 for a discussion of the Pipkin development.

28 *General Electric Company* v. *Save Sales Company et al.*, 82 F(2d.) 100 (C.C.A., 1936).

29 General Electric brought twenty-three infringement suits under the Pipkin patent during its life.

30 *General Electric Company* v. *Wabash Appliance Corp. et al.*, 19 F. Supp. 887 (1937), 93 F(2d.) 671 (C.C.A., 1938).

31 The company has since been renamed Jewel Products, Inc.

32 *General Electric Company* v. *Jewel Incandescent Lamp Company et al.*, 47 F. Supp. 818 (1942), 146 F.(2d.) 414 (C.C.A., 1943), 66 S. Ct. 81 (1945).

33 The British and Canadian Pipkin patents were both invalidated in 1940.

34 The same difficulty had been faced by the lamp industry in connection with the basic Edison patent, the status of which was not clarified for about twelve years after it was issued.

courts delayed the final determination in some cases for many years, or even until the patent had expired. Even where the patents were eventually held invalid, General Electric had some measure of protection.

The increasing strictness of the American courts, particularly the Supreme Court, in passing on the validity of patents is noteworthy. The trend became more and more apparent during the late twenties and the thirties. The policy appeared first in the high court and was accepted more gradually by the lower courts. The state of the prior art and the exact conformity of specifications and claims to patent laws and regulations were treated with increasing strictness. It is now more difficult to obtain a patent monopoly in the United States than it was from twenty to fifty years ago. In this evolution of the legal interpretation of patent rights, the American courts seem to be moving along a path which the British took somewhat earlier.[35] In Germany, France, and other continental countries, the policy was established even sooner; in the entire history of electric lighting it was not possible in those countries for any single firm to obtain a broad legal monopoly in incandescent lighting. It was partly for that reason that continental lamp producers turned more quickly to patent pools and cartelization as means of conducting their business.

An important factor in the collective rise of the unlicensed lamp producers during the thirties was their organization of the Incandescent Lamp Manufacturers' Association in June, 1933. It was strongly encouraged and supported by Charles Eisler of the Eisler Engineering Company and by other outside suppliers of lamp parts and equipment. The suppliers naturally wished to keep the unlicensed manufacturers in business to provide a continuing and growing market for their own products.

The Association has advanced the common interests of the unlicensed producers through the exchange of information, coordination of activities and by a variety of other ways. One of its principal functions has been in connection with patent litigation. Prior to 1933 the individual small producers could not afford to fight General Electric on patents. With the organization of the

[35] The stern attitude of the Supreme Court has been relaxed slightly since the end of the war, however.

Association and the expansion of their production,[36] they pooled their resources to hire outstanding counsel in the defense of infringement suits initiated by General Electric against any one of them. Each independent company had a similar interest and stake in the outcome, and their joint action permitted them to afford defenses which would have been too expensive for individual companies.

Although new patents in great number have been issued to General Electric covering the design of incandescent lamps, none granted since 1928 has been of major importance. The jackets enclosing standard lamps for general illumination sold by General Electric in 1944 were typical of those used in 1941; they listed twenty patents under one or more of which the lamp was being produced and sold.[37] Those patents are listed and summarized in Table XXII. There was no longer a fundamentally important patented feature in the design of standard incandescent lamps, although the Phelps, Rudd, and various other listed patents represented useful improvements. On the jackets of their lamps Westinghouse and the other licensees listed in addition to the patents under which they were licensed by General Electric some of their own patents. In each instance they were minor improvement patents. Actually, many of the General Electric patents listed by the licensees were not even used by them. Of General Electric's ten most important design patents issued after 1920, seven were never litigated. Of the three litigated, two were held invalid and one not infringed. The patents owned by independent manufacturers similarly covered only minor details of lamp design, which were not essential to the production of lamps made by other companies.

During the thirties the patents owned by General Electric covering machinery and equipment for assembling finished lamps

[36] Along with their expansion of production and reduction of overhead at that time, the independents were able to buy somewhat better machinery and obtain price reductions on lamp parts and supplies. Typically, when General Electric announces price reductions on electric lamps, Corning grants price cuts on glass bulbs.

[37] Besides the standard incandescent lamp for general illumination, various special General Electric filament lamps were produced under other patents. In addition, the big company had title to or control over hundreds of other patents on incandescent lamps which were not used in the production of commercial lamps.

TABLE XXII: PATENTS COVERING THE PRODUCTION OF STANDARD INCANDESCENT LAMPS BY THE GENERAL ELECTRIC COMPANY

1944

Patent No.	*Date of Application*	*Date of Issue*	*Patentee*	*Original Assignee*	*Principal Subject of Patent*
1,652,398	Oct. 26, 1925	Dec. 13, 1927	Edward A. Everett, New York	————————	Collar on lamp base which grips neck of bulb
1,687,510	June 29, 1925	Oct. 16, 1928	Marvin Pipkin, Cleveland Hgts., O.	General Electric Co.	Method of inside frosting of lamp bulbs
1,694,997	Sept. 20, 1926	Dec. 11, 1928	Irving H. Van Horn, E. Cleveland, O.	General Electric Co.	Extension on lamp base to grip neck on large sizes
1,723,920	June 9, 1921	Aug. 6, 1929	Paul O. Cartun, Cleveland Hgts., O.	General Electric Co.	Arrangement of lead-in wires and support wires for particular filament arrangement
1,795,181	Apr. 29, 1927	Mar. 3, 1931	Roscoe G. Phelps, Cleveland, O.	General Electric Co.	Shoulder in neck of bulb, and portion extending into base
1,809,661	Feb. 19, 1929	June 9, 1931	Daniel K. Wright, Cleveland Hgts., O.	General Electric Co.	Removing deposit from bulb by loose granules of refractory material
1,832,751	May 15, 1929	Nov. 17, 1931	Ralph B. Thomas, Cleveland, O.	General Electric Co.	Shoulder and sleeve arrangement on bulb and base for firm clamping of base
1,906,819	Aug. 23, 1928	May 2, 1933	Carl Severin, Cleveland Hgts., O.	General Electric Co.	Construction of stem, lead-in wires, and filaments for multi-filament lamp
1,983,362	Apr. 24, 1934	Dec. 4, 1934	Walter J. Geiger and Alfred T. Gaskill, Cleveland Hgts., O.	General Electric Co.	Method of locating concentrated filament in definite position in bulb
2,021,758	Dec. 8, 1933	Nov. 19, 1935	Irving H. Van Horn, E. Cleveland, O.	General Electric Co.	Fuse in lead-in wire surrounded by non-conductive shield

TABLE XXII: PATENTS COVERING THE PRODUCTION OF STANDARD INCANDESCENT LAMPS BY THE GENERAL ELECTRIC COMPANY—*Continued*

1944

Patent No.	*Date of Application*	*Date of Issue*	*Patentee*	*Original Assignee*	*Principal Subject of Patent*
2,069,079	July 10, 1935	Jan. 26, 1937	Frank H. Rudd, Cleveland, O.	General Electric Co.	Construction of stem
2,074,246	Oct. 17, 1936	Mar. 16, 1937	Charles Adler, Jr., Baltimore, Md.	————————	Double filament construction for traffic-signal lamp
2,084,176	Oct. 17, 1936	June 15, 1937	Charles Adler, Jr., Baltimore, Md.	————————	Arrangement of double filaments in traffic-signal lamp
2,132,368	Mar. 16, 1936	Oct. 4, 1938	Walter J. Geiger, Cleveland Hgts., O.	General Electric Co.	Miniature lamp having small head and larger neck fitting into base
2,134,574	Aug. 24, 1937	Oct. 25, 1938	Emma B. Pinkle, E. Cleveland, O.	General Electric Co.	Methods of connecting coiled filament in lamp
2,145,186	July 1, 1938	Jan. 24, 1939	Wells J. Meeker and Lucas Renftle, Warren, O.	General Electric Co.	Method of attaching filament to hooked lead-in wire
2,164,288	June 25, 1938	June 27, 1939	Paul O. Cartun, Cleveland Hgts., and Will D. Pew, E. Cleveland, O.	General Electric Co.	Filament arrangement
2,198,919	Mar. 21, 1939	Apr. 30, 1940	Gwilym F. Prideaux, Cleveland Hgts., O.	General Electric Co.	Construction for miniature lamps so that lead-in wires and filaments have same vibration frequency
2,227,324	May 24, 1940	Dec. 31, 1940	Carl Severin, Cleveland Hgts., O.	General Electric Co.	Flattened end on lead-in wire into which filament sunk and welded
2,232,816	Jan. 19, 1940	Feb. 25, 1941	Irving H. Van Horn, E. Cleveland, O.	General Electric Co.	Disk and screen in high-wattage lamps to diffuse hot gases

Principal Source: *Official Gazette of the Patent Office*, Washington, 1927–1941.

were far more important to the B licensees than those covering the lamp itself. The use of highly efficient machinery developed, constructed, and sold by the licensor aided in reducing costs below the levels at which most unlicensed firms operated, and typically resulted in larger unit profits for the licensees. Since machinery was sold by General Electric with the understanding that it might be repurchased at predetermined prices in the event of termination of the license, the licensees felt that they would lose their principal advantage over the unlicensed firms if they should terminate their licenses. Besides the potential danger of losing their existing equipment, they were faced with the long-run problem of obtaining new and improved machinery. They wanted better equipment than was available from the independent machinery suppliers, yet at that time they did not have adequate facilities or experience in machinery development themselves. They continued to restrict their outputs within the quotas established by General Electric, therefore, even when they might have expanded sales beyond those quantities had they been free to do so. The B licensees turned their expansionary impulses in other directions. For example, Hygrade Sylvania expanded its radio tube production and after 1938 produced fluorescent lamps as an unlicensed firm. Ken-Rad also made radio tubes, and Consolidated expanded into the production of a line of equipment quite unrelated to electric lamps.

SUPPLY OF LAMP PARTS AND MACHINERY

The general situation with respect to sources of lamp parts and lamp-making machinery for the various groups of producers continued unchanged from 1927 to 1941, despite the increasing importance of the unlicensed manufacturers. General Electric and Westinghouse were still the only domestic producers of lamp bases. General Electric supplied the complete needs of its B licensees, while the unlicensed firms bought both from General Electric and from foreign sources until wartime conditions halted imports. Even though after 1927 discriminatory pricing by the Providence Base Works was discontinued, the situation gave continuing advantages to the large companies.

In the production and sale of glass bulbs, tubing, and cane, the situation also remained much as it was before 1927. General Electric and Corning continued to hold or to be licensed under the principal patents relevant to the production of glass parts for incandescent lamps and produced almost all such glass made in this country.[38] Under the series of agreements executed between them, General Electric filled most of its own needs. After 1928 it reduced its glass purchases from Corning from 12 per cent to 6 per cent of its annual requirements, mostly in special sizes. Under sales agreements with Westinghouse, with the B licensees and with many of the unlicensed firms, Corning continued to supply all needed glass to most of the rest of the American incandescent-lamp industry. Westinghouse and Tung-Sol were licensed to manufacture miniature bulbs for their own use from tubing supplied by Corning, however, and some of the independents made their own miniature bulbs.

Prior to 1933 imports of glass bulbs amounted to 2 or 3 per cent of domestic production; after that date they fell to considerably less than 1 per cent. Most of the imported bulbs came from N. V. Philips before 1933; after that year such imports as there were came largely from independent producers in Germany and consisted of sizes and types not ordinarily made in this country. The Tariff Commission states that the sudden cessation of imports from the Netherlands was "due principally to the operation of the international licensing agreements."[39] It is claimed by General Electric that the devaluation of the dollar made it impossible for Philips to sell bulbs in this country. However, in 1936 Corning accepted a ten-year exclusive license from Philips on lamp-bulb patents at an annual $20,000 royalty, and it granted a sublicense to General Electric for $10,000 a year. Philips agreed not to export bulbs, tubing, or cane to the United States. The international agreements, the 20 per cent tariff duty, and the low costs of production of the American producers effectually served to limit foreign competition in the lamp-glass business, while internal conditions, including patent rights and licenses, relative costs of production, and distribution of the market, kept domestic lamp-glass production in the hands of General Electric and Corning.

The United States Department of Justice brought antitrust proceedings a few years later against General Electric, N. V.

[38] See pp. 353–356 for discussions of the principal lamp-glass patents.
[39] U.S. Tariff Commission, *op. cit.*, p. 17.

Philips, Corning, and six officers of the companies for alleged criminal conspiracy to prevent the importation of glass bulbs and tubing into the United States from Holland. The defendant companies and most of the accused officers pleaded *nolo contendere* and paid fines totaling $47,000 which were imposed by the Southern New York District Court on September 9, 1941. Wartime conditions by that time made it impossible to import bulbs from Holland, however, and no change in the conduct of the industry resulted.

Under the arrangements followed in this country until the expiration of most of the sales agreements in 1940,[40] General Electric was favored by Corning over all other producers of electric lamps. Westinghouse was favored over the B licensees and the independents, while the B licensees were favored over the independents. In the determination of prices of glass parts the General Electric group was charged the minimum prices, whereas the independents were charged prices not more than 10 per cent greater than these minima.[41] General Electric and Corning interchanged patent licenses, technical information, and all cost data. Corning's prices were based in part on General Electric's own production costs. Westinghouse had the right to obtain certain information from Corning regarding costs and sales. The B licensees and the independents were not entitled to such information.

With respect to other parts and equipment necessary to the production of electric lamps, General Electric's position also continued to be equal or superior to that of any other domestic lamp producer. Filament and lead-in wires were made by the two large companies for themselves. General Electric continued to supply most of the needs of its B licensees, and the independent producers continued to buy their wire from outside suppliers or make their own. The Callite-Tungsten Corporation, a higher-cost producer than General Electric, was the principal outside source for filament wire and lead-in wire.

40 The agreement between General Electric and Corning had an expiration date of Jan. 1, 1951.

41 If either the B licensees or the independent manufacturers purchased 20 per cent or more of their requirements in less than carload lots, the prices on those purchases could be increased by 5 per cent.

After the expiration in 1933 of certain patents held by the Air Reduction Company, Inc., General Electric shared the domestic production of argon gas for use in gas-filled lamps with the Air Reduction Company and with the Linde Air Products Company, a subsidiary of the Union Carbide & Carbon Corporation.[42] Prior to World War I, General Electric had purchased argon from Germany. When the foreign source of supply was cut off, General Electric bought the gas from Linde Air Products Company until 1921. At that time, the American leader was experimenting with a process of its own for producing argon. The Air Reduction Company objected that the proposed process would infringe its patents and offered to sell argon to General Electric at a lower price than was being charged by Linde. Accordingly, General Electric bought its argon from Airco until 1933, when the latter's principal patents on the separating process expired. General Electric then produced argon for its own requirements, in addition to selling high-ratio[43] argon to its miniature-lamp licensees after 1933 and to its large-lamp licensees after 1937. Low-ratio argon was purchased by the licensees from Airco. Prior to 1933 the independents were not able to buy argon and had to use pure nitrogen in their lamps. After about 1938 the entire argon requirements of the independents were met by the outside suppliers, Linde and Airco, since European sources were cut off by the war.

The industry leader also maintained its position in the production of lamp-making machinery. Alfred Hofmann & Company and the York Electric & Machine Company were licensed by General Electric during the twenties to produce lamp-making machinery for sale only to General Electric licensees. Under those agreements few sales were made inasmuch as the licensees obtained most of their machinery directly from General Electric, which had instituted a leasing system shortly after signing the agreements with Hofmann and York. The license arrangement with Hofmann was terminated in 1930, when General Electric paid Hofmann $65,000 for damages claimed to have been suf-

42 See United States of America *v.* General Electric Company et al., *Brief for General Electric Company and International General Electric Company*, Dec. 2, 1946, pp. 383–391.

43 High-ratio argon contains smaller percentages of nitrogen than low-ratio argon. The nitrogen is introduced to prevent arcking through the argon, and the ratio required varies with the size and type of lamp.

fered in connection with the agreement.[44] After 1930 Hofmann and the Eisler Engineering Company shared most of the small percentage of domestic business in lamp-making machinery available to firms outside the General Electric group. While the Hofmann and Eisler equipment was adequate for most of the independents, it lagged far behind the high-efficiency equipment designed by General Electric's larger and more expert machine-development laboratory.

Table XXIII presents a summary of the discussion of the preceding paragraphs, indicating for the principal parts and equipment the typical pattern of supply to the various producing groups in the late thirties.

TABLE XXIII: MAJOR SOURCES OF SUPPLY FOR LAMP PARTS AND MACHINERY IN THE UNITED STATES DURING THE LATE 1930's

Major Sources of Supply for	*Licensor*	*A Licensee*	*B Licensees*	*Unlicensed Domestic Manufacturers*
Lamp bases	Self	Self	General Electric	General Electric Imports
Glass parts	Self	Corning	Corning	Corning Imports
Wire and welds	Self	Self	General Electric Outside supplier	Outside suppliers Self
Argon and other gas	Self	General Electric Outside supplier	General Electric Outside supplier	Outside suppliers
Machinery and equipment	Self	General Electric Self	General Electric Self	Outside suppliers Self

Source: Arthur A. Bright, Jr., and W. Rupert Maclaurin, "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp," *Journal of Political Economy*, University of Chicago Press, Vol. LI, p. 433 (Oct., 1943).

OTHER RELATIONSHIPS IN THE LAMP INDUSTRY

There were certain other conditions and relationships in the electric-lamp industry which contributed to the favorable competitive position of General Electric and Westinghouse, the two "Mazda" manufacturers. A large proportion of their lamps was sold to ultimate consumers through agents, who sold for the lamp companies at prices set by the principals.[45] Some of the ten different classifications of agents acted as jobbers, distributing lamps to other smaller agents. The second dealer also was required as a subagent to fix his prices in accordance with the wishes of the lamp producer. Through the agency method, the "Mazda" manufacturers were enabled to control the marketing of their lamps far more strictly than would have been possible under normal jobbing procedure.

General Electric and Westinghouse were able to obtain as agents many of the principal chain and independent grocery, drug, notion, electrical, and other stores throughout the country. In 1939 General Electric had a total of more than 80,000 domestic agents of all types, and Westinghouse had another 30,000. In addition, both General Electric and Westinghouse owned supply companies which aided materially in their distribution of lamps as well as other products. The sale of lamps through central stations continued to decline during the thirties. Under the agency system, distribution costs for General Electric in 1940 were 16.5 per cent of sales. Although the situation by no means excluded competing lamps from the market, it did guarantee a great number of the best wholesale and retail outlets for the two largest lamp producers in most areas. Partly because of their relative disadvantages in retail selling, the B licensees and unlicensed producers made a very large proportion of their sales directly to large users of electric lamps. The independents also began to look abroad for markets.

The size and strength of General Electric and Westinghouse gave them a considerable advantage in the marketing of electric lamps, quite apart from the size of their respective lamp divisions

44 Hofmann's lamp-making machinery business was almost completely lost as a result of the operation of this license agreement. (See United States of America *v.* General Electric Company et al., *Complaint*, Jan. 27, 1941, pp. 108–109, and *Answer of Defendant General Electric Company*, May 15, 1941, pp. 28–29.)

45 In 1941 General Electric made 23 per cent of its lamp sales directly to large consumers by its own sales department, 52 per cent to large buyers through wholesale agents, and 25 per cent to the general public through retail agents (United States of America *v.* General Electric Company et al., *Brief for General Electric Company and International General Electric Company*, Dec. 2, 1946, pp. 174–175).

in relation to the other lamp producers.[46] The names General Electric and Westinghouse are almost as old as the electrical industry, and they are known in connection with almost every type of electrical equipment from turbines and generators to fuses and flashlight lamps. The reputation of each company in every other field tended to enhance its reputation in the production of electric lamps.[47] Continued heavy advertising by all divisions of each company in amounts unapproachable by smaller producers aided in increasing consumer acceptance for all General Electric and Westinghouse products. The joint trade-name "Mazda" was well known, and the unknown or less well known brands of the unlicensed lamp manufacturers and even of the B licensees made sales by those producers more difficult. Although they could not hope to compete on a national basis, even the smaller lamp producers could obtain sufficient sales by concentrating on a restricted area or market and by selling some lamps for export. That is one reason why most independent lamp producers and manufacturers of lamp-making machinery are located in or near New York City.

During the long histories of the two largest lamp manufacturers, favorable relationships were maintained between them and other groups outside the lamp industry. Hundreds of the operating utility companies had originally been organized as licensees of the Edison, Thomson-Houston, Westinghouse, or other pioneer electric companies. The utilities grew as the electrical manufacturing companies grew, and each group was dependent on the other. For many years General Electric and Westinghouse had important stock interests in a large number of utilities. Even though the financial ties were broken, the strong community of interest led to continued cooperation between the manufacturing companies and the utilities. The "Mazda" lamp made by General Electric and Westinghouse was accepted as standard by the utilities,[48] who bought and recommended principally the lamps made by General Electric and Westinghouse.

46 The Westinghouse Lamp Company, which had formerly been operated as a wholly owned subsidiary, was absorbed by the Westinghouse Electric & Manufacturing Company in 1936 for tax purposes. The organization and activities of the lamp-making subsidiary were continued virtually unaltered as a division of the parent company.

47 In the actual conduct of operations, the lamp business of both General Electric and Westinghouse has been permitted a very high degree of autonomy.

A relationship somewhat similar to that with the utilities existed between the "Mazda" lamp producers and certain fixture manufacturers and commercial testing laboratories. The RLM Standards Institute[49] is an association of about a dozen of the largest manufacturers of industrial electric-lighting fixtures. This association, in collaboration with the two large lamp producers[50] and the utilities, established standards which the products of its members had to meet. RLM favored the use of fixtures made by its members with lamps having the performance characteristics of "Mazda" lamps. The fixtures were tested and certified by the Electrical Testing Laboratories, which, although it was impartial in its judgment of electrical goods submitted to it, seems also to have been favorably disposed toward General Electric and Westinghouse by virtue of its long-established contacts with them and its knowledge of the high standards of their lamps. It has conducted routine and special tests of electric lamps and other appliances and equipment for them for fifty years. The testing and certifying arrangements among the "Mazda" manufacturers, RLM, and ETL enhanced the prestige of all three groups.

SITUATION UPON ENTRY OF THE UNITED STATES INTO WORLD WAR II

The situation in the incandescent-lamp industry during the thirties, which has been described above, began to change shortly before the entry of the United States into World War II. Although many factors and relationships remained unaltered, the license system which had been in existence for so many years began to show signs of cracking up. Westinghouse, the A licensee, and Sylvania, the biggest producer of large lamps among the B licensees, became somewhat more restive under their license re-

48 Standards based largely upon the characteristics of General Electric and Westinghouse lamps have also been established by the U.S. Bureau of Standards. The two large companies used the Bureau of Standards specifications as competitive selling points for many years, until other manufacturers were finally able to meet the same specifications.

49 RLM stands for Reflector and Lighting-equipment Manufacturers.

50 Westinghouse is a producer of lighting fixtures and, through its Lighting Division, is a member of RLM. General Electric does not make fixtures.

strictions. The impending expiration of the licenses in 1944 raised certain doubts as to whether there might soon be important changes in the organization of the industry. The patent situation no longer favored a continuation of the licensing and quota system for the production of incandescent lamps. The growing importance of the fluorescent lamp by 1941 was also a factor in the loosening of control over the older type. Sylvania had already broken away from General Electric in the new field. Fluorescent lighting promised to replace much of incandescent lighting, and a strong patent position with respect to it rather than with respect to the incandescent lamp had become of increasing importance to General Electric and to the other individual companies.

Another perhaps even more important factor leading to change in the incandescent-lamp industry was the prosecution initiated against General Electric and eleven other defendants by the federal government under the antitrust laws. As a part of the antitrust campaign against alleged monopolies initiated by the Department of Justice, on January 27, 1941, a new civil suit was brought against the leading firms of the American lamp industry in the New Jersey District Court. Included as defendants with General Electric were the International General Electric Company, Inc., Westinghouse, the five B licensees, N. V. Philips' Gloeilampenfabrieken,[51] and the Corning Glass Works and two companies associated with it.

The complaint recounted the history of the incandescent-lamp industry and pointed out the manner in which patent accumulation, patent-licensing agreements, and various other acts and agreements had led to a continuation of General Electric supremacy in the industry after the expiration of all basic patents. It was alleged that the effect of all these acts and agreements had been to acquire and maintain an illegal monopoly in the production, sale, and use of incandescent lamps. It was charged that domestic competition was unlawfully restricted in a variety of ways, and also that patent-licensing agreements executed by General Electric with foreign producers unlawfully restricted international trade in electric lamps. The quota arrange-

[51] N. V. Philips was brought into the suit primarily because of its licensing and other agreements with General Electric. Those agreements were alleged to have restricted competition in the American market for incandescent lamps.

ments and agency-distribution method, which had been attacked and upheld in the 1926 antitrust suit, were alleged to be illegal as modified since 1926 in conjunction with the other acts enumerated.

Answers to the complaint of the federal government were submitted by the defendants. General Electric contested the case; it admitted various facts but denied that they were in violation of the law. Similarly, most of the other defendants denied the complaints. Westinghouse and Hygrade Sylvania took different stands, however. Without admitting that it had participated in illegal restraints of trade, Westinghouse consented to have entered against it a final judgment of the court in which it agreed to abide by whatever judgment should eventually be entered in the remainder of the case.[52] In this consent decree, which was entered April 10, 1942, Westinghouse was enjoined from participating in any restriction as to price, quota, or territory in the production, use, or sale of lamps, lamp parts, or lamp-making machinery. It agreed to license royalty-free all who desired licenses under its lamp patents, providing the licensee similarly granted royalty-free licenses to it. It agreed to treat all other firms equally and without discrimination. Most of the injunctions and restraints were to become effective when and if the same injunctions should become effective against General Electric, although the compulsory licensing became effective at once.

That action of Westinghouse in the antitrust case marked its most important split with General Electric in the lamp business since 1912. Westinghouse apparently felt that its long-established junior partnership in the production of incandescent lamps was no longer advantageous. Even though the license agreement of 1927 was soon to expire, Westinghouse was willing to end it sooner. Pending later developments, however, the industry went on much as before.

Hygrade Sylvania also denied the allegations of the federal government with respect to the legality of its own acts, and it entered counterclaims against General Electric and Corning.[53] It claimed that the two companies, by various methods, had monop-

[52] United States of America *v.* General Electric Company et al., *Final Judgment Against Westinghouse Electric and Manufacturing Company*, Apr. 10, 1942.

[53] United States of America *v.* General Electric Company et al., *Answer and Cross-Claims of the Defendant Hygrade Sylvania Corporation*, 1941.

olized the sale of glass parts for electric lamps so that it had been unable to satisfy its needs for glass except at monopolistic prices from Corning. It claimed damages of $1,250,000 and requested an award of three times that sum. Regarding its own alleged complicity in illegal license and quota restrictions, Hygrade Sylvania pleaded that its own actions had been necessitated by conditions in the industry. A principal factor in its willingness to continue the license arrangement was said to have been the General Electric option to repurchase machinery sold by the licensor if the license had been canceled. Much of Hygrade's best machinery might have been lost.

That was the situation in the lamp industry at the end of 1941. The license system was tottering; the independents were continuing to rise; the fluorescent lamp was increasing in relative importance; and the entire conduct of the lamp business was under vigorous attack by the Department of Justice. It was clear that the industry was approaching a turning-point. And then came the war.

2. *The Wartime and Early Postwar Industry, 1942–1947*

LITIGATION DURING THE WAR YEARS

The trial of the antitrust action against General Electric and other members of the incandescent-lamp industry was originally set for March 18, 1942. After two brief postponements the case was postponed indefinitely upon request of the Secretaries of War and Navy. Active participation by the United States in World War II made it inadvisable, in the eyes of the military services, to occupy the time of the executives of General Electric in court action. It was felt that the months which would be required for making the necessary preparations and for participating in the court proceedings would interfere with the war production effort. Further prosecution of the case was suspended for the duration of the war.

Although the antitrust trial was suspended, there were certain other legal developments during the war years of importance to the incandescent-lamp industry. Following the indefinite postponement of the case, the Jewel Incandescent Lamp Company, on behalf of itself and ten other unlicensed producers of large

incandescent lamps, on October 1, 1942, petitioned to intervene in the antitrust suit against General Electric and the other members of its group. The independent lamp manufacturers typically had confined themselves to a limited number of sizes and types of lamps for which large markets exist. They made principally lamps of 40, 50, and 60 watts. These constituted their "bread and butter" lines. As of September 1, 1942, General Electric had announced a reduction in list price from thirteen to ten cents each for the most commonly used standard lamps in these three sizes. Prices for incandescent lamps of the larger sizes were not reduced. It was claimed by Jewel and the other independents that General Electric made the reductions, which all other producers had to follow to maintain their sales, in order to force the independents out of business.[54] They claimed that with a list price of ten cents they would not be able to cover their production and selling costs. They further claimed that changes in production costs did not justify a decrease in list prices, for costs were rising. Moreover, they pointed out that the only lamps for which reductions were announced were these three sizes of incandescent lamps, fluorescent lamps, and a few vapor types. No price reductions were made for incandescent lamps of higher wattage, on which profit margins are considerably greater, and which the independent producers do not make in large quantities. The independents therefore sought an injunction restraining General Electric and Westinghouse from selling the 40- to 60-watt lamps at the new low prices. The petition was denied by the lower court on January 21, 1943, and by the Supreme Court on April 20, 1943.

After denial of their petition for intervention, a group of the independents brought new actions against the industry leaders, who they claimed were unlawfully monopolizing the production and sale of incandescent lamps. One action was brought by five of the unlicensed lamp producers against the Corning Glass Works on June 6, 1944. The complainants were the Jewel Incandescent Lamp Company, the Wabash Appliance Corporation, the Elram Lamp Works, the American Lamp Works, and the Dura Electric Lamp Company, all of which are located in

54 United States of America *v.* General Electric Corporation et al., *Notice of Petition and Motion for Injunction Pendente Lite, Petition, Complaint of Intervention and Affidavits in Support Thereof*, Oct. 1, 1942.

the vicinity of New York City. They claimed that monopolistic prices charged by Corning, which is their sole source of supply for glass bulbs, tubing, and cane, had caused them substantial losses. They requested triple damages to a total of $34,500,000. General Electric, Westinghouse, the Libbey Glass Company, N. V. Philips, and other companies were named in the complaint. They were not made defendants in that suit, however. The plea of *nolo contendere*, which Corning had filed in the 1941 antitrust action over glass bulbs and tubing, did not constitute an admission of guilt, and Corning contested the new case. It was eventually settled with the payment by Corning of damages totaling $400,000 to the five plaintiffs and to other of the unlicensed concerns who had price grievances.

Prior to their action against Corning, the same five unlicensed manufacturers listed above had brought another triple-damage suit against General Electric in the New Jersey District Court. They asserted in their complaint of December 6, 1943, that the big company had violated the antitrust laws in its conduct of the lamp business and had caused them severe losses. Since the issues involved were so inextricably tied up with the federal antitrust case in the same court, the suit was adjourned indefinitely by stipulation pending the outcome of the earlier proceedings.

To add further to the worries of General Electric, still another federal antitrust suit was filed against the company and its subsidiary, the International General Electric Company, on January 18, 1945. The complaint charged that the agreements of the American companies with six foreign firms in Great Britain, France, Belgium, Germany, Japan, and Italy and the investments in them had restrained international trade and had violated the Sherman Antitrust Act and the Wilson Tariff Act. The Department of Justice restated its intention of eliminating the effects of cartels on the American economy. The government attack in that instance was on the General Electric Company as a whole, not just the lamp department. Nevertheless, the lamp department, with its patent agreements with other leading lamp producers throughout the world, was intimately concerned with the proceedings. That trial was also postponed until the end of the war.

WARTIME AND POSTWAR CHANGES IN THE INDUSTRY

Despite the wartime delays in the readjustment of the incandescent-lamp industry, a number of events and changes are worthy of note. The demand for lamps rose to new heights. Signs of the loosening up of competition increased, and yet other developments led to greater difficulty in competition by the independent group of manufacturers.

The war created a strong demand for incandescent lamps, including a great number of special types never made before. The demand continued high after the end of hostilities. Domestic shipments of large lamps, excluding photoflash lamps, reached the following levels: [55]

Year	*Lamps Shipped*	*Manufacturers' Value* [a]
1942	792,700,000	$91,000,000
1943	700,000,000	80,500,000
1944	750,000,000	86,300,000
1945	759,300,000	88,700,000
1946	714,300,000	78,500,000
1947	830,300,000	91,800,000

[a] Retail value is almost double manufacturers' value.

The production and sale of miniature incandescent lamps, which were used in enormous quantities in military aircraft and motor vehicles, similarly reached new heights during the war and immediate postwar years. In 1945, 315,400,000 units valued at $20,800,000 were shipped for domestic consumption, and by 1947 the total had risen to 444,900,000 units valued at $29,900,000. During the war European sources of supply were cut off for many nations, and American producers found themselves called upon to export in much greater volume than had been customary. Total exports in 1945 were 60,724,000 lamps valued at $7,423,000, as compared with average prewar exports valued at about $1,000,000. In 1947 lamp exports totaled 81,300,000 units valued at $10,600,000.[56]

General Electric and Westinghouse received a very large pro-

[55] See Bureau of the Census, U.S. Dept. of Commerce, *Facts for Industry Electric Lamps*, Washington, Nov. 22, 1944; Mar. 29, 1946; July 15, 1946; Mar 6, 1947; June 13, 1947; Sept. 2, 1947; Dec. 2, 1947; and Mar. 9, 1948.

[56] See Appendix G for a detailed analysis of production and domestic and foreign shipments of electric lamps during 1945, by types of lamp.

portion of the military orders for electric lamps, partly because of the ability of their engineering staffs to develop quickly more than 150 new lamps for specialized needs.[57] Their combined share of the domestic market rose from about 76.1 per cent in 1941 to 77.7 per cent in 1942, 78.5 per cent in 1943, and 79.1 per cent in 1944. It went even higher during the next two years. The B licensees maintained their market share practically unchanged through 1942 and rose to 10.5 per cent in 1943 and 1944. The independents fell steadily from 14.2 per cent in 1941 to 10.5 per cent in 1944 and even farther in 1945 and 1946. Despite the expanded total market for lamps, the numerical output of the unlicensed manufacturers declined. They received none of the federal government orders and had difficulty in obtaining adequate labor forces, materials, and machinery. In most instances output fell to 40 to 60 per cent of capacity. They were able to maintain dollar volume fairly well, however, by concentrating on higher-priced specialties.

The most significant wartime change in the structure of the lamp industry was the virtual end of the General Electric patent-licensing system. The pending antitrust action seems to have been partially responsible for the termination of the scheme. On December 31, 1944, the B licenses of Sylvania, Tung-Sol, Ken-Rad, and Chicago Miniature expired and were not renewed. The A license arrangement with Westinghouse was canceled soon afterward, on August 1, 1945. In December of 1944, General Electric acquired all the assets of Ken-Rad which had been used in the manufacture and sale of radio tubes. A few months later, in May, 1945, after Ken-Rad's license had been terminated along with those of the other companies, Westinghouse purchased all of Ken-Rad's lamp business, which has since been operated by Westinghouse as a wholly owned subsidiary.

The only lamp producer which has retained its old license from General Electric for the production of incandescent lamps is Consolidated. In 1939 its B license was amended to allow the production of fluorescent lamps under General Electric patents.

57 The wartime engineering and production problems of the electric-lamp industry were not critical. Aside from the substitution of certain materials, the elimination of unnecessary varieties of lamps (such as decorative lamps, the 50-watt and 75-watt standard lamps, and the Type D lamp), and the addition of new military lamps, the product line was changed very slightly.

At the same time its incandescent-lamp license was extended to 1957 with the specification that either license should automatically cease upon termination of the other. The permission to make fluorescent lamps was thus tied to the incandescent lamp, and it was greatly to Consolidated's advantage to continue its previous relationships with General Electric. The same compulsion did not exist for the other B licensees, who had not been offered or had refused fluorescent licenses. Except Consolidated, Westinghouse had been the sole producer of fluorescent lamps under General Electric patents. Upon termination of its A license, arrangements were made between the two big companies to use without royalty or price or quota restrictions each other's lamp, lamp-part, and machinery patents issued or applied for by August 1, 1945. That permitted them to avoid patent infringement and yet ended the license pattern which had been under attack by the Department of Justice.

The free interchange of technical data between the two companies was also terminated, and the jointly used trademark "Mazda" was dropped for the standard line. The Department of Justice had charged that the trademark had been used by the two companies to monopolize the lamp industry and restrain trade. With the end of the licensing system, it was not feasible to continue to use the mark generally, and it is now used only for special lamps.

When the licenses of the B group expired, the companies were permitted to keep the machinery which they had purchased from the licensor. The machinery problem had been one of the principal reasons for the continuation of the licenses to 1944, since patents covering the design of the lamp itself were no longer of great importance. General Electric also waived claim to any damages resulting from future infringement of incandescent-lamp patents owned or applied for by General Electric by January 1, 1945.[58] Despite the end of quota restrictions, there has not yet been any significant increase in the share of the business done by the former licensees.

Events during the war raised several new problems for the unlicensed manufacturers. Prior to the war, it had been customary

58 The waiver was subject to termination by General Electric on three months' notice.

for them to pay lower wage rates than those paid by the General Electric group. In 1937 the averages for the two groups were 45 cents an hour and 62 cents an hour, respectively.[59] Even the materially lower wage rates only partially offset the greater labor requirements of the independents' slower machinery, and their profit margins were smaller than those of the license group. The price reductions initiated by General Electric in 1940 and 1942 and the wartime increases in wage rates and other costs put great pressure on the independents. Most of the unlicensed firms were unionized in 1942. The negotiation of union contracts and the diminishing supply of available labor resulted in a wartime increase in wage rates to an average of about 65 cents an hour, and the unions appear to wish to equalize wage rates with those paid by the larger companies. Without the wide profit margins, the greatly expanded output, and the broad product lines of the larger companies, the independents realized that they would have to obtain better machinery and lower their labor costs to continue in business.

Faced with such a situation, the independents have had three major alternative courses of action. One is to obtain the necessary improved machinery from Eisler, Hofmann, or other outside suppliers. Another is for each company to develop better equipment itself. The third is to band together in machinery development. Neither Eisler nor Hofmann has undertaken major redesigning of its product as yet, and there is not a great deal of expectation that they will assist materially, in the near future, in solving this urgent problem. No other machinery manufacturer is now active in this field. As for the banding together of the various companies to cooperate in their mutual problem, there also seems to be little to be expected there, for the present at least. Most of the small lamp companies are relatively independent of one another as well as of the rest of the industry, and they hesitate to participate in such an action. While some information has been exchanged on a bilateral basis and the idea of group action is acceptable to most independents, they have been unable to agree on any specific method for making and pooling technological advances. A few companies such as the former Wabash Appliance Corporation, Duro Test Corporation, and Jewel Products,

[59] U.S. Tariff Commission, *op. cit.*, p. 41.

Inc., have done a great deal to speed up and improve their equipment. The very small companies are more seriously threatened. A few of the marginal firms have already gone out of business, and many of the others will also go if they are not able to find a solution for their machinery problem. The situation will be particularly difficult if General Electric, Westinghouse, and Sylvania initiate more active price competition. Few, if any, of the independents could stand extensive further price reductions at this time.

Continued success for the independents also requires that they break into the fluorescent-lighting market sooner or later. Although there is no foreseeable likelihood that the fluorescent lamp will entirely eliminate the incandescent device, the market for the older type will definitely be more limited. Here again machinery is an extremely important factor. It is evident, therefore, that while patents and monopolistic restrictions are no longer the danger they once were, more purely competitive factors have made the future of the independent group uncertain.

One of the first defensive measures taken by the smaller companies was the development of specialties. Several of them attempted to carve out sections of the market by concentration on special designs of lamps. The former Wabash Appliance Corporation specialized in photoflash lamps, "Superlite" incandescent lamps, and a line of large reflector lamps. The latter were originally designed by the Birdseye Electric Company of Gloucester, Massachusetts, which was bought out by Wabash. Another firm, the Save Electric Corporation, built up the sale of its Verd-A-Ray and insect repellent lamps. Other companies undertook similar policies. Although such a procedure helped temporarily, it alone was not enough to guarantee success for the independents. As a group, they need economical mass production of standard lamps for general illumination to remain solvent. Despite the end of the war, their wartime difficulties in machinery and labor continued through 1947 and resulted in production below capacity and losses on the "bread and butter" line. With the declining profitability of specialties, the independents have turned to long-life lamps as a new source of premium prices. The largest companies in the industry do not promote long-life lamps, although their rough-service lamps do last somewhat longer than the standard lamps.

That course of action is another makeshift, however, and the situation remains critical for the independents.

Hourly wage rates paid by General Electric, Westinghouse, Sylvania, and the other former licensees in lamp making rose during the war to an average of over 90 cents. While the larger concerns were far better able to absorb the increases than the independent manufacturers, lower productivity of labor and increases in labor and other costs led to a partial restoration of some of the previous price cuts in the low-wattage lamps. On July 1, 1946, the list prices of the 15-watt to 60-watt standard lamps were raised from ten to eleven cents each. On June 1, 1947, all lamp manufacturers announced that the entire 20 per cent wartime excise tax on manufacturers' net billings of lamps would thereafter be passed along to the purchaser. Previously, the manufacturers had absorbed one-fourth of the tax. On the same date in 1947 price increases were announced for certain special lamps, while other specialties and standard lamps of high wattage were reduced somewhat in price. The relative stability of lamp prices contrasts favorably with the rapid postwar increases in most other prices. However, that stability has been achieved at the expense of profit margins, and it would seem likely that General Electric's legal and competitive position has been an important consideration in its determination of list prices. As long as the heavy electrical-equipment business is booming, General Electric can afford to take smaller profits in its incandescent-lamp business. The undiversified smaller companies have no comparable profit cushion.

The most spectacular expansion during the war years was that of Sylvania Electric Products, Inc. Within a few years it has grown from a fairly small company making incandescent lamps and radio tubes to a very important factor in several branches of the electrical-goods industry. Its place in fluorescent lighting is of special significance; this will be treated in later chapters. In addition, the company has undertaken to be more self-sufficient regarding its supply of parts for lamp and radio-tube assembly. In 1943 the assets of Electro Metals, Inc., of Cleveland, were purchased for the production of welds and wire products. Then in May of 1944 Sylvania purchased the entire capital stock of the Colonial Radio Corporation of Buffalo. The acquisition of this

company, which has since been operated as a subsidiary, put Sylvania into radio-set production on a large scale.

Shortly after the end of the war, Sylvania also purchased all the assets of the Wabash Appliance Corporation, which had previously been the largest and soundest of all the unlicensed firms by virtue of its leadership in photoflash-lamp production.[60] That move, which put Sylvania into the market for photoflash and other photographic lamps in a major way, indicated the aggressive policy to which Sylvania has committed itself in the incandescent-lamp field, as well as in fluorescent lighting. The assets of Wabash and its former subsidiaries, which have been taken over by a newly formed company, the Wabash Corporation, are operated as a wholly owned subsidiary of Sylvania. Since the end of the war, Sylvania has also decided to manufacture incandescent Christmas-tree lamps in competition with General Electric, previously the only important domestic producer. While Westinghouse has sold Christmas-tree lamps, they have been made for it by General Electric.

Various other new wartime activities of Sylvania, such as the formation of an English subsidiary and investment in other foreign enterprises, have further assisted it in "growing up." All in all, it is now in a far better position to increase its share of the incandescent-lamp business from its customary 5.5 per cent to a figure rivaling its 20 per cent in fluorescent lamps than it would have been a few years ago.

There is one final concern, the North American Philips Company, which became a potential factor in the domestic lamp industry during the war years. The Dutch firm of N. V. Philips' Gloeilampenfabrieken, which until 1940 had played such an important role in the lamp business of the Netherlands, Europe, and indeed the whole world, had to move away from the German occupation zone or accept Nazi domination. The company's executives saw the danger, prepared for it, and fled Holland in time. They moved first to the Dutch West Indies, and then they

[60] The Wabash Appliance Corporation was established around 1930 to succeed a series of unsuccessful companies dating from the early twenties which had made lamps, furniture, radio tubes, and other items. Serious lamp production began in 1930, and the company was built up gradually to a leading position among the unlicensed lamp manufacturers through the efforts of its two owners and chief officers, Messrs. Adler and Parker.

came to the United States. The North American Philips Company was organized in 1942, and within a very few years the new company had built up an extensive organization.[61] It has made crystals, X-ray and cathode-ray tubes, and electronic equipment; it has set up a plant to make tungsten and molybdenum rod and wire; and it has established a research laboratory, among other things. Although it has not produced lamps, it has sold lamps made for it by General Electric and Westinghouse under its trademark for export to former customers of the Dutch parent. While it is unlikely that Philips will attempt to invade the American market, particularly as long as its agreements with General Electric are in force, the long record of its chief executives suggests that it might become a force to be reckoned with if those agreements are terminated.

As for incandescent-lamp parts, glass continues to be produced by General Electric and Corning as before, although Corning has further reduced its prices. The situation for argon has remained unchanged. With regard to lamp bases, since its consent decree of 1942 Westinghouse has supplied some to the independent producers in addition to those made for its own use. That represents a partial loosening of the supply situation for this important part.

In the production of tungsten wire for filaments, General Electric and Westinghouse have continued to fill their own needs. Callite-Tungsten is still a major source of supply for the independents. Sylvania has undertaken to make tungsten wire at its fluorescent-powder plant, and it has offered to sell wire to the independents. During the war, Westinghouse also for the first time set out to sell tungsten wire to all comers. The Sirian Wire Company, an old-time tungsten-wire producer, sold out during the war and is no longer in production. The small lamp manufacturers now hold a better position with respect to tungsten wire than they had a few years ago. During the war, the independents were even able for a time to buy tungsten wire from General Electric, under the War Production Board directive pooling orders and plant capacity. With the end of the war and the end of governmental control, General Electric announced that because

[61] See "Philips of Eindhoven," *Fortune*, Vol. XXXI, pp. 127–129, 197–206 (June, 1945).

of the heavy demand on its facilities for wire production it could accept orders only from those who had bought from it before the war. General Electric, Westinghouse, and Callite-Tungsten continue to be the only domestic producers of "dumet" wire for lead-in wires.

During the war, the tie-in of the Electrical Testing Laboratories, the principal testing laboratory for incandescent lamps, with General Electric, Westinghouse, and the utilities became somewhat looser. The utilities, which had jointly owned ETL since around 1900, suddenly dissolved the laboratory in 1942. They evidently wished to limit their interstate activities as much as possible because of Securities and Exchange Commission regulations, and to end the accusation that ETL was dominated by and partial to the utilities. ETL's employees bought out the organization and have since run it themselves without outside control. The reorganization and changes in procedure should lessen somewhat the intangible yet definite competitive advantage which the former "Mazda" manufacturers obtained from their relationships with the testing laboratory.

With the end of the war the incandescent antitrust case was resumed. The presentation of evidence began on March 11, 1946, in the New Jersey District Court. The court hearing was completed in May, and the briefs were filed by the end of 1946; but the judge's decision has not yet been announced. An appeal from the district court might postpone the eventual outcome for a lengthy period.

The ranks of the defendants to the antitrust action were thinned by the entry of a consent decree against Corning on March 7, a few days prior to the reopening of the case. Corning, which had been charged with monopolizing and restraining trade in the manufacture and sale of glass bulbs, tubing, cane, and glass machinery in violation of the Sherman Act, agreed to license its present patents on a royalty-free basis and without restriction to any legitimate applicant. It also agreed to grant licenses under all future patents applied for on or before January 1, 1950, at reasonable royalties and to sell glass products for electric lamps in the future at nondiscriminatory prices. Moreover, Corning agreed to furnish technical information to licensees for five years relating to the manufacture of glass products and machinery and to remove artificial barriers to international trade in such products.

Some of the goals of the Department of Justice had thus been achieved before the case was reopened. Westinghouse and Corning had accepted consent decrees; the license and quota system had been virtually ended; and the trademark "Mazda" had been abandoned for all but a limited number of special lamps. There still remained several other aims of the Department of Justice in its action. It wished to end the agency method of distribution used by General Electric and Westinghouse in their control of lamp prices to the retail level. It wished to force General Electric to give up around 25 per cent of its lamp business, on the assumption that no single company should control more than half the lamp market. It wished to require General Electric to grant royalty-free licenses freely under its present lamp and lamp-machinery patents and low-royalty licenses under its future lamp and lamp-machinery patents.[62] It also wished to end all restrictions and discrimination in the supply of lamp parts and lamp-making machinery. Although some of the government's goals may not be realized, it appears that the eventual outcome of the case may well be to loosen up the patent situation in lamp making, end discriminatory parts pricing and generally increase competition in the domestic-lamp industry.

The government had quicker success in another of its antitrust suits against General Electric and Westinghouse over their conduct of international operations in other product lines. On March 12, 1947, a consent decree was entered in which the principal defendants and their international subsidiaries agreed to end cartel agreements with European producers which allocated orders, divided the business with competitors, and established prices for electrical equipment. Even though the decree did not apply directly to electric lamps, it indicated growing success in the government's attempts to reduce General Electric's control over competition in various phases of the electrical-goods business.

62 Temporary compulsory licensing in the incandescent-lamp business might encourage such large buyers as Ford, General Motors, and Chrysler to manufacture their own lamps in the future.

Chapter XI: INTERNATIONAL RELATIONSHIPS IN THE ELECTRIC-LAMP INDUSTRY: 1912–1947

After 1912 the production of tungsten-filament and other incandescent lamps increased rapidly in all nations. The expansion of output in Germany, Japan, the Netherlands, the United Kingdom, France, Belgium, and the Scandinavian countries was particularly noteworthy. Nevertheless, the United States increased its percentage of world output to exceed that of all other countries combined.

The leading lamp producers in the principal industrialized nations evolved a working arrangement whereby international sales competition was reduced to a minimum while technological advances were passed from one to another. International competition came mostly from small producers who were not associated with the cartel. Since the allocation of territory by the cartel customarily gave to each nation its colonies as well as the mother country, only a few industrially undeveloped areas of the world remained free for competition by the largest manufacturers. In addition to restrictive cartel and license agreements, most countries imposed tariffs and import quotas for the protection of their domestic electric-lamp industries. Exports by the American industry were smaller than those by any other important producing country in relation to the size of total production. Exports by the Netherlands, Germany, the United Kingdom, and Japan were each normally more than double in value those of the United States.

1. *Growth of the Cartel*

The international lamp cartel was a European development. It grew out of the 1894 association of continental producers and was formalized in 1903.[1] The cartel was strengthened by the

1 See pp. 113, 159–161.

formation in Germany in 1911 of the Drahtkonzern, which brought tungsten-filament lamps under control as well as carbon lamps. During the next two years patent-licensing and trade agreements were executed by the Drahtkonzern with British, French, Dutch, Hungarian, and other lamp manufacturers. Like the United States lamp industry, however, the German industry experienced an inrush of new manufacturers after the development of the tungsten-filament lamp. The German patent rights to the ductile tungsten filament had been included in the pool of patents held by the Drahtkonzern. When that patent was upheld in 1917, most of the new lamp producers were forced to cease production. The leading survivors entered into the price-fixing agreements of the Drahtkonzern, and the agreements were soon extended to include manufacturers in other central European nations.[2] The outbreak of World War I disturbed the community of interest that had reduced international competition in electric lamps, nevertheless, and the international agreements among the lamp manufacturers of opposing belligerents were terminated.

During World War I N. V. Philips increased its relative importance in the international lamp industry. Markets which had customarily been supplied by Osram and other belligerents were seized by Philips, and the Dutch company retained a considerable proportion of that trade after the end of the war. After General Electric won its patent-infringement suit on the Just and Hanaman patent against Laco-Philips, the Dutch parent discontinued its export of lamps to the United States. Each of the two companies agreed not to disturb the domestic markets of the other, while marking out exclusive areas to reduce competition.

The Osram-Werke G.m.b.H. was formed in Germany in 1919, to regain the markets which had been lost during the war years. It comprised the lamp works of A.E.G., the German Welsbach Company (Deutsche Gasglühlicht Aktien-Gesellschaft), and the Siemens group, which had been associated in the Drahtkonzern, and it controlled most of German lamp production. Within a very short time the Osram company had acquired other German lamp producers and had extended its influence into the lamp industries of several countries. It acquired part or con-

[2] George W. Stocking and Myron W. Watkins, *Cartels in Action*, Twentieth Century Fund, New York, 1946, pp. 316–317.

trolling financial interests in a number of active companies and organized several new firms in addition. By 1929 Osram's financial interests included companies in Spain, Czechoslovakia, Norway, Poland, Switzerland, Austria, Denmark, Sweden, and Italy.

The international lamp cartel was revitalized after World War I, mainly through the efforts of the Osram company. The dislocation of normal trade during the war years had led to a considerable expansion of productive capacity in many countries, and Osram desired to avoid price competition from producers striving to hold their gains. Osram encouraged the formation in 1921 of the International Union for Regulating Prices of Incandescent Lamps (Internationale Glühlampen Preisvereinigung). This organization, composed of the Osram company and producers of Central Europe, together with N. V. Philips and a Swiss company, allocated markets and established prices and conditions of sale. Although British and American companies did not at that time join the cartel, in 1921 and 1922 Osram made bilateral agreements with the British and the American General Electric companies regarding sales territories and other matters. The agreement with the American concern provided for "the exchange of patents and technical experience and 'marked out exclusive sales areas for the two contracting parties, and thus set territorial limits to the competition between these undertakings by applying for the first time the principle of the protection of the home market.' "[3]

By 1924 the cartel had grown to include about twenty-seven producers of electric lamps, including eight trusts made up of thirty-six affiliated companies. The Osram company and Philips were leading forces in its activities. By 1939 almost every important lamp producer in Europe was a member, in particular Osram, Philips, the French Compagnie des Lampes, the Italian Società Edison Clerici Fabbrica Lampage, and the leading British producers.

In 1917 the leading British companies had incorporated the Electric Lamp Manufacturers' Association of Great Britain, Ltd., to succeed the earlier Tungsten Lamp Association of 1912. The

[3] U.S. Tariff Commission, *op. cit.*, pp. 57–58. (Original source, *Review of the Economic Aspects of Several International Agreements,* League of Nations, Geneva, 1930, p. 70.)

Tungsten Lamp Association had been the vehicle for patent pooling and allocation of the market. Its usefulness had been impaired by the 1917 invalidation of Coolidge's British patent of 1906 on the drawn-tungsten filament.[4] The new organization brought in additional lamp manufacturers, pooled all remaining patents, fixed prices, and established a common policy of resale price maintenance.[5] Association members controlled more than 90 per cent of British lamp production. Out of this stronger domestic association and bilateral agreements with foreign concerns grew a more active participation in the activities of the cartel. About 1925 the General Electric Company, Ltd., British Thomson-Houston Company, Ltd., Edison-Swan Electric Company, Ltd.,[6] Siemens Brothers, Ltd., and the Metropolitan Vickers Electric Company, Ltd.,[7] became full members of the cartel. The British market was then set aside largely for British producers, in accordance with the established practice. The British industry was further concentrated in 1928 by the amalgamation of British Thomson-Houston, Edison-Swan, Metropolitan-Vickers, and another electrical-goods manufacturer, the Ferguson Comany, as the Associated Electrical Industries, Ltd.

A Convention for the Development and Progress of the International Incandescent Electric-Lamp Industry was established in 1924, when the previous system of price control broke down. Under the agreements supporting the new and more rigid Convention patents were pooled, technical experience was exchanged, and territorial limits of competition were determined. The American General Electric Company played a very important part with Osram, Philips, and the other leading European lamp producers in setting up the Convention. Its agent in the arrangements was the International General Electric Company of New York, Ltd., a British subsidiary of the American International General Electric Company.

Although the cartel does not itself fix uniform prices, its sales committee does decide general sales policies and gives directions for the fixing of prices and conditions of sale to the national assemblies of producers in various territories. Furthermore, and notwithstanding the fact that limitation of output is stated not to be a function of the cartel, production is indirectly regulated through the allocation of specified market territories to the members, the quota assigned to each national group usually comprising most or all of the consumption in its home market.[8]

[4] See p. 245, n. 25.

[5] See Stocking and Watkins, *op. cit.*, p. 320.

[6] The Edison-Swan Electric Company, Ltd., amalgamated with the British affiliate of Philips around 1920.

[7] The Metropolitan Vickers Electric Company, Ltd., was controlled by Westinghouse.

The success of the cartel in maintaining high prices varied with the organization of the industry in the various countries. Where control was strongest, as in Holland and Germany, prices were particularly high, even though the leaders in these countries were technologically the most active lamp producers in Europe. In some countries patent loopholes, more active independent manufacturers, cartel conflicts, and other conditions weakened the cartel somewhat. Even though the cartel's effectiveness declined somewhat after 1930, until World War II between 80 and 90 per cent of the total electric-lamp production of Europe was controlled by the cartel. This percentage was applicable to the production of Germany, Austria, Hungary, Czechoslovakia, the Netherlands, and Belgium; and only slightly smaller proportions were controlled by cartel members in France, Italy, and the United Kingdom. Even in Japan, cartel members produced more than half the total output.

To administer the terms of the Convention and the agreements signed under it, the Phoebus Company (Phoebus S. A. Compagnie Industrielle pour la Développement de l'Éclairage) was organized. It was located at Geneva and acted as an intermediary in the exchange of technical information and in the acquisition of patents. Although the agreements were originally scheduled to expire in 1934, they were extended to 1955. The outbreak of World War II again disrupted the operation of the cartel.

2. *The Cartel and the American Lamp Industry*

Despite the fact that the American General Electric Company has never been an official member of the international cartel, it has operated in essential harmony with it through foreign subsidiaries and through a long series of licensing agreements with

[8] U.S. Tariff Commission, *op. cit.*, p. 58.

the leading foreign companies, financial investments in them, or both. The first agreements were signed with German, British, and other producers around 1904, and subsequent arrangements were made with Philips and more than a dozen other large foreign producers. The list of companies with which General Electric has had patent-licensing and sales-territory agreements is virtually a list of the most important lamp producers of the world. Most of them have been members of the international cartel. Among such firms are the following:

England	Associated Electrical Industries, Ltd., and its subsidiary, British Thomson-Houston Company, Ltd.[9] General Electric Company, Ltd. International General Electric Company of New York, Ltd.
France	Compagnie des Lampes
Netherlands	N. V. Philips' Gloeilampenfabrieken
Germany	Osram-Werke G.m.b.H.
Japan	Tokyo Electric Company, Ltd.
Italy	Società Edison Clerici Fabbrica Lampage
Mexico	Compañía Mexicana de Lámparas Eléctricas, S.A.
China	China General Edison Company, Inc.
Brazil	General Electric S.A.
Hungary	Vereinigte Glühlampen und Elektrizitäts A.G.

The American General Electric Company conducts most of its foreign business, including the granting and receiving of patent licenses, through its subsidiary, the International General Electric Company. The principal exception to this rule is its Canadian lamp business, which is carried on directly by a manufacturing subsidiary, the Canadian General Electric Company, Ltd.[10] Besides its 95 per cent stock interest in the Canadian company, the General Electric Company, either directly or through its international subsidiary, has owned stock interests in every one of the

[9] The British Thomson-Houston Company had originally been a subsidiary of the American General Electric Company.

[10] Majority control of this concern was acquired in 1923.

concerns listed above except the Italian concern. Some of the stock interests have been or are very large.[11]

The International General Electric Company has made licensing agreements with the above-mentioned companies since its organization in 1919.

> Under the terms of the agreements now in effect, the companies apportion among themselves the principal world markets. The General Electric Company has granted to the foreign companies with which it has agreements exclusive licenses under its patents to manufacture and sell electric lamps in specified countries, which are described as exclusive territory, and nonexclusive licenses under its patents in other countries referred to as nonexclusive territory. . . .
>
> The licenses prohibit the given foreign licensed company from manufacturing or selling lamps outside the territory in which it is licensed. The General Electric Company is prohibited from engaging directly or indirectly in the manufacture of lamps in any of the territories assigned exclusively to the foreign companies.
>
> In return for the grants which it makes to the foreign companies, the General Electric Company receives from each of the companies an exclusive license to make and sell lamps in the United States under all patents owned or controlled by these companies. It also receives from some of the foreign companies royalties for the use of its patents and developments.
>
> . . . .
>
> Inasmuch as the exclusive territories of the firms listed above include virtually all of Europe, Japan, China, Brazil, and Mexico, together with the colonies, protectorates, possessions, and mandates of the countries included in the agreements, competition in the United States market from these

[11] "As of December 31, 1940, General Electric had the following percentages of ownership in its licensees: in Osram—21.45%; in Philips—11.85%; in Cie des Lampes—ordinary, 37.03%—founders, 33.47%; in Vereinigte—10.64%; in A.E.I. —ordinary, 40.66%—preferred, 20.72% and in Tokyo Shibaura—28.14%. In addition to a financial interest in each of its licensees, International General Electric maintained representation on the boards of directors of licensees." (United States of America *v.* General Electric Company et al., *Brief for the United States of America*, Aug. 30, 1946, p. 417.)

sources is largely eliminated and conversely the General Electric Company is prohibited from competing in many important foreign markets.[12]

According to the terms of its A license from General Electric, Westinghouse was permitted to export lamps only to those countries to which the licensor itself might export under its international agreements. The Westinghouse Electric International Company, a wholly owned subsidiary, conducts most of its foreign business.[13] Although Westinghouse has executed many patent-licensing agreements with foreign companies, its secondary role in the American lamp industry has held down its importance in the international aspects of the lamp business.

Almost all the international agreements of the lamp producers, whether made bilaterally or through the cartel, have been based upon patent licenses. As in the domestic lamp industry, patents have provided the instrument of control, and the particular technique has been the granting of exclusive licenses for agreed territory. This arrangement has allowed a free interchange of patents and technical data among the participating companies; but it has reduced competition and trade. In Europe in particular, the limitation of competition has resulted in very high prices for incandescent lamps. In the United States prices have probably been higher than they would have been if international competition had been unrestricted, even though they have been far lower than those in any other country except Japan.

There have been few instances in which the American companies have gained important knowledge for the design or production of incandescent lamps through the interchange of patent licenses. The American product seems to have been superior to that of almost all foreign nations; the closest competitor in lamp quality has undoubtedly been Philips.[14] The principal American benefits have come in the field of electric-discharge devices. Of fifty-eight patents acquired by General Electric from Philips between 1923 and 1939, only seven were used in this country; of eighty-six patents acquired from Osram during the same interval, only six were used; and of ten patents acquired from the Tokyo Electric Company, none were used.

12 U.S. Tariff Commission, *op. cit.*, pp. 59–60.

13 In Canada its business is conducted by the Canadian Westinghouse Company, Ltd., in which Westinghouse owns a 39 per cent interest.

14 For a comparison of the qualities of "Mazda" lamps with other domestic and imported lamps, see Preston S. Millar, "The Qualities of Incandescent Lamps," *Electrical Engineering*, Vol. LV, pp. 516–523 (May, 1936).

Of all the European companies, Philips seems to have been the most outstanding in research and development. It pioneered in the design of photoflash lamps, in the use of the heaviest inert gases for gas-filled lamps, in machinery development, and in other directions of incandescent-lamp design and production. Osram has also carried on significant developmental work in lamp design and lamp-making machinery. The other European nations have contributed little of importance to incandescent lighting.

To counterbalance the greater flow of technical information from this country, International General Electric collected about $5,000,000 in royalties and service charges from foreign lamp producers between 1919 and 1941. Osram and Philips paid no service charges after 1929 and 1930, respectively. The American leader thus protected its domestic market, which constituted half of the world market, and drew its profits from abroad largely out of the export of lamp technology to cartel members rather than out of the export of electric lamps. While nominally not a member, the American concern adjusted its actions to the cartel as if it had been a member and expanded the cartel's sphere of influence to cover the world. General Electric's contracts with Philips, Osram, and the other European concerns were continued during the war, and the contract with Philips was renewed upon the termination of hostilities.

3. *Characterizations of the Lamp Industries of Leading Producing Countries*

As in the United States, the production of electric lamps in most other countries has been highly concentrated. Domination by one or a few very large producers has been typical, although concentration has sometimes been obtained by combining a number of firms into a trust or by a holding-company arrangement. The control of patents, economies of large-scale production, and the desire to avoid competition have been the principal factors in the concentration. Besides the large producers there have normally been, in most countries, a number of small lamp manufacturers, either licensed or unlicensed, comparable to the small licensees or the independent manufacturers of this country.

To round out the picture of the international electric-lamp industry, the size and organization of lamp production in the largest foreign producing countries will be characterized briefly, as follows.

Japan. Electric lamps were made in Japan as early as 1890, and the Japanese industry developed to world importance after its German source of supply had been cut off during World War I. The country quickly rose to a position second only to the United States in the number of lamps produced, although several other nations still outrank it in value of output. Japanese production averaged over 300,000,000 lamps a year during the thirties. More than two-thirds of all production was exported, mostly in miniature lamps.

The Tokyo Electric Company, Ltd., most of whose original capital was supplied by the American General Electric Company, is by far the largest producer; but there are a great many others. During the thirties there were about a dozen other large-scale manufacturers and about three hundred small-scale factory producers. In addition, well over 1,500 household establishments made miniature and decorative lamps for export. The large-scale manufacturers, producing under the patent rights of General Electric, were organized into an association which controlled the output and sales of each. They were members of the international cartel and supplied most of Japan's domestic consumption of electric lamps. Other organizations controlled the output and prices of the small-scale factory producers, but the competition with household producers made the control ineffective. Imports were restricted to small quantities of special lamps.

Germany. Osram is the principal producer of electric lamps in Germany. Its organization has already been described. In addition to its domestic facilities for making the largest part of Germany's lamp needs, Osram has subsidiary lamp producers in many other European countries. Most of the smaller producers in Germany make low-voltage miniature lamps. Total German production of large incandescent lamps averaged about 100,000,000 per year between World War I and World War II, increasing

during the thirties. Close to 200,000,000 miniature lamps were also made annually during much of that interval. Imports, primarily from Hungary, Czechoslovakia, and other neighboring countries, averaged under 10,000,000 lamps a year. They were held down by tariffs, quotas, and other import restrictions. Exports, mostly to countries in western Europe and South America, averaged about 50,000,000 lamps per year.

Holland. Until 1940, N. V. Philips controlled virtually all the Dutch output of incandescent lamps, although there were a few other small producers. Philips also had a large number of subsidiary lamp-producing plants in other European and in some non-European countries. Total prewar production was about 100,000,000 lamps per year. Imports were severely restricted by quotas and high tariffs and amounted to only about 3,000,000 lamps a year. Exports, on the contrary, averaged more than 20,000,000 lamps annually.

The United Kingdom. Most electric lamps produced in the United Kingdom since 1930 have been made by subsidiaries of the Associated Electrical Industries, Ltd., and by the British General Electric Company, Ltd.[15] These and other producers have been organized into an association through which patents and technical information are exchanged, and which establishes prices and discounts in a manner tending to restrict outside producers. Association members during the late thirties produced about 80 per cent of the total output of nearly 100,000,000 lamps a year, most of which were large lamps. Imports, primarily from Japan, consisted mostly of low-value miniature lamps. During the thirties they averaged about 50,000,000 units annually. The tariff on lamps was 20 per cent ad valorem. Exports, mainly of large lamps, were sold for the most part to the Empire. They usually totaled less than 20,000,000 a year.

France. Of late years the Compagnie des Lampes has been the dominating lamp producer in France. It was established in 1921 by the merger of the lamp departments of the Compagnie Française Thomson-Houston and the Compagnie Générale d'Elec-

[15] From 1928 to 1934 the American General Electric Company owned a large block of stock in its English namesake. There has since been no financial tie between the two companies, although they have signed cross-licensing agreements.

tricité with the Établissements Larnaude. Further concentration of the French industry and investment in foreign subsidiaries occurred later. The American General Electric Company has retained a substantial minority interest in the Compagnie des Lampes. The total annual prewar production of large lamps in France may be estimated roughly at 70,000,000 lamps a year.[16] Prewar imports were principally from Germany and Holland, while exports were mainly to the French colonies.

Canada. During the middle thirties there were six lamp-producing companies in Canada, including the Canadian General Electric Company, Inc., and the Canadian Westinghouse Company, Ltd. General Electric controls the former, and Westinghouse owns a 39 per cent interest in the latter. Total Canadian production during the thirties averaged about 30,000,000 lamps a year, more than two-thirds of which were large lamps. The United States and Japan supplied most of the few million lamps normally imported into Canada each year. Export figures are not available but were probably small.

Sweden. Production of electric lamps in Sweden is concentrated in two principal groups of manufacturers. The members of one group, some of which are subsidiaries of foreign companies, belong to the international cartel. The other producers belong to the North-European Luma Cooperative Society, which was organized in 1931 in protest against the high prices charged by cartel members. It includes cooperatives in Norway, Denmark, and Finland, as well as Sweden. Luma was successful in reducing its own prices and forcing down the cartel prices. Production totaling about 12,500,000 lamps was divided between the two groups during the thirties in about a 70 to 30 proportion, with the cartel members supplying the larger percentage. Imports, almost entirely from Germany, the Netherlands, and Hungary, slightly exceeded exports, which went mainly to Norway, Denmark, Turkey, and South America during the thirties.

4. *Future International Trade in Incandescent Lamps*

The defeat of Germany, Italy, and Japan and the bombing of their factories have temporarily eliminated their lamp producers

[16] Reliable figures are not publicly available.

from major roles in world trade. The lamp factories of some of the Allies were stripped by the Germans or damaged by Allied bombing during the German occupation. It will take many years to restore lamp production and trade in Europe to its prewar level. In the meantime the potential export market has grown, and for a few years at least the foreign demand for American-made lamps will be far greater than ever before.

The Department of Justice is attempting in its antitrust actions to eliminate the artificial barriers to both exports and imports of lamps and related products. With the end of wartime restrictions and the increased competition in the domestic industry, many American producers will look abroad for markets to a greater extent than in the past. For example, Sylvania has undertaken to expand its foreign activities, in keeping with its policy of expansion and independence from General Electric, and the independent manufacturers have shown more interest in export markets. The moderately high tariffs and the relatively lower domestic prices will probably prevent any great flood of imported lamps, however. Even the complete end of international licensing would not appear to threaten seriously the American market, although the slightest increase in domestic competition as a result of increased international competition should have a salutary effect. The Japanese export industry is recovering quite slowly, and the German lamp industry is completely disorganized. The most important potential foreign competitor is Philips, which is already on the scene in the form of the North American Philips Company; but it is very doubtful if Philips will attempt to invade the home territory of General Electric.

The European lamp producers aim at cartelization, very high prices, and the division of markets. General Electric is evidently sympathetic to their goal and has cooperated with them to keep foreign producers out of the domestic market. It would seem likely that General Electric and Philips, which has emerged as the dominant continental lamp producer, will take whatever steps the American courts and circumstances permit to restore the international organization to its former status. If foreign nations undertake to restore trade barriers and protect their domestic lamp industries, and if the cartel comes back into operation, much of the foreign market may dry up within a few years. Even if individual incandescent-lamp patents should not regain major importance, exclusive licensing and cartelization might use patent pools as means to control prices and restrict trade. However, the difficulties in restoring the cartel are great, and it seems probable that the international lamp business will be conducted on more openly competitive lines in the foreseeable future.

Chapter XII: IMPROVEMENTS IN THE DESIGN OF INCANDESCENT LAMPS: 1912–1947

WHILE spectacular changes in the design of incandescent lamps for general illumination were rare after 1912, efficiency and general performance were improved steadily until 1937. During the next ten years there were no important advances in the design of incandescent lamps for general illumination. Of late years developmental effort has been concentrated upon the design of incandescent lamps for special applications and upon the newer electric-discharge lamps. The principal changes in incandescent lighting from 1912 to 1937 were initiated by General Electric and a few other world leaders. The smaller lamp-manufacturers played a minor role in efficiency advances and innovations in design, although they shared with the larger companies the credit for developing important new incandescent lamps and lamp features for special applications.

The technological progress in incandescent lighting between 1912 and 1947 was conditioned by the economic and legal conditions in the industry, as well as by the declining opportunities for advancement offered by incandescent lighting. The work done by the various firms, the direction of their efforts, and their relative success were intimately affected by their positions in the industry.

1. The Gas-Filled Lamp

The use of tungsten for incandescent-lamp filaments, particularly after the development of ductile tungsten, represented a substantial advance. However, the incandescent electric lamp remained very wasteful: less than 5 per cent of the electric energy put into an ordinary tungsten-filament lamp in 1912 came out as useful light, and the rest was dissipated in heat.

One of the greatest difficulties with tungsten was evaporation at temperatures below its melting point. Like carbon, the tungsten deposited on the inside of the glass caused bulb blackening, and the filament disintegration hastened lamp failure. The light wasted by the blackening of the bulb could be reduced to some extent by the use of getters which lightened the color of the bulb deposit and permitted the passage of more light. It was generally believed that the best solution to blackening was a high vacuum in the bulb. It was impossible to remove all the gases and vapors, however, and even the best exhaust processes and getters left many millions of molecules.

In the summer of 1909 Dr. Irving Langmuir entered the General Electric Research Laboratory,[1] intending to return to teaching at Stevens Institute of Technology in the fall; but the work so captured his interest that he remained with General Electric and later became an associate director of the Schenectady laboratory. His work in both chemistry and physics was a major factor in its outstanding success.

Langmuir was instructed to spend some time investigating the work of the laboratory and then to select a problem on which he wished to work. At that time a large part of the laboratory was engaged in the development of ductile tungsten wire, and Langmuir was attracted by the difficulty of avoiding "offsetting" when a tungsten-filament lamp was operated on alternating current. He wondered if offsetting might be caused by gaseous impurities in the filaments, and set out to study the gas content of wires.

The work with filaments at high temperatures showed that amazingly large quantities of gas were produced. Langmuir learned that glass surfaces which have not been heated a long time in a vacuum will give off water vapor which reacts with hot tungsten to produce hydrogen. He found that the occluded gases had nothing to do with filament offsetting, however. When he accepted Dr. Whitney's offer to remain permanently with General Electric, he proceeded to study further the sources of gas within vacuum lamps and related devices and to investigate the bulb-blackening effects of introducing various gases into tung-

[1] Langmuir graduated from Columbia University in 1903 and studied physical chemistry under Nernst at the University of Göttingen until 1906. He then served as an instructor in chemistry at Stevens Institute of Technology until 1909.

sten-filament lamps. No specific commercial results were expected; Langmuir merely hoped to learn more about the behavior of gases in incandescent lamps.

The researches were continued by Langmuir for three years before any commercial results were obtained. He studied the gases and vapors given off during operation by the various parts of the lamp as well as the residual atmospheric gases. The principal substances in the bulb were found to be water vapor, carbon dioxide, carbon monoxide, hydrogen, hydrocarbon vapors, and nitrogen. Each of these, as well as a number of other gases, was studied separately to determine how bulb blackening was caused. Certain gases, such as hydrogen and oxygen, were found not to result in any discoloration of the bulb. Others, such as nitrogen, carbon dioxide, and carbon monoxide, resulted in a brown deposit. The only substance present which produced a black deposit was water vapor. Even in very small quantities it resulted in bulb blackening and shortened lamp life. When water molecules came into contact with the hot filament, they were decomposed. The oxygen combined with tungsten atoms thrown off by the filament, and the hydrogen remained in the atomic state. The tungsten oxide was deposited on the inside wall of the bulb, where it was reduced to a metallic state by the atomic hydrogen. The oxygen recombined with disassociated hydrogen atoms to form water vapor which was then free to repeat the process indefinitely. To complete this phase of his investigations, Langmuir immersed tungsten-filament lamps in liquid air to prevent water vapor from coming into contact with the filament. The bulbs still became blackened. After two years of research, Langmuir had proved that filament evaporation was the sole cause of the blackening of a well made lamp.

Since he had found that bulb blackening could not be prevented even by a perfect vacuum, Langmuir endeavored to find some other solution to the problem. Other than water vapor, the gases which were present in the bulb did not cause blackening; and he found that if they were introduced into the lamp the rate of evaporation of the filament was considerably reduced. They were particularly effective at about atmospheric pressure. Simply by being in the way, the molecules of nitrogen or some other gas tended to block the escape of tungsten atoms from the filament, bouncing some of them back and slowing down the others. Similarly, the water vapor present had a much more difficult time in transporting tungsten from filament to bulb when it was diluted by some other gas.

Although the idea of introducing a gas into the bulb was an old one, all its implications had never been investigated thoroughly.[2] It will be recalled that the Lodyguine, Kosloff, Farmer, Lane-Fox, Sawyer-Man, and other early lamps had been nitrogen-filled. Edison had failed in 1883 in a serious effort to make a gas-filled lamp. The Novak lamp had employed bromine vapor, and certain of the getters used with tungsten filaments were known to give off small quantities of gases without harming the lamp. German engineers tried hydrogen and carbon monoxide fillings, and a French inventor once again tried nitrogen in 1908. All those attempts were gropings in the right general direction; yet a complete understanding of the characteristics of gas fillings was not achieved before Langmuir's work. A major drawback of the experiments before 1910 was that the gas fillings had been used at very low pressures, which did not provide maximum protection against filament evaporation.

The nitrogen and other fillings proposed before Langmuir had slowed the disintegration of the carbon filament somewhat by reducing its rate of evaporation and by diluting the residual oxygen which combined with and destroyed the filament. The increased dissipation of filament heat by the gases had reduced filament efficiency and life by a greater extent, however. Gas filling of carbon lamps never proved successful; even today all carbon lamps made are of the vacuum type. The gases produced by getters or introduced as in the Novak lamp were used to lighten the color of the bulb deposit rather than to prevent it. The gas filling in tungsten lamps was a new type of getter and required a great deal of experimentation for final development.

It was as true for tungsten as for carbon that the gas filling conducted heat away from the filament.[3] A gas filling, however, made it possible to operate the tungsten filament at a higher temperature with greater efficiency. The filament temperature of

[2] See pp. 131–133, 208–209.

[3] The bulb temperature of a gas-filled lamp is much higher than that of a vacuum lamp of the same wattage, because of the conductivity of the gas filling.

the gas-filled lamp was around 2500°C., which was about 400°C. higher than that of the corresponding vacuum lamp. The problem was to find the conditions under which the two opposing forces would result in a more efficient and longer-lived lamp. Various gases under various conditions were studied systematically, and Langmuir found that of those available to him nitrogen at nearly atmospheric pressure gave the most satisfactory results.[4] Besides the type and temperature of the filament and the type and pressure of the gas, Langmuir discovered that the diameter of the filament greatly affected the rate of heat dissipation. Heat was dissipated from the outside of a stationary sheath of gas about the filament. Since the thickness of the sheath was nearly constant, the larger the filament the less the relative rate of dissipation.[5] Langmuir then discovered that, if the filament was coiled in a close helix, the diameter of the helix, not that of the filament, was the determining factor in heat loss.[6] By combining his discoveries he produced incandescent lamps of greatly improved efficiency. The tungsten wire was coiled about a mandrel made of another metal, which was then dissolved out by acid or

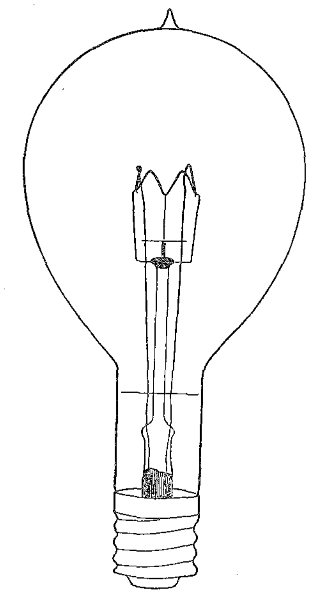


Fig. 27. Gas-Filled Tungsten Lamp, 1915

A mica disc across the neck of the lamp prevented the hot circulating gas from overheating the base.

[4] Argon was not available in the United States at the time of Langmuir's original work, but he had read of its properties in the European journals and specified it in his patent application. Argon quickly displaced nitrogen in actual use when it became commercially available.

[5] The discovery of the stationary sheath was a major factor in Langmuir's success. Among the earlier attempts, for example, Edison had tried to reduce the size of the filament in the belief that that would reduce the cooling effect.

[6] The coiling of tungsten filaments *per se* was of course not new with these experiments; it had been employed in projection lamps, miniature lamps, and other types ever since tungsten had been made ductile.

removed in some other way. The danger of sag in the tungsten filament required a careful sizing and spacing of coils to prevent contact between adjacent turns. Instead of a long zigzag filament, a simple loop of the coiled wire was all that was necessary.

The first tungsten lamps containing nitrogen gas, which was introduced at a pressure somewhat less than that of the atmosphere, were the 1,000-watt and 750-watt lamps. They appeared on the American market in 1913 and were called Mazda C lamps, to distinguish them from the vacuum lamps. Other nitrogen-filled lamps in sizes down to 200-watts were introduced by 1914. The bulb was elongated for gas-filled lamps to permit the neck to act as a cooling chamber; at first the lamps had to be burned base up. Argon has a lower heat conductivity than nitrogen, and it replaced nitrogen in all except high-voltage types as soon as it could be obtained commercially, around 1918,[7] although even with normal voltages about 15 per cent of nitrogen had to be added to prevent arcking of the current.[8] With the use of argon, gas filling of smaller wattage lamps became feasible, and at the present time lamps designed for 120-volt circuits are gas-filled down as far as 40 or 50 watts.[9] The efficiency improvements from the use of gas in the bulb vary according to the size of the lamp; the rate of improvement increases with the larger sizes. For the

[7] The heaviest of the inert gases, krypton and xenon, would have been even better than argon for gas-filled lamps. Their lower rates of conductivity and greater atomic bulk would have permitted still higher operating temperatures. However, they occur in the atmosphere in ratios of only 1 to 20,000,000 and 1 to 70,000.000, respectively. It was not until after 1930 that the Frenchman, Georges Claude, who early in the twentieth century had made notable contributions in the separation of the components of air and the development of the neon tube, developed a semicommercial method for the separation of krypton and xenon. European lamp producers, notably Philips, quickly took up the idea and sold krypton lamps on a specialty basis for some years. In this country General Electric conducted some experiments along the same line and then decided that the heavy gases were too expensive for the improvement which they produced. Widespread use of krypton-filled lamps will have to await the development of a low-cost process for extracting the gas from the air.

[8] In making the gas-filled lamp it is not necessary to pump the bulb to a complete vacuum. After a partial vacuum is obtained, the rest of the gases and water vapor are removed by flushing with dry air and dry nitrogen. Some nitrogen remains and the correct amount of argon is added to this. Phosphorus and other getters are also used with gas-filled lamps as well as with vacuum lamps.

[9] Many types of lamps of 40 and 50 watts still employ the vacuum because of their special characteristics. In some of the lower-voltage lamps even smaller lamps are gas-filled.

very largest lamps at the standard life of 1,000 hours the efficiency was approximately doubled; it rose from about 10 to around 20 lumens per watt. For the 100-watt gas-filled lamp, introduced in 1917, the increase was from 10 to 12.5 lumens per watt. For the smaller lamps, the improvement was relatively slight.

When the gas filling was added to the ductile tungsten lamp, it pushed the efficiency of incandescent lighting high enough for it to eliminate fairly quickly most of the remaining general-purpose gas and arc lighting. The combination of convenience, cleanliness, efficiency, low first cost, low maintenance cost, and simplicity made incandescent lighting supreme.

Langmuir applied for an American patent on the gas-filled lamp on April 19, 1913, and it was issued and assigned to General Electric on April 18, 1916. Foreign patents were also obtained.[10] Along with the Just and Hanaman pressed tungsten patent and the Coolidge ductile tungsten patent, the Langmuir patent was the cornerstone of the General Electric patent-licensing system and the consequent control of General Electric over the domestic electric-lamp industry.

The General Electric Research Laboratory spent $195,000 on the development of the gas-filled lamp. The annual expenditures from 1909 to 1915 were as follows:

1909	$ 7,503	1913	$27,060
1910	16,322	1914	57,111
1911	16,118	1915	44,392
1912	25,967		

This was a very modest sum to spend on such a significant line of research and development, for it produced important commercial results in welding with atomic hydrogen, radio tubes, and other fields besides incandescent lamps. Far greater sums had been paid by General Electric for earlier lamp patents of much less significance. The results of Langmuir's work also indicate how greatly a program of fundamental research carried on by able industrial scientists can benefit both manufacturer and public.

[10] It was reported that A.E.G. had also been working on the nitrogen filling of incandescent lamps in simultaneous and independent experiments, *Electrical World*, Vol. LXII, p. 1130 (Nov. 29, 1913). It is clear, however, that Langmuir had priority in the successful solution of the problem.

2. *Other General Advancements in Incandescent Lighting*

Although the development of the gas-filled lamp was the last revolutionary improvement which has taken place in incandescent electric lighting, there were a number of subsequent changes which greatly increased efficiency and improved lamp performance. Filament advances continued until 1936, and low-cost commercial solutions were found for such long-standing problems as the elimination of the lamp tip and the reduction of glare.

NON-SAG TUNGSTEN

The ductile tungsten filament available in 1914 had an unfortunate tendency to sag. That made it impossible to space closely the filament coils of a gas-filled lamp, and the greater dissipation of heat interfered with maximum lamp efficiency. When the ductile filament was first developed, it was found that in operation the fibrous structure of the tungsten wire changed to a crystalline structure, since the metal was heated above its annealing temperature. The crystals of tungsten were held together by amorphous tungsten, and if the faces of the crystals lay in a plane across the wire it was easy for them to slide across each other and offset. This was true particularly when the lamp was operated on alternating current, as in the case of the tantalum filament. If the crystals did offset, the smaller continuous wire at that point became hotter and destroyed the lamp more rapidly. To hold the crystals in place and prevent offsetting, about 0.5 per cent of thoria was added.[11] Thoriated wire did not offset, but the thoria limited the size to which the tungsten crystals could grow and resulted in a wire which bent easily at high temperatures.

The problem of sag was a troublesome one. Coolidge had found during his experiments that if he heated purified tungstic oxide in a covered Battersea crucible, some of the substances in the crucible volatilized and became mixed with the oxide. The added materials, which consisted largely of silica and alumina, produced a coarser-grained wire which did not sag. Nevertheless, Coolidge was not able to produce non-sag wire on a commercial

[11] The use of thoria was first suggested by European experimenters. Other substances, such as calcium oxide, were also used to reduce offsetting.

scale. That problem was undertaken by Dr. Aladar Pacz, also an employee of General Electric.

After a great many experiments, Pacz found on his two hundred and eighteenth attempt that he could add very small quantities of an alkali silicate to produce large crystals of tungsten of a shape that would neither offset nor sag. The crystals were irregular and overlapped one another. With the Pacz wire it was possible to space the turns in a coiled filament more closely and increase the efficiency of tungsten lamps. A patent on the development was applied for on February 20, 1917, and granted on March 21, 1922. The invalidation of the Pacz patent by the Second Circuit Court of Appeals was based on the earlier Coolidge description of his experiments with Battersea crucibles. Since he had made a wire that did not offset or sag, even though his technique was very crude, it was decided that the Pacz claim for a non-sag wire had been anticipated. Despite the fact that the patent was declared invalid, it remains true that the work done by Pacz in discovering a commercial method of making a uniform wire that would neither offset nor sag was very important to technological advance in incandescent lighting.

TIPLESS LAMPS

The next major technological development was a cheaper method of producing large tipless lamps, developed in 1919 by L. E. Mitchell and A. J. White of General Electric.[12] Their method was similar to that of Jaeger,[13] which had been developed in 1903, but it was somewhat simpler and easier to mechanize. Whereas Jaeger's exhaust tube was L-shaped and was inserted into the stem after the latter was made, the new construction permitted the tube to be inserted while the stem was being made. While the glass was soft at the top of the stem, where the exhaust tube was imbedded, air blown in from outside made a small hole in the glass through which the bulb could later be exhausted. Patents on the method of construction and a machine for employing it

[12] The problem of making a tipless miniature lamp was not so great. In most miniature lamps the filament was supported solely by the lead-in wires, and no stem was needed. It was easy to exhaust lamps of this construction through the base, and the construction was used in telephone switchboard lamps in 1898 and was extended to flashlight lamps in 1913 and to certain automobile lamps in 1915.

[13] See p. 209.

were applied for on March 20, 1919, and granted on July 25, 1922.

The Mitchell and White process permitted General Electric to make tipless lamps more cheaply than tipped lamps, and the big company and its licensees rapidly adopted the new style as standard. The unlicensed firms were forced by consumer demand to follow the lead of General Electric and also shifted to tipless lamps. After the successful infringement suit by General Electric against Save under the Mitchell and White patent, the independents used the Jaeger technique, the patent on which had expired in 1920. It is significant that the early method, which was later used by the independents, lay virtually idle for seventeen years until the industry leader made a change in its product. The small percentage of the market supplied by the independents made it very difficult for them to take the lead in product design, even where one of their general group had made a genuine advance.

INSIDE FROSTING

Another noteworthy change in the design of incandescent lamps was the general introduction of inside frosting. Many methods had been employed since 1880 to reduce the glare of incandescent filaments. Although bulb frosting offered many advantages, no completely satisfactory frosting technique had been adopted by 1925. Inside frosting was held to be commercially impracticable, because the single-dip acid-etching process then known tended to weaken the glass and increase breakage. Outside frosting by acid etching, sand blasting, or painting was partially satisfactory, yet the rough surface had a tendency to catch dirt and reduce light output. In addition, outside frosting reflected back into the bulb a large portion of the light and reduced lamp efficiency even when clean.

The obvious superiority of inside frosting had led to a number of early attempts to develop a practicable frosting method. The first patent on a proposed process was granted to Patrick Kennedy of the Consolidated Electric Lighting & Equipment Company of New York on July 21, 1903. His was a single-acid-bath process. No real improvement over the Kennedy process was made in practice for more than twenty years. At the same time it was well known in the glass industry that the sharp angular

crevices of etched glass could be smoothed and rounded out by a second treatment with a weaker acid. The suggested use of successive acid treatments for the etching of electric-light bulbs was made, among other places, in a German trade paper in 1912 and in an American patent of 1918 to Robert W. Wood of Baltimore.

Despite the prior art, no change was made by the incandescent-lamp industry until 1925. In that year Marvin Pipkin of General Electric combined the ideas of his predecessors. He used a two-bath process, the second of which rounded out the sharp cracks and restored the bulb to a satisfactory strength. A patent was applied for on June 29, 1925, and granted on October 16, 1928. Process claims were not allowed because of the prior art, and only product claims appeared in the patent as issued. Besides having the advantage of staying clean longer, Pipkin's inside frosting was not so wasteful of light as outside frosting and produced better light diffusion.[14] When the Pipkin patent came into litigation, it was eventually decided by the Supreme Court that the prior art was sufficient to invalidate all the claims of the patent. It was also established that the water bath used in the Kennedy process to wash out the hydrofluoric acid became a weak acid solution itself. Kennedy, therefore, was using a double-dip process without knowing it, and a court demonstration in the Wabash case proved that a sufficiently strong bulb could be produced by the method. Although this took most of the glory from Pipkin's achievement, it remains true that he was the first to realize that the form of pitting affects the strength of the bulb and to adapt the old technique to the new use. His process and General Electric's use of it achieved a great commercial success.[15]

The inside-frosted lamp was introduced to the market in 1925 by General Electric and its licensees. Corning was licensed to use

[14] It is still necessary to employ painted coatings or colored glass to produce colored light by incandescence, and the efficiency of that type of illumination is very low.

[15] The Pipkin process is still in use at the present time. In 1937, for $90,750, General Electric purchased from the Inwald Company of Austria the American rights to its new process for the inside frosting of bulbs. Tiny glass particles were sprayed onto the inner portion of the bulb and attached by heating. The bulb was then treated with acid. Although hopes were high that the Inwald process would produce a stronger bulb, it was soon found that it was not as satisfactory as the Pipkin process, and it was abandoned.

the Pipkin process to supply frosted bulbs to General Electric licensees only. The independents had to buy unfrosted bulbs and do the frosting themselves or have it done elsewhere. The inside-frosted lamp was first made in six sizes, ranging from 15 to 100 watts, which were designed to replace about forty-five different sizes and types used for general lighting in the same wattage range. A new pear-shaped bulb was employed. It thus made possible the third major standardization program in the electric-lamp industry.[16] Those bulbs with straight sides tapering to the base and a number of types with round ends were displaced except for special applications. While clear bulbs were still offered for sale, their displacement was hastened by pricing them above the inside-frosted type after a year or so. Since lamps for general lighting in sizes of 15 to 100 watts typically constitute about 85 per cent of all large lamps sold in this country, the reduction in varieties permitted far more efficient production and distribution.

THE COILED-COIL FILAMENT AND OTHER CHANGES

Only one significant change in fundamental incandescent-lamp design was made after 1926. The desirability of increasing the effective diameter of the filament in the gas-filled lamp to reduce heat losses led to a recoiling of the once-coiled filament. The apparent length of the filament was much shortened, and the heat-radiating surface was greatly reduced. The coiled-coil filament was introduced for standard lamps by General Electric and other American lamp makers in 1936. With that improvement, the filaments of certain lamps could be operated at still higher temperatures and greater efficiencies for the same average life. With the coiled-coil filament, the efficiency of the 60-watt lamp was increased from 12.5 to 13.8 lumens per watt, and that of the 100-watt lamps was increased from 15.3 to 16.0 lumens per watt. The new filament construction was used only in the 50-watt to 100-watt standard lamps for general illumination and in a few special

16 The other two were the standardization of bases around 1900, and the standardization of voltages. The introduction of ductile tungsten filaments made control over lamp voltages more accurate than had been possible with carbon filaments. Since the second decade of this century there has been a continuing program to narrow the range of circuit voltages so that the voltages of lamps and other appliances can be reduced to a smaller number of standards.

types, yet they represented between a third and a half of all large lamps sold in this country.

Double coiling had been employed as early as 1913 in projection lamps, where a high degree of concentration of light output was necessary. The application to standard lamps was new, however, and it raised troublesome problems of spacing, coiling, and removing the mandrels that were not solved for many years. When achieved, it led to definite lamp improvement. Certain European lamp manufacturers, especially Philips, led in the commercialization of the double-coiling technique. The higher voltages widely used abroad required longer filaments and encouraged double coiling to shorten the mounted filament and to concentrate the light output. Although it was not possible to obtain a basic patent on the idea, a number of American patents, including General Electric's early Benbow patent of 1917, have been granted on various methods of making and mounting coiled-coil filaments.

The lives and efficiencies of most incandescent lamps were also raised after 1912 by further progress in getters. Among the most outstanding new suggestions were the following:

Inventor	*Country or Company*	*Date*	*Getter*
Ernst Friedrich	Germany	1913	Barium chlorate or other substance which gave off oxygen
F. W. Gill	Gen'l Electric Co.	1915	Inorganic halogen compound
Fritz Blau	Germany	1916	Barium or other metallic compound which decomposed to produce drying effect
Antonius de Graaff and Dirk Lely, Jr.	Holland	1920	Non-hygroscopic substance which decomposed upon heating to form a hygroscopic material
Antonius de Graaff	Holland	1938	Metallic zirconium (absorbs hydrogen)

The number of experiments with new filament materials dropped off rapidly after the introduction of ductile tungsten.

The attempts to replace tungsten by nitrates, carbides, oxides, etc., have shown no real promise of success.[17] At present there seems little chance that tungsten will be replaced by a more efficient illuminant.

Numerous minor innovations in the design of incandescent lamps for general illumination have occurred since 1912, of course, although even in this respect the rate of progress seems to have slowed down of late. For example, no noteworthy changes occurred during World War II or the first few postwar years. Among the previous useful innovations were such techniques as the construction of lamp stems to reduce the danger of short circuits between the lead-in wires, and the construction of shoulders on the necks of lamp bulbs for stronger and straighter seatings into the lamp bases. Minor changes in bulb sizes, filament mountings, etc., for particular lamp sizes still go on.

3. *Evaluation of the Improvements in Incandescent Lamps for General Lighting, 1912–1947*

Among the most important properties of incandescent lamps from the consumer's point of view are efficiency and life. In addition, the fragility or durability of the lamp, its pattern of light distribution, the color quality of the light given off, the glaring or diffused nature of the light, and numerous other features must be considered in evaluating lamp performance.

Notwithstanding the fact that the same filament material has continued in use from 1912 to 1947, improvements in the tungsten lamp to 1937 resulted in an increase in efficiency of roughly 100 per cent for standard lamps of medium wattage for general lighting purposes. Table XXIV summarizes the histories of rated initial lumens per watt[18] of selected sizes of large lamps for the General Electric group of producers. It will be noted that, al-

[17] Among the more recent suggestions are a 1937 patent granted to a General Electric worker on a type of lamp using tantalum carbide as the illuminant. Also, in 1936 the *Philips' Technical Review* mentioned experiments with metallic oxides and nitrides which volatilize more slowly than tungsten.

[18] The lumen ratings of lamps represent the averages obtained from life-testing sample groups of lamps. Individual lamps may vary slightly from these figures. Lumen output diminishes gradually over the life of the lamp. At present in the case of the 100-watt lamp it falls from 16.3 to 15.3 lumens per watt at 70 per cent of rated life.

TABLE XXIV: RATED INITIAL EFFICIENCIES FOR SELECTED SIZES OF LARGE TUNGSTEN-FILAMENT LAMPS FOR GENERAL LIGHTING [a]

1907–1947

Year	Type of Lamp (*Tungsten Filament*)	Rated Watts	Initial Lumens per Watt	100-Watt Tungsten Filament		
				Year	*Type of Lamp*	*Initial Lumens per Watt*
1907	Vacuum (pressed fil.)	40	7.8	1907	Vacuum (pressed fil.)	7.8
1912	Vacuum (drawn wire)	40	8.3	1910	Same	8.2
1914	Same	40	8.9	1911	Vacuum (drawn wire)	8.4
1915	Same	40	9.5	1912	Same	8.7
1918	Same	40	9.2	1913	Same	9.2
1920	Same	40	9.3	1914	Same	9.6
1921	Same	40	9.9	1915	Same	10.4
1922	Same	40	10.1	1917	Same	10.0
1926	Same	40	10.3	1917	Gas-filled (drawn wire)	12.6
1926	Same	60	10.5	1921	Same	12.8
1926	Gas-filled (drawn wire)	60	11.1	1923	Same	12.9
1927	Same	60	11.2	1925	Same	13.4
1928	Same	60	11.3	1926	Same (inside frosted)	13.2
1929	Same	60	11.5	1928	Same	13.4
1930	Same	60	12.0	1929	Same	13.7
1932	Same	60	12.4	1930	Same	14.1
1935	Same	60	12.5	1931	Same	14.2
1937	Same (coiled coil)	60	13.8	1932	Same	14.4
1939	Same	60	13.9	1933	Same (750 hours)	14.9
1941	Same	60	13.9	1934	Same	15.1
1942	Same	60	13.9	1935	Same	15.2
1943	Same	60	13.9	1936	Same	15.3
1944	Same	60	13.9	1937	Same (coiled coil)	16.0
1945	Same	60	13.9	1938	Same	16.2
1946	Same	60	13.9	1939	Same	16.2
1947	Same	60	13.9	1940	Same	16.2
				1941	Same	16.2
				1942	Same	16.2
				1943	Same	16.2
				1944	Same	16.2
				1945	Same	16.2
				1946	Same	16.3
				1947	Same	16.3

[a] All data are for 115-volt lamps.

Sources: General Electric Company, Westinghouse Electric Corporation, Sylvania Electric Products Inc., and Electrical Testing Laboratories, Inc.

though the major innovations to 1937 resulted in marked increases in efficiency, the cumulative effect of smaller improvements was responsible for a large part of the total increase.

The rated life of tungsten-filament lamps for general lighting has remained at 1,000 hours in most instances since the introduction of ductile wire in 1911. Experience at that time indicated that a life in the neighborhood of 1,000 hours was the most practical in a large percentage of installations. Accordingly, the improvements which could have been put into an increase in lamp efficiency or into a lengthening of lamp life have been concentrated in the former.

Lamp life has not been maintained unchanged since 1910 for all sizes of general-purpose lamps, however. During the early thirties, to counter the threat of foreign lamps, General Electric and its licensees introduced a cheap line of Type D lamps having shorter lives of 500 hours. They also increased the efficiencies of lamps in the 75-watt to 200-watt range by reducing their rated lives to 750 hours. A few other changes were made in the lives of low-wattage lamps.[19]

The policies followed by General Electric in fixing lamp life have frequently been criticized.[20] The company has been accused of deliberately shortening the burn-out time in order to increase its sales. It is certainly true that the lamp producers have kept down lamp life and have benefited from greater sales; but that alone is not a valid argument against the shorter-lived lamp. The validity of the 750- to 1,000-hour average life depends upon its effect on lighting costs. In electric lighting the usual object is to obtain the desired number of lumens as cheaply as possible. Optimum lamp life depends on the complex relationships among lamp efficiency, lamp prices, lamp life, cost of changing lamps, and power rates. The cost of electric current is far greater than that of lamp replacement. But electric rates have declined by more than 60 per cent since 1910,[21] and yet most of the few

[19] See Appendix H for a historical record of the average rated life for the most important lamp sizes.

[20] The international cartel has also tried to increase lamp sales by standardizing on short-life incandescent lamps. Owing to less complete control by the cartel over the European market than General Electric obtained in this country, European lamps have generally had somewhat longer life and lower efficiency.

[21] See p. 361.

changes in incandescent-lamp life have been downward. If the 1,000-hour life was optimum in most installations in 1912, it would appear to be too short at the present time. However, from an ideal cost standpoint in many installations a much shorter life than 1,000 hours would actually have been most economical in 1912. The same is true today. The lives actually established by the lamp manufacturers have been somewhat longer than their calculations of the theoretical ideal to reduce the annoyance of frequent lamp replacement. Moreover, the rapid decline in efficiency with longer life indicates that for a large proportion of applications longer life would not be desirable. A sweeping and unqualified condemnation of present average lamp life does not seem justified, therefore.

Nevertheless, the emphasis which General Electric has placed on lamp efficiency at the expense of lamp life has in many instances led consumers to forget the importance of over-all installed efficiency. Where lamp shades or globes frequently reduce lamp efficiency by 25 per cent or more, a 1 or 2 per cent increase in efficiency may be of less consumer benefit than the equivalent lengthening of lamp life. Greater public knowledge about the efficient use of lamps would benefit most residential users, and even many institutional, industrial, and commercial users.

There are other particular circumstances in which American consumers have grounds for complaint about lamp life. Where lamps are located inaccessibly or where current costs are very low, long life may lead to greater economy than high efficiency. General Electric and its former licensees do not list standard-wattage lamps rated at more than 1,000 hours except for traffic-light, street-railway, street-lighting, and low-wattage lamps. It has been impossible for consumers to prevail on General Electric to add long-lived lamps to its standard line so that the purchaser may select for himself the type he wants.[22] This insistence by the industry leader that it knew best what its customers needed has in individual instances proved costly to them, for what General Electric made standard was virtually forced on 90 per cent

[22] Some large individual purchasers, such as railroads and utilities, have been able to buy special long-lived lamps made to order by General Electric; its smaller customers have not been in a position to insist on this "privilege." Some long-life lamps are made by independent manufacturers, however, and they have been promoted more vigorously during the last few years.

of the domestic market. Consumers have not had the freedom of choice with respect to burning hours to which they would seem to be entitled.

Another illustration of General Electric's attitude regarding lamp life and consumer option was its reaction to the increasing tendency of consumers in 1936 to buy 2,000-hour miniature night lamps for use on Christmas trees instead of the similarly priced 500-hour lamps expressly designed for Christmas-tree use. General Electric discouraged that substitution through instructions to its salesmen and agents. It argued that each lamp was expressly designed for its intended purpose, and that the less efficient night-lamp would produce less sparkle on Christmas trees and was not able to withstand rough handling so well. While those arguments may have been valid, it seems clear that the prospective loss of sales was the primary motive behind the objection.[23] In any event, General Electric's policy here again was to urge upon the consumer what it wanted him to buy rather than to permit him to select for himself.

Still another instance of which much has been made was the attempt by General Electric to reduce the life of flashlight lamps from a three-battery basis to a life which would last about as long as a single battery.[24] The battery manufacturers went part way in 1925 and accepted a lamp with two battery lives instead of three. The life reduction was not publicized. In 1933 General Electric added a new line of flashlight lamps which had one-battery lives; they were priced at seven cents each, two cents below the two-battery lamps. Although flashlight users benefited somewhat by obtaining stronger beams, it appears that the primary motive behind the change was to increase lamp sales. The advantage from the consumer's point of view was not nearly so clear-cut as in the reduction of the life of some of the general lighting lamps to 750 hours.

[23] See United States of America *v.* General Electric Company et al., *Brief for the United States of America*, Aug. 30, 1946, pp. 180–182, and *Brief for General Electric Company and International General Electric Company*, Dec. 2, 1946, pp. 419–421.

[24] See United States of America *v.* General Electric Company et al., *Complaint*, Jan. 27, 1941, p. 140; *Answer of Defendant General Electric Company*, May 15, 1941, pp. 55–56; and *Canada and International Cartels*, Report of the Commissioner, Combines Investigation Act, Ottawa, Oct. 10, 1945, p. 23.

The over-all performance of incandescent lamps for general illumination has been improved in various other ways, however. Brilliancy has been considerably reduced, primarily through the inside frosting of the bulb. Although in many applications the greater glare of clear bulbs would not be harmful, it seems that for common use this change has been desirable. The durability of incandescent lamps has been increased by eliminating the tip and by improving filament mounting and basing, although the bulb has been somewhat weakened by inside frosting. Concentration of the filament by coiling and recoiling has permitted greater control over the distribution of light given off by the lamp. The color quality of standard incandescent lighting has always been and is still quite different from that of daylight; it is deficient at the blue end of the spectrum and too strong at the red end. Nevertheless, the higher filament temperatures in gas-filled lamps did produce some improvement in color quality over the vacuum lamp.

Despite the advances cited above, even the 1,500-watt filament lamp converts only about 13.5 per cent of the electric energy which it consumes into visible light, and the 100-watt size is but 10.0 per cent efficient. Their light output is concentrated at the red end of the spectrum, for which the eye has a low sensitivity, and their initial efficiencies of 22.0 and 16.3 lumens per watt, respectively, represent only 3.5 and 2.6 per cent of the maximum theoretical visual effect of a monochromatic green light. There have been no appreciable efficiency advances for ten years. Although the possibility of improvements in basic filament materials cannot be categorically denied, it remains true that the possibility is very slim. The opportunities for further increases in incandescent-lamp efficiency seem to lie primarily in the economical use of gas fillings of krypton and xenon and in metallurgical advances in the uniformity and density of tungsten. The possibilities are very limited, and there is no chance that incandescent lighting can rival the efficiencies of modern fluorescent and other electric-discharge lamps. Moreover, color quality has about reached its peak, since tungsten filaments cannot be operated at much higher temperatures than are now employed, and further important progress in most other lamp characteristics seems improbable.

4. *The Design of Special Types of Lamps*

Another phase of incandescent-lamp progress has been the design and improvement of special types of lamps. Among the leading developments have been new types of miniature lamps, train and street-railway lamps, lamps for high and low voltage, rough-duty lamps, projection lamps, aviation lamps, photoflood and photoflash lamps, silvered-bowl lamps, sealed-beam headlamps and self-contained reflector and projector lamps of both the spotlight and the floodlight variety.[25]

One wave of specialty development, which occurred immediately after the introduction of the tungsten filament, provided for some of the more obvious special applications of incandescent lighting. A second wave during the thirties resulted partly from the increase in competition, partly from the growth of new uses for incandescent lighting, and partly from the greater maturity of the industry. Much of the effort that had formerly been directed toward more basic improvements in the incandescent lamp was shifted to the development of new varieties after it became evident that diminishing returns had to be expected in fundamental incandescent-lamp research. In addition, the growing body of knowledge made it relatively easy to design new filament lamps for specific applications which had not yet been taken care of.

The design of most special lamps called for engineering skill rather than research. None of the new types differed much in their fundamentals from the kind used for standard lighting. Bulb size and shape, filament dimensions and arrangement, base design, and filament mounting techniques—these were the principal variables involved. In most of the special developments General Electric and Westinghouse, as the industry leaders, did the bulk of the work. In some instances the independents took the lead. Since only minor innovations have been involved in the majority of the specialties, patents have been of importance in relatively few instances.

Table XXV gives for General Electric the dates of introduction, introductory list prices, and 1946 list prices for one or two

[25] Infrared heat and drying lamps have also been introduced as modifications of the usual filament lamps for illumination.

TABLE XXV: DATES OF INTRODUCTION BY GENERAL ELECTRIC AND PRICES FOR SELECTED SIZES OF PRINCIPAL TUNGSTEN-LAMP SPECIALTIES

1908–1946

Lamp Type	*Size*	*Date of Introduction*	*Introductory Price*	*Jan. 1, 1946, Price*
Flashlight	No. 31	1908	$0.60	$0.10
	No. 223	1913	.40	.09
Automotive	No. 63	1908	.75	.07
	No. 89	1914	.60	.15
Train Lighting	25 watt (32 volt)	1909	.70	.20
High voltage	100 watt	1910	2.15	.31
	25 watt	1911	1.25	.22
Spotlight	100 watt	1912	2.00	.80
Floodlight	250 watt	1918	3.00	1.15
Street lighting (series)	4,000 lumens (6.6 amp.)	1914	4.15	.95
Street railway	36 watt	1914	.30	.17
	56 watt	1914	.40	.20
Low voltage	50 watt	1917	.65	.20
Daylight	100 watt	1917	1.20	.25
Vibration	50 watt	1918	.40	.20
Projection	1,000 watt (T–20)	1919	8.00	4.75
	200 watt (T–10)	1928	2.35	2.00
Aviation	5,000 watt	1929	50.00	23.00
	500 watt	1935	3.90	3.50
Photoflood	No. 1	1932	.35	.15
	No. 4	1934	2.55	1.20
Photoflash	No. 75	1932	.75	.55
	No. 21	1938	.20	.15
Three-lite	150–200–350–watt	1933	1.50	. . .
	100–200–300–watt	1935	1.00	.55
Lumiline	60 watt	1934	1.00	.85
Photo enlarger	No. 213	1936	.35	.25
Silvered bowl	100 watt	1936	.70	.25
	500 watt	1936	2.60	1.70
Projector (spotlight or floodlight)	150 watt	1938	1.70	1.40
Reflector (spotlight or floodlight)	300 watt	1939	1.90	1.40

Sources: General Electric Lamp Department, *Chronological Record of Standard Lamp List Prices*, Jan. 1, 1942; Westinghouse Lamp Division, *Standard Price Schedule*, Oct. 1, 1945.

sizes of each of the leading tungsten-lamp specialties. The list prices set by General Electric have typically been followed by all other lamp producers. Dates of introduction of new products vary for the different firms, however. Westinghouse has in the past generally introduced new products at the same time as General Electric. The former B licensees have also followed the lead of General Electric in adding those new products which they were entitled to make under their license agreements. As for the independents, the pattern is less clear-cut. Occasionally they have preceded the larger companies. More often they have taken up the new product after the market for it has been developed. Each of the small companies has acted independently, adding some but not all of the specialties, and none of them sells a full line of large and miniature types.

Although it would be impossible to give full accounts of the introduction of all the specialties listed in Table XXV, it is worth while to consider briefly a few of the most significant items. The earliest types, which were introduced while General Electric controlled all but a very small portion of the industry, were almost exclusively the work of the leader and call for no special explanation. The developments after 1930 were more unusual and interesting.

Self-contained projector and reflector lamps represented one important development of the middle thirties. Large glass bulbs

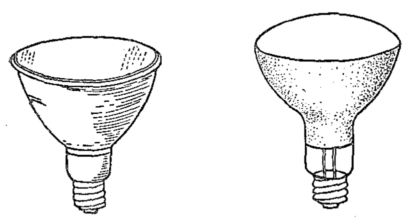


Fig. 28. Projector Lamp (Left) and Reflector Lamp (Right) Each type is made in floodlight and spotlight varieties.

were designed with mushroom tops which contained silvered coatings on the inside for reflection. Depending on the type of lens in the projector lamp and on the density of frosting in the reflector lamp, either type could be designed as a floodlight or a spotlight. Lamps with unsilvered mushroom-shaped bulbs were first introduced in Europe by N. V. Philips, and the idea was imported into this country by the independents. Clarence Birds-

eye of the Birdseye Electric Company[26] of Gloucester, Massachusetts, which was later absorbed by Wabash, was the first to silver the insides of the bulbs and use them for spotlights and floodlights. The market reception for the Birdseye style was so enthusiastic that similar lamps were soon put on the market by General Electric, its licensees and a number of the other unlicensed companies.

The multiple-filament or, as it is often called, three-light lamp gained a new lease on life during the early and middle thirties. General Electric brought out some large multiple-filament lamps in 1933 with extra-size bases. Shortly thereafter, independent manufacturers initiated the expansion to multiple-filament lamps with medium bases, despite General Electric's initial opposition.[27] General Electric later adopted the medium-based type itself. Such lamps are now standard items for most large-lamp manufacturers in the former General Electric group as well as for many of the independents.

One of the most interesting developments of the thirties was the rise of various new types of photographic lamps. Around 1932 General Electric introduced a photoflood lamp for interior photography. It was an ordinary tungsten lamp so designed as to give off a very large output of light for around ten hours. The lamp was well received and has secured a good market.

Another new photographic aid, the foil photoflash lamp, was introduced in the United States by General Electric in 1931. Prior to that time only photoflash powder had been employed, either in the air or enclosed in a glass bulb. The new type had been developed in Europe in 1929, and General Electric bought the basic American patent, which was issued to Johannes Ostermeier of Althegnenberg, Germany, on September 23, 1930.[28] It covered a loose filling of magnesium or similar foil in an oxygen-

[26] Clarence Birdseye is a prolific inventor in many fields, including frozen and dehydrated foods. Up to 1946 he had been granted more than 200 patents on his inventions.

[27] When the Northern Incandescent Lamp Corporation sought to buy medium bases for three-light lamps from General Electric, its order was rejected. The desired bases were then specially made by the Eagle Electric Manufacturing Company.

[28] A reissue patent was granted two years later.

filled glass bulb with a slender tungsten filament to serve as an ignition device.

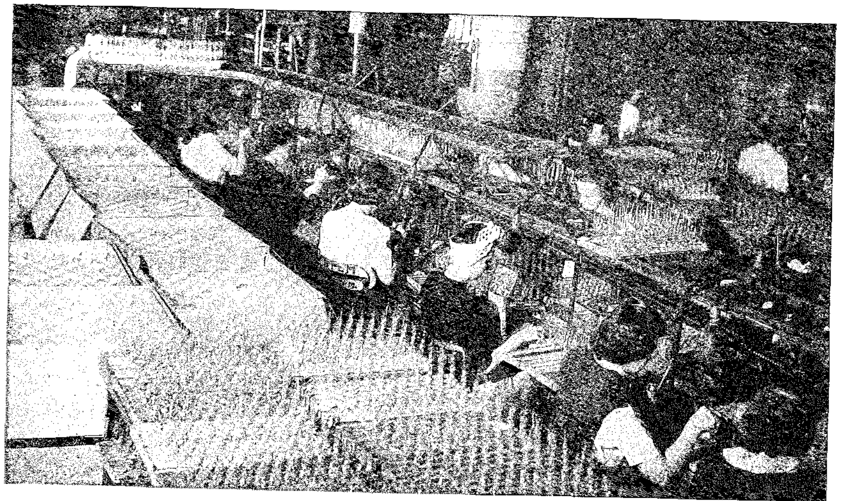
The foil lamp was so far superior to the older powder technique that it immediately took over the photoflash market, which at that time was restricted almost entirely to professional photographers. Only a few other lamp companies tried to enter the photoflash field.[29] The outstanding unlicensed competitor was the Munder Electrical Company of Springfield, Massachusetts. General Electric sued Munder for infringement of the Ostermeier patent. The validity of the patent was sustained, and the infringing company ceased production after a court injunction. At least one of the other small companies was also required to suspend its photoflash operations.

In 1935 the engineers of N. V. Philips developed and introduced in Europe a new wire-type photoflash lamp. With wire the peak of light output was broader than with foil, and synchronization with the camera shutter was less difficult. Moreover, much smaller bulbs could provide the same light output. A series of American patents was issued to Philips, starting in 1936 on the distinctive features of the wire lamp, such as the use of a wire alloy of aluminum and magnesium, the distribution of the wire in the bulb, and a machine for introducing the wire into the bulb. These and other patents, while important, were not all-inclusive, for the idea of using wire antedated the foil photoflash lamp. Nevertheless, the Philips innovation was the first successful wire lamp.

Non-exclusive licenses under the Philips photoflash patents were offered in turn to General Electric and Westinghouse in 1936. Each company refused to accept a license, although General Electric made a counter offer to buy the patents. Philips was unwilling to sell the rights and repeated its license proposal to the Wabash Appliance Corporation, which saw great possibilities in the lamp and accepted Philips' terms.[30] Further development was necessary to make the lamp operable with American photographic synchronizers. By the end of 1936 the first Wabash wire

[29] For a few years Westinghouse made and sold the foil lamp as a General Electric licensee. Around 1938 it gave up production of the device and until 1946 sold lamps made for it by General Electric under the Westinghouse trademark.

[30] Philips retained the right to produce photoflash lamps in the United States itself. It has not exercised that right.



Courtesy Westinghouse Electric Corp.

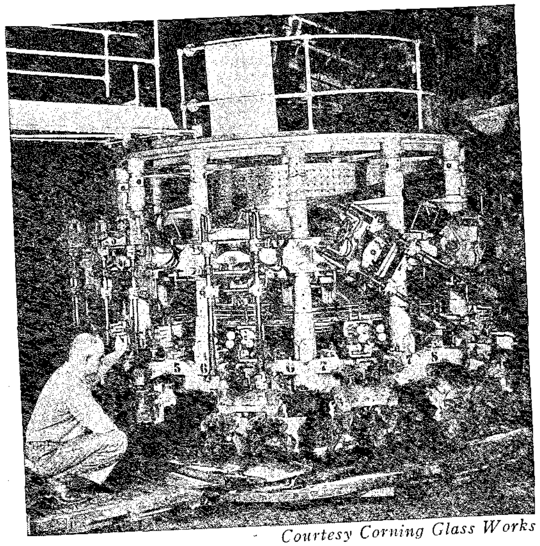
FIG. 29. Assembly of Stems for Rough-Service Lamps

The operators mount filaments for these special lamps on machine-made stems. Completed filament assemblies move to the lamp-assembly machines at the upper left.

Courtesy Westinghouse Electric Corp.

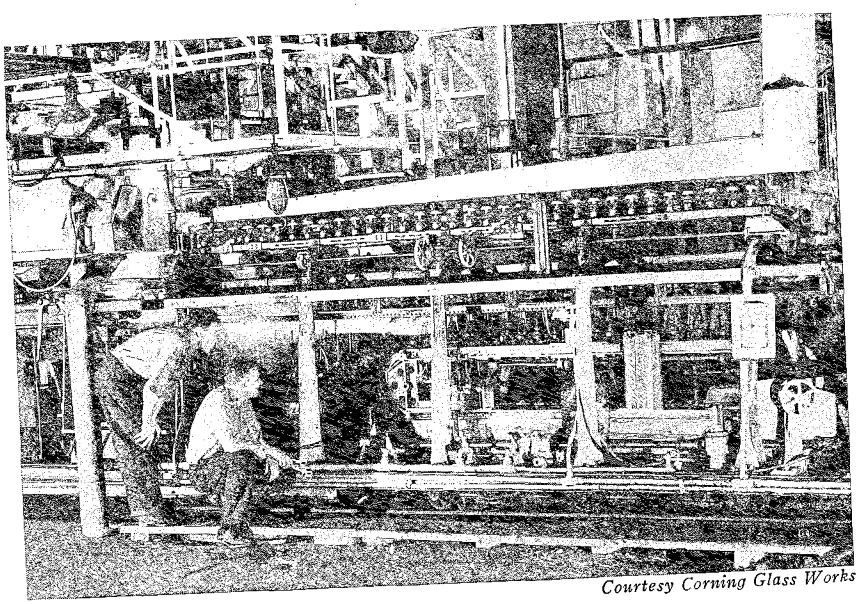
FIG. 30. Lamp-Assembly Machine

Completed filament assemblies are inserted into the glass bulbs and sealed in by the machine. Excess glass is removed, the lamp is then exhausted and gas-filled, and a base is put on.



Courtesy Corning Glass Works

FIG. 31. Modern Bulb-Blowing Machine of the Westlake Type
This automatic machine is used for producing small quantities of special bulbs, about 10,000 bulbs an hour.



Courtesy Corning Glass Works

FIG. 32. Corning Ribbon Bulb-Blowing Machine
Moving blow-heads and molds are synchronized with the movement of a continuous ribbon of glass. The machine can turn out 50,000 bulbs an hour.

lamps were on the market, and large-scale production was started early in 1937.

The advantages of the new type of photoflash lamp were so great that Wabash rapidly cut into General Electric's share of the market. Moreover, the market expanded tremendously as amateur photographers adopted photoflash techniques. Wabash gained an important advantage by promoting its product through photographic suppliers rather than through normal lamp-selling channels. By 1940, Wabash was supplying around three-fourths of the domestic market. Even though the flashlamp business of the industry leader was rising, that of Wabash was increasing much faster. General Electric was forced by the competition to shift to a wire-type lamp of its own, using aluminum wire instead of the alloy. Later the industry leader shifted from wire to shredded foil.[31] With that change and with the use of photographic dealers as outlets, General Electric was able by 1946 to increase its share of the market again to around 50 per cent. Westinghouse has also begun to make wire-type photoflash lamps, and Sylvania has acquired Wabash. Thus we see the three largest companies in the industry, two of which refused the original Philips offer, all deeply involved in making wire-type lamps. In fact, they are now the only three American producers of the lamp. Patent infringement proceedings have been instituted against General Electric by Wabash, which is a rare turnabout in the electric-lamp industry.

A further important development in incandescent lighting was the design and production of sealed-beam automobile headlight lamps. The sealed-beam lamp combines into one easily replaceable unit the headlamp reflector, a pre-focused light source and a well designed lens. The lamp is sealed against dirt, and since the reflector is replaced every time the lamp is replaced, the wastes of poor reflection are almost eliminated. The lamp was developed by General Electric at great expense with the cooperation of Westinghouse and the automobile manufacturers and attracted a great deal of attention within the two industries. While improving automobile headlamps, it is also apparent that the sealed-beam device greatly increased the sales value of headlight lamps and

[31] Only the very largest size of General Electric flashlamp still contains unshredded foil.

was a highly successful innovation from a commercial point of view.

A patent on the sealed-beam lamp was applied for by E. A. Howard and K. D. Scott on March 23, 1937. It was issued and assigned to General Electric on October 24, 1939. A number of other patents on improvements over the basic design were later issued to several different inventors who represented various companies. The lamp was first marketed around 1938, and it is now used in most newly manufactured automobiles.

5. *Sources of Advances in Incandescent-Lamp Design*

The American lamp industry during most of the last thirty-five years can be divided for purposes of analysis into four classes: General Electric, the licensor, in the first class; Westinghouse, the A licensee, in the second class; the B licensees in the third class; and the unlicensed firms in the fourth class.

General Electric has unquestionably remained the dominating force in the lamp industry. Until 1945 it made or licensed on the average 90 per cent of the industry's sales, and it is by far the best able to carry on research and development. Even during depression years, technical expenditures have been maintained at fairly high levels. The General Electric lamp department alone spent between $1,500,000 and $2,000,000 a year on research and development activities during the thirties and early forties. These expenditures have been in large part both the cause and the effect of tremendous profits in lamp making. Besides the resources of the lamp department itself, the strength and prestige of the rest of the company lie behind its lamp-making activities. Research and development are long-run problems to General Electric, and it is not necessary that such expenditures be profitable immediately. In fact, even a high percentage of complete failures can be financially tolerated. As the leader in the lamp industry, the company attracts capable scientific and engineering personnel and can pay it well.

Besides immense ability to carry on technical research and development in incandescent lighting, the big company has had strong incentives to do such work. Patents have been of great importance in maintaining its superiority, and it has continually

had to work to improve its products in quality and style. It has had to improve processes and methods of manufacture in order to achieve cost reductions. It has had to bring out new lamp specialties from time to time in order to meet developing consumer needs. As long as its patents were important, it was able to license and control some other firms and restrict the activities of those which were unlicensed.

Another inducement for General Electric to continue large research and developmental activities in lamp making was their relatively low real cost. Nearly $400,000 of such annual expenditures was typically covered by royalty fees from the A and B licensees. In effect, the licensees contributed to pooled research. They obtained the technical benefits and ability to maintain their positions in the industry, while General Electric obtained the basis for continued licensing and commercial leadership of the industry as well as the technical benefits. Furthermore, under the tax rates of recent years, the real costs of research and development have been much less than the dollar outlay on them.

The top management of General Electric has been farsighted in its attitude toward research since the founding of the Research Laboratory at the beginning of the century. Fundamental investigations have been encouraged, even where they have shown no obvious commercial applications. Outstanding men have been brought to the central laboratory and given great leeway in the selection of research problems. A fairly liberal budget, which has averaged about ½ per cent of total company sales, has been provided. Interference by manufacturing and sales representatives has been held to a minimum. It is seldom that a discovery of the laboratory cannot sooner or later be used profitably by some manufacturing department of the company.

The executives of the lamp department have been equally aware of the importance of continual technological advance. They have carried on extensive activities of their own, and they have collaborated with the Schenectady laboratory, which had to approve every new lamp before it could bear the "Mazda" trademark. Prior to 1915 the relationship was particularly close, for the development of the GEM lamp, ductile tungsten lamp, and gas-filled lamp drew the two units together. After 1915 there were fewer fundamental problems to be solved in incandescent lighting, and the lamp department relied more heavily upon its own expanding technical force. The Research Laboratory became more and more a consulting organization to be called on in the event of particularly troublesome problems. Most actual work on new developments in incandescent lighting was done at Nela Park in Cleveland, the site of the lamp department's headquarters.

Under these circumstances, and once having achieved leadership in the lamp industry, it is not surprising either that General Electric has been the principal domestic source of technological developments in incandescent lighting, or that it has retained its leading commercial position. Actually, the two go together. The big company has made a strenuous effort to maintain its position, which has been a much easier task than to rise in the face of some other concern's domination.

Despite the evident interest of General Electric's lamp department in technological progress and its high level of activity, there was a serious weakness in its attitude. Its effort was directed almost exclusively to the incandescent lamp until 1935, and it did not press strongly toward new and revolutionary light sources. It was content to improve the incandescent lamp where possible, to develop incandescent-lamp specialties, and to lower production costs.

The Westinghouse lamp division has until recently been limited by license agreement to one-third the size of the General Electric lamp department. Nevertheless, Westinghouse was less than one-third as effective as General Electric in achieving significant product developments in incandescent lamps. This is explicable in terms of the reduced incentives of Westinghouse to develop new products on its own. Where Westinghouse did develop a new product, General Electric was in a position to benefit three times as much, for the licensee had to license General Electric under its patents royalty-free. Under those circumstances, Westinghouse was encouraged to work along with the licensor and cooperate in the later stages of its new developments rather than to strike off on its own. In 1939 Westinghouse discontinued much of its incandescent-lamp research and concentrated its research effort in the electric-discharge field. Thereafter, until the cancellation of the A license, Westinghouse relied more

heavily than ever on General Electric's developments in incandescent lighting. The Westinghouse lamp division made slight use of the facilities of the central Westinghouse Research Laboratory, which paid little attention to incandescent lighting. With the end of the license system, the incentives have changed, however. A more intimate relationship within the Westinghouse organization seems probable, and it appears that more important innovations will come out of Westinghouse's own activity.

The third class in the incandescent-lamp industry has until recently consisted of the B-licensee group. They have made relatively few noteworthy technical contributions in incandescent lighting.[32] Their abilities to contribute were somewhat less, of course, and in addition under their license restrictions they had virtually no incentives for conducting pioneering work in the field. Their limitations to quotas and the requirement that they license General Electric royalty-free under any patented improvements made by them discouraged creative work of their own. They received the same benefit from General Electric advancements and paid the same royalties regardless of their own activities. They could ride on the appellation "licensee of General Electric" as well as, or better than, on their own efforts. Their development work consisted mostly of process and minor design improvements. Their failure to do anything of major importance in the field is quite understandable. When they desired to expand faster than the licensor, they had to turn to other products. The policy of Sylvania in fluorescent lighting was quite different, for example.

The fourth class in the incandescent-lamp industry contained the so-called independent manufacturers. They have been and remain small firms in comparison to the firms in the other three classes. Only a few of the largest have been able to carry on real product development, and none has been able to conduct basic research. Since company reserves have typically been small, any expensive development has had to pay for itself very quickly, and they have not dared to embark on many risky ventures. Their

[32] Prior to its acceptance of a B license from General Electric around 1920, the Tung-Sol Lamp Works developed a two-filament headlight lamp, which has since come into universal use for the depressed passing beam operated by the driver. The lamp has been made in large quantities by other manufacturers as well as by Tung-Sol.

engineering staffs have been limited in size and, in many instances, in ability.[33] The engineering work done by the small firms has been largely production engineering and process engineering; in practice little time has been spent on product development.

A further factor of importance in connection with incentives for technological contributions by the independents has been their difficulty in promoting and capitalizing on an innovation when they have made it. They have not had the national reputations to accompany their new products which General Electric and Westinghouse, and more recently Sylvania, have possessed. They have not had the large promotion and advertising budgets or the extensive distribution systems of the larger companies. They have not been in a position to educate the public to the use of fundamentally new products. They have been confronted with the prospect that whatever General Electric has made standard has immediately become the national standard, for about 90 per cent of the lamp purchasers in this country customarily bought from General Electric or its licensees. The independents have had to concentrate on catching up to or keeping even with General Electric; they have generally followed the leader rather than competed with him. They would have found it impossible, for example, to put over the fluorescent lamp.

It is evident that many of the difficulties of the independents spring from their financial weakness. Their position has been too risky to make them attractive public investments, for the most part, and the banking system has not generally supported their desire to compete with General Electric. The capital problem has become progressively more difficult, since much greater sums are now required to set up a lamp factory than were formerly needed. Whereas during the twenties $5,000 and liberal credit from machinery and other suppliers were enough to start a small plant, at the present time a minimum of $200,000 in cash is necessary. The financial demands of ordinary operation have left little to spare for new-product development and promotion.

Despite their limitations, the unlicensed manufacturers have

33 One helpful factor in the situation has been the possibility of hiring engineers formerly employed by General Electric and Westinghouse, who could bring with them the latest ideas and techniques of the big concerns. When Westinghouse discontinued its incandescent-lamp reseach in 1939, several of its former employees were hired by the unlicensed firms.

always had the opportunity of developing or acquiring something new which would permit them to improve their positions in the industry and to increase their profits. New designs in lamps are frequently not expensive. Since about 1933, the independents have become more novelty-conscious and less inclined to follow General Electric designs exclusively. The alertness of Wabash with the wire photoflash lamp is the outstanding example of what could be done. Other independents have pioneered in reflector lamps, three-light lamps, and similar products. Nevertheless, the collective product contributions of the small firms cannot be compared with those of General Electric.

One area in which the independents have concentrated a considerable amount of attention is the development of differentiated bulb coatings or materials. Several of them have tried to make distinguishable products which could command premium prices or provide them a specialized monopoly. The Verd-A-Ray lamp of Save, the Eyease lamp of Warren, the Superlite of Wabash, and the Eyesaver lamp of Jewel are examples of this. While these specialized products were of assistance during the highly unusual war period, they could not solve the competitive problem for the small concerns; and they constituted but a minor contribution to lighting technology.

Chapter XIII: TECHNOLOGICAL PROGRESS IN PRODUCTION METHODS: 1912–1947

SINCE 1912 great strides have been made in the productivity of labor and machinery for the manufacture of incandescent lamps and lamp parts. This progress has resulted in far lower costs of production, which have made possible substantial reductions in lamp prices. The standardized machine processes have also resulted in materially improved efficiencies for the lamps themselves. In addition, technological progress in the generation and distribution of electric energy has brought about very large reductions in power rates and has been the most important single factor in the reduced total costs of electric lighting.

1. Improvements in Lamp-Making Machinery

Around the turn of the century a wave of mechanization transformed the production of incandescent lamps from a manual basis to a semimechanized, mass-production basis. The preoccupation with machinery development increased after 1912. By the end of World War I, most processes were being carried on with the aid of machinery. In 1913 a double electric-welding machine was developed for the making of lead-in wires.[1] In 1914 a new sealing-in machine was made in which the lamps were indexed automatically to successive working positions in the machine. During the same year an automatic miniature beading and filament-mounting machine was developed, and a machine was also constructed which automatically inserted the support-wires in stems for large lamps. In the following year, two more important machines were developed. One automatically inserted the proper amount of cement into lamp bases; the other automatically exhausted lamps and sealed off the exhaust tubes.[2]

[1] Witt Bowden, *Technological Changes and Employment in the Electric-Lamp Industry*, Bureau of Labor Statistics, Bull. No. 593, Washington, 1933, pp. 30–31.

[2] See Appendix I for a complete list of these and other changes as given by Bowden, *op. cit.*, pp. 30–32.

The important machinery development from 1912 to 1918 was done almost exclusively by General Electric. The industry leader had its own machinery-development engineers and production shops in its lamp department and devoted considerable effort to that activity. The licensees obtained the majority of their equipment from the licensor or from outside manufacturers who were licensed under General Electric's machinery patents. The unlicensed manufacturers at that time used older, less automatic equipment of slower speed.

By 1918 most processes for making lamp parts and for assembling completed lamps had been or were in the process of being mechanized; yet the successive operations in lamp assembly were still carried on in separate departments. Lamp-making consisted of a series of successive but uncoordinated operations. A stem was made from glass tubing, glass rod, lead-in wires, and small wire filament supports. The filament was mounted on the filament supports and attached to the ends of the lead-in wires. The finished stem was then inserted in a glass bulb, and its flared edge was fused to the neck of the bulb. The air in the bulb was next exhausted, and, if the lamp was to be a gas-filled lamp, nitrogen or argon was inserted in the bulb in the proper amount. Finally, the base was attached to the lamp, the lead-in wires were soldered to the base, and the lamp was tested and packed. Partially completed lamps were transported from department to department, and created a serious storage problem when the various processes were not kept synchronized. The nature of the manufacturing processes made it difficult to remedy the situation.

Confronted with this problem, W. R. Burrows, works manager of General Electric's Edison Lamp Works at Harrison, New Jersey, conceived a group or unit system of manufacture, in which production was arranged by units rather than by departments. The unit consisted of a number of machines, each of which performed one or more of the principal processes of assembly, carrying production from the basic parts to the completed lamp.[3] A great deal of work was required in adjusting and improving

[3] Departmentalized processes for parts preparation remained, even for the standard lamps. For special sizes and types it was also sometimes necessary for certain of the assembly processes to be conducted along departmental lines, many even by hand.

the machines to produce satisfactory synchronization; but, once that had been achieved, an enormous increase in efficiency resulted. The productivity of floor space was tripled, while the productivity of labor was doubled. Over-all plant output increased from 9.5 lamps per man-hour to 18 lamps per man-hour. A crew of five workers on the unit machine could turn out from 2,000 to 3,000 lamps per day, at the rate of 300 to 400 each hour.[4] The entire development and transition took only a few years, and by 1921 it was well under way. Besides the General Electric Company, Westinghouse and the other licensees were able to take advantage of the new machines and methods. The independent lamp manufacturers were free to group their machines as they chose, of course, but they were not able to secure as efficient machinery as that of the General Electric group.

During and after the transition from the departmental to the group basis, continued improvements were made in individual machines and processes, in both part making and lamp assembly.[5] As during the earlier period, most of the advances were made by General Electric, which built up its lamp-machinery laboratory to include from 50 to 60 machine designers, engineers, and draftsmen. In 1920 a machine was developed for making hot-cut flares for stems. This was the first really high-speed machine used in lamp production. In the following year a high-production tipless-stem machine was introduced to make use of the Mitchell-White method of construction; the tipless design made several mechanical processes much easier. A high-production support-wire-inserting machine was built in 1922, and a new coiling machine for miniature-lamp filaments followed in 1923. The next year brought the Sealex machine, which combined sealing, exhausting, and gas-filling. At about the same time an improved basing and soldering machine was invented.

Further progress was recorded in 1925 and 1926 with the inside-frosting machine, a combination miniature filament-coiling and coil-mounting machine, and an automatic miniature bulb-sealing machine. In 1929 an automatic machine was developed for mounting filaments in certain large lamps, and in the following year automatic filament mounting was extended to additional sizes

[4] "A Romance in Lamp Making," *Electrical World*, Vol. LXXXIV, pp. 242–243 (Aug. 2, 1924).

[5] See Appendix I.

of large lamps. In 1930 stem-making and sealing-in machines were designed for 5,000- and 10,000-watt lamps. In the same year a new machine was built for butt-sealing automobile headlight lamps of the flange-seal type. Improved devices for soldering lead-in wires to the base were devised in 1931.

Most of the major advances had been made by 1930. From 1930 to World War II machinery developments increasingly became faster and more automatic versions of existing machines rather than fundamentally new designs. The few basic improvements made after 1930 were concentrated largely in the automatic mounting of filaments. Filament mounting increased in speed from 900 per hour in 1927 to 1,700 per hour in 1940. All other machines were considerably speeded up as well, and the output of a unit increased from 300 or 400 lamps per hour in 1921 to around 1,000 lamps per hour in 1942. Even higher speeds of 1,200 lamps per hour are now obtainable for certain types. The number of workers required per unit dropped from five to three for many styles of standard lamps. Average large-lamp productivity per man-hour in the General Electric plants increased from about 18 in 1921 to 30 in 1926 and to about 95 in 1942. In individual plants which concentrated on high-production items, output per man-hour rose as high as 160 lamps. After the entry of the United States into World War II, the development of improved types of equipment was temporarily suspended. During the war labor turnover and inefficiency increased. Productivity did not rise along its previous straight-line trend; in many plants, productivity even declined. The end of the war made possible the resumption of productivity advances.

The preceding discussion has been confined to machinery progress in the United States, where the pace has been set by General Electric. The American leader spent large sums for the development and construction of improved machinery. Process development was going on at the same time in other countries. The outstanding European designers of lamp-making machinery were N. V. Philips and Osram, which began to develop high-speed equipment at about the same time as General Electric. The apparatus designed by Philips in particular rivaled the efficiency of much American equipment. Other European lamp producers also devoted some effort to machinery development, yet it appears that they were not as successful as the two companies mentioned above. Philips and Osram were prevented from selling their machinery to the unlicensed manufacturers in this country by their contracts with General Electric. They did, however, pass on their developments to General Electric in accordance with their license agreements. For example, the weld feeder on the stem-making and mounting machine was adapted by General Electric from a device obtained from Osram in 1932.

Westinghouse did some machinery development on its own. There was not much inducement for it to push strongly in that direction, however, inasmuch as it had access to the General Electric developments. Substantially the same was true of the smaller licensees, except that their ability to pursue individual development was less. With the end of the licensing system, the former licensees have been thrown more on their own, and their activity in machine design will undoubtedly become much greater.

The equipment made by the lamp-machinery suppliers for the independent lamp manufacturers was much cheaper than that supplied to the licensees by General Electric, but it was slower and less automatic. For example, while unit productivity of 1,000 to 1,200 lamps per hour is normal in 1947 within the former General Electric group for the standard sizes of large lamps, outputs of 500 to 700 lamps an hour are still the rule among most of the unlicensed manufacturers. On the average, the machinery used by the independents has been from five to fifteen years behind that designed by General Electric.

The two surviving independent suppliers of machinery, Alfred Hofmann and Eisler, have not yet undertaken any thorough revision of their lamp-making machinery. They apparently feel that the cost would be too great in view of the small portion of the industry which they service and the risk of infringing General Electric patents. The availability of highly efficient machinery in the future appears to depend more than ever before upon the individual lamp producers themselves or upon cooperative machinery development among the smaller companies. A few independent companies have already moved part of the way toward self-sufficiency in equipment. The others may have to move in the same direction, unless Hofmann, Eisler, or some other supplier can quickly come to the rescue, or unless they can work out a satisfactory scheme for cooperative effort.

2. *Improvements in Lamp-Glass Technology* [6]

Since glass is the principal raw material for incandescent lamps, improvements in the machinery for making bulbs, tubing, and cane were of great importance to incandescent lighting. A much improved semiautomatic bulb-blowing machine was introduced in 1912. It surpassed the early Owens machine of 1894 which had supplemented hand-blowing methods in some plants. The new machine, designed by the Empire Machine Company, a subsidiary of Corning, permitted one skilled and two unskilled workers to produce over 400 bulbs an hour. With hand blowing, two skilled workers and one unskilled could at best turn out only about 150 bulbs an hour, and with the Owens semiautomatic machine the output was also much less. Although a completely automatic bulb-blowing machine was announced in 1912, it was not developed satisfactorily for commercial use for several years thereafter. The machine was developed by the Westlake Machine Company, a subsidiary of the Libbey Glass Company.

Up to World War I, lead glass was used for lamp bulbs, tubing, and cane. This type of glass is workable at a relatively wide temperature range and is well suited for manual blowing techniques. It is not so good for automatic blowing, where a narrower working range is desirable. Imports of potash, which was used in lead glass, were cut off by the war. A new formula for lime glass was developed by Corning and General Electric as a substitute. Lime glass is softer than lead glass and melts more rapidly, although at a higher temperature, and it also has a narrower working range. Moreover, lime glass is not melted in pots, and automatic gathering is possible. With the introduction of lime glass around

[6] For more complete accounts of these developments, see the forthcoming book by Robert L. Bishop (tentatively titled *The Glass Container Industry: Technology and Economic Organization*); and Warren C. Scoville, *Revolution in Glass Making: Entrepreneurship and Technological Change in the American Industry, 1880–1920*, Harvard University Press, Cambridge, 1948. See also Witt Bowden, *op. cit.*, pp. 16–23 and 44–49; U.S. Tariff Commission, *op. cit.*, pp. 9–20; and George E. Barnett, *Machinery and Labor*, Harvard University Press, Cambridge, 1926, pp. 65–115.

1915, the use of the Westlake machine for large-scale production was greatly facilitated.[7]

Despite the improvement in automatic and semiautomatic machinery, more than half of all bulbs blown in this country as late as 1918 were blown manually into molds. Most of the remainder were made on the Empire "E" semiautomatic machines. In Europe, almost all bulbs were blown manually. Corning and General Electric by that time shared most of the domestic bulb business, except for small quantities made by two minor glass producers. Each of the two principal bulb-making companies was working toward complete mechanization.

A further improvement in glass technology was the invention of a tube-drawing machine by Edward Danner of the Libbey Glass Company, patented in 1917. All tubing and cane had previously been made by hand. With the new machine it was possible for both to be made automatically and much more efficiently. Although the Corning Glass Works had not yet developed a tube-drawing machine as satisfactory as that of Danner, it later purchased for $350,000 an exclusive royalty-free license to manufacture tubing and cane under a patent granted in 1926 to Karl E. Peiler of the Hartford-Empire Company [8] bearing on this type of machine.[9] After the purchase by General Electric of Libbey's tube and bulb rights, in so far as they pertained to incandescent lamps, General Electric and Corning licensed each other under their relevant patents. The Danner and Peiler patents came together in a joint control, and the tube-drawing machine became known as the Danner-Peiler machine.

By 1926 virtually all bulbs for large lamps in the United States were made automatically, either on improved Westlake machines or on the Empire "F" machine, which replaced the old Empire semiautomatic bulb blower. The machines for blowing bulbs were of the rotary type, with 12, 24, or 48 bulbs blown during a single revolution of the machine. Gathers were made from the glass

[7] Lead glass is still used for stem glass and other internal glass parts, since it does not become conductive when heated and it resists electrolytic destruction.

[8] The Hartford-Empire Company is a glass-machinery-development company controlled by Corning.

[9] United States of America *v.* General Electric Company et al., *Complaint*, Jan. 27, 1941, pp. 87–88, and *Answer of Defendants Corning Glass Works, Empire Machine Company and American Blank Company*, June 2, 1941, pp. 16–17.

furnace at appropriate intervals as the machine operated. The improved 48-unit Westlake machine of 1926 could turn out about 5,000 large bulbs an hour, with only one operator and one mechanic required for each two machines.

In 1927 a radically new type of bulb-blowing machine was developed by Corning. A continuous flow of glass from the furnace was shaped into a moving ribbon and blown into molds which moved at the same rate of speed along a conveyor. By eliminating the gathering operation and replacing the rotary motion by straight-line motion, it was possible to turn out about 15,000 bulbs an hour with one operator, four mechanics, one relief operator (for two machines), and one transfer mechanic (for two machines). Later improvements by Corning and General Electric increased the ribbon machine's capacity to more than 50,000 bulbs per hour. Since the machine can be operated continuously twenty-four hours a day, its daily capacity of 1,250,000 bulbs and its maximum annual capacity of well over 300,000,000 bulbs have made the use of other machines inefficient for the mass production of standard sizes. Moreover, very few machines are necessary to supply the entire needs of the incandescent-lamp industry. In 1933 General Electric installed its first ribbon machine under Corning license to make bulbs for its own needs only. General Electric currently uses five ribbon machines for 98 per cent of its bulb production; Corning uses seven ribbon machines to make lamp bulbs and also such items as Christmas-tree ornaments, tumblers, and radio tubes.

Improvements have also been made in the rotary-type machine, which is used by Corning for special bulbs produced in smaller quantity than is economical on the ribbon machine. The original Westlake type was superseded by the Ohio machine and later by the Huron machine, which have capacities of more than 10,000 bulbs per hour.

With its entry into glass production in 1911, General Electric became increasingly interested in lamp-glass technology. In 1916 it organized a Glass Technology Laboratory, and in 1919 it set up a Glass Machine Works. Since that time it has cooperated with Corning in the design of improved glass-making equipment and has spent large sums on this type of machine development. Much of the speed-up in output by the Westlake, ribbon, and

Danner-Peiler machines resulted from General Electric's work.

Other improvements in the making and handling of glass parts were made during the years up to 1931, as is indicated by the listing of Appendix I. For example, an automatic bulb-blowing machine for miniature bulbs was developed by 1918.[10] An improved miniature-bulb hot-cut machine was introduced in 1931. An automatic burn-off machine for removing surplus glass from the necks of bulbs was built as early as 1920. Continued improvements have been made since 1931.

The Danner-Peiler tube-drawing machine is still in widespread use for glass tubing and cane. Its efficiency has increased 800 per cent since its first use in 1918. It has been supplemented, however, by the so-called Vello machine, which was invented in France around 1930 and was later improved in the United States by Corning. General Electric declined a license under the Vello patents and has continued to use the Danner-Peiler machine exclusively for making tubing and cane.

European developments in glass-bulb and tubing machinery have generally lagged behind those of the United States. Philips developed high-speed automatic equipment of its own, as it did in lamp-assembly machinery, and it conducted a large export business in glass bulbs until World War II. The rest of Europe seems largely to have used the Westlake and other American-built machines. Ribbon machines have not been exported, since no foreign manufacturer produces enough lamps to use even one machine to its capacity. Some attempts by A.E.G. to mechanize bulb blowing early in the twentieth century ended unsatisfactorily, and the German concerns continued to blow bulbs by hand until the Westlake machine became available.

3. *Machinery Development and Labor*

The improvements in machinery for assembling incandescent lamps and for making lamp parts have reduced costs tremendously since 1912 and particularly since 1920.[11] At the same time,

[10] Although certain of the larger sizes of miniature lamp bulbs are blown directly from molten glass, most miniature bulbs are made from glass tubing.

[11] The experience of the lamp industry supports Bloom's criticism of Hicks's theory of invention (see Gordon F. Bloom, "A Note on Hicks's Theory of Invention," *American Economic Review*, Vol. XXXVI, pp. 83–96, Mar., 1946).

they have restricted the demand for labor in the lamp industry and in associated parts-supplying industries. Despite the great expansion in output between 1920 and 1945, productivity increased even faster, and total employment was reduced.

The rate of increase in productivity was especially noteworthy during the twelve-year period studied by Witt Bowden.[12] From 1920 to 1931 the numerical production of large and miniature lamps combined increased by 39 per cent. This larger output was produced by the lamp-assembly plants with 68 per cent fewer man-hours and 66 per cent fewer employees. Table XXVI shows the year-by-year changes in output, productivity, and employment.[13] These figures do not show total employment in the industry, of course; for there was much indirect labor. Although complete data are not readily available for all the years after 1931, productivity continued upward until World War II. Productivity in large-lamp assembly as a whole rose from 43.6 lamps per man-hour in 1931 to about 95 lamps per man-hour in 1942, an increase of 118 per cent. Output increased during the same interval by about 140 per cent, and total man-hours required rose from 7,520,000 to around 8,260,000. Despite the slight increase in labor requirements, employment in lamp assembly is still only one-third what it was in 1920.

Productivity increases have been great in plants making lamp parts as well as in lamp-assembly factories. The improvements in bulb blowing and in making glass tubing and cane have already been recounted. Average output per unit in large-bulb blowing increased from around 120 bulbs per hour by manual methods before 1920 to around 50,000 bulbs per hour for the Corning ribbon machine. On a unit-hour basis the increase was about 41,500 per cent. Total plant productivity did not increase so rapidly, of course, but even there the long-run increase has been

There is very little evidence of innovations induced by changes in factor costs. Rather, there was a continuous effort to discover means of reducing all costs—in which labor costs bulked large. The increases in wage rates during the war have made the independent manufacturers more acutely aware of the need for taking fuller advantage of existing knowledge of machine techniques, however.

[12] *Op. cit.*

[13] Productivity figures are given only for the total of all lamps. Comparable figures for the large or miniature lamp categories may easily be computed by dividing the man-hours required into the number of lamps produced, in each instance.

TABLE XXVI: OUTPUT,[a] PRODUCTIVITY, AND EMPLOYMENT IN INCANDESCENT-LAMP ASSEMBLY PLANTS IN THE UNITED STATES
1920–1931

YEAR	LARGE LAMPS			MINIATURE LAMPS			TOTALS			
	Number Produced[b]	*Man-Hours Required*[b]	*Average No. Employees*	*Number Produced*[b]	*Man-Hours Required*[b]	*Average No. Employees*	*Number Produced*[b]	*Lamps Produced Per Man-Hour*	*Man Hours Required*[b]	*Average No. Employees*
1920	234,770	25,194	12,196	127,370	10,951	5,087	362,140	10.019	36,145	17,283
1921	161,665	15,764	7,826	80,850	5,946	3,103	242,515	11.171	21,710	10,929
1922	206,019	16,484	8,387	105,246	8,065	3,737	311,265	12.679	24,549	12,124
1923	248,347	18,459	8,844	155,879	8,362	3,989	404,226	15.071	26,821	12,833
1924	251,752	14,240	6,574	183,420	7,839	3,639	435,172	19.710	22,079	10,213
1925	274,087	13,055	5,915	185,188	6,698	3,147	459,275	23.251	19,753	9,062
1926	281,588	11,498	5,383	200,867	6,078	2,907	482,455	27.450	17,576	8,290
1927	340,545	12,064	5,442	203,967	5,858	2,657	544,512	30.382	17,922	8,099
1928	313,475	9,902	4,564	243,478	6,074	2,689	556,953	34.862	15,976	7,253
1929	362,826	10,097	4,425	281,131	5,906	2,833	643,957	40.240	16,003	7,258
1930	335,001	8,521	3,987	218,198	4,903	2,473	553,199	41.210	13,424	6,460
1931	326,613	7,520	3,753	176,737	3,928	2,064	503,350	43.968	11,448	5,817

[a] The output figures given by Bowden are somewhat different from those presented in Table XIV and Table XVII for sales during the same years. Variations in inventories, imports, and exports account for the differences.

[b] 000 omitted.

Source: Witt Bowden, *Technological Changes and Employment in the Electric-Lamp Industry*, Bureau of Labor Statistics, Bull. No. 593, Washington, 1933, pp. 33–35.

substantially greater than the increase in output. Bowden gives figures for the years 1920 through 1931:[14]

	1920	*1931*	*Change*
Bulb output	255,815,000	348,203,000	+ 36%
Productivity per man-hour	38.8	189.2	+388%
Man-hours required	6,587,400	1,840,000	− 72%
Employees	2,892	968	− 67%

Between 1931 and 1946 bulb output more than doubled, but productivity kept pace.

Much the same situation occurred in the production of glass tubing, cane, and miniature glass bulbs. Enormous increases in productivity were registered during the years 1920 through 1931. Man-hour productivity in tubing plants increased by as much as 1250 per cent, while man-hour productivity in miniature-bulb making increased by 425 per cent. Further productivity advances were made after 1931. Fewer man-hours were required in 1946 than in 1920, and output was vastly greater.

Productivity advances in the making of other lamp parts, such as bases, have also been tremendous. Automatic base-making machinery in 1941 turned out ten times the number of bases made in 1910 with only twice the number of employees. Labor-hour productivity increased by well over 500 per cent, considering the shortening of the working day. Although base-making machinery is highly automatic, there are no important patents covering these machines at present. The limited number of domestic producers of lamp bases seems to be primarily the result of the very high efficiency of existing manufacturers.

Despite the absolute decline in employment by the lamp-assembly plants, there is no indication that workers offered serious opposition to the introduction of the new equipment which reduced their numbers. There were several reasons for this. In the first place, the changes came gradually over the years. Except for the transition to the unit system of production, the new lamp-assembly equipment was introduced to produce as little disruption as possible within the labor force. Since most employees in lamp plants were semiskilled women, whose training required only about three months, and among whom turnover was rather

[14] *Op cit.*, p. 46.

high, normal resignations were sufficient in most years to avoid layoffs. Persons already employed were not affected so much as those who would otherwise have found employment in the lamp plants.

In the making of glass bulbs and tubing, the shock of new machinery was much greater. Many skilled glassblowers were forced out of work, and their places were taken by smaller numbers of mechanics and machine operators. There was little that the glassblowers could do to stem the advancing mechanization, however, and they had to shift to other less mechanized branches of the glass industry or learn other trades.[15]

The lack of unionization may have been another reason for the absence of opposition to the displacement of men by machines in both lamp making and lamp-glass making. Only a few lamp plants were organized before 1940. Almost complete unionization in both lamp plants and glass plants has been effected since 1940. There is, as yet, insufficient evidence to determine how unionization will affect future mechanization and productivity advances.

4. The Effects of Reduced Energy Rates on Total Lighting Costs

Besides the performance and price of the lamp itself, the cost of incandescent lighting depends primarily upon the cost of electric current.[16] Very important reductions in the cost of energy have been achieved which would have more than halved the cost of electric lighting since 1913 even if lamp performance had not improved at all.[17] Table XXVII indicates how steadily residential electric rates have been reduced in the United States. In only

[15] The earlier mechanization of bottle making, despite union organization and opposition, had indicated how powerless skilled glassblowers were in preserving their trade. Between 1908 and 1917 alone, half of the skilled bottle blowers in the United States lost their jobs. (See Barnett, *op. cit.*, pp. 65–115.)

[16] In addition, the rates of depreciation and interest chargeable against the lighting installation form important elements of lighting cost. These elements are so variable and, in many cases, arbitrary that they cannot be treated here in the same manner as the other factors.

[17] The reductions in power rates have resulted from many factors. Among the most important has been the steady improvement in generating and transmission equipment. General Electric, Westinghouse, and all the other large producers of heavy electrical apparatus have collaborated with the utilities in achieving this advance. In addition, the expanding use of electric energy has produced more efficient utilization of facilities and has substantially reduced overhead charges.

TABLE XXVII: RESIDENTIAL ELECTRIC ENERGY RATES 1913–1946

Year	Average Revenue per Kw-h	
	Cents	*Index* (1913=100)
1913	8.70	100.0
1914	8.30	95.4
1915	8.00	92.0
1916	7.60	87.4
1917	7.52	86.4
1918	8.27	95.1
1919	7.70	88.5
1920	7.45	85.6
1921	7.39	84.9
1922	7.38	84.8
1923	7.20	82.8
1924	7.20	82.8
1925	7.30	83.9
1926	7.00	80.5
1927	6.82	78.4
1928	6.63	76.2
1929	6.33	72.8
1930	6.03	69.3
1931	5.78	66.4
1932	5.60	64.4
1933	5.52	63.4
1934	5.33	61.3
1935	5.01	57.6
1936	4.67	53.7
1937	4.30	49.4
1938	4.14	47.6
1939	4.00	46.0
1940	3.84	44.1
1941	3.73	42.9
1942	3.67	42.2
1943	3.60	41.4
1944	3.51	40.3
1945	3.41	39.2
1946	3.22	37.0

Source: *Edison Electric Institute Bulletin*, March issues, annually; and *Statistical Bulletin: 1946*, Edison Electric Institute, New York, No. 14 (July, 1947).

two years have the average rates increased over those of the previous year. The cumulative amount of the decline is impressive. Similar reductions have been made in rates for other categories of electric utilization. The average for small commercial and industrial users declined from 4.51 cents per kilowatt-hour in 1926 to 2.74 cents per kilowatt-hour in 1943. For large commercial and industrial users the decline was from 1.49 cents to 0.90 cents in the same interval.[18] However, average kilowatt-hour rates for the small and large commercial and industrial users rose somewhat by 1946 to 2.80 and 0.98 cents, respectively.[19]

To bring together all the factors affecting lighting cost, one must consider what has happened to the average cost of obtaining a given amount of light. This takes into account the reductions in energy cost, the reductions in lamp price, the increases in lamp efficiency, and the increase, if any, in lamp life. Table XXVIII presents a condensed summary of the record for residential lighting. Lighting costs in 1945 were 1.3 per cent of what they were in 1882; they were 13 per cent of what they were in 1906; and they were 45 per cent of what they were in 1923. About 60 per cent of the saving since 1923 is attributable to reductions in the cost of electric energy; about 30 per cent is attributable to increases in lamp efficiency; and about 10 per cent is attributable to reductions in lamp prices. If large commercial and industrial rates had been used in these computations with 60-watt lamps, the cost per thousand lumen-hours would have been less than 30 per cent of the cost at residential rates. Moreover, if high-wattage lamps had been used at industrial rates, the cost would have been still further reduced to around 15 per cent of residential cost. The over-all decline in cost and improvement in quality is impressive.

5. *Summary of Incandescent Lighting from 1912 to 1947*

In the American incandescent-lamp industry the period from 1912 to 1947 was one of continued expansion in quantity and value of production and sales. While General Electric and West-

[18] *Edison Electric Institute Bulletin*, Vol. X, p. 105 (Mar., 1942), and Vol. XII, p. 65 (Mar., 1944).
[19] *Statistical Bulletin: 1946*, Edison Electric Institute, New York, No. 14, p. 26 (July, 1947).

TABLE XXVIII: REDUCTIONS IN THE COST OF RESIDENTIAL INCANDESCENT ELECTRIC LIGHTING
1882–1945

Year	*Lumen-Hours for 1¢* [a]	*Cost per Thousand Lumen-Hours*	*Cost in Percentage of 1882*
1882	50	20.00¢	100.0%
1888	143	7.00	35.0
1894	220	4.55	23.0
1900	300	3.33	17.0
1904	364	3.02	15.0
1905	440	2.27	12.0
1906	501	2.00	10.0
1907	635	1.57	7.9
1912	1020	0.98	4.9
1914	1300	0.77	3.9
1915	1620	0.62	3.1
1923	1700	0.59	2.9
1933	2000	0.50	2.5
1937	2400	0.42	2.1
1942	3400	0.29	1.5
1945	3720	0.27	1.3

[a] The 60-watt incandescent lamp or the closest approximation thereto has been used as the basis for these computations.
Principal Source: *Edison Electric Institute Bulletin*, Vol. X, p. 331 (Sept., 1942).

inghouse lost some ground in percentage of lamp sales made, their combined sales in 1947 exceeded those of all other domestic manufacturers by a ratio of about four to one.

The license and quota system, which was in operation from 1912 until 1945, depended entirely upon the ownership by General Electric of the principal patents applicable to incandescent lighting. The company made great use of its research and development activities and the resulting patents to strengthen its hold on the industry. The Just and Hanaman sintered-tungsten-filament patent of 1912, the Coolidge drawn-tungsten-filament patent of 1913, and the Langmuir gas-filled-lamp patent of 1916 provided the principal patent strength during most of that period. The Just and Hanaman and the Langmuir patents were upheld by the courts; the product claims of the Coolidge patent were not finally invalidated until 1929. The successful defense of its principal patents permitted General Electric to license and set sales quotas for virtually all other domestic producers of tungsten-filament lamps until 1930. Most of those producers who were not offered licenses or who would not accept them were successfully prosecuted for infringement. After the expiration or invalidation of the basic patents, in 1929 and 1933, unlicensed firms were better able to compete. At the same time, various other patents owned by General Electric hindered their operations and permitted a continuation of the licensing and quota system for many more years. The Pacz and Pipkin patents were not invalidated by the Supreme Court until their legal terms were about to expire or had already lapsed.

Challenges from several sources were quite successfully met by General Electric between 1912 and 1942. The first group of infringing producers of tungsten-filament lamps was brought under control by the granting of patent licenses which established maximum sales quotas. The growth of a second group of infringing independents was checked after 1923 by a series of successful patent-infringement prosecutions. The federal antitrust prosecution of 1926 regarding the licensing and agency-distribution methods was successfully defended by General Electric and Westinghouse before the Supreme Court. The expansion of imports from Japan during the thirties was at least partially checked by the introduction of a new cheap line of lamps, by price reductions in the standard line, by patent-infringement actions, and by other devices. The growth of new unlicensed firms during the thirties was not completely checked; nevertheless, their share of the business had not risen much above 10 per cent when World War II brought to a halt several trends in the industry. The competition during the thirties between the unlicensed firms and the General Electric group was stimulating to both sides. War conditions also permitted General Electric to postpone its defense in a new antitrust prosecution brought by the federal government in 1941.

At the end of 1944 all B licenses except the one granted to Consolidated expired, and they were not renewed. A few months later the A license to Westinghouse was canceled. At the present writing the antitrust action, which was resumed early in 1946,

has not been decided. General Electric is the only principal defendant which has continued to fight the charges. The combination of patent expiration and invalidation, rising independent manufacturers, license expiration and cancellation, and antitrust prosecution places General Electric's control over the incandescent lamp industry in greater jeopardy than at any time since the expiration of the basic Edison patent in 1894. Nevertheless, General Electric's low cost position, the rising importance of fluorescent lighting, and the leader's entrenched position in the market give it advantages that cannot easily be overcome. It is the degree of General Electric's leadership rather than the fact of it that is in doubt.

The power of General Electric in the domestic electric-lamp industry has been strengthened by its continued favorable position with respect to sources of essential parts and machinery and with respect to international competition. The big company's costs of production have been and remain below those of its competitors. The control over parts production and over lamp-making machinery, of which General Electric is the principal designer and producer, has depended in large part upon the ownership and control of patents by the industry leader and by the other large companies with which it has had agreements.

International trade in electric lamps is small primarily because of patent-licensing arrangements under which the leading producers of the world exchange technical information but do not compete in one another's home markets. High tariffs and other import restrictions also interfere with trade in electric lamps. Another extremely important factor restricting imports of electric lamps has been the superior productive efficiency and lower costs and prices of manufacturers in this country as compared with producers in most other countries. The small volume of imports has come almost entirely from unlicensed foreign producers.

Technological progress in the American incandescent-lamp industry since 1912 has been made primarily by General Electric. Its licensees had access to the advancements made by the big company, and in general they had little incentive to carry on major research and developmental activities of their own. The unlicensed producers have been severely handicapped in making important changes by their small size and limited resources. Useful developments in the designing of special types of incandescent lamps have occasionally come from the small firms; important design progress has come almost exclusively from the industry leader. Independent inventors, who had done a great deal of work prior to 1912, were of much less importance after that date. Where outside inventors did obtain relevant patents, General Electric made every effort to secure their rights. The financial, production, and marketing difficulties were generally too great for individual inventors to attempt to promote their own developments.

The only revolutionary improvement in standard incandescent lamps after 1912 was the introduction of an inert gas filling into tungsten-filament lamps by Dr. Irving Langmuir of General Electric. That innovation produced an appreciable increase in efficiency, particularly in the high wattages. The coiling of filaments accompanied gas filling. Other noteworthy innovations made by General Electric were the development of non-sag tungsten wire and an easy and inexpensive method for the elimination of the tip on lamp bulbs. Inside frosting of glass bulbs was made standard by the industry leader. The double coiling of tungsten filaments in standard lamps was introduced on a large scale in the United States by General Electric, after a similar development abroad. Of the foreign producers, Philips and Osram conducted the most important development work in incandescent lighting. The flow of technical information out of the United States was considerably greater than the import of such data. There was a decided contrast between the systematic development of the gas-filled lamp, the non-sag tungsten filament, and other innovations by highly trained men with rich scientific backgrounds and the essentially cut-and-try methods of the early inventors of the incandescent and arc lamps.

Great increases in incandescent-lamp efficiency were also achieved after 1912 as a result of improved methods of lamp assembly. Faster and better machinery resulted in greater product standardization as well as in much lowered costs. The introduction of the group method of assembly was a tremendous improvement over the former departmental method. General Electric led in the improvement of machinery and assembly processes as well as in lamp design.

Over-all progress in incandescent lighting since 1912 has approximately doubled incandescent-lamp efficiency with the same average rated life in most instances. Prices have dropped to about 15 or 20 per cent of their 1912 levels for most sizes of standard tungsten-filament lamps. Besides these striking improvements in performance and cost, the user of electric lighting has also benefited from reductions in the cost of electric energy to less than two-fifths of its 1912 level.

A great many new types of incandescent lamps have been developed for special applications since 1912, including various decorative lamps, numerous miniature lamps, reflector and projector lamps, sealed-beam headlight lamps, and photoflash lamps. Most of these types were first introduced by General Electric, many with the collaboration of Westinghouse. A few of them were initially designed by other producers. In addition to the multiplication of lamp types for specialized purposes, there was a reduction of unnecessary varieties of lamps for general illumination during and after the standardization program of 1925.

Chapter XIV: NEW ELECTRIC-DISCHARGE LIGHT SOURCES: 1912–1938

EVEN though the incandescent lamp appeared to have a firm hold on the market for artificial illumination during almost the entire period from 1912 to 1947, a new type of electric lighting was growing in importance. Arising out of the work of Geissler, Arons, Moore, Hewitt, Bastian, Küch, and the other pioneers of electric discharges through gases and vapors, many new lamps have been developed and commercially introduced. These new types and their successors promise to provide a very large portion of the electric lighting of the future.

In Chapters IV through XIII the improvements in incandescent lighting since its introduction are described in detail. They have been important improvements and have aided materially in raising standards of artificial lighting. Incandescent lighting seems almost to have reached its practical limits, however. The best present tungsten filaments can produce up to 32.7 lumens per watt in the large 10,000-watt aviation lamps. Even the development of new filament materials or new methods of operation, such as the economical introduction of krypton or xenon, would certainly not bring incandescent efficiencies up to the level of electric-discharge efficiencies. The old-type arc lamp has fallen into almost complete discard for ordinary illumination, and, although many varieties of tungsten-arc lamp have been developed and tested, it does not appear likely at this time that further important commercial results will be achieved in that direction.

Chapters XIV and XV are devoted to a consideration of the developments in electric-discharge lighting since 1912. There have been many such innovations, the most important of which is the practical low-voltage fluorescent lamp. This innovation has an importance in the history of electric lighting similar to that of the first practical incandescent lamp. Its importance will undoubtedly continue in the future, unless it is superseded by some still more revolutionary artificial light source.

1. Progress in Non-Fluorescent Electric-Discharge Lighting

The science of electric-discharge lighting is almost a hundred years old. Nevertheless, its channels of investigation are so diverse that scientists and engineers seem still to be a long way from achieving the limits of efficiency. In addition to the Moore tube, the Cooper-Hewitt lamp, the Küch lamp, and the other early commercial devices discussed in Chapter VIII, the Claude neon tube, high-pressure mercury vapor lamps of a variety of kinds, the sodium lamp, and a number of others have been developed, to say nothing of the combinations of these light sources with fluorescent coatings on the glass containers. The present section contains discussions of the principal non-fluorescent discharge-lighting devices developed since 1912.

THE NEON TUBE

The first really important commercial development in electric-discharge lighting was the neon tube. Georges Claude demonstrated his first neon sign in 1910 at the Grand Palais in Paris,[1] and within a few years a large industry grew up about the neon tube. The principal differences between the Claude tube and its immediate predecessor, the Moore tube, were the substitution of neon for carbon dioxide or nitrogen and the improved electrode design. These changes made widespread commercial use possible, for the characteristic red light of neon tubing at efficiencies of 10 to 15 lumens per watt was ideally suited for advertising purposes. The operation of neon tubes is based on the principles already discussed in connection with the Moore and Cooper-Hewitt developments.

The use of neon in discharge tubes was logical, once it could be obtained, for electric-discharge experiments were being made with all promising gases and vapors. That phase of the development of neon tubing depended more on the state of scientific knowledge, therefore, than on a flash of inventive genius. Improved processes for the liquefaction of air and the separation of its various components were developed by both Claude and

[1] Samuel C. Miller and Donald G. Fink, *Neon Signs*, McGraw-Hill, New York, 1935, p. 1.

Linde around 1907, and a few years later neon was available in moderately large quantities at reasonable prices.

The new electrode design was a real improvement over previous types and constituted Claude's major inventive contribution to electric-discharge lighting. The great difficulty in early electric-discharge devices was their short life as a result of chemical combination of the gas or vapor and the sputtering of the electrodes. Chemical activity could be held to a minimum by the careful selection of materials; sputtering proved to be more difficult. Sputtering is caused by the violent force of ionized particles striking the cathodes and tearing off particles of the cathode material. These cast-off metallic particles entrap gas molecules and reduce the gas pressure to a point where the tube becomes inoperative long before the electrode material is used up.

The basic Claude invention lay in devising a type of electrode which would reduce sputter to a minimum. The Claude electrode was large and could be operated at a low current density. Claude patented the discovery that "at least 1.5 square decimeters (about 23 square inches) of untreated surface area are required for every ampere of current carried." [2]

No important obstacles stood in the way of the expanded use of neon tubing with large electrodes, and progress was rapid. The European development made the greatest headway at first, although a plant was started in the United States as early as 1914. During World War I the Claude interests in France offered General Electric an exclusive license under their patents at a price of $5,000,000 for the development of the American neon-tubing market. Neon tubing was particularly suited for advertising lighting, which until then had been provided exclusively by small incandescent lamps. General Electric misjudged the potentialities of neon tubing and felt that its incandescent lamps could meet the new competition successfully. It also felt that the tailor-made neon installations did not fit into its product line of mass-produced, standardized lamps which could be quickly installed and replaced by anyone. The offer was rejected.

To develop the American market the French then organized an American corporation, Claude Neon Lights, Inc., which licensed under its patents large numbers of small sign companies

[2] *Ibid.*, p. 49.

throughout the country. These small concerns normally operated within the restricted geographical limits for which they had exclusive licenses. They made, installed, and maintained signs on a contract basis. Their aggressiveness is indicated by the appearance of almost any main street in America after dark. Statistical evidence of growth is presented in census figures for the value of neon-tube signs produced in the United States: [3]

1929	$11,373,028	1935	$17,469,619
1931	16,783,098	1937	21,934,242
1933	(not reported)	1939	21,960,650

The growth in physical volume until World War II was even greater, owing to price reductions.[4]

Despite the steady expansion of sales in the industry, the commercial development of neon-tube lighting in the United States was not smooth. Claude received a number of American patents on his developments in connection with neon tubing, including the fundamental patent on electrode construction, which was issued on January 19, 1915. The initial profit-making of the neon-sign business led to the growth of rival organizations under other patents or under no patents. Although many of the claims of the Claude patents were held invalid by the American courts, the basic electrode patent was consistently upheld, and Claude Neon used the patent aggressively against infringing unlicensed companies.[5] After the expiration of the patent in 1932 entry into the industry became easier, and there was a great increase in the number of companies engaged in the business. There were about 500 manufacturers of neon-type tubing in 1938.

The patent conflicts in neon lighting were centered primarily on electrode design. Since the untreated electrodes employed in

[3] Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures, 1929 to 1939*, Washington.

[4] International trade in neon tubing and signs has been very small. For one thing, transportation costs are high. In addition, neon signs imported into the United States were dutiable until 1939 at a rate of 35 per cent ad valorem. The rate was then reduced to 25 per cent. International patent-licensing agreements have also restricted foreign trade by a significant extent. (See U.S. Tariff Commission, *op cit.*, p. 86.)

[5] Among the American companies successfully prosecuted by the Claude interests were E. Machlett & Son in 1928 and the American Neon Light Corporation in 1930.

commercial neon tubes were much larger than the minimum cited by Claude in his patent, he had a very strong legal protection. His competitors concentrated their efforts upon the development of non-infringing electrodes of small size. Special coatings and special designs were employed to make up the difference in surface area. To reduce the drop in voltage at the cathode, and consequently the destructive force of ion bombardment, it was found possible to coat the electrodes chemically with various substances which emitted free electrons.[6] Although these developments have proved valuable in other connections, they have not been as generally satisfactory in neon tubing as the Claude electrode. Claude's shell of copper, iron, or some other metal is still the type most commonly used.

Cold cathodes, which emit electrons only at relatively high voltages, are used in most neon tubing. It is also possible to employ hot cathodes. If a filament or some other type of heating device is coated with barium oxide or some similar material and is connected to a separate warming circuit, electrons are given off readily and the tube can operate at a much lower voltage, although the flow of current is greater than in high-voltage tubes. The use of hot cathodes in discharge devices was known early in the twentieth century; yet, because of the greater simplicity of the cold cathode and a lack of familiarity with the hot cathode, most neon-tubing manufacturers have confined themselves to the high-voltage type.[7]

The phrase "neon tubing" is commonly used as a generic term to include all low-pressure gas-filled tubes of the high-voltage type. Mercury vapor, helium, and many other gases are used, either alone or in combination, to produce colors different from neon's characteristic red. Additional colors may be obtained by

[6] Cathode voltage drop also depends upon the material used in the electrode and the type and pressure of the gas filling in the tube.

[7] Electrodes employing coatings of oxides of metals such as barium, which increase the electron emissivity of hot cathodes even at considerably reduced temperatures, are commonly known as Wehnelt cathodes. Nevertheless, it appears that during his early experiments in 1902, Moore anticipated Wehnelt's discovery of 1904. Besides the self-heating oxide-coated cathode, Moore described electrodes heated by a continuous auxiliary supply of current. He was aware at that early date of the necessity of keeping down the cathode voltage drop. See André Claude, "Lighting by Luminescence," *Light and Lighting,* Vol. XXXII, p. 130 (June, 1939).

the use of colored glass tubing. During the twenties the desire for more distinctive colors led to the use of fluorescent glasses. By a proper selection of fluorescent materials, which were introduced into the glass itself, it was possible to transform some of the ultraviolet light given off by low-pressure mercury-vapor or other discharges into visible light of almost any desired color.

Until the end of the twenties neon-type tubing was employed almost exclusively for advertising and other outdoor illumination. It was not considered that the device was satisfactory for interior lighting because of the high voltages employed, the poor color quality of the light, and the expense of installation. Moreover, the efficiency of neon-type tubing was little if any greater than that of incandescent lighting. European producers, particularly in France, pioneered in the application of neon-tube lighting in the indoor field around 1930.[8] Combinations of neon and mercury tubes gave a fairly balanced light output which was satisfactory in certain restaurant, store, and other interior applications. In the United States neon tubing was confined to the outdoor field for a much longer time. One reason for this was the restraint shown by General Electric and the Claude interests in not invading each other's market. Their previous unwritten understanding was put into more definite terms in 1938, with the signing of a twenty-year licensing agreement whereby Claude Neon was granted manufacturing and sales rights in the United States for made-to-order electric-discharge lamps for outdoor display and illumination only.[9] General Electric evidently wished to hold down the cost of its failure to promote neon itself by limiting it to outdoor uses as much as possible.

Most further technical progress in neon-tube lighting was made in Europe, until after 1938. By the end of the twenties techniques had been devised by the Frenchman, Jacques Risler, among others, for the coating of fluorescent powders on the inside or outside of glass tubing. This development extended the range of colors available and, along with the introduction of fluorescent glass, marked the first important commercial application of fluo-

[8] No major technological changes in the neon tubing were involved in its indoor use.

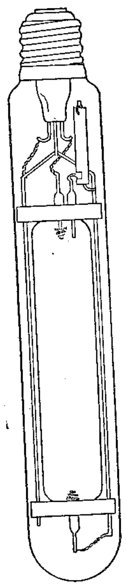
[9] Even though Claude Neon in 1931 announced the availability of a line of low-voltage neon-type tubes for interior lighting, that line was not promoted vigorously; and it made little impression on the American market.

rescence in lighting. Even in France, however, the first use of fluorescence was in connection with advertising and decorative lighting rather than general illumination.

The Claude interests in France continued to be the most active technologically in this field.[10] In most other European countries, as in the United States, various producers were licensed under the Claude patents. The British General Electric Company was the principal incandescent-lamp manufacturer which took part in the development. As in the United States, the other leading lamp producers for the most part considered the new field to be outside their normal spheres, and they did not actively participate. In fact, they resisted the use of neon tubing in interior lighting.

HIGH-PRESSURE MERCURY-VAPOR LAMPS

After the triumph of the tungsten lamp over the Moore and Cooper-Hewitt lamps, the use of electric-discharge devices for space lighting made no important progress for about twenty years. Nevertheless, experimentation in the field continued, and after



General Electric Co.

FIG. 33. 400-Watt High-Pressure Mercury-Vapor Lamp The inner bulb contains the electrodes and mercury in a low-pressure argon atmosphere; the outer bulb contains the resistance, leads, and support wires.

[10] The controlling patent-holding company for the Claude interests has been the Société Anonyme pour les Applications de l'Electricité et des Gaz Rares Etablissements Claude-Paz et Silva.

1930 several improved high-pressure mercury-vapor lamps that descended from the Cooper-Hewitt [11] and Küch lamps were commercially introduced. They received a great deal of attention from Philips in Holland, Osram in Germany, and the General Electric Company, Ltd., in England before much was done in the United States. Lamps of 400 watts and smaller sizes entered into limited use in England and on the continent of Europe during the early thirties for street, factory, and other large-space lighting. The 400-watt size was introduced into the United States early in 1934 by Westinghouse and was brought out a few months later by General Electric through its subsidiary, the General Electric Vapor Lamp Company. Other sizes followed within a few years (see Table XXIX). A third producer, the Spanner Vapor Lamp Company of New York, also produces high-pressure mercury-vapor lamps in the United States.[12]

Mercury-vapor lamps at high pressure give off mostly visible light with relatively little ultraviolet, although they are deficient in the reds. The need for auxiliaries adds to lamp cost and decreases over-all efficiency by about 20 per cent. The vapor pressure within the different lamps varies considerably. The term "high pressure" was originally applied to lamps containing gases or vapors at about atmospheric pressures as opposed to those containing just a few millimeters of gas pressure, such as the early Cooper-Hewitt lamps.[13] Since greater efficiencies and a more balanced light output can be obtained with mercury vapor at even higher pressures, however, the 1,000-watt lamp mentioned above is operated at a pressure of about 80 atmospheres. To maintain this terrific pressure and to keep the temperature from rising too high, it is necessary to employ a quartz tube and enclose the tube in a glass jacket through which water passes at a rapid rate. The use of thermionic cathodes of the Wehnelt type in several of the modern high-pressure mercury-vapor lamps is another major mark of distinction between them and the quartz lamps made earlier in the century.

[11] The Cooper-Hewitt Electric Company had made some high-pressure mercury-pool lamps before 1920 in addition to the low-pressure variety.

[12] There is no appreciable international trade in mercury-vapor lamps, primarily as a result of the international patent-licensing agreements.

[13] At high pressure the discharge is constricted to an arc, whereas at low pressure the discharge extends to the walls of the tube.

TABLE XXIX: PRINCIPAL MERCURY-VAPOR LAMPS MADE IN THE UNITED STATES
1934–1946

Rated Lamp Watts[a]	*Date of Intro-duction*	*List Price*[b]	*Rated Initial Lumens per Watt*[b] *(Lamp only)*	*Rated Average Life, Hours*[b]	*Outer Bulb*[c]	*Inner Bulb*[c]	*Over-All Length of Lamp, Inches*
100	1938	$ 9.50	30	1,000	T-10	T-3 (quartz)	5⅝
250	1936	8.50	28	2,000	T-9	None	8
400	1934	9.50	40	3,000	T-16	T-11	13
1,000	1938	9.00	65	75	Enclosed by water jacket	T-2 (quartz)	3¼
3,000	1942	40.00	40	2,000	T-9½	None	55

[a] Total wattage, with auxiliary, is approximately 120 per cent of lamp wattage.
[b] As of Jan. 1, 1946.
[c] Bulb sizes are given in eighths of an inch (outside diameter). T stands for "tubular."
Sources: General Electric Company and Westinghouse Electric Corporation.

Mercury-vapor lamps are used to a limited extent in the United States to light streets and industrial plants where economical high-level illumination over large areas is required, and where color quality is not of primary importance. Although eminently satisfactory in such installations, they are not adaptable to wide-spread application. The brilliant light from the 1,000-watt lamp has been used for television, photoengraving and other special purposes where extremely high levels of illumination are desired.

Attempts began to be made early in the century to correct the poor color quality of mercury lamps and produce a whiter light. The efforts were intensified after the developments of the early thirties. One method used an incandescent lamp in combination with the mercury lamp in such a way that the filament acted as

the ballast for the vapor lamp. An alternative technique involved the addition of a neon filling or the alloying of mercury with cadmium or other metals. Each modification strengthened the emission of red rays at the expense of efficiency.

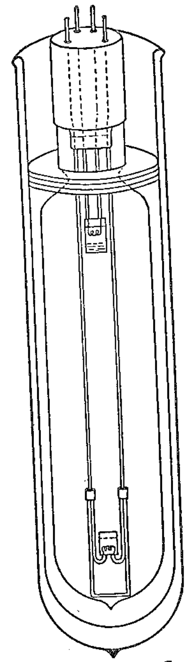
A third method was the use of a fluorescent screen or coating on the surface of the tube or bulb. In this way some of the ultra-violet output could be transformed into visible light at the red end of the spectrum, although total efficiency was reduced. The fluorescent powder was used only for color correction and was not the principal source of visible light as in a true fluorescent lamp. Hewitt and other early workers had conducted some partially successful experiments along this line. Philips utilized the idea around 1933 in its new high-pressure mercury-vapor lamps. The German Osram company brought out a lamp similar to that of Philips within a very short time, and a British model came out a little later. The fluorescent-corrected lamp was not made in the United States, although General Electric and Westinghouse obtained models for study.

SODIUM-VAPOR LAMPS

Another recent electric-discharge lighting device is the sodium-vapor lamp. Sodium vaporizes at a relatively low temperature and can be used in a discharge lamp to produce a yellow light at efficiencies of from 45 to 55 lumens per watt.[14] Maximum efficiency is reached at an operating temperature around 220° C. At that temperature the pressure of the sodium vapor is low and the discharge fills the tube instead of forming an arc as in the high-pressure mercury lamp. The discharge is started through neon gas and is maintained with the aid of hot cathodes. Special glass must be used to prevent destruction by the ionized sodium. The inner tube is enclosed by an outer vacuum jacket. The life of these lamps is about 2,500 hours.

In use the sodium lamp has many of the characteristics of the high-pressure mercury-vapor lamp. It is a highly efficient light producer for large spaces, and it produces a monochromatic light

[14] See W. L. Schallreuter, *Neon Tube Practice*, Blandford Press, London, 1939, p. 232; and E. L. E. Wheatcroft, *Gaseous Electrical Conductors*, Oxford University Press, Oxford, 1938, pp. 257–258.



General Electric Co.

Fig. 34. 10,000-Lumen Sodium-Vapor Lamp
The inner bulb contains the electrodes and a small quantity of sodium in a neon atmosphere.

that is objectionable in most applications. The principal use for the lamp has been in the lighting of highways, road intersections, tunnels, docks, and similar large outdoor areas. Because of its excessive yellowness, sodium lighting is less acceptable in factory lighting than the mercury lamp.

The sodium lamp was first developed and introduced in Europe. The three leading companies—Philips in Holland, Osram in Germany, and to a lesser extent the General Electric Company, Ltd., in England—were primarily responsible for the development. One of the principal obstacles to sodium lighting had been the need for a glass that would resist the chemical activity of hot sodium vapor. Such a glass was developed in Germany around 1931. In 1932 Philips announced a low-voltage sodium-vapor lamp designed in its laboratories by Dr. Giles Holst. Street-lighting installations were soon made in Holland, Germany, England, and other European countries. Under their international agreements General Electric and Westinghouse received full information about the European development.[15] They developed new designs for lamps rated at 145 and 180 watts, made experimental installations in 1933, and have manufactured sodium lamps since that date. Although the potential market for sodium lighting is limited, it provides a highly useful tool in outdoor space lighting. No other companies in the United States make sodium lamps. International trade is negligible, largely as a result of the exclusive patent licenses exchanged among the world's leading producers.

[15] General Electric and Westinghouse had also done experimental work on sodium lamps during the early twenties; their lack of a sodium-resistant glass had prevented commercial development at that time.

OTHER NEW ELECTRIC-DISCHARGE LAMPS

Practicable general-purpose lighting remained the ultimate goal for electric-discharge devices until the late thirties. A few imaginative observers had begun to realize the limited future of incandescent lighting and to point out the great promise of discharge lighting even before 1900. The intensity of effort grew steadily after World War I. Rapid strides were made in the knowledge of electric discharges by university and industrial scientists in many countries. Besides lighting engineers, individuals interested in the telephone, radio, and all related fields worked to utilize the continual advances in fundamental knowledge. As happens so often in technological progress, many advances were made simultaneously in two or more countries.[16]

Despite the evident improvement in discharge-lighting technique and the obvious nature of its ultimate goal, many lighting engineers until the late thirties thought that the new type of lighting was adaptable only to special applications and not to general illumination. Most of the new lamps had only limited utility. Many others were devised in addition to those mentioned above. Special neon tubes were developed for use in aviation and marine beacons, where the high visibility of red light is desirable. Special mercury-vapor lamps were designed for use as sun lamps, therapeutic lamps, and sterilizers. During the thirties Westinghouse devoted a great deal of attention to a low-pressure, low-voltage sterilizing lamp, which it introduced to the market in 1936. The Hanovia Chemical & Manufacturing Company of Newark and the Science Laboratories, Inc., of Cincinnati have for many years made ultraviolet quartz mercury lamps for therapeutic purposes. Other mercury lamps have been designed for photographic purposes, blueprinting and special laboratory applications. Improved Cooper-Hewitt lamps and Moore carbon-dioxide color-matching tubes continued in restricted use. Attempts were also made to adapt neon-type tubing to small interior lighting fixtures.

Another discharge device introduced during the twenties was

[16] See André Claude, *op. cit.*, for a history of the fundamental developments in electric-discharge lighting.

the neon or argon glow lamp. These small lamps, which are similar in outward appearance to ordinary incandescent lamps, contain two cold cathodes, spaced closely together in an atmosphere of either neon or argon, and produce light by the ionization of the gas near the electrodes. Because the light output is very small, these lamps are used chiefly as signals or indicators and for advertising. Glow lamps have been made in the United States by General Electric and Westinghouse and by the former Birdseye Electric Company.

The domestic production and sale of vapor lamps other than neon-type tubing had a value of only $2,000,000 to $3,000,000 a year during the late thirties. In 1945 manufacturers shipped 10,084,000 vapor lamps other than fluorescent lamps valued at $3,587,000, and shipments rose in 1946 to 11,927,000 lamps valued at $4,971,000.[17] Commercial conditions in their manufacture and sale in the United States have been similar to conditions in incandescent lighting, except that concentration and control by the two leading lamp companies has been even greater. Only a few other companies have made vapor lamps, and but one of them has been a producer of incandescent lamps.

After the work of Moore and Hewitt in this country the principal new ideas in electric-discharge lighting came from Europe for many years. In the United States the concentration of the leading lamp producers upon incandescent lighting and their vested interest in it precluded serious efforts to discover major new light sources. When new devices were developed abroad, however, they were imported and introducd here. In the subsequent development of certain types, such as the high-pressure mercury-vapor lamp, it appears that General Electric and Westinghouse have equaled or surpassed the European leaders.

The few small producers of electric-discharge lamps in this country have not possessed the financial or technical abilities for major innovations. Each small producer has confined his activities to but one or two types of vapor lamp. Nevertheless, it seems that their contributions and place in the industry are gradually increasing. Dr. George Sperti of Sperti, Inc.,

[17] U.S. Dept. of Commerce, Bureau of the Census, *Facts for Industry: Electric Lamps, 1946*, Washington, Mar. 6, 1947.

has made important developments in the sun-lamp field, among others.[18]

2. *The Scientific Background of the Fluorescent Lamp in 1935*

The phenomenon of fluorescence has been well known for a long time, and there have been many attempts to utilize it in artificial lighting. Nevertheless, all suggestions up to 1935 had serious defects which made them unsuitable for general-purpose illumination. Fluorescent neon-type tubing was not at that time highly efficient; it was awkward and expensive to install and maintain; and it required very high voltages. The high-pressure mercury lamps gave off too much light for most applications where color correction was important. Other proposals were equally unsatisfactory. The first successful commercial "fluorescent lamp," in which almost all the visible light was produced by fluorescent substances, was introduced in the United States in 1938.[19] The evolution of the fluorescent lamp was a continuation of the evolution of discharge lighting, which has just been described, with the addition of a second chain of development in fluorescence.

THE PHENOMENON OF FLUORESCENCE

The first recorded discovery of fluorescence appears to have been made in 1602 by an Italian cobbler named Vincenzio

[18] With the end of World War II, several new types of sun lamp have been introduced. Among others, Sperti has brought out a new 600-watt portable mercury-arc lamp. General Electric and Westinghouse have also lowered the price and promoted more vigorously their self-contained 275-watt mercury-vapor lamp, which was originally introduced in 1941. The lamp is contained in a mushroom bulb and can be operated in ordinary sockets without external auxiliaries.

[19] A brief description of the fluorescent lamps introduced in 1938 may make the scientific background leading up to their introduction easier to follow and understand. The first lamps were tubular and ranged from 18 to 36 inches in length and from 1 to 1½ inches in diameter. They were rated at from 15 to 30 watts, depending on size. They contained argon gas at a pressure of 3 or 4 millimeters and a small amount of mercury which vaporized during operation. Oxide-coated filamentary cathodes were placed at either end of each lamp, and discharges through the tubes at ordinary household voltages produced large quantities of ultraviolet light. Fluorescent powders attached to the inside of the glass tubes transformed the ultraviolet light into visible light at rated efficiencies of from 20 to 35 lumens per watt. For further details of the nature and operation of the fluorescent lamp, see section 4 of this chapter.

Cosciarola.[20] He was an alchemist on the side, and in his search for the philosophers' stone he noticed that certain rocks glowed with an eerie light when he flashed his lantern on them. He was not able to discover the cause of this strange light, but he began the study "which fifty years later led to the discovery of fluorescence." [21] Although it is doubtful whether this 1602 date actually represents the first acquaintance of men with fluorescence, the phenomenon has been known and studied for hundreds of years.

Sir George G. Stokes is credited with the discovery in 1852 that ultraviolet light induces fluorescence in various substances.[22] He diffracted sunlight with a piece of quartz, filled a test tube with a solution of quinine sulphate, and moved it through the solar spectrum. When he reached the ultraviolet stage, the solution gave off light. He had found that the quinine sulphate absorbed invisible ultraviolet light and gave off visible radiation of longer wave lengths. Stokes seems to have been the first to understand the nature of fluorescence, and it was he who named it after the mineral fluorite, which strongly exhibits the phenomenon.

Besides ultraviolet light, it has since been discovered that a number of other activators may cause fluorescence in both organic and inorganic substances.[23] The normal use of ultraviolet light as the particular exciter in lighting has resulted from its high efficiency, convenience, and economy. Ultraviolet light may be generated by very hot bodies, as in sunlight, incandescent lamps, mercury-arc lamps, spark discharges, and carbon-arc lamps, or by excited gases. Excited gases are used in the commercial fluorescent lamp, although experiments have frequently been made with hot-body excitation.

There are two principal ways in which fluorescent substances, or phosphors, as they are often called, may be used in providing

[20] H. C. Dake and Jack De Ment, *Fluorescent Light and Its Applications*, Chemical Publishing Co., Brooklyn, 1941, p. 1.

[21] Charles L. Amick, *Fluorescent Lighting Manual*, McGraw-Hill, New York, 1942, p. 1.

[22] Dake and De Ment, *op cit.*, p. 5.

[23] Infrared radiation, visible light, X rays, radio waves, cathode rays and other streams of moving particles, friction, pressure, heat, crystallization and still other types of excitation are possible.

illumination.[24] Only one of these, the fluorescent lamp, has yet been developed to a successful commercial stage. The other, which involves the use of fluorescent paints or coatings, has not yet proved successful for high-level illumination. Such coatings have had many specialized applications where low-level illumination is desired, as in airplane instrument dials and black-out signs. The war stimulated those developments, and they proved quite satisfactory. For general illumination, however, visible light emission must be plentiful, economical, safe, and convenient. High-level illumination using fluorescent and phosphorescent paints or coatings on ceilings and walls will undoubtedly continue to be studied and may some day be feasible.[25] Since eventual success is not at present in sight, the following discussion of fluorescent lighting will be confined to the development of fluorescent lamps and related devices.

EARLY FLUORESCENT LAMPS

The first actual electric lamp containing fluorescent materials was made by Alexandre Edmond Becquerel. Becquerel used a Geissler discharge tube, and in a paper published in 1859 and later in his book, *La Lumière*, published in 1867, he described "low-pressure (1-2 mm.) discharge tubes containing various luminescent solids in fragments or in powder form. He suggested the preparation of tubes or bulbs in which a thin coating of such material was stuck to the inner surface of the glass." [26] The original Becquerel lamp was plagued by very low efficiency and by short life. The broad fundamental principles were there, but a great deal of progress had to be made before commercial success could be achieved.

Very little further progress in fluorescent lighting was made

[24] Lighting is but one of many practical applications of fluorescence. The fluorescent properties of minerals and gems are very helpful in their identifica tion. The identification of ceramics, antiques, and art objects is also aided by studying their fluorescent properties. In chemistry, criminology, medicine, bacteriology, biology, and many other fields, applications of fluorescence are manifold.

[25] The cold and extremely efficient light of the firefly is a long-range goal for scientists and lighting engineers. Fluorescent lamps represent a step in that direction. The use of fluorescent coatings for high-level illumination, if they should ever become practicable, would constitute further progress.

[26] Claude, *op. cit.*, p. 128.

during the nineteenth century. The success of arc lighting and the incandescent lamp focused attention on those types of electric lighting. Relatively little headway was achieved in making the Geissler tube acceptable for illuminating purposes, and there was not much improvement in phosphors.

In 1896 Thomas A. Edison applied for a patent on a fluorescent lamp. The patent (which was granted in 1907) covered a short vacuum tube coated on the inside with calcium tungstate and containing two widely separated electrodes. Cathode rays excited the fluorescent tungstate to produce a light, which was supposed to be cold and like sunlight in appearance. Another fluorescent lighting device was developed before World War I by W. S. Andrews of the General Electric Research Laboratory in Schenectady. He employed a sheet of metal coated with calcium tungstate and phosphorescent zinc sulphide. Light was produced when this device was connected to an induction coil. Still another method of excitation of fluorescent materials in a lamp was proposed in 1934 by Gilbert T. Schmidling, an independent American inventor. He used a glass bulb lined with a fluorescent powder. The fluorescence was caused by electron emission from an oxide-coated sphere in the center of the bulb. A filament within the sphere warmed it sufficiently to give off the electrons. Low efficiency and other difficulties prevented all these lamps from becoming commercially successful.

There have undoubtedly been many other attempts to develop fluorescent lamps activated by other than ultraviolet light. It is possible that some such lamp may some day be commercially practicable, but so far all attempts have been unsuccessful.

The progress in gaseous-discharge lighting around the turn of the century encouraged experimentation in the use of fluorescent materials with ultraviolet excitation. The problem was attacked in many ways.[27] Steinmetz described lamps in 1902 in which the material was on the outside of the tube. In 1904 Fleming used glass impregnated with uranium. Becquerel's use of tubes with the material contained internally was revived in 1910 by the French inventors E. Urbain, Feige, and Clair Scal. W. S. Andrews of General Electric spent a number of years experimenting on fluorescence. According to Dake and De Ment, by 1912 he had

[27] See Claude, *op cit.*, p. 128.

"constructed an excellent working model of our present-day fluorescent lighting tube."[28] The lamp employed cold cathodes, however, and produced light only at low efficiencies.

After the war neon tubing came into important use, and with the demand for new colors for advertising purposes fluorescent substances came to be mixed into the glass or used as coatings within the tube. The powders served simply as color adjusters, much as colored pigments were being used on the surfaces of incandescent bulbs. Jacques Risler, in France, was a leader in the introduction of fluorescent powders into neon-type tubing. In an article written in 1923 he described "tubes coated externally with zinc sulphide."[29] His tube was filled with neon gas and mercury vapor and was of the cold-cathode type.[30] In a French patent, filed in March, 1925, and issued in 1926, Risler described such tubes further. In the later type he put his fluorescent material on the inside of the long tube and used thermionic electrodes at either end.[31] Risler had trouble with his internal coating, for the adhesive varnish he used "not only acted as an absorbing screen, but gave off vapor which made it more difficult to exhaust the tube or keep the pressure constant."[32] The practical obstacles were eventually overcome, and the use of fluorescent powders in high-voltage tubing became practicable for advertising signs during the twenties.

The main limitation in the development of a fluorescent lamp which could be used safely and easily on 120-volt circuits was the design of a satisfactory electric-discharge device. Progress in this direction appears to have been made by individuals working on rectifiers, oscillators, and similar devices as much as by those working on low-voltage gaseous-discharge lighting tubes. Advances were made over a broad front by workers in many countries. Only a few of the most important specific developments have been or can be mentioned here.

The Schenectady Research Laboratory of the General Electric

[28] *Op cit.*, pp. ix–x, 202.
[29] Claude, *op. cit.*, p. 128.
[30] General Electric Company *v.* Hygrade Sylvania Corporation and Raytheon Manufacturing Company, U.S. District Court for the Southern District of New York (Civil Action No. 9-35), *Brief for Plaintiff*, 1942, p. 98.
[31] General Electric Company *v.* Hygrade Sylvania Corporation and Raytheon Manufacturing Company, *Brief for Defendants*, July 31, 1942, pp. 146–147.
[32] Claude, *op cit.*, p. 128.

Company conducted many experiments on gaseous discharges in general. During the twenties Dr. Irving Langmuir studied what went on in an electric-discharge tube. His work in determining optimum operating conditions for low-pressure discharges led to improvements in the whole range of devices, including lamps, which employed low pressures. Continuing along the lines opened up by Langmuir, Dr. Albert W. Hull of the same laboratory made other advances which proved of value to the fluorescent lamp. In 1927 Hull employed electron-emissive hot cathodes in conjunction with gas pressures of from several microns [33] to several millimeters of mercury to produce discharge devices of high efficiency and long life. Hull claimed in his patent application [34] that his invention permitted the use of the pressure range from one to one thousand microns of mercury, which previously had not been used successfully for discharge devices. Most of the

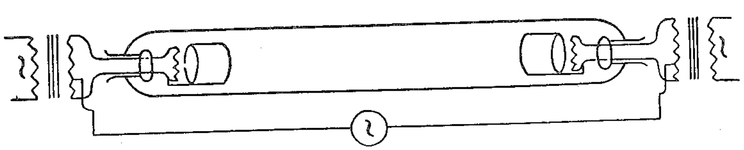


FIG. 35. Illustration from Meyer, Spanner, and Germer Patent (U.S.) No. 2,182,732

Glow cathodes are contained in a glass tube with a small quantity of mercury and an inert gas such as argon.

patent claims referred to rectifiers, but there was a brief reference to a rectified vapor lamp. This development later assisted in the designing of cathodes and the determination of gas pressures for the successful fluorescent lamp.

The first low-voltage gaseous-discharge device suitable for use as a fluorescent lamp was made in 1926. The Germans, Friedrich Meyer, Hans Spanner, and Edmund Germer, engineers for the Rectron company in Berlin, filed an application for a German patent on a new vapor lamp in that year and filed for an American patent on the same innovation on December 19, 1927. Among other devices, they described a low-voltage fluorescent lamp and an ultraviolet lamp that had a glass tube containing an inert gas

[33] A micron is one-thousandth of a millimeter.

[34] U.S. patent no. 1,790,153 filed Oct. 15, 1927, and granted Jan. 27, 1931.

and mercury vapor, with hot cathodes at the ends. They thought that the addition of fluorescent materials would make the lamp useful for advertising purposes. Nevertheless, the employers of the German inventors made no apparent effort to manufacture a commercial fluorescent lamp, and the Meyer patent played no part in the actual development of the American lamp. General Electric was not aware of its existence until the lamp was on the market.[35]

The fact that the Hull and Meyer patents have been used by General Electric as the basis for its claim to legal monopoly of the fluorescent lamp which it designed indicates that these two patents, in conjunction with the prior art, included all the fundamental features of commercial low-voltage fluorescent lighting. By 1927 all the major features of the eventual lamp were known; it remained only to combine them in the proper fashion. Notwithstanding the state of fundamental technical knowledge, no important steps were taken anywhere toward the actual commercial development of a low-voltage fluorescent lamp until 1935.[36]

3. The Development of the Hot-Cathode Fluorescent Lamp[37]

During the late twenties and early thirties the technical background for the fluorescent lamp was ripe. Progress was "in the wind," just as it had been for the incandescent lamp in 1877. Commercial development was slow, nevertheless. The leading electric-lamp manufacturers in Europe were devoting much of their time to high-pressure mercury-vapor lamps, sodium lamps, neon-type tubing, and other such special devices. In the United

[35] The patent has been very important legally, however. See section 2 of Chapter XV.

[36] Early in the thirties, however, high-voltage fluorescent tubing began to find some applications abroad in the interior illumination of restaurants, stores, and public buildings. The indoor use grew gradually in France, England, and other industrialized European nations. In the United States, fluorescent tubing was confined almost completely to sign and other outdoor lighting until about 1939.

[37] Some of the material included in this section and in certain sections of Chapter XV has appeared in a somewhat different form in "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp," by Arthur A. Bright, Jr., and W. Rupert Maclaurin, *Journal of Political Economy*, Vol. LI, pp. 429–450 (Oct., 1943).

States discharge-lamp experiments were centered on sun lamps, sterilizing lamps, and other specialized devices as well as on the lamps originated abroad. Most producers were quite satisfied with incandescent lighting for general illumination and were trying to develop new types of discharge lamps for special purposes only, to round out their lines. The lack of a strong incentive to push forward to a totally new source of artificial illumination delayed the advent of practical fluorescent lighting.

DEVELOPMENT BY GENERAL ELECTRIC AND WESTINGHOUSE

Under the conditions prevailing in the American electric-lamp industry it has been extremely difficult for the smaller companies to make important technical contributions. At the time of the actual designing of the fluorescent lamp the only two concerns in the United States able to perform the technical research and development and the subsequent market development for this type of device were General Electric and Westinghouse.[38] There was no inducement for the large companies to move with great rapidity in such an undertaking.

General Electric did not set seriously to work on the task of designing a low-voltage fluorescent lamp for the American market until 1935. Before that time a few of its scientists and engineers had experimented within the field, both at the Schenectady research laboratories and in the lamp department's own engineering laboratories at Nela Park. No real effort had been made to develop a practical fluorescent lamp since Andrews's work before World War I. In 1933 Dr. W. L. Enfield, the manager of development and engineering of General Electric's lamp department, had seen fluorescent coatings in neon-type tubing in Paris.[39] He had been impressed by what he had seen, and upon his return to America he had discussed with his physicists and engineers the possibility of incorporating the fluorescent principle into a standardized lamp. The direction of the European development did not seem promising, because long lengths of tubing which would

[38] The expense and difficulty of market promotion in the face of competition by General Electric and Westinghouse have been almost as great deterrents to new-product development by the small concerns as the costs of the technical activities themselves. Lack of capital has been one of their greatest handicaps.

[39] The material in this paragraph is based upon an interview with the late Dr. W. L. Enfield.

have to be specially designed for each installation did not fit well into the line of a company specializing in the mass production and mass distribution of standard lamps. A uniform, easily replaceable lamp suitable for low-voltage operation was required. No immediate action resulted from this discussion. Then late in 1934 Dr. Arthur H. Compton, a consultant for General Electric, wrote from Europe to Dr. Enfield, after observing laboratory improvements in the efficiency of cold-cathode fluorescent tubing in England, that fluorescent lighting was the lighting of the future. That letter seems to have provided the final stimulus necessary, for shortly thereafter an engineer was assigned to the problem of making a practical low-voltage fluorescent lamp.

Results were achieved rapidly, in spite of the general feeling prior to that time that a satisfactory lamp could not be made. After a few experiments with alternative types of excitation, an ultraviolet exciter was selected. Within six weeks a lamp had been developed which showed improvements in efficiency over any lamp of the same type yet made. The elements of such a device were well known. To produce ultraviolet light, a low-pressure mercury-vapor lamp containing some argon for starting purposes was required. The cathode caused a great deal of trouble, however. Cold cathodes were tried at first, but they were not satisfactory. To keep down the cathode voltage drop and permit low-voltage operation with long life, hot cathodes of the Wehnelt type were eventually employed. As the success of the experiments grew, more and more men were put to work on the various aspects of a fluorescent lamp and lighting system. A great deal of experimentation had to be done on lamp sizes and shapes, cathode construction, gas pressures of both argon and mercury vapor, base construction, colors of fluorescent powders, methods of attaching them to the inside of the tube, and other details of the lamp and its various auxiliaries before the new device was ready for the public.

Most of this work was strictly developmental. The Schenectady Research Laboratory played a very small part in developing the lamp, except as consultant when certain specific problems arose. Its most significant contribution was in connection with cathode design for keeping down the voltage drop. The Schenectady laboratory had had a long background in gaseous-discharge devices, however. From 1926 to 1935 the section devoted to lamp research had had an annual budget of about $100,000 to be spent on developing the fundamental laws of gaseous discharges. Although those activities had not dealt with a fluorescent lamp *per se*,[40] they proved to be of some assistance in basic problems. Without the help of the scientists at Schenectady the development by the engineers would have taken longer; it would not have been impossible.

The lamp-development department of General Electric spent a total of $170,200 on the development of the fluorescent lamp to a commercial stage. The increasing tempo of activity until 1938 is indicated by an annual breakdown on the figures:

1934	$ 200	1937	$65,000
1935	13,400	1938	49,000
1936	42,600		

Developmental expenditures continued at about $50,000 a year after the lamp had reached the market. The total investment was very small in relation to the tremendous industrial activity that followed.

In its approach to fluorescent lighting, General Electric showed both imagination and conservatism. The leading industrial nations of Europe had been working with fluorescent substances for years before the big producer in this country became seriously interested. Satisfaction with the existing state of arti-

[40] Around 1926 the Schenectady laboratory missed by a narrow margin discovering a fundamental law which might have speeded up the development of the fluorescent lamp. General Electric workers had heard of the French work in sign tubing coated internally with fluorescent powders. Their interest was aroused, and they began experimenting with a hot-cathode neon tube and mercury vapor. They tried a coating of zinc silicate in the neon tube and used a three-ampere current to maintain the discharge. Such a low efficiency was obtained that the experiment was abandoned.

Looking backward, it is possible to say that, if lower current densities had been tried, greater efficiencies would have been obtained. Neon gas gives off light almost directly proportional to the amperage, while the fluorescent glow of zinc silicate activated by a low-pressure mercury discharge reaches its maximum light output at a current of only a fraction of an ampere. It remains practically constant thereafter as the amperage increases. Therefore, if a lower current density had been employed, the green fluorescent light would not have been overwhelmed by the red neon glow, and higher efficiencies would have resulted. Also, if some gas other than neon had been used, the fluorescent light might not have been blotted out.

ficial lighting by incandescence made the American leader slow to change to a new light source. Once its attention was focused upon fluorescent lighting, however, General Electric improved upon foreign conceptions of the problem. In spite of its late start in the development of a generally applicable fluorescent lamp, General Electric was the first to achieve it. The parallel which can be drawn between that situation and Edison's first commercial incandescent lamp is apparent.

It is evident that a late start on the technical solution of a problem is not always a serious handicap, if an organization has vigorous and capable men and bountiful resources. Indeed, a late start may be an advantage, for a fresh point of view can frequently realize the mistakes of previous workers and capitalize on their positive contributions. The pioneers who first conceived the idea of fluorescent lighting and pointed the way to their successors received little or no reward for their contributions, like the pioneers in incandescent and arc lighting.

Before 1935 Westinghouse had not been active in the application of fluorescent materials to lighting; after that date it collaborated actively with General Electric in developing the lamp and certain of its auxiliary devices. The background of Westinghouse in the technology of the mercury-vapor sterilizing lamp was of assistance. Nevertheless, General Electric, as the licensor and senior partner, was primarily responsible for the final design of the lamp. It was placed on special listing by the two companies on November 29, 1937, and announced as an addition to their regular lines on April 1, 1938.

ACTIVITY BY SYLVANIA

Sylvania Electric Products Inc.,[41] the largest of the General Electric B licensees, had for a long time been restive under quota restrictions and was seeking a way to "grow up" in the lamp industry. It had bought out several other B licensees, but it had not been able to expand beyond 5 or 6 per cent of the total market for large incandescent lamps. In 1931 it had made certain cathode-

[41] The company name was changed from Hygrade Sylvania Corporation to Sylvania Electric Products Inc., on Aug. 12, 1942. For convenience, reference to the concern throughout Chapters XIV and XV will be under the present name, even though some of the events discussed took place before the change.

ray experiments which had led to studies of fluorescence. In the course of that work, Sylvania engineers developed the method of coating glass with fluorescent powders which is used in the present fluorescent lamp.[42] For a few years Sylvania conducted intermittent experiments on fluorescence in electric-discharge devices. In 1934 its engineers made a few tubular fluorescent lamps with oxide-coated cathodes, an argon filling and mercury vapor at very low pressure.[43] Cathode difficulties and other problems led to short lamp life. The experimental lamp did not appear to be commercially promising, and the experiments were discontinued.

Not much more was done by Sylvania until General Electric and Westinghouse undertook to develop a fluorescent lamp. When news of their progress reached Sylvania, the company's executives first gave serious consideration to the fluorescent lamp. A model of the General Electric lamp was obtained from the industry leader and analyzed,[44] and Sylvania spurred its own efforts to produce such a lamp. The B licensee saw in fluorescence an opportunity to break away from General Electric control. Vigorous encouragement was given by E. J. Poor, who at that time was chairman of Sylvania. The activities of the company were limited, but some progress was made toward a practical fluorescent lamp by following the lines that General Electric had already taken.

In the fall of 1938 Sylvania announced a line of fluorescent lamps almost identical to those which General Electric and Westinghouse had brought out the preceding April.[45] Although Sylvania was on its own in producing the lamp and also made some early contributions to the development of the fluorescent lamp, as by its development of the method for applying powder, its

42 A patent on the method was issued to James L. Cox of Sylvania on Oct. 19, 1937. During the patent litigation between General Electric and Sylvania over the fluorescent lamp the patent was declared invalid because of use in cathode-ray tubes for more than two years prior to the date of application.

43 General Electric Company *v.* Hygrade Sylvania Corporation and Raytheon Manufacturing Company, *Brief for Defendants*, July 31, 1942, p. 21.

44 General Electric Company *v.* Hygrade Sylvania Corporation and Raytheon Manufacturing Company, *Brief for Plaintiff*, 1942, pp. 29–32.

45 In 1940, after the lamp had been on the market for two years, the General Electric lamp department requested a complete standardization of lamp characteristics, including efficiency, life, and color as well as external characteristics.

outstanding role during the first few years was in the commercialization of the new lamp.

Sylvania's B license did not extend to vapor lamps, and it did not wish to take a new license under General Electric's existing and future patents covering the fluorescent lamp, for that would have meant continuing under a small quota. It set out to obtain control over enough patents to break away from General Electric and compete as an independent in the fluorescent-lamp business even while continuing as a B licensee in the production of incandescent lamps. It already owned the Cox patent on the method of applying fluorescent powders. Exclusive licenses under two other patents covering electric-discharge devices, including the right to sue for infringement, were granted to Sylvania by the Raytheon Manufacturing Company, a producer of radio tubes and related devices.[46] These three patents formed the basis for Sylvania's commercial independence in fluorescent lighting. Besides Sylvania, a few other concerns were interested in the new lamp and have since come into production; they have not held any significant patents covering fluorescent-lamp design.

After the standard low-voltage fluorescent lamp had been introduced to the American lighting market in 1938, with the aid of foreign inspiration and considerable foreign technical experience, European lamp producers recognized its advantages. Within a very short time the British borrowed the American fluorescent lamp for general lighting purposes, and the French also brought out a new fluorescent lamp substantially like that made in this country.

4. Characteristics of the Hot-Cathode Fluorescent Lamp

DESIGN FEATURES AND ADVANTAGES

The fluorescent lamp which was first marketed in the United States in 1938 operates on the general principles of many of the earlier electric-discharge lamps. As in other similar lamps, a long glass tube contains argon gas and a very small amount of mercury and has electrodes at each end of the tube. The glass is internally coated with fluorescent material. By proper control of the various elements, an electric discharge can be started and maintained

46 See pp. 421–422 for a discussion of the Raytheon patents.

through the mercury vapor to produce ultraviolet light, which strikes the fluorescent coating and is absorbed. A portion of the energy is then reemitted in the form of visible light.

The fluorescent lamp is distinguished from other discharge devices by its particular electrical characteristics. The pressure of argon in the tube is three or four millimeters. Only a small drop of mercury is used. It becomes vaporized in the lamp when the discharge starts in the argon gas. Since mercury has a lower ionization voltage than argon, the mercury then takes over the entire discharge, even though its pressure during operation usually ranges only from five to thirty-nine microns. Current flow is only from 0.30 to 0.35 amperes in the sizes which were first introduced. Those lamps were designed for circuits of 110 to 125 volts, and potentials across the lamps range from 48 to 103 volts.

The cathodes employed in fluorescent lamps are drawn-tungsten filaments of coiled-coil construction similar to those used in many incandescent lamps. They are coated with barium or strontium oxide, which facilitates the emission of electrons and permits operation at low voltages. Two untreated anodes are associated with each cathode and are connected to the leading-in wires.

Fluorescent powders may be prepared from minerals which are fluorescent, or they may be compounded synthetically. Since the presence of foreign substances as activators is sometimes necessary for fluorescence, natural minerals are usually used. Tungstates and silicates are widely employed for many colors, and by blending different minerals in the proper proportions, almost all varieties of color are obtainable. The powders are selected and prepared for maximum activation by ultraviolet light of the 2537 angstrom unit wave-length,[47] which predominates in the light output of the low-pressure mercury-vapor lamp.

When first introduced in 1938, the lamp was made in four sizes from 15 to 30 watts. They were 18 to 36 inches long and one or one and a half inches in outside diameter.[48] For the white lamp they were rated at initial efficiencies ranging from 30 lumens per

47 An angstrom unit is one ten-millionth of a millimeter, or one ten-thousandth of a micron. It is frequently designated by the abbreviation A.U. or Å.

48 See Appendix J for the fundamental specifications of all sizes of standard fluorescent lamps introduced by the middle of 1942.

watt for the 15-watt lamp to 35 lumens per watt for the 30-watt lamp, and lumen output was fairly well maintained to the end of life. They were all given initial rated lives of 1,000 hours, and that figure was quickly raised to 1,500 hours.[49] Upon introduction list prices for the white and daylight lamps ranged from $1.50 for the 15-watt lamp to $2.00 for the 30-watt lamp. The lamp was also brought out in blue, green, red, and other colors.

The efficiencies of even the first fluorescent lamps were much greater than those of the incandescent lamps used for general illumination. The fluorescent lamp has other advantages as well. The tubular lamp has a large surface which gives off light uniformly along its entire length. Despite the greater quantity of light given off, the brightness of the lamp is low and glare is avoided. Only about one-fourth as much energy is radiated in the form of heat by a fluorescent lamp as by an incandescent lamp of the same light output.[50] The color versatility of fluorescent lighting is another important advantage. Since colors other than white can be obtained simply by the proper selection and blending of phosphors, and since some of these colors may be produced even more efficiently than white light, the superiority of fluorescent over incandescent colored lighting is evident.

DISADVANTAGES AND SPECIAL PROPERTIES

Despite its important advantages, fluorescent lighting has some disadvantages which limit its application. Inasmuch as it is a line source of light, it gives diffused area lighting. Where a beam of light is desired, fluorescent lighting cannot at present be used. Fixtures are large and costly, and auxiliaries are expensive. Proper installation and maintenance require much more knowledge and skill for fluorescent lighting than for incandescent, because the newer type is more complicated and there are more things that may go wrong.

In a fluorescent lamp the two ends of each cathode are connected to the pins in the bases of the lamp. When the circuit

49 Fluorescent lamp life varies with the length of burning between starts. Cathode disintegration is greatest during the interval of starting. The original standard lives of 1,000 and 1,500 hours were based on 3-hour burning periods. As with the incandescent lamp, the rated life is an average figure.

50 The reduced heating effect of fluorescent lighting can provide large savings in air-conditioning installation and operating costs.

switch is closed, current flows through the electrodes in series. The current warms the electrodes and lowers the required starting voltage. A neon-glow or bimetallic-thermal starter or switch is inserted in the wire connecting the electrodes.[51] After a few seconds the circuit is automatically broken. A surge of current at somewhat greater than the line voltage, which has meanwhile been built up by the ballast,[52] is then sufficient to leap the gap

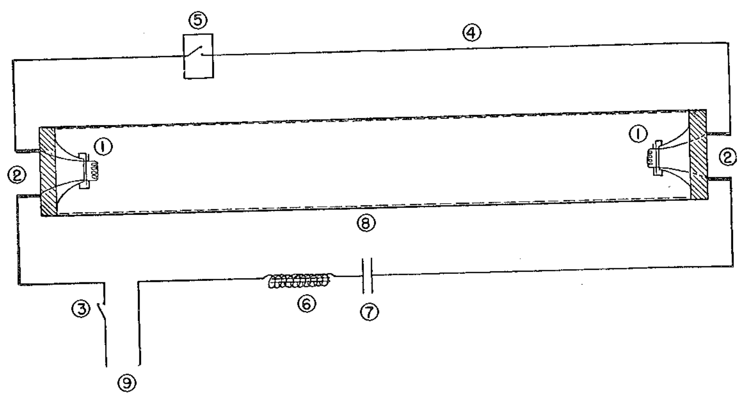


Fig. 36. Typical Single Fluorescent-Lamp Circuit

The parts of the lamp and circuit are as follows: 1,1, electrodes; 2,2, bi-pin bases; 3, system switch; 4, wire connecting the electrodes; 5, lamp switch or starter; 6, inductance; 7, capacitor; 8, glass tube lined with fluorescent powder; 9, system supply wires.

and start a discharge through the argon. The discharge is quickly taken over by the mercury. During lamp operation the argon slows down the movement of mercury ions toward the cathodes and reduces the violence of cathode bombardment, thereby lengthening lamp life.

After the preheating stage the electrodes are kept at the proper temperature by the action of the electric discharge. The starter automatically opens after the preheating and remains open as long

51 The first fluorescent-lamp starters were designed by General Electric engineers at Nela Park. Various difficulties in the original magnetic starters resulted in their replacement by the bimetallic-thermal design, which is still commonly employed. The neon-glow switch, a novel type that has become widely used in fluorescent lighting, was developed by the Westinghouse Lamp Division.

52 The ballast is an inductance, consisting of a coil of wire wound around an iron core.

as the lamp is operating satisfactorily. If the lamp does not light the first time, the starter circuit repeats its cycle until the lamp does light.[53] The delay in starting is sometimes an annoying, though minor, feature of fluorescent lighting. The inductance necessary for starting the lamp also serves to stabilize the voltage within a narrow range during operation.[54]

If only the inductance is placed in the usual alternating-current circuit a low power factor results.[55] That is, the lamp wattage is less than the product of line voltage and current flow. Under such conditions only part of the current drawn from the central supply lines does useful work. This may overload wiring systems, and it requires central stations to maintain larger generating capacity and line capacity than would be needed at high power factor. To correct low power factor, a static condenser, or capacitor, is frequently combined with the inductance in the ballast.

Another method of correcting low power factor is by the use of two-lamp ballasts. One of the lamps controlled by the ballast is controlled only by a reactance, while the other is controlled by a reactance and a condenser. The two lamps operate out of phase, and power factor correction is almost complete. The two-lamp ballast also helps to overcome one of the operating difficulties of the fluorescent lamp. Since the lamp operates on alternating current, the direction of current flow is reversed 120 times a second. If the fluorescent powder has no phosphorescent properties[56] the tube is blacked out 120 times a second. If it is phosphorescent, there is a diminution in light intensity instead of a complete darkening. If an object is in rapid motion under the light, flickering,

53 If the lamp has failed and the main switch remains closed, with ordinary starters the attempted starting will continue until the lamp is replaced or until the starter also fails. Special types, such as the "No-Blink" starter, have been designed to cut out automatically if the lamp does not light after a designated number of attempts. More recent developments have eliminated the need for starters in certain styles of fluorescent lamps.

54 Within the range of voltages for which it is designed, the fluorescent lamp is less sensitive to voltage variation than the incandescent lamp. A 1 per cent change in voltage changes output by 3 per cent in incandescent lighting but only by 1 or 2 per cent in fluorescent lighting. Operation outside the designed range hastens fluorescent electrode disintegration, however.

55 Incandescent lamps have a perfect power factor of 100.

56 Those materials in which luminescence stops when the exciter is removed are called fluorescent substances. If the luminescence continues for a time after the exciter is removed, the phenomenon is known as phosphorescence.

or stroboscopic effect, is quite noticeable and may be very uncomfortable. When two lamps are operated out of phase with one ballast, crests and troughs of light output cross, and an approximately constant emission of light is secured.

Radio interference and hum were at first difficulties in fluorescent lighting. Radio interference can be reduced by proper positioning of the aerial circuit to minimize the effects of direct radiation from the lamp or supply line. A capacitor filter on the lamp circuit near the lamp can eliminate the feed-back that frequently affects radios. Hum may best be overcome by using rigid fixtures and cushioning the ballast to avoid vibration. Discoloration is also a serious problem with fluorescent lamps, as it has been with incandescent lamps. Blackening of the tube at its ends is normal toward the end of lamp life, but other types of discoloration have been problems. Discoloration has been reduced as better exhaust and powder-control methods have reduced impurities. Control of the quantity of mercury contained in the tube, as by the mercury-bomb method, also helps to avoid discoloration.

Chapter XV: THE COMMERCIALIZATION OF FLUORESCENT LIGHTING: 1938–1947

1. The Commercial Development of the Hot-Cathode Fluorescent Lamp, 1938–1947

INTRODUCTION OF THE LAMP

THE hot-cathode fluorescent lamp was formally introduced to the public by General Electric and Westinghouse on April 1, 1938, after about three years of development. A great deal of work was necessary to determine the optimum combination of variables for the different sizes and colors of the lamp and its necessary auxiliaries. The two large companies desired to perfect the lamp before its commercial introduction. Their products had established reputations for excellence of performance, and they did not wish to jeopardize the record with a half-developed product. Since the lamp would be made and sold in very large quantities, even a small error might prove costly.

The timing of the introduction of the fluorescent lamp in 1938 is attributable directly to the New York and San Francisco World's Fairs. Lighting engineers of the fairs insisted on fluorescent lighting, once they knew it was on the way. If the American companies had not supplied their new lamp, cold-cathode fluorescent tubing using high voltages would have been imported from Europe for demonstration purposes. General Electric and Westinghouse had to bring out the lamp at that time, even though they felt that it was not quite perfected. Most of the production during the first year went to the fairs, however, and another year elapsed before the lamp was sold to the public in large quantities. Even though there were still many technical problems connected with the lamp and its use, its defects were not serious enough to prevent satisfactory service in most of the new installations.[1]

Once the fluorescent lamp was on the market, three other firms went into production as soon as they could. Sylvania claimed to

[1] Many of the early difficulties with fluorescent lighting were caused more by the fixtures or other components of the installation than by the lamp itself.

be producing the lamps under its own patents. Consolidated began production in 1939, with the expectation that a new B license would be granted to it by General Electric. Such a license was granted on July 1, 1939, and at the same time the incandescent license was extended. The quota of 3.89093 per cent of the licensor's net sales and the other terms of the incandescent license were carried over into the fluorescent field. Each license was to remain in force until December 31, 1957, provided the other was retained.[2]

The other early producer of fluorescent lamps, and the only member of the independent group to pioneer in this field, was the Duro Test Corporation of North Bergen, New Jersey. It brought out a single-base tubular fluorescent lamp of its own design in 1938. The lamp operated on principles similar to those of the General Electric variety. Around 1941 Duro Test switched to the General Electric type after it had become apparent that the latter was superior and was gaining a large market.

EARLY MARKET EXPANSION AND OBSTACLES

By 1939 the technical advantages of the new lamp had become well known, and sales increased rapidly. The increase was accompanied by numerous conflicting forces, however, which should be considered in an evaluation of progress.

General Electric and Westinghouse originally intended to introduce the fluorescent lamp over a period of years as conditions warranted. At first only the engineers and a few other individuals in the large companies realized the extent of its advantages over incandescent lighting. It took a few years of experience for the entire organizations of the two companies to appreciate the advantages of fluorescent over incandescent lighting. In the beginning the lamp was advocated exclusively for colored and decorative lighting and for supplementary illumination in connection with incandescent lighting. It was not recommended as a general substitute for the incandescent lamp, despite its very high efficiency.

2 Ken-Rad, General Electric's third B licensee in the large-lamp field, did not engage in the manufacture of fluorescent lamps up to the time of the acquisition of its lamp business by Westinghouse in 1945. For some years, however, it distributed fluorescent lamps made by Sylvania and etched with the Ken-Rad trademark.

There were several reasons for the limited endorsement of fluorescent lighting by the two firms which first developed it and produced it on a large scale. Some of the reasons arose out of conditions within the lamp industry, and some resulted from external considerations. One of the major factors was the difficulty for such large organizations to veer off in a completely new direction in a short time. As leaders in the lamp industry, General Electric and Westinghouse had a keen interest in all new types of lighting and were almost certain to be intimately connected with any such development in this country; at the same time, as large concerns supplying about 78 per cent of all electric lamps sold in this country, they had a very strong vested interest in the standard incandescent lamp. Incandescent lighting had been the source of their commercial predominance in the lamp industry for fifty years; they were cautious and deliberate in the promotion of new light sources, particularly where they threatened large portions of the incandescent-lamp market.

Another very important reason for the initial restraint in promoting the sale of fluorescent lamps lay in the close relationships between the large-lamp producers and the electric-utility companies. Each group is dependent upon the other, for the utilities purchase much of their equipment from General Electric and Westinghouse. Even though the financial tie between the manufacturing companies and the electric companies has been broken, a strong community of interest has led to continued cooperation between the two groups. Each group typically takes into consideration the effects of any important new development or policy on the other. During the early thirties a nation-wide "Better Light—Better Sight" program was instituted jointly by the "Mazda" lamp manufacturers and the utilities. Recommended standards of artificial lighting were raised, and a concerted effort was made to sell higher-wattage lighting.

The introduction of fluorescent lighting was initially very disconcerting to the utilities. Since the fluorescent lamp had been acclaimed as several times more efficient than incandescent lighting, there was a possibility that the lighting load would be seriously affected. That view was held by many utility men, although previous experience had indicated that, whenever there were efficiency improvements in incandescent lighting, within a relatively short time the lighting load had grown instead of declined. In general, the utilities seem to have wished to retard the rate of introduction of fluorescent lighting. For example:

Regardless of what we wish to think, most fluorescent installations of the last year have resulted in a decreased load for the utility. This does not mean that saving in energy costs has always been the incentive—better lighting has as often been the most important point. Nevertheless a lessened load results.

The average utility man sees in the rise of fluorescence a decrease in his relative importance. Here is a comparison, based on a 4-cent rate, with equal costs to the user and equivalent results. . . . For every dollar the user spends annually with incandescence the utility gets 80 per cent, the contractor 10 per cent, the equipment suppliers 6 per cent, the lamp suppliers 4 per cent. For fluorescence, the dollar is divided: the utility 44 per cent, the lamp suppliers 24 per cent, the equipment suppliers 20 per cent, the contractor 12 per cent.[3]

And:

I am very, very much disturbed over the utility reactions which I am sure we are going to have as soon as we announce the longer, larger and higher wattage fluorescent lamps. With these lamps, it's going to be possible to produce the same or increased footcandles at a very practical installation cost and with a very decided drop in wattage.[4]

Many utility executives also felt that the fluorescent lamp had not yet been adequately tested. It was feared that too rapid promotion of the lamp would jeopardize the incandescent standards which had been built up over a long period of years. Utility men favored waiting until the lamp and its fixtures and auxiliaries had been perfected, and until more information on its use had been accumulated by illuminating engineers. They proposed in general to carry over to the new light source the principles which had been developed for the incandescent lamp. Despite the low

[3] Letter from R. G. Slauer, of the Westinghouse Lamp Division Commercial Engineering Department, to A. E. Snyder, executive sales manager of the Westinghouse Lamp Division, July 12, 1939. From *Hearings Before the Committee on Patents*, U.S. Senate, 77th Congress, 2nd Sess., on S. 2303 and S. 2491, Government Printing Office, Washington, Part 9, Aug. 18, 1942, p. 4818.

[4] Memorandum from H. F. Barnes of the General Electric lamp department to various executives of the General Electric lamp department, *ibid.*, p. 4824. For other similar statements, see *ibid.*, pp. 4800–5012.

surface brightness of fluorescent and the greatly reduced glare, they insisted that all fluorescent lamps for general lighting should be shielded.[5]

A final objection by the utilities was that the fluorescent lamp had a low power factor, which tended to limit the capacity of installed wiring and was in general costly to the electric companies. The matter of low power factor was a valid objection to the fluorescent lamp. If uncorrected, it would have led to a considerable waste of utility investment. The solution to low power factor was quite simple, however. All that was necessary was to incorporate a capacitor, or static condenser, in the lamp auxiliary. That could be done for each lamp individually or for a pair of lamps, as in the two-lamp ballast. Soon after the lamp appeared on the market the lamp producers, with the coöperation of the fixture manufacturers and the utilities, succeeded in achieving a high degree of power-factor correction in most installations. Sylvania, although not the leader in fluorescent lighting, made a definite contribution by early insisting on high power-factor auxiliaries in the fixtures used with its lamps. In many states power-factor correction is now compulsory.

With respect to the utilities' fear of load losses, experience has indicated that fluorescent lighting has led to much higher levels of illumination, and that reductions in wattage have in general not been so great as was originally feared. In many installations, fluorescent even seems to have resulted in increased consumption of lighting current. At the outset, the utilities were opposed to the use of fluorescent lighting except where it did not entail a wattage reduction from the old incandescent installation or its equivalent. It took more than a year of experience to convince them that they should encourage the use of the new lamp for other than decorative and supplementary lighting.

The utilities exerted considerable pressure upon General Electric and Westinghouse in connection with fluorescent lighting.

[5] The desirability of shielding *all* fluorescent lamps, other than those used in industry, is debatable, except on aesthetic grounds. Shielding requires more expensive fixtures than are otherwise required or costly wall or ceiling constructions. Since effective lamp efficiency is thereby reduced by as much as 25 per cent, more lamps and greater current consumption are necessary for a given level of illumination. In practice, many consumers have used unshielded fluorescent lamps without discomfort.

After the entry of Sylvania into fluorescent-lamp production and in defense against its vigorous promotion, the big companies stepped up their own sales efforts and conducted an advertising campaign pointing out the efficiency advantages of the fluorescent lamp. The utilities immediately took exception to the emphasis upon the lower consumption of electric energy for the same light output. A conference was held among representatives of the large-lamp producers and the utilities, and understandings were worked out whereby future promotion was to be based upon what were considered to be "sound illuminating engineering principles." The lamp producers met the demands of the utilities, and on May 1, 1939, General Electric issued a statement of policy which included the sentence: "The fluorescent Mazda lamp should not be presented as a light source which will reduce lighting costs." [6] Westinghouse concurred by stating, in part: "We will oppose the use of fluorescent lamps to reduce wattages." [7] Thereafter the large-lamp producers worked more harmoniously with the utilities in promoting fluorescent lighting. In their advertising and promotion they played down the efficiency advantages and stressed supplemental and decorative lighting for another year or so, until competition from Sylvania again forced more aggressive selling.

THE PROBLEM OF FIXTURES

The early complaints of the utilities were based in part upon a number of poorly engineered installations, which had been made by irresponsible promoters in violation of established principles of good lighting. The poor performance was attributable more to the fixtures and the engineering of those installations than to the lamp itself. When the public learned of the fluorescent lamp at the World's Fairs and in early advertising, it bought eagerly. For a time adequate fixtures were not available. The demand far outstripped the ability of experienced fixture manufacturers to supply well designed equipment. Many individuals took advantage of the situation and set themselves up in the fixture business. Despite the element of chaos introduced by those "tin-knockers," their presence was not an unmitigated evil. While some installations were objectionable, a great many others were satisfactory

[6] *Ibid.*, p. 4849. [7] *Ibid.*, p. 4848.

in spite of imperfect fixtures. The fluorescent lamp was pushed into the public attention more rapidly than would have been the case if the utilities and the large manufacturers had been the only promoters. The situation also stimulated the established lamp and fixture producers to hasten the development of adequate luminaires for all purposes.

Sylvania broke away from the General Electric group in fluorescent lighting, and it was not willing to follow the larger company in its distribution policies as it had been willing to do in product design. When the big companies toned down their advertising after the objections of the utilities to their initial promotions, Sylvania increased the vigor of its own sales effort. Much fluorescent lighting was bought at the insistence of the buyer rather than sold by the manufacturers, and Sylvania saw an excellent opportunity to expand. The small company undertook to advertise and market its product nationally, and within a fairly short time it had increased its share of the domestic fluorescent-lamp market to almost 20 per cent. The importance of its expansion is evident from the fact that previously Sylvania had supplied only about 5.5 per cent of the domestic incandescent-lamp market.

Some initial difficulty was experienced by Sylvania in developing a market for its fluorescent lamps. The established marketing channels and reputations of the larger companies gave them a great initial advantage, which was overcome by Sylvania in part through vigorous promotion and in part by adding a line of fluorescent fixtures to its product list in 1939. In that way it was able to sell a "complete unit of light" guaranteed by a single manufacturer. Sylvania had never before made fixtures; nevertheless, its "Miralumes" were made to high standards and were well designed. The line included a wide variety of styles, so that the buyer could use fluorescent lamps shielded or unshielded, as best suited his needs. The company rapidly developed a sizable market for "Miralumes" and also increased its lamp sales. In addition, the move stimulated the raising of standards by other fixture manufacturers, which aided in expanding the demand for fluorescent lamps in general. Sylvania's frontal attack on the fixture problem was a major contribution in the successful commercial development of fluorescent lighting.

Shortly after Sylvania undertook to produce luminaires, an association of commercial and residential fluorescent-fixture manufacturers—the Fleur-O-Lier Manufacturers Association—was organized with the assistance of General Electric and Westinghouse. The large companies, with the cooperation of the utilities and the Electrical Testing Laboratories, established minimum specifications to which the fixtures of member producers were to conform. Certification of equipment was to be

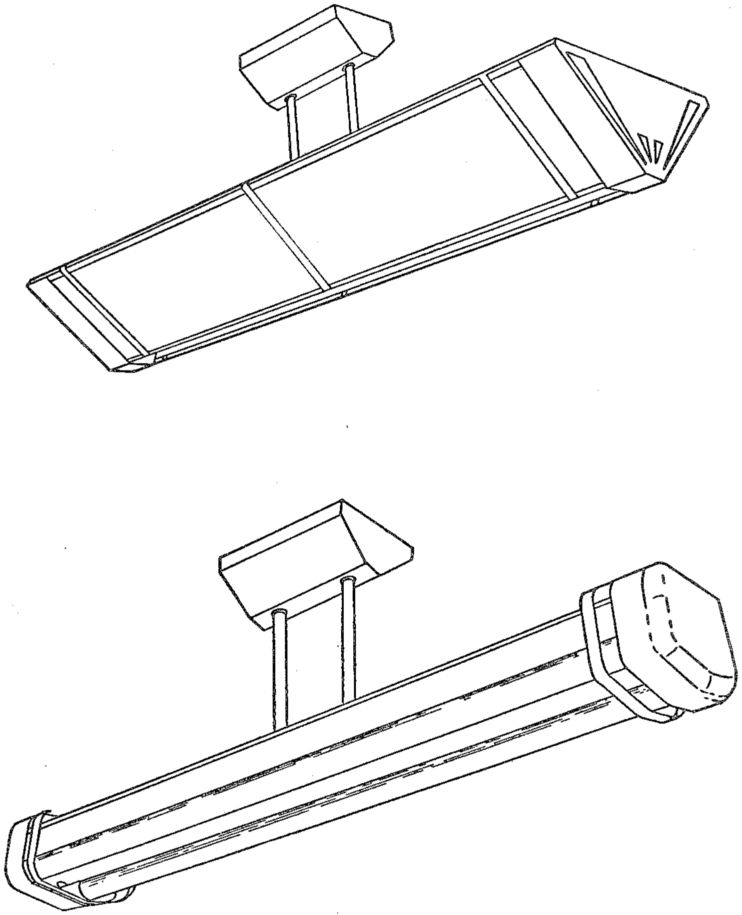


FIG. 37. Typical Commercial Fluorescent Fixtures
The lamps in the upper fixture are shielded by frosted glass; those in the lower one are left exposed.

made by ETL. By the end of 1942 more than fifty fluorescent-fixture manufacturers, including a number of the largest ones, had submitted models which had been certified or were in the process of being certified.

General Electric and Westinghouse also encouraged the leading manufacturers of industrial incandescent-lighting shields and reflectors, who belonged to the RLM Standards Institute, to manufacture industrial fluorescent fixtures.[8] The Westinghouse lighting division makes fluorescent fixtures as a member of the RLM group, although it is not the largest of such producers. General Electric does not make fluorescent luminaires at all, on the ground that to do so would be to compete with many of its customers. General Electric sells large quantities of auxiliaries to the Fleur-O-Lier and RLM manufacturers for assembly into completed fixtures.[9] The former "Mazda" lamp companies recommend the use of their fluorescent lamps with equipment meeting the specifications of the associations; and the associations recommend lamps with the specifications established by the large-lamp companies for use in luminaires sold by their members.

THE GROWTH OF FLUORESCENT LIGHTING, 1940–1947

By the end of 1940 the principal initial shortcomings of fluorescent lighting had been effectively overcome. Improvements in the lamp itself and in production methods had resulted in greater efficiency, longer life, lower costs and prices, and generally improved performance.[10] The fluorescent lamp was able to compete more strongly on a cost basis and was able to give improved service. Better and cheaper fixtures had also been designed. The opposition of the utilities had been largely overcome. Illuminating engineering had caught up with the new light source. Within three years fluorescent lighting had matured and was ready to take its place as a leading source of artificial illumination.

As technical improvements in the fluorescent lamp established it more firmly in the market, and as Sylvania continued its intensive promotion, the two large manufacturers increased the

[8] RLM equipment is also tested and certified by ETL.
[9] Its development, patent control, and production of essential fluorescent-lamp auxiliaries, such as starters and ballasts, added greatly to the strength of General Electric in the fluorescent field.
[10] These matters are discussed in greater detail in section 4 of this chapter.

vigor of their own selling activities. In the battle for markets it was primarily a struggle between Sylvania on one side and General Electric and Westinghouse on the other side.[11] The two big companies were competitors, of course, but they were bound together by the A license and by their traditional collaboration in the lamp industry. The terms of the license agreement, General Electric's much greater size, and General Electric's customary position as leader in the industry, all combined to induce Westinghouse to continue to stay in line. Consolidated, as the only B licensee making fluorescent lamps, also followed along after General Electric.

Duro Test and the few other independents who made fluorescent lamps were limited more by their capacity to produce the lamp at a profit than by the availability of a market. Demand for their product was created by the general advertising given to fluorescent lighting by the large producers. Besides the activity of Duro Test, there were two other attempts by unlicensed incandescent-lamp manufacturers to break into the fluorescent field. One was a joint undertaking by Wabash, Jewel, and the Dura Electric Lamp Company. The three companies pooled resources and set up Luz Incorporated to make fluorescent lamps. A combination of circumstances caused the venture to end in failure. Wartime difficulties in obtaining materials and mechanical equipment blocked expansion at the outset. The split in ownership and control led to some internal dissension and a lack of complete cooperation. Finally, and perhaps most important of all, the three concerns did not have the $750,000 or so required to set up a fluorescent-lamp plant on an efficient basis. The experiment was abandoned during the war and has not been revived.

The Warren Lamp Company of Warren, Pennsylvania, was the only other independent to try to make fluorescent lamps. It set up a subsidiary, the Solar Electric Corporation, which has made small quantities of lamps for a few years. Solar is still in an experimental stage, however, and it has not yet succeeded in placing the production of fluorescent lamps on a profitable basis.

[11] According to *Advertising Age* (Aug., 1942), advertising expenditures for fluorescent lighting in national magazines by the three companies were as follows: General Electric, $72,000 in 1940, $160,000 in 1941; Sylvania, $26,000 in 1940, $64,000 in 1941; Westinghouse, $8,000 in 1940, $28,000 in 1941.

Duro Test also is still having difficulty in turning out enough lamps to keep costs below the net selling price.

Despite the increased share of Sylvania in the fluorescent field, General Electric and its licensees[12] have continued to control almost as much of the American fluorescent-lamp market as the former General Electric group did for incandescent lamps. The big company itself has produced an average of about 56 per cent of the national total, and Westinghouse has made around 22 per cent. Consolidated has added another 2.5 per cent to produce a total for the General Electric bloc of roughly 80 per cent. Sylvania has produced all the rest, except very small quantities made by Duro Test and Warren. The market shares have remained remarkably constant since 1940.

The growth in sales as a result of increased promotion and improved performance is indicated by the statistics of Table XXX. When low-voltage fluorescent lighting first came upon the market, it was expected that the colored lamps would constitute an appreciable proportion of total sales, and that the daylight lamp would be the most popular shade. That was true at first. In 1939, about 60 per cent of fluorescent lamps sold were daylight lamps, 27 per cent were white lamps and 13 per cent were colored.[13] Moreover, in September, 1939, the largest-selling size was the 20-watt lamp, which was used for domestic and commercial lighting.[14] Subsequent developments altered that situation drastically.

The primary factor influencing the later trends in fluorescent-lamp sales was World War II, which altered the nature of fluorescent-lamp demand and restricted production. As industrial plants were constructed for war production, fluorescent lighting

[12] The Westinghouse A license to produce fluorescent, incandescent, and other lamps was canceled on Aug. 1, 1945. Since that time Westinghouse has produced fluorescent lamps under General Electric patents on a royalty-free basis. The Consolidated B license for fluorescent remained in force when the B licenses of other producers expired.

[13] A. B. Oday and R. F. Cissell, "Fluorescent Lamps and Their Application," *Illuminating Engineering Society Transactions*, Vol. XXXIV, Discussion, p. 1187 (Dec., 1939).

[14] The various sizes were sold in the following percentages: 15-watt T-8, 26 per cent; 15-watt T-12, 11 per cent; 20-watt, 33 per cent; 30-watt, 22 per cent; and 40-watt, 8 per cent. See "Signs of Progress; Report of I.E.S. Committee on Progress," *ibid.*, Vol. XXXVI, p. 172 (Feb., 1941).

was used in greater quantities for space lighting. By 1943 the 40-watt size constituted about 63 per cent of sales for one leading manufacturer and the 100-watt lamp contributed about 8 per cent more. The white lamp displaced most daylight lamps, and the production of colored lamps was completely eliminated.

TABLE XXX: SALES OF HOT-CATHODE FLUORESCENT LAMPS IN THE UNITED STATES[a]
1938–1947

Year	*No. Lamps*	*Retail Value*
1938	200,000	$ 390,000
1939	1,600,000	3,000,000
1940	7,100,000	12,300,000
1941	21,000,000	28,200,000
1942	33,600,000	33,900,000
1943	37,500,000	33,500,000
1944	36,500,000	32,500,000
1945	40,700,000	36,000,000
1946	50,600,000	45,000,000
1947	79,100,000	72,700,000

[a] These figures are based in part upon data for shipments by manufacturers rather than for completed sales.

Sources: Data supplied by the principal producing companies and by Bureau of the Census, U.S. Dept. of Commerce, *Facts for Industry; Electric Lamps*, Washington, Nov. 22, 1944; Mar. 26, 1946; July 15, 1946; Mar. 6, 1947; June 13, 1947; Sept. 2, 1947; Dec. 2, 1947; and Mar. 9, 1948.

The upward trend in fluorescent-lamp sales was checked more by wartime restrictions on fixture production than by restrictions on lamp production. To conserve sheet steel, fixture output was limited in 1942 to supply only those installations for which high priorities could be obtained. For more than three years almost all new installations were for industrial illumination. After the period of tooling up for war production was past, the number of new installations dropped considerably. That accounts for the decline in total fluorescent-lamp sales in 1944, despite the larger number of sockets in use. With the end of hostilities, domestic fluorescent-lamp sales resumed their rapid

advance.[15] In 1947 more than 79,000,000 lamps were sold in the United States. Continued increases in consumer demand and intensified promotion by lamp and fixture manufacturers and by the utilities have led to sales forecasts of 100,000,000 units for 1948 and even larger figures for succeeding years.

Even though the future position of the fluorescent lamp in electric lighting is not yet certain, it appears highly likely that the new lamp will some day replace a sizable proportion of incandescent lighting. Its higher efficiencies and longer life have led to use in virtually all newly constructed industrial plants and in great numbers of older factories on a cost basis. Industrial and commercial uses may expand much farther in the future. Even residential users may well find outstanding cost advantages for fluorescent lighting, and they will almost certainly be attracted by its superior quality of light. A fluorescent installation requires more fixtures and more lamps than an incandescent installation, and their prices are on the average higher than those for incandescent lighting; but the greater efficiencies and longer lamp life generally overbalance the higher carrying charges. Where the lamps are burned more than about 1,000 hours a year, fluorescent lighting can usually provide more light than an incandescent-lighting system for the same cost.

The improved competitive position of the fluorescent lamp has resulted in part from price reductions. Seven major reductions in five years left list prices in 1942 only about one-third as high as they had been in 1938 (Table XXXI). A 7 per cent increase was announced on July 1, 1946, to compensate for increased production costs. In general, price policies for fluorescent lamps have been the same as those for incandescent lamps. The initial list prices were set by General Electric in 1938 and followed by all other producers. All subsequent reductions and increases have been initiated by General Electric and followed by the other producers. Where the smaller companies have made price concessions, it has been, as usual, by the adjustment of discounts granted to large users or to distributors. As in incandescent lighting,

[15] Exports of fluorescent lamps have also risen in importance since the end of the war. In 1946, American lamp producers shipped abroad 2,580,000 fluorescent lamps with a retail value of $2,300,000, and those figures were almost doubled in 1947.

TABLE XXXI: LIST PRICES OF FLUORESCENT LAMPS [a]
1938–1947

List Price Changes	*6–W*	*8–W*	*14–W*	*15–W T–8*	*15–W T–12*	*20–W*	*30–W*	*40–W*	*65–W*	*100–W*	*85–W RF*
Apr. 21, 1938				$1.50	$1.80	$2.00	$2.00				
Mar. 1, 1939				...	...	...	...	$2.80			
Sept. 1, 1939				1.35	1.70	1.90	1.85	2.70			
Nov. 1, 1939				...	...	...	...	...			$7.50
Mar. 1, 1940				1.15	1.45	1.65	1.50	2.30			...
Apr. 1, 1940			$1.60	...	...	...	...	...			6.50
June 1, 1940			1.35	.95	1.25	1.25	1.25	1.90			...
Sept. 1, 1940			...	...	...	...	...	...			5.00
Oct. 1, 1940	$1.15		...	...	...	...	...	...			...
Oct. 14, 1940	...		...	...	...	...	...	...		$3.75	...
Dec. 1, 1940	...		1.20	...	...	...	...	...		...	...
Jan. 1, 1941	...		...	.85	1.10	1.10	1.10	1.60		3.50	4.25
Feb. 1, 1941	1.00		1.05	...	...	...	...	...	$2.75	...	...
Apr. 1, 1941	...	$1.25	...	...	...	...	...	...	...	...	...
Aug. 1, 1941	.90	1.10	.90	.75	.95	.95	.95	1.35	2.50	3.00	3.65
Jan. 1, 1942	.80	.90	.80	.65	.80	.80	.80	1.15	2.30	2.60	3.00
Sept. 1, 1942	.70	.80	.70	.57	.70	.70	.70	.95	[b]	2.15	2.75
July 1, 1946 [c]	.75	.85	.75	.62	.75	.75	.75	1.00		2.30	3.00

[a] Prices quoted refer to daylight and white lamps. Higher prices are charged for soft white and colored lamps.
[b] Discontinued.
[c] The price schedule announced on July 1, 1946, remained in force throughout the rest of 1946 and all of 1947.
Sources: General Electric Company, Westinghouse Electric Corporation, and Sylvania Electric Products, Inc.

General Electric's stated price policy was to maintain production costs at a fixed percentage of list price. There is some evidence, however, that the price reductions of 1939 through 1942 were initiated by General Electric more rapidly than normal, as a competitive measure. It appears that the reductions in list prices preceded reductions in cost in some instances, rather than followed them. The industry leader evidently wished to limit the growth of Sylvania and the independents in fluorescent lighting by reducing prices as rapidly as possible. The strategy worked with the independents. It did not succeed against Sylvania, although the latter was forced to sell below cost for a short time. Since the end of the war, improved mechanization of assembly processes and expanded output have led to increased profits in fluorescent-lamp production.

FLUORESCENT-LAMP PARTS AND MACHINERY

The situation in sources of supply for fluorescent-lamp parts and machinery is similar to that for incandescent-lamp production with a few notable exceptions. The glass tube for the lamp is the largest and most costly single part. Smaller tubing is employed in the electrode assemblies. Lead-in wires, support wires and coiled-coil tungsten filaments are similar to those in the incandescent lamp, with the addition of an oxide coating on the fluorescent cathode. Two bases of a new design are required for each lamp. Argon gas is used, with the addition of a small amount of mercury. The fluorescent powders are new raw materials with no counterpart in incandescent lighting.

Glass is a critical raw material. General Electric has built two new glass plants to draw the large-diameter tubing required for fluorescent lamps, and it fills all its own needs. Westinghouse has also erected a glass-tube factory. That represents a deviation from the established pattern of supply in incandescent-lamp production, where Westinghouse purchases all its glass from Corning. Sylvania, Consolidated, and the few small companies which set out to make fluorescent lamps continue to obtain all their glass from Corning, which has built a new glass-tube plant in Rhode Island. Although Sylvania has considered the desirability of making its own glass, it has been able to secure price concessions from Corning which have made that unnecessary.

The glassworks built by General Electric and Westinghouse were established in conjunction with entirely new lamp-assembly factories. The space and machinery requirements for producing fluorescent lamps made it impossible to utilize existing facilities for large-scale production. Moreover, the need for cheap fuel in glassmaking and lamp assembly encouraged the building of works in natural-gas areas. By 1943 General Electric had established two new lamp factories, one in Jackson, Mississippi, and the other in Bucyrus, Ohio. Each cost about $1,250,000 to construct and equip, and each was designed to have a capacity of about 12,000,000 lamps a year on a three-shift basis. Of the installed plant value, about $400,000 was for the glassmaking facilities and the rest was for lamp assembly. The Westinghouse factory was built in 1941 in Fairmont, West Virginia, and cost around $3,000,000 to build and equip. It was designed to have a capacity of about 50,000,000 lamps a year on a three-shift basis.

A new fluorescent-assembly plant was also set up in 1941 by Sylvania at Danvers, Massachusetts. The location of that factory has been an important factor in the decision of the company not to make its own glass tubing. It cost about $1,000,000 to build and equip without a glass plant and had a designed capacity of 25,000,000 lamps a year on a three-shift basis. Consolidated and Duro Test have not constructed new facilities for fluorescent-lamp assembly but have turned over portions of their existing floor space to the new product. Warren converted some of its floor space to the production of fluorescent lamps in a building separate from its incandescent-lamp factory.

Until recently fluorescent-lamp bases were made only by General Electric and Westinghouse. Westinghouse produced primarily for its own use, although it sold some bases. General Electric filled its own requirements and sold bases to all other producers. Now, however, Sylvania is also producing bases for fluorescent lamps. Fluorescent powders are prepared by each of the producers of fluorescent lamps for itself. When Sylvania found it difficult to obtain sufficient powder from outside suppliers, it bought out the Patterson Screen Company of Towanda, Pennsylvania. The small producers prepare the phosphors in their lamp plants. The remaining fluorescent-lamp parts are supplied

according to the pattern existing for incandescent lamps[16] or are bought on the open market.

Lamp-assembly machinery has been of even greater importance in fluorescent lighting than in incandescent lighting. The fluorescent lamp has been so new that outside machinery manufacturers have not designed such equipment for general sale. The lamp industry has had to rely on its own efforts. Many assembly operations are similar to those in incandescent-lamp manufacture. Nevertheless, the lamp sizes and shapes are so different that complete redesigning of equipment has been necessary. Some entirely new machinery has also been required to take care of such processes as coating the tube with fluorescent powders. General Electric and Westinghouse took the lead in machine design, of course, as they had for incandescent lamps. Consolidated was permitted to obtain much of its equipment from the licensor. Sylvania was no longer able to buy its machinery from General Electric, and it set about designing its own equipment. Some productive assistance was secured from Alfred Hofmann. Despite its initial disadvantage, Sylvania was eminently successful in developing efficient machinery for its Danvers plant, and in a number of instances it preceded the "Mazda" manufacturers in machinery and methods developments.

Duro Test, Luz, and Solar were in a much more difficult position. They could not buy ready-made equipment, and they did not have large amounts of money to invest in its design. They limped along on relatively small amounts of money and relatively slow-speed equipment. Alfred Hofmann and Eisler collaborated with them to some extent in the building of the equipment. During the past few years, however, Duro Test has greatly improved its equipment. While still behind the larger concerns, its unit output per hour is closer to the leaders in fluorescent-lamp production than is customary among the independents in incandescent lighting. If other small concerns are to enter the fluorescent field in the future, they will have to be able to obtain adequate machinery. Neither Hofmann nor Eisler has yet shown any indication of designing a complete line of high-speed equipment. The machinery problem is the blackest part of the fluorescent picture for the independent group of lamp manufacturers.

[16] See Table XXIII on p. 284.

THE ECONOMIC IMPORTANCE OF HOT-CATHODE FLUORESCENT LIGHTING

Some indication of the economic importance of the hot-cathode fluorescent lamp is given by the sales figures of Table XXX. The value of lamp sales is only a small part of the total contribution of fluorescent lighting to national product, however. The value of fluorescent fixtures sold, the value of electrical contracting services and wiring, and the value of electric energy consumed in fluorescent lighting must all be added to obtain its total positive influence. Moreover, the displacement of incandescent lighting must be considered before the net effects can be stated.

In 1942 the total of all the principal activities associated with fluorescent lighting contributed about $273,000,000 to national product (Table XXXII). About half that sum represented a displacement of incandescent lighting,[17] and the balance was a net addition to economic activity.

Although average employment in fluorescent-lamp assembly in 1942 was only 3,300, employment in previous stages of manufacture of lamp parts, machinery and plant and in the distribution and sale of the product raised the total of direct and indirect employment to about 14,000 persons. Total direct and indirect employment in fixture assembly, electrical contracting, etc., added almost another 100,000 jobs. Even after allowing for the displacement of workers in incandescent lighting, there was a net addition of about 56,000 jobs. Similar calculations for the four years from 1939 through 1942 indicate that over that period fluorescent lighting contributed about $400,000,000 to national product and 180,000 man-years of employment, despite some displacement of incandescent lighting. The expansionary effect may be expected to continue for several years as fluorescent lighting continues to grow.[18]

From an investment standpoint, fluorescent lighting has not yet

[17] Roughly 30,000,000 large incandescent lamps worth $5,000,000 were displaced by fluorescent lamps in 1942. The major displacements, however, were in electric power consumption by incandescent-lighting systems, the production of incandescent-lighting fixtures, and the installation of incandescent-lighting systems.

[18] See my paper, "Some Broad Economic Implications of the Introduction of Hot-Cathode Fluorescent Lighting," already cited, for more detailed figures for the years 1938 through 1942 and for rough estimates as of 1944 for the first three postwar years.

TABLE XXXII: ESTIMATED ECONOMIC CONTRIBUTION OF HOT-CATHODE FLUORESCENT LIGHTING 1942

Activity	Total Fluorescent Lighting		Displacement in Incandescent Lighting		Net Contribution of Fluorescent Lighting	
	Value	*Total Employment (Direct Plus Indirect)*	*Value*	*Total Employment (Direct Plus Indirect)*	*Value*	*Total Employment (Direct Plus Indirect)*
Lamp production	$ 33,900,000	14,000	$ 5,000,000	2,000	$ 28,900,000	12,000
Fixture assembly (including auxiliaries, if any)	59,000,000	25,000	15,000,000	6,000	44,000,000	19,000
Installation of lighting fixtures (minus lamps and fixtures)	135,000,000	55,000	60,000,000	25,000	75,000,000	30,000
Use of electric energy in lighting	45,000,000	18,500	56,000,000	23,000	−11,000,000	−4,500
Total	$272,900,000	112,500	$136,000,000	56,000	$136,900,000	56,500

Source: Adapted from Arthur A. Bright, Jr., "Some Broad Economic Implications of the Introduction of Hot-Cathode Fluorescent Lighting," *Transactions of the Electrochemical Society*, New York, Vol. LXXXVII (1945), pp. 83–93.

been very important. About $15,000,000 in new fixed investment were required from 1938 through 1942. Lamp and glass plants accounted for about $9,000,000 of the total. The rest was used to provide new facilities for the production of other parts, auxiliaries, and fixtures. Only $1,000,000 or $2,000,000 in new incandescent-lamp investment was displaced, however. During the war years little new outlay was made for facilities to produce fluorescent-lighting equipment. A new period of investment will probably occur soon, when existing plants become utilized to their full capacity. Additional investment will also be required if the independents move into the field in greater numbers. The greatest opportunity for investment is the expanded utility plant that will be encouraged when and if the displacement of power used for incandescent lighting is overbalanced by the expansion of power used for fluorescent lighting.

2. *The Legal Status of the Hot-Cathode Fluorescent Lamp*

GENERAL ELECTRIC AND SYLVANIA PATENT LITIGATION

The patent controversy over the fluorescent lamp deserves special attention. When General Electric and Westinghouse added the fluorescent lamp to their regular lines on April 1, 1938, Westinghouse owned a few detail patents, while General Electric had title to what it considered to be the basic fluorescent-lamp patents and patent applications. On December 30, 1937, Westinghouse's license was extended to cover the fluorescent lamp under the same terms regarding quota, prices, conditions of sale, etc., as for incandescent lamps. Sylvania, however, attempted to build up a patent position of its own.

In the spring of 1940 General Electric proposed to Sylvania that it accept a new B license covering fluorescent lamps at the incandescent royalty rate of 3 per cent and the incandescent quota of 9.124 per cent of General Electric's net sales and under all the other terms applying to incandescent-lamp production. Sylvania refused.[19] In May, 1940, a patent infringement suit was instituted

[19] It is possible that, if General Electric had offered a larger quota and had made other modifications in terms, Sylvania might have accepted a license, for it was expensive and risky for the smaller concern to compete on even terms with the industry leader. If that had occurred, almost the entire American market would have been divided by quota.

against Sylvania by General Electric in the Southern New York District Court. Sylvania denied infringement and instituted a countersuit for patent infringement against General Electric.

Two General Electric patents were involved in the suit.[20] The first had been granted to Dr. Albert W. Hull of the Schenectady Research Laboratory on January 27, 1931. That patent dealt with electric-discharge devices in general and pertained principally to rectifiers. It covered a method of reducing cathode disintegration in connection with inert-gas pressures and mercury-vapor pressures similar to those used in the fluorescent lamp. Such pressures had not been successfully used in electric-discharge devices before Hull. Claim number 3 of the seventeen claims in the patent was alleged to be infringed by the Sylvania fluorescent lamp.[21]

The second General Electric patent in suit was granted to Friedrich Meyer, Hans Spanner, and Edmund Germer and assigned by them to General Electric. It covered a type of metal-vapor lamp which could be used in connection with luminescent substances to produce a fluorescent lamp. The characteristics of the General Electric fluorescent lamp were very much like those described in the Meyer patent, although it appears that the German inventors did not make such a lamp on more than an experimental basis. Four of the patent's twenty-eight claims were involved in the suit.[22]

The Meyer patent had a long and interesting history. Applica-

[20] The patents on the use of fluorescence in neon-type tubing and in the high-pressure mercury-vapor lamp had no relevance to the low-voltage, low-pressure fluorescent lamp introduced in 1938. It was the electrical properties of the lamp, rather than the use of fluorescent materials, that were important.

[21] Claim no. 3 reads as follows: "The combination of an electric current source having a voltage materially greater than fifty volts, an electrical discharge device connected thereto comprising a thermionic cathode, an anode, a container therefor, and a gas therein having a pressure within the range of several microns to several millimeters of mercury and means for maintaining the ion bombardment voltage with respect to such cathode less than a critical value characteristic of the nature of the gas in said container at which destructive disintegration of said cathode would occur." (U.S. patent no. 1,790,153.)

[22] Claim no. 27, which is typical of the four disputed claims, reads as follows: "A mercury vapor lamp comprising an elongated vessel, a filling of rare gas and mercury vapor, the latter constituting, in operation, the main source of spectral ray emission, two fixed main discharge electrodes, at least one of which is a Wehnelt type cathode, spaced apart in said vessel to form therebetween a luminous discharge column defined by the vessel wall and fluorescent material disposed in the path of said spectral ray emission." (U.S. patent no. 2,182,732.)

tions for patents were made in Germany on December 10, 1926, and in the United States on December 19, 1927. The rights to the American application were sold by Meyer, Spanner, and Germer to Electrons, Inc., which for more than ten years sought to have the patent issued. Various legal difficulties led to lengthy proceedings in the Patent Office and in the courts. On October 12, 1938, an interference was declared by the Patent Office between claims in the Meyer application and in an application by LeRoy J. Buttolph, an employee of the General Electric Vapor Lamp Company. The Buttolph application, which had been filed early in the twenties on a claimed invention of October, 1919, and which was still pending in the Patent Office, purported to cover the fundamental principles and construction of General Electric's fluorescent lamp. General Electric was pressing the early Buttolph application to strengthen the basic legal protection for its new fluorescent lamp, for the "improvement" application made by George Inman, the engineer who designed the first lamp, had not yet been granted.[23] General Electric also sought to amend the original claims of the Buttolph application to increase its coverage of the fluorescent lamp.

When the interference between Buttolph and Meyer was declared, some six months after the fluorescent lamp had been placed on its general price list, General Electric learned of the existence of the Meyer application for the first time. To guarantee its own position, General Electric bought the Meyer application from Electrons, Inc., for $180,000. New claims were added to the Meyer application by amendment, and after an analysis of both patent applications by General Electric the Buttolph application was withdrawn on October 9, 1939. General Electric felt that the substance of its own application did not cover the actual fluorescent lamp as well as that of Meyer. Moreover, speed was important, and interference delays are often lengthy. On October 11, 1939, the interference was dissolved in favor of Meyer, and the patent was eventually issued on December 5, 1939. The Meyer patent will not expire until 1956, although the invention was made in or prior to 1926.

[23] The Inman patent application was filed on Apr. 22, 1936, and issued on Oct. 14, 1941, some seventeen months after the infringement suit had been instituded.

The Sylvania patents were originally four in number, but two of them were withdrawn in the course of the trial. One of those patents, issued to James L. Cox of Sylvania on October 19, 1937, had reference to a method of coating glass tubes with fluorescent substances. Inasmuch as the method described in the patent had been used by Sylvania in cathode-ray tubes for more than two years prior to the application, the patent was held to be invalid. The other patent on which claim was dismissed covered a type of electrode construction and had been issued on December 4, 1934.

The two remaining Sylvania patents were the Smith and Le Bel patents. Both were owned by the Raytheon Manufacturing Company, which granted exclusive licenses under them to Sylvania, with the right to take infringement action and collect damages. The first was a patent applied for by Charles G. Smith of Raytheon in 1925 to cover a particular type of electric-discharge device containing gases at low pressure. Although the patent had particular reference to rectifiers, amplifiers, and oscillators, some of its features were similar to those of the fluorescent lamp. Among other things, it included a method of keeping down cathode voltage drop which was alleged to be employed in the fluorescent lamp. It was granted by the Patent Office on May 21, 1940, after a lengthy and complicated history. The Sylvania license was thereupon granted. Changes were made in the claims between 1925 and 1932; and in 1938 and 1940, after the fluorescent lamp was on the market, changes were made in both specifications and claims to make it apply more closely to the new lighting device. Sylvania claimed infringement by General Electric of ten of the eighty claims.[24] Because of its ownership of the patent, Raytheon was made a party to the legal action.

The Le Bel patent, first granted in 1938 on a 1929 application, covered a method for producing large quantities of light in any desired portion of the spectrum and referred particularly to ultra-

[24] Claim no. 72, which is typical of the disputed claims, reads as follows: "An electrical discharge device comprising a gas having a substantial pressure when cold, and a gas having a lower pressure when cold, means including a thermionic cathode for starting a discharge through first-named gas and for maintaining the discharge by ionization of the latter gas, said latter gas having a pressure of the order of one to one hundred microns during normal operation." (U.S. patent no. 2,201,817.)

violet lamps for sterilizing or therapeutic use. It was alleged that the combinations of argon and mercury vapor referred to in the patent, along with certain other features described, had bearing on the fluorescent lamp. The original Le Bel patent contained fifteen claims. On May 24, 1939, application was made for a reissue patent. The revision was granted on November 25, 1941, and it contained changes in specifications and thirty-four new claims. Sylvania received an exclusive license under the reissue patent while it was pending in February, 1940 and sued General Electric for infringement of fifteen of the claims included in the later version.[25]

It is noteworthy that the original applications for each of the four patents remaining in suit had been filed before 1930, whereas the first models of the successful fluorescent lamp were not constructed until 1935. The Hull invention was the only one made by an employee of an American lamp company, and none of the patents was primarily concerned with a fluorescent lamp as such. From this it is evident that the fluorescent lamp as developed in 1935 contained relatively little that was fundamentally new at that time. Each contestant merely collected as many patents as it could which read on the discharge device employed in the lamp, and the claims of three of the four patents were amended and broadened after the lamp had been developed and placed on the market.

The legal and technical matters involved in the consideration of validity and infringement of these patents were highly complicated. The court hearings started in 1942, and many months of involved testimony were required before the case went to the judge for decision. An additional year and a half elapsed before Judge Vincent L. Leibell announced his opinion on March 30, 1944. The judge declared the Hull patent valid and infringed and the Meyer patent valid and infringed, except to the extent

[25] Claim no. 25, which is typical of many of the disputed claims, reads as follows: "An ultraviolet lamp comprising an envelope exposed to the air, said envelope containing mercury vapor at a pressure of between 1 and 8 microns during the normal operation of the lamp, and an inert gas at a pressure of the order of between 1 and 8 mm. and means for producing an electrical discharge in said gaseous filling, said lamp being designed and adapted to generate for utilization ultraviolet light having a wave length of the order of 2537 Angstrom units." (U.S. reissue patent no. 21,954.)

that those claims which had been broadened by General Electric in 1939 were held invalid. Both the Smith and the Le Bel patent were proclaimed invalid in their entirety.

Despite the sweeping triumph of General Electric in the lower court, the degree of its legal control over the fluorescent lamp is not yet established. An important complicating factor is the intervention of the Antitrust Division of the Department of Justice in the case. The interest of the Justice Department in the fluorescent lamp grew out of its investigations of the incandescent-lamp industry initiated in 1939.[26] If it had so chosen, Sylvania could have raised as a defense in the patent suit that General Electric had not come into court "with clean hands," and that, as a result of illegal monopolistic practices, the big company was not entitled to a legal monopoly in the production and sale of the fluorescent lamp. Sylvania did not raise that defense, inasmuch as it wished to settle the suit on the strength of the various patents alone. If its own patents had been upheld, Sylvania would have been in a position to license General Electric. Since Sylvania had not made the "unclean hands" defense, the government asked permission to intervene. Judge Leibell denied permission pending issuance of his opinion on the validity and infringement of the patents at bar. At the same time, he consented to permit the Justice Department to intervene before his final decision was handed down.

FLUORESCENT ANTITRUST ACTION

To make sure of its position, on December 9, 1942, the Justice Department filed a new complaint in the New Jersey District Court against General Electric and nine other defendants under the antitrust laws.[27] The trial of that case, along with the other antitrust prosecution in the field of incandescent lighting, was postponed at the request of the military services in order not to

[26] A complaint about its incandescent lighting activities was filed against General Electric, *et al.*, in Jan., 1941. See pp. 288–292 and 301–302 for a discussion of that suit.

[27] The other defendants were International General Electric, Westinghouse, Corning, Consolidated, Claude Neon Lights, Inc., RLM, Fleur-O-Lier, N. V. Philips, and ETL. Fourteen other parties were named as co-conspirators, although they were not made defendants.

interfere with the wartime production efforts of the defendant companies.

As of the present writing, the fluorescent antitrust case is inactive, pending the outcome of the fluorescent-patent litigation between General Electric and Sylvania. Although the judge's opinion has been rendered in the patent case, his final decision is in turn awaiting the outcome of the incandescent antitrust case and the government's requested intervention in the patent case. The three cases are thus inextricably woven together, and the future pattern of operations in the lamp industry as a whole will not be clear until all three are settled. In addition to the other complications, Sylvania will probably appeal the invalidation of its fluorescent patents after Judge Leibell's decision is handed down. An appeal may also be taken in the antitrust cases.

The fluorescent complaint of the Justice Department attacked the agreements made by General Electric with the remaining defendants and alleged co-conspirators by which it was claimed trade had been restrained and monopolized in the manufacture and sale of fluorescent lamps, parts, fixtures, auxiliaries, and machinery.[28] The acquisition and use of patents pertaining to fluorescent lighting was also attacked. Specific offenses charged included the international agreements under which General Electric and its licensees refrained from exporting lamps, parts, and equipment to certain countries. The limitation of imports under the agreements was also alleged to be illegal. The licensing and quota system under which Westinghouse and Consolidated produced fluorescent lamps was also attacked, as was the agreement between General Electric and Claude Neon Lights, Inc., under which General Electric and its licensees were not to enter the outdoor lighting field and Claude Neon and its licensees were not to make indoor lighting installations. Additional restraints were alleged in connection with the control over fluorescent-lamp glass by General Electric and Corning, the so-called agency system of distributing lamps employed by General Electric and Westinghouse, and the relationships among General Electric, Westinghouse, the utilities, the associations of fixture manufacturers, and the testing laboratories. These allegations parallel very closely the allegations in the incandescent-lamp industry complaint. Both actions are, in fact, a part of the same broad prosecution.

[28] See U.S. District Court for the District of New Jersey, United States of America *v.* General Electric Company et al., Civil Action No. 2590, *Complaint*, Dec. 9, 1942.

3. *The Commercial Development of Other Fluorescent-Lighting Devices*

Although the hot-cathode, low-voltage fluorescent lamp has so far been the most important application of fluorescence to electric lighting, two other fluorescent-lighting devices have been used commercially in the United States. One is cold-cathode fluorescent tubing; the other is a fluorescent adaptation of the Cooper-Hewitt mercury-vapor lamp.

COLD-CATHODE FLUORESCENT TUBING

Cold-cathode fluorescent tubing had been used in decorative and sign lighting for many years by the time the hot-cathode fluorescent lamp appeared on the market. Under the agreements between General Electric and Claude Neon Lights, Inc., General Electric and its licensees were not licensed to manufacture and sell for "outdoor" lighting while Claude Neon and its licensees were not licensed for "indoor" lighting. Although a few unlicensed sign companies may have made a small number of isolated installations of fluorescent tubing for interior lighting, they were not commercially significant. There was also the problem of the utilities. Fluorescent tubing involved even more radical changes from traditional incandescent-lighting principles than did the fluorescent lamp. Initially, at least, the utilities opposed its use for any general-lighting installation, despite its high efficiency and very long life.

By 1939 the hot-cathode fluorescent lamp was establishing a good market. Similarly, starting around 1939 there began to be some promotion of cold-cathode fluorescent tubing for general illumination. The major technical changes necessary for adaptation to space lighting were changes in tube dimensions and the substitution of white phosphors for the colored materials which had been employed in sign and decorative installations. The promotion was at first carried on in a small way by sign companies, particularly by those which were not licensed under the Claude-Neon patents. By that time fundamental patents no longer restricted the field solely to licensed concerns. It was not until 1941, however, that the use of cold-cathode fluorescent tubing was pushed vigorously. In that year the Fluorescent Lighting Association was organized. The association included manufacturers of parts and producers of completed tubing. The president and guiding spirit was Victor H. Todd of the Swedish Iron and Steel Corporation, a leading maker of electrodes and other equipment used in neon-type tubing.

The organization of the association and its vigorous activities were stimulated in large part by the war. Outlets in the sign business were being restricted, but there was an entirely new field to be exploited. The sign companies engaged in promotion in the indoor-lighting field to try to maintain their sales. The technical features of their product made it very useful in a variety of types of illumination, from decorative restaurant lighting to factory illumination.

At first the lamp-producing companies did not participate in the expansion of cold-cathode fluorescent tubing. Their traditional insistence on a standardized product which could be easily replaced made them unsympathetic to custom-built fluorescent lighting, just as it had at the time of the introduction of the neon tube. At the same time, the lamp companies were intimately concerned with the development, for it promised to cut into their market. General Electric and Sylvania began to coat glass tubing [29] with fluorescent powders for sale to the sign companies, which used it both in sign lighting and in general illumination. However, more than half the requirements of the sign companies for coated tubing continued to be met by other concerns which were not lamp producers.

During the war a number of changes were made in cold-cathode fluorescent tubing to increase its efficiency and economy. The Fluorescent Lighting Association and its members standardized tube dimensions and bases to make for greater uniformity and convenience in replacement. Standard lengths of 72 inches, 96 inches, etc., were established, and an effort was made to design

[29] Virtually all glass tubing used in neon and cold-cathode fluorescent installations is made by Corning.

a single base type that could be used by all manufacturers. Other features such as diameters [30] and current values were also made standard. The program has been of great value in the expanded use of cold-cathode fluorescent lighting, since only the irregular lengths and curved pieces must be custom-built. Sylvania joined the Association and makes the customary lengths of tubing, although it prefers a base of its own design. It does not make curved tubing or install complete systems. General Electric and Westinghouse were slower in starting to produce complete cold-cathode lamps, although they are now making them. The two largest lamp manufacturers have not been enthusiastic about the new development, for they claim that the hot-cathode lamp can do almost anything that the cold-cathode device does, and that their design has a greater efficiency.

Cold-cathode fluorescent lighting is very versatile and has certain advantages, although it has some definite disadvantages. Any length of tubing can be used in any desired shape and color, and a multiplicity of effects can be obtained. The circuit and operation of cold-cathode fluorescent tubing is somewhat simpler than that of the fluorescent lamp, because no auxiliary starter is required. Circuit potentials normally range from 700 to 15,000 volts, however, and transformers are required in every installation. The high voltage was once considered to be a serious disadvantage of neon-type tubing, for it was deemed inadvisable to use equipment of this sort indoors. It is, of course, true that high voltages are more dangerous than low voltages, other things being equal; but the difficulty may be overcome by proper safeguards for permanent ceiling, wall, and similar installations.

The necessity for tailor-making each cold-cathode fluorescent installation makes mass production of tubing more difficult, despite the increasing use of standardized lengths. To take full advantage of the flexibility offered by this type of lighting, one must design, assemble, and install the system virtually by hand. Production is carried on with relatively simple machines; and, by the nature of its product, a company making installations of fluorescent tubing is normally restricted to a relatively small geographical area. Tube renewal of the non-standardized lengths is difficult and is normally done by the concern which made the

[30] Tubing is now made in diameters of 12, 15, 18, 22, and 25 mm.

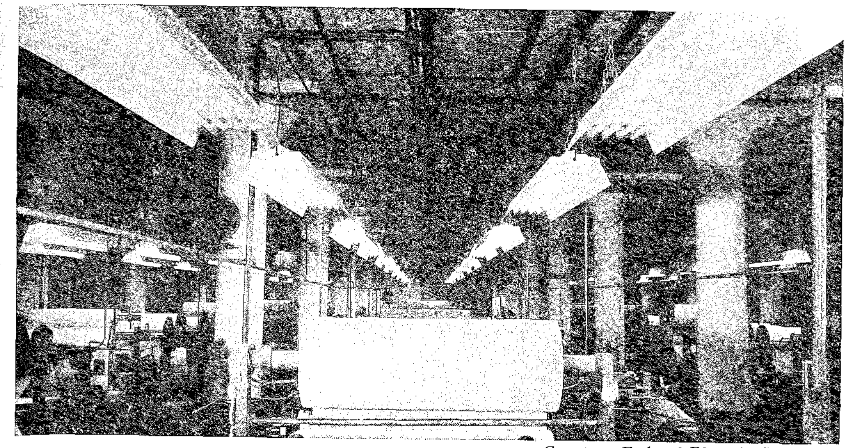
original installation. Installation and tube replacement costs are even greater than with hot-cathode fluorescent lighting. In addition, the small neon-sign companies have not all had adequate experience in illuminating engineering, and many of them are not yet fully prepared to market cold-cathode tubing on a large scale.

In use, cold-cathode fluorescent tubing has a number of desirable features. One outstanding advantage is its life of 10,000 or more hours. The surface brightness of cold-cathode tubing is low, slightly less than that of the fluorescent lamp. The tubing may be employed without shields or reflectors, if desired. Although some special construction is frequently required in installation, the purchaser has a great deal of leeway in designing his system. Instant starting eliminates the sometimes irritating wait required for the hot-cathode lamp and makes the cold-cathode type useful for flashing. Cold-cathode tubing is somewhat less efficient than the fluorescent lamp, however. Whereas the 40-watt daylight fluorescent lamp was rated in 1942 by its producers at 45 lumens per watt, a seven-foot length of one-inch daylight cold-cathode tubing, which draws 60 watts, was rated at 37.1 lumens per watt. In addition, lumen output falls off more rapidly over life in the latter. The efficiencies of colors other than daylight vary much as the efficiencies of the various colors of hot-cathode fluorescent lamps.

During the six years from 1940 through 1945 about 1,750,000 lengths of tubing with an installed value of $24,500,000 were placed in operation. Sales increased rapidly after the end of the war, and during the first six months of 1946 about 1,325,000 lengths of tubing worth $18,800,000 were installed. While future sales prospects are bright, cold-cathode fluorescent lighting will undoubtedly continue to find its greatest use in custom-built applications. The hot-cathode fluorescent lamp will probably retain the bulk of fluorescent illumination.

THE RECTIFIED-FLUORESCENT LAMP

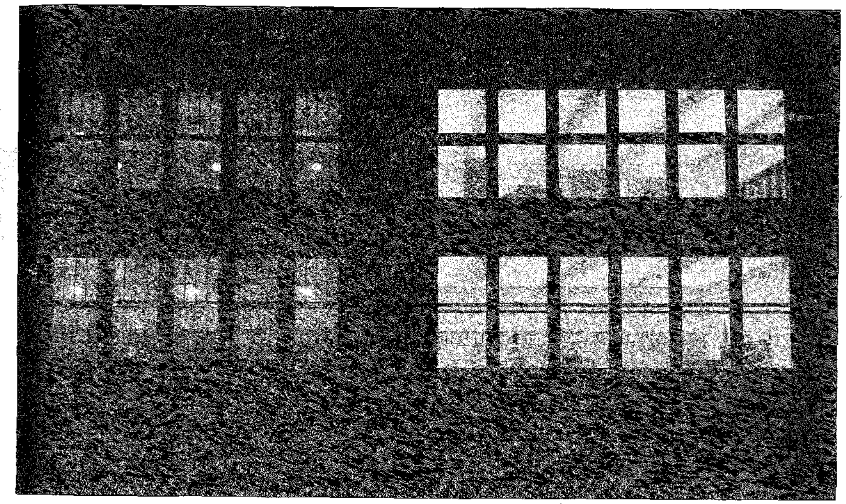
The other new fluorescent device was a rectified-fluorescent lamp developed by the General Electric Vapor Lamp Company, a wholly owned subsidiary of General Electric. That concern, the former Cooper-Hewitt Electric Company, was active in the pro-



Courtesy Federal Electric Company

FIG. 38. A Cold-Cathode Fluorescent Installation in an Industrial Plant

The longer and narrower tubes differentiate cold-cathode installations in appearance from similar industrial lighting systems employing hot-cathode fluorescent lamps.



Courtesy Federal Electric Company

FIG. 39. Contrast Between Incandescent and Cold-Cathode Fluorescent Lighting

In this school installation the rooms at the left are lighted by incandescent lamps, and the rooms at the right are lighted by cold-cathode fluorescent lamps shielded by cellular louvers on the ceiling.

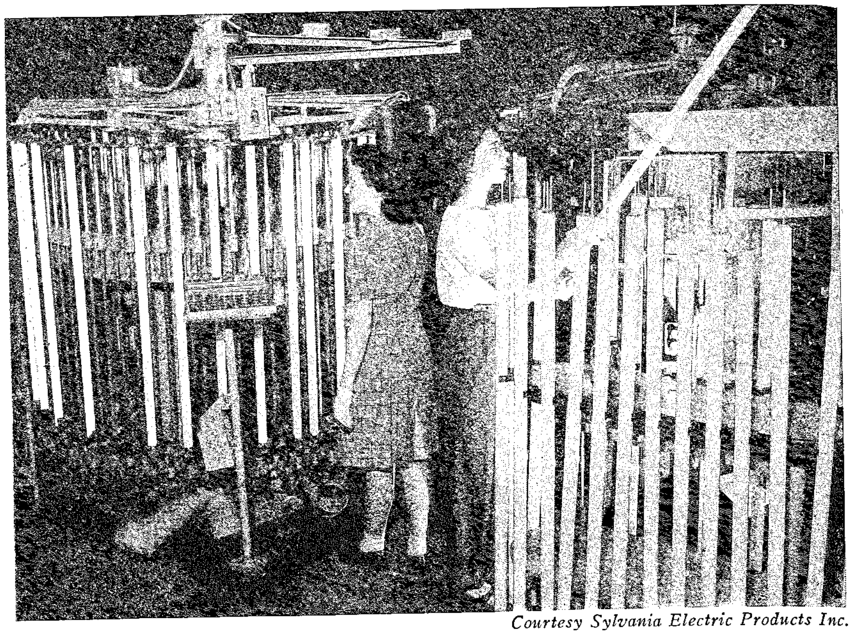

Courtesy Sylvania Electric Products Inc.

FIG. 40. Fluorescent-Lamp Exhausting and Basing Machines
Lamps with stems already sealed in are transferred from the rack in the right foreground to the exhaust machine and then to the basing machine at the left.

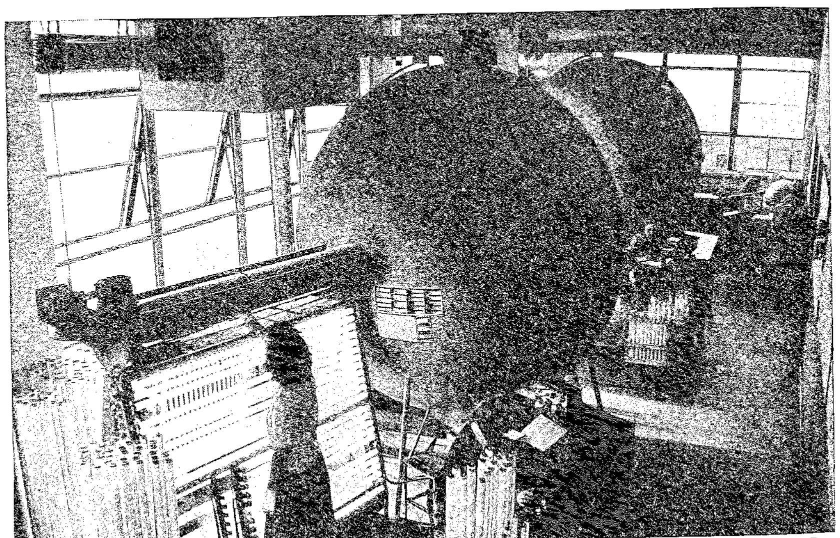

Courtesy Sylvania Electric Products Inc.

FIG. 41. Lamp Photometry as Part of Quality Control
The light emission of fluorescent lamps is checked continually to maintain quality standards.

duction and development of Cooper-Hewitt mercury-vapor lamps, neon-glow lamps, high-pressure mercury-vapor lamps, sodium lamps and other electric-discharge lighting devices. After 1935, when the lamp departments of the two large companies had set to work on the development of a low-pressure, hot-cathode fluorescent lamp, the subsidiary concern undertook to add fluorescent substances to the Cooper-Hewitt lamp. Phosphors were used for increasing light output and for color correction.

The modified Cooper-Hewitt lamp was announced in 1939 and was called a rectified-fluorescent (RF) lamp, because of its rectifying characteristics. The lamp operated on principles similar to those of the Cooper-Hewitt lamp, with similar auxiliaries and fixtures and similar external characteristics. It was an 85-watt lamp, 58 inches long and 1¼ inches in diameter. It had a life of 3,000 hours and an efficiency of 47 lumens per watt, and it sold initially for $7.50. Despite the fluorescent coating, color correction was only partial. The two colors introduced were blue-white and industrial-white.

The lamp came into production quickly, and within two years it was being used extensively in industrial lighting. Although it had several desirable features which made it initially successful, improvements in the efficiency and life of the standard fluorescent lamp resulted in a victory for the latter. Greater complication and expense in both the RF lamp and its fixture were difficulties which could not be overcome. The General Electric Vapor Lamp Company and Westinghouse, which was licensed under the covering patents, produced the lamp and fixtures for it [31] from 1939 to 1942. At that time, wartime production restrictions ended the manufacture of RF fixtures and limited the production of RF lamps to the number necessary for replacements in existing installations.[32] The General Electric Vapor Lamp Company has since been absorbed into the parent company's lamp department,

[31] This was General Electric's only venture into the production of lighting fixtures.

[32] Sales of RF lamps amounted to 300,000 units in 1941 and rose to 366,000 for the first six months of 1942. They fell off rapidly thereafter. Well over 300,000 RF fixtures had also been sold by the middle of 1942. At an average price of over $20 per fixture, this amounted to a sales value of between $6,000,000 and $7,000,000.

and all effort is now concentrated upon the standard fluorescent lamp.

4. Further Improvements in the Hot-Cathode Fluorescent Lamp

In the nine years that it has been on the market, the hot-cathode fluorescent lamp has not been altered appreciably in its basic characteristics. Nevertheless, its performance has been improved very considerably as a result of minor changes in design and refinements in production methods. Both efficiency and lamp life have been increased. In addition, the range of fluorescent-lamp sizes has been expanded to include twenty lamps of from 4 to 100 watts.

LAMP LIFE AND EFFICIENCY

There is not the same inverse relationship between lamp life and efficiency in fluorescent lighting that there is in incandescent lighting. Fluorescent-lamp life depends primarily upon the ability of the cathodes to withstand the bombardment of positive mercury ions. Maintenance of the correct argon gas pressure is an important factor in this respect. The oxide coating of the cathode is even more critical. The coating is electron-emissive and helps keep down voltage drop, but it is gradually knocked off by the ion bombardment, particularly during starting. The efficiency of a fluorescent lamp, on the other hand, is dependent primarily upon the efficiency of generation of ultraviolet light of the 2,537 A.U. wave length and its conversion into visible light by fluorescent powders.

When the lamp first appeared on the market it had not been fully tested for life, and the values assigned were conservative. Further testing, plus improvements in cathode construction and the elimination of impurities, resulted in increases in rated life from 1,000 hours in 1938 to 2,500 hours in 1940 (Table XXXIII). During the war it was discovered that long burning periods produce even longer lamp life up to 6,000 hours.[33] Since the end of the war experimentation has shown that long-life fluorescent lamps can yield lives up to 10,000 hours; public ratings have not yet been changed, however.

[33] The life of standard incandescent lamps is generally 750 or 1,000 hours.

TABLE XXXIII: RATED LIVES[a] OF FLUORESCENT LAMPS 1938–1947

Rated Life Changes	*6–W*	*8–W*	*14–W*	*15–W T–8*	*15–W T–12*	*20–W*	*30–W*	*40–W*	*65–W*	*100–W*	*85–W RF*
Apr. 21, 1938				1000	1000	1000	1000				
Aug. 1, 1938				1500	1500	1500	1500				
Mar. 1, 1939				....	....	....	....	1500			
May 1, 1939				2000	2000	2000	2000	2000			
Nov. 1, 1939				....	....	....	....	....			3000
Apr. 1, 1940			1500	....	....	....	....	....			....
June 1, 1940			....	2500	2500	2500	2500	2500			....
Oct. 1, 1940	750		....	....	....	....	....	....			....
Oct. 14, 1940	....		....	....	....	....	....	....		2000	....
Feb. 1, 1941	....		....	....	....	....	....	....	2000	....	....
Apr. 1, 1941	....	750	....	....	....	....	....	....	....	....	....
Aug. 1, 1941	....	....	....	....	....	....	....	....	....	....	....
Sept. 1, 1941	....	....	....	....	....	....	....	....	....	2500	....
Feb. 1, 1942	1000	....	....	....	....	....	....	....	[b]	3000	....
Jan. 1, 1945 [c]	1500	1500	....	....	....	....	....	....		....	....
Sept. 1, 1945 [d]	....	....	2000	....	....	....	....	....		....	....

[a] Rated life is an average figure obtained from tests under specified conditions. All figures in the table are based on a 3-hour burning cycle.

[b] Discontinued.

[c] For 6- and 12-hour cycles, rated lives of the 15- to 40-watt lamps were increased during the war to 4,000 and 6,000 hours, respectively. For the 100-watt lamp, the longer burning cycles yield lives of 4,500 and 6,500 hours.

[d] Rated lives remained unchanged from Sept. 1, 1945, to the end of 1947.

Sources: General Electric Company, Westinghouse Electric Corporation, and Sylvania Electric Products, Inc.

Increases in rated efficiency have accompanied the increases in rated life for the principal sizes of fluorescent lamp. As of July 1, 1947, an initial efficiency of 58 lumens per watt was obtained with the 40-watt white lamp,[34] and even the very small lamps showed efficiencies of 35 or more lumens per watt.[35] Some lamp engineers now feel that the fluorescent lamp is close to its maximum practical efficiency, however. Table XXXIV shows the changes in ratings that have occurred for each principal size of fluorescent lamp. It will be noted that it is not necessarily true for the fluorescent lamp, as it usually is for incandescent lighting, that efficiencies are highest for the largest lamps. The 100-watt lamp is materially less efficient than the 40-watt lamp, and the much lower efficiency of the 65-watt lamp was the primary reason for its failure.[36]

FLUORESCENT-LAMP SPECIALTIES

Several special types of fluorescent lamp were designed after 1940 to broaden the applications of the new light source, just as had been true for tungsten-filament lamps after 1910. Among the new styles were lamps for low-temperature operation and for instant starting. Another new type was a very slender 21-inch lamp of 13 watts (see Table XXXV).

A very significant innovation was the "long slim" fluorescent lamp announced in 1944. The tubes are from 42 to 96 inches long and an inch or less in diameter. Lives are the same as for the medium-wattage regular type, while efficiencies range from 56

[34] That efficiency, although a tremendous improvement over incandescent lighting, is still only 9.3 per cent of the theoretical maximum of 621 lumens per watt for monochromatic light and 20 per cent of the theoretical maximum of 289 lumens per watt for white light. The lamp converts 20.5 per cent of the energy input into useful light.

[35] The white lamp is the most efficient of those fluorescent lamps used for general illumination. Daylight lamps are about 10 to 15 per cent less efficient, and the soft white lamps are still less efficient. Except for green, which is produced at the very high efficiency of 60 to 75 lumens per watt, the production of colors is also less efficient than that of white light. Red is the least satisfactory of present colors; it yields only 3 or 4 lumens per watt.

[36] Rated initial lumens are based on lamp values after 100 hours of use. When first put into service, efficiencies may be 10 per cent greater than this. After 100 hours efficiency declines more gradually to about 90 per cent of rated output at 1,000 hours and 85 per cent at 2,000 hours. The over-all efficiency is about one-sixth less than the lamp efficiency because of wattage loss in the auxiliary.

TABLE XXXIV: RATED INITIAL EFFICIENCIES[a] OF FLUORESCENT LAMPS[b] 1938–1947

Efficiency Changes	*6–W*	*8–W*	*14–W*	*15–W T–8*	*15–W T–12*	*20–W*	*30–W*	*40–W*	*65–W*	*100–W*	*85–W RF*
Apr. 21, 1938				30	30	32	35				
Mar. 1, 1939				. .	. .	. .	. .	35			
May 1, 1939				35	35	38	44	47			
Sept. 1, 1939				37	37	41	46	50			
Nov. 1, 1939				. .	. .	. .	. .	. .			47
Mar. 1, 1940				39	. .	. .	48	53			. .
Apr. 1, 1940			32.8	. .	. .	. .	. .	. .			. .
June 1, 1940			. .	. .	39	45	48.3	52.5			. .
Oct. 1, 1940	30		. .	. .	. .	. .	. .	. .			. .
Oct. 14, 1940	. .		. .	. .	. .	. .	. .	. .		44	. .
Jan. 1, 1941	. .		. .	. .	. .	. .	. .	. .		42	. .
Feb. 1, 1941	. .		. .	. .	. .	. .	. .	. .	32.3	. .	. .
Apr. 1, 1941	. .	37.5	. .	. .	. .	. .	. .	. .	. .	. .	. .
Aug. 1, 1941	. .	. .	. .	. .	35	43	46.7	. .	. .	. .	. .
Jan. 1, 1942	. .	. .	33.9	. .	. .	. .	48.3	. .	c	. .	. .
Nov. 1, 1945	32	40	34.5	. .	37	46	. .	58		. .	. .
July 1, 1946[d]	35	41.3	35	42	40	48	50	. .		44	. .

[a] Efficiencies are given in lumens per watt. For total lumens multiply by the lamp wattage. Over-all efficiencies are somewhat reduced by wattage loss in ballasts.

[b] Until May 1, 1939, efficiencies were for the warm white (2800°) lamp. From that date on, efficiences refer to the 3500° white which replaced the warm white. Lamp efficiencies vary considerably for the other colors (daylight, soft white, blue, green, pink, gold, and red).

[c] Discontinued.

[d] Rated initial efficiencies remained unchanged from July 1, 1946, to the end of 1947.

Sources: Sylvania Electric Products, Inc., and *Electrical Engineering*, Vol. LX, p. 202 (June, 1941).

TABLE XXXV: PRINCIPAL NEW TYPES OF HOT-CATHODE FLUORESCENT LAMPS
1940–1947

Lamp	Tube Length (Inches)	Tube Diameter (Inches)	Characteristics, Jan. 1, 1946		
			Rated Average Life (hours)	*Initial Efficiency[a] (lumens per watt)*	*List Price*
40-watt low temperature	48	1½	1500	[b]	$1.05
40-watt instant starting	48	1½	2500-6000[c]	58	1.15
13-watt	21	⅝	1500	45	.90
22-watt long slim[d]	72	1	2500-6000[c]	64	2.00
52-watt long slim[d]	96	1	2500-6000[c]	63	2.70
32-watt circular[e]	12″ diameter	1¼	2500	50	1.30

[a] For white lamps. [b] Efficiency not stated by manufacturers.
[c] Life dependent on length of burning cycle.
[d] Other "long slim" lamps are made in sizes down to 42 inches and 15 watts.
[e] Other circular lamps of 8½- and 16-inch diameters were also developed.
Source: Sylvania Electric Products, Inc.

to 65 lumens per watt. Moreover, no starters are required. These lamps are useful in the continuous lines of light for which cold-cathode fluorescent tubing has been promoted. Indeed, it appears that the "long slim" is part of General Electric's answer to the increased competition from cold-cathode fluorescent lighting. Duro Test has also added a long, slim lamp of its own design. In type it falls between the hot-cathode and the cold-cathode lamps, and the claim is that it provides the high efficiency of the hot-cathode variety with the long life of the cold-cathode lamp. This is the first innovation made by one of the independent group in the design of commercial fluorescent lamps since hot-cathode fluorescent came on the market.

With the end of hostilities, the attention of lamp manufacturers was directed to the areas of residential and commercial fluorescent lighting, which had been neglected during the war. The first new fluorescent lamp for the home was a 12-inch circular tube for installation in table and floor lamps and in ceiling and wall fixtures.[37] The circular shape permitted uses which were not feasible with straight tubing. General Electric announced the new lamp in 1945, and production began in a small way early in 1946. The other companies, particularly Westinghouse and Sylvania, had also been working on a circular lamp for many years, and they too announced the availability of the new style. High production costs and limited demand at the announced prices made the circular lamps unprofitable; they have not been pushed aggressively. In 1947 a semicircular lamp rated at less than 20 watts was added to the list of sizes, but it too was not commercially successful. The next few years should produce more fruitful advances in lamp design for residential and commercial fluorescent lighting.

MACHINERY AND METHODS OF ASSEMBLY

A fluorescent lamp passes through numerous intricate processes during assembly. First the glass tube, which forms the body of the lamp, is cleaned and coated on the inside with a mixture of finely ground fluorescent powder and a liquid binder. After the surplus material has dripped off and the binder is dry, the tubes are baked to drive off the binder and leave the correct porosity in the fluorescent coating. The stems required for the fluorescent lamp are similar to those of incandescent lamps, although they have different dimensions. Lead-in wires and filaments are mounted in much the same way, but anode horns or shields are placed on either side of the filament. There are two stems in each lamp, only one of which requires an exhaust tube. The stems are sealed in on a machine very similar in character to that used for

[37] Another postwar innovation in fluorescent lighting for the home was Christmas-tree lamps. They were first made in small quantities in the summer and fall of 1945 by Westinghouse and Sylvania. General Electric was not interested in the new idea. Westinghouse made small lamps about the size of incandescent Christmas-tree lamps, as an outgrowth of the fluorescent glow lamp which it had developed for the Navy, while Sylvania decided on a larger size to make the bulbs look like luminous ornaments. Both Westinghouse and Sylvania have since dropped the idea because of high production costs.

the incandescent lamp,[38] although it handles glass tubes up to five feet in length instead of small glass bulbs. Each end of the tube has to be sealed. As in the case of incandescent-lamp assembly, the next steps are exhausting the tube of air, introducing the correct amount of argon, and closing off the exhaust tube. The mercury may also be introduced at that point, or it may be introduced at an earlier stage encased in a small "bomb" which releases the mercury when the lamp is first operated. The bomb method was introduced to fluorescent lighting by Sylvania; it had previously been used by other producers for sodium lamps. The bases are put on and the lead-in wires are soldered to the pins of the bases in the final assembly operation. The lamp is then tested, aged for a short time, and packed for shipment.

Like incandescent lamps, fluorescent lamps are assembled by the group or unit method. Once the various parts are prepared and ready for assembly, all steps in making the finished lamp are carried out by a small number of workers on a few correlated machines. The unit idea was extended to fluorescent-lamp making as soon as the lamp passed from the development laboratory to commercial production. Continuous improvement in machinery and handling techniques resulted in a rapid increase in production efficiency until the war. Machine speeds are still far below those in incandescent-lamp assembly, and it is possible that they will never mount that high, but already some units can turn out about 650 lamps an hour.[39]

The many major and minor improvements in production methods have contributed greatly to life and efficiency increases in the fluorescent lamp as well as to the reduction in lamp prices. Further price declines will probably occur in the future as costs are reduced; but because of its greater size and complexity the fluorescent lamp cannot be expected to fall in price to the level of incandescent lamps. When lamp price is related to lamp life for these two leading types of electric lighting, quite apart from the matter of efficiency, the fluorescent lamp compares favorably.

[38] Sealing in was initially done with the aid of electrically heated carbon rings. That method was slow and relatively expensive and was soon superseded by gas-flame sealing.

[39] High-speed incandescent-lamp assembly units can turn out from 1,000 to 1,200 lamps per hour.

For example, consider the 40-watt white fluorescent lamp and the 150-watt inside-frosted incandescent lamp:[40]

Lamp	Total Initial Lumen Ouput	List Price	Life in Hours
Fluorescent	2,320	$1.00	2,500 to 6,000
Incandescent	2,600	.20	750

5. *Summary of Electric-Discharge Lighting from 1912 to 1947*

Many varieties of electric-discharge lighting devices were developed and introduced to the market between 1912 and 1947. The work of Georges Claude in neon-type tubing made possible the growth of a large business in advertising and decorative lighting. Improved high-pressure mercury-vapor lamps, the sodium lamp, neon-glow lamps, and various other types were designed during that period. The great bulk of the early technical advances were made in Europe. Most foreign developments, except neon tubing, were quickly taken up in this country by General Electric and Westinghouse, the two largest American firms in the vapor-lamp field, which did a considerable amount of development work themselves.

Fluorescent powders were used in connection with both neon-type tubing and the high-pressure mercury-vapor lamp. Their use was primarily for color correction rather than supplying the complete visible light output. Cold-cathode fluorescent tubing was used abroad to a limited extent for general illumination by the early thirties. The only important application in this country was in sign and decorative tubing.

Fluorescent lighting had a long technical history. It started with the work of Becquerel around the middle of the nineteenth century. A great many other experimenters became interested in the application of fluorescence to lighting, epsecially after 1900, but no suitable fluorescent device for general illumination was developed until relatively recently. The first successful low-voltage fluorescent lamp was designed by the American General Electric Company. Work was started in 1935, and the lamp was placed on the market in 1938. That effort was stimulated by foreign progress and depended to some extent on foreign data, but

[40] Data as of July 1, 1947.

it was directed along a new channel which had not been successfully employed in a commercial lamp. Very little research had to be done by General Electric in designing the fluorescent lamp; it was almost entirely a matter of development. The commercial success of the lamp depended far more on engineering, low-cost production, and sales promotion than on research.

Westinghouse collaborated with General Electric in the initial development and continued its A-license arrangement for the new product until 1945. Sylvania broke away from the General Electric group in fluorescent lighting and competed vigorously with the large companies. It built up a substantial market for itself and stimulated more rapid promotion by the larger companies. A few smaller companies have also made the fluorescent lamp. They have not yet become an important factor in the progress of the industry. The difficulty of obtaining adequate machinery has been the principal factor holding down the number of producers.

The market for the fluorescent lamp expanded rapidly after 1938, because the new device produced useful light at very high efficiencies and possessed a variety of other characteristics which made it extremely valuable. The initial opposition of the electric utilities to fluorescent lighting was overcome, and the early difficulties in connection with fluorescent fixtures were straightened out. Improvements in the performance of the new lamp were rapid. The lower costs of lighting with fluorescence made it preferable to incandescent or other forms of lighting in a host of applications. It has expanded far beyond the original recommendations of the former "Mazda" producers and the utilities for supplementary and decorative lighting. Most factories now make important use of fluorescent lighting, and war production plants relied on it heavily. With the end of World War II, the commercial and residential fields have been developed more vigorously.

The patent status of the fluorescent lamp has not yet been finally determined. General Electric and Sylvania, the two principal contestants, instituted infringement suits against each other under their respective patents in 1940. The opinion of the district court judge in 1944 upheld the General Electric patents, applications for both of which were made in 1927, eight years before the first effort was made to design a low-pressure, hot-cathode

fluorescent lamp. The Sylvania patents were all declared invalid. The judge did not hand down his decision pending the outcome of other legal proceedings. The Department of Justice petitioned for intervention into the patent suit and also instituted a new fluorescent antitrust prosecution against General Electric and nine other defendants. The antitrust suit was suspended because of the war, along with the suit in the incandescent-lamp industry. The patent situation will not be settled until the antitrust prosecutions are completed, and an appeal by Sylvania may still further delay determination of the future organization of the fluorescent-lamp industry.

Cold-cathode fluorescent lighting has also come into important commercial use since 1938. The expansion of fluorescent-coated neon-type tubing into the field of general lighting had been restricted until that time, in large part through the agreements between General Electric and Claude Neon Lights, Inc., the principal patent-holding companies in the "indoor" and "outdoor" lighting fields. After the low-voltage, hot-cathode fluorescent lamp appeared on the market, cold-cathode fluorescent tubing began to be used for "indoor" lighting. After 1941, when a promotional association was formed, cold-cathode fluorescent lighting expanded more rapidly. Its technical characteristics have many similarities to those of the hot-cathode fluorescent lamp, although it is somewhat less efficient and somewhat longer-lived.

PART V

CONCLUSIONS

Chapter XVI: AN EVALUATION OF TECHNOLOGICAL PROGRESS IN THE AMERICAN ELECTRIC-LAMP INDUSTRY

WITH the historical record before us, what can we say about technological progress in the American electric-lamp industry? Has it been unusually rapid, unusually slow, or "average"? What are the principal factors which have determined its speed? How have they influenced its direction? In what ways has the organization of the industry affected the nature and speed of technological progress? What can we say about the legal framework, such as the patent system and the tariff and antitrust laws, in which the industry has operated? What changes in internal and external environment would stimulate future technological activity? In what other ways could American consumers of electric lamps be better served? These are some of the questions which we must try to answer, even if only tentatively, in concluding our technological analysis of the electric-lamp industry.

1. The Goals of Lighting Technology

It is true for lighting, as for most other products, that the goals of technology are high quality and low cost. High quality in lighting is a complex concept, which covers a great many different and sometimes conflicting features. Since the most important variable in lighting quality is the lamp, that has been the principal focus of attention in this study. The fundamental characteristics of a lamp which determine its quality as a producer of artificial illumination include the following:

1. Initial lamp efficiency
2. Maintenance of efficiency throughout life
3. Color of light output
4. Lamp life
5. Simplicity of operation

6. Fragility
7. Coolness of operation
8. Light diffusion and glare
9. Uniformity from lamp to lamp
10. Adaptability of source to various sizes and shapes
11. Adaptability of source to special uses
12. Pattern of light distribution and ability to concentrate light into a beam
13. Dependability
14. Steadiness of light output
15. Susceptibility to voltage variation
16. Adaptability to various electrical circuits
17. Power factor
18. Noisiness.[1]

Several of these attributes are also major determinants of the cost of lighting.

The range of lighting applications is tremendous. Electric lamps are required for dozens of uses, such as residential lighting, factory lighting, show-window illumination, flashlights, automotive lighting, blueprinting, color matching, airport lighting, advertising, highway and street lighting, and railway lighting. In some applications certain quality characteristics are much more important than others, and each individual installation makes its own peculiar demands. No one type of lamp can give optimum performance for each characteristic of lighting quality. A very broad range of different lamps has proved to be necessary.

Improvements in lamp quality have required two major types of technological activity: (1) the improvement of existing light sources and (2) the development of entirely new light sources. Efficiency, life, and color quality are of particular importance in both directions of activity. In addition, (3) the lowering of lamp costs and prices through improvements in methods of production is fundamental. Technological progress in the lamp industry must be judged primarily on its success in achieving advances in each of these three directions.

Besides the lamp, the principal additional requirement for electric lighting is electric energy.[2] The effects of electric current on lighting quality are simple but important. For ordinary use, the voltage must be steady at a predetermined value, whether on direct current or on alternating current. For series-wired lamps, as in street lighting, the amperage must be held constant. Variations in voltage or amperage affect lamp efficiency, color quality, life, and other characteristics of lamp operation. Since 90 per cent or more of the total cost of electric lighting frequently consists of charges for energy consumption, reductions in generating and transmission costs through technological advances are obviously of great importance.

[1] In addition, certain individual lamps have special quality problems such as radio interference and starting delays in fluorescent lamps.

2. *The Record of Technological Progress in Electric Lighting*

How well has electric lighting fulfilled the criteria discussed above? From the detailed record of the preceding chapters, it is clear that technologically the electric-lighting industry has been highly active. The entire history of electric lighting since 1880 has seen a continuous multiplication of special lamps for particular applications[3] as well as marked quality improvements in older varieties.[4]

SUMMARY OF ADVANCEMENTS IN LIGHTING DEVICES

The arc lamp was the initial commercial source of electric illumination. Conceived and developed abroad during the early and middle nineteenth century, it was improved both in Europe and in this country after its commercial introduction around 1877. It excelled in the production of large quantities of light at fairly high efficiencies, but it was not applicable to small-space lighting. The numerous limitations of arc lighting created a demand for "subdivision of the electric lamp," and in 1880 the first

[2] Lighting fixtures also affect lighting quality by influencing the distribution pattern of light output and the installed efficiency of the lamp. Since the principles of fixture design have become well known, it has been possible for capable manufacturers to produce satisfactory equipment for each new light source or each new use of an old light source that has come along. Actual practice is subject to great variation, however, and many fixtures waste enormous amounts of light. The primary focus of this study on the electric lamp does not provide a basis for extensive generalizations about lighting fixtures.

[3] See above, especially chaps. VIII, XII, XIV, and XV.

[4] See chaps. V, VII, VIII, XII, and XIII.

successful incandescent electric lamp was commercially introduced by Thomas A. Edison. The carbon-filament lamp was successful in spite of its low lighting quality because all other light sources for indoor use were even poorer, although many were cheaper. The efficiency of the incandescent lamp in 1881 was only 1.68 lumens per watt, and that value fell off markedly through a useful life of approximately 600 hours. Even though the light was too red and lamps were not standardized, the device was simple and flexible and gave a steady light.

During the eighties and nineties both the arc lamp and the incandescent lamp matured. Competition with gas lighting, which was considerably improved during those years, was fundamental to much of the technological advance. The efficiency of the incandescent lamp was doubled between 1881 and 1884. After 1884 it remained virtually constant for about fifteen years, although the decline in light output over life was somewhat reduced. During that period technical effort was devoted largely to lamp standardization, the improvement of various minor features, the design of specialties, and the lowering of production costs. The price of individual carbon lamps fell from $1.00 in 1880 to 25 cents in 1894 and went even lower during the succeeding years.

Around 1894 the development of a satisfactory enclosed arc and the expanded use of the Welsbach gas mantle seemed to threaten the future of the incandescent lamp. But great new advances in chemistry were opening up further possibilities for progress in incandescent lighting. Between 1897 and 1904, many new filament materials were commercially introduced. The Nernst, osmium, tantalum, tungsten, and other new lamps were brought out in Europe. The GEM lamp, an improved carbon lamp, was developed in this country. With the non-ductile tungsten filament, lamp efficiency was increased to 7.85 lumens per watt and useful lamp life became 800 hours.

Fundamental progress was also made in arc lighting and in the new field of electric-discharge lighting during the first decade of the twentieth century. The years from 1897 to 1913 were the most technologically active in the entire history of electric lighting. The flame arc and the magnetite arc were developed, and the Moore, Cooper-Hewitt, Küch, and Claude electric-discharge devices were introduced. Several of the new designs were considerably more efficient than even the improved incandescent lamps, and they performed many specialized lighting tasks more satisfactorily than the older types.

The two most significant contributions to incandescent lighting after 1907 were the ductile tungsten filament and the gas-filled lamp. Efficiencies were approximately doubled by those two developments. Later changes, such as the use of non-sag tungsten and the double coiling of filaments, further increased lamp efficiency. The advances were so great that gas and arc lighting were forced out of all but restricted lighting applications. Even the new electric-discharge lamps, which were just raising their heads, were for a time submerged by the rejuvenated incandescent lamp.

After 1914 methods of producing incandescent lamps were improved enormously. Costs and prices declined, except for a few years after World War I. New designs and sizes for hosts of special applications were brought out in rapid succession. The incandescent lamp was supreme in most types of lighting.

Not until after 1930 was there a rapid rise in new electric-discharge devices for general illumination. They included cold-cathode neon-type tubing, the high-pressure mercury-vapor lamp, and the sodium-vapor lamp. Most of them were originally developed in Europe, like the new filament materials around 1900. Finally there came the hot-cathode fluorescent lamp and cold-cathode fluorescent tubing. Those devices now produce white light at efficiencies as high as 60 lumens per watt with very long life and have other definite advantages. At the same time, certain of their qualities are not so well suited as those of incandescent lighting for many applications, and it appears that both incandescent and fluorescent lamps will continue to be needed.

While most industries can point to productivity increases which have resulted in price reductions during various periods of their histories, and most industries can claim substantial product improvement, relatively few can advance as striking a record as that of the seventy-year-old electric-lamp industry. Such industries as clay products, bakery products, boots and shoes, coke, cotton goods, flour, lumber and furniture, and woolen and worsted goods have shown much less improvement in either quality or cost of production.[5] Others, such as beet sugar, canning and preserving, cement, knit goods, tobacco products, plate glass, many chemicals, and manufactured ice, have shown marked productivity improvements with less striking changes in quality. Some of the principal rivals of electric lamps in the record of technological advance are petroleum, rayon yarn, rubber products (such as automobile tires), radios, and motor vehicles.

While it is difficult to draw clear-cut lines of demarcation among the various industry types, it seems obvious that the age of the industry and the nature of its technology are major factors in its potentials for technological progress. Relatively young industries which have come into existence as a result of advances in chemical, physical, or engineering knowledge are especially well situated for continued advances. Electric lamps are much more closely related technologically to rayon yarn production than to cotton-goods production, for example. In judging the relative progress of specific industries, therefore, it is necessary to weigh actual advancement against estimated potential advancement rather than against the improvements of an "average" industry. Rapid advances were to be expected in lighting technology; the question is whether the progress could or should have been more rapid.

SOURCES OF ADVANCEMENTS IN LIGHTING DEVICES

There is a clear-cut difference between the United States and the European countries in their technological contributions in electric lamps. The fundamental scientific knowledge for electric lighting came largely from abroad, while inventors and producers in this country have been outstanding in the engineering development of lighting devices, in their promotion and market development, and in their low-cost, high-quality production. The scientific background for the incandescent lamp, the arc lamp, and the numerous electric-discharge lamps was developed in Europe.[6] England and France, and later Germany and Holland, were the outstanding contributors. The broad advances in chemistry that made possible the introduction of metallic filaments came from Europe, and most of the new filaments themselves were originally introduced there. The flaming arc came from abroad, as did the neon tube, quartz mercury-vapor lamp, and sodium lamp.

Although most of the fundamental knowledge originated abroad, the American lamp industry can point with pride to several striking engineering developments. In incandescent lighting, Americans produced the first practical carbon-filament lamp, the ductile tungsten filament and the first practical gas-filled lamp. The Moore tube and the Cooper-Hewitt lamp were the first commercial electric-discharge lighting devices. The enclosed arc of Marks and Jandus and the magnetite arc of Steinmetz were other noteworthy contributions. The modern fluorescent lamp is of even greater importance. The American inventors achieved their results primarily through engineering skill and strong financial support rather than through basic scientific discoveries.

The lamp industry as a whole is an excellent illustration of the gradual accretion of technical knowledge, from the birth of a new idea to commercial fruition.[7] Every new lamp or improvement in an old lamp had its roots deep in the past. As the lamp industry matured, inventions became less and less the result of "flashes of genius" and more and more the result of deliberate painstaking labor toward a recognized goal. In most instances the pioneering was done by "independent" scientists and inventors. Frequently, the laboratories of leading American and European lamp manufacturers adopted the new ideas at a relatively late stage, developed them to a commercial level, and reaped the financial benefits.

In the mechanization of lamp production the large American manufacturers led from the start; and they have retained that advantage. The mass market and enormous volume of output, aided by generally enthusiastic consumer acceptance of new products, by a higher standard of living than has existed abroad, and by extensive advertising and promotion, encouraged the design of automatic machinery and the reduction of costs and prices. Product uniformity and high quality were also stimulated.

[5] For a convenient compilation of productivity records in the leading American manufacturing industries, see National Research Project, *Production, Employment, and Productivity in 59 Manufacturing Industries, 1919–1936*, Report No. S-1, Works Progress Administration, Philadelphia, May, 1939.

[6] See pp. 21–24, 36–42, 218–221.

[7] For an amplification of this thesis see A. P. Usher, *A History of Mechanical Inventions*, McGraw-Hill, New York, 1929, esp. pp. 19–22.

Similar generalizations apply to the production of glass, bases, wire, and other parts for electric lamps. A further outstanding feature of electric lighting in this country has been its leadership in illuminating engineering, the effective application of light sources to lighting needs.

Within the United States, the relative contributions of the different producers have varied greatly. At first independent inventors carried on almost all the work. The contributions of Brush in arc lighting and Edison in incandescent lighting were particularly outstanding.[8] After the formation of the General Electric Company in 1892, only Westinghouse and a group of small companies competed with it in the production of incandescent lamps. There were even fewer competing concerns in the manufacture of arc lamps. A large proportion of the major American contributions since 1892 in both of those fields and in the mechanization of lamp production have been made by General Electric, as would be expected of a company that has consistently supplied from 40 to 80 per cent of the domestic market for electric lamps. On the other hand, a surprisingly large number of important innovations were made by independent inventors up to 1910. Where others did make advances, the industry leader was usually successful in buying out their rights. Independent inventors declined rapidly in importance after about 1910, as a result of the changed conditions in the industry.

ADVANCEMENTS IN ELECTRIC ENERGY

Technological advances in the electric-power industry since 1882 have produced both stability of line voltages (or amperages) and large reductions in energy rates. Voltage stability, which affects lighting quality, was largely achieved by 1910 through improved generating and transmission equipment and through broadened markets for electric current.

Technological progress in generating and distribution costs has also produced a steady rate of decline in power charges.[9] The price of electric energy in the United States dropped from around forty cents per kilowatt-hour in 1882 to twenty cents in 1897 and to an average of less than two cents in 1947. The decreases produced an enormous decline in the cost of electric lighting,

[8] See pp. 30–31, 56–69.

[9] See pp. 360–362.

along with the improvements in lamp efficiency and reductions in lamp prices. About 60 per cent of the decline in lighting costs since 1923 is attributable to reductions in the cost of electric energy. The fundamental technological basis for declining power rates was the improvement of generating and transmission equipment and techniques. Larger and more economical steam engines, generators, and turbines followed one another in rapid succession. Improved techniques of high-voltage transmission reduced distribution losses. Improved fuel-using techniques reduced costs. Such economies are still continuing, and in percentage terms may be very important, although their future magnitudes must be smaller. The recently developed possibility of replacing combustion fuels by atomic energy indicates one future avenue of progress.

The utilities and the producers of heavy electrical equipment, such as General Electric and Westinghouse, have been jointly responsible for the American advances in power technology. As in lamps, the greatest American strength has been in engineering and the exploitation of basic ideas. In addition, however, American companies have shared with Europeans in the design of fundamentally new types of equipment.

3. *Conclusions on the Technological Environment of the Electric-Lamp Industry*

THE STATE OF SCIENTIFIC KNOWLEDGE

It is axiomatic that the state of scientific knowledge is a fundamental factor in the ability of engineers to design entirely new light sources. It is also of great importance in their ability to make revolutionary improvements in existing light sources. The manner in which scientific discoveries lead to commercial results has been revealed throughout the entire history of electric lighting. The discoveries of Volta, Davy, Faraday, and the other early nineteenth century scientists made possible the original development of arc lighting and incandescent lighting. The work of Geissler, Crookes, and others in the second half of the nineteenth century opened up the field of electric-discharge lighting. Metallurgical advances before 1900 made metallic filaments possible. The isolation of the inert atmospheric gases and Langmuir's high-vacuum work led to the gas filling of incandescent lamps and the invention of neon-type tubing and other electric-discharge devices.

During the nineteenth century the time lag between scientific discovery and commercial application gradually declined. The extension of education, communication, and industrialization created a continually more favorable environment for technological progress. By the turn of the century the lag had been reduced in many instances in the lamp industry to but a few years. For example, new incandescent illuminants followed rapidly upon the expanded knowledge of chemistry during the 1890's, and the neon tube was developed only a short time after the separation of the atmospheric gases.[10] Some lag has persisted, however, as in the late introduction of double-coiled filaments for standard lamps and in the tardy initiation of fluorescent-lamp development.[11] The reasons for the lag will be discussed shortly. At this point, however, we can conclude that, while scientific progress has been transformed into improved electric lamps much more rapidly in the twentieth century than was characteristic of the nineteenth century, further progress in that direction is possible.

The sources of scientific advancements have also influenced the speed of their exploitation in the United States, for American commercial applications have generally been more rapid when the successful research has been done in this country, particularly if it has been carried on by a lamp manufacturer.[12] In addition, the sources of new knowledge have frequently affected the subsequent control over patent rights and the later commercial development of the entire American industry.

European nations led the world in science through World War I, and in many fields that leadership continued in the twenties and the thirties. Until 1900 the United States relied almost wholly on Europe for its basic scientific knowledge. During the nineteenth century, the energies of the new nation were devoted mostly to an exploitation of its rich resources, to expanding its frontier, and to assimilating European industrial progress. It was

[10] See pp. 168–169, 224. [11] See pp. 328–329, 385–389.

[12] The contrast between the speedy development of the gas-filled lamp by General Electric after the research of Langmuir (pp. 317–323) and its somewhat slower pace in introducing the sodium lamp (p. 378) is characteristic.

not until the geographical frontier had almost vanished and the nation began to show signs of maturity that American science became important. By about 1900 American universities were able to make more than isolated contributions to scientific knowledge, and industry began to realize the importance of research.

The place of science in the American lamp industry was similar to that in industry as a whole. While the United States led in production methods and lamp quality from the beginning, its fundamental knowledge still came from abroad. In 1900 General Electric attempted to change that situation by establishing a research laboratory, for it recognized the weakness of depending completely on foreign nations for scientific progress in lighting and other fields.[13] Its attempt was eminently successful for incandescent lamps, in which since about 1910 it has led the world in virtually every respect. The work of Coolidge, Langmuir, Pacz, and others produced important knowledge which was transformed almost immediately into a better and cheaper product.

In electric-discharge lighting, General Electric did not have the same success for a long time. Until about 1935, Europe continued to make the major contributions.[14] Since then, the scientific leadership in discharge lighting has been shifting to this country.

American universities and non-profit research institutions have not contributed significantly to fundamental lighting research.[15] They have evidently felt that the field has been adequately covered by the large lamp manufacturers. Even the Europeans gave only a little more attention to lighting in their universities. The basic development of the Nernst lamp is the outstanding contribution of the educational institutions to lighting practice. However, the European universities did contribute greatly to advancements in scientific discoveries fundamental to lighting progress, as in the expanded knowledge of chemistry which led to the metallic filaments.

The present state of electric-lamp technology suggests that new scientific discoveries in related fields will be required for further major lighting progress. The failure of incandescent

[13] See pp. 179–181. [14] See pp. 218–229, 368–387.

[15] The American universities have made far greater contributions in lighting by the training of engineers and scientists for the manufacturing concerns.

lighting to show significant improvement since 1937 and the technical limitations to its further betterment virtually shut off that avenue. The greatest present hope for advancement is in the electric-discharge field. Yet even the relatively new fluorescent lamp is now considered by some engineers to be close to its maximum practical efficiency. New knowledge is required to open up the remaining possibilities in electric-discharge lighting and to determine the feasibility of such ideas as the use of fluorescent paints and coatings for high-level illumination.

At the present time the principal research on electric-lighting devices in the United States is that conducted by General Electric and Westinghouse. While some work on fluorescence, discharge devices, and related problems is carried on by other organizations, many of them not connected with the lighting industry, the relevance of their findings to lighting might not be realized in some instances for many years. There appears to be a strong need for more widespread and more interrelated applied research in lighting. At the same time, the field of electric lighting is inevitably dependent on fundamental research in related fields. I do not personally think that it is desirable to place the primary responsibility for progress on but two industrial organizations that work rather closely together, however capable they may be. Their fluctuating research budgets and their vested interests in the current situation are not likely to provide the ideal environment for further fundamental progress. Broader research efforts in additional industrial laboratories, in educational and non-profit research institutions, and possibly in government laboratories seem desirable. Unfortunately, the narrow product lines of the small lamp manufacturers are not conducive to fundamental research. It does appear, however, that the nation will benefit in this field in the long run as well as in others from the peacetime mobilization of science with governmental support.

ORGANIZATION OF THE DOMESTIC LAMP INDUSTRY

Given the state of scientific knowledge and the opportunity for technological advances in an industry, actual progress depends both on the *abilities* of industrial laboratories and private inventors to achieve important results and on their *incentives* to do so.[16]

[16] See pp. 342–347.

Our present task is to review those elements in the organization of the lamp industry and in its methods of conducting business which have affected the technological abilities and incentives of its members and to point out possible changes which would tend to increase the technological effectiveness of the industry.

It must be recognized, first of all, that the General Electric Company and its predecessor Edison companies have maintained commercial superiority in the electric-lamp industry since 1880. General Electric's share of the domestic industry since 1900 has fluctuated within a range of 40 to 80 per cent and has averaged about 65 per cent. The A and B licensees have been subservient to General Electric during most of that time and have controlled around 25 per cent of the market. The independent manufacturers as a group have remained relatively small, despite occasional periods of expansion.

Technologically, also, General Electric has dominated the industry. It has set the standards for lamp design and production efficiency, conducted most of the lamp research, and designed the most modern machinery. It has introduced most of the important new incandescent lamps and many of the new electric-discharge lamps. It designed most of the special lamps required for military use in World War II and, with Westinghouse, produced them in enormous quantities. The industry leader has possessed immense *ability* to achieve technological advances, arising out of its direct control of two-thirds of the lamp market, its high profits, its Schenectady research laboratory, the broad strength of the entire company, and its eagerness to attract able men. General Electric has also had strong *incentives* to make improvements in lamp design and production methods. The importance of patents in maintaining the license and quota system, the need for cost reductions to match price cuts and maintain profits, and the need for new designs to retain its market leadership and reputation, all have encouraged continuous research and development.

The incentives of General Electric have not been so strong, however, for the rapid development of new light sources for general illumination, which would jeopardize its vested interest in the older incandescent lamp. Because of its size and momentum in incandescent lighting it could not easily veer off in a completely new direction. New products were, in general, conceived to round out the product line and to meet specialized lighting needs. For the most part, General Electric concentrated its efforts on improving the filament lamp and production methods. It resisted the growth of neon-type tubing for general illumination.[17] Outside inventors conducted almost all the work on electric-discharge lamps early in the century,[18] and the industry leader was slow in undertaking to improve the old carbon filament.[19] It also lagged in developing fluorescent lighting to a commercial stage.[20] When General Electric did bring out the hot-cathode fluorescent lamp, the new lamp was initially promoted only for decorative and supplementary lighting.[21] The lack of strong competitive pressure at most times permitted General Electric to concentrate its attention on improving the older incandescent lamp, which would not endanger its established interest in the status quo. My own conclusion, therefore, is that General Electric's control over the lamp industry has not provided an ideal environment for the rapid development and introduction of major new *light sources*.

The A and B licensees operated under quite different conditions from those faced by the industry leader. While Westinghouse was a strong company with a large lamp department able to make important technological contributions in lighting, its incentives were weakened by the terms of its A license. The B licensees were much smaller and had still weaker incentives to conduct extensive research and development.[22] They were sheltered by their licenses and also restricted by them. Access to General Electric's developments in lamp design, lamp parts, and lamp-making machinery compensated them in part for the quota restrictions, royalty payments, limitations on exports, and other prescribed conditions.

The quota restrictions prevented unfettered sales competition and helped to preserve for General Electric its commercial predominance in the industry. The access to General Electric's technological improvements and the limited incentives for work on their own reduced the technological contributions of the licensees in fields covered by their licenses below their capabilities.

[17] See pp. 373–374, 425–426.
[18] See pp. 221–232.
[19] See pp. 180, 230–231.
[20] See pp. 386–389.
[21] See pp. 400–401.
[22] For license terms, see pp. 258–259.

They did not have a reasonable opportunity to show what contributions they could make on their own. The approximately 25 per cent of the domestic market served by the licensees was kept within the General Electric orbit, and it was not permitted to grow more rapidly than the licensor's own sales increased. Lacking sufficient development work of their own, the licensees were not in a strong position to break away from General Electric, and the situation tended to perpetuate itself. Price control was maintained over most of the lamps sold by Westinghouse, and the B licensees closely followed the licensor's prices. The role of the licensees was largely passive, therefore. They added little to the vitality of the lamp industry; and they aided General Electric in retaining its hold over the industry. They did not provide any real downward pressure on prices. They gave only the *appearance* of competition.[23]

While the unlicensed manufacturers of electric lamps were not subject to the restrictions of the licensees, they were in no position to make significant technological contributions. They have typically been small concerns with limited finances. Their machinery and labor have been inferior to those of the General Electric group. Their engineers have limited their activities primarily to production and process engineering. They have found it difficult to promote new ideas in competition with the General Electric group. The patents controlled by General Electric have made operations risky during certain periods and difficult during all periods. Many of the independents have had little desire to contribute technological advances to the industry; they have been much more interested in mere freedom to produce and sell lamps. Despite their formation of a unifying association in 1933, they have remained individualistic and have not yet banded together in such joint activities as machinery development or parts supply.[24]

[23] The need for greater competition in the lamp industry is a need for greater price-quality competition, of course, not merely price competition. The latter is of importance and has been lacking in the lamp industry, but it is not desirable for price cuts to lead to quality deterioration or to obstruct quality improvements. The early experience of European producers, for example, indicated that violent price competition could seriously affect lamp quality (see p. 113). However, adequate public education and suitable conditions in the industry should permit real price competition to be carried on in relation to lamp quality.

[24] See pp. 296–297.

Nevertheless, in spite of their limited technological contributions and other deficiencies, the independent lamp producers have played an important role in the lamp industry. Their existence has served as a continual threat to General Electric supremacy, though in the past it has been but a mild one. Their actual and potential expansion speeded price reductions during the thirties [25] and accelerated the developmental activities of the industry leader.[26] In a few instances, the independents actually took the lead in the introduction of new lamp specialties and caused General Electric to move more rapidly than it would have moved otherwise. The wire photoflash lamp first introduced by Wabash is the outstanding example of the potentialities of the independents. During the 1930's the lamp industry was more alert and vital than it had been since about 1910, and the rise of the independents was probably an important factor in that vitality.

Until World War II General Electric maintained its position at the head of a carefully organized industry with the aid of a strong patent position, commercial and technical aggressiveness, strong control over lamp parts and machinery, extensive advertising, and good public relations. Few possibilities were ignored. The cornerstone of control was the mass of patents accumulated by the industry leader. Besides the Just and Hanaman, Langmuir, and other major lamp patents, there were numerous lesser ones on lamp design, lamp parts, and lamp-making machinery. The basic tungsten-lamp patents permitted General Electric to set up its license and quota system and to eliminate many independent manufacturers between 1912 and 1929,[27] and the later "improvement" patents provided the means for continuing the quota scheme until 1944.[28]

Aggressive infringement litigation during the thirties, much of it on patents eventually held invalid, repurchase clauses on patented machinery sold to licensees, and other procedures allowed General Electric to extend its license system for a dozen years after its last basic incandescent-lamp patent had expired. As part of its drive to check the independents during the twenties and early thirties, General Electric also brought infringement suits against users of lamps made by the independent manufacturers. Patents were an important part of its efforts to limit external sources of lamp parts and machinery. General Electric also attempted to use patents as the basis for control over fluorescent lighting when it came upon the market.[29]

[25] The cost differential between the independents and the General Electric group has been so great that the independents have not been able to initiate price cuts themselves. Hence, General Electric and Westinghouse profits have remained high despite the reductions in prices. (See pp. 270–271.)

[26] See pp. 268, 336–341. [27] See pp. 236–246. [28] See pp. 271–280.

General Electric supremacy in the lamp industry has also been extended by its control over lamp parts and machinery. The licensor has supplied almost all its own parts and equipment from low-cost plants. It has worked with Corning in glass development and with other large companies, such as Airco, for other parts. It has filled the needs of its licensees for wire, bases, argon, and machinery, while independent manufacturers have had to rely on outside suppliers or themselves for all but lamp bases. Since the independents typically served less than 10 per cent of the total market, they were almost inevitably at a great disadvantage in obtaining many necessary items, particularly machinery.[30] Outside suppliers unaffiliated with the General Electric group had only a limited market and little incentive to indulge in expensive and risky development programs.

Other elements in the supremacy of General Electric have centered in its tremendous size and strength in the entire electrical-goods industry. As a broad-line manufacturer producing about 20 per cent of all electrical equipment turned out in the United States, it has towered over all other lamp manufacturers except Westinghouse, which fills about 10 per cent of total domestic needs for electrical equipment. A long history, a well known name, a reputation for good merchandise, an outstanding research laboratory, active product development, extensive advertising and sales promotion, excellent distributive outlets, virtually unlimited finances, long and favorable relationships with utilities and other major customers, close contacts with the leading fixture manufacturers—these and other relationships aided greatly in the preeminence of the General Electric lamp department. Similar though somewhat less powerful advantages have assisted Westinghouse in retaining its second position in the lamp industry.

Although General Electric has made most of the American

[29] See pp. 418–423.

[30] See p. 284 for a summary of the parts-supply situation.

contributions to electric-lamp technology in the twentieth century, and although those contributions have been noteworthy, that alone is not sufficient proof of the ideal nature of progress in the American lamp industry. The limitations on the technological abilities and incentives of the other manufacturers, the limited sales competition in the industry, and the shortcomings of General Electric in the development of major new light sources suggest that a different set of conditions would have been even more productive. As an executive of one of the leading competitors of General Electric in the lamp field once said, "Almost any horse running alone around a track looks fast. To determine his actual speed he must be paced."

If the situation in the lamp industry during the first part of the twentieth century was not ideal, what improvements are possible? First of all, one must recognize that many of the sources of General Electric strength are relatively fixed. The size and power of the parent company, its name, its research and development laboratories, its marketing organization, the general acceptance of its products, and similar conditions provide continuing advantages. The principal opportunities for change are in the internal organization of the industry, the relationships among lamp manufacturers and parts and machinery suppliers, and in changes in the status of the smaller manufacturers.

My own belief is that the changes that have recently taken place in the lamp industry, partly as a result of the federal antitrust suits in incandescent and fluorescent lighting, should improve somewhat the technological environment of the industry.[31] While final decisions in the cases are still unannounced, developments during the incandescent prosecution have already realized certain goals of the Department of Justice in increasing competition within the lamp industry.[32] The restrictive quota and license system was virtually ended in 1944 and 1945 with the expiration of all B licenses except that of Consolidated and with the cancellation of the A license. This should eventually increase both price and technological competition and lead to real benefits for the

31 See pp. 294–295, 300–302.

32 The two previous lamp-industry prosecutions under the antitrust laws did not achieve any material improvement in the technological environment of the lamp industry. The government lost the 1926 case, and the consent decree of the 1911 case did not produce any basic changes in the situation. (See pp. 156–159, 253–255.)

American consumer. Westinghouse and Corning have accepted decrees in the incandescent antitrust case in which they have agreed to grant licenses under their patents without restrictions and to end all other restrictive agreements and discrimination. This should provide a broader usage of technical knowledge and greater freedom and fairness in the supply of lamp parts. The elimination of the "Mazda" trademark from most General Electric and Westinghouse lamps may reduce slightly the competitive advantage of General Electric and Westinghouse over the other lamp manufacturers.

Another significant change in the competitive organization of the industry is the important position that Sylvania has achieved in fluorescent lighting and, more recently, in incandescent lighting.[33] From the beginning, Sylvania refused to accept quota restrictions on fluorescent-lamp production. The risks of conflict with General Electric were great, but the potential gains from success were greater. The vigor with which Sylvania promoted fluorescent lighting was very important to the early commercial progress of the new light source. Under the new conditions in the industry, even without any further changes, both Westinghouse and Sylvania are in a position to add more significant technical progress and more vigorous competition than the lamp industry has seen for decades.

While Westinghouse and Sylvania can press the industry leader strongly under present conditions, there is no certainty that they will continue to do so indefinitely. If General Electric, Westinghouse, and Sylvania should control jointly 90 per cent of the large-lamp industry, for example, it would seem probable that the desire to avoid "destructive" competition might lead to increasing cooperation and the evolution of a new pattern of industry control and restriction. Further antitrust actions might well be necessary to check the monopolistic tendencies of the industry.

A permanent solution for the problems of the lamp industry requires more positive steps. The tendency to monopolization in the lamp industry has persisted in almost all leading industrial nations since the origin of the industry. Patents have been of crucial importance, whether through direct patent monopolies as in

33 See pp. 298–299, 391–393, 405–415, 418–423.

the United States or through patent-pooling and cartel arrangements as in the European nations. If patentable inventions in lighting continue to represent the major sources of technological progress, the operation of the American patent system will control in large part future conditions in the lamp industry. Since the patent system is such a vital part of the technological environment of an industry, the next section of these conclusions will be devoted exclusively to that matter. At this point, we need note only that the present patent system has assisted in the breeding of monopoly, and that suggested modifications deserve careful consideration.

One constructive measure, not unassociated with the patent problem but better treated at this point, would be the sponsoring of a strong group of medium-sized and small producers in the industry. Their principal function from the point of view of optimum industry progress would be to act as gadflies to the larger concerns, to spur them on to rapid advances and real competition, and to seize whatever opportunities are presented to them by the lapses of the larger companies. The mere presence of such producers, eager to improve their own positions, would be an ever-present stimulus for the industry as a whole. The growth of the independent group of manufacturers during the thirties indicates some of the possible benefits to American consumers of a strong group of small and medium-sized producers. Price reductions represent one avenue of benefit. A second is the more rapid introduction of new lamp specialties, such as the projector and reflector lamps of the thirties and the wire-type photoflash lamp. A third is the possibility that some small concern might make a fundamental improvement in the design of existing types of lamps or develop an important new light source.

For maximum benefits under such a situation, the smaller concerns should form a sizable group. Their maximum strength before the war was 14 per cent of the large-lamp market. The war years pushed them down again below 10 per cent. In my opinion, a figure of from 20 to 25 per cent of the industry, divided among a dozen or more companies of varying size, would produce more effective competition in the industry. Most of the companies should be large enough and strong enough to carry on significant

developmental activities and to exploit whatever new ideas they produce. Collectively, they should be large enough to support cooperative machinery development or to guarantee an adequate market for one or more outside manufacturers of lamp-making machinery. Similarly, their collective size should be great enough to encourage the growth of competing suppliers of lamp parts.

At present, the independent group does not meet these requirements. The companies are too small and too weak. They are too independent to work out effective cooperative policies in machinery development and parts supply.[34] Their financial weakness makes new-product development impossible for many and difficult for all. Financial pressures also account for much of their "labor-machinery" problem and their slowness in entering the field of fluorescent lighting.

In my judgment the smaller companies need assistance at the present time. Some can be provided by the courts, if the Department of Justice is successful in its antitrust prosecutions. Some can be provided by the federal government through aid to small business and through modifications in the patent system. The courts can prevent discrimination in the sale of parts and machinery by requiring that merchandise formerly sold only to "favored customers" or at discriminative prices be offered to all bidders on equal terms. The consent decrees of Westinghouse and Corning, while in part contingent on the success of the government case against General Electric, should help to end discrimination. But General Electric continues to be the key concern in the industry, and it should also eliminate all discrimination.

I think that for a limited number of years the independents should be given the opportunity to receive licenses under any lamp, process, or machinery patent at a reasonable royalty. Westinghouse and Corning have already agreed to grant unrestricted licenses without royalty under all relevant patents issued to them at the time of the consent decrees. Corning has further agreed to license publicly all future patents applied for on or before Janu-

[34] While association and cooperative action of certain types among the small manufacturers are desirable, outright consolidation of all or most of them would probably not be an advantageous solution. Many firms of varying size are desirable in the industry, not just a very few large ones. While an extreme example, the history of the National Electric Lamp Company indicates how consolidation may work out in practice. (See pp. 145–148.)

ary 1, 1950, at reasonable royalties. The government antitrust suit in incandescent lighting was designed to secure a similar order for General Electric as well. I believe that increased access to lamp and machinery technology by the independents would assist them in improving their competitive positions and building up their business to the benefit of the public. Regardless of the outcome of the fluorescent-patent struggle between General Electric and Sylvania, a similar solution in that branch of the lamp industry seems highly desirable.

In the antitrust suit the government has also urged the courts to provide for the compulsory furnishing of "know-how" to patent licensees at reasonable charges for a limited number of years in order that their use of patents may be most effective. Such information would increase the competitive abilities of the smaller concerns temporarily and assist them in achieving more stable positions in the industry. On the other hand, compulsory furnishing of know-how would weaken the incentives of the small companies to improve their techniques by their own efforts, and there is no certainty that it would add to the vitality of the industry. I do not think that it is necessary or desirable to go so far in artificially improving the competitive position of the independents.

Another issue upon which the courts must rule is the agency system employed by General Electric and Westinghouse to maintain fixed lamp prices to the consumer. The legality of the device was upheld in the 1926 case and may well be upheld again. From the consumer's standpoint, price maintenance may either protect him from the above-list prices in areas of low retail competition, or prevent retail prices from declining in areas of high competition. In the lamp industry it appears that price maintenance by the agents of General Electric and Westinghouse has assisted in the creation of an artificially rigid and uniform retail-price structure above competitive levels. Broad markups allowed to the agents enlisted their support. If sufficient price and brand competition were achieved at the factory level, price maintenance by agents would probably not be unduly harmful. It is also true that less than 30 per cent of General Electric's lamp sales reach the consuming public through "retail agents." Nevertheless, the

past disadvantages of the agency system from the public point of view seem to have outweighed its advantages, and the proposed restoration of more nearly equal competitive positions for all lamp manufacturers suggests that the agency system as now constituted should be discontinued. Unfortunately, state laws and the Miller-Tydings Act of 1937 legalized resale price-maintenance contracts for nationally advertised products throughout most of the country. If the agency system is abolished, General Electric is at present in a position to fall back upon other contractual arrangements with its wholesale and retail outlets for electric lamps. That option was not available to it when the agency scheme was first instituted.[35] Accordingly, it does not now make much difference whether or not the agency system is maintained, unless the Miller-Tydings Act is also repealed.

Many of the other problems of the independents would be lessened if they could obtain adequate financial backing. They could expand their plants, afford high-quality labor, buy or develop better machinery, promote their product, expand their developmental activities, and better their positions in other ways. As small concerns in the lamp industry under the old set of conditions, most of them were not good risks for bank loans or the public sale of securities. With the proposed changes in conditions, private capital would probably be more favorably inclined toward investment in many of the independent companies. If private sources were still insufficient, short-term loans through governmental agencies or the Federal Reserve banks would be helpful. If the individual companies built themselves up adequately during a short transition period of special preference, private capital would take over. If the individual independents were unable

[35] Resale price maintenance has had a stormy and confused legal history in the United States. Prior to passage of the Sherman Act in 1890, the courts upheld the practice as a reasonable restraint of trade. Under the Sherman Act, such contracts were held to be illegal, although refusals to sell to price cutters were upheld. Court rejection of its contracts with dealers in the 1911 suit led General Electric to set up the agency system, which has been successfully employed by other manufacturers as well to maintain prices. Cooperation between manufacturers and distributors in the maintenance of prices was also found to constitute an unreasonable restraint of trade. Continued agitation by those in favor of price maintenance led to state and federal laws exempting such contracts from the Sherman and Federal Trade Commission acts. The economic justification of such exemption is very weak.

to build themselves up, their survival would be economically unjustifiable.[36]

Under the proposed arrangement, the small companies would have a greater opportunity for growth. It is to be hoped that one or more could rise to major positions in the industry as Sylvania has done over a twenty-year period. Unfortunately, the sale of Wabash to Sylvania ended the independent existence of the largest and one of the most vigorous of the smaller companies. There are others with potentialities, however, including Jewel, Duro Test, Save, and Warren. More nearly equal competitive positions under more truly competitive conditions throughout the industry would permit them to rise or fall by merit in a vigorous environment. The same would be true of the remaining present or former B licensees—Consolidated, Tung-Sol, and Chicago Miniature.

Some independents look forward with certain misgivings to a government victory in the antitrust suits. They feel that an intensification of competition, with General Electric holding its former advantages, would be difficult for them. In the past fifteen years, the small size of most of the independents led General Electric to tolerate their existence, although their group has been beset by infringement prosecutions and has faced numerous other obstacles. They feel that whatever elements of benevolence have existed in General Electric's attitude will vanish if the government wins, and price reductions will make their positions insecure. They fear that competition would be increased by the entry into the lamp industry of such concerns as General Motors and Ford.

Undoubtedly, a greater degree of competition would eliminate some of the weaker independent manufacturers. A few have perished already under the stringent wartime and postwar conditions. However, elimination of certain of the advantages enjoyed by the large producers in the past should assist in equalizing competitive positions, and I should expect the more able independents

36 The $100,000 exemption for registration of new security issues with the Securities and Exchange Commission is less than the sums needed by many of the independents. While the burden of registration may be real for many of the small lamp manufacturers, in the past the limited market for their securities has been an even greater handicap. Under more favorable competitive conditions, the S.E.C. regulations may not prove to be excessively burdensome. In any event, in the short run the lending agencies of the government can give the greatest financial help to those independent lamp producers who need and deserve assistance and cannot obtain it from private capital.

to survive and grow. The weaker concerns cannot claim the right to shelter under General Electric domination any more than the licensee group could in the past. More vigorous competition in *all* parts of the industry is desirable.

Each of the individual changes supported here would tend to lessen General Electric's present or potential control over the domestic lamp industry and lamp market. In my opinion, that control has been greater than is desirable for maximum consumer welfare. If the courts do find that General Electric has violated the antitrust laws in its management of the lamp industry, it is to be hoped that they will retain jurisdiction over the case for several years in order that the operation of the original decree may be watched and the provisions of the decree may be modified, if necessary.

To conclude, these suggestions are based on the premise that the organization and operation of the lamp industry have not been ideal. In many ways, the American public has been very well served, and the contributions of the American industry, which is to say the industry under General Electric domination, have certainly been greater than those of the industry in virtually all other countries. Whatever proposals are advanced should recognize the accomplishments and competence of General Electric and make every effort to preserve its incentives and ability to produce further technological advances. I believe that the changes mentioned above would accomplish that end, and at the same time would help to stimulate greater progress from other segments of the industry and achieve a more healthy competitive situation, all of which would aid the industry in making its optimum contribution to public welfare.

These conclusions on the organization of the domestic electric-lamp industry cannot be carried over to all other industries indiscriminately, although they should be applicable to certain similar industries. Differences in technological and operating conditions seem to call for quite different relationships within industries of each general type. For example, the organization of the shoe, lumber, petroleum, railroad, garment, and furniture industries should probably not follow that of the lamp industry for maximum public benefit. This suggests that judgments regarding the ideal forms of industrial organization should be based largely on technological and operating conditions, which vary widely, rather than on any limited theoretical ideals of competition alone. New standards of classification and judgment are called for.

THE PATENT SYSTEM

Although the experience of the lamp industry alone is not a sufficient basis for detailed or comprehensive recommendations for modifications in the patent laws, the operation of the patent system in this industry adds important evidence of value in considering revisions of certain aspects of the system. Any conclusions of a broad nature must be regarded as tentative, however, subject to the total weight of evidence provided by all industries.

The American patent laws rest upon the constitutional grant of power to Congress to "promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." The rationale of the laws passed by Congress rests on the assumption that, if an inventor serves society by disclosing to it a new idea, he is entitled to an exclusive franchise for its exploitation over a limited period of time. The grant of temporary monopoly is intended, therefore, to provide incentives for inventors to produce new ideas and devices of value to society.

There is no doubt that the patent incentive has provided a very strong stimulus to progress in electric-lamp technology. That incentive has applied both for individual inventors and for large corporations. The early Edison laboratory was concerned almost entirely with patentable inventions, and financial returns were expected from all developments.[37] Most of the other pioneer arc-lamp and incandescent-lamp inventors likewise sought profits through patent-protected invention. The desire for strong new patents was also a fundamental factor in the foundation of the General Electric Research Laboratory and in much of the technological activity of the mature lamp industry.

Although both individual and corporate inventors have been stimulated by the patent incentive, that incentive has operated in different ways. The independent inventor in the lamp industry was concerned primarily with the development of new lighting devices which would benefit the American public as well as provide financial return. All the early experimenters—Edison, Brush, Sawyer and Man, Maxim, Thomson and Houston, Farmer, and the others—were working on new ideas. A second major wave of independent invention in electric lighting around the turn of the century resulted in the Moore tube, the Cooper-Hewitt lamp, and numerous proposals for new filament materials in incandescent lighting. While major corporate laboratories have also produced important new lamps, the efforts of their scientists and engineers have often been directed more toward the improvement of older lamps and production methods.[38] By about 1912 systematic corporate invention, almost entirely by General Electric, had largely replaced private invention in the lamp industry, and the primary emphasis had shifted from the development of new ideas to the amassing of sufficient improvement patents to insure continued control over the industry after the expiration of basic patents. The Pacz, Mitchell and White, and Pipkin patents on incandescent lamps and the many machinery patents provided the basis for the continuation of the patent-licensing and quota system until 1945. The patent incentive for the individual inventor and for small lamp producers, both licensed and unlicensed, was reduced after 1912 by the conditions current in the industry. Improvement patents are of little value to potential competitors if one large concern holds all the basic patents. Even at the present time discouraging factors more than counterbalance the patent-monopoly stimulus for many companies.

The patent laws now do not normally protect and reward the original inventor, in terms of whom the patent laws were written. As a hired employee working on salary, the corporate inventor typically turns his patents over to his employer to work, shelve, license, and sue under, as the employer desires. Most of the lamp patents acquired by General Electric since 1912 were assigned to the company by its employees. In addition, however, the patent incentive for the leader of the lamp industry grew to include the incentive for acquiring protection of its position by the purchase of patents. General Electric resorted to the purchase of patents particularly at the beginning of the twentieth century, when the activities of its own newly organized research laboratory were still very narrow, and when private inventors were

[37] See pp. 59–60, 65–66.

[38] See, for example, pp. 388–389.

especially active. Among the important American patents or patent applications which General Electric has purchased or otherwise acquired at a cost of many millions of dollars are the following: Malignani chemical exhaust, tantalum filament, nonductile tungsten filament (Just and Hanaman, Kuzel, and Welsbach applications), Marks enclosed arc lamp, Cooper-Hewitt lamp, Moore tube, Küch lamp, and the Meyer, Spanner, and Germer vapor lamp. General Electric was also willing to purchase patents covering the Jaeger tipless lamp construction and the wire photoflash lamp, but it was unwilling to accept non-exclusive licenses under them.[39] Its desire to control the inventions completely thus led to much slower commercialization of the tipless lamp, though it did not appreciably delay introduction of the wire photoflash lamp.

While there is no evidence of the outright suppression of important patents in the lamp industry, it seems clear from the various instances cited above that patent ownership or patent agreements gave General Electric power to speed or retard the commercial application of certain new devices. That power almost inevitably led to policy decisions based on profits rather than on maximum public benefits from the new technology.

In what other ways has the original intention of the patent laws been set aside in the lamp industry? As mentioned above, General Electric succeeded in creating a strong monopolistic position in the lamp industry by amassing vast numbers of lamp and machinery patents, and it was able to prolong that position after the expiration of its principal patents.[40] The quota and other restrictions of its license system, which virtually froze the pattern of industry organization for about thirty years, were manifestations of the power which patents conveyed in the lamp industry. The exports of licensees were limited; they were required to grant royalty-free cross-licenses to General Electric; the prices at which Westinghouse lamps were sold were set by the licensor; the B licensees were restricted to either large or miniature lamps; the rate of growth of the licensees was limited; and numerous other phases of lamp-industry operation were similarly controlled. Patent-licensing agreements also formed the basis for joint General Electric and Corning control over the lamp-glass business and

39 See pp. 210, 340.

40 See pp. 263–284.

were of great importance in impeding the growth of adequate sources of efficient machinery for the independents.[41] Similarly, international patent licenses provided the principal means for reducing foreign competition in the American and world lamp markets,[42] and cross-licenses between General Electric and Claude Neon Lights served to restrict the entry of each into the other's principal lighting fields.[43]

The aggressive use of its patents against the unlicensed manufacturers was also a characteristic of General Electric's patent philosophy. The Just and Hanaman and Langmuir patents were used to force many small manufacturers out of business during the twenties.[44] After the expiration of those important patents, the best ones that remained formed the basis for new legal proceedings.[45] The great number of infringement suits on patents of doubtful validity or of doubtful coverage constituted a heavy financial drain on the unlicensed lamp producers. The suits brought by General Electric under the Mitchell and White, Pipkin, and Pacz patents and the suits against Eisler for alleged infringement of detail machinery patents had that effect, for example.

The use of patents to establish and preserve monopolistic control of an industry has not yet been fully reconciled with the antitrust laws. After the passage of the Sherman Anti-Trust Act of 1890, many corporations took refuge in the patent laws to achieve restrictions in competition. Supreme Court decisions early in the twentieth century supported the position that licensors could specify restrictive conditions in the patent licenses, even if they tended to maintain a monopoly and fix prices.[46] The reasoning was that, since a patent grants an absolute monopoly, even a restrictive license is a concession by the owner. That interpretation was continued and strengthened by later cases, including the Supreme Court decision of 1926 in the antitrust action

41 See pp. 252–253, 280–281, 283–284.

42 See pp. 309–310.

43 See p. 373.

44 See pp. 243–246.

45 See pp. 271–276.

46 For example, in *E. Bement and Sons* v. *National Harrow Company*, 186 U.S. 70 (1902), a license that forbade selling at lower prices and more favorable terms was upheld. Similar doctrines were laid down in such cases as *Heaton-Peninsular Button-Fastener Company* v. *the Eureka Specialty Company*, 77 Fed. 288 (C.C.A. 6, 1896).

against General Electric and Westinghouse.[47] Other decisions on alleged Sherman Act violations and the passage of the Clayton Anti-Trust Act in 1914 made it clear, however, that combinations among patent owners, as in patent pools, violated the antitrust laws if the patents were used to restrain trade.[48] The legality of restrictive patent practices is still a matter for court decision in conjunction with all other evidence in each case, and there is no advance certainty that many individual practices, such as those questioned in the current incandescent antitrust action, will be held legal or illegal. Public protection against the abuse of government-granted patent monopolies thus depends upon the Department of Justice and the courts, not upon any inherent public protection in the patent laws themselves.

The foregoing sketch of certain phases of patent-system operation suggests that various aspects of the current patent laws are out of date. The original purpose of the laws, which was solely to promote the progress of science and the useful arts, has been distorted by the increasing importance of industrial invention. In the lamp industry, the useful arts have been stimulated by the patent incentive, without question, but not in an optimum manner. Many of the technological weaknesses of the industry rest upon the use of patents by General Electric to preserve its leading position.

Numerous suggestions have been made repeatedly to modernize the patent system and realign its provisions with the constitutional intent. The experience of the lamp industry casts some light on certain of these suggestions, though it does not provide a final answer for any of them. One of the more extreme proposals calls for the elimination of all restrictions in the granting of patent licenses. If such an amendment were passed, the patent owner would retain no control over the licensee's actions regarding the purpose of use of the patent, the prices at which patented articles were sold, amounts of production, geographical sales areas, etc. With the history of the electric-lamp industry fresh

[47] See pp. 254–255.

[48] An early case which brought out this concept was *Standard Sanitary Manufacturing Company* v. *United States of America*, 226 U.S. 20, 48–49 (1912). A more recent case was *Hartford-Empire Company* v. *United States of America*, 323 U.S. 386 (1945), which possessed many similarities with the current antitrust prosecution in the incandescent-lamp industry.

before us and with its ample illustrations of many undesirable effects of restrictive license provisions on the development of the industry, one's first impulse might be to support the elimination of all restrictive provisions. In all probability, however, the elimination of all restrictions in the grant of patent licenses would greatly reduce the willingness of patent holders to give permission to others for their use. Without the restrictions of its A and B licenses, it is doubtful if General Electric would have granted as many, if any, licenses under its tungsten-lamp and other patents between 1912 and 1925, for example. The royalties received certainly did not compensate for the profits lost. General Electric could have sued all domestic tungsten-lamp manufacturers successfully for infringement of the Just and Hanaman patent and forced them out of the tungsten-lamp business. The General Electric Company had attempted to follow such a course in the legal exploitation of its original carbon-lamp patent.[49] As long as the patent owner possesses the right to determine for himself whether or not he will grant licenses on any given patent, therefore, it seems quite likely that the forced elimination of all restrictions might well do more harm than good in many instances.

Where restrictive provisions are incorporated in licenses granted under a patent pool, however, the situation is somewhat different. After the expiration of the fundamental patents in the lamp industry by 1933, the restrictive provisions were continued for a dozen more years. Detail patents in great mass provided the basis for the restrictions. Their unessential nature or invalidity was demonstrated by the successful growth of the independents from 1930 until World War II; yet the B licensees continued to operate under the old restrictions until the agreements expired. Restrictions under those circumstances are not desirable, yet it is difficult, if not impossible, for the patent laws themselves to distinguish between the different situations. The desirability of permitting restrictions thus seems to depend entirely upon the circumstances. We must evidently continue to rely upon the antitrust laws and the courts for primary protection against this form of patent abuse, imperfect and slow as it is. Continued vigor and speed of investigation and prosecution by the Department of Justice are urgently required. There is at least one possible minor

[49] See pp. 88–91.

modification in the patent laws which would aid in reducing objectionable restrictions in patent licenses, however. A public record in the Patent Office or Department of Justice of all patent agreements, or at least all those containing restrictive clauses, would permit continual governmental surveillance and more prompt action by the Department of Justice when needed.

Another even more sweeping modification proposed by many patent-system critics is compulsory licensing. The power to grant or not to grant patent licenses would be taken away from the patent owner, and with it his power to insert restrictive provisions. Under compulsory licensing, all applications must be granted at fair royalty rates. This would deprive the patent owner of a monopoly in its use, though it would bring him greater or lesser sums in royalties, depending on the importance of the patent and the size of his competitors.

The possible effects of compulsory licensing are complex, for the change might affect the relationships among all the firms in an industry and considerably modify their technological incentives. In the lamp industry, for example, the commercial development would have been quite different if the Edison, Just and Hanaman, Langmuir, Hull, Spanner, and other patents had been made generally available when issued. Production and sales competition would have been considerably greater, thus lowering the preeminent commercial position of the Edison and General Electric companies. The patent monopoly of electric lamps would have been impossible to achieve. From that point of view, compulsory licensing might well have had a salutary effect on the lamp industry.

The possible effects of compulsory licensing on technological incentives are less clear-cut, however. One important disadvantage under such a situation would be the inducement for corporate inventors to avoid making patent disclosures by keeping new processes secret. In the lamp industry the Just and Hanaman and Coolidge processes would have been subject to that sort of treatment for a time, at least. Secret processes would defeat the intent of compulsory licensing. Nevertheless, most patentable inventions are not susceptible to secrecy, and the desirability of change from this point of view depends on its effect upon the incentive to conduct research and development. It would appear that the

technological incentives of large corporations would not be very greatly affected. Such concerns as General Electric in the lamp industry must make continual progress or lose their technical and commercial leadership. They would probably continue to push their research and development, possibly even more vigorously than under noncompulsory licensing, in view of the greater sales competition that compulsory licensing would stimulate.

The effect of compulsory licensing on the technological incentives of smaller concerns and private inventors would probably be depressive, for they would know that any important patent granted to them could be exploited much more vigorously by the more powerful concerns in the industry. The development of hot-cathode fluorescent lighting by an independent lamp manufacturer, for example, could not have brought that manufacturer appropriate rewards if General Electric and Westinghouse had been able to demand licenses under its patents. But on the other hand, in the lamp industry as constituted between 1912 and 1945, no small manufacturer was in a position even to develop the hot-cathode fluorescent lamp or any other major new device, much less to exploit it fully. The licensees had the added handicap of operating under compulsory licensing to General Electric, anyway. It seems evident that nation-wide compulsory licensing, as an alternative to conditions that actually existed in the lamp industry from 1912 to 1945, would not have changed the situation for the smaller firms greatly and would have increased sales competition and quite possibly the technological incentives of General Electric.

The foregoing conclusion does not necessarily mean that compulsory licensing on a national scale would be beneficial, nevertheless. During other periods in lamp industry history and in dozens of other industries smaller manufacturers and private inventors have been more important. The destruction of the patent-monopoly incentives of Marks, Jandus, Moore, Cooper-Hewitt, and the others might well have limited their work. Where an individual inventor or small corporation wishes to exploit his or its own invention, compulsory licensing would make extensive financial investment unusually risky. Royalties could be collected from licensees, if the difficult task of determining a fair rate could be surmounted; but royalties received would not in most instances compensate for profits lost. To conclude, while compulsory licensing as a normal state of affairs might have been beneficial in the lamp industry from 1912 to 1945, the universality of its advantages is still highly questionable.[50] Less sweeping patent-law revisions, in conjunction with continued antitrust vigilance, seem more desirable at this time.

Compulsory licensing has much more to recommend it in particular situations, such as where patents are used oppressively in building up a monopoly position in violation of the antitrust laws. Such a policy was adopted in the consent decrees entered by Westinghouse and Corning in the incandescent antitrust suit.[51] This type of compulsory license is far different from a general scheme for all patents and is normally limited to a moderate period of years.[52] It permits the smaller companies to improve their competitive positions for a time before resuming the usual rules of business. Its use in the lamp industry should be highly beneficial, particularly through the entry of additional firms to fluorescent-lamp production and through the access of the independent group to improved machinery. After the period of compulsory licensing, it would be desirable for the lamp industry to set up a voluntary open patent pool at low royalty rates.

The two most extreme proposals for revision of the patent system, therefore, seem to be unwise at present, even in an industry such as the one with which we are concerned here. The patent system, despite its failure to keep abreast of changing economic conditions, has displayed remarkable strength. Progress in the lamp industry, while not optimum, has been noteworthy.

There are other aspects of the present patent system which are not so easily defensible, however, and changes in them would go far toward strengthening patent incentives and preventing excessive patent monopolies. One important defect is the length of time

[50] This discussion has not considered the constitutional or ethical nature of the limited monopoly granted to patent holders, which would be largely negated by compulsory licensing.

[51] See pp. 289, 301. A similar provision was contained in the decree of *Hartford-Empire Company* v. *United States of America*, 323 U.S. 386 (1945).

[52] An alternative scheme might follow the British plan of requiring compulsory licenses if the demand for a patented article is not met on reasonable terms by the patent owner, or if trade is prejudiced by refusal to grant licenses on fair terms.

required for the Patent Office to process and grant patent applications. Periods of five to fifteen years are common (see Table XXXVI). Intentional or unintentional delays in the prosecution of an application may prolong patent protection for many years, and at the same time Patent Office delays sometimes make it possible for competitors to infringe patentable products or processes for many years before the patent is finally issued and court proceedings can be brought. In addition, the expense of long pend-

TABLE XXXVI: IMPORTANT AMERICAN LAMP PATENTS ISSUED FIVE YEARS OR MORE AFTER DATE OF APPLICATION

Patentee	*Subject*	*Date of Application*	*Date of Issue*	*Years in Patent Office*
Smith	Electric-discharge device (alleged basis for fluorescent lamp)	Sept. 9, 1925	May 21, 1940	15
von Welsbach	Osmium filament	Aug. 9, 1898	Nov. 22, 1910	12
Meyer, Spanner, and Germer	Vapor lamp (alleged basis for fluorescent lamp)	Dec. 19, 1927	Dec. 5, 1939	12
Fink	Dumet lead-in wire	Jan. 23, 1915, extension of 1912 application	June 24, 1924	12
Le Bel	Ultraviolet lamp (alleged basis for fluorescent lamp)	Aug. 14, 1929	Aug. 16, 1938	9
Just and Hanaman	Non-ductile tungsten filament	July 6, 1905	Feb. 27, 1912	7
Sawyer and Man	Paper filament	Jan. 9, 1880	May 12, 1885	5
Whitney	GEM lamp	Feb. 8, 1904	Mar. 30, 1909	5
Pacz	Non-sag tungsten filament	Feb. 20, 1917	Mar. 21, 1922	5
Jandus	Enclosed arc lamp	Dec. 4, 1886	Nov. 17, 1891	5

Source: *Official Gazette of the Patent Office*, Washington, 1885–1940.

ency is often prohibitive for private inventors and small concerns.

Another discouraging feature of the patent system is the expense and difficulty of determining the validity of patents in court. The issuance of a patent is only presumptive evidence of its validity, and the courts must make the final determination. Unfortunately, the standards of patentability employed by the Patent Office have been consistently below those established by the courts. In the lamp industry, court action has invalidated, among others, patents covering the Sawyer-Man paper filament, the Coolidge ductile tungsten filament, the Pacz non-sag tungsten filament, the Pipkin process for the inside frosting of glass bulbs, the Smith and Le Bel electric-discharge devices, and a number of lesser patents on other features of lamp design and lamp-making machinery. While inventors and corporations had to accept the situation, the frequent court invalidations have had a disturbing effect on industry operations.

Also, the various courts have not followed the same standards of validity. In general, the district courts and circuit courts of appeal have been less strict in their judgment of lamp patents than the United States Supreme Court. In fact, no lamp patent that has reached the Supreme Court has ever been completely upheld, and none has been held valid and infringed in part or whole by a court of last resort since 1933. Under those circumstances, the final determination of validity in several important instances has taken ten or more years. The following tabulation indicates the length of court delays in the legal clarification of some of the outstanding lamp patents:

Patentee	*Subject of Patent*	*Years Required for Clarification of Validity*
Edison	Carbon filament	12
Sawyer and Man	Paper filament	10
Just and Hanaman	Non-ductile tungsten filament	4
Coolidge	Ductile tungsten filament	15
Langmuir	Gas-filled lamp	4
Pacz	Non-sag tungsten filament	16
Pipkin	Inside frosted bulb	17

The validity of the Hull patent of 1931 and the Meyer patent of 1939, both of which are of importance in fluorescent lighting, still remain in doubt in 1947, although they have been upheld by the Southern New York District Court.

Proposals for mitigating the defects mentioned and illustrated above include limiting the life of patents with long pendency, exercising greater care in the granting of patents, and revising the court system in infringement cases. The experience of the lamp industry strongly supports the proposal that the over-all life of a patent should be limited to a maximum of twenty years from the date of application. Unduly long patent protection not in the public interest would be avoided in that way. In fact, lamp-industry history suggests that a shorter patent term of perhaps fourteen years would adequately reward both independent and corporate inventors and would make it more difficult for a corporation to secure and perpetuate a patent monopoly over an entire industry.

To reduce delays in granting patents and to raise the validity standards of issued patents, greater care should be exercised by the Patent Office. More, higher quality, and better paid examiners having better information could give more thorough examinations of patent applications with fewer delays. If the standards of patentability in the Patent Office had been in accord with those of the higher courts, much confusion during the thirties in the lamp industry over conflicting rights would have been eliminated. Objective standards of patentable invention followed by both the Patent Office and the courts would be of great assistance.

Greater speed by the courts in determining patent validity and infringement would also have aided the development of the electric-lamp industry during several periods in its history. This study itself provides no basis for recommending detailed means of legal expedition, but it strongly supports the need for uniformity in judicial standards and the need for more rapid and cheaper legal action, whether by the use of a special patent court to hear appeals from the district courts, by provision for appeal to the Supreme Court without conflicting circuit court decisions, or by some other modification.[53]

[53] The conclusions stated in this section are corroborated in general by the conclusions of Frank J. Kottke's study of the electrical industries as a whole,

INTERNATIONAL RELATIONSHIPS AND TARIFF REGULATIONS

Both the technological and the economic development of the American electric-lamp industry have been influenced by the relationships between the American producers and those in other major nations. During the early part of the twentieth century, a cartelization movement spread from the German lamp industry to the lamp industries of most countries in western Europe.[54] One or a few large lamp producers emerged in each country, particularly after the introduction of the tungsten filament. Under the cartel, which customarily controlled more than 80 per cent of European electric-lamp production, world markets were divided among the members. The industry of each country was normally allotted all or most of its domestic market and certain other areas throughout the world. Exclusive licenses under the lamp patents controlled by the large companies provided the basis for the market-sharing agreements. Cartel members also exchanged technical information and agreed upon prices to be charged in the various areas. The effect of the cartel was to pass technical advances from one country to another for the benefit of cartel members, while international sales competition was held to a minimum. High prices inevitably restricted production and consumption.

The American antitrust laws caused General Electric to approach the world cartel indirectly. It never became a full-fledged member. Several of its foreign subsidiaries were members, however, and it negotiated exclusive bilateral patent licenses with the principal members of the cartel.[55] The effect was very nearly what it would have been if the membership had been outright. Lamp imports and exports were restricted, and General Electric was assured that it would have the first chance at technological advances made by the other world leaders. By limiting or denying export licenses for its domestic licensees, General Electric was able to secure compliance with cartel goals by suppliers of an additional 25 per cent of the American market.

Under the international arrangements, important technological

Electrical Technology and the Public Interest (American Council on Public Affairs, Washington, 1944), especially Chap. X. My own conclusions were reached independently and were written before Kottke's work came to my attention.

54 See pp. 303–307.

55 See pp. 307–310.

advances in electric lighting made abroad have with few exceptions been brought to this country and introduced by General Electric. The international arrangements thus permitted General Electric to maintain its product leadership in the American market while claiming credit for the introduction of the new devices. Only those domestic concerns which it chose to license could normally participate in new foreign developments. The independents were usually frozen out.[56] While this might have served to encourage some of the small companies to try to make innovations of their own, in fact their limited resources have rendered them largely impotent. In conjunction with the domestic arrangements and activities of General Electric, the international arrangements helped perpetuate the leader's position.

It seems likely, however, that in addition to the undesirable reduction of international competition in lamp sales, the cartel arrangements have somewhat reduced the incentives of General Electric to push on to entirely new light sources. Where the big company was virtually certain to have the first chance at foreign inventions, it made relatively little difference to it whether it made the initial developments itself or acquired them from abroad. The limitations on imports and domestic sales competition under the international licensing system seem also to have reduced technological incentives as well as to have deprived the American market of a desirable downward pressure on prices.

In addition, the system whereby General Electric has an option on most foreign inventions concerned with lighting seems unfair to other domestic producers. While it is highly desirable that foreign technological progress in lighting should be imported to the United States as rapidly as possible, it seems equally desirable that the importation should not be monopolized by one firm. The end of past restrictions and agreements should restore some semblance of competition in the importation of both lamps and technological advances. There is no good reason why the termination of cartel restrictions should prevent the inflow of foreign technical progress, for if a new idea or device possessed merit more than one American concern would be interested in introduc-

56 The only notable recent exception to this situation was the success of Wabash with the wire photoflash lamp after General Electric had refused a license for it under the Philips' patents. (See pp. 340–341.)

ing it. The reduced importance of foreign lighting developments during the past ten to fifteen years further lessens the desirability of continuing restrictive foreign licenses or agreements.

The courts may take positive action to remedy the international situation in the current antitrust actions in the lamp industry. In addition, it should prove helpful if copies of all such international licenses and agreements were filed with the Patent Office or the Department of Justice. Restraints of trade would be both discouraged and discovered more readily if they were recorded in a government department. This suggestion parallels that made in reference to restrictive patent licenses in the domestic sphere. In addition to actions directed specifically against cartel restrictions, it is evident that an increase in competition within the United States would weaken cartel control over American foreign trade in lamps.

While tariff rates potentially affect the volume of lamp imports, the international license arrangements have been far more important in that respect since 1909.[57] Furthermore, the higher production costs in most foreign nations have lessened the competitive pressure exerted in the United States by non-cartel manufacturers abroad. Despite the cost advantages of American producers over most foreign producers, however, tariff rates on lamps remained at 20 or 30 per cent ad valorem during the period from 1909 to 1947.[58] Because of the other more effective restraints on trade, these moderate protective tariffs on lamps have had relatively little effect on imports, sales competition, and lamp technology in the United States. If the influence of the cartel over trade in electric lamps can be broken, tariffs might come to play a more important part. On the basis of its age, size, and ability, I do not see any present justification for tariff protection of the American lamp industry. A revenue tariff of not more than 10 per cent would seem much more reasonable.[59]

[57] Before 1909 the tariff rates on lamps ranged up to 60 per cent ad valorem.

[58] See p. 249.

[59] The conclusions in this chapter have stressed the major factors influencing technological change and economic development in the electric-lamp industry where the situation has been less than ideal, and where changes are possible. There are other factors where changes are not feasible. Some other factors of potential importance which have played much less important roles in the lamp industry than in other industries are considered briefly in Appendix K.

APPENDICES

Appendix A: METHODS USED IN MAKING ESTIMATES APPEARING IN TABLE III

TABLE III on page 9 shows the relative economic importance of the major activities directly involved in electric lighting, and it also estimates the importance of activities indirectly involved. Certain estimates included in this table require explanation.

1. *Estimated Contribution to Value of Electric Lighting*. This column represents the value added by each activity to the total value of electric lighting. Except for electrical contracting associated with lighting, these figures are identical to the value of the activity. Because part of the value of contracting work performed is composed of parts and equipment already included under other headings, a deduction had to be made from the total of $66,800,000. It was estimated that roughly 50 per cent of the $30,600,000 cost of materials, etc., had already been counted. Because the estimate is only approximate, a rounded figure of $50,000,000 has been used.

2. *Estimated Contribution to Employment Provided by Electric Lighting*. This column represents the sum of employment provided directly by the activity concerned and employment indirectly provided in previous stages of manufacture, mining, transportation, and other necessary activities. The direct employment is given in the first column of the table. The indirect employment was estimated in the following manner:

According to the *Survey of Current Business* for June, 1941, the total national income in 1939 was $70,674,000,000, of which all but $67,000,000 consisted of shares transferred by enterprise; and of the shares transferred, 62.8 per cent consisted of salaries and wages. Therefore, if each industry were an "average" industry, about 62.8 per cent of its value produced would be represented by wages and salaries, paid either to individuals working in it or in previous stages of manufacture or service. This broad assumption was made in arriving at the estimates of "anticipated wages and salaries."

From the anticipated wages and salaries were deducted those wages and salaries actually paid, leaving an extra amount attributable to previous stages of economic activity. Assuming that these previous stages were typical of industry in general, an average wage or salary of $1,280 was used to obtain an estimate of the number of individuals represented by the extra wages and salaries. This constituted the estimate of indirect employment.[1] The figure of $1,280 is the average wage and salary (combined) reported by the *Census of Manufactures* for 1939. It was extended to cover transportation and other services in the absence of any better figure.

The assumptions employed in this computation are not carried out perfectly in reality, for the prior stages of each activity are not entirely typical of industry as a whole. There is undoubtedly a degree of error in the results obtained. For the present purpose of showing orders of magnitude, however, these assumptions seem justified.

3. *Value Added by the Generation, Transmission, and Distribution of Electric Energy to Ultimate Consumers for Lighting.* Value added for the electric-power industry is not given in census reports, owing to the special nature of this industry. The figure which appears in the table has been estimated to provide a degree of comparability with the other activities under consideration. The cost of fuel consumed constitutes the bulk of materials, supplies, purchased electric power, contract work, etc., which are given for the other industries. The cost of fuel, therefore, plus an additional allowance to cover miscellaneous supplies, etc., was deducted from revenues from ultimate consumers to produce an estimate of value added. The appropriate amount of this applicable to lighting was then determined by using the established percentage.

Since only the actual quantities of fuel consumed are given by the Census of Electrical Industries, the value of that fuel was estimated with the aid of 1939 wholesale prices for each type.

[1] The formula used in this calculation was $\frac{(V \times P) - W}{A} + E = T$, where V is the value of the direct activity, P is the percentage of salaries and wages in industry as a whole (62.8 per cent in 1939), W is the wages and salaries paid in the particular activity, A is the average wage in industry as a whole ($1,280 in 1939), E is the direct employment in the activity, and T is total equivalent employment.

Appendix B

TABLE XXXVII: WORLD PRODUCERS OF INCANDESCENT LAMPS, BY COUNTRIES
1889–1896

Country	Number of Producers of Incandescent Lamps, Jan. 1							
	1889	1890	1891	1892	1893	1894	1895	1896
United States	26	35	32	34	57	58	44	35
Mexico	0	1	0	0	0	0	0	0
Great Britain	11	12	14	8	7	24	27	22
Canada	3	3	2	2	3	3	4	4
Australia	0	0	0	0	0	1	2	2
Total	40	51	48	44	67	86	77	63
France	7	9	18	15	17	18	21	18
Germany	4	9	10	11	13	16	17	16
Holland	2	4	5	4	5	6	6	6
Austria	4	4	5	6	6	6	6	4
Belgium	1	3	5	4	6	5	4	3
Italy	2	2	5	3	3	3	3	3
Hungary	1	1	3	3	4	4	4	2
Switzerland	0	0	1	1	2	2	2	2
Russia	0	0	1	1	2	1	1	1
Denmark	0	0	0	1	1	1	1	1
Sweden	0	0	0	0	0	0	1	1
Total	21	32	53	49	59	62	66	57
Total, World	61	83	101	93	126	148	143	120

Source: Electrician, *Electrical Trades' Directory and Handbook*, Vols. VII–XIV, London, 1889–1896.

Appendix C

TABLE XXXVIII: WORLD PRODUCERS OF ARC LAMPS, BY COUNTRIES
1889–1896

Country	Number of Producers of Arc Lamps, Jan. 1							
	1889	1890	1891	1892	1893	1894	1895	1896
United States	15	24	32	34	43	48	45	44
Great Britain	27	43	45	55	48	51	48	54
Canada	1	1	2	2	2	4	5	5
Australia	0	0	0	0	0	0	2	2
Total	43	68	79	91	93	103	100	105
France	6	23	25	25	39	35	36	37
Germany	1	6	9	12	20	20	22	23
Belgium	1	2	5	4	5	6	5	5
Austria	1	2	3	3	4	4	5	3
Hungary	1	1	1	1	2	2	3	2
Bohemia	1	1	1	2	2	2	2	2
Switzerland	1	4	3	3	3	3	3	1
Holland	1	1	1	0	0	0	1	0
Denmark	0	1	1	0	0	0	0	0
Russia	0	0	1	1	1	1	1	1
Italy	0	0	1	0	0	0	0	0
Sweden	0	0	0	0	0	0	1	0
Total	13	41	51	51	76	73	79	74
Total, World	56	109	130	142	169	176	179	179

Source: Electrician, *Electrical Trades' Directory and Handbook*, Vols. VII–XIV, London, 1889–1896.

Appendix D: PRODUCTION OF ELECTRIC LAMPS IN THE UNITED STATES 1899–1939

This appendix includes all data on the production of electric lamps which have been published in the *Census of Manufactures* from 1899, when lamp statistics were first reported, to 1939. Because of the continually changing coverage and classifications, the data are here presented in three tables, covering the periods 1899 to 1919, 1921 to 1929, and 1931 to 1939, respectively.

TABLE XXXIX: PRODUCTION OF ELECTRIC LAMPS IN THE UNITED STATES
1899–1919

Type of Lamp	*1899*	*1904*	*1909*	*1914*	*1919*
Large					
Carbon, number	25,320,198	[a]	55,038,378	14,092,055	13,330,273
Carbon, value	$3,442,183	$6,308,299	$6,157,066	$1,397,572	$1,830,644
Tungsten, number	....	....	11,738,619	74,434,059	211,383,193
Tungsten, value	....	....	$6,241,133	$11,886,354	$46,628,343
GEM, tantalum, glower, vacuum, and vapor lamps	....	$395,155	$2,715,991	$2,363,730	{$2,512,435[b] 783,267[c]
Total	$3,442,183	$6,703,454	$15,114,190	$15,647,656	$51,754,689
Decorative and miniature lamps, X-ray bulbs, vacuum tubes, etc.	$72,935	$249,751	$600,619	$1,702,729	$5,892,211
Total, all electric lamps	$3,515,118	$6,953,205	$15,714,809	$17,350,385	$57,646,900

[a] The accuracy of the census figure for the number of large carbon lamps produced in 1904 is highly doubtful and has been eliminated from this tabulation.
[b] GEM, vacuum and vapor lamps.
[c] Other types.
Source: Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures*, 1899–1919, Washington.

TABLE XL: PRODUCTION OF ELECTRIC LAMPS IN THE UNITED STATES

1921–1929

Type of Lamp	*1921*	*1923*	*1925*	*1927*	*1929*
Large tungsten					
Vacuum, number	....	....	204,973,625	174,527,279	149,802,848
Vacuum, value	....	....	$34,540,038	$28,879,712	$20,713,116
Gas-filled, number	....	....	61,488,129	160,078,714	202,451,663
Gas-filled, value	....	....	$20,352,400	$41,914,184	$44,724,296
Total, number	154,971,269	232,699,601	266,461,754	334,605,993	352,254,511
Total, value	$46,084,138	$54,179,645	$54,892,438	$70,793,896	$65,437,412
Miniature tungsten					
Automobile, number	35,951,863	88,243,456	114,800,550	93,336,957	139,162,835
Automobile, value	$5,713,647	$11,354,546	$12,432,676	$10,058,720	$11,115,752
Other types, number	49,634,294	61,008,765	65,946,289	95,428,023	132,869,936
Other types, value	$6,760,781	$4,860,701	$4,840,733	$5,452,016	$7,351,461
Total, number	85,586,157	149,252,221	180,746,839	188,764,980	272,032,771
Total, value	$12,474,428	$16,215,247	$17,273,409	$15,510,736	$18,467,213
Carbon					
Large, number	5,998,497	7,420,528	7,102,572	6,826,234	2,287,596
Large, value	$1,169,832	$1,571,333	$1,392,363	$1,628,612	$409,917
Miniature, value					$1,004,973
Total, all electric lamps	$59,728,398	$71,966,225	$73,558,210	$87,933,244	$85,319,515

Source: Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures*, 1921–1929, Washington.

TABLE XLI: PRODUCTION OF ELECTRIC LAMPS IN THE UNITED STATES

1931–1939

Type of Lamp	*1931*	*1933*	*1935*	*1937*	*1939*
Incandescent filament					
Large tungsten, number	319,820,492	305,820,440	387,914,279	500,534,548	516,661,048
Large tungsten, value	$57,043,426	$41,811,340	$51,046,338	$59,140,140	$58,379,740
Miniature tungsten					
Motor vehicle, no.	95,262,653	65,048,436	132,435,562	176,356,972	136,553,456
Motor vehicle, value	$7,944,008	$4,005,221	$6,780,733	$8,822,490	$7,240,976
Christmas tree, flashlight, and misc., number	70,459,378	(incomplete)	(incomplete)	[a]	[a]
Same, value	$2,912,702	$2,539,092	$4,685,702	$5,961,389	$7,105,175
Total miniature tungsten, number	165,722,031	(incomplete)	(incomplete)	(incomplete)	(incomplete)
Same, value	$10,856,710	$6,544,313	$11,466,435	$14,783,879	$14,346,151
Carbon, number			1,030,546	2,322,098	1,639,015
Carbon, value			$189,997	$379,598	$392,638
Vapor and photoflash					$5,359,164
Photoflood, number					1,885,793
Photoflood, value	$2,601,918	$1,493,647	$2,071,511	$3,587,798	$340,440
Other lamps and vacuum tubes					$485,511
X-ray			$1,772,243	[a]	[a]
Industrial electronic tubes	[a]	$292,311	$1,004,799	[a]	[a]
Total, all electric lamps and similar products	$70,502,054	$50,141,611	$67,551,323	$77,891,415	$79,303,644

[a] Not included in census report.

Source: Bureau of the Census, U.S. Dept. of Commerce, *Census of Manufactures*, 1931–1939, Washington.

Appendix E

TABLE XLII: PRODUCTION OF ARC LAMPS IN THE UNITED STATES 1899—1909

Type of Lamp	*1899*	*1904*	*1909*
Open arc, number	23,656	1,748	5,004
Open arc, value	$276,481	$29,989	$83,660
Enclosed arc, number	134,531	193,409	118,981
Enclosed arc, value	$1,551,290	$1,544,433	$1,623,299
All arc lamps, number	158,187	195,157	123,985
All arc lamps, value	$1,827,771	$1,574,422	$1,706,959

Source: Bureau of the Census, U.S. Dept. of Commerce, *Thirteenth Census of the United States, 1910,* Washington, Vol. X, p. 292.

Appendix F: THE PRICE ELASTICITY OF DEMAND FOR LARGE INCANDESCENT LAMPS: 1920—1946

WHILE a detailed analysis of the demand for large incandescent lamps is not appropriate to this study, some further comments and data on the matter may be of interest. At any given time a 10 per cent change in lamp prices produces on the average only about a 1 per cent change in total lighting costs. Because of the essential nature of artificial lighting, the short-run demand for large incandescent lamps in the United States is extremely inflexible.

Over a period of years, a number of factors tend to increase the flexibility of consumer demand for lamps. The decline in power costs, increase in population, higher per-capita income, expanded rural electrification, increased urbanization, extensive advertising and promotion of incandescent lamps, and other forms of public education to higher lighting levels—all these would seem to be of sufficient importance to produce a greater total expenditure on large incandescent lamps as the years go by. Yet the list-price value of large lamps sold in the United States was almost exactly the same in 1940 as it was in 1920—$113,000,000. While numerical sales were three times as large in 1940, average prices were only one-third of their 1920 level. The 26 per cent increase in lamp efficiency during that interval was a significant factor in limiting the expansion of sales to 200 per cent, but it was by no means wholly responsible.

The accompanying Figure 42 shows the numerical sales of large incandescent lamps for general lighting in the United States plotted against the average list prices for the years 1920 through 1946. The year and national income are indicated for each point. As an aid to interpretation, the dotted line with the formula $XY = \$110,000,000$ has been added. The chart casts considerable light on lamp demand,

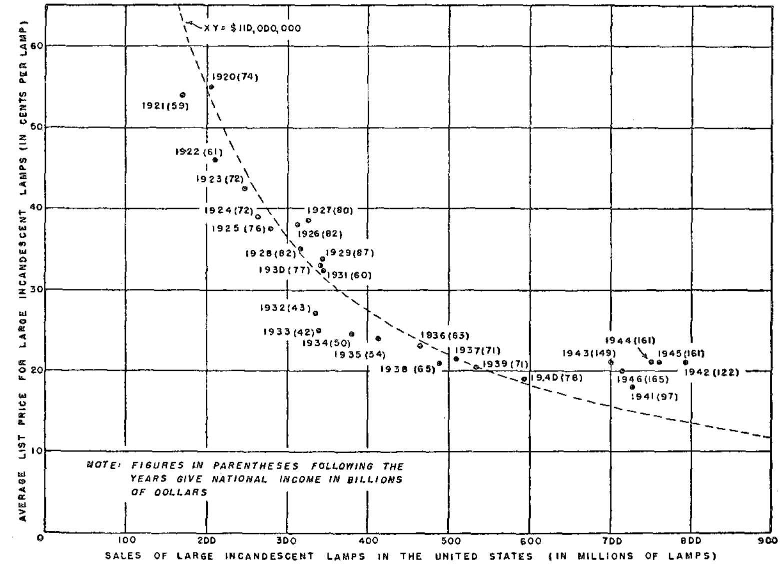


FIG. 42. Sales and List Prices of Large Incandescent Lamps for General Lighting in the United States, 1920–1946

Sources: *Electrical World,* Vol. LXXXIX, p. 78 (Jan. 1, 1927); *Census of Manufactures,* 1921–1929, Bureau of the Census, Washington; members of the lamp industry; and others.

although it is not possible to construct a statistical demand curve from these data alone. Over the years, sales have increased and prices have fallen to produce a fairly close conformity of actual experience with the equilateral hyperbola. For the years in which national income was between sixty and eighty billion dollars, the points lie very close to the line. For years in which national income was lower than sixty billion, the points lie well to the left of the line. For years in which the national income was higher than eighty billion, the points generally lie well to the right of the line. It was only during the war years of greatly swollen national income and lamp demand and in 1946 that the differences were exceptionally large.[1]

The great dependence of dollar sales for large incandescent lamps on the level of national income in current dollars is further emphasized in Figure 43, where the two series are plotted on the same graph for the years 1920 through 1946. Their year-to-year fluctuations were very similar until the war, with the exception of one or two years. Moreover, except for the conversion and reconversion years, 1942 and 1946, the war years produced remarkable conformity to the previously established relationship.[2] With the increasing importance of fluorescent lighting, the level of incandescent lamp sales may decline somewhat from the level indicated by the historical relationship, but the associations between direction and rate of change should remain reasonably constant for the two series.

While lamp prices have some influence on lamp demand, it is highly likely that the price elasticity of demand over time is considerably less than 1. A study of Figure 42 reveals no instances in which large increases in lamp sales can be explained better by price reductions than by reductions in power rates, by cyclical fluctuations in national income, or by other factors. In fact, the great wartime increases in sales occurred despite higher average prices.[3]

The charts indicate that there has been little economic inducement other than competitive pressure to reduce the prices of large incandescent lamps. Price cuts have not generally increased total sales by amounts large enough to offset the lower profit margins. The fact that average prices have been reduced by more than 60 per cent in the last twenty-six years suggests that maximum monopolistic prices have been impossible, although profits realized from lamp making by the large companies indicate that prices have been well above a "purely competitive" level.

[1] The average list prices of 21.0 cents for 1942 through 1944 have been estimated from incomplete data. The actual prices probably varied somewhat from the estimates.

[2] For the period 1920 through 1946, the two series have a Pearsonian correlation coefficient of .92. Their average relationship can be expressed by the equation $Y_c = .565\ X + 67.9$, where Y is total domestic sales of large incandescent lamps in millions of dollars and X is national income in billions of dollars. The standard error of estimate is 8.6. All computations have been adjusted for sample size. These results are, of course, subject to the usual limitations of time series correlation, for the successive values are not independent and other variables are important.

[3] The higher average prices resulted from a shift in demand toward the larger and more costly lamps rather than from changes in list prices.

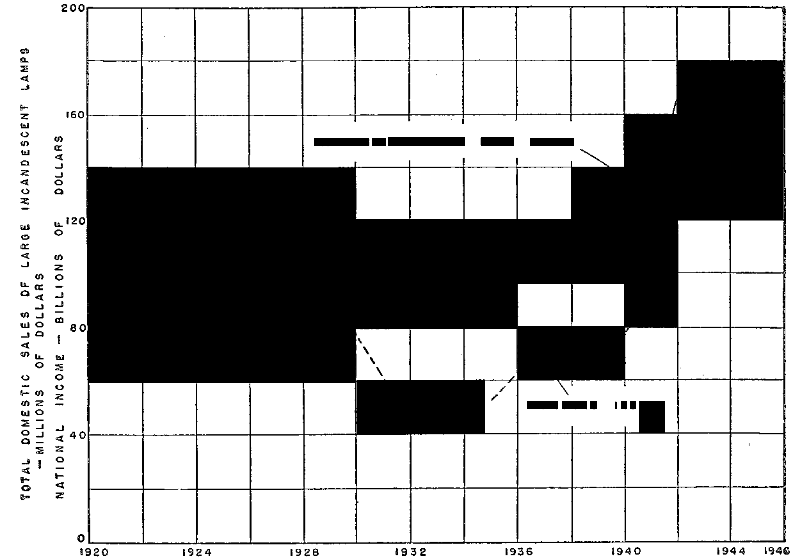


FIG. 43. National Income and Sales of Large Incandescent Lamps in the United States, 1920–1946

Sources: Simon S. Kuznets, *National Income and Its Composition,* Vol. I, National Bureau of Economic Research, New York, 1941, p. 137; Bureau of Labor Statistics, *Survey of Current Business*, Washington; *Electrical World*, Vol. LXXXIX, p. 78 (Jan. 1, 1927); members of the lamp industry; and others.

Appendix G

TABLE XLIII: AMERICAN PRODUCTION AND SHIPMENTS OF ELECTRIC LAMPS, 1945

(All quantity and value figures in thousands)

Product	Number of Companies[a]	Production (Quantity)	Shipments: Total		Shipments: Domestic		Shipments: Export	
			Quantity	*Value*	*Quantity*	*Value*	*Quantity*	*Value*
Incandescent lamps:								
Large lamps:								
150-watt and under	16	709,229	712,769	$ 61,948	680,791	$ 58,517	31,978	$3,431
Over 150-watt	14	77,883	81,633	31,882	78,522	30,196	3,111	1,685
Total	16	787,112	794,402	93,82[illegible]	759,313	88,713	35,089	5,116
Miniature lamps:[b]								
Automotive, sealed beam	3	12,360	12,363	5,308	12,038	5,184	325	124
Other automotive	7	145,971	142,228	7,642	135,856	7,264	6,372	378
Other than automotive	14	165,657	182,734	8,946	167,532	8,364	15,202	581
Total	14	323,988	337,325	21,896	315,426	20,812	21,899	1,083
Total incandescent	26	1,111,100	1,131,727	115,725	1,074,739	109,525	56,988	6,199
All other lamps:								
Christmas-tree[c]	3	31,360	29,650	956	29,442	950	208	6
Fluorescent, RF and F[d]	5	37,017	42,781	20,892	40,686	19,824	2,095	1,068
Germicidal	3	371	163	434	158	430	5	4
Photoflash	3	37,592	36,447	2,988	35,157	2,882	1,290	106
Misc. electrical discharge[e]	3	8,733	9,921	3,153	9,783	3,113	138	40
Total all other lamps	6	115,073	118,962	28,423	115,226	27,199	3,736	1,224
Total all lamps	26	1,226,173	1,250,689	$144,148	1,189,965	$136,725	60,724	$7,423

[a] The operations of 26 companies, representing virtually the entire American electric-lamp industry, are included.

[b] Except Christmas-tree lamps.

[c] Includes fluorescent Christmas-tree lamps.

[d] Does not include fluorescent Christmas-tree lamps or RP-12 "black light" bulbs.

[e] Includes glow, sodium, RP-12 "black light," photochemical, mercury, and sun lamps.

Source: Bureau of the Census, U.S. Dept. of Commerce, *Facts for Industry: Electric Lamps,* Washington, July 15, 1946.

Appendix H

TABLE XLIV: RATED AVERAGE LIVES[a] FOR SELECTED SIZES OF LARGE TUNGSTEN-FILAMENT LAMPS FOR GENERAL LIGHTING, 1907–1947[b]

Date of Rated Life Change	*15–W*	*25–W*	*40–W*	*50–W*	*60–W*	*75–W*	*100–W*	*150–W*	*200–W*	*300–W*[c]	*500–W*	*1000–W*	*1500–W*
Nov. 25, 1907			800		800								
May 12, 1908			....		....		800						
Oct. 1, 1908		800	....		....		....						
July 12, 1909		....	....		....		....	800					
Jan. 1, 1910		1000	1000		1000		1000	1000					
Dec. 16, 1911	1000	....	....		....		....	....					
July 1, 1914	....	....	....		....		....	....			1000	1000	
Oct. 1, 1914	....	....	....		....		....	....	1000	1000	....	....	
July 1, 1916	....	....	....	1000	....	1000	....	....	....	....	....	....	
Mar. 1, 1931	....	....	....	....	....	....	....	....	....	....	....	....	1000
Apr. 1, 1933	....	....	....	....	....	750	750	....	....	....	....	....	....
May 1, 1936	....	....	....	....	....	....	....	750	....	....	....	....	....
June 1, 1937	....	....	....	....	....	....	....	....	750	....	....	....	....
June 1, 1940	750	750	....	....	....	....	....	....	....	....	....	....	....
Jan. 1, 1942	1200	1000	....	....	....	....	....	....	....	....	....	....	....

[a] Rated life is an average figure obtained from tests under specified conditions.

[b] There have been no changes in the rated lives of any of these lamps since Jan. 1, 1942.

[c] The 300-watt lamp introduced in 1914 had a mogul base. A medium base lamp of 750-hour life with a rating of 300 watts was introduced in 1937.

Sources: General Electric Company, Westinghouse Electric Corporation, and Sylvania Electric Products, Inc.

Appendix I: TECHNOLOGICAL CHANGES IN THE ELECTRIC-LAMP INDUSTRY, 1907–1931 [1]

1907 (1) Mechanical mixing and control of batch for glass furnace
(2) Electric welding machine for making lead-in wires
1910 (3) Standardization of formulas for bulbs and tubing
(4) Tungsten made ductile
(5) Regenerative pot furnaces
1912 (6) Empire semiautomatic bulb-blowing machine
(7) Westlake bulb machine
1913 (8) Dumet wire for welds
(9) Double electric welding machine
(10) The gas-filled lamp
1914 (11) The first automatic indexing machine (for sealing)
(12) Automatic miniature beading and mounting machine
(13) Automatic support-wire inserting machine
1915 (14) Lime glass for bulbs (facilitating automatic bulb making)
(15) Automatic base-filling machine (for inserting cement)
(16) Metal dies for drawing tungsten and molybdenum
(17) Automatic exhaust machine
1916 (18) Danner tube-drawing machine
1917 (19) Magnetic separator for automatically removing iron from glass
1918 (20) Development of standard machine parts for glass manufacture
(21) Continuous mandrel coiling machine
(22) Automatic miniature-bulb blowing machine
1919 (23) Tipless lamp
(24) Automatic glass-tube-sorting machine
(25) Tank furnace for automatic bulb production
(26) Tank cars for shipping sand
(27) Mixing of tungsten ores
1920 (28) Spray coating process
(29) Automatic safety stop, Westlake bulb machine
(30) Burn-off machine for automatically removing surplus glass from necks of bulbs
(31) Hot-cut flare machine

[1] Only outstanding changes are included, and particularly those that have tended to reduce the amount of labor time per unit of output. The dates given are in some cases approximate.

1921 (32) Miniature percussive welder
(33) Large percussive welder
(34) Development of group or unit system of manufacture
(35) Printing of monograms and labels on bulbs
(36) High-production tipless stem machine
1922 (37) High-production support-wire inserting machine
(38) Tungsten wire annealing
(39) Bulb annealing furnace (as high as 600,000 a day)
1923 (40) Elimination of trays in bulb works
(41) Coiling machine for miniature-lamp filaments
1924 (42) Use of natural gas in cutting-off and burning-off processes
(43) Basing and soldering machine
(44) Photoelectric cell applied to photometry (measuring the light output of lamps)
(45) Sealex machine (for sealing, exhausting, and gas filling)
1925 (46) Automatic batch (glass) feeder
(47) Inside frosting machine
(48) Improved type of steel for cams
(49) Simplified and standardized line of bulbs, facilitating mass production
(50) Improved mandrels for use in making glass tubing
(51) Mercury pumps
(52) Combination miniature coiling and coil-mounting machine
(53) Standardization of lamps, facilitating mass production (6 standard lamps replacing 45 types and sizes for ordinary lighting)
1926 (54) Improved packing of glass tubing
(55) The 48-spindle bulb machine
(56) Elimination of bulb washing
(57) Automatic miniature butt-sealing machine
1927 (58) The Corning ribbon bulb machine
(59) Improved method of mixing tungsten powder
(60) Mechanical temperature indicator for exhaust
(61) High-frequency test device
(62) Cutting of glass tubing to predetermined length
(63) Elimination of tissue-paper bulb wrapping
(64) Improved dimension gauges
1928 (65) Tubular bulb machine
(66) Tank furnace for tubing
1929 (67) Electric bulb annealing
(68) Automatic weighing of glass tubing

(69) Use of the photoelectric cell for sorting
(70) Machine for coiling filament wire without a mandrel
(71) Automatic mounting machine for mounting filaments in large lamps
(72) Centering of filament in focusing type miniature lamps by beam-of-light method

1930 (73) The Ohio bulb machine
(74) Improved methods of coil production and coil cleaning
(75) Extension of automatic mounting of filaments
(76) Improved lamp conveyor on sealex machine
(77) Multiple dip gettering machine
(78) Stem-making and sealing machine for 5,000- and 10,000-watt lamps
(79) Mechanical cullet (waste glass) pull-down device for sealex machine
(80) Development of butt-lamp sealing machine to seal automobile headlight lamps of the flange-seal type
(81) Development of conveyor and other units to allow continuous progressive operations in making automobile headlight lamps
(82) Improved soldering devices

1931 (83) Automatic cutting, sizing, and glazing of tubing for butt sealing
(84) Improved gas burners for glass cracking and burning operations
(85) Rivet soldering on basing machines
(86) Improved miniature-bulb hot-cut machine

Source: Witt Bowden, *Technological Changes and Employment in the Electric-Lamp Industry*, Bureau of Labor Statistics, Bulletin No. 593, Washington, 1933, pp. 30–32.

Appendix J

TABLE XLV: SPECIFICATIONS OF ALL SIZES OF FLUORESCENT LAMPS

(as of June 1, 1942)

Nominal Lamp Watts[a]	*4-W*	*6-W*	*8-W*	*14-W*	*15-W T-8*	*15-W T-12*	*20-W*	*30-W*	*40-W*	*65-W*	*100-W*	*85-W RF*
Date of introduction	1941	1940	1941	1940	1938	1938	1938	1938	1939	1941	1940	1939
Nominal lamp amperes	.13	.15	.18	.37	.30	.33	.35	.34	.41	1.35	1.45	.90
Nominal lamp volts	37	45	54	41	56	48	62	103	108	50	72	132
Circuit volts	110-125	110-125	110-125	110-125	110-125	110-125	110-125	110-125 220-250 199-216	110-125 220-250 199-216	110-125	110-125 220-250 199-216	95-125 190-250
Bulb	T-5	T-5	T-5	T-12	T-8	T-12	T-12	T-8	T-12	T-17	T-17	T-10
Diameter (inches)	⅝	⅝	⅝	1½	1	1½	1½	1	1½	2⅛	2⅛	1¼
Length (inches)	6	9	12	15	18	18	24	36	48	36	60	58
Base	Min. Bi-pin	Min. Bi-pin	Min. Bi-pin	Med. Bi-pin	Med. Bi-pin	Med. Bi-pin	Med. Bi-pin	Med. Bi-pin	Med. Bi-pin	Mogul Bi-pin	Mogul Bi-pin	Special

[a] Add auxiliary watts for total.

Sources: General Electric Company, Westinghouse Electric Corporation, and Sylvania Electric Products, Inc.

Appendix K: SUBSIDIARY CONCLUSIONS ON TECHNOLOGICAL CHANGE IN THE AMERICAN ELECTRIC-LAMP INDUSTRY

MANY factors in the environment of an industry in addition to the major ones treated in Chapter XVI are of potential importance in technological progress. In the lamp industry the following topics deserve brief mention.

Competition Among Light Sources. During several periods in the history of electric lighting, the competition between alternative light sources has provided an important stimulus to technological activity. That competition was most keen and effective in reducing costs and improving lamp quality around the turn of the century, when the high-pressure Welsbach gas mantle and the enclosed and flaming arcs were pushing the carbon-filament lamp so hard.[1] Even earlier, the rise of electric-light sources had put pressure on gas lighting and had resulted in various improvements including the Welsbach mantle.[2] The arc and incandescent sources provided mutual stimulation from 1880 until the filament lamp finally won out around 1915. The rise of the Moore tube, the Cooper-Hewitt lamp, and other electric-discharge sources also had a stimulating effect on incandescent lighting early in the century.[3]

At the present time the only important commercial rivalry that has stimulated technological rivalry is that between hot-cathode and cold-cathode fluorescent lighting. Since they still control but a small proportion of the total lighting market, and since each has fairly distinct advantages in certain types of applications, the area in which the competition can be effective is fairly limited. Nevertheless, the interplay between them has already had some beneficial results, and continued competition is desirable. Of course, incandescent lighting competes with each of the fluorescent sources, but the fact that the same companies promote both hot-cathode fluorescent lighting and incandescent lighting has led to a lessening of the effect in that instance. In addition, incandescent lighting has about reached its practical limits in efficiency and life, and even the threat of major displacement probably cannot have much effect on its rate of improvement.

Labor and Technological Change. An essential characteristic of labor in the United States during most of its history has been its relative scarcity and high cost as compared with labor in virtually

[1] See pp. 127–129, 211–218.
[2] See pp. 126–127.
[3] See pp. 221–229.

all other countries. In the lamp industry this situation provided an initial and continuing stimulus to mechanization and the improvement of production methods. During the years before 1910, lamp prices in each producing country reflected competitive conditions in the industry. In some countries prices were higher than in the United States; in a few they were slightly lower. Where they were lower, lamps were usually poorer in quality. Nevertheless, the lower prices in France and Germany were factors in the first wave of mechanization in the American lamp industry after about 1900. So much momentum was picked up early in the twentieth century by General Electric and Westinghouse in cost and price reductions that they completely outdistanced their foreign competitors.

The small American producers have been affected in a somewhat different fashion. Their prices have been established, in effect, by General Electric. Their slower machinery and lower productivity have forced them to pay somewhat lower wage rates than those paid by the General Electric group. Nevertheless, the continuous upward long-run pressure on wages has created a definite incentive for method improvements.

On the other hand, there is very little evidence of resistance by labor to technological progress in electric lighting. The outstanding example was the opposition by arc-lamp trimmers to the introduction of the enclosed arc.[4] The enclosed carbons lasted considerably longer and required less attention. The resistance was ineffectual, however, and did not last long. The lack of opposition to mechanization in lamp assembly resulted from many factors. After about 1900 most employees were semiskilled women, among whom the turnover was high. Where the labor force was reduced through productivity increases, as was true particularly from 1922 to 1931, normal retirements and reduced hiring took care of most of the shrinkage without layoffs. Workers were not unionized until after about 1940, and any protests that were made about the displacement of workers by machines were ineffective without organization.[5] It is still too early to conclude what the effect of unionization will be on future productivity advances.

The Business Cycle and Technological Change. The principal effect of the business cycle on technological activity in electric lighting has been its influence on research and development budgets. Although the large companies have made efforts to keep such expenditures up during poor years, there have been cyclical fluctuations about the rising trends. Less downward flexibility in technical expendi-

[4] See pp. 128–129.
[5] See p. 360.

tures would be beneficial. Owing to the lag between research or basic development and commercial use, some of the technological fruits of prosperity have been introduced during poorer years. The high-pressure mercury-vapor lamps and sodium lamps were introduced during the middle thirties; the fluorescent lamp came out in 1938; the group method of lamp assembly was introduced in 1921. Nevertheless, lamp-company executives had no established policy of introducing new devices or methods during depression years. In general, the policy has been to bring out new products and introduce new methods as soon as they are ready. The new products have enjoyed their most rapid expansion and made their greatest economic contributions during boom periods, however, regardless of when they were introduced.[6]

Public Attitude Toward Technological Change. The reaction of consumers to product changes is of great importance to the effectiveness and speed of introduction of new devices. Except for a few years after 1880, when both the arc lamp and the incandescent lamp were commercially new, the American public as a whole has responded enthusiastically to all genuine improvements in electric lighting, particularly when they reduced the cost of a given amount of light. There is no evidence of any important public resistance to change after the initial prejudice against electric lighting was overcome, although there was the usual caution by many over accepting new devices that required extensive investment for changes in wiring, fixtures, etc. Ignorance on the part of the public and the lack of competitive technological information reduced the pressure for the discovery of major new light sources, however. Although large buyers frequently pressed successfully for specific changes and for special lamps, their efforts did not appreciably speed the development of the revolutionary new fluorescent lamp. The situation was highly favorable to General Electric. Its control of the bulk of lamp sales, and the high degree of confidence placed in it by most lamp buyers permitted it to direct its technological efforts largely as it saw fit. Other American manufacturers for the most part were compelled to accept what General Electric made standard and attempt to duplicate the quality of its products.

Despite the receptiveness of the public to product innovations, it has exerted a relatively small pressure on lamp prices and, through prices, on lamp costs. Since lamps are only a small fraction of the total lighting bill, total lamp demand is insensitive to moderate price

[6] See, for example, the economic contributions of hot-cathode fluorescent lighting (pp. 410, 416–418).

changes.[7] While large purchasers have always been interested in lower prices, the limited supply of lamps outside the General Electric license group has greatly weakened their bargaining strength. Gradual reductions in prices over the years have mollified, if not satisfied, the large buyers, and cost reductions have preserved profit margins for General Electric. Despite the limited sales pressure of the independent firms, their expansion from 1912 to 1914, from 1921 to 1923, and during the late thirties in each instance provided an important stimulus for General Electric to reduce its prices.[8] The presence of a group of unlicensed firms at almost all times has helped keep prices below the full monopolistic level, although they have usually been above completely competitive prices.

While consumers as a group have willingly accepted innovations in electric lighting, opposition to the most revolutionary advances has continued to come from special groups with vested interests in the status quo. During the nineteenth century, the gas companies strongly resisted the introduction and spread of all electric lighting, both arc and incandescent.[9] The electric power companies have repeatedly offered short-term resistance to the commercialization of more efficient lighting devices, including the Nernst lamp,[10] the tungsten-filament lamp,[11] and fluorescent-lighting devices.[12] They have feared load losses where the new lamps could produce more light with lower current consumption. Fortunately, in each instance the opposition was ineffective or short-lived, and it seems unlikely that such groups will present more than temporary obstacles for future major innovations.

[7] See p. 270 and Appendix F.
[8] See pp. 250, 268.
[9] See pp. 43–44.
[10] See p. 173.
[11] See pp. 193–194.
[12] See pp. 401–404, 425.

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