CHAPTER VIII.

HISTORY AND DEVELOPMENT OF ELECTRIC LIGHTING.

General discussion.—Luminous effects, associated with the production of electric phenomena, were noted by many experimenters and physicists prior to 1800, but the history of electric lighting dates back only to the beginning of the last century; while the history of central stations proper belongs to the second half of the century, and, in reality, so far as its relation to the public is concerned, may be considered as belonging only to the period dating from 1875. In other words, although a great deal of work done in the preceding seventy-five years was of an eminently practical nature, embodying the inventions of a long series of illustrious discoverers and experimenters, many of whom have lived to see this great art in its present manifestations, the commercial and industrial development is limited to a quarter of a century.

The thousands of central stations and isolated plants, with their millions of lamps and motors scattered throughout the world, are based fundamentally on the application of a few elementary principles of electricity, and even the newer appliances which have marked the opening of the present century are the reduction to practical form of theories and principles determined at a very early stage, needing but the energy of the inventor or the skill of the engineer to render them useful and available.

I.

THE ARC LIGHT.

Batteries as sources of current.—Electric lighting may be said to have begun with the work of Sir Humphry Davy while an assistant lecturer in the Royal Institution in London. He demonstrated Volta's theory of obtaining electricity from cells consisting of unlike metals immersed in a liquid, and was one of the first to apply this new source of power to the investigation of the elements. In 1808, with the aid of a few wealthy members of the institution, Davy constructed a battery comprising no fewer than 2,000 cells (up to that time the institution had had but 500 cells) grouped in 200 porcelain troughs. The liquid employed in each cell was a mixture of 60 parts of water with 1 of nitric and sulphuric acid, the plates were zinc and copper squares, affording 32 inches of surface. While the effect produced by any one of these cells (which were quite analogous to those still in general use) would be very feeble and insignificant, their combined action was quite notable, especially when applied to the consumption of sticks of wood charcoal. Davy exhibited his battery before the members of the Royal Institution in 1809–10 with brilliant and impressive results, which he described as follows: "When pieces of charcoal about an inch long and one-sixth of an inch in diameter were brought near each other (within the thirtieth or fortieth of an inch), a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and by withdrawing the points from each other a constant discharge took place through the heated air in a space equal to at least 4 inches, producing a most brilliant ascending arc of light, broad and conical in form in the middle." These sticks of wood charcoal, exposed to the air and to such a current, wasted away very rapidly by combustion in the arc; and as the apparatus was not provided with a regulator, such a demonstration was necessarily of a very fugitive character. For over thirty years the production of electric light in the arc thus described remained a brilliant and expensive laboratory experiment, and, indeed, but for the invention of the modern dynamo electric machine, would have so continued, although a great deal of interesting work was done in the improvement of the carbons by experimenters who still employed primary batteries as the source of current.

Earliest exhibition and use of arc lights.—In 1844 the French physicist, Foucault, after whom well-known electric phenomena have been named, hit upon the idea of replacing the soft wood carbon by that deposited in gas retorts; this he cut into square sticks. This carbon, while a decided improvement, contained silica and alkaline earths, which in fusing and vaporizing broke up the carbon and disturbed the arc. Foucault was able, however, by using the Bunsen battery in conjunction with such carbons, to produce a remarkably steady and continuous light. He was able to use the light even for photographic purposes by employing these graphitic carbons and powerful batteries. A great step forward was thus made.

It deserves mention here, however, in connection with the use of electric light for photographic purposes that some work had already been done in America. In the Journal of the Franklin Institute for 1843 record is made of the fact that in November, 1840, with the large

ISLE OF SAFETY ON LOWER FIFTH AVENUE, NEW YORK CITY.

This artistic fixture combines arc and incandescent lighting and serves also as a halting place for pedestrians.

battery of 500 cells belonging to the laboratory of Yale College, Prof. B. A. Stillman, jr., and Dr. W. H. Goode secured photographic impressions by light reflected from the surface of a medallion to the iodized surface of a daguerreotype plate. Two pictures were thus obtained, one of the medallion only and the other just showing a blur or halation due to the light from the charcoal points, just as to-day one sometimes sees the halation in poorly executed photographs.

The Foucault arc light was exhibited publicly in Paris by Deleuil, and its availability and adoption for lighting houses, squares, and streets began to be generally discussed. The new illuminant was not able, however, to compete on anything like equal terms with such rivals as gas, oil, and tallow. The inconvenience attaching to the use of the batteries, as well as that attendant upon controlling the lamps by hand, discouraged anything but the most limited use. As a matter of fact, however, the first practical work belongs to this period, when "an electric sun" shed its beams upon the stage during the presentation of Rossini's opera "Moses" at the Paris Opera House. This interior employment was matched by Deleuil on the Place de la Concorde, where the lamp was placed on the knees of the statue of a woman typifying the town of Lille. This out-of-door illumination excited a great deal of attention and comment. It is hardly necessary to add that the presence of a man to regulate the lamp by hand was not particularly impressive as to its features of economy and availability. After the exhibition in the Place de la Concorde other electric lamps were set up in Paris on the Pont-Neuf over the Seine, on the Arc de Triomphe at the crest of the Champs Elysées, in the large court of the Palais Royal, and at the Porte Saint-Martin. All such work, however, was evanescent, though well directed and backed by persons of influence.

The first public exhibition of arc lighting in England was made by Mr. E. E. Staite at Sunderland, and during the next four years he gave demonstrations in other English towns. His work made such an impression that in 1852 the dock commissioners of Liverpool built a high tower for the purpose of placing an electric arc upon it for light house purposes; but Mr. Staite died in that year and the project seems to have gone out of existence with him.

Automatic adjustment of carbons.—In 1845 Thomas Wright, of London, made another long step forward by devising a lamp in which the carbons were automatically adjusted. In this lamp the carbons were made in the form of disks rotating by clockwork, with a slow, continuous motion, the arc forming at that point on the two peripheries where they most closely approached each other, so that the arc may be roughly described as having nibbled away the edges of the two carbon wheels as they revolved. To obtain an arc between the two plates or pencils of carbon it was necessary to start a current in the circuit, either by bringing the carbons into contact with each other or by some other device, and when the current had been thus established the edges of the carbons had to be fed together and kept within a certain slight distance of each other so as to maintain the proper length of the arc. The operation of "striking the arc" and regulating the feed of the carbons toward each other was done by hand before Wright's invention, which was followed by those of Staite in 1847, Foucault in 1849, Serrin in 1857, and Duboscq in 1858. The last named made what is spoken of as the first real arc lamp, one for laboratories.

In 1855 La Cassagne and Thiers, of France, brought out their regulator patents, which employed a column of mercury and special mechanism—two separate electromagnets—to lift and feed the carbons. With this apparatus they lighted the Quai des Celestins, at Lyon, in June of that year, eliciting very enthusiastic descriptions from the journals of the day.

Improvements in carbons.—About the same time these two inventors improved also the carbon used in arc lamps by dipping pieces of gas carbon in a solution of caustic potash or soda, and then exposing them to a very high temperature to transform the silica of the carbon into soluble silicate. By washing the carbon sticks in hot water, and then subjecting them to chlorine at red heat, the components that had not been acted upon by the potash were transformed into volatile chlorides of silicon, potassium, iron, etc. The light obtained from these carbons was steadier, but a great deal of ashes and dust resulted.

In 1846 Greener and Staite also patented processes for improving the manufacture of carbons, and in this as well as in other ways the quality of the light was improved, subject, however, to the fatal limitation of the batteries as sources of current. As the best of the batteries could give a pressure of only 1 or 2 volts, while that needed to maintain an arc of one-tenth inch is 60 volts. With the amount of pressure needed increasing rapidly as the arc or space between the carbon points is lengthened, it is readily seen that a large number of batteries would be required to maintain even a single arc lamp in operation; hence an attempt to operate a circuit from batteries, whether the lamps were strung in series or in parallel, would make the problem quite unmanageable. Some of these features, in connection with the lamp itself, will be dealt with more fully in the discussion of that part of the system.

Dynamos as sources of current.—It has been the custom of popular writers to date the beginning of the modern period of arc lighting, dependent upon dynamos as sources of current, from the work of Z. T. Gramme, a Belgian inventor, residing in Paris. His first patent was taken out in 1870 and his first dynamo electric machine was submitted to the Academy of Sciences in 1871. While this view is fair and broadly justified, and while the modern central station was founded upon

such apparatus, it must not be forgotten that commercial arc lighting had already been accomplished with other types of electric machines; that a vast amount of successful work had already been performed in the production of such apparatus, and that all this machinery was based primarily upon the law or principle discovered by Faraday, according to which, if magnets or coils of wire be constantly moved or displaced in relation to each other, electric currents are set up in the wires or conductors, the quality of the current depending upon the strength and number of magnets, the velocity and direction of their movements, and the number of coils or the turns of wire in each one of them. Such a mechanism of magnets and coils can be operated by hand or by animal power. The magnets can be thrust rapidly into the coils of wire and be drawn from them by reciprocal motion. Some of the earliest electric motors were devised to operate upon this method, but the reciprocating plan has never found successful application in electric generators, although within recent years Mr. Tesla has revived the idea by some very ingenious work in that field with his "oscillators." Ordinary revolution of the coils in juxtaposition to the magnets, or vice versa, is more simply effected than the reciprocating movement, and can be best applied by means of a steam engine or a water turbine, insuring a smooth rotary motion, which can be maintained for several hours, even with extremely heavy revolving parts. In some of the first apparatus of this character bar or permanent horseshoe magnets were employed in what are still known as magneto-electric machines, but these were soon replaced by electro-magnets, in which coils of wire were not only revolved in front of the magnets, but other coils were placed on the limbs of the magnets, so that the slight current at first produced in setting the apparatus in motion could be increased and intensified by the reaction between the magnets and the revolving armature coils.

The following is a quotation on this subject from the significant discourse of Professor Tyndall on the discoveries of Siemens and Wheatstone in this direction:

On the 4th of February, 1867, a paper was received from the Royal Society, from Mr. William Siemens, bearing the title, "On the Conversion of Dynamic into Electrical Force without the use of Permanent Magnetism." On the 14th of February a paper from Sir Charles Wheatstone was received bearing the title, "On the Augmentation of the Power of a Magnet by the Reaction thereon of Currents Induced by the Magnet Itself." Both papers, which dealt with the same discovery, and which were illustrated by experiments, were read upon the same night, viz, the 14th of February. The whole field of science hardly furnishes a more beautiful example of the interaction of natural forces than that set forth in these two papers. You can hardly find a bit of iron, you can hardly pick up an old horseshoe, for example, that does not possess a trace of permanent magnetism; and from such small beginnings Siemens and Wheatstone have taught us to rise by a series of interactions between magnet and armature to a magnetic intensity previously unapproached. Conceive the Siemens armature placed between the poles of a suitable electro-magnet. Suppose the latter to possess at starting the faintest trace of magnetism; when the armature rotates, currents of infinitesimal strength are generated in its coil. Let the ends of that coil be connected with the wire surrounding the electro-magnet. The infinitesimal current generated in the armature will then circulate around the magnet, augmenting its intensity by an infinitesimal amount. The strengthened magnet instantly reacts upon the coil which feeds it, producing a current of greater strength. This current again passes round the magnet, which immediately brings its enhanced power to bear upon the coil. By this play of mutual give and take between magnet and armature the strength of the former is raised in a very brief interval from almost nothing to complete magnetic saturation. Such a magnet and armature are able to produce currents of extraordinary power; and if an electric lamp be introduced into the common circuit of magnet and armature we can readily obtain a most powerful light. By this discovery, then, we are enabled to avoid the trouble and expense involved in the employment of permanent magnets; we are also enabled to drop the exciting magneto-electric machine and the duplication of electric magnets. By it, in short, the electric generator is so far simplified and reduced in cost as to enable electricity to enter the lists as the rival of our present means of illumination.

A great tribute is paid here to Siemens and Wheatstone, but some of the merit of this remarkable discovery of the principle of mutual accumulation must be claimed also for the late Prof. Moses G. Farmer, a distinguished American, who, as early as 1865, built small dynamo electric machines in which, to use his own language, "I had the satisfaction of seeing the problem of mutual reaction and accumulation fairly solved." In confirmation of this, may be quoted the following passage from the Manchester, England, Literary and Philosophical Society's Proceedings, Volume VI, page 107:

Mr. Wilde has also received a letter on the subject of his recent experiments in magnets from Moses G. Farmer, of Salem, Mass., U. S. A., dated November 9, 1866, in which he says that he had obtained an increase of 31 per cent in the power of a magneto-electric machine, by transmitting the current from the armature through the coils of wire surrounding pieces of soft iron, forming prolonged extremities of the permanent magnets of the machine.

It will thus be seen that before the day of Gramme others had done work in connection with the evolution of dynamo electric machinery of the modern type, and, moreover, arc lighting had actually been accomplished on a large scale with the older type of apparatus. For example, under the superintendence of Faraday, the light house department of England, employing the Alliance apparatus devised by Nollet and Van Malderen, of Belgium, introduced the electric light in its important beacons at South Foreland and Dungeness, commanding the Straits of Dover. The preliminary trials were made in 1857, and the protecting beams of the intense electric arc were first thrown over the sea from South Foreland on December 8, 1858, and from the cliffs of Dungeness on June 6, 1862. The Alliance dynamo thus employed was built originally for the strange purpose of decomposing water, in order to employ the resulting gases in the production of light, but a much more direct and pertinent application was now made of it. The outer framework supported 24 com-

pound steel permanent magnets in banks of 3 each, and within the circular area they thus inclosed revolved the armature, which consisted of a drum carrying 32 spools of copper wire wound on iron cores. As these coils of wire thus revolved in front of the magnetic poles pointing inward, currents of an alternating character were developed in the coils, and were taken off by metallic collectors at the end of the armature shaft and were carried by wires to the large arc lamps devised by Professor Nollet. Similar work was done in 1863 at La Heve, near Havre, France, and the light was also employed at the Cherbourg docks. It is obvious that such machinery and methods were too uncertain and expensive to become generally available to the public, although they were in a sense commercial.

Alternating and direct currents.—The alternating current had to wait a score of years before its usefulness for general distributing purposes in connection with central stations could be demonstrated, all the initial lighting work from central stations being done by means of direct or continuous currents which were employed alike for arc and incandescent lighting. The alternating current may be imagined as flowing or surging to and fro in the circuit, so that if the circuit be compared with a water pipe the current would be discharged into the pipe at one end with one impulse and into the other end with the succeeding impulse from the feeding source. On the other hand, the direct or continuous current may be pictured as flowing steadily in one direction around the circuit so that the polarity is never changed or reversed.

Electric motors.—The supply of current to stationary motors for power purposes has been shown by many portions of the preceding text to constitute an important element in the central station industry of to-day. It is hardly necessary, however, to enter here into a discussion or historical review of the motor development, as it has already been done at some length in the bulletin on Electrical Apparatus and Supplies, issued on August 25, 1902.[1] It was pointed out that the discovery of the reversibility of the dynamo released electric power from the trammeling conditions that had hindered its development, and that following the first electrical exhibition in Philadelphia in 1884, the work of such men as Brush, Thomson, Daft, Sprague, Curtis, and Crocker, Wheeler and many others, soon resulted in the development of highly efficient motors, capable of application to the widest range of industrial requirements. The early motor work, as in the case of electric lighting, was done with direct current motors, and the next step forward was taken in the development of single phase alternating current motors. Then the inventions of Mr. Nikola Tesla and of other prominent inventors created the successful polyphase motor, and for some years past, as a result of such work, the entire art of electric generation and utilization of current has been dominated by polyphase conditions in a manner that has already been indicated in this text.

The Gramme armature.—The chief merit in the work of Gramme, whose improved dynamo gave such a stimulus to electric lighting, consisted in the construction of an armature employing essentially the soft iron ring wrapped around with consecutive lengths of insulated wire, which thus formed a number of short distinct coils. Up to that time all armatures had been constructed like unbroken spools of cotton on a reel or like balls of yarn wound on blocks. The ends of the Gramme coils were brought out and formed into one circuit. In other words, the bobbins or coils were placed close together on the iron core, and the inner end of each bobbin was soldered to the outer end of the neighboring one, so that the entire number of bobbins formed a series of convolutions constituting an endless electric circuit. Each coil or bobbin might have any number of convolutions of insulated wire, and the number of bobbins might also be varied, the changes in both respects depending upon the object for which the machine was intended. The ends of these coils were then brought out to the commutator delivering current to the collector brushes that rested on it, which in turn connected with the wires of the outer circuit upon which were grouped the lamps or motors.

Jablochkoff's lamp.—Shortly after the introduction of the Gramme machine a new era in electric lighting began on both sides of the Atlantic. A further advance in arc lighting was made by Jablochkoff, who in 1876 patented his arc lamps all over the world. This type of lamp was marked by an absence of much of the mechanism that had previously encumbered electric illuminating appliances. It consisted, broadly, of two vertical, parallel sticks of carbon separated slightly by an insulating material, such as kaolin, which was consumed at the same time as the carbons. These lamps were found to burn best with alternating current, which insured an even consumption of the carbons. They were soon to be seen burning on the streets of European cities, and found popularity in the United States as well, one of the first places in this country in which they were employed being the Wanamaker stores in Philadelphia.

American achievements.—American inventors were loath to leave this field to foreign competitors, and the closing years of the third quarter of the last century saw an enormous outburst of activity on their part also, with a corresponding movement in finance and industry. Among the leading workers of this period were Messrs. Charles F. Brush and Edward Weston, the former working at Cleveland, Ohio, and the latter at Newark, N. J. Both of these men worked along the line of the development of methods of series arc lighting, and their systems were soon largely and widely introduced here and in Europe.

[1] Twelfth Census, Vol. X, page 153.

The first Brush series arc lights were erected in the public squares of Cleveland, Ohio, in 1879, and shortly thereafter local Brush electric lighting companies were started in all the large cities and towns of the country, millions of dollars being raised for the purpose, and leading public men associating themselves readily with the enterprises. The first central station operating arc lamps was installed by the California Electric Light Company of San Francisco in 1879; the Brush system was employed. Neither Europe nor Asia escaped this American influence, for the Brush system was introduced in England at a very early date, and companies were organized in Japan and China also.

The Brush arc lamps were not only erected on short poles like ordinary gas lamp posts, but were also raised to the summit of lofty masts and metal towers so as to give the effect of a subdued moonlight, and for a time it was a question whether the tower or the lamp post would survive for urban electric illumination.

A very interesting and important chapter in the arc lighting history of this period was that contributed by William Wallace, of Ansonia, Conn., and Prof. Moses G. Farmer, of Salem, Mass., the former a pioneer copper and brass manufacturer, and the latter a prolific and original inventor of electric appliances. At an early date Mr. Wallace began to build dynamos intended for the work of electric deposition. It was inevitable that this work should lead to experiments in the field of electric illumination, and as a result the Wallace-Farmer dynamo was constructed and exhibited at the Philadelphia Centennial Exposition of 1876, where it was the only dynamo that supplied current for use in any way for the illumination of the Exposition buildings and grounds. The same inventors also exhibited at Philadelphia another machine, which had a capacity of energizing 11 arc lamps; an interesting feature in connection with this machine was the use of laminated iron plates in the armature, instead of solid cast iron cores, with corresponding increase of efficiency, lessening of heat in the machine, etc. A number of arc lamps also were built by Mr. Wallace, the first dating back to 1875; in this lamp and also in later ones flat or plate carbons were used. The arc traveled along the edges of the plates and thus maintained itself for a considerable period.

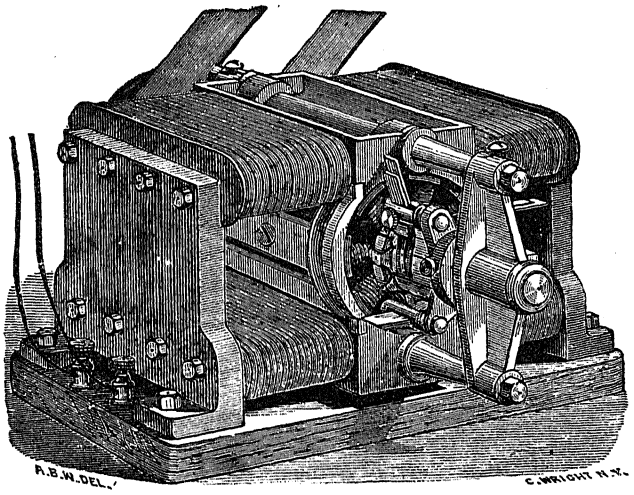
Mr. Wallace was one of the first to construct machines from which arc lamps were run in series, and at an early date began the manufacture of carbons, it being claimed in his behalf that he was the pioneer in the production of the round carbon pencil or point now so universally used. His works and appliances in carbon manufacture thus antedated those of Carré and others in Europe.

The work done by Mr. Wallace was on the whole of an intensely interesting character and of great originality. In some of his lamps as many as 12 carbons were employed, and in one lamp no fewer than 48 carbon pencils were operated—24 above and 24 below—the arc traveling from pencil to pencil as they burned away and the feeding being accomplished by a small electromagnet at the side of the lamp frame. The Wallace work, however, was based generally upon the use of low potentials, in contradistinction to the high potential with which commercial arc lighting is associated.

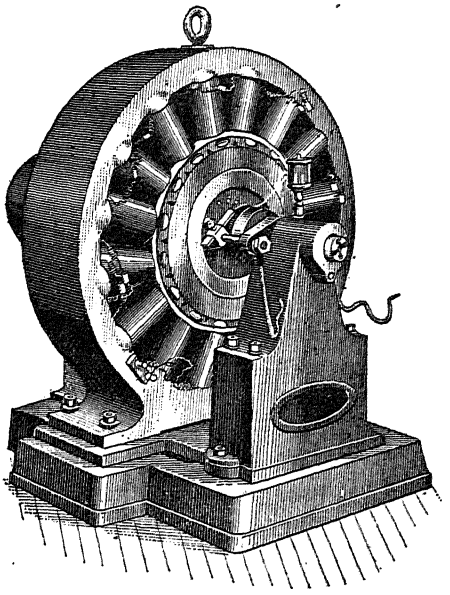
The Wallace and Farmer inventions soon became merged in the body of the industry and lost individuality, but not before imparting a tremendous impetus, the effects of which were directly felt by such men as Edison and Sprague, and are to-day freely acknowledged.

Indoor use of the arc lamp.—Early efforts were also made to introduce the arc lamp indoors, and Boston, Mass., witnessed one of the first attempts in this direction. Mr. Brush exhibited a small arc lighting dynamo at the Mechanics' Fair in Boston in October, 1878, and the following month this plant was put into regular service in a clothing store on Howard and Washington streets, its use being intended as much for advertising as for illuminating purposes. The lamps instead of using the cylindrical copper-coated carbons with which we are familiar had uncoated square carbon rods costing 25 cents each. The dynamos to which these lamps were connected had four cast-iron magnet arms with four flat pole pieces, between the faces of which revolved a cast-iron armature, upon which were wound four separate circuits of insulated wire, connected to as many pairs of independent commutator segments, upon which rested the brushes that collected the current from them. The eight coils of wire on the armature were wound in slots and were grouped into four separate pairs, to form four circuits. Each of these circuits to the commutator and from it was connected with a single arc lamp, so that the machine was what is known as a "four-arc lighter," and each lamp had a circuit of its own. There being no automatic cut-outs for the lamps in those days, the circuit was completed only through the shunt coils of the lamp magnets when the carbons burned out. The wiring was equally primitive, and when the four circuits were installed in the clothing store they consisted of bare No. 6 copper wire, secured in place by iron staples spiked over them into the woodwork.

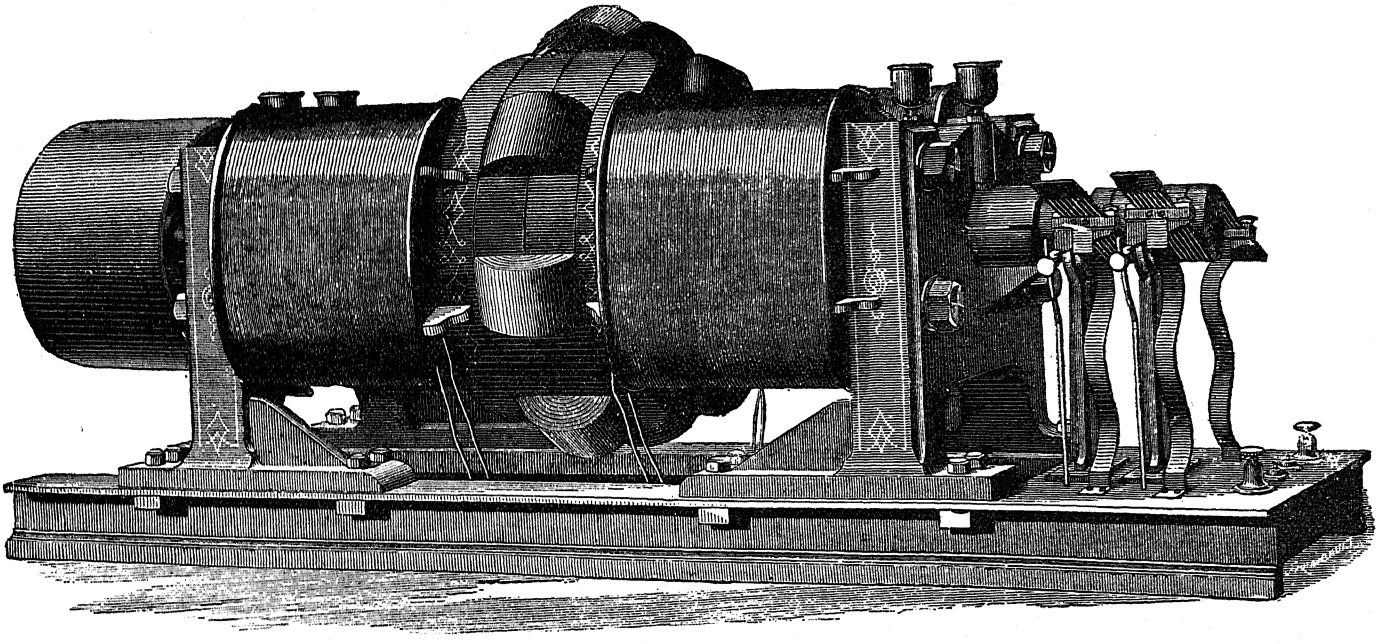
Earliest improvements.—Among the earliest improvements were those looking to the increase of capacity in arc lighting dynamos; the regulation of the lamp; the introduction of devices which should allow a circuit to remain in operation even if one or more lamps became disabled; the placing of two sets of carbons in one lamp so that when one became consumed the other could be cut in, continuing the lamp in operation; and the electric copper plating of carbons, which lessened the resistance of the circuit within the lamp itself.



FULLER TYPE OF GRAMME DYNAMO BUILT IN U. S. A., 1878.



EARLY TYPE OF STANLEY ALTERNATOR.



EARLY TYPE OF BRUSH OPEN-CIRCUIT ARC-LIGHTING DYNAMO.
Fac-simile reproduction of an early engraving.

Street lighting.—The arc lighting companies began to take contracts for city street lighting, and $1 per night per arc lamp was by no means an unusual price, the amount of light furnished being what is known as "2,000 candlepower." This invasion of the field of street lighting led to another increase in the capacity of the machines, and in the length of the circuits to which they furnished current.

Weston's arc lamps and dynamos began to be used in considerable numbers during this period, and several of his 10-light machines would be coupled into a single series circuit of 40 or 50 lamps. The arcs were of the short hissing character requiring a pressure of from 20 to 30 volts per lamp and a volume of 18 or 20 amperes of current on the circuit. The dynamos and lamps of J. J. Wood and W. Hochhausen also became widely known and used.

About 1881 the Thomson-Houston system made its appearance and the first 25-light arc machines of that type were built at New Britain, Conn., circuits of 10 amperes and 40 or 50 volts to the arc being employed. The best summary of the conditions encountered in 1883 and 1884 is that furnished by Prof. Elihu Thomson, when he said:

> The arc lighting systems were not without their difficulties. Good carbons were not always to be had, and crooked ones were common. Opal globes were very thick and absorbent, while for indoor uses the 10-ampere arc with clear ground globe was too intense. Construction of the line and apparatus was not easy, owing to the lack of suitable materials and labor. Copper wire without soldered joints could be obtained only in lengths aggregating a few pounds. Armature iron for dynamos was of uncertain and irregular quality. Of insulating material there was very little variety and often it was not high grade. Baking ovens came later. We had to construct our own measuring instruments and standards, as suitable ones were not to be bought. The plant after construction and installation was often at the mercy of poor power and of unskilled attendants. The plant had to take care of itself in a large measure. It is interesting to note that the man in charge of the Lynn arc lighting station in 1883, who ran the engine and several arc lighting dynamos, would lock up the station for an hour or so at a time, while he was out patrolling the line; everything continuing in full blast.

II.

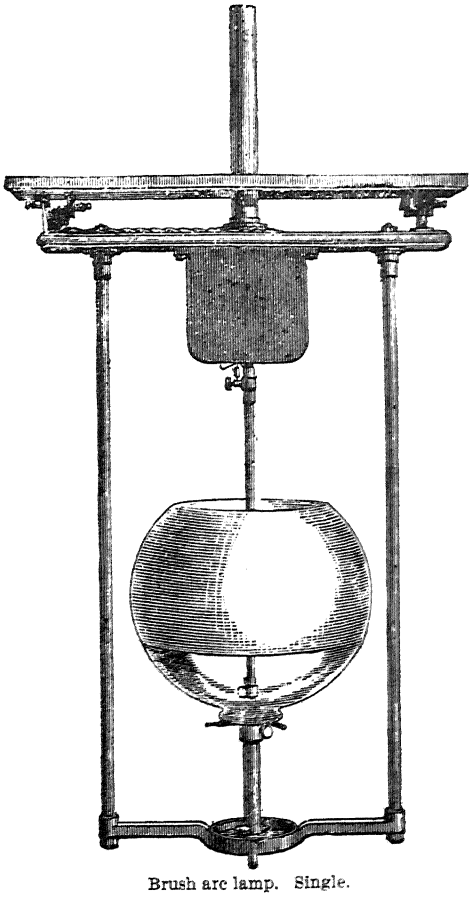
THE INCANDESCENT LIGHT.

The furore and success attending arc lighting had had its influence upon the perfecting of the incandescent lamp, and several distinguished inventors on both sides of the Atlantic—notably Swan, Lane-Fox, and Crookes in England, and Edison, Brush, Sawyer and Man, Weston and Maxim in this country—devoted their energies partly or exclusively to this field. The production of a perfect commercial incandescent lamp soon virtually resolved itself into a race with a prize of inestimable value as its goal. The result aimed at was a lamp that would permit the minute subdividing of the electric current, so that lights corresponding to gas jets in their size, general utility, and economy could be furnished. Arc lamps run at high pressure with currents of dangerous voltage were applicable only to large spaces, and with aerial circuits, more particularly to street illumination—a comparatively restricted field. They left untouched almost the entire domain of interior illumination—the largest market and principal area for artificial illumination.

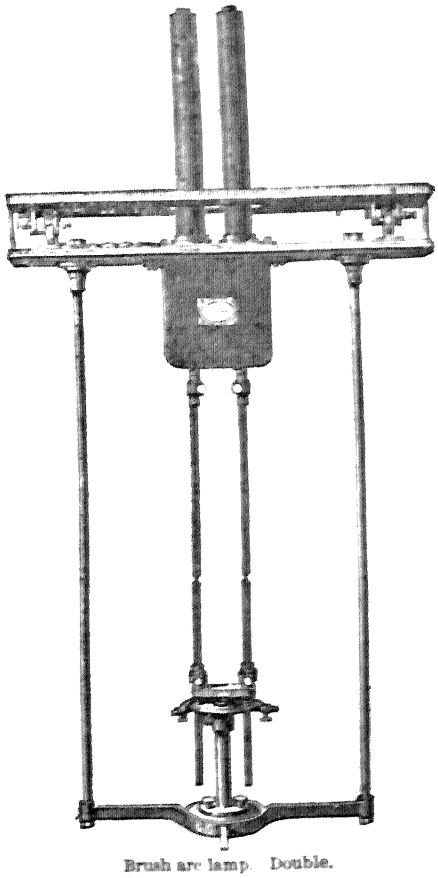
The first lamps.—The fundamental principle of obtaining illumination by rendering a body incandescent with electric current was by no means new, but dated back to the first half of the century. The essential ideas were described as early as 1841 by De Moleyns, who in that year patented in England an electric lamp of crude form in which a platinum wire to be rendered incandescent by the passage of an electric current was inclosed in an exhausted glass bulb. A few years later a most interesting lamp was devised by Starr, of Cincinnati, Ohio. He died in 1847 at the early age of 25 years, but before his death he had done a great deal to perfect his lamp and a magneto-electric dynamo with which to furnish current to it. This young man, as early as 1844, called attention to his apparatus in the Cincinnati "Advertiser," and proposed to install on high towers some lamps that would "enable a light to be diffused all over Cincinnati equal for practical purposes to that of daylight." The Starr lamp consisted of an exhausted glass globe in which was a thin strip of graphite held between two clamps affixed to a porcelain rod, the latter being suspended by a platinum wire sealed in the globe. This lamp is said to have given an excellent light and, as will be noted, involved the essential elements of incandescent lamps of the present day, namely, a carbon member inserted, and brought to incandescence by current, in a globe exhausted of air. This early American lamp was patented by King in England in 1845, and was described as being extremely promising for its purity, brilliance, and strength. Dredge's "Electric Illumination," a standard work, asserts that King manipulated affairs so as to keep Starr in the background and deprive him of reward and credit for inventions that anticipated much valuable work of later date.

Edison's experiments.—None of this early work left any permanent results, and the commercial subdivision of electric lighting was set down as impracticable by some of the foremost scientific authorities up to the very moment (twenty-five years ago) when Edison produced his first lamps and used them for general illuminating purposes. Without detraction to the other notable and meritorious work done in this field, his achievements may be cited as typical and illustrative of the underlying principles, of the difficulties to be overcome, and of the results attained.

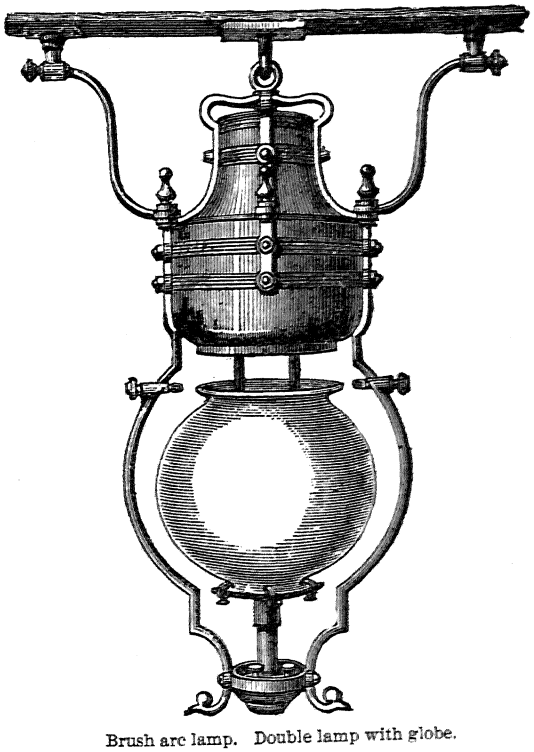
His experiments on carbon as a material for use in electric work began in 1876, and in the fall of 1877 strips of carbonized paper were tried as an incandescent conductor suitable for use in small lamps. Work along this line was continued until January, 1878, and resumed again in the fall of that year, when Mr. Batchelor, one of Mr. Edison's leading associates, made for illuminat-



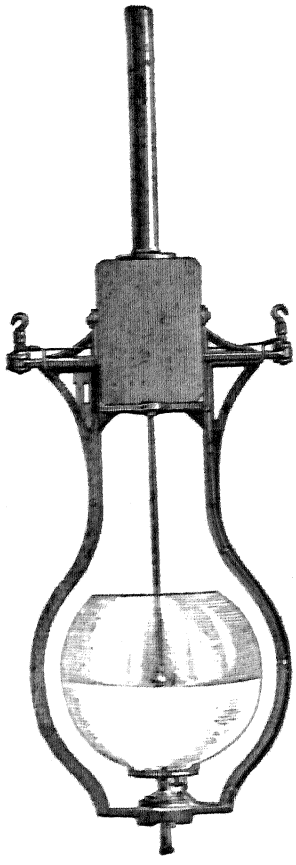
Brush arc lamp. Single.



Brush arc lamp. Double.



Brush arc lamp. Double lamp with globe.



Thomson-Houston arc lamp.

EARLY TYPES OF ARC LAMPS.

ing purposes a great number of carbons from tissue and other kinds of paper, coating their surface with a mixture of lampblack and tar, rolling them up into the fine long form of a knitting needle, and then carbonizing the "filament" thus obtained. These filaments were put into circuit, in a vacuum in a glass globe, and brought to incandescence so that they gave light; but they would only last an hour or two. Other carbons made from wood and broom corn were tried. To quote Mr. Edison, "What we desired at that time and had settled our minds upon as the only possible solution of the subdivision of electric lighting was that the lamps must have a high resistance and a small radiating surface." The carbons made at that time showed that the lamps must have at least 100 ohms resistance to compete successfully with gas. This means that with filaments of such a resistance the current flowing in the circuit would bring them to light giving incandescence. If the lamps were of lower resistance, requiring more current, and therefore more copper in the circuits delivering the current to the lamps, the cost of the copper main conductors would be so great and the cost of power so increased as to render the system expensive and commercially impracticable.

At this time Mr. Edison went back to some of the earlier experiments involving the use of platinum strips, and by means of the Sprengel mercury pump he obtained an almost perfect vacuum; but it was soon found that metal filaments were not feasible, at least not under the conditions prevailing at that day. In October, 1879, separate lamps independent of the air pump were made by Mr. Edison, the receiver or bulb being entirely of glass, with filaments of common sewing thread carbon attached to leading-in wires, sealed in by fusion of the glass, the whole contrivance being exhausted by the Sprengel pump to nearly one-millionth of an atmosphere. The filaments of carbon thus employed were quite fragile, but because of their minute mass and length of only a few inches they had a smaller radiating surface and a higher resistance than had been expected, and the point had virtually been reached at which the carbons were in a stable condition. In other words, the filaments under the action or attrition of the current would not break down within an hour or two, but would remain incandescent for some time. Some of these paper filament lamps yielding from 12 to 16 candlepower had a remarkably long life, the average being 300 hours, while one of them lasted 940 and another 1,350 hours.

Mr. Edison was not satisfied, however, with filaments made from carbonized paper, nor with those made from the more regular and homogeneous wood fiber. One day a palm leaf fan was lying upon one of the tables of the Menlo Park laboratory, and the bamboo rim on the outside attracted Mr. Edison's attention. This bamboo he cut into strips which he carbonized and put into the lamps. He was gratified to find that the filaments were several times better than anything he had succeeded in making before. Mr. Edison proceeded immediately to study the whole subject of bamboo, and sent a man to Japan to investigate the bamboo growths of that country. Before he had selected what was most suitable for his purpose he had tested no fewer than 6,000 vegetable fibers. Until 1894 all the Edison filaments were made from bamboo, each piece passing through eight separate hand operations.

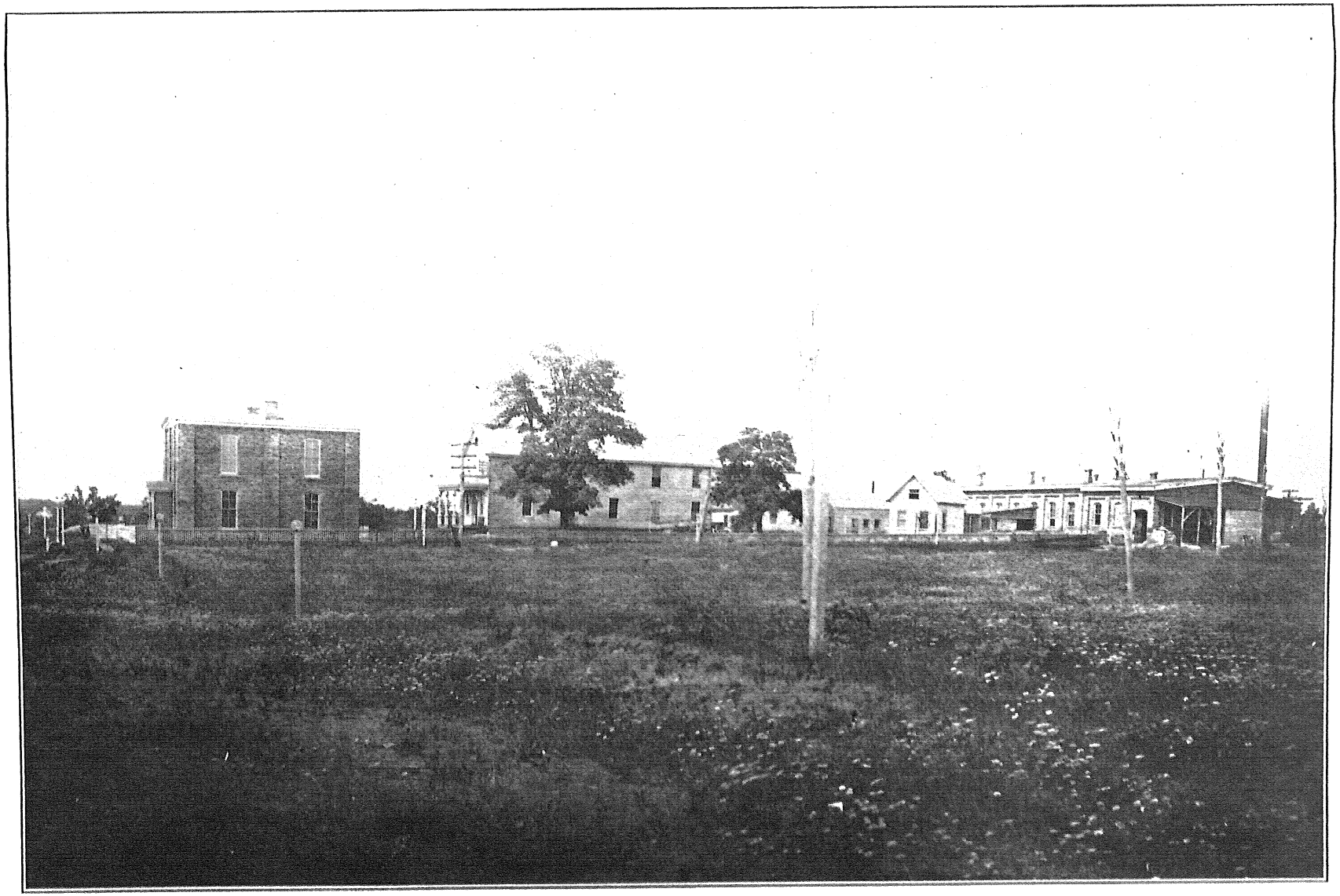
Summary of subsequent history.—The subsequent history of the incandescent lamp, embracing the inventions and improvements of a large number of workers in this field, may be briefly summarized at this point. Mr. Edison at this time reached the conclusion that a successful lamp must be inclosed by a globe made entirely of glass, with all the joints fused, and with the air exhausted to a very high degree, and that the lamp must be made durable and yet so cheap that it could be thrown away when broken down, with the exception of the platinum used for the leading-in wires, to which the carbon filament was attached. At the outset the price of the lamps was very high, some few being sold for as much as a dollar, or a dollar and a half each, but as soon as the industry was placed upon a manufacturing basis the price settled to 35 cents. The reduction of the average selling price to 15 cents at the time of this report has been due to a great many radical changes as well as to the increase in the volume of production; but in structural features the lamp has remained the same throughout.

Mr. John W. Howell, who has been an expert in this field from the beginning, has noted the chief changes in conditions governing the industry, which at the outset was based almost entirely upon manual operation, or required the invention of new machinery.

The lamp of 1880 and 1881 contained about thirty times as much platinum in leading-in wires as the lamp of the present day. The amount and cost of the glass and other materials used have also been greatly reduced.

The exhausting of lamps by mercury pumps required from four to six hours in 1881. Improvements in pumps and methods reduced the time to half an hour in 1895, and since then, with the single piston pump and "chemical exhaust," only one minute is necessary for even better results. At the end of 1882 the cost of exhausting a lamp was considerably greater than the total cost of a lamp at the present time. All the glass blowing operations have been changed from handwork by skilled glass blowers to machine work by unskilled labor, and the labor cost of the present glass operation is now only a little more than 10 per cent of what it was in 1882.

The photometric methods and apparatus employed in testing the lamps before sending them to the consumers have been remarkably improved and developed; the cost of photometric measuring is now only 9 per cent



EDISON LABORATORY AT MENLO PARK, 1880, SHOWING POSTS FOR OUTDOOR INCANDESCENT LIGHTING.

Incandescent lamps here used were connected with underground multiple or parallel circuits.

of what it was in 1882, and this decrease in cost has been accompanied by a great gain in accuracy and evenness in output. The greatest production of lamps reached at the Edison Menlo Park factories in 1882 was a thousand lamps in a day of twenty-four hours, for in those days it was the habit to have the work carried on continuously.

By 1894 many manufacturers had given up the bamboo or vegetable fiber filaments, and cellulose came to be almost wholly used. One of the first workers in this country to experiment with this material and to employ it successfully for commercial lamps was Mr. Edward Weston.

While this report has been in preparation, metallic filaments have been introduced, as, for example, those of the metal known as "tantalum."

Some of the very earliest carbon filament lamps were those supplied by Mr. Edison to Mr. Henry Villard for the steamship *Columbia*, plying on the Pacific. These had paper filaments and consumed about 100 watts of energy in furnishing a light of 16 candlepower. At the present time, the standard 16-candlepower incandescent lamp consumes only 50 watts. The useful life of a 50-watt lamp is undoubtedly longer than was the useful life of a 100-watt lamp in 1880, while the estimated useful life of a 100-watt 16-candlepower lamp made to-day is over 10,000 hours, or about twenty times as long as it was twenty-five years ago.

In the last quarter of a century a total of over 250,000,000 lamps has been produced, or not less than 10,000,000 a year.

III.

DEVELOPMENT OF COMPLETE SYSTEM OF ELECTRIC LIGHTING.

Edison's work.—The development of the incandescent lamp was associated, in Mr. Edison's mind, with the creation of a complete system of electric lighting, the current to be furnished from a central station to a large number of buildings in a manner exactly analogous to that in which the supply of gas was furnished. With this end in view, Mr. Edison experimented with dynamo electric machinery, and brought out new types of machines intended especially for use in this work. The chief aim was that the machine should have massive and powerful field magnets and that at the same time the resistance of its armature should be extremely low as compared with the combined external resistance of the supply mains and lamps, so as to enable current to be produced and distributed more economically than had hitherto been possible. In other words, Mr. Edison realized the commercial necessity of having the armature of the dynamo of low resistance as compared with the external resistance of the circuits, in order that a larger percentage of the electric energy developed, should be available for utilization in the lamps. General practice prior to that time had been to employ dynamos of high internal resistance as compared with the external circuit. The Edison idea, broadly stated, was to employ lamps of very high resistance operated in parallel or multiple arc, instead of in series, and dependent upon current of constant potential.

In the summer, fall, and winter of 1880, Mr. Edison installed such a system at Menlo Park, lighting the houses, streets, laboratory, machine shop, etc., with 425 16-candlepower lamps, the out-of-door lamps being mounted on short poles. The average resistance of the lamps used was 110 ohms and the electro-motive force of the current varied from 95 volts for lamps at the outer ends of the supply conductors to 110 volts for the lamps nearest the dynamos. The circuits were underground conductors, a system to which Mr. Edison has always adhered, not only because of the obvious difficulty there would be in carrying overhead the large mass of copper necessary for low voltage constant potential lighting, but because he believed that with the conductors underground there would be attained the constancy of service without interruption which is obviously necessary for all central methods of artificial illumination. The current for this interesting pioneer plant was generated by ten 8-horsepower dynamos, the field coils of which were connected in series and excited by a separate similar machine.

Use of steam engine developed.—No special attention up to this time had been given to the development of a steam engine of close regulation, which would maintain under wide fluctuations of the load the proper potential of current, so as to prevent flickering in the lamps; and the original workers, like Mr. Edison, in this field, had to take the engines that the market offered. These dynamo machines at Menlo Park were driven by an old-fashioned slow speed engine, widely and favorably known for stationary power plants. In order to obtain the necessary speed for the armature rotation there was no alternative but to connect this engine with the dynamos through a complicated and cumbrous system of countershafting which was highly wasteful of power. Mr. Edison thereupon conceived the idea—bold for that day, but now universally adopted—of substituting one large single dynamo for the several small machines and of connecting this directly with the driving engine on the same base, thus securing the requisite high armature speed without separate belting, shafting, and countershafting, and making possible closer regulation as well as various economies of space and such benefits as attend large production as compared with small.

Several of these Edison "Jumbos" were produced and used in this country and in Europe. Some of them continue in operation at the present time. One was shown at the International Electrical Exposition at Paris in 1881, where its appearance was looked upon as a notable technical and historical event and where with its capacity of 700 lights its size excited wonder. To-day it is reduced to insignificance in comparison

with machines that supply current readily to 70,000 lights, in many of the Edison central stations.

In the early eighties a great many radical improvements were made: the apparatus devised toward the close of the preceding decade had remained crude, needing use and the lapse of time to eradicate the defects and develop the necessary lines of perfection. Such work included the elaboration of the three-wire system by Edison and Hopkinson and the work of Weston in the refinement of continuous current constant potential dynamos.

Attempt to unify arc and incandescent lighting.—The two systems—arc lighting and incandescent lighting—were still wide apart and remained incongruous in their essential elements: Arc lighting with its high voltage and large units of light was suited, in reality, only for exterior use, with lamps scattered; while the incandescent system with its low voltage, large amounts of copper in the circuits, and small units of light was limited almost entirely to indoor service. Thus the two systems, while growing side by side, were irreconciled in a technical and engineering sense, and although their two fields of employment could hardly be said to overlap, the competition and rivalry that developed between the persons interested were literally of a ferocious character. Despite personal and financial antagonism, however, the underlying necessity led to many efforts to harmonize the two methods of lighting, and for some years inventors attempted to introduce compromises in the shape of composite hybrid systems that would bridge the gap between the series and multiple forms and methods of the industry. Some of these contrivances were highly ingenious, but their temporary character was soon proved, and thus the way was clear for the introduction of the modern alternating current system, which more than any other factor has simplified and unified the field of electric illumination as well as that of power transmission, as it exists to-day.

Development of use of the alternating current.—A very interesting review of this development has been made by Mr. William Stanley, jr., who was foremost in this department of work in the United States. In 1883 an inventor named Gaulard brought out in Europe a system of operating induction coils in series by means of which the high potential current of an alternating current generator could be delivered as low potential currents, through the induction coils, on local circuits and at the point of consumption, so that the advantages of economical high voltage transmission, as in arc lighting, could be enjoyed in association with the no less important advantages of the safe low potential current on the premises of the consumer, as in the existing methods of incandescent lighting. There was the further great advantage that arc and incandescent lamps and motors could be supplied with current from the same common source and from the same machine. Gaulard proposed to place a series of his "inductoriums" or open circuit magnetic transformers in a line, connected with his alternating current generator supplying a constant current, and he showed that if these were made open circuit with a very high mutual induction between the primary and secondary coils, and if the current from the generator were constant, each induction coil would give a correspondingly constant potential on its secondary circuit throughout all variations of resistance in that circuit; such, for example, as variation in the number of lamps turned on or off. Following out these principles a great deal of interesting work was done with a system known in Europe and this country as the "Gaulard-Gibbs," but it was soon found to be wanting in many of the essential requirements of a general practical lighting system.

Mr. Stanley himself took up the subject in 1883 and 1884, with particular reference to alternating current distribution which would be inherently self-regulating. After producing a number of induction coils, or, as they are now called, transformers, he sought in 1885 to secure assistance in the exploitation of an alternating current system in which the transformers should be arranged in parallel or in multiple arc and operated at a constant potential. In that year he hired an abandoned rubber mill at Great Barrington, Mass., and began to devise an operative self-regulating system. He borrowed for this purpose a Siemens alternating current dynamo and built about a dozen transformers, each of which was wound so as to reduce the main line potential from the dynamo to 100 volts in the secondary circuits to which the lamps were connected. In the spring of 1886 the dynamo was set up and connected with the transformers that were installed in some of the stores in the village of Great Barrington, where they were put into service on a regular commercial basis.

The transformers were naturally of crude design and workmanship, the primary and secondary circuits being separated from each other only by shellacked paper and other substances of equally fragile nature. But they stood up excellently under the test. As a matter of fact, this system was operated on the double conversion system, which is to-day so familiar in power transmission enterprise. In this system the 500-volt primary electro-motive force of the generator could be transformed or "stepped up" to 3,000 volts by "raising" transformers in order to increase the distance of the regular line transmission and reduce the amount of copper in the main line circuits. The 3,000 volts could be taken by the local transformers and reduced to 500 volts; and again "stepped down" to 100 volts for the distributing circuits. This system was seen in operation by Mr. George Westinghouse in 1886, and he soon made it the basis of a great electrical and industrial development, beginning with the first regular alternating current station at Buffalo, N. Y., in the fall of the same year.

A great many elements, particularly the development of alternating current dynamos, or alternators, were

still necessary, however, to make the system a commercial success. Mr. Stanley perfected an alternating current dynamo designed to give a potential of 500 volts with the possible minimum drop of pressure between no-load current and full-load current. Upon tests at Pittsburg, at the predetermined speed and exciting current, the electro-motive force of the machine was 490 volts instead of 500, and fell off less than 5 per cent when the load was increased from the minimum to the maximum full-load.

The difficulties attendant upon all this work may be gathered from Mr. Stanley's own statement: "It is remarkable how little of modern electricity we all knew in those days. The terms inductance, self-induction, armature reaction, transformer, converter, single phase, multiphase, hysteresis, and a number more were unknown. When we saw phenomena that we did not understand we had to try and fit some sort of names to them. It was some years later before the art was ready for high potential work, for it was necessary that the alternating machines, the transformers, and the system devised should attain a certain degree of perfection before engineers dared to introduce the idea of serving electricity over great distances by means of very high potentials, as the profession understood that term."

The induction coils or transformers thus developed—the work of Mr. Stanley being quickly rivaled by that of many other American inventors, prominent among them being Prof. Elihu Thomson—are now an essential feature of a very large proportion of electric lighting work and power transmission in the United States.

When the circuits are carried overhead in suburban or rural districts, it is a common thing to see the transformers mounted on the poles which constitute part of the overhead system, the wires from the main circuits being tapped into the top of the transformer and the wires from the secondary circuit to the local points of consumption being tapped out of the lower part of the transformer. These devices are of varied type, known principally by their distinguishing names, such as "core transformers" and "shell transformers," while the additional descriptive phrases "air-cooled," "water-cooled," and "oil-cooled" are also used. In the transformer of the core type, the magnetizing core is usually built up of rectangular punchings of soft sheet iron about one-twentieth of an inch thick, with the primary and secondary windings of copper wire around the core or in efficient juxtaposition thereto. In some types of shell transformers, primary and secondary coils are partially or wholly surrounded by the laminations of the iron core. The coils are generally so arranged that they can readily be connected in series, or in parallel, or in other relation to each other, so as to vary the ratio at which the incoming generator primary current is transformed into the outgoing secondary consumption current.

In the early days the transformers were quite small, equal to supplying current to only a few lights, but of late years the tendency has been toward the construction of larger transformers on account of their high efficiency; and some of the units are of several hundred horsepower capacity. These larger transformers are necessarily not placed on poles, but are sometimes placed in cellars or basements and very often placed in separate buildings known as "substations." If the alternating current is to be converted into direct current, they are associated with dynamo electric apparatus known as "converters," and often with storage batteries in which part of the current delivered from or to the line can be stored until needed.

These larger transformers develop a considerable amount of heat and are kept cool in one of three ways—by oil, by air, or by water. In the oil transformers the case of the transformer is virtually an oil tank in which the entire core and coils are immersed, the circulation of the oil acting to equalize the temperature and to carry the heat to the case from which it is radiated, such case being made with external ribs or corrugations, so as to increase the radiating surface. The transformers, in which the cooling is effected by means of air, often by means of a forced draft, are supposed to have advantages over the oil-cooled type, as the cooling effect can be regulated in accordance with working conditions and there is an avoidance of possible danger from fire in case of a short circuit inside the transformer or the sudden scattering of the ignited oil. A well-built, oil-cooled transformer should not increase in temperature beyond 125° and water-cooled transformers, if well constructed, should not increase in temperature beyond 122°. Some of the water-cooled transformers are also oil filled. A continuous flow of cooling water is kept up, either through a water jacket in the casing, through hollow conductors, or through pipes immersed in the oil.

Later arc lamps.—For many years a large part of the arc lighting of the country was done exclusively by means of direct current constant voltage lamps, but the greater vogue of the alternating current has renewed and developed the utilization of lamps of the alternating type. The two classes of lamps have distinctive features. In the direct current lamps the positive carbon is the upper one, and is that from which the current flows to the negative or lower carbon, the cavity or crater of the arc being formed in the upper carbon. In alternating current arc lamps, however, each carbon becomes alternately positive and negative, and if the reversal of the current was not very rapid there would be visible periods of light and darkness or an equivalently disagreeable fluctuation. The frequency of the alternations must therefore be high in order to overcome this feature, and in practice it has been found that with 60 periods or cycles per second—that is, 120 alternations of current—the light is quite steady, so far as

the eye can determine. Even with slightly less than this the light appears steady, while with a proper frequency and proper mechanism the alternating current arc compares favorably as to apparent steadiness with its direct current competitor. As a matter of fact, alternating current arc lamps have come into use on both constant potential and constant current circuits, and their presence can usually be detected, if not otherwise known, by the slight humming sound that proceeds from them as a result of the variations in current strength during each cycle which set up corresponding vibrations in the surrounding air. Direct current arcs of nominal 2,000 candlepower require ordinarily about 10 amperes of current and a pressure of 45 volts between the carbons. Alternating current arcs require about 15 amperes at a pressure of from 30 to 35 volts.

Change from open to inclosed lamps.—A further development in arc lighting during the past few years has been the employment of "inclosed" arc lamps. It has not been an uncommon thing, ever since the beginning of the modern arc lighting, to see arc lamps burning without a shield of any kind between the arc and the eye. This is particularly the case in such places as rolling mills or open spaces where the glare of the arc is not offensive and where the flying sparks from the carbons do not create any fire hazard. In general practice, however, "open arcs," as they are called, have always been inclosed by globes of glass, open generally at the top, and if indoors, they have been equipped with spark arresters. Instead of globes, panes of glass were sometimes used. Whether in globes or panes the glass was usually ground or opalescent instead of clear, so as to mitigate the glare.

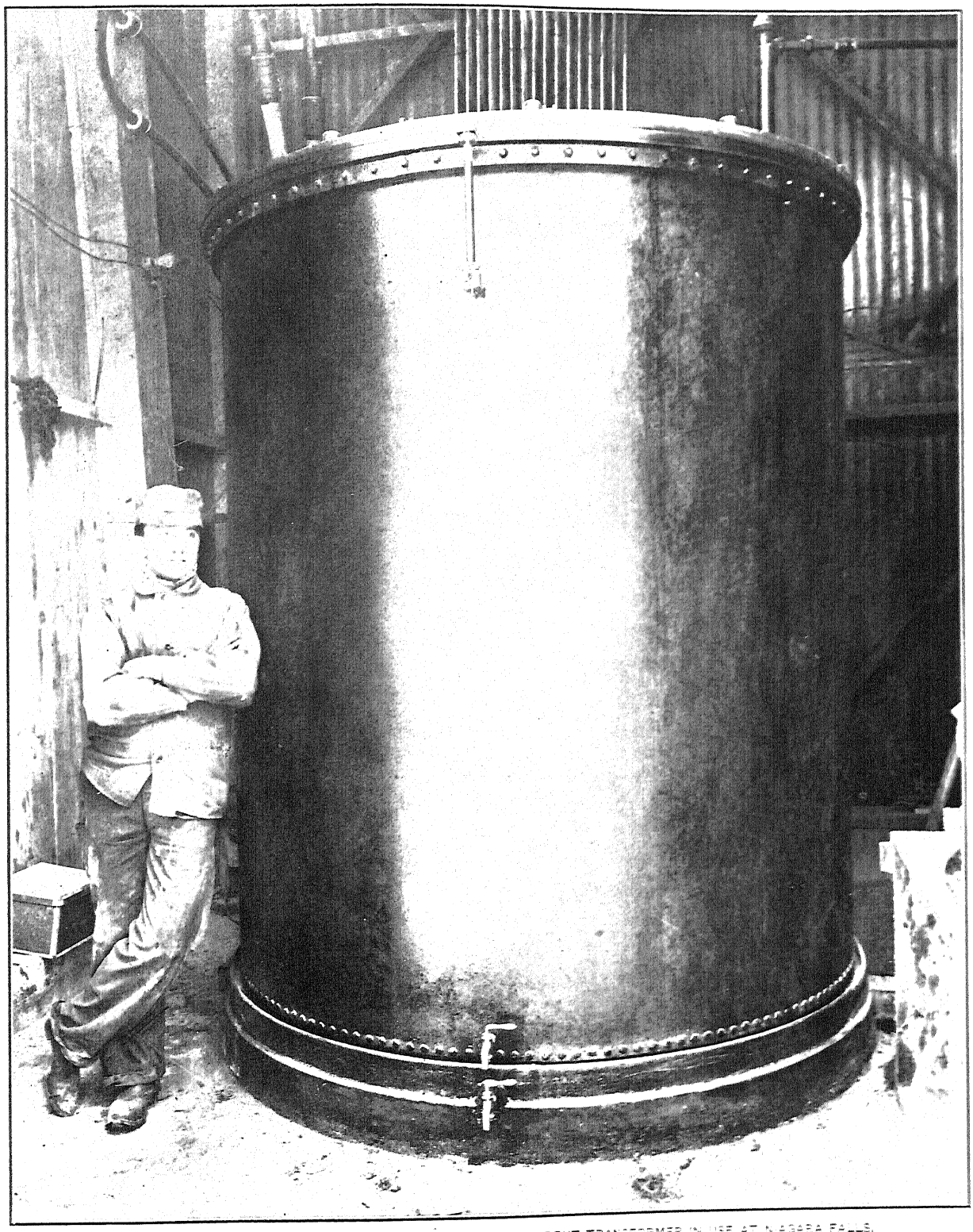
The use of inclosed arcs was a notable step. Since 1894 the open arc has been very generally superseded by the inclosed arc, so that to-day the inclosed type is manufactured almost to the entire exclusion of the open type. In regard to this subject, Mr. L. B. Marks, a leading inventor in that field, says: "Those who are familiar with the steps in the evolution of the inclosed arc lamp of commerce know that this type of lamp was made possible by the discovery that when the arc is inclosed in a small globe having a suitably restricted air inlet a long arc of abnormal voltage may be steadily maintained by a small current—a condition impossible in free or open arcs. This discovery was followed by the construction of a lamp that would strike a long arc and maintain it under the proper conditions. Herein lay the secret of the modern inclosed arc lamp. Broadly speaking, that secret was not in the carbon but in the arc. The solution of the problem therefore involved, first, a method of operation, and second, apparatus for carrying out that method. So far as the records go, neither the method nor the apparatus was known to the world prior to the year 1893. Once these features were given to the art the commercial inclosed arc lamp became an accomplished fact."

The carbon in an ordinary open lamp burns away in a few hours, say ten or twelve, but in an inclosed lamp the homogeneous carbons will last from 60 to 125 hours, although what are known as "cored carbons," with a pencil of softer carbon as the core, are employed, on account of the steadier and smoother burning insured. The small inner globe inclosing a portion of the carbon pencils is virtually air-tight, and is made of refractory glass so as to resist successfully the intense heat of the arc; such inner globes are of an elongated egg shape. The consumption of the carbon in the arc in the inner globe results in filling the little bulb with carbon monoxide and carbon dioxide, which in turn shortens the arc to a length of about three-tenths of an inch and permits a pressure of 80 volts to be employed. It will be readily understood that under these conditions an increase in the life of the carbons takes place, all the oxygen of the air having become combined with the carbon and no fresh air or oxygen to help waste the carbon away being admitted. The carbons in the inner globe burn with a crater somewhat different from that seen in open lamps, the crater being broad rather than sharply pointed. Although the pressure in an inclosed lamp is increased from 45 or 50 volts up to 80, the actual consumption of the current is not greater, since but half the current strength is required.

These lamps not only are desirable for street illumination, but also have become popular for interior purposes on account of the agreeable appearance and effect of the inclosed arcs, the excellent distribution of light, and the softness of the illumination, and because of the fact that the complete inclosure of the arc reduces the fire hazard from flying carbon sparks to an absolute minimum.

Perhaps the greatest recommendation to electric lighting companies for the adoption of the inclosed arc is the fact that the labor of trimming is reduced so materially by them. In the earlier days, with open arcs, a large number of men were required for the daily trimming of the lamps, and as the carbon pencils were not wholly burned away, and the remnants were too small to carry back to the station, it was not uncommon to see the fragments wasted and scattered about the streets. Inclosed arc lamps of the modern type, however, need trimming only once a week or once a fortnight, according to the daily hours of burning, and the carbon points are very thoroughly consumed.

A large number of alternating current arc lamps have gone into use in the last few years, requiring further modification of the inclosed arc practice. In such lamps the lower carbon is necessarily consumed about as rapidly as the upper, so that in inclosed alternating lamps the globes have to be made a little



AN OIL FILLED WATER COOLED 1,500 K. W. ALTERNATING CURRENT TRANSFORMER IN USE AT NIAGARA FALLS.

longer so as to allow the use of a longer negative carbon than is necessary in direct current lamps. With 6 inches of negative carbon in an alternating current inclosed lamp the supply is sufficient to keep the lamp burning for eighty or one hundred hours. In order to utilize such lamps in series, constant current transformers are necessary and have been introduced. These transformers maintain a constant current strength, no matter how many lamps may be cut in or out on the circuit, and are so arranged that the mechanism automatically adjusts the distance between the primary and secondary transforming coils, thus keeping the current constant. These "tub" transformers are located at the central station and will carry as large a series of lamps as would one of the familiar arc lighting dynamos of the old régime.

The general extent of the change from open to inclosed arcs may be inferred from the fact that, according to the returns of the Census Bureau in 1900, over 150 cities in this country had then replaced open arcs with those of the inclosed type, and 51 of these cities had permanently adopted arc lights of the inclosed type. Further segregated figures as to the trend of the development were presented at the same time, showing that of the 158,187 lamps manufactured in 1900 only 23,656 were of the open type, so that at that time the annual production of the inclosed arcs was six times as great as that of the open arcs. This tendency has been intensified in the period that has since elapsed. Moreover, as to street lighting, it is noteworthy that in that year some work was done with direct current series inclosed arcs in 73 cities, while in no fewer than 326 cities it was done with series alternating inclosed arcs, deriving current from constant current transformers.

Production of lamp globes.—The production of globes for arc lamps has developed into a considerable industry, the renewal of such globes being a large percentage of the cost in the operation of the lamps. These globes have been given a great variety of shapes and have been made with clear glass and with opaque glass in various degrees of transparency. Sometimes the globes have been made partly clear and partly opaque or ground. The relative position of the two portions depends upon the use of the lamps. For show window use or on bridges, where it is desired to illuminate the roadway but to intercept the beams that might dazzle the navigator on the stream below, the clear and shaded portions have been arranged vertically.

Another type which has come into general use alike for arc and incandescent illumination is the holophote, which is made entirely of clear glass, but has the outer surface molded in the shape of hollow prismatic rings. The inclination of the ring is different at various points of the globe so that the light striking the upper part is reflected downward, and that striking the other ring emerges from the globe either horizontally or in a direction below the horizontal lines. A still better effect is obtained by ribbing the globe vertically also.

A great many of the interesting developments and features connected with arc lighting and arc lighting fixtures pertain more particularly to searchlight projectors, focusing, and light house work, and are therefore not considered within the range of this review.

Lamp supports.—During the earlier years of electric lighting there were no suitable appliances and appurtenances for supporting the lamps. High poles or iron framework towers were used in the first attempts to display arc lights out of doors. The ring of lamps at the top was sometimes lowered in order that the lamp might be recarboned, although it was a general practice for the linemen to ascend the tower to attend to the trimming. These tower supports were extensively adopted in the cities of Cleveland, New Orleans, Detroit, and New York, and also on the Pacific coast, and by this means an agreeable, well-diffused light, comparable to soft moonlight, was afforded. Such illumination was soon found to be expensive and where the streets were overhung by shade trees quite ineffective in summer; hence resort was soon made to short poles similar to those employed in gas lighting.

Poles of wood, iron, and steel have remained a permanent feature in the industry whether overhead wires or underground circuits are used, and of late years there has been a perceptible gain in their appearance from an aesthetic point of view.

Another method of suspending arc lamps having considerable vogue is that of placing them at street intersections across the roadway, the lamp being held up by cross suspension wires from poles on either side of the street. Another form of support is that known as the "mast arm," consisting of an arm carried at right angles to the pole and projecting outward over the roadway. On these last two forms considerable energy has been expended to secure safe and easy methods of lowering and raising the lamps to trim them.

Still another method of placing arc lamps is that of carrying them on brackets suspended from side walls. A great deal of energy has also been expended in the production of hoods, cut-out switches, shades, and reflectors for the better and more economical distribution of the light. In some instances in interior illumination the arc lamp has been inverted, the shade coming below the arc instead of above it, so that the rays are reflected upward to the ceiling, and a very good diffusion of light is thus secured.

Series and multiple methods.—The development of incandescent lighting with circuits carried into dwellings, public buildings, and interiors of all descriptions called for many subtleties and refinements far beyond the province of arc lighting, and this field has been peculiarly prolific of inventions and improvements. It was not sufficient to invent and perfect an incandescent

lamp, nor to produce dynamos to furnish the current, nor to devise means for the installation of the copper circuits connecting the generator with the lamps.

The original series arc lighting system was what may be called a one-wire system, that is, the lamps were distributed along it like beads along a necklace, the dynamo being the clasp, from one end of which the circuit started and to the other side of which the circuit returned. Incandescent lighting work began with a two-wire system; two main wires running out from each side of the dynamo and continuing, free ended, the lamps being placed in circuit across or between them like the rungs in a ladder. In view of the low voltage employed the two-wire system necessitated the use of large quantities of copper, and this led to the development of the three-wire system, in which two dynamos are employed with three mains or conductors, that which may be called the "middle one" serving as a common return for the two outside wires. By the use of this method a saving amounting to over 65 per cent could be made in the total weight of copper required to deliver the current as compared with the amount of copper necessary in the two-wire system. These methods have been refined and developed so that four, five, and seven wire systems have been introduced, all aiming to reduce the amount of copper in the circuits while maintaining the advantages of the multiple low voltage distribution. It must not be overlooked, however, that, as in most cases of this kind, there are some drawbacks resulting from the complications and additional appliances introduced into the system. Incandescent lighting as a rule is now practiced on the two and three wire methods.

Appliances.—In addition to the distributing system a great variety of detail appliances had to be devised, including meters, fixtures, switches, cut-outs, and safety fuses. Some of these instruments are necessary for the registration of current as it flows out of the central station, while others are required at the points of consumption. In the earlier days of the industry scarcely anything was known of exact measurement, but to-day both the absolute electric units and the practical electric units have been determined and fixed by national and international agreement, and there is no field of scientific or engineering work in which results or determinations are arrived at with more careful precision.

As a general thing arc lighting has not been complicated by consumption measurement, the instruments in use being those located at the central station to indicate to the attendants in a simple manner the maintenance of the dynamo amperage at a constant point under all variations as to the number of lamps on the circuit. With incandescent lighting and the sale of electric power, a large variety of instruments and meters have been called for and are now in use. A brief discussion of meters was given in the article on electric apparatus and supplies as presented in the Census report of 1900.[1]

For central station use many varieties of indicating instruments and meters have been devised, and the switchboards upon which they are mounted, and to and from which the circuits are led, are to-day elaborate and costly. Some boards in large plants attain a length of 40 or 50 feet, and cost, with their instruments, marble or slate bases, copper bars, brass trimmings, and other paraphernalia, a great many thousand dollars.

In addition to the instruments in use by central stations and their customers, a large number of portable types have been devised for electric lighting and power transmission work so that tests may be made "out on the line" at any point on the circuit where trouble may arise, or where it is desired to determine certain conditions. There are a great many varieties of such portable testing sets, an ordinary type of which will include what is known as a "Wheatstone bridge, galvanometer, battery, and keys." The battery consists of a few chloride of silver cells.

A general classification of measuring instruments in common use would include the electro-magnetic, the electrostatic, the electro-chemical, the electro-thermic, the tangent galvanometric, the dynamometric, and the D'Arsonval and Weston types. Some of these devices indicate visually. Others, by means of magnets or electro-magnetic action associated with clockwork escapement, record results subject sometimes to a certain "constant" for exact correction.

Electrostatic instruments are in use to some extent for high tension measurements and as ground detectors, etc. These depend for their action upon the mutual attraction of two plates connected with the opposite sides or poles of the circuit when any difference of potential exists between them. If one of these plates or conductors be fixed and the other free, the free one will be attracted to the one that is fixed and thus indicate the amount of tension. Some beautiful apparatus of this character is manufactured by large concerns in America, especially for circuits carrying currents of 10,000 volts and upward, the readings of which would be difficult to secure with precision otherwise.

Other measuring instruments like those in the electrochemical or voltameter class depend upon the amount of metal, such as silver, deposited by the action of the current in a small cell through which a definite portion of the current in the consumption circuit is made to flow, the plate being weighed periodically.

When Mr. Edison began his incandescent lighting he designed and brought out a voltametric or electrochemical meter which remained in extensive use for a long period, its indication depending upon the transfer of silver from one small plate to another. Although in Europe meters of the voltametric type have again

[1] Twelfth Census, Vol. X, page 198.

found some favor, they have been very little used in the United States of late years, and the Thomson wattmeter and others of the same class, like the Shallenberger, have had the greatest vogue. These are either essentially small motors or are based upon the revolutions of a moving part which actuates the registering escapement.

The electro-thermic instruments depend for their action upon the principle of expansion by heat, the expansion of a fine resistance wire or strip of conducting material being proportionate to the square of the current passed through. This principle is applied in various ingenious ways. For example, in one instance in consumption service, the meter is a glass tube with two bulbs, around one of which the conductor is coiled. The passage of the current in the coils heating the air in the one bulb forces some of the liquid out of it into the other and into an overflow tube, where it remains until the meter has been read and tipped back again for another turn of duty. This meter makes possible the grading of the charges for current according to its use. Thus a large consumption of current will cause a correspondingly large quantity of liquid to pass into the overflow indicating tube, while a lesser current will cause either a small quantity or none at all to pass off; so the consumer benefits by the application of a scale of charges which encourages his liberal use of current, such a scale being applied, moreover, scientifically instead of arbitrarily.

Central station ammeters and voltameters have in more recent years come to be largely of the Weston and D'Arsonval type. The broad principle of these is that a coil suspended in a magnetic field between the poles of a magnet will rotate through a small angle when the current passes. The swing of the coil carries a needle attached to it over the graduated face of a dial, on which are legibly indicated the figures to be watched or noted by the attendants. In case large currents are to be measured by this instrument, shunts are employed so that only a small part of the current goes through the coil. Weston instruments of this type have become standard the world over and are largely exported.

Fixtures.—When the incandescent lamp was first introduced there were no fixtures for it, and the first "electrolier" was nothing more than a gas chandelier, around which the wires to the lamps were twined, the sockets of the lamps being fastened just below the gas burner outlets. It was thus demonstrated that the incandescent lamp could be burned upside down as well as in any other position, and special fixtures were soon brought out, many of them of a high standard of artistic merit. Improvements, due to Mr. Luther Stieringer and others, next allowed the wires to be carried with safety within the stem of the gasolier or chandelier, and the combination fixture, burning both gas and electricity, thus became a permanent feature.

In 1881 the residence of J. Hood Wright in New York city was lighted with Edison electric incandescent lamps, and most of the lamps, with the exception of those in fixtures, were protected by individual fuses, the object of which was to cut off the flow of current by fusing, should the proper amount be exceeded. The fixtures carrying more than one light were protected by placing fuses outside or safety catches within the canopy at the top of the fixture.

Fusible cut-outs on the lamps attached to flexible cords were first used at the Mechanics Fair in Boston in 1882. No ceiling construction for flexible pendants had hitherto been used, and at this fair five such pendants were employed, made of ordinary cotton covered cord, like that used in men's suspenders, sewed into a flat strip. The earliest regular flexible conductors for incandescent lamps were made for the Louisville Exposition in 1883 and consisted of ordinary cotton covered with an insulation.

Out of this early and cruder practice have grown the methods and fixtures in use to-day. The fixtures are now made in an infinite variety of shapes and forms, but consist essentially of six distinct groups: The simple drop or pendant lights with adjusters to regulate their height from the ground; the portable lamp, which can be carried around freely and plugged into any wall receptacle for contact with the supply circuit; the special small fixtures for desks, tables, lecterns, etc.; the side or bracket fixtures made for single or clustered lights; the fixtures for entrance stairways, "isles of safety," etc.; and the whole range of small and large electroliers, some of which, as those in the Metropolitan Opera House and in the St. Regis Hotel, in New York city, carry hundreds of lamps in special group sockets.

The lamp socket itself has undergone a course of evolution and choice has gradually narrowed down to one or two specific types of simple design. The lamp is secured to and contacted with the screw socket by metal plates in the base of the lamp and of the socket and by contact between the shell of the socket and the brass cap of the lamp. In some of the earlier forms of the socket and lamp, the lamp was held in place by means of a bayonet catch in the socket and a peg on the lamp, but this method has virtually disappeared. For out-of-door use, or for places where the lamps are exposed to the elements, ingenious forms of weatherproof sockets have been worked out. These are largely needed for special and regular street illumination, and at expositions and fairs on the illuminated towers, arches, etc., these being nothing more than fixtures on a large scale, which combine in a brilliant and attractive manner the elements of electrical manufacture with those of architectural construction and artistic proportion.

Fuses and cut-outs.—The fuses and cut-outs used in electric lighting also have undergone a remarkable process of evolution. For many years past fuses have consisted of short pieces of fuse wire or metal strips

inserted at predetermined points. The fuse wire and the copper wire circuit guarded by it will carry the normal amount of current for which the circuit has been calculated, but if undue current comes on the circuit the fuse wire, which has a much lower melting point than the copper, gets hot much sooner and melts or "lets go," so that the circuit is interrupted before damage is done or before a fire can ensue. Service on the circuit can not be resumed until another fuse has been inserted by hand, although in some automatic forms the fuses are put up in "barrel" or reservoir fashion, so that a new fuse can be dropped into place automatically. These safety devices are made usually of an alloy of tin and lead, and are of a certain fixed diameter and carrying capacity, in accordance with specified insurance and engineering rules. These fuses are set on slabs of porcelain, slate, etc., and are boxed in so that the melting metal can not be spattered around, the covering being either of porcelain or of some transparent material, like mica, permitting examination of the interior parts.

The later developments include fuses of the inclosed or cartridge type. In one form of these fuses the inclosing tube is filled with a material intended to stifle the fire or arc caused when the fuse "blows" or is melted. In other forms the filling material is so employed as to leave part of the fuse uncovered, an air chamber or vent being thus afforded so that the rush of air may assist in extinguishing the arc. The filling material consists of chalk, asbestos, potash powder, etc. These inclosed fuses are usually made up in a stout paper jacket of cylindrical form with metal ends, and in some instances they have a small target or disk on the interior of the paper shell which becomes discolored when the fuse is "blown," and in this way indicates when it should be renewed. These inclosed fuses are applied more particularly to larger circuits carrying current in some appreciable volume, and the simple fuse cut-outs or safety catches are applied more particularly to a single lamp or a group of a few lamps.

Methods of wiring.—The use of electric lighting for interior purposes has led to the development of improved methods of wiring, with the object of securing a maximum of safety and accessibility to the circuits. The first interior circuits for incandescent lighting purposes were bare wire. Then came insulated wire carried along the ceilings or walls by means of cleats, leaving the wires exposed between the supporting points. At the same time molding nailed to the walls or ceiling was used and the wires were concealed in grooves inside the molding. Practically all the primitive incandescent lighting was done in this crude manner. The next step was the location of insulated wires and cables in the plastering of walls, a sheathing of lead being frequently added to the insulated wire for greater protection.

Wiring exposed by means of cleats has been found to have elements of safety, for the exposed wires can radiate quite freely the heat due to resistance; but on the other hand they collect dust and moisture from which incipient short circuits follow, as a result of the bridging between the two parallel wires. Wiring in molding has come to be regarded as dangerous because its concealment prevents prompt discovery of deterioration, while the fact that the wires are entirely incased prevents the radiation of heat and tends to cause fires by the ignition of adjacent woodwork. Wires embedded in plaster and thus removed from contact with inflammable material have elements of recommendation, but it was soon found that in order to get at the wires thus embedded, the destruction not only of walls but also of costly decorations, woodwork, etc., was frequently involved.

These four methods have practically died out, or, if permitted in modified form, are subjected to severe restrictions by the underwriters and other authorities. Some wiring also has been done by means of metal staples or wooden fiber cleats, and has therefore been of a most temporary character. The insurance rules recognize only porcelain cleats or insulators for interior work, with the wires 2½ inches apart and at least one-half of an inch from the surface of the wall or ceiling.

Several years ago Mr. E. H. Johnson, one of the pioneers in incandescent lighting, came to the conclusion that electric wiring should be as exact in its methods as water or gas piping, and began the development of a system of interior wiring, the objects of which were a definite location for the wires, facilities for removal or renewal, prompt accessibility, and a minimum danger of fire. From crude beginnings the approved modern method of carrying all the interior wires in conduits developed.

The first conduits employed in this class of work, although quite primitive in character, being composed of stout paper or fiber, twisted spirally into a tube and then asphalted to render it waterproof, marked a great step forward. It was soon found that these paper conduits were not sufficiently strong to resist wear and tear, and the next step was to give them a metal protection, either by inclosing them in iron pipe or by incasing them with metal ribbon, such as brass, wound spirally around them. This practice has developed into two standard types of conduits: One being the insulated metal conduit with an interior insulated lining, having a wall not less than half an inch in thickness, so smooth as to allow the wires and cables to be drawn through easily, but tough enough to resist the abrasive effect of such work; the other being the uninsulated metal conduit, consisting of plain galvanized iron or steel pipe with a smooth inside finish or with the inner surface coated or enameled, so as to permit easy passage of the wire. Where such bare metal is used the best practice is to employ an insulated wire with superior insulation. Other types of conduit, however, in which metal is not employed are recognized

and permitted by the underwriters. These conduits are usually of woven textile fabric, heavily saturated in insulating material, the wall presenting almost as much resistance to crushing pressure or to the attack of nails or edge tools as though it were of metal.

Thus, instead of the wires being placed haphazard or "fished" loosely in between walls and partitions, wiring is now accomplished on a definite plan, with the conduit in definite places leading to the proper switches, junction boxes, and panel boxes, and the slight added cost of the conduit is more than offset by the gain in safety and other conditions. Flexible cord, by means of which a lamp or fan motor or other device can be carried from place to place, is still in considerable use, however, and probably will remain so for extension lighting.

Insulated devices of nonabsorptive or noncombustible material are required in a great many special places and for a great many uses. Circuits carried into wet or damp places, such as chemical works, breweries, and dyehouses, are peculiarly susceptible to insidious attack by moisture, fumes, etc., and have to be carefully guarded by means of waterproof sockets and other devices. These precautions are required also in connection with the outdoor use of arc and incandescent lamps, particularly with regard to the advertising signs and decorations now so prominent a feature at night in every large city.

Modern conveniences.—The refinement of modern conveniences in the utilization of current from central station sources of supply can best be understood by seeing in the modern city house the elevators operated by electric motors, electric cooking apparatus and flatirons in use in the kitchen, incandescent lamps and fan motors in the living rooms, and electric curling irons and foot warmers and electro-thermic pads in the bedrooms, all connected by flexible cords and wall plugs to circuits that are brought to them by means of interior conduits, which run back to the main cut-out box in the area vault, where the circuits are tapped off from the street mains.

Novel types of lamps.—During the past few years attempts have been made to break away from the approved and familiar forms of arc and incandescent lighting, and at the time of the preparation of this report there were already in use in large numbers two types of lamps whose future may not be regarded as definitely settled, but for which a special place appears to await.

Nernst incandescent lamp.—The Nernst incandescent lamp differs in many respects from the incandescent lamp proper and from the arc lamp. The long carbon filament of the incandescent lamp is replaced by a short strip of a material which, while it is an insulator and nonconductor at ordinary temperatures, becomes both a good conductor and an excellent illuminant at higher temperatures. This material consists of a mixture including such rare earths or oxides of refractory character as yttrium, thorium, zirconium, cerium, and magnesium. These oxides have a high point of fusion and even when highly heated can be exposed to the air without any perceptible deterioration. Some of this material or mixture is worked up into an incandescent device known as the "glower," which is about an inch in length and one thirty-second of an inch in diameter. When this glower is brought up to incandescence it gives a beautiful white light, each glower being calculated to give an amount of light equal to that of an ordinary 16-candlepower incandescent lamp. The current required by each glower is about 88 watts, and the lamps are operated at an economy of about 1.8 watts per candle, or about one-half of that required by the carbon filament lamp. In order to increase the size of the Nernst lamp, the number of glowers is increased; therefore the lamp may consist of 2 glowers, 3 glowers, 6 glowers, etc.

A great deal of inventive ability has been shown in perfecting automatic Nernst lamps, in which the glower can be heated so as to bring it up to the temperature at which current will begin to flow through it. Generally speaking, this preparatory heating of the filament is effected by means of small heater coils, consisting of platinum wire wound around little porcelain tubes covered with an insulated refractory paste. These are mounted in the lamp in the vicinity of the glower, and when the current is turned on it flows momentarily through the heater, which quickly cuts itself out of circuit and leaves the glower in operation at incandescence. A further lighting device, called the "balance," consists of coils of iron wire placed in series with the glower, thus steadying the current or equalizing its flow so as to offset the sharp decrease in the resistance of the circuit, which is a necessary result of the increase in the temperature of the glower.

The Nernst lamp differs also from the high vacuum incandescent lamp and resembles the arc lamp in that it can be burned without injury in the open air—that is, without any inclosing glass bulb—although in ordinary practice the mechanism above described is inclosed in a white ground glass globe, which prevents too rapid a dissipation of the heat from the glower, which would waste the light giving power, and also protects it from drafts, which would have the effect of making it appear to fluctuate through the variations in temperature.

One objection to the Nernst lamp has been the fact that it has hitherto been found useful chiefly on alternating current circuits and not freely available for direct current circuits; but it is understood that lamps available for both circuits are now on the market.

The mercury vapor lamp.—Another prominent type of lamp for electric illumination still in the early stages is that known as the "mercury vapor lamp," the introduction and commercial perfection of which has been largely due to Mr. Peter Cooper-Hewitt, of New York city, although of late years a number of other eminent

inventors have worked in this field. In the ordinary commercial lamps of this character, of which large numbers have already been introduced, the lamp consists of a glass tube an inch in diameter and 4 feet long, exhausted to a vacuum, with platinum leading-in wires sealed into the two ends of the tube. The anode or positive pole of the tube consists of an iron grid or a small quantity of mercury, and the cathode or negative pole consists of mercury. The lamp is put into operation by either the tilting method or the quick breaking method. In the latter the high potential discharge from an induction coil is employed to break down the high initial resistance within the lamp, this coil being assisted in its action by a starting band of metallic paint around the lamp at the negative end. In the former method, when the current is turned on, the lamp is tipped or tilted so that the stream of mercury trickling down the interior of the tube makes a contact between the two electrodes; when the stream breaks, as the lamp tips back again, the mercury is vaporized, and the mercury vapor or arc being heated to incandescence by the current, emits its intense light. The illumination of the Cooper-Hewitt lamp has not been of a particularly agreeable character, because of the absence of the red rays of the spectrum and the predominance of bluish or yellow-green rays, but the lamp is of high economy and has been found peculiarly applicable for the illumination of large spaces, while it has also been largely adopted by photographers and in photo-engraving establishments on account of its intensity and high actinic value.

One of the best illustrations of the adoption of mercury vapor illumination is to be found in the new building of the New York "Times," where these tubes have been introduced in the composing room at the top of the building and in the pressrooms 55 feet below the street surface. No fewer than 42 of these tubes are thus employed with a consumption of current of 5.46 kilowatts, whereas the original estimate for current for the arcs and incandescents to do the same service was 15 kilowatts. In the press and stereotyping rooms the 26 mercury vapor tubes light an area of 17,000 square feet of floor space as well as 4 large presses installed in a chamber with a ceiling 21 feet in height. In the composing room the light appears to be equally satisfactory, especially as the peculiar quality of the light gives new type a rather dull appearance so that it can be easily read. Up to the present time such tubes have been operated with the direct current only, but lamps for alternating current are also being developed.

Vacuum tube lighting.—A modern and novel contrivance for electric illumination is represented by vacuum tube lighting, or the light produced by the electric discharge passing through tubes containing only air at a high degree of rarefaction. Experiments in this field date back to the beginning of the eighteenth century and have long furnished spectacular phenomena for the investigation of physicists and the amusement of the crowd. Some fifteen years ago, however, Mr. Nikola Tesla developed and exhibited vacuum tubes with which a large amount of useful light could be produced, and since that time other lines of work have been followed out to commercial practicability by Mr. D. McF. Moore. Mr. Tesla has employed in this work his well-known currents of high tension and high frequency, produced chiefly by special forms of generation or induction coils. Mr. Moore has worked along the line of employing ordinary central station circuits and currents as well as low potentials. He developed at first an automatic electro-magnetic brake, consisting of a little vibrator which, when placed in a vacuum, served to interrupt the current suddenly and thus secure the extra current effective within the tube. Mr. Moore also developed special forms of generators to produce high potential currents and other means whereby the effects required could be obtained by the use of current from the street circuits. Beginning with small incandescent bulbs, Mr. Moore developed long vacuum tubes, and has carried his work so far as to illuminate large rooms by means of a continuous vacuum tube run completely around the ceiling, after the manner of a cornice or picture molding. In some of these tubes Mr. Moore has employed a gas of such character or degree of rarefaction that by the application of electric current to the terminals of the tube the gas is rendered luminous by the transfer of the energy from one terminus to the other, the consumption of current, moreover, being economical. These continuous tubes have been made by Mr. Moore as long as 40 or 50 feet, and have been built up in situ by novel applications of the glass blower's art. The light from these tubes is of a cheerful white character and the effect of the bar of light around the ceiling is pretty and effective. Such tubes have been shown in commercial operation since 1896 in various buildings and upon the streets in New York, Newark, and other cities so that now they are a part of the art.