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"The Arc-Light"

by

Charles F. Brush

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THE ARC-LIGHT

BY CHARLES F. BRUSH

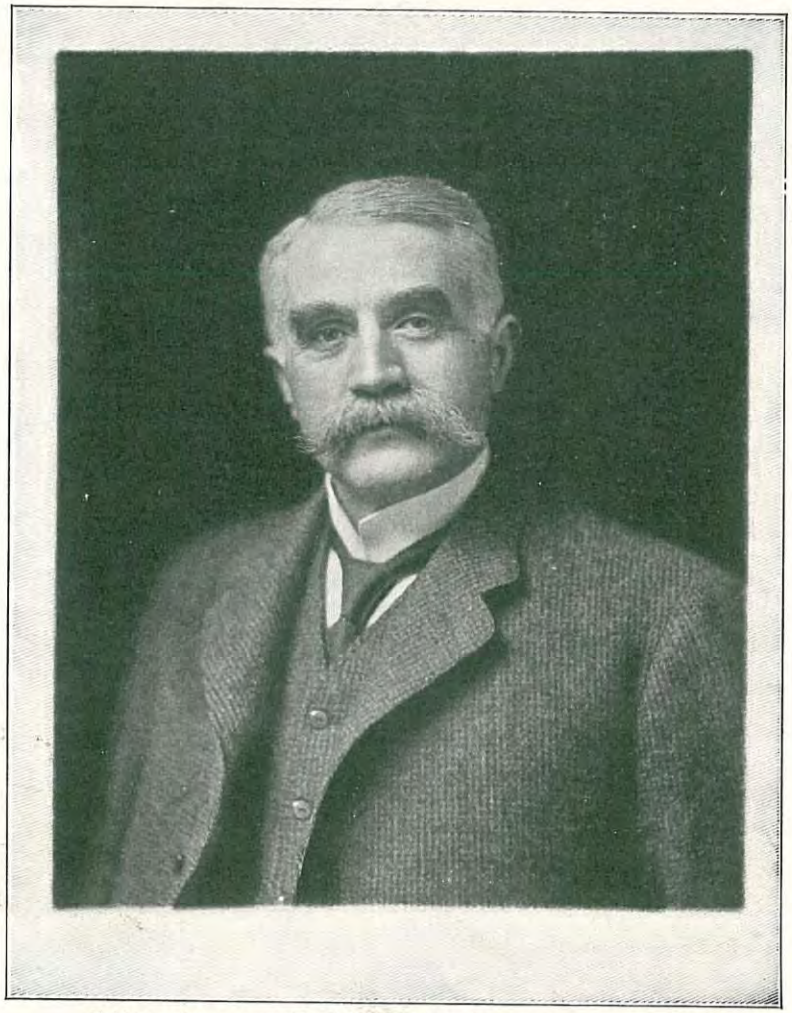
THE electric arc was first produced by Sir Humphry Davy barely a century ago. Davy was then at the head of the Royal Institution of Great Britain, and had at his command the largest and most powerful voltaic batteries ever constructed up to that time. By means of copper wires he connected a pair of carbon rods made of hard-burned charcoal with the terminals of a battery of two thousand cells. When the ends of the carbon rods were brought into contact to establish the electric current, and then separated several inches, a splendid bow, or arch, or "arc" of electric flame spanned the space between them. Incidentally the tips of the charcoal sticks were heated to brilliant whiteness.

Thirty or forty years passed before anything further was done. Then, with improved forms of battery and carbon rods, other experimenters continued the work that Davy had begun. They found that with shorter arcs and larger currents much more brilliant lighting effects were produced. Since the carbon rods, white-hot at their ends, gradually burned away and increased their distance apart, clockwork mechanism, magnetically controlled by the current passing through the carbons, was devised to push them forward as they receded, and thus maintain them in proper relation with each other.

The first advance from Davy's charcoal carbons was made by sawing square rods from solid blocks of gas-retort carbon, a very laborious operation. After many years these were followed by molded carbons made from very finely pulverized gas-retort carbon. This was intimately mixed with a small proportion of hard pitch and molded under heavy pressure in hot iron molds. The molded carbons were then packed in sand and baked at a high temperature, whereby the pitch was carbonized and the whole structure made electrically conducting.

During the sixties several crude forms of dynamo-electric machines appeared—machines for the conversion of mechanical into electrical energy through the agency of electromagnetic induction. They were of small efficiency, and consequently very wasteful of driving power; but for the production of strong currents, such as were necessary for the electric arc, they were a great improvement over batteries. Some experiments were made in lighthouse work at this time by the French government. Prior to the early seventies, however, the electric light remained virtually unknown outside of lecture-rooms.

The electric arc-light as now so commonly used is produced by the passage of a powerful electric current between the slightly separated ends of a pair of carbon rods, or "carbons," about twelve inches long and from three eighths to one half inch in diameter, placed vertically end to end in the lamp. The lamp mechanism is so constructed that when no current is passing, the upper carbon, which is always made the positive one, rests upon the lower by the action of gravity; but as soon as the electric current is established the carbons are automatically separated about an eighth of an inch, thus forming a gap of high resistance in the electric circuit, across which the current is forced, resulting in the production of intense heat. The ends of the carbons are quickly heated to brilliant incandescence, and by the burning action of the air are maintained in the form of blunt points. As the carbons burn away, the lamp mechanism feeds the upper one downward just fast enough to maintain the proper separation. The carbons are not heated equally, the upper or positive one being much the hotter. A small cup-shaped cavity, or "crater," ordinarily less than an eighth of an inch in diameter, is formed in its end, the glowing concave surface of which emits the greater part of the total light. In lights of the usual size, something like half a horse-power of energy is concentrated in this little crater, and its temperature is limited only by the vaporization of the carbon. Carbon being the most refractory substance known, the temperature of the crater is the highest yet produced artificially, and ranks next to that of the sun. It is fortunate that nature has provided us with such a substance as carbon, combining, as it does, the highest resistance to heat with the necessary electrical conductivity. Without carbon, or an equivalent,—and none is known,—we could have no arc-light.

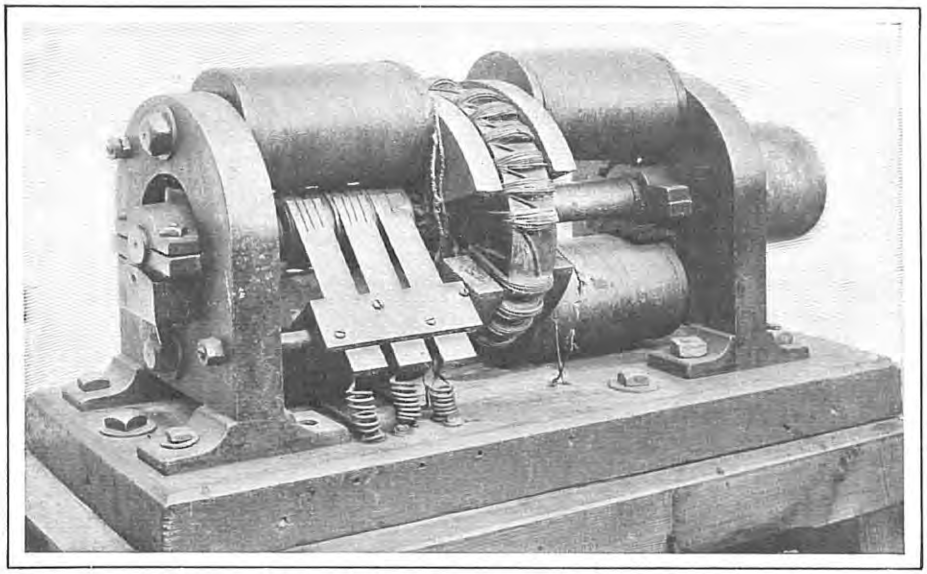


Half-tone plate engraved by C. W. Chadwick, from photograph by Gessford

CHARLES F. BRUSH

Arc-lights are customarily operated in "series"; that is to say, the current passing through each lamp is forced through all the others in the line. The size or volume of the current is only that necessary for one lamp, but the pressure or "electromotive force" varies directly with the number of lamps operated.

The "incandescent" lamp in common use differs radically from the arc-lamp in construction and operation. It consists of a long, thin filament of carbon attached to metal wires and sealed in a glass globe from which the air is exhausted. Passage of electric current through the filament heats it to incandescence. There is no gap in the circuit, and no combustion of the carbon filament. Incandescent lamps are always operated in "parallel," each lamp tapping its own current from the mains.



FIRST BRUSH DYNAMO, 1876
(Diameter of armature nine inches)

My only apology—and I hope a sufficient one—for these elementary remarks is that they are addressed to that part of the reading public having little or no technical knowledge of electrical science.

I am often asked what first drew my attention to the electric arc-light,—a mere laboratory curiosity not so very long ago,—what inspired my belief in its industrial possibilities, and led me to work out the many necessary inventions which finally led to commercial success.

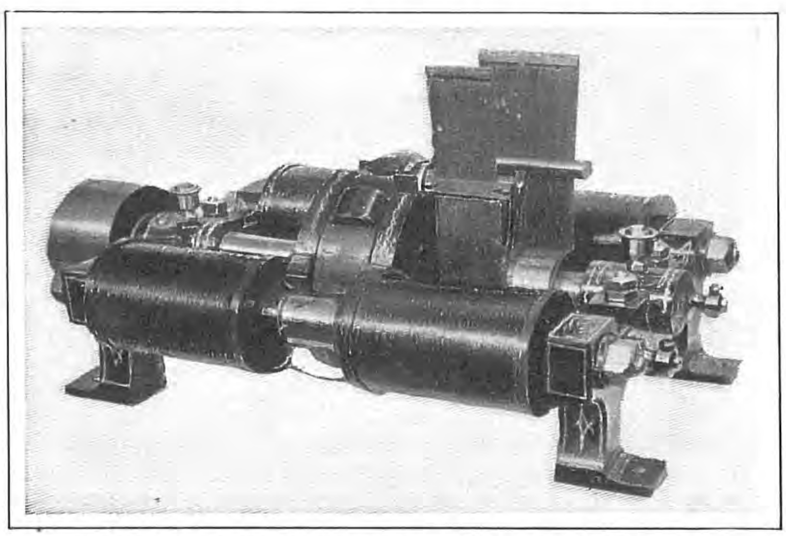
These questions are not readily answered. Keen but passive interest in the brilliant experiments of Sir Humphry Davy, and others of later date, followed by much thought, study, and experiment, led gradually to the fixed idea. It was an evolution covering a period of many years.

From early boyhood I was an omnivorous reader of scientific literature. Such parts of astronomy, chemistry, and physics as I could understand were a never-ending source of delight. I also constructed much crude apparatus—telescopes, microscopes, and photographic appliances.

In my early high-school days I made, among other things, many pieces of electrical apparatus—static machines, Leyden jars, batteries, electro-magnets, induction coils, and small motors. But the electric arc as described in the text-books, with its dazzling light and intense heat, was for a long time beyond my reach. I finally succeeded, however, in getting together enough batteries to make a small one—very small indeed. But it was the first I had seen, and filled me with joy unspeakable.

Soon after this came the news of Wilde's experiments in London with his dynamo and single arc-light. The light was probably about the size of our ordinary street lights; but it was deemed a wonder at that time, and interested me so much that I wrote a graduation essay on it the following year (1867).

In the early seventies the Gramme dynamo made its appearance in Paris. It was the first really efficient dynamo, and excited wide-spread interest. Some stores and factories were lighted by it at that time,



EARLY BRUSH ELECTROPLATING DYNAMO, 1877
(Diameter of armature nine inches)

but a separate dynamo and complicated clockwork lamp were required for each light, and these were too expensive for general use.

Some queer notions about the electric light were still prevalent. As late as 1873, Deschanel's "Natural Philosophy," a well-known text-book, said: "The light of the voltaic arc has a dazzling brilliancy, and attempts were long ago made to utilize it. The failures of these attempts were due not so much to its greater costliness in comparison with ordinary sources of illumination, as to the difficulty of using it effectively. Its brilliancy is painfully and even dangerously intense, being liable to injure the eyes and produce headaches. Its small size detracts from its illuminating power—*it dazzles rather than illuminates*—and it cannot be produced on a sufficiently small scale for ordinary purposes of convenience. There is no mean between the absence of light and a light of overpowering intensity."

The advent of the Gramme machine interested me deeply, and from that time the industrial possibilities of dynamos were never out of mind.

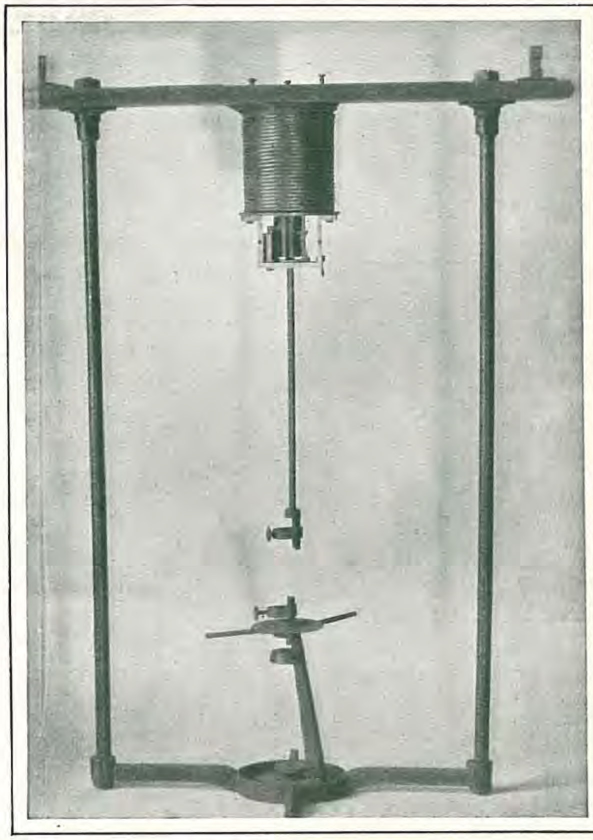
Early in 1876 I completed drawings for a dynamo of my own designing. This turned out to be a distinctly new type, since known as the "open-coil" type, preëminently well fitted for the production of the high-tension currents necessary for series arc-lighting, which developed later.

Such parts of that first dynamo as required machine-shop work were made under my direction at the shop of the Telegraph Supply Company, and together with necessary materials were shipped to my old country home near Wickliffe, Ohio, where I spent my summer vacation in 1876. There, in the little workshop where I had made my first crude electrical apparatus in boyhood days, I wound the armature and field-magnets, and completed the machine.

The day of trial was a memorable one for me. I belted the little dynamo to an old "horse-power" used for sawing wood, and attached a team of horses. After a little coaxing with a single cell of battery to give an initial excitation to the field-magnets, the machine suddenly "took hold," and nearly stalled the horses. It was an exciting moment, followed by many others of eager experiment. That was my first acquaintance with a dynamo.

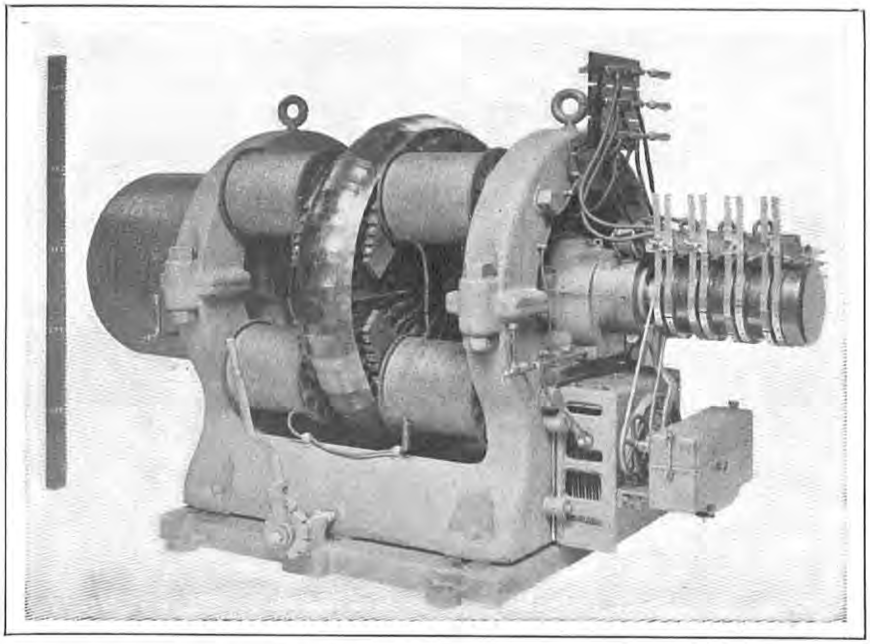
This pioneer machine has been preserved, and formed a part of the United States Government Historical Exhibit at the last Paris Exposition.

In the autumn of 1876 the Telegraph Supply Company, with which I had made business arrangements, began the manufacture of dynamos of the new type adapted to electroplating. A considerable business was developed in this direction. It is of historical interest that my compound field winding for constant potential, now so generally used in incandescence lighting and power transmission, was first applied to plating machines. It was, in fact, invented for that purpose in the autumn of 1877.



EARLIEST COMMERCIAL BRUSH ARC-LAMP, 1878

During the summer of 1877 two of the new dynamos built for lighting were exhibited and tested at the Franklin Institute in Philadelphia. In connection with the dynamos, a new lamp of very simple con-



LATEST TYPE OF BRUSH 125 ARC-LIGHT DYNAMO

(12B, form K Brush arc-generator with armature-shield and form 3 commutator. Diameter of armature about forty-eight inches)

struction was also exhibited. This, since known as the "ring-clutch" lamp, was the first simple lamp which appeared, and it marked a very great advance in the art. Costing perhaps a quarter as much to make as the other lamps then used, it was far less liable to derangement. Its salient features are embodied in nearly all arc-lamps of to-day.

The first dynamo and lamp actually *sold* by the Telegraph Supply Company were shipped to Dr. Longworth of Cincinnati about January, 1878. I went down to Cincinnati to show the doctor how to run his machine, and one evening while I was there he exhibited the light from the balcony of the building in which he lived, on one of the principal streets. It was a four-thousand-candle light, and of course attracted a large crowd, every man of which was ready and willing and eager to tell his neighbors all about it. I mingled in the throng for a time to hear the comments. One man who had collected a considerable audience called attention to the solenoid at the top of the lamp and said, "That is the can that holds the oil"; and, referring to the side rod, said, "That is the tube which conducts the oil from the can to the burner." He said nothing at all about electricity—a little oversight apparently unnoticed by his hearers, and they went away happy in their newly acquired knowledge of the electric light.

The early single-light machines were quickly followed by two- and four-lighters: that is to say, machines furnishing two or four separate and distinct currents, each adapted to operate a single arc-lamp.

Then began the tedious education of the public to the new light. The principal difficulty arose from the propensity of everybody to stare directly at the arc, and then declare that everything else looked dark. It took years fully to outgrow this habit. I had often to ask, "Why don't you stare at the sun if you wish to be dazzled? It is vastly brighter than the electric light." Furthermore, most early purchasers of electric lights thought each lamp giving as much light as fifty gas-burners would *replace* fifty gas-lights, notwithstanding the great advantage of distribution possessed by the latter. Altogether too much was expected.

However, a number of two- and four-light units were sold during the season of 1878 for lighting stores and shops. The largest plant of this kind, about twenty lights, was bought for a great department store in Philadelphia.

A four-light dynamo and lamps were used to light a part of the Mechanics' Fair in Boston in the autumn of that year. The electric light was a novelty in Boston at that time, and a great attraction at the fair.

One of the earliest four-light machines was exhibited to a number of invited guests at the works of a large manufacturing company in Cleveland. One gentleman on that occasion looked the whole apparatus over very carefully for perhaps half an hour, and then, pointing to the line wire, said to me, "How large is the hole in that little tube that the electricity flows through?" The shop superintendent of the company observed the machine for perhaps five minutes in complete silence; then he had fully digested the whole matter, and was ready to explain it to me. He said: "The electricity is generated by that there revolving affair rubbing the air up against them iron blades [meaning the pole-shoes of the magnets], just as you get sparks when you rub a cat's back." I suggested that while his was a simple and beautiful theory, it did not fully meet the facts. But he would hear nothing from me. He said: "The whole thing is plain. If you should run that machine in a vacuum, where there is no air to get rubbed, you could n't get any electricity."

The year 1878 was a memorable one in the history of electric lighting. Not only did it witness the first industrial use of electric lights on any considerable scale, but it was in that year that I had the great good fortune to invent and develop the modern series arc-lamp with its regulating shunt coil. It was this invention which made arc-lighting from central stations commercially possible; and I think it may justly be regarded as marking the birth of the electric-lighting industry as it exists to-day.

It had become evident by this time that a "fool-proof," or nearly fool-proof, lamp was essential to commercial success. The users of lamps could not be induced to let them alone, and no end of trouble was caused by meddling with them. So, in designing the new series lamp, I endeavored to make it completely fool-proof, and nearly succeeded, but not quite. The mechanism was locked together like a Chinese puzzle, and difficult to get apart. It was entirely devoid of screws that could be taken out and lost, or adjusting devices with which users could tinker. All necessary adjustments were made in the shop when the lamp was tested, and were made permanently.

But of course it was possible to take a lamp apart, and in this sense it was not fool-proof. Complaining of a lamp which failed to operate, a man once said to me, "Why, I 've had that lamp all to pieces *four times*, and *yet* it won't work!"

The high-tension dynamos for series lighting were "fool-killers," and usually able to look out for themselves. They discouraged undue familiarity.

Of course "series" lighting immediately superseded "parallel" lighting. A single large dynamo and one lamp circuit were much cheaper, simpler, and more easily managed than several small dynamos and many lamp circuits. Furthermore, the line cost and losses were vastly less, thus permitting the location of lamps at any desired distance from the dynamo—miles, if necessary. The stimulation of the business by the introduction of series lighting was enormous.

The first series plant, a six-light outfit, was sold in December, 1878, for lighting a clothing-store in Boston. One of the lights was hung over the sidewalk in front of the store, and nightly attracted crowds of people. This was the first electric light ever used in the streets of Boston.

Quickly following the six-light machines came the sixteen-lighters; and they remained the standard size until late in 1880, when they were followed by the forty-light machines.

One of the earliest sixteen-light outfits was installed, in February, 1879, in a worsted-mill at Providence, Rhode Island; another was purchased in March, another in April, and two more in September, making eighty lights in all—the largest electric-light plant in the world at that time. Other purchasers of plants in 1879 were mills in Providence, Hartford, and Lowell, a hotel in San Francisco, and several New York dry-goods houses.

Many plants were sold in 1880, and by the end of that year about six thousand lights had been installed.

Of course it was difficult to educate men fast enough properly to install and operate the plants, and much annoyance was caused by trivial accidents and poorly constructed and poorly insulated lines, which led to "short circuits" and "grounds." It often fell to my lot to straighten out these troubles. Once I traveled fifteen hundred miles to take a common staple tack from the bottom of a dynamo, where it happened to short-circuit a field-magnet. Sometimes malicious tampering with the dynamos occurred, but, fortunately, not often. Long, fine wire nails were occasionally found driven into the field-magnet coils in inconspicuous places.

Some difficulties were never traced to their source. On one occasion sixteen lamps were returned by our Boston agent with the statement that his men were quite unable to make them work decently. I examined and tested the lamps carefully, and found them all right. Without making any change or adjustment whatever, except to change the numbers so as to conceal their identity, I sent the lamps back, with a letter stating that I had personally examined and tested *this* lot, and could guarantee them to be all right. They were put back in their original places, and worked beautifully, so the agent said; and he requested me as a personal favor to look over all lamps he might order in future before they were shipped. He wanted to know what was the matter with the first set, but I never told him.

We had much trouble with carbons in the early days. Our first carbons were crooked and soft. They had high electrical resistance, burned out rapidly, and were very expensive. They were made from gas-retort carbon, which was difficult to pulverize, and contained from three to five per cent. ash. The ash was fatal to the steadiness of the light, causing the arc to flicker badly. It was necessary to find some better material than gas-retort carbon without delay.

After much anxious thought and a prolonged study of industrial processes likely to yield such material, I hit upon "still coke," a by-product of the destructive distillation of mineral oils. As the result of many analyses of different specimens of this substance, it was found that by careful selection the ash could be kept as low as two or three hundredths of one per cent. Still coke could be pulverized with comparative ease, and was obtainable in unlimited quantities at small cost. It has ever since been almost everywhere used in making carbons.

But the early carbons made from still coke shrank enormously in baking, and consequently were very crooked. Much experimenting was necessary to find out how best to work this material. Then, too, special machinery and furnaces had to be designed for grinding, mixing, molding, and baking. These details occupied much of my time during the first two or three years.

To decrease their electrical resistance and retard the burning of the carbons, we electroplated them with copper, which is still customary. This little scheme of covering the carbons with just enough, but not too much, copper was the only easy invention that it was my privilege to make; and it paid well, considering its seeming simplicity. It yielded, if I remember correctly, something like $150,000 in cash royalties before serious competition set in.

The very early carbons were sold at the rate of $240 a thousand. I say at the *rate* of $240 a thousand, because nobody thought of ordering a thousand carbons at once. Fifty or a hundred were ordered at a time. When the business increased a little, we reduced the price to $150 a thousand. This involved loss for a time, then covered cost, and afterward afforded profit as the business grew larger. We soon again reduced the price, this time to $62.50, on the theory that cheaper carbons would stimulate the growth of the electric-light industry; and our expectations were abundantly justified. The growth of the lighting business was very rapid from that time on, so that while we lost money on carbons at first, we far more than made it up in increased sales of dynamos and lamps. After a while, however, with largely increased and growing output, we made a handsome profit.

During the first ten years or so of the electric-lighting business, the price of carbons gradually settled down to about ten dollars a thousand, and has remained not very far from that figure ever since. But the quantity used grew to amazing proportions. Before the introduction of the "inclosed-arc" lamp, the annual consumption of carbons reached nearly two hundred millions.

The first instance of public-street lighting in this country was in the Public Square of Cleveland, a little park of about ten acres. In April, 1879, twelve lamps of the ordinary so-called two-thousand-candle power were installed in the park on high ornamental poles.

While we were putting up the poles and line circuit, a great deal of interest was manifested by the public, and on the evening when the lights were formally started the park was crowded with people. Many evidently expected a blinding glare of light, as they had provided themselves with colored spectacles or smoked glass. Of course there was at first a general feeling of disappointment in this respect, although every one was willing to admit that he could read with ease in any part of the square. After a few weeks, however, when the novelty had worn off, and the people had tired of staring at the lamps, the general verdict was highly favorable to the new light.

As the Public Square lights were required to burn all night, this necessitated putting fresh carbons in each lamp sometime during the night, because a single set would not last until morning. But the nightly trimming of the lamps required an extra man and added materially to the cost of lighting. To meet this difficulty, I devised the "double-carbon" lamp, which afterward grew into general use for all-night lighting, and became famous through much patent litigation.

The new lights were exhibited in London in 1880. For that purpose we sent over a sixteen-light outfit and some smaller ones. The English capitalists whom we sought to interest were incredulous at first, and would not believe that sixteen powerful lights could be operated by one dynamo, certainly not in a single circuit. They thought some trickery was behind it. But they were soon convinced, and the Anglo-American Brush Electric Light Corporation, Limited, was organized to exploit the new industry in England and throughout Europe. The corporation was capitalized at eight hundred thousand pounds, and started a large manufacturing plant in London.

The earliest public lighting in London was that of the Houses of Parliament, Charing Cross Station, Ludgate Hill Station, Blackfriars Bridge, and St. Paul's Churchyard.

The industry experienced a rapid growth during the next two or three years, but was afterward greatly hampered by adverse legislation limiting the electromotive force of lighting circuits. This was thought to be instigated by the gas interests. In the meantime the lights were introduced on the Continent, and also in India, Australia, and other British possessions.

In the early summer of 1882, the Brush Electric Company of Cleveland gave a public exhibition of arc-lamps in the main street of Tokio. It was the first time arc-lights had been seen in Japan, and they excited great interest.

This exhibition was followed by several large contracts with the Japanese government. The first was for lighting the navy-yard and docks at Yokosuka, on the Bay of Tokio, at that time the only navy-yard in Japan. Another was for lighting the Tokio arsenal, where the small arms for the army and navy were manufactured. This contract was made with General (now Field Marshal) Oyama, who was then Minister of War. Another contract was for lighting the government woolen-mills near Tokio, where the cloth for army and navy uniforms was manufactured. Search-lights for the chief vessels of the Japanese navy were also supplied.

In the summer of 1882 the Shanghai Electric Company was organized to light the foreign municipality of Shanghai, China. This was the first central station organized anywhere in the Orient. The company started with about a hundred arc-lights, and, I understand, has continued its operations down to the present time.

Starting with public-street lighting in Cleveland early in 1879, the central-station idea rapidly took root, and before the end of 1881 lighting stations were in operation in New York, Boston, Philadelphia, Baltimore, Montreal, Cleveland, Buffalo, San Francisco, and several other cities.

Perhaps the largest of the early stations was that of the Brush Electric Light Company of New York, located at 133 and 135 West Twenty-fifth street. On December 20, 1880, Broadway from Fourteenth to Twenty-sixth street was first lighted from this station, with a circuit nearly two miles in length. Fifteen lamps were used, mounted on ornamental iron poles twenty feet high, and placed at the street intersections. A few weeks later the lights were extended to Thirty-fourth street.

The lights were the ordinary nominal two-thousand-candle power still in vogue; but the lamps gave this amount of light only when measured in the zone of greatest illumination. The average horizontal illumination was about eight hundred candles, and not quite uniformly distributed in all directions.

Not long afterward some of the lights were measured by a famous college professor and patent expert employed by a gas company. Naturally he did not select the most favorable conditions for measurement, and in his report stated that he thought the electric-light company must have arrived at its two-thousand-candle-power rating by measuring the lights north, south, east, and west, getting five hundred candles each way, and adding all together.

The opposition of the gas companies everywhere was moderate at first, but became strenuous when central-station lighting began to develop, and continued several years.

I argued from the first that the general introduction of arc-lights in cities would greatly stimulate the consumption of gas, on the ground that the public, becoming accustomed to brilliantly lighted streets and stores, would burn far more gas at home. This prediction, paradoxical as it seemed, was abundantly and admittedly fulfilled.

The name of the Telegraph Supply Company was changed in 1881 to the Brush Electric Company, capitalized at three million dollars, a very large corporation for those days. About ten years later the Brush, Thomson-Houston, and Edison companies were combined to form the present General Electric Company, and the works of the Brush Electric Company were removed from Cleveland, Ohio, to Schenectady, New York.

The forty-light dynamos of 1880 were followed in due time by the sixty-five-lighters. Next came the hundred-and-twenty-five-light machines, which are the standard Brush arc-dynamos of to-day, and in general use for long-circuit series lighting from central stations.

Within the last few years the "inclosed-arc" lamp has come into very extensive use. It differs from the ordinary "open-arc" lamp in having its carbons inclosed in a nearly air-tight glass globe, whereby consumption of the carbons is so greatly retarded that their life may be prolonged twentyfold or even more. This effects a great saving in attendance as well as in carbons.

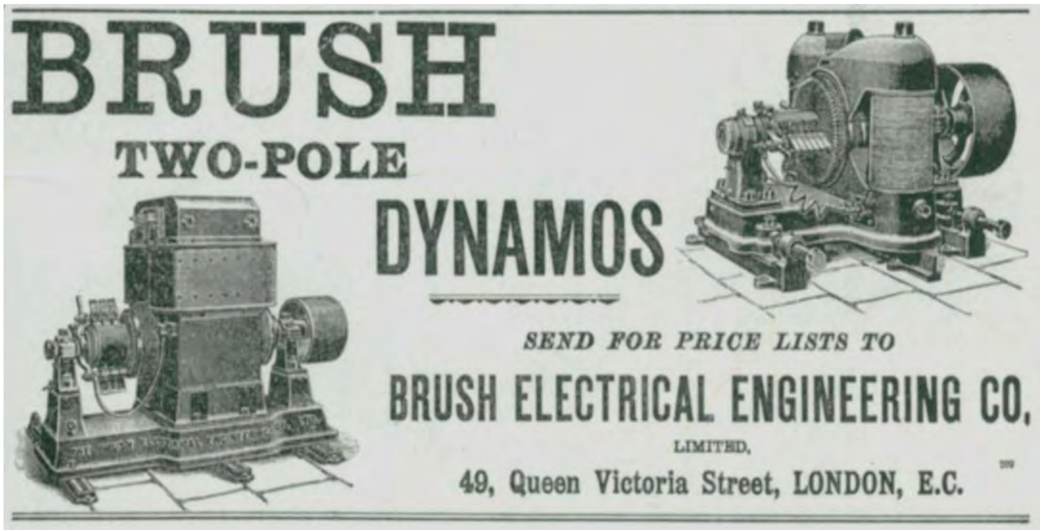
For convenience many of these lamps are operated from constant-potential circuits where such circuits are available, though this involves much loss in efficiency.

The use of inclosed arcs has become large enough to stop the growth of carbon manufacture, notwithstanding the steady and large increase in the number of arc-lamps in use. The General Electric Company alone sold about eighty-five thousand inclosed-arc lamps in 1903—far more than of the open-arc variety.

Almost from the beginning of its commercial success, down to the time of consolidation, the Brush Electric Company met with vigorous competition, made practicable by the hostile attitude to all patents manifested by the Federal courts throughout that period. Inventors in every field of effort suffered from this cause for about ten years before reaction came. All competitors in arc-lighting used the Brush series arc-lamp, more or less modified in appearance. It was indispensable. The most successful used the open-coil dynamo also.

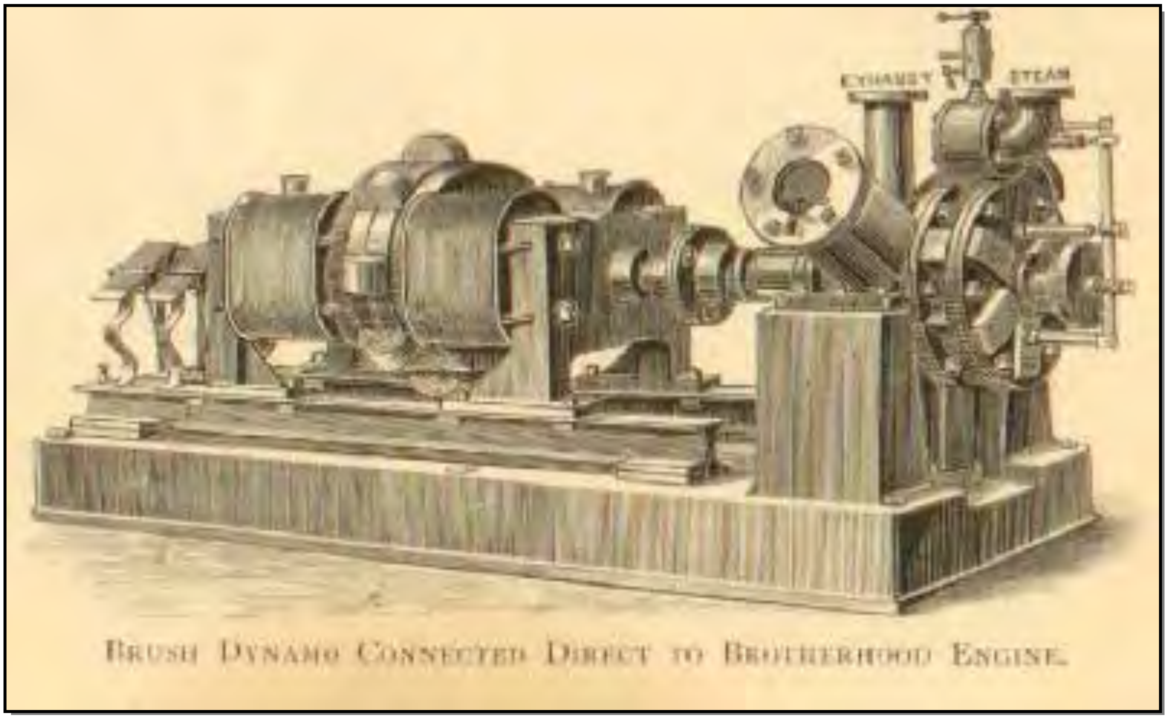
The early success of arc-lighting undoubtedly prompted and hastened the development of incandescence lighting as well as power transmission and electric traction.

The capital invested in these industries has grown from virtually nothing in 1877 to something like four thousand million dollars, in 1904, in the United States alone. It is difficult to estimate what part of this vast total should be assigned to arc-lighting, as this industry is intimately involved with the others; but it certainly constitutes a very respectable fraction of the whole.



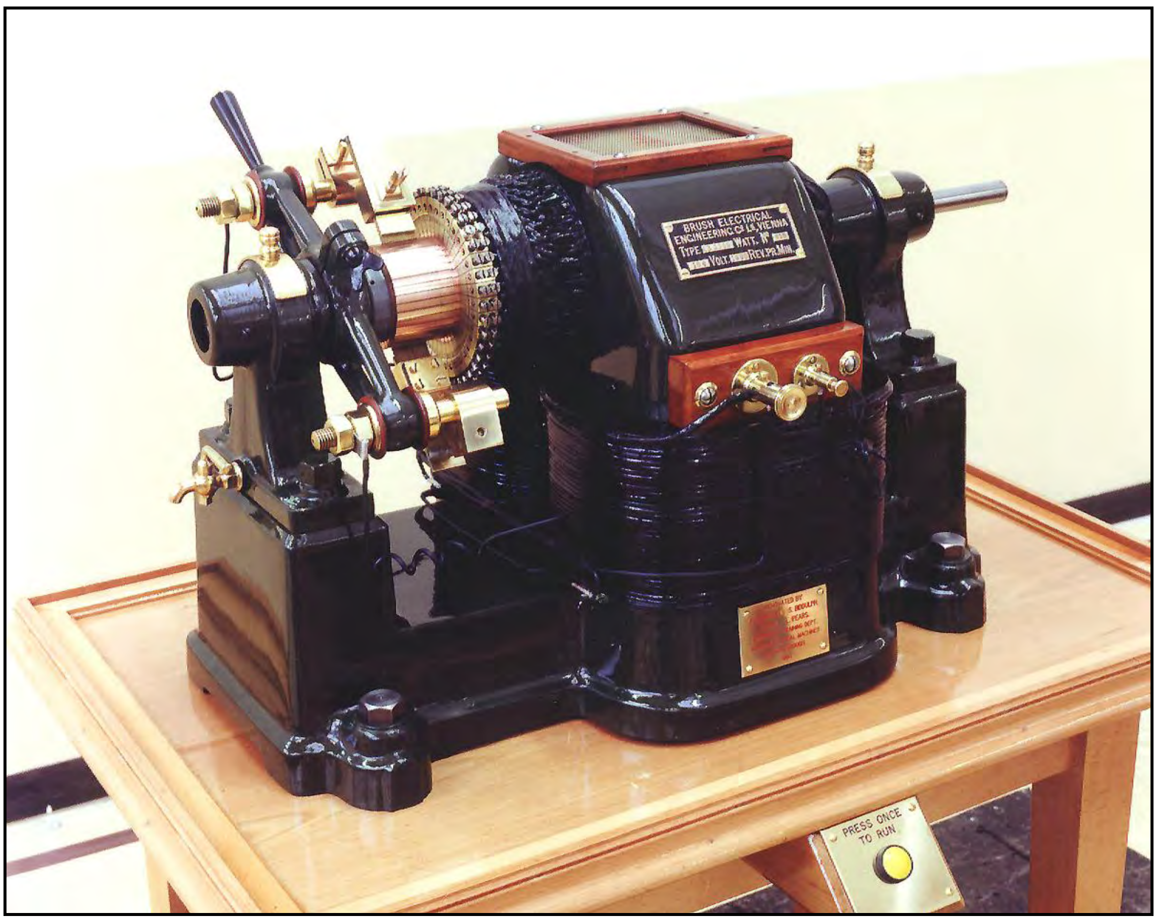
1892 ENGINEERING Advert by Brush

Hartford Electric Light Co in Connecticut began operations on April 7, 1883, when it inaugurated commercial electric service at sundown with a lighting demonstration at Hartford's Union Station. HELCO began with six customers and one public street lamp, shown in this picture. The HELCO generating station was on Pearl Street next to the boiler house of the Hartford Steam Company, whose coal-fired boiler produced steam to drive HELCO's prime mover - a 50-horsepower steam engine - which was belt-connected to drive a Brush 28-light electric generator. Through wires strung temporarily along Asylum Street building walls and rooftops, this steam engine-generator supplied direct current to 21 arc lamps to illuminate the railroad depot, two pharmacies, a saloon, bakery, carriage shop and - on Pearl Street - a single lamp in front of the HELCO engine shed.



BRUSH DYNAMO CONNECTED DIRECT TO BROTHERHOOD ENGINE.

Peter Brotherhood (Peterborough – UK) steam turbine and Brush dynamo – 1885



In 1992, Brush Apprentices renovated and rebuilt this 1880 Brush “Vienna” dynamo for company display.