

# The Brush Arc Lamp

by Jeffrey La Favre

During his childhood, Brush read about the first arc light experiments performed by Sir Humphrey Davy in the early years of the nineteenth century. Using a battery as his power source, Davy was able to sustain an electric arc between two carbon electrodes. When the electrodes were momentarily brought in contact at their tips and then withdrawn from each other, an arc developed across the gap. The relatively high resistance to electric current in the gap region caused the electrode tips to heat to incandescence and emit a brilliant light.

At the time of Davy's experiments, the battery was very new to science. Volta had developed the first one only a few years earlier, in 1800. These early batteries were inefficient and very expensive to construct. The lack of an economic source of electricity confined the arc light of the time to the laboratory.

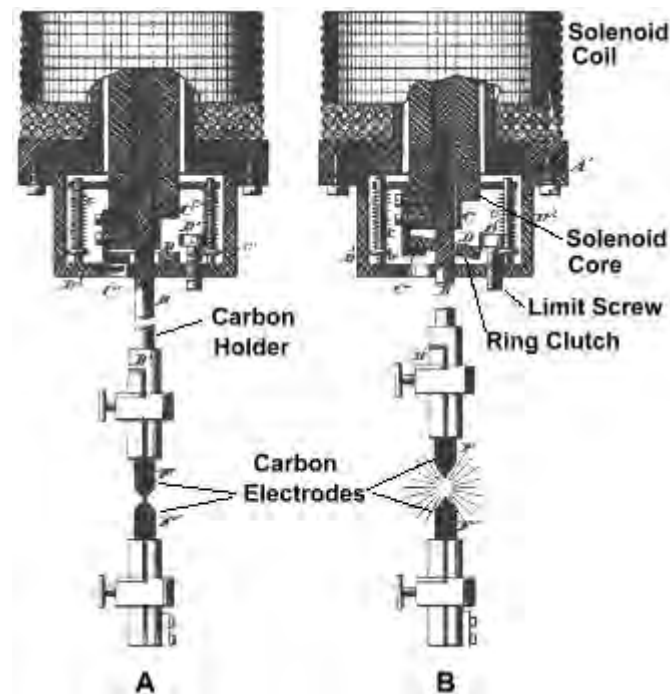
Improvements in batteries by the middle of the century stimulated further development of the arc light. Regulation of the gap between the electrodes was a primary design challenge in producing a practical lamp. During operation, the carbon electrodes are consumed at their tips, resulting in a widening of the gap between them. Left unattended, the lamp will cease to operate when the gap becomes too wide to allow current flow between the electrodes. The problem can be solved by providing a mechanism to adjust the gap during operation.

The electrode gap can be maintained with a simple mechanical device actuated by hand. The earliest lamps were of this type. However, it was desirable for the lamp to adjust itself during operation without the need of human attention. Various schemes were developed to regulate the electrode gap automatically but these were typically clumsy, complicated and expensive to manufacture. Furthermore, these lamps usually had poor regulation characteristics. This was the state of the art at the time when Brush began to develop his arc light (for further information on early arc lamps, consult the following references: [History of Electric Light](#), by Henry Schroeder, published by the Smithsonian Institution, 1923; [The Electric Light: Its History, Production, and Applications](#), by E.M. Alglave and J. Boulard, published by D. Appleton & Co., 1884).

In developing an arc lighting system, Brush initially concentrated on

finding an economical source of electric power. His vision was to light America on a grand scale and this would not be possible with expensive batteries. At the time, the only alternative for producing electricity was the dynamo. Brush realized that the dynamo was the key to a successful lighting system and it would represent a great challenge to his inventive skill. Using sound logic, Brush developed a viable dynamo before working on the arc lamp itself. By 1877 he had enough confidence in his dynamo to start work on the arc lamp.

Brush set forth the following design criteria for his lamp: simplicity, reliability, durability, and automatic regulation. These were the characteristics that would insure wide-scale adoption of the lamp. Initially he experimented with electromagnetic control devices for maintenance of the arc gap. This was not a new idea; several inventors had produced lamps with electromagnetic regulators prior to Brush. However, Brush found that he could not obtain the desired regulation with an electromagnetic device alone. Better control was achieved when Brush combined electromagnetic and mechanical means to control the arc.



The illustrations to the left were derived from Brush's US patent no. 203 411, Improvement in Electric Lamps, dated May 7, 1878. They illustrate a control mechanism that Brush developed for maintaining the arc gap. The lamp electrodes and solenoid are wired in series so that electric current always flows through the solenoid coil while the lamp is operating. The solenoid contains an iron core which is free to move up and down inside the coil.

The core is hollow and the carbon holder rod can pass freely through it. At the bottom of the core there is an L-shaped hook which provides

a mechanical link between the solenoid and the ring clutch. The ring clutch is a disk with a central hole, like a washer. The carbon holder rod is sized to freely pass through the central hole of the ring clutch as long as the clutch is perfectly horizontal.

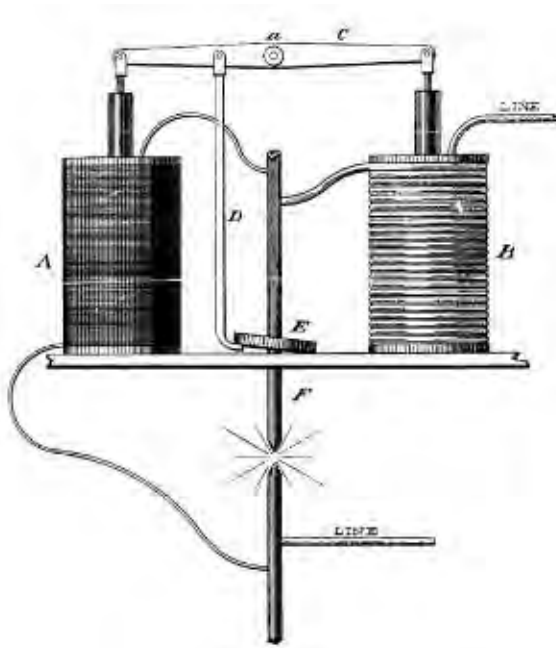
Prior to application of electric power, the parts of the lamp are positioned as in figure A. The ring clutch is horizontal and rests upon the bottom of the regulator housing. The upper carbon holder is free to move through the central hole of the ring clutch and the upper electrode is maintained in contact with the lower electrode by the weight of the upper electrode assembly. Initial contact of the electrodes is required to close the electric circuit and provides the conditions required to strike (initiate) the arc. Immediately after the power is applied, the parts are positioned as in figure B. Upon powering the lamp, a magnetic field is induced by the coil of the solenoid. The magnetic field draws the solenoid core up. As the core moves up, the attached hook lifts one side of the ring clutch, tilting it from the horizontal. As the clutch tilts, it grabs onto the carbon holder. Subsequent upward movement of the core then takes with it the ring clutch and carbon holder. The upward movement of the upper carbon electrode establishes a gap and the arc of the lamp is "struck". The initial gap distance in the control cycle is limited by the limit screw, which arrests the upward movement of the ring clutch.

As the lamp operates, the carbon at the tips of the electrodes is consumed, resulting in a widening of the gap. As the gap widens, increasing resistance reduces the current flow. This results in a weaker magnetic field in the solenoid and eventually a downward movement of the core. The downward movement reduces the gap. If the current drops low enough, the core will drop to its lowermost position and the ring clutch will then come to rest again upon the bottom of the housing in a horizontal position. When the clutch assumes this position, the carbon holder is released and is free to drop by gravity. As the gap is reduced, higher current flow is established and once again the ring clutch engages the carbon holder to set a proper gap. This regulation cycle repeats itself many times until the carbons are expended.

By utilizing this scheme, Brush was able to create an arc lamp with good regulation characteristics. The light output was fairly stable and of high intensity. The clever ring clutch design allowed the use of relatively long carbon electrodes, which could be fed repetitively in small increments to maintain a proper arc gap. The long electrodes allowed extended operation times of up to 8 hours. Brush tested and refined the design over a period of about one year before he was

satisfied with the lamp's performance.

The solenoid and ring clutch regulator represented a breakthrough in arc lamp technology. It provided the basis for a commercially viable lamp. However, Brush was also working on other improvements to the lamp at the same time. Taken together, these improvements would yield a line of lamps eminently suited for commercial use.



The illustration to the left is a semi-schematic drawing from Brush's US patent no. 312 184, Electric-Arc Lamp, dated February 10, 1885. It represents an improved regulator for the carbon arc and utilizes two solenoids, one with a heavy gauge coil (labeled **B**) and one with a light gauge coil (labeled **A**). The solenoid **A** is wired in parallel with the electrodes and solenoid **B** in series with the electrodes. The solenoid **B** serves the same function as the solenoid described above (patent 203 411). The solenoid **A** adds finer control to the regulator.

The regulation cycle of this design starts out the same as described for patent 203 411. When the lamp is first powered on, the current through solenoid **B** pulls its core down which also pulls the right side of the linkage lever (labeled **C**) down. The linkage rod (labeled **D**) and ring clutch (labeled **E**) move up because they are connected to the lever on the left side of its pivot point (labeled **a**). As the lamp operates and the arc gap widens, the current flow through the electrodes is reduced. And according to Ohm's Law for the case of parallel circuits, it is evident that the current through the coil of solenoid **A** will increase as the current through the electrodes decreases. Therefore, as the gap widens, solenoid **A** will pull down with increased force on the linkage lever and at the same time solenoid **B** will pull down with decreased force. The interplay of the two solenoids results in a finely controlled downward movement of the ring clutch as the current through the electrodes decreases. And as the current through the electrodes increases, the two solenoids work together to raise the

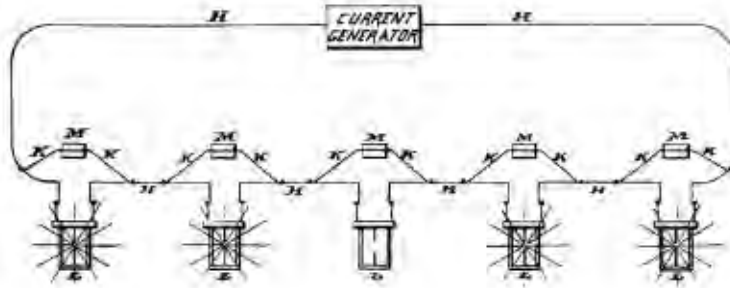
carbon holder in a finely controlled manner. The regulator will move the upper carbon up and down until an equilibrium position is obtained, where the pull from both solenoids is balanced and the linkage lever remains stationary.

Brush also worked on improving the lamp electrodes. Carbon electrodes at the time were commonly made from retort carbon, a material that yields a poor quality electrode. Retort carbon contains a high level of impurities (ash), is soft, and has a high resistance to electric current. Brush needed a better electrode for his new lamp.

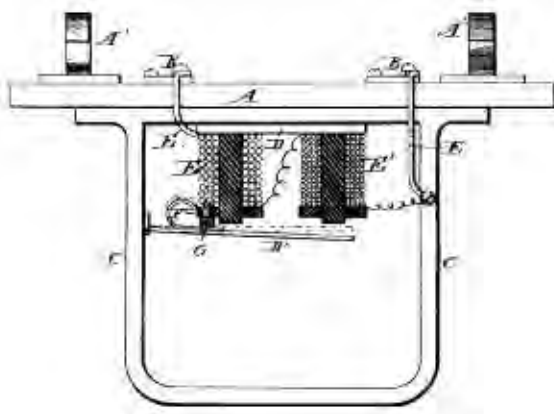
Relying on his knowledge of chemistry, Brush developed a new carbon material from still-coke, a by-product of petroleum refining that was readily available from the Standard Oil Company in Cleveland. The still-coke carbon proved to be much higher in quality than the retort carbon. Furthermore, the manufacturing process and raw material were very economical compared to the retort carbon method. Brush was able to produce an electrode of longer length and smaller diameter with the new carbon material. The new electrodes were more efficient because they could yield a longer burn time per unit weight of carbon

While the new carbon material improved the quality of the electrode, further improvements were needed to provide an electrode suitable for the new lamp. The new carbon material had a high resistance to current flow and was not strong enough to yield the length of electrodes that Brush desired. In a flash of inspiration, Brush quickly devised another method to improve the electrode. By applying a thin layer of copper to the exterior surface of the electrode, Brush was able to improve the conductivity of the carbons and at the same time increase the strength so that longer rods could be manufactured. The copper-enhanced electrodes also yielded a longer burn time because the metal cover reduced the consumption rate of the carbon.

The lamp designs described above were suitable for single-lamp systems, where one dynamo was used to power one lamp. However, these lamps were not optimal for use in series where one dynamo powered multiple lamps. Brush knew that this was a critical limitation in his system. If the arc was extinguished in one lamp due to a malfunction, all lamps in a series circuit would cease to operate.



The problem could be overcome by adding another control device that would allow current to bypass a malfunctioning lamp. Brush developed a shunt that he could add to each lamp for multiple-lamp systems. The system is diagrammed in the above figure, which is taken from Brush's US patent no. 234 456, Automatic Cut-Out Apparatus for Electric Lights or Motors, dated November 16, 1880. In this system, each lamp is equipped with a cut-out device, labeled **M** in the illustration. If a lamp should fail to sustain its arc during operation, a shunt would close, providing a bypass route for current.



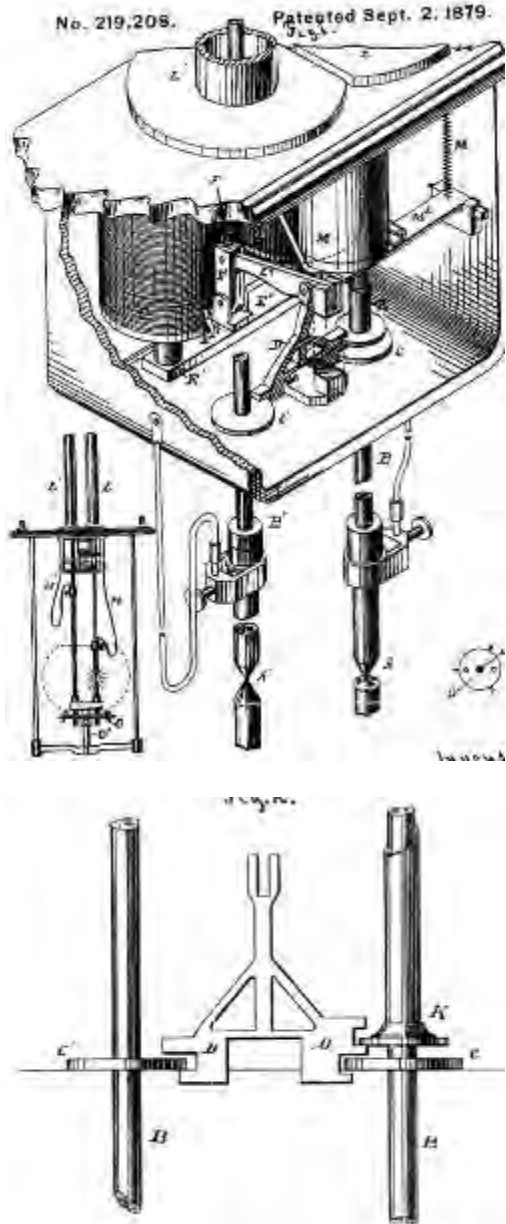
The illustration to the left, also from patent 234 456, depicts a cut-out device. The cut-out contains two coils, one with heavy gauge wire, labeled **E**, and one with light gauge wire, labeled **E'**. The two coils are wired in series with each other and the combined coils are wired in parallel with the lamp. During normal operation of the lamp, the major portion of current passes through the lamp and only a small amount passes through the coils of the cut-out.

However, if a lamp begins to malfunction, with a resultant rise in resistance to current flow through the lamp, more current will flow through the cut-out coils. The current flow through the lamp and cut-out can be understood and calculated by applying Ohm's Law for resistances in parallel circuits. As the current increases in the cut-out coils, the armature below the coils (labeled **D'**) is drawn up by the increased magnetic field. The cut-out is designed in such a way that just prior to lamp failure, the armature will be drawn up enough to

close a pair of electrical contacts, which provides a route for the current directly through the heavy gauge coil, **E**. Since the shunt route for current passes through the heavy gauge coil, the armature is maintained in the up position and the contacts remain closed. If the upper carbon of the lamp should happen to drop to make contact with the lower carbon, the lamp circuit will be closed again and will route the major portion of current through the lamp. When this occurs, the armature in the cut-out will drop and restore this device to the original condition.

The addition of the cut-out to Brush's lamp was a critical element in developing a multiple lamp system. This was the system that was used for street lighting, where a number of lamps were powered by one dynamo, housed in a central station. Brush now had a product that could replace the gas lamps used in many cities in America and throughout the world. His superior system of lighting was purchased by many municipalities during the 1880's and his name became known to the general public.

One other limitation in Brush's lamp was the operation time. His single-carbon arc lamp would operate up to 8 hours on a set of carbons. Continued operation required replacement of the electrodes by maintenance personnel. Some cities, like New York, desired a street lamp that would operate from sunset to sunrise without replacement of the carbons. Brush solved the problem by designing a double-carbon arc lamp. This lamp would operate off one pair of carbons until they were expended and then current was transferred to the second pair.



The illustration at left is from Brush's US patent 219 208, Improvement in Electric Lamps, dated September 2, 1879. It depicts the double-carbon lamp regulation system. A new element in this design was the triangular lifting device for the ring clutches. The illustration below is also from patent 219 208 and provides a detail view of the lifting device that is linked to the ring clutches. Upon close examination, it should be evident that the slot on the left side of the lifter will actuate the left ring clutch prior to actuation of the right ring clutch, housed in the lower slot on the right side of the lifter (there is a gap between the bottom surface of the right ring clutch and the contact surface of the lifter). When power is applied to the lamp, the left carbon holder will rise first, establishing a gap between the left electrode pair while the right pair of electrodes are still in contact. At this instant, current will flow only through the right pair of electrodes and as the lifter moves up more, the right ring clutch will grab its carbon holder, resulting in an arc between the right pair of electrodes. The sleeve labeled **K** functions as a stop for the right carbon holder, which prevents this pair of carbons from contacting when they are nearly consumed. At this point the left pair of carbons come into contact and proceed to serve as the active electrodes for the remainder of the operation cycle.

The composite photograph at left





shows two styles of single-carbon Brush arc lamps. The lamp on the left is complete and has a globe that encloses the electrodes in the gap region. This lamp was probably designed primarily for indoor applications ([several appear in an illustration of the interior of a Brush central station](#)). The lamp on the right has a larger frame of the type used for street lights. The globe has been removed so that the electrode gap can be seen (the upper electrode was propped in place so that the lamp can be seen with an electrode gap). This style of lamp was housed in a decorative frame with a hood as depicted in the drawing of a double-carbon lamp at the left.



**For additional information on the Brush arc lights, you might like to take a look at a web site authored by Charles Brush's great grandson, [Charles F. Brush IV](#).**

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*The primary sources for this article were US Patents referenced in the text and [Charles F. Brush: Pioneer Innovator in Electrical Technology](#), a Ph.D. dissertation by Harry Eisenman III. The author would like to thank Charles F. Brush IV, the great grandson of Charles Brush, for helpful comments during the preparation of this article.*

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