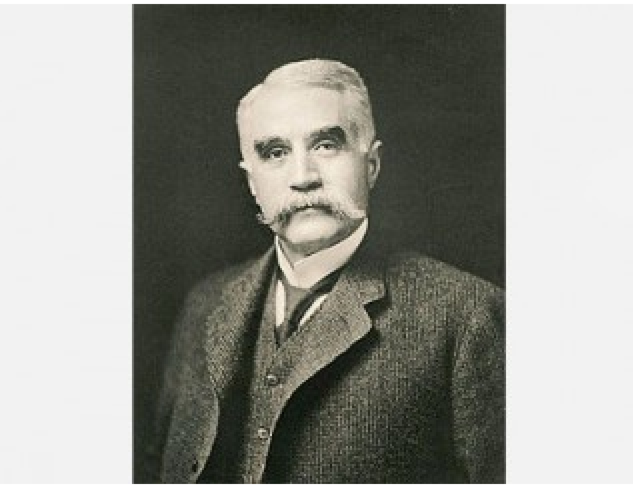

Charles Francis Brush **(March 17, 1849 – June 15, 1929) was a U.S. inventor, entrepreneur and philanthropist. Known for** Arc Lamp.
Notable awards: **Edison Medal; Rumford Prize; French Legion of Honor; Franklin Medal .**

Charles Francis Brush was an American pioneer, inventor and industrialist in the commercial development of electricity. His inventive genius ranked with an elite group of electric pioneers including Thomas A. Edison. Brush designed and developed an electric arc lighting system that was adopted throughout the United States and abroad during the 1880's. He also devised a generator that produced a variable voltage controlled by the load and a constant current.

Charles Francis Brush was born on his parents' farm in Euclid, Ohio, on March 17, 1849. Charles Brush was the youngest of nine children of Isaac Elbert and Delia Williams Phillips Brush. He was an eighth generation American on his father's side, descending from Thomas Brush, who was born in England about 1610. On his mother's side, Charles was a descendent of Rev.

George Phillips, 1593-1644. Isaac Elbert Brush (Charles' father) (b. August 30, 1803 d. February 4, 1893) married Delia Phillips (b. September 13, 1808 d. March 15, 1876) on May 2, 1827. Isaac was a successful businessman in the woolen manufacture trade.

However, his business did not survive the depression of 1837, which precipitated his move to the Western Reserve in Ohio. He spent five years preparing the land and moved his family in 1846 to the Walnut Hills Farm. At the time Isaac and Delia had seven children (5 girls and 2 boys). Another daughter and then Charles were born on the farm, which was located about 10 miles east of Cleveland.

Charles' early years were spent on the Walnut Hills Farm. Being the youngest child of nine, Charles probably did not have as many responsibilities on the farm as his older sisters and brothers. Rather than waste his free time on trivial activity, Brush spent it reading about astronomy, chemistry, physics and other areas of science. However, his thirst for knowledge was not satisfied by reading alone.

He started to do experiments in the workshop on the farm. Brush was probably most interested in electricity, a source of energy that was poorly understood during the time of his childhood. When he was 12, Brush constructed his first static electric machine, using a bottle, a piece of leather and amalgam from an old mirror. He also made batteries, electromagnets, induction coils and small motors. The fact that he was able to produce such devices from items around the farm was a testament to his ingenuity. He could not afford expensive insulated wire but this did not deter him from making coils.

He used rusty wire and shellacked paper for insulation between layers of wire. The rust on the wire, while not being an ideal insulator, provided enough insulation to make a functional coil. During this time Brush learned of Humphrey Davy's 1808 experiment with an arc light. Davy attached two carbon electrodes to a battery and found that he could produce an arc between the electrodes. The arc light held special fascination for Charles but he was not able to construct one with the discarded materials found around the farm. For this he would have to wait until high school, where he would have the necessary materials to assemble such a device.

Brush's parents appreciated the talents of their youngest child and realized that he would benefit greatly from a formal education. They made the financial sacrifice to send him to a high school. In 1863 he entered Cleveland's Central High School. The school was too far from the farm for Charles to live at home so his parents sent him to a boarding house downtown.

This boarding house was also the temporary home of other young men soon to make their mark in history, including John D. Rockefeller. Central High provided the environment that Brush needed to develop his interest in science and electricity. It contained the only large public library in the city at the time and there he found printed matter which allowed him to develop his knowledge in frontier areas of science. Furthermore, the science laboratories at the school would provide the facilities he needed to do more advanced experimentation.

During his junior year, Brush fulfilled his boyhood dream of constructing an arc light. Using materials from the school laboratory, he made a zinc-carbon and nitric acid battery and fashioned carbon electrodes from gas retort carbon. He later related that the making of electrodes from retort carbon was quite laborious. Brush's teachers were very impressed with him and he was placed in charge of supervising the electrical apparatus at the school. This also allowed him to have free access to the physical laboratory, which he used to great advantage.

While in high school, Brush learned of Wilde's pioneering experiments with a dynamo and arc light, which were performed in London in 1866. He would incorporate this knowledge into his speech at commencement in 1867, which covered the conservation of energy, following a path from the sun to vegetation, coal, steam, electricity and finally light. By this time Brush surely had a vision for the future of electricity in commercial applications. He graduated from Central High with honors.

Brush now had a good high school education under his belt but this was not enough. He had a strong desire to continue his education at a higher level. But his parents did not have the means to send him to college. They had already spent all they could for his room and board during the high school years. A brother of Charles' mother agreed to finance his education in the form of a loan. The uncle felt that the University of Michigan was a fine institution, which apparently had some influence on Charles' choice for a higher education.

Brush entered the University of Michigan in the fall of 1867 to pursue a degree in mining engineering. At the time the university did not have a course of study in electricity. Furthermore, it did not seem that one could make a living in the area of commercial electricity at the time. Brush felt that mining engineering would give him the practical education that would provide for employment after graduation–much needed employment for repayment of his loan.

While the university did not have any course work in electricity, the science courses did provide Brush with the necessary knowledge to be successful in his future endeavors. His course work included history, English, botany, French, rhetoric, chemistry (qualitative analysis, assaying & analytical), mathematics (geometry, algebra, differential & integral calculus), geology, mechanics, machine drawing, metallurgy, civil and mining engineering.

Brush was a very busy young man during his stay at the university. He had worked hard to finish his course of study in a short time, working through the summer months to accelerate his rate of progress. Repayment of the debt to his uncle was part of the motivation for his fast track approach, reasoning that an early graduation would mean earlier employment and resolution of the debt. Somehow he also found time for membership in the social fraternity Delta Kappa Epsilon. He graduated from the University of Michigan in June of 1869, at the age of twenty, with a degree in mining engineering.

After graduating from the University of Michigan in 1869, Brush returned to Cleveland to establish a professional life. The city was developing into a major industrial center and it seemed reasonable that there would be a demand for someone practicing in the field of chemistry. Brush struggled as an analytical and consulting chemist for the first few years of his career.

This endeavor did not prove to be very profitable and in 1873 he joined forces with a boyhood friend, Charles Bingham, to market Lake Superior pig iron and iron ore. It was during this time that he became reacquainted with another boyhood friend, George Stockly, vice president and general manager of the

Telegraph Supply Company of Cleveland.

The iron ore business turned out to be more profitable for Brush. Now that he was earning a comfortable living his thoughts turned toward marriage. He courted Mary Ellen Morris and they were married on October 6, 1875. They made their home in one of Cleveland's first apartment buildings, located on Prospect Avenue between Cheshire and Huntington (now East 18th and East 19th).

Brush had a private laboratory in the apartment building, where he experimented with electricity. One day there was a loud noise and the inhabitants of the building rushed from their apartments to investigate. Mary explained that there was an accident in the laboratory and her husband had suffered a burn. Brush relocated the laboratory to another building upon the request of the owner but the couple continued to live in the apartment.

In 1873, he began to experiment with electricity. Brush related some of his early experimentation with electricity to Stockly and discussed his vision for the development of arc lighting. The lighting system would need an efficient means of generating electricity, which Brush proposed to do by using a dynamo. Stockly was very impressed with Brush and his ideas and agreed to financially support his effort to construct a small dynamo. The Telegraph Supply Company provided material and facilities needed for preliminary development work.

Brush's Dynamo

When Brush was formulating his plans for an arc lighting system he realized that an efficient and economic power source was the key to success. Volta had produced the first battery in 1800 and there were improvements by others in the middle of the century. Nevertheless, Brush did not consider the battery a viable power source for arc lighting. The cost of battery power was simply prohibitive for the lighting systems he wanted to develop. The dynamo seemed to be a promising source of electricity but Brush felt that there was a need to increase the efficiency of existing machines.

Hippolyte Pixii, a French instrument maker, constructed the first direct current dynamo in 1832. The machine contained a permanent magnet which was rotated by a hand crank.

The spinning magnet was positioned so that its north and south poles passed by a piece of iron wrapped with wire. Pixii found that the spinning magnet produced a pulse of current in the wire each time a pole passed the coil. Furthermore, the north and south poles of the magnet induced currents in opposite directions. By adding a commutator, Pixii was able to convert the alternating current to direct current (current that flows only in one direction).

In 1867 Cooke and Wheatstone produced a dynamo that was clearly superior to Pixii's. Their dynamo was constructed with electromagnets rather than permanent magnets. Electromagnets were found to be superior because they could develop a stronger magnetic field, thereby increasing the electric output. In addition, electromagnets provided a degree of built-in regulation because the field strength would adjust in direct proportion to the output of the dynamo.

Another innovation in dynamo design during this time period was conceived by an Italian scientist, Antonio Pacinotti. He wrapped a ring of iron with a continuous coil of wire to form an armature. The "ring armature" was set to spin between electromagnets. This design produced a fairly steady stream of current because the wire wrappings of the armature were continually passing the electromagnet poles. Pacinotti's machine was the first practical direct current dynamo because it did not produce severely isolated pulses of electric current.

Brush considered the dynamos available in 1875 to be ill-suited to his needs. "The best forms of magneto-electric apparatus at present before the public are unnecessarily bulky, heavy, and expensive, and are more or less wasteful of mechanical power." (US Patent 189 997). Nevertheless, Brush was aware of a commercially successful dynamo in use in Europe. This was the machine developed by Zenobe Gramme in 1870.

The Gramme dynamo was similar to Pacinotti's in design, containing a ring armature. Brush started with the basic Gramme design and set out to improve the dynamo. In the end the Brush dynamo represented a marked divergence from the Gramme. The ring armature was the only element that Brush retained from the Gramme design.

The initial work on the dynamo was done by Brush on a part-time basis, working after hours while continuing with his sales activity in iron ore. In 1877 Brush quit the iron ore business and devoted his full attention to the dynamo. He assembled his first dynamo in the summer of 1876 while "vacationing" at his old home, Walnut Hills Farm.

At first Brush worked out his designs on paper, considering the weak points of the Gramme design and how he might improve upon it. One major fault of the Gramme was the poor contact of armature coils with the electromagnet fields. The pole shoes of the electromagnets were formed to fit around the circumference (edge) of the ring armature.

Therefore, only the outside portion of the coils would cut through the strong magnetic field. The wire on the sides and interior of the ring were outside the effective zone of the field. To improve upon this design, Brush would need to find a way to bring a larger percentage of the armature wire close to the magnetic pole shoes. Another weakness of the Gramme was a tendency to retain heat in the armature. The continuous winding acted as an insulating layer that retarded cooling of the armature core. Excessive heating of the armature would result in a drop in the efficiency of current generation.

Brush armature

Brush had completed his dynamo design on paper early in 1876. His ring armature was shaped like a disc rather than the cylinder shape of the Gramme armature. The field electromagnets were positioned on the sides of the armature disc rather than around the circumference.

There were four electromagnets, two with north pole shoes and two with south pole shoes. The like poles opposed each other, one on each side of the disc armature. With this arrangement Brush was able to bring a major portion of each loop of wire on the armature very close to the field magnets, thus increasing the efficiency of the machine. The armature was wound with several wire coils and the core was exposed between the coils, which promoted air cooling.

The armature coils were connected to a commutator in such a way that they did not form a continuous coil around the circumference of the armature. The commutator was designed to remove armature coils from the current circuit when they were midway between north and south field magnets.

This open coil design was more efficient because it removed coils from the circuit while they were making the transit between pole shoes, in a region where they would not generate electricity but only add unwanted resistance to the circuit. The open coil design was unique to Brush's dynamo and it was often called an open-coil dynamo.

Brush presented his dynamo design to George Stockley, VP and general manager of the Telegraph Supply Company of Cleveland. He believed that his design would prove superior to the Gramme. Stockley had great confidence in his boyhood friend and also saw the potential profit in the dynamo for his company. Continuing under a contractual agreement, Brush would now proceed to construct a working model of the dynamo. The Telegraph Supply Company supplied the resources necessary to build the dynamo and Brush supervised the machine shop work closely.

For his involvement as the inventor, Brush would receive substantial royalties for sales of all equipment manufactured as a result of his inventions. By the summer of 1876, the parts of the model dynamo were ready for assembly. Brush returned to his old home, the Walnut Hills Farm, with the parts of the dynamo. Working in the workshop where he had experimented with electricity as a boy, he carefully wound the armature and electromagnets. Then he assembled the parts to complete the dynamo. These early efforts resulted in U.S. Patent No. 189 997, "Improvement in Magneto – Electric Machines", issued April 24, 1877.

Brush was an unusual man of many talents. Not only did he possess the scientific and engineering skills needed to create a dynamo, he was also skilled in the mechanical arts needed to fabricate a dynamo. Brush connected the dynamo to a horse-drawn treadmill, the only source of mechanical power available on the farm. At first it appeared that the dynamo could not generate electricity.

After some thought, Brush connected the field magnets to a battery, reasoning that this would energize the electromagnets and provide the conditions necessary to initiate current generation. With the battery in place, Brush applied mechanical power to the dynamo and found that it produced a current. After the dynamo

started generating electricity, the battery could be disconnected, it was only required to provide the needed starting conditions. Brush had fulfilled his boyhood dream of constructing a dynamo.

Early commercial Brush dynamo

Brush returned to Cleveland with his new dynamo and continued development work at the Telegraph Supply Company. By the end of 1877 he had also developed a commercially viable arc lamp and was ready to market his lighting system. At the time Brush was a relatively unknown figure in the emerging electrical industry. He soon found the opportunity to gain recognition for his new dynamo.

The Franklin Institute of Philadelphia announced their desire to obtain a dynamo. In order to select the best model, the institute called upon manufacturers to submit their machines for evaluation. Several manufacturers declined the invitation, fearing adverse publicity if their dynamo was determined to be inferior. Brush felt that the risk of an unfavorable evaluation was offset by the potential benefits of a top evaluation. He submitted a small and large dynamo for consideration. The Wallace-Farmer Company was the only other American manufacturer to submit a machine.

Two pictures of the arc-generator, 10,000 volts

The Franklin Institute was not satisfied with the number of dynamos submitted for testing and sought another machine for comparison.

They were able to obtain a Gramme dynamo which had been shipped from Europe for the Centennial Exhibition of 1876. The institute evaluation committee commenced testing of the four dynamos in the spring of 1878, using them to power arc lights for the tests. Test runs were done for 5 hours, evaluating each machine for mechanical efficiency, power, range of currents, sparking, losses due to friction and local action of heat. The tests were completed by June of 1878.

The Wallace-Farmer machine was rated inferior due to inefficiency and excessive overheating. Tests of the Brush and Gramme dynamos yielded mixed results. The Gramme was found to be the most efficient in the conversion of mechanical energy to electrical energy. However, Brush's machines were found capable of producing stronger currents at a wide range of voltages.

The Brush dynamos had a simple design compared to the Gramme and the committee felt that the Brush dynamos were easier to maintain. In the end the Franklin Institute purchased the small Brush dynamo. The testing committee at the institute included a prominent electrical scientist, Elihu Thomson, who added an element of authority to the testing results.

By placing their stamp of approval on the Brush dynamo, the Franklin Institute was effectively endorsing it as the machine of choice for generating electricity. Brush used the testing results to his advantage in marketing his dynamo. Ironically, Thomson later formed a company to produce arc lighting, which became a significant competitor to the Brush Electric Company until the two merged in 1889.

The dynamo provided an economic and efficient source of electricity for the arc light and this was a key factor in developing a commercially viable system of lighting. With a functional dynamo in hand, Brush turned next to developing an arc lamp while simultaneously continuing with development of the dynamo. By 1877 he had enough confidence in his dynamo to start work on the arc lamp.

Brush's Arc Lamp

Like several inventors during the 1870s, Brush wondered if electricity could be used for lighting. Scientists had known for a long time that they could create a very bright light by passing an arc of electricity between two carbon rods. The light didnÃ¢â‚¬â„¢t last long, though, because the electric current burned up the carbon rods. Brush invented a way to solve this problem.

His invention was called the electric arc light. The arc light was not a new idea but those in existence at the time were not very practical. The chief drawback in lamps was the lack of a good regulating system for the carbon electrodes.

As an arc light operates, the electrodes are consumed at their tips, where the electric arc occurs. Extended operation of the lamp requires the maintenance of a specific gap between the electrodes, which can be effected by moving the electrodes during operation with a regulating device. The poor regulation of existing arc lamps resulted in variable light output and unreliable operation.

How do arc lamps work? Well two carbon rods connected to a current limited source are brought together and then drawn apart. As the carbons separate, a hot ionized path is created between them (the arc) that continues to conduct after the carbons have been separated.

This arc burns at thousands of degrees and heats the ends of the carbons to incandescence. Most of the light comes from the tips of the carbons, not the arc itself. As the carbons burn down they need to be constantly adjusted to maintain the proper spacing so that the arc does not go out.

Part of what is fascinating about early lamps is the range of ingenious mechanisms that were used to do this. Everything from manually adjusted designs to complex clockwork mechanisms were tried, and as you might guess reliability became a major issue. One design overcame this hurdle and became commercially successful by the late 1870s ushering in the era of electric light.

Brush developed an arc light that was regulated by a combination of electrical and mechanical means. The elegant design, as often is the case, was simple and easy to maintain. An electromagnet was used via a mechanical linkage to move the upper carbon electrode.

However, the movement was modulated and limited by a "ring clutch". In hindsight one might think a simple design solution could be conceived quickly; but simple designs are not always obvious until the inventor is successful. Brush's clever design was perfected after a considerable amount of time in the laboratory.

There were other arc lamps before Brush's that utilized electromagnets as part of a regulation system but it was the combination of the electromagnet with the ring clutch that made Brush's design superior in regulating the arc. Brush's lamps featured other design improvements including copper plated electrodes, regulators for operation of multiple lamps connected in series to one dynamo, and double carbon arc lamps for extended 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.

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.

Brush set forth the following design criteria for his lamp: simplicity, reliability, durability, and automatic regulation. These where 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 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.

This picture 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 diagramed in the figure (left), 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 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 cites, 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 (A) 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 (B) 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 (C) at the bottom 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. 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 below.

Here is an exceptional “functional” Brush-Swan Incandescent Lamp more than a century old. It is an excellent example of the inventive work of Charles Francis Brush and Sir Joseph Wilson Swan. This beautiful Brush-Swan Lamp is for domestic lighting and is outfitted with a fantastic example of the Brush-Swan early bayonet brass base. This lamp base is plaster secured, it has crystal clear glass, is 5.0 inches long with a 2.5 inch diameter glass globe and platinum lead-in wires employing single welds in the stem press. This lamp is another extremely fine vintage piece of early lighting history.

Brush’s Arc Lighting

Apart from lighting outfits set up for experimental purposes, the first dynamo and lamp actually sold were shipped to Dr. Longworth, father of Nicholas Longworth, at Cincinnati, about January, 1878, and Brush went to Cincinnati to show how the machine should be operated. The light was exhibited from the balcony of the Longworth home on one of the principal residence streets.

Brush, who went purposely into the crowd to hear comments, later described the scene: “It was a four-thousand candle power light and, of course, attracted a large crowd. In the gathering were a few men of the type who, if they know nothing about a subject and find others who know nothing about it, will promptly explain it.

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.”

Brush told also of an exhibit of one of the earliest four-light machines to a number of guests at a large factory in Cleveland: “One man looked the whole apparatus over carefully and then, pointing to the line wire, asked, ‘How large is the hole in that little tube that the electricity flows through?’”

A number of indoor installations soon followed. The following year, John Wanamaker hired Brush to install lights in his Philadelphia department store. The lights, described by one observer as “twenty miniature moons on carbon points held captive in glass globes,” created a sensation. The age of electrical lighting had been born.

Within months, merchants all over the country rushed to have the new lights installed. He was keen to develop further outdoor lighting, an application eminently suited to the power of the arc light. These would be public lighting systems that would replace the gas lamp. At the time the average citizen knew very little about electricity and had no appreciation for its potential as a power source.

Brush needed some way to demonstrate the power of his arc lamp to the public. This he did on Cleveland's Public Square, then known as Monumental Park, on April 29, 1879. Twelve arc lamps were positioned around the park and they were powered in series by a dynamo housed in the Telegraph Supply Company nearby.

A news article in the Plain Dealer described the occasion: "At five minutes before eight o'clock there was a flicker in the lamp nearest the Telegraph Supply Company's headquarters and immediately the twelve lights beamed forth from their various stations. The lamp posts are much higher than the gas posts, making the electric lamps like beacon lights."

Thousands of people gathered to witness the scene and as the light shot around and through the Park a shout was raised. Presently the Grays Band struck up in the Pavilion and soon afterward a section of artillery on the lake shore began firing a salute in honor of the occasion.

The light varied some in intensity at intervals, when shining brightest being so dazzling as to be painful to the eyes to look long at a lamp. In color it is of a purplish hue, not unlike moonlight, and by contrast making the gaslights in the store windows look a reddish yellow. Some people had raised their expectations too high and were disappointed because it was not as light as day but most people seemed struck with admiration, both by the novelty and brilliancy of the scene.

The reaction of the crowd must have been pleasing to Brush and confirmed his vision of the utility of the arc light. Soon cities across America would place orders for the Brush arc lights, and his name became known to many. Before the end of 1881 Brush arc light systems were illuminating the streets of New York, Boston, Philadelphia, Baltimore, Montreal, Buffalo, San Francisco and other cities. Arc lights changed life in American cities greatly. Nighttime activities became more popular with the new form of lighting. Streetlights made it safer to be out after dark. Electrical lights in factories even made it possible for people to work at night.

Broadway lit by Brush lamps in 1881

Books on the history lighting often inaccurately state that Edison's Pearl Street station was the first central station in New York City (or anywhere) powering the first electric lights. In reality a full two years earlier Brush arc lights were lighting sections of Broadway, and by 1881 there were large central stations set up for arc street lighting. The April 1881 issue of Scientific American featured a cover story on the Brush system in New York and it has some great illustrations of the giant steam engines powering rows of dynamos. Many other large cities had similar plants.

Brush's inventive genius gave him his opportunity, but it may have been his knowledge of human psychology that enabled him to turn that opportunity into wealth and power. When the electric lighting of city streets was first proved practical, neither the new lights themselves, nor the inventor was popular with corporations that sold gas. They did all they could to discourage use of the new invention. They might have done more harm than they did if Brush had not quietly explained to them why they were wrong, even from their own selfish viewpoint, in fighting electric lights.

His knowledge of crowd psychology was superior to theirs when he predicted: "Electric lights will increase rather than decrease use of gas. People have been living in darkness so long that they have organized their lives on that basis. But when they get used to light, they are sure to want more of it. After seeing brilliantly lighted streets and stores, they'll want more light in their homes and will burn more gas. As they use more gas for lighting, you can make gas cheaper and that will open up almost limitless industrial uses."

Another problem was to educate the public itself. Brush knew how conservative are the masses. He did not underestimate the slowness and tediousness of overcoming public suspicion of novelty. A frequent argument against the new lighting was that it would ruin eyesight. People stared at the brilliant arc and then complained that it was too dazzling.

"After looking at it, everything else looks dark," they said. "We'll ruin our eyes." To which Brush calmly retorted: "The same objection may be raised against the sun!"

The habit of staring at the arc hung on for many years and continued to be used as an argument against electric lighting. Scientists themselves had promoted foolish beliefs.

As late as 1873, Deschanel's Natural Philosophy, a well-known textbook, 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."

One reason people stared was that they wondered where the light really came from. They thought there must be some trick to it. The light must come from oil, and where was the oil supply?

Another early problem was that users of an electric-light apparatus could not be induced to let it alone. This was especially true when outfits were sold to cities for street lighting. Someone mechanically inclined was sure to try to "improve" the device. Nearly every workman thought he knew more about the mechanism than the inventor did.

Complaining of a lamp which had not worked properly, one man said; "I've had it all apart four times, and still it doesn't work." If the lamps didn't work, and news of this became widespread, it would wreck the business. Brush saw that he must make the whole mechanism as nearly foolproof as possible.

He put it together without screws or bolts of any kind that could be taken out and lost. All necessary adjustments were made at the factory when the lamp was tested and then the parts were riveted, to make further testing or tinkering impossible. Also they were assembled a little like a Chinese puzzle.

The high-tension dynamos for series lighting that came later did not suffer so much tinkering because, as Brush used to say, they were powerful and "able to look out for themselves; they discouraged familiarity."

Nevertheless, it was impossible entirely to eliminate difficulties caused by trivial accidents and the lack of trained men to install or operate lighting plants. Poorly insulated lines led to "short circuits." Since commercial electricity was just starting, not many experts were available to whom Brush could delegate important work, and he himself used to go about as trouble man.

Once he traveled fifteen hundred miles to take a common double-pointed tack from the bottom of a dynamo where it had short-circuited a field magnet. Occasionally damage appeared to have been done maliciously– perhaps by an employee who disliked the mechanism because unable to understand it. Long, fine wire nails were sometimes discovered in the field-magnet coils.

Brush used to tell of one lot of sixteen lamps sent back to the factory by a Boston agent with a letter stating that no one was able to make them work. "I examined and tested the lamps carefully, " said Brush, "and found them all right.

Without making any change or adjustment whatever, except to change the numbers to conceal their identity, I sent the lamps back, with a letter stating 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 the future before they were shipped. He wanted to know what was the matter with the first set, but I never told him."

Perhaps it was his experience, in the early days of lighting, with the seeming stupidity of a great mass of human beings that made Brush, all the rest of his life, dubious if not contemptuous of the intelligence of the average man.

But no matter how much he may have doubted the average man's wisdom, he always retained his sympathy and kindliness and never lost the common touch. Certainly there was nothing intolerant or haughty about him. He never shut himself off from the public. True, he was fairly inaccessible, but he could always be seen by almost anyone who had a semblance of an excuse to take up his time.

In order to keep pace with the rapidly increasing demand for Brush lighting systems, the Telegraph Supply Company of Cleveland underwent significant restructuring, giving birth to the Brush Electric Company in the summer of 1880.

The new company constructed a 200,000 square foot factory located between Belden and McHenry streets at their intersection with Mason St. This new facility would thrive for a short time in the 1880's before it was closed due to the merging of Brush Electric with competitor Thompson-Houston Electric Company in 1889 and in turn with the Edison General Electric Company in 1891 to form the General Electric Company still

known by the same name today.
The Brush Electric Company, 1889
These mergers marked Brush's exit from the emerging electrical industry. He sold his interest in Brush Electric and moved on to other fields of endeavor, never to return to the electric industry. Nevertheless, his innovations were an essential part of the development of electricity for commercial use.
The arc light made Brush a wealthy man. In 1884 he moved to his famous mansion, located on Euclid Ave. at East 37th Street. The new home included a laboratory in the basement and a large windmill in the backyard used to generate electricity for the house. His was a story of a self-made man, who elevated himself from humble beginnings on a farm near Wickliffe, Ohio, to a prominent citizen of the Cleveland community.
Brush's arc light was more satisfactory than the candle of Pavel Yablochkov of Russia because the Brush light burned twice as long as the Yablochkov candle. The arc light preceded Edison's incandescent light bulb in commercial use and was suited to applications where a bright light was needed, such as street lights and lighting in commercial and public buildings.
A key element in Brush's arc lighting system was his dynamo (electric generator). The dynamo was the workhorse of the Central (power) Station, a concept developed independently by Brush and Edison, which eventually grew into the electric power generating industry. Arc lights, while useful, had drawbacks. It fell to another Ohio inventor, Thomas Edison to improve electric lighting. Edison invented a light that was cheaper, easier to use and required less power to operate. A half-century later, yet another Ohioan, Arthur Compton, invented a third type of electrical lighting, the florescent lighting tube.
Brush's Private Life
Brush's genius was not confined to inventing. He was a good philosopher, a shrewd psychologist, and had plenty of humor. He was not one of those inventors who turn over all profits from their talents and efforts to others. Brush's new arc light was a huge commercial success and as the sales of his electrical equipment skyrocketed, he quickly became a wealthy man.
There was something regal about his appearance. When he was receiving his decoration as a Chevalier of the Legion of Honor, at Paris in 1881, Gambetta, the French statesman, remarked: "I do not know which to admire most, his extraordinary mental talents or his magnificent physique."
The Brushs purchased a 7 acre plot of land off Euclid Avenue for a new home. Construction of their famous mansion commenced in 1880 and they moved there in 1884. This was the house where Brush would spend the rest of his life.
The three story graystone mansion contained 17 rooms and the interior was finished with oak from England and rosewood from Japan. The full basement housed Brush's private laboratory, a place where he worked continually until his death. The mansion was the first home in Cleveland to have electricity. A large windmill behind the house, completed in 1888, was used to generate electricity.
The sail was 56 feet in diameter and it was connected to a dynamo. Current from the dynamo was used to charge 12 batteries, each with 34 cells. The batteries were the power source for 350 incandescent lamps, 2 arc lamps and 3 motors. Thus, the home was a showcase for the technology that Brush had developed.
Brush's laboratory in the basement of his residence on Euclid Avenue:
Mary and Charles raised their three children in the stately mansion on Euclid Avenue. Their first child, Edna, was born March 25, 1880. Their second daughter, Helene, was born April 27, 1884. Nine years later, September 30, 1893, Charles Francis Brush, Jr. was born.
Brush was a devoted family man. Although very busy with business affairs and his scientific studies, he always found time to spend with his loved ones. When his daughters were young he enjoyed bicycling along the street with them.
Later he would teach his son about chemistry and electricity in the basement laboratory. Family gatherings on Sunday evenings became a tradition and these were times when relatives would visit and have dinner with the family. In addition to conversation, playing bridge was a favorite activity and Brush would enjoy telling his latest jokes. The home was equipped with a magnificent pipe organ and Brush would frequently operate the instrument, which played music programmed on large paper rolls.

The happy family life at the Brush mansion was rocked in the summer of 1902 with the death of Charles' wife. Brush was deeply devoted to his wife of twenty-seven years and lived the remaining twenty-seven years of his life as a widower. With his wife gone and his daughters approaching an age of independence, Brush's family life would never be the same.

While Brush was a busy man, he did find time for relaxation, especially after his children were grown. He enjoyed golf, playing 3 or 4 days a week at one point in his life. Duck hunting was another sport he enjoyed at the Winous Point Shooting Club. After his son went to college, Brush spent most of his weekday afternoons at Cleveland's exclusive Union Club. Here he would play his favorite card game, bridge, and catch up on personal correspondence. He also enjoyed good music and had a season's box ticket to the Orchestra.

Brush was a devout Christian and walked to the Episcopal Trinity Cathedral every Sunday for morning services. He was very generous with financial support to the church and served as a Junior Warden.

Philanthropy was quite important to C. F. Brush. He supported countless societies, churches, and scientific organizations, as well as endowing the controversial "Brush Foundation" for the study of Eugenics. Near the end of his life Brush suffered another family tragedy.

In 1927 he lost his son and granddaughter, Jane. Charles Jr. gave a blood transfusion in an attempt to save his daughter, who was very ill. She did not survive and he died from complications brought on by the transfusion.

Charles Brush won many awards, including the French Legion of Honor, the Rumford medal (1899), Edison medal (1913), Franklin Medal, and three honorary doctorates. He was a leader in the community, and much respected in the field of science. Brush was active to the end of his life. He has obtained more than fifty patents, two thirds of which are sources of revenue.

They relate principally to details of his two leading inventions–the dynamo and the lamp–and to methods for their production. All of his patents, present and future, are the property of the Brush electric company of Cleveland, and his foreign patents are owned by the Anglo-American Brush electric light corporation of London. His daily routine included walking to his office at the Arcade, 30 blocks from his home. He would spend about half of his working day at the office and half in his basement laboratory.

He was known to favor late evening and early morning hours for the exacting work done in the laboratory. At other times the heavy street car traffic on Euclid Avenue would shake the ground and distrurb some of his more sensitive experiments. It was not uncommon for him to return from a concert at 11:00 PM and then work into the early hours of the morning. During these hours he could expect fewer interruptions when he needed to concentrate on sensitive experiments.

Charles Brush maintained social contacts with many of his friends for a long time till very last of his days. Pictures below show him with some of his friends:

Photo of (left to right) Elihu Thomson, Frank J. Sprague, C. F. Brush, E. A. Sperry, and E. W. Rice, April 1928

Work was an essential part of Brush's life. He derived great pleasure from working in his basement laboratory and believed that retiring to a life of leisure was a sure formula for loss of vitality. Brush's final illness was the only thing that prevented him from working in his laboratory.

During the winter of 1929 Brush contracted bronchitis. For a while it appeared that he would recover but later in the spring his condition worsened. He died from pneumonia on June 15, 1929 at the age of 80 years. In his will he stipulated that the mansion must be demolished when it was no longer occupied by a family member.

He did not want his home degenerating into a boarding house, like others on "Millionaires Row", a section of Euclid Avenue that was considered by many to be "the most beautiful residential street in the world" at the turn of the century. After Brush's death in 1929, shortly after his reaching the age of eighty, the house was dismantled and torn down. The place which had cost a small fortune and had been one of the show places of the city went to wreckers for exactly three hundred dollars.