

Switching the Light: From Chemical to Electrical

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There are many good reasons to celebrate light besides the scientific achievements triggered by al-Haytham's work 1,000 years ago, which was described in the "Historical" column in the last issue of *IEEE Industrial Electronics Magazine* [1]. Long before Maxwell discovered the secret nature of light, mankind had learned how to manage it to improve life. Far back in the Stone Age, 1.5–0.5 million years ago, ancient progenitors of modern man were able to conserve fire and use it in many ways, including lighting the dark of the night, promoting socialization among the individuals gathered around the fire. Much later, the light of oil lamps and candles illuminated the dwellings and palaces of ancient and classical civilizations, allowing a much richer social life after dusk [2].

For thousands of years, the only sources for illuminating the night were implements that used liquid or solid fuels such as olive oil, seed oil, beeswax, and animal oil (with possibly the only exception being natural gas, carried indoors through bamboo piping, in certain Chinese areas 1,700 years ago [3]). Whale oil became a lucrative fuel starting in the 16th century, after ruthless whaling began in the northern Atlantic by European nations, often in fierce competition with each other [4]. At the end of the 18th century, when the industrial revolution was booming, coal gas, a by product of coke manufacturing, opened the door to the development of a more advanced lighting technology.

The first experimental gaslight plant was installed by Prof. Jean-Pierre Minkellers (1748–1824) in his laboratory at the Collège du Faucon of the University of Leuven, Belgium, in 1784. Developments with wood gas by Philippe Lebon (1767–1804) followed in France between 1792 and 1801, but the demonstrations did not capture the attention of the revolutionary government, which was involved in war obligations. William Murdoch (1754–1839) brought the idea to the United Kingdom, using coke gas to light his house in 1792. Ten years later, together with Samuel Clegg (1781–1861), he lit the Boulton-Watt foundry, where they worked. Another two years later, Fredrick Winsor (originally Winzer, 1763–1830), a German-born Englishman, gas-lit the first public building, the Lyceum Theatre in

London [5]. Gas lighting became public in 1807 with the plant installed in Pall Mall, central London, by Winsor (Figure 1). The first commercial lighting network was also installed in London a few years later by the company of Winsor and Clegg in 1814. Modeled on water supplies, it featured a centralized large-scale coal-gas generator and pipe distribution to the consumers, and it was an immediate success, the piping soon exceeded 42 km.

In a few decades, commercial and public gas lighting boomed in many cities in Europe (e.g., France, Belgium, Germany, and Russia) and the Americas (starting in the United States) because of its lower cost compared to conventional oil lamps and candles. The savings was about 75%. Even if gas lamps could



FIGURE 1 – A satirical cartoon showing people marveling at the early public gas lighting in London. (Image courtesy of Wikimedia Commons.)

only provide the feeble light of 15 cd, they made the city streets much safer at night and allowed nightlife and social and cultural life to flourish. The economic impacts were much longer work hours in offices and factories in winter time, resulting in increased production. However, despite various technological improvements, some risks of explosion (related to the piping technology of the time) and of toxicity from combustion products in indoor use persisted. Gas grids were highly profitable in densely populated areas where many consumers could be supplied with relatively short piping. In rural areas and small towns, oil lamps, or more expensive candles, remained the only viable sources of light, and whale oil was still vital in illuminating dwellings and workshops.

Following the invention of the processes to derive kerosene from petroleum in 1853–1855 and early successful drilling in the period 1846–1859 in several areas (Baku, Azerbaijan; Galicia, Poland; Hannover, Germany; Ontario, Canada; France; Romania; and Titusville, Pennsylvania), the crude-oil-extraction industry quickly grew [6]. By 1874, Pennsylvanian production alone had reached 10 million 360-lb barrels, yet the main world producer was the area of Baku. It was at that time, in 1870, that John Davison Rockefeller (1839–1937) and his partners founded Standard Oil. Thanks to the rapidly expanding market and unconventional management methods, in a few years, he became the richest man in the world. Of course, he was not the only one. The Nobel brothers, who drilled in Baku and produced kerosene by continuous cracking with their Branobel Company, amassed a fortune also. This success came from substituting whale oil with cheaper kerosene for lighting, not from gasoline, which was then still too dangerous a by-product and was usually released in rivers. In fact, there was almost no demand for it since the internal combustion engine had not yet become an industrial reality.

If coal gas and kerosene, the forms of lighting that were the first to expand in the second half of the 19th century, stemmed from chemistry, it was electricity, the other technology that characterized the second industrial revolution,

that soon attacked their domains. The possibility of producing light by a persistent electric arc was an immediate outcome of the invention of the electrochemical cell by Italian Alessandro Volta (1745–1827) in 1800 [7], [8]. Russian Vasilij Petrov (1761–1834) produced the first persistent arc in 1802 by means of the largest battery then existing, made of 4,200 cells, and the celebrated English chemist Humphry Davy (1778–1829) gave its first public demonstration in 1809 with a huge stack of 2,000 cells that produced a 10-cm arc. However, it took some decades to develop a viable technology. An arc lamp was based on two carbon electrodes put in touch to establish the electric current and then detached and put at a proper distance to create the arc. A very intense light was obtained, together with a strong heat that caused electrode erosion. The consequent increase in the gap distance had to be gradually compensated for to avoid stretching and extinguishing the arc.

In 1845, Thomas Wright patented the first arc lamp in England, provided with automatic regulation of the distance between carbons. Improved models were developed by William Staite in the United Kingdom in 1846–1853, V.E.M. Serrin in France in 1858, Charles F. Brush (1849–1929) in the United States in 1877, and František Křizík (1847–1941) in Bohemia in 1881, among others. In 1846, the Opera theater in Paris was the first public building equipped with electric lighting from arc lamps, which were powered by a battery of 360 relatively cheap zinc–carbon cells, invented in 1841 by the great German chemist Robert Bunsen (1811–1899). However, the high level of power needed by arc lamps made their supply with disposable electrochemical cells very expensive.

Use prospects changed in the third quarter of the 19th century [9]. In 1858, Frederick Hale Holmes (1830–1875) put the first electric lighthouse into service at South Foreland, near Dover, United Kingdom, on the suggestion of Michael Faraday. Its arc lamp was powered by a 36-magnet generator capable of 1.5 kW at 600 r/min (derived from an early Alliance alternator) powered by a steam engine and equipped with a rectifier device. Though neither completely

reliable nor efficient, it was one of the first electromechanical generators capable of practical operation at relatively high power. Based on its model, several other lighthouses were electrified.

Starting in the 1870s, more efficient dynamos, produced by companies such as Siemens (Germany, 1867), Gramme (France, 1869), and Brush (United States, 1878) and capable of supplying cheap electric power, became available. France was the first nation to take the path, in 1875, when a factory in Mulhouse (Alsace) was illuminated with four Serrin arc lamps powered by four Gramme dynamos, and a chocolate factory in Noisiel-sur-Marne was provided with similar equipment. They were soon followed by other French factories. The Gare du Nord and the *grands magasins* in Paris were the first public buildings illuminated with arc lamps powered by Gramme dynamos.

In 1876, while arc light was booming, Pawel Yablochkov Nikolayevich (1847–1894), a Russian telegraph engineer who just arrived in Paris, developed an arc lamp that operated at low current (about 9 A, half that of previous

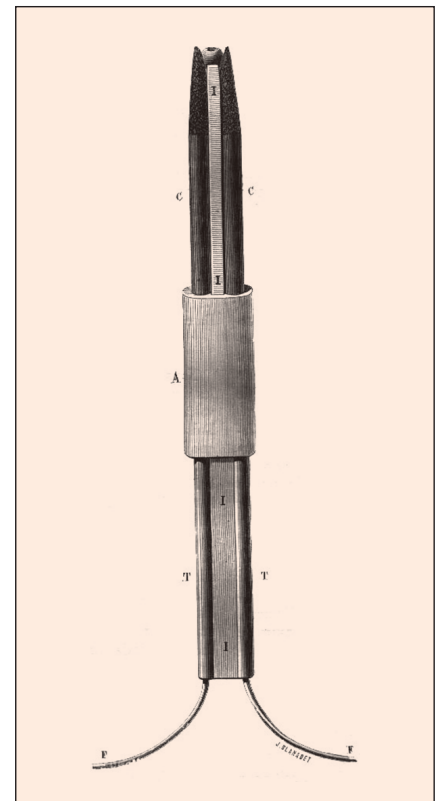


FIGURE 2 – A Yablochkov candle consisting of two carbon rods separated by a thin layer of plaster of Paris. (Image courtesy of Wikimedia Commons.)



FIGURE 3 – Electric lighting with Yablochkov's candles along the Avenue de l'Opéra at the 1878 Paris Exposition. It triggered a boom in gas utility stocks. (Image courtesy of Wikimedia Commons.)

models), the Yablochkov candle [10]. Its design featured two parallel electrodes set side by side to maintain their distance while consuming, with no need for automatic adjustment (Figure 2). To improve its performance, Gramme developed an efficient alternator in 1878 whose alternating current ensured the balanced consumption of the two carbon electrodes. The same year, the Grands Magasins du Louvre in Paris was supplied with eight Yablochkov candles powered by a Gramme alternator. Similar systems were soon implemented in the Avenue de l'Opéra and the Place de l'Opéra on the occasion of the Paris Exposition of 1878 (Figure 3).

Simple and economical to produce, the Yablochkov candle was the first arc lamp to be widely used in Europe. It brought electric lighting to the general public and increased the demand for electromechanical generators. In Britain, arc lamps based on French technology began to spread in 1878. Systems with Yablochkov candles were placed in service in London's West India Dock, Billingsgate Market, Holburn Viaduct, and the Thames Embankment. The first electric street lighting system, powered by a generator driven by a water wheel, was put into service in Godalming, United Kingdom, in 1881 by Siemens, and it was soon duplicated in Brighton, United Kingdom.

The first American arc-light system was installed in the Wanamaker department store in Philadelphia in 1878 by

Charles Francis Brush (1849–1929), who had started to develop it from European technology (that of Gramme, Pacinotti, and Yablochkov). One year later, the same Brush put into operation in San Francisco the first commercial system that sold electric lighting from arc lamps to several customers, and, by 1881, major U.S. cities (New York, Boston, Philadelphia, Baltimore, Montreal, Buffalo, San Francisco, Cleveland, etc.) were equipped with public lighting systems with arc lamps, supplied mainly by Brush. In subsequent years, arc-light installations spread in Europe and in the Americas. To exploit the blooming market, the American Electric Company was founded by British-born American electrician Elihu Thomson (1853–1937) and Edward J. Houston (1847–1914) in 1880 (Thomson–Houston Electric Company from 1883).

Nevertheless, arc lamps had a major limitation. Their harsh light was successful in the open air (e.g., parks, squares, and streets) and in large buildings (e.g., mills, factories, large stores, churches, hotels, depots, and stations), but it was completely unsuitable for offices and dwellings, where gaslights continued to dominate. A potential solution was envisaged after the experiments performed by Humphry Davy in 1801 on the incandescence produced by the electric current flowing in a platinum strip, another early outcome of the electrochemical cell. But all attempts to produce a practical incandescent lamp, including the first

patent registered by Irish politician Frederick De Moleyns (1804–1854) in 1841, remained frustrated for several years. The filaments quickly caught fire, causing the life of the lamps to be too short.

Technology develops through combinations and occasional mutations, introduced by stochastic external factors, in a process that resembles biological evolution [11], and this is what happened with incandescent lighting. In this case, the evolutionary factor consisted of the mercurial air pump invented by German chemist Hermann Sprengel (1834–1906) in 1865, a simple and robust device capable of reducing the pressure in a chamber to 1 millionth of an atmosphere, thus almost eliminating oxygen, which was responsible for the combustion in the glass bulbs where the filaments were housed. This gave new impetus to the search for durable bulbs, and, by the end of the 1870s, early successes occurred.

Englishman Joseph Wilson Swan (1828–1914), who had been researching incandescent lighting since 1848, made a bulb with a carbon filament capable of several hours of operation for the first time in 1878. Soon after, another Englishman, St. George Lane-Fox (1856–1932), and Hiram S. Maxim (1840–1916), an American who lived in the United Kingdom from 1881, also produced their own bulbs. And so did Thomas A. Edison (1847–1931), of course, who tested an incredible number of filaments (more than 6,000, including beard hairs) and, in 1879, produced a bulb that lasted 14 h before burning. A much more durable (1,200-h) model, based on a carbonized bamboo fiber, followed in 1880 (Figure 4). The incandescent bulbs of these four inventors were presented and compared at the 1881 International Exhibition of Electricity in Paris. More bulbs were developed in the following years, including the very efficient and durable carbon/platinum bulb made by Alessandro Cruto (1847–1908) in 1880.

Soon, in 1878–1879, Swan used his bulbs to light his house in Gateshead-on-Tyne as well as the residence of Lord Armstrong, a wealthy industrialist of Northumberland, powering it with the first British hydrogenerator, and similar plants were built soon after. In 1881, 1,194 of Swan's lamps made the Savoy Theatre in London the first public

building with incandescent lighting. Likewise, Edison used his own bulbs to light the residence, on 5th Avenue in New York City, of John Pierpont Morgan, who was ready to back him in new electric enterprises.

We now tend to forget all other inventors and deem Edison as the sole inventor of the incandescent bulb. The reason is that he made a decisive step ahead with lighting technology. At the time, each electric lighting plant, whether public or private, included its own generator. Whoever wanted electric lighting had to buy his or her own power station. Edison had in mind to attack the gaslight market, and, to succeed, he conceived of selling bulbs and power, not power stations [12]. Thus, after founding the Edison Electric Illuminating Company, backed by Morgan and other major Wall Street financiers, in 1880, he invented the commercial distribution of electricity from a centralized 110-V dc power station, presenting it at the Paris Exhibition of 1881. The idea was a tremendous success, as seen in the early plants of 1882, Holborn Viaduct in London (with 2,000 lamps) and Pearl Street in New York that supplied 80 customers.

Edison stopped his litigation against Swan on invention priority, preferring to set a commercial agreement with him for market exploitation in 1883 (indeed, this was not his only litigation regarding the incandescent bulb), but the 1886–1891 war of the currents against Westinghouse’s ac system was much harsher [13]. The latter was initially intended for lighting too and was extended to power uses after commercial models of Tesla’s induction motor became available in 1891. Thanks to voltage changes provided by transformers, it had the fundamental advantages of much longer line extension and more flexible operation than Edison’s dc system. When Edison’s competitor was prevailing, the wizard’s business talent came out with another masterstroke: he merged his electric company with Thomson–Houston Electric Company, creating the General Electric Company (GE). With the same spirit, in 1898, he acquired rights on the 1896 patent of Italian inventor Arturo Malignani (1865–1939) for an evacuation method for mass production based on

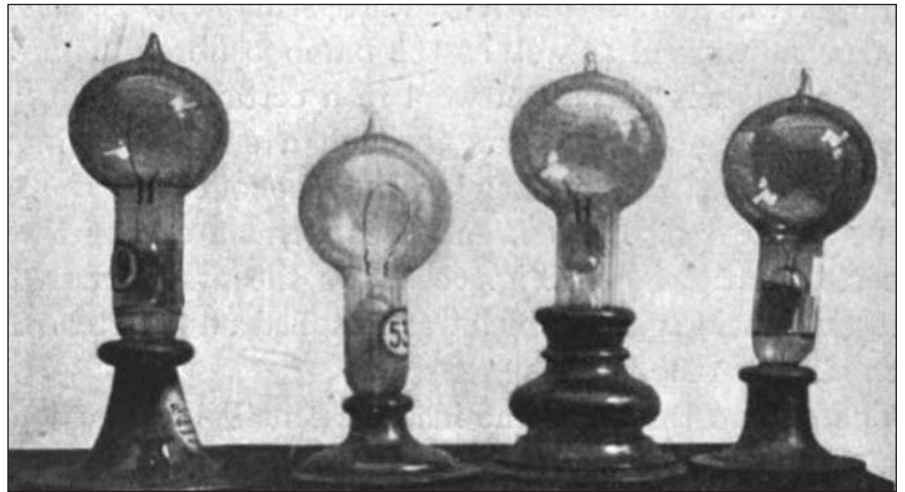


FIGURE 4 – A series of Edison’s early incandescent bulbs. (Image courtesy of Wikimedia Commons.)

getters, which allowed economic bulbs lasting 800 h to be made.

Major advances in the incandescent light came with the tungsten filament bulb, first patented in 1904 by Hungarian Sándor Just (1874–1937) and Croatian Franjo Hanaman (1878–1941) and marketed by a Hungarian company the same year. A similar bulb was created by William David Coolidge (1873–1975) in 1907, whereas the inert-gas bulb (nitrogen first and argon later) was invented by Irving Langmuir (1881–1957) in 1913. Both of these American engineers worked at GE, and their innovations ensured a dramatic increase in incandescent-bulb efficiency and definitive supremacy over gaslights (and a net advantage to GE).

In the same decades, new electric lamps were born. Peter Cooper Hewitt (1861–1921), another American engineer, invented the mercury vapor lamp in 1901, which was widely exploited for industrial illumination, and French chemist George Claude (1870–1960) created the neon fluorescent lamp in 1909. Neon signs soon became extremely popular, particularly in the United States, and made Claude a wealthy man. An important patent on the illuminating fluorescent lamp was registered in Germany by Edmund Germer (1901–1987) in 1926, and its rights were acquired by GE in 1939, when production was started by more companies. Some years before, in 1927, Hungarian Dénes Gabor (later a British citizen, 1900–1979), at Siemens and

Halske, serendipitously invented the high-pressure mercury-vapor lamp, which, perfected by more companies, in a few years spread in street lighting due to its high efficiency, despite of its low chromatic behavior.

At that time, electrification had reached rural areas in Europe and North America, producing the substitution of kerosene lamps with electric light. The reign of light had definitely become electric.

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