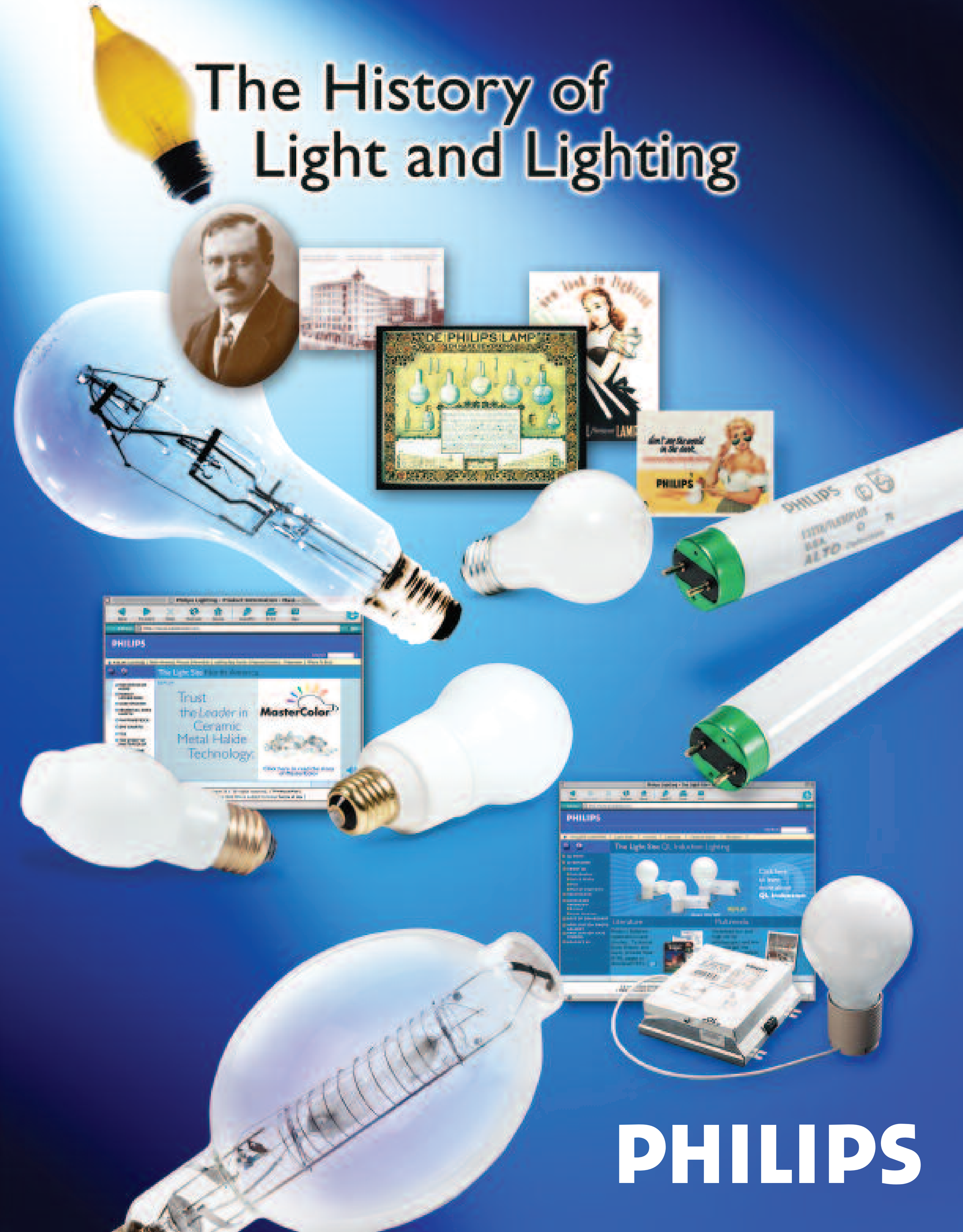
The History of Light and Lighting



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CONTENTS

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While the lighting industry is generally recognized as being born in 1879 with the introduction of Thomas Alva Edison's incandescent light bulb, the real story of light begins thousands of years earlier. This brochure was developed to provide an extensive look at one of the most important inventions in mankind's history: artificial lighting.

From early oil lamps that predate the Pyramids by 10,000 years to gas lamps of the 19th century to modern lamp developments, lighting has proven to be an invention that keeps improving itself and the world around it and it touches our lives everyday.

Philips Lighting Company, one of the largest lighting manufacturers worldwide, and part of Royal Philips Electronics, is pleased to provide this information on the *History of Light and Lighting.*

Fig. 1.1. A simple oil flame—in addition to the light of the open fire—is the only source of light in this sixteenth century household. There was no street lighting in those days, so the man entering from outside carries a portable light suspended from his belt.

INTRODUCTION

The story of the history of light and lighting is a fascinating one, going back almost as far as the history of mankind. It started when man learned to control fire, and for thousands of years afterwards the simple flame remained the only source of artificial light available. Subsequent attempts to refine the process of light generation and separate it from heat production can be roughly divided into four stages.

Stage one was marked by the wish to produce a constant flame, which could be left relatively unattended for a longer period. This resulted, still in the stone age, in the first bowl-type lamps, burning animal or vegetable oil and fitted with a wick, and later—probably in Roman times—to the invention of the candle. The lamp and the candle, like the torch, made light "portable".

The next big stride in the development of light sources took place just two centuries ago, when the first successful steps were taken to increase the light output of the flame. It was the physicist Amié Argand who gave his name to the tubular burner, which incidentally launched the era of lighting technology.

The third stage began a little over a century ago, when the flame as a light source was abandoned in favor of an incandescent solid body. The incandescent electric lamp and the gas mantle were the two important inventions during this period of development.

Finally, in the second decade of the present century, it became possible to produce light without wasting energy on its traditional by product—heat, for discharge lamps in various forms went into commercial production. Development of these lamps is still in full swing today.

Along with the proliferation and refinement of light sources came the development of the social role of light. With only the most primitive of light sources at his disposal, man's activities performed during the hours of darkness were necessarily both simple and homebound. This has all changed today, as the absence of daylight is now scarcely a deterrent to the pursuit of every commercial, social or leisure interest.

THE ROLE OF LIGHTING IN MODERN SOCIETY

It is difficult to overestimate the importance of artificial light in our present-day society. Without it, commercial, social and cultural life would come to a virtual stand-still with the onset of darkness. And yet, task lighting—allowing work to be continued after dark, rather than facilitating basic orientation—like so many other achievements, is a by-product of the Industrial Revolution.

In the opinion of many historians, this started at the beginning of the eighteenth century, triggered off by two inventions taking place around 1710 almost simultaneously. These were Abraham Darby's discovery of a process to convert pit-coal into cokes, which could be used for the production of iron as a substitute for charcoal, and the invention, by Thomas Newcomen, of the atmospheric steam engine.

The new movement, as the Industrial Revolution might be seen, would in a few hundred years change the face of the earth as never before in the history of mankind. It was not just a technical revolution, but even more an economical and social one, that

Fig. 1.2. Primitive oil lamp dating from approximately 6000 B.C. It is made of a hollowed-out stone.

brought with it industrial mass production and mechanized transport.

It also meant the end of a way of life that was dictated by the daily passage of the sun and the change of seasons, a way of life that had changed very little over thousands of years. Daylight and weather were the factors governing agricultural activity, and with it the associated crafts and trades.

Although oil lamps and candles existed, the costs of the fuel they burned was so high as to make it uneconomical to continue most types of economic activity after darkness, and for the poorer classes of the population—the great majority—the open domestic fire remained the only source of light. Even within the comparative security of the town walls, very few would venture outdoors in the dark, and once out of town one was at the mercy of thieves and robbers.

All this changed dramatically with the advent of planned production and the organized long-distance transport of people and goods. Contemporary lighting was both inadequate and expensive, and so seriously hampered expansion of these activities. Consequently inventors were pressed to turn to alternative light sources, and at the same time reduce the costs of the fuel. The success of their efforts is clearly demonstrated by the following example. Compared with the most advanced light source currently available for domestic use, the SL lamp, candles producing the same amount of light would be approximately 2000 times more expensive in terms of energy consumption, a staggering figure indeed!

It is difficult, if not impossible, for us to imagine life in those days, when artificial light was as scarce and costly as it is now abundant and cheap. Even the candles and oil lamps we still use today on a limited scale bear little relation to their forerunners, as they both use for fuel sophisticated, yet cheap products of the mineral oil industry.

We are reminded of the almost mystical role that artificial light played in the past by the fact that in many cultures the lamp is still seen as a symbol, associated with truth, inspiration, progress, hope and wealth (Alladin!). Indeed, it is safe to state that our present-day society would be unrecognizable without artificial lighting.

1. THE OLDEST LIGHT SOURCES

Before the advent of the lamp

Artificial light entered into the history of mankind with the harnessing of fire. This, along with the introduction of the first primitive tools, must have been one of man's earliest achievements. Indeed, paleontologists generally take traces of a fireplace as proof that they are dealing with remainders of human origin. It is difficult to say exactly when man first learned to use fire, rather than flee from it, but conservative estimates put this at half a million years ago.

Needless to say, in those early days fire was certainly not primarily used as a light source, but far more for its warmth, as a protection against animals, and to prepare food. And yet it could not have been long before the first portable light source was "invented", in the form of primitive torches made from the branches of resinous trees.

The oldest lamps

The oldest known artifacts made especially for lighting purposes date from at least 20,000 years ago. They take the form of primitive oil lamps, made of a hollowed out-stone. The same basic design of lamp has been used all over the world, remaining

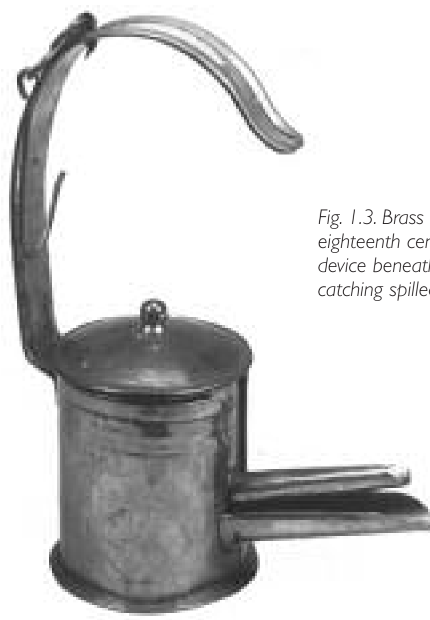


Fig. 1.3. Brass oil lamp from the eighteenth century. The gutter-shaped device beneath the spout is for catching spilled oil.

Fig. 1.4. Greek oil lamp made of earthenware in the form of a shell. The wick is lead through the lip.

principally unchanged until well into the eighteenth century. It consisted basically of a fuel reservoir and a wick, sometimes completed by a pedestal or suspension device and a collector for spilled oil. The fuel reservoir could take the form of a dish, bowl, vase or globe. Depending on the natural resources and cultural level, this would be made of stone, from a sea-shell or coconut, or of earthenware, glass, silver, copper, bronze, brass, pewter or iron. Vegetable or animal oil or fat was burned. Depending on availability, this could be fish or whale oil, fat from domestic animals, olive, sesame, peanut, coconut, palm or colza oil. Sometimes the whole dried carcasses of certain fat-bearing animals—sea-birds or fishes—were used as lamps. During the later centuries in Europe either olive or colza oil was generally used, as it burned with a steady, smoke-free flame.

The wick would be made of bark, moss or plant fibers, and was either free-floating, supported by a spike, or laid in a sloping groove or lip in the rim of the reservoir. With later types of oil lamp the wick was usually led through a spout. Some oil lamps had multiple wicks—up to sixteen in certain Greek and Roman types.

Fig. 1.8. Seventeenth-century scene, with a tallow candle on the table.

Candles and torches

Compared with the oil lamp the candle is relatively recent, and is said to have been invented by the Romans soon after the birth of Christ. The first candles were made either of hard animal fat (tallow) or beeswax. The latter were of superior quality, but also far more expensive.

In the eighteenth century an urgent need arose for a candle material of better quality than tallow, but less costly than beeswax. This led from about 1780 on to the use of spermaceti—fat from the sperm whale—for candles, followed around 1830 by stearin, a product obtained by chemical treatment of animal or vegetable fat or oil. Finally, in the second half of the nineteenth century, paraffin became available for candle-making. This is a distillation product of mineral oil or pitch, but can also be obtained from the residues of coal-gas production. These new materials, together with the braided cotton wick, which was introduced around 1800, resulted in the domestic candle as we know it today.

"Poor-man's" versions of the candle—mainly used in Northern Europe—were the rushlight, a piece of stripped rush dipped in molten tallow, and the bog-deal torch, a splinter of long-burning pine wood found in peat bogs.

Outdoor lighting usually took the form of torches or flambeaux which were sticks topped off with rope or tow and dipped in resin, fat or pitch. They were used to illuminate outdoor festivities, and

Fig. 1.5. Persian spouted oil lamp of earthenware.

Fig. 1.6. Typical Dutch brass "slush-lamp" from the seventeenth century.

Fig. 1.7. Roman oil lamp for ten wicks.

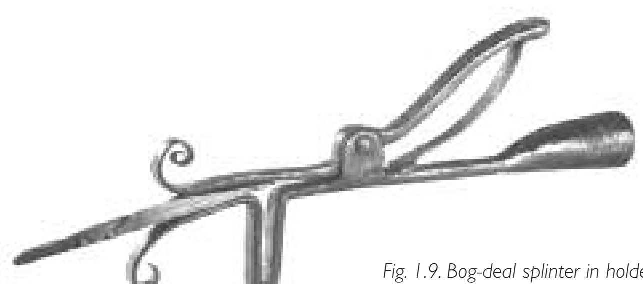


Fig. 1.9. Bog-deal splinter in holder for use indoors.

Fig. 1.10. Because of the smoke they produced, torches were seldom used indoors.

were carried by runners to light the way for the carriages and sedan chairs of the rich. Permanent street lighting in the big cities of the time didn't come into general use before the middle of the seventeenth century.

Further development of the oil lamp

After Roman times, the development of light sources stagnated for a considerable period, although this is not the main reason why

Fig. 1.12. Nineteenth century wall lamp, fitted with a "Duplex" burner and two flame regulator knobs.

Fig. 1.13. A "Moderator" lamp for colza oil, with pressure feed to the burner.

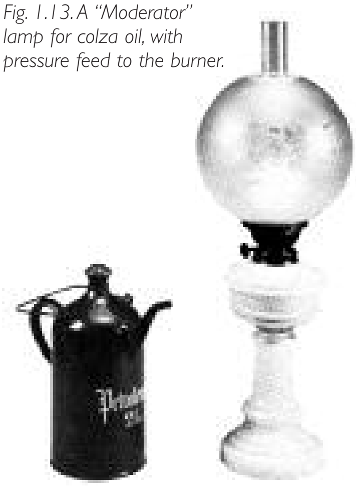


Fig. 1.14. The heyday of the oil lamp came after paraffin oil became cheaply available around 1860.

Fig. 1.11. A typical modern Argand burner, fitted with a flame spreader.

the millennium between AD 500 and 1500 is often referred to as the "Dark Ages". It was a period during which both science and technology suffered from a deep repercussion, after the heydays of Greek and Roman civilization.

The economic and social pressure for more, better and cheaper lighting, brought about by the Industrial Revolution, led, from about 1780 on, to a flood of inventions aimed either at improving existing light sources (especially the oil lamp) or at the development of completely new methods of light production—for example gas lighting, and later on electric lighting.

A first step toward improving the light output of the oil flame was made in 1773, when the Frenchman Leger used a flat wick, instead of a round one. This gave a more complete combustion, as oxygen had better access to the core of the flame. More important in this respect was the work of the Swiss physicist Amié

Fig. 1.15. At the end of the nineteenth century oil lamps in all shapes and sizes came on the market.

Argand, who in 1784 invented a round burner with a tubular wick, which was named after him. As air is drawn up inside the wick, combustion is improved, resulting in an increase in light output from the flame and less risk of smoke. The upward air draught was considerably increased by the subsequent invention, by Argand's partner Quinquet, of the glass chimney. Still later, in 1865, Joseph Hinks placed two flat wicks side by side, thereby introducing the so-called "Duplex" burner.

Fig. 1.16. Three generations of miner's lamps. From left to right: an open-flame "frog" lamp, a Davy safety lamp burning paraffin oil, and as ultimate development a "Wolf" lamp burning petrol.

Vegetable oil was used exclusively in these improved lamps; olive oil or, in countries with a climate too cold for growing olives, colza oil, pressed from rape seeds. Both oil types were somewhat sticky by their nature, and much intelligence was spent on finding methods to ensure a constant supply to the burner without overflowing. Carcel introduced a lamp, named after him, which had a clockwork pump to raise the fuel. This would long be used as a photometric standard. For general lighting purposes, however, the "Carcel" lamp was, from 1836 onwards, replaced by the less complicated "Moderator" lamp invented by Franchot, which was fitted with a spring-loaded piston to pressure-feed the burner.

Because of the relatively high price of vegetable oil and its tendency to clog the burner, making frequent cleaning necessary, a fuel that could be used as a substitute was eagerly sought after. In 1847 the Scotsman James Young discovered a refining process for mineral oil, and thus produced the first paraffin oil. It proved to be an ideal fuel for oil lamps, rapidly replacing vegetable oil after it became cheaply available around 1860.

In less than a century the oil lamp had evolved from a rather primitive light source into one that was highly effective. The largest single-flame types, as used in churches, schools and public rooms, had a light output of some 2500 lumens. Further more, availability of cheap fuel helped its proliferation at all levels of Victorian society, and even the most modest of households had at least a dozen lamps at their disposal.

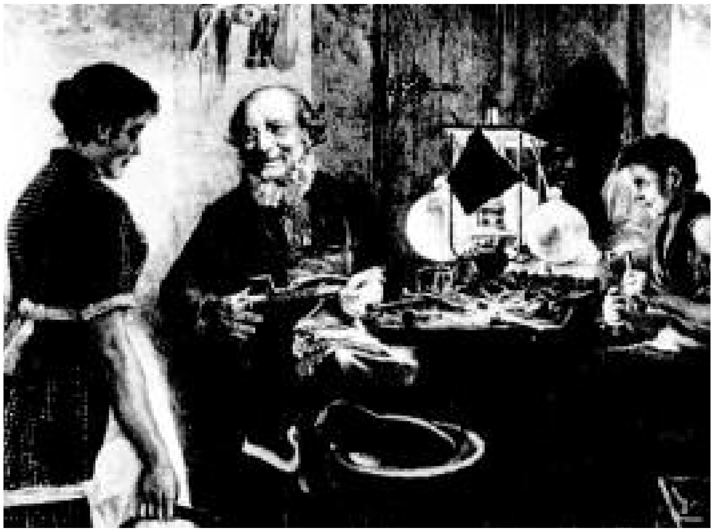


Fig. 1.17. Cobbler's lamp with three glass globes. A piece of cloth screens the direct light from view.

Fig. 1.19. English hexagonal oil burning street lantern from the end of nineteenth century, later converted to gas.

Apart from differences in size and decoration, a host of specially adapted lamps came about, for portable, industrial and marine use, as well as for street and vehicle lighting. Perhaps the most famous among these special versions is the miner's safety lamp, invented in 1813 almost simultaneously by George Stephenson and Sir Humphry Davy. It is still widely used today in coal mines, although no longer for general lighting purposes.

An early form of "task lighting" was found in the so-called cobbler's lamp, whereby the light was concentrated on the work spot by means of a glass globe which, filled with water, acted as a lens.

Fig. 1.20. Modern pressurized paraffin oil lamp, fitted with an incandesent mantle.

Fig. 1.18. "Jan van der Heyden" street lanterns depicted in a lamp-lighters' New Year's greeting. The inset gives a more accurate picture of the type of lamp used.

Street lighting of any magnitude was unheard of before the middle of the seventeenth century—people going out after dark carrying their own lights. The invention of an oil lantern specially suited to street lighting is usually attributed to the Dutchman Jan van der Heyden, who first used it to light the streets of his hometown Amsterdam in 1669. The all enclosed lantern housed a sprouted oil lamp, fitted with a special reservoir that maintained a constant oil level on the wick. Filling, lighting, snuffing and cleaning required the attention of one "lighter" for every twenty lamps.

In the following fifty years most of the major cities of the old world received street lighting, be it on a very limited scale by present day standards. From 1810 on, gas lighting quickly gained ground in towns, it being both cheaper in fuel and maintenance, but in rural areas the oil lantern lasted well into the resent century.

After 1870 development of the oil lamp had almost come to an end. The only significant improvement made after that date was in around 1895 when Auer von Welsbach's gas mantle (q.v.) was adapted for use with oil lamps. In some cases the oil reservoir was also pressurized to improve combustion. However, this development came too late for universal application, and it also spoiled the only advantages left for the oil lamp—simplicity, ruggedness and low price—in a time when gas and electric lighting had already won the day.

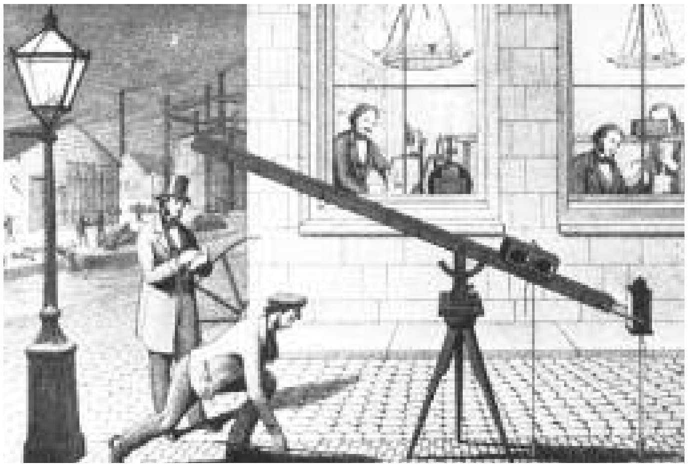


Fig. 2.1. Visual photometer in use for measuring the light output of a gas-lantern fitted with a bats-wing burner. In the background can be seen—from left to right—the gasworks, the gasometer and the laboratory of the gas company.

2. GASLIGHT

Introduction

With the passing of the primitive light sources, burning either solid or liquid fuel stored in the lamp itself, and before the coming of the electric light, came the era of the gaslight. It is a typical spin-off from the Industrial Revolution, as it did not primarily involve the development of a suitable lamp—which was simple enough—but the setting-up of town-sized gas production and distribution systems. The organization and financing of these enterprises would have been next to impossible within the social structure existing prior to the Industrial Revolution. And the technical resources were also totally lacking.

With the advent of the incandescent electric lamp, around 1880, the use of gas lighting seemed to have come to an end, but it experienced a second heyday thanks to the invention of the gas mantle. In the long run, however, this could not prevent its ultimate demise in favor of electric lighting.

Early history

The existence of flammable gas was known for ages, but it was not until the eighteenth century that man attempted to use it to his advantage. The earliest experiments using gas for lighting purposes were carried out by three scientists, working independently of each other. They were the Dutchman Jan Minckelers, who in 1783 produced coal gas to light his lecture room at the university of Louvain; the English colliery owner George Dixon, who around 1780 lighted his house with coal gas; and the French engineer Philippe Lebon, who produced gas for lighting purposes by heating sawdust in a retort.

The first to exploit coal gas commercially must have been William Murdock, a Scot. In 1803 he successfully lighted the Soho works of the Boulton and Watt Company, where he was employed. The following year he sold a lighting installation with fifty lights to a cotton spinning mill in Salford, near Manchester. Over the following years the capacity was extended to cover the whole premises, the owner claiming that, compared with tallow candles, annual lighting costs had dropped a fifth.

Those early lighting installations produced their own coal-gas in retorts, which in the beginning were little more than glorified tea-kettles. A serious draw-back was the nasty smell of the unpurified gas, which leaked through the imperfect joints of the piping. One of the first concerns of William Murdock was therefore to invent a method to "wash" the gas by passing it through water.

The idea of centralizing gas production and distributing it over the town through a network of pipes came from a German working in London, Friedrick Albert Winzer, or Winsor as he called himself in England. He was neither an engineer nor a scientist, but a businessman of considerable enterprise who was able to interest political and financial circles in his plan.

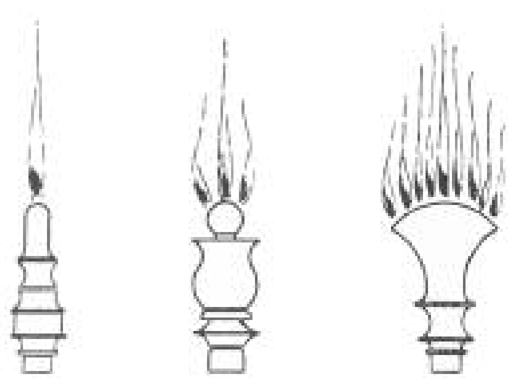


Fig. 2.2. From left to right: "rat tail", "cockspur" and "cockscomb" burners.

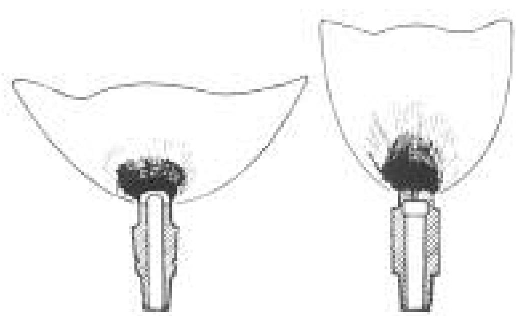


Fig. 2.3. From left to right: Flat-flame burners: "bats-wing" and "fishtail".

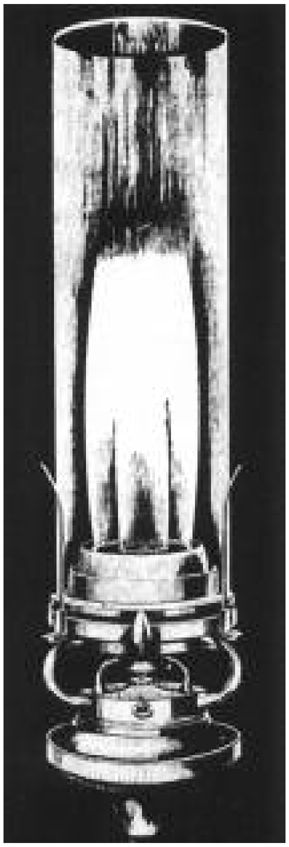


Fig. 2.4. Two-ring "Argand" burner for the gas.

In 1807, after a successful demonstration in London, he formed the National Light and Heat Company. This was later renamed the Gas Light and Coke Company and started public supply in 1813, soon growing into becoming the largest gas company in the world. By the end of 1815 the gas main in London already stretched over 26 miles.

Yet, in those early days, gas lighting was far from ideal. Supply was erratic and the pressure in the mains would drop to almost zero during peak loads. The smell of the insufficiently purified gas restricted its use indoors, and the price was still high. Nevertheless, because of the low maintenance costs of the burners and the absence of the smell problems outdoors, it was strongly favored for street lighting. The first town to switch over to gas for its public lighting was the mining settlement of Freiberg in Saxony—now in the German Democratic Republic—in 1812, closely followed by London and the other major cities of the world.

Heavy competition—in 1823 there were in London alone already three rival gas companies—meant that the quality of the gas and the reliability of its supply quickly improved, while the price dropped steeply during the same period. Gas-meters came into use in the 1850s; before that time the user was charged according to the number of outlets in his dwelling.

Gas production

Coal gas is produced by heating bituminous coal in cast-iron retorts, in an air-free atmosphere. The methane liberated during this process is cleaned of tar, ammonia, benzene and other undesirable constituents before being stored in the gasometer, a familiar landmark in many towns. From there it is pressure-fed into the mains, either by pumping or by the weight of the movable upper part of the gasometer. What is left in the retorts is highly carboniferous coal, called cokes, which is used for the production of iron from its ore in blast furnaces, or for heating purposes.

Other combustible gases used for lighting purposes are natural gas, from wells; oil-gas, produced by distilling or cracking mineral oil; water-gas, produced by passing steam over a bed of hot coal; and acetylene, obtained by adding water to calcium carbide. Before the 1830s gas was also commercially produced by heating animal fats and oil (whale oil).

Gaslight burners

The first gaslight burners were nothing more than narrow apertures at the ends of pipes. The number and configuration of the openings gave the flame(s) a specific shape, and thus names like "rat-tail", "cockspur" and "cockscomb" burner evolved.

As with oil lamps, attempts were made to increase the light output of the gas flame. This resulted in the introduction of flat-flame burners, from 1816 on. They were named "bats-wing" or "fishtail" burners after the shape of the flame, which was obtained by placing two single jets in such a way that they impinged on each other. In 1809, Samuel Clegg had already managed to adapt the Argand burner for use with gas, which—fitted with a glass chimney—would remain the most popular type until the introduction of the gas mantle. Often Argand burners for gas were built-up of several (up to four) concentric rings. After about 1860, non-metallic materials—steatite or porcelain—were used for the tip of the burner to prevent corrosion. The burner was also sometimes fitted with a governor to compensate for variations in the gas pressure. Both inventions are attributed to the Englishman William Sugg.

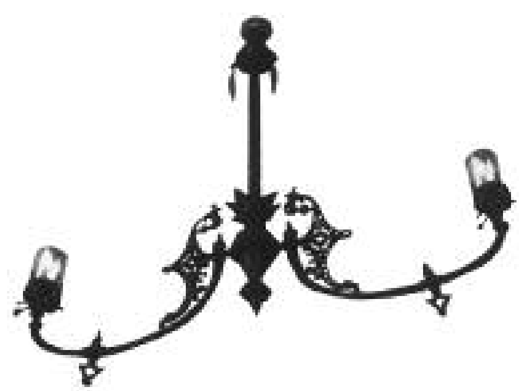


Fig. 2.5. Two-branched chandelier, dating from about 1870, fitted with open-flame "Argand" burners.

Fig. 2.6. Regenerative gaslight, from about 1910, used for workshop lighting. It is fitted with an inverted incandescent mantle.

A further improvement, aimed at increasing the burner's specific light output, was introduced in 1886 whereby the incoming air needed for combustion was preheated by the flue gases. This resulted in the so-called regenerative gaslight.

Fig. 2.7. Carl Auer von Welsbach

Fig. 2.8 Early upright "Auer" gas mantle.

Fig. 2.9. Advertisment in "Illustrated London News" of 1887 for incandesent gaslight from the "Sugg Company", boldly stating that it is superior to electric light.

The gas mantle

A dramatic step forward was made in 1887. Following numerous attempts by a host of inventors—even including Thomas Alva Edison—over a period of twenty-five years, to improve the luminosity of the gas flame by bringing solid material in it to incandescence, it was at last the Austrian physicist Carl Auer von Welsbach who met with success.

The story of the origin of the incandescent gaslight is not unlike that of the electric incandescent lamp, invented some ten years earlier. It was not so much a problem of finding a material that could be brought to brilliant incandescence, but rather that of finding one that would last long enough to become practically visible. Most experiments tried platinum gauze, coated with various oxides, or magnesia, but these materials were prone to premature disintegration. Auer von Welsbach used a tube of fabric, impregnated with a mixture of thorium and cerium salts. The fabric would burn away, leaving a brittle but heat-resistant structure consisting of the oxides of the aforementioned metals—the so-called gas mantle. The correct composition of the mantle to gain the highest light output had to be found empirically, as even twenty or thirty years after the invention the underlying processes were still not fully understood.*

** For the technically minded: It is in fact the cerium oxide—of which there is only one percent present in the mantle material—that is the true light-emitting agent, this being attributable to the phenomenon of candoluminescence—fluorescence stimulated by heat. The thorium oxide, because of its poor thermal radiation properties, keeps the mantle at the high temperature required to maintain the process of candoluminescence.*

Fig. 2.10. Beautiful three-branched gas chandelier from about 1925, with a three-mantle inverted burner in the center, encircled by three upright single-mantle burners.

Fig. 2.11. Two gas-lanterns from about 1890, fitted with an upright mantle and a clockwork-operated valve (left), or a four-mantle inverted burner and a pressure-surge operated valve (right).

Fig. 2.12. Dutch office at the turn of the century, lighted by upright gas-mantle burners.

For his gas-mantle lamp, Auer von Welsbach used the aerated or bunsen burner, invented in 1855 by R.W. Bunsen. This type of burner results in a very hot, almost invisible flame. The first gas-mantles were excessively brittle, but by 1890 this problem had been largely solved.

The gas-mantle lamp came in the nick of time to provide the mighty gas companies with an adequate answer to the electric incandescent lamp. And so successful was it that the proliferation of electric lighting was seriously set back by it for many years. In many parts of the world it was only after the 1940–1945 war that electricity took a definite lead in lighting technology.

Over the years the gas-mantle lamp underwent a number of improvements, the most important being the introduction, by Kent in 1897, of the inverted burner. This had two advantages over the upright one: the downward light was no longer intercepted by the burner, and the heat of the flame stayed inside the mantle, thus increasing the efficiency of the burner. The inverted burner could, however, only be used because the gas companies had learned to supply the gas at higher and more constant pressure than before.

Fig. 2.13. Dutch billiards hall of about 1910, illuminated by gaslight.

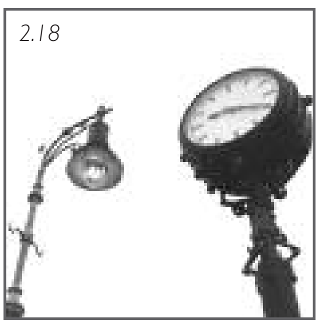


Fig. 2.14. German gas-lantern for road lighting, fitted with a four-mantle linear burner and a pressure-surge operated valve. Two of the flames are automatically switched off late in the evening. This type is still in production in Germany.

Fig. 2.15. German gas-lantern for street lighting, constructed around 1935. Fitted with a four-mantle inverted burner and a clockwork-operated valve.

Fig. 2.16. Modern German gas-lantern for residential area and park lighting. Fitted with a four-mantle inverted burner and a valve that is operated by photocell. This type was extensively used in Hamburg.

Fig. 2.17. Beautiful ornamental four-armed street-lantern, fiitted with inverted gas-mantles.

Fig. 2.18. Gas-lit electric street clock, dating from 1911. In the background stands a Berlin gas-lantern from about 1890, fitted with a four-mantle inverted burner and a pressure-surge operated valve for evening and night switching.

Fig. 2.19. English gas-lantern for industrial area lighting, from about 1925. Fitted with a six-mantle inverted burner and a manually operated valve.

Fig. 2.20. Acetylene lantern for use on bicycles.

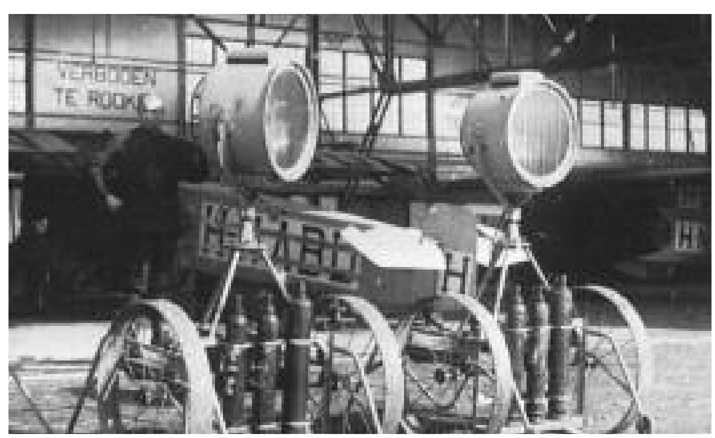
In their attempt to compete with electric lighting—which could be switched so conveniently—gas-lighting companies even introduced wall switches for home lighting early in the present century. These worked either mechanically, pneumatically or with batteries. For ignition after switch-on, either a permanent pilot flame or an electric incandescent filament was employed. Gas lanterns for street lighting were switched by a built-in clockwork mechanism or a momentary increase in the gas pressure serving to actuate a valve. Present-day gas lanterns often employ a photocell connected to a relay, which is supplied from a battery. Some sophisticated types of gas lanterns even automatically switch down to half their number of mantles late in the evening.

Gas was also used for lighting all sorts of vehicles, from bicycles to railway carriages. This was accomplished using acetylene gas, which was produced by dripping water onto calcium carbide in a special reservoir. Owners of isolated houses and mansions could buy their own "gasworks" based upon the same principle for lighting the premises. Nowadays, propane gas in pressurized containers is used to the same end.

An almost forgotten form of gas lighting, except in the metaphorical sense, is the "limelight", reputedly invented by Drummond in 1825. By heating a block of quicklime to incandescence in a flame of oxyhydrogen or acetylene, a compact, extremely intense light source was obtained. This was used for projection or theater lighting, and also for flood and searchlights.

Although in the home long since superseded by electricity, gas is still extensively used for street lighting in some countries. The city of West Berlin, for example, still uses some 40,000 gas lanterns mostly of a modern design. Bottled propane gas is also used for lighting purposes where electricity is not available.

Fig. 2.21. Acetylene-burning lime search-lights, as used on Amsterdam's "Schiphol" airport in the mid-twenties.



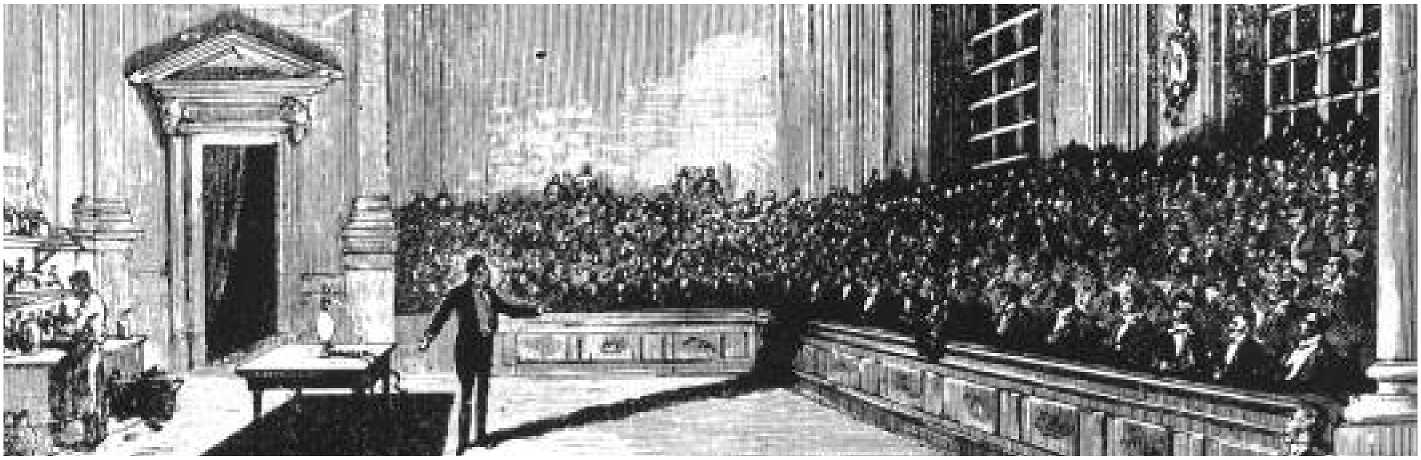


Fig. 3.1. Humphry Davy's demonstration of the arc light, held before the Royal Institution in London in 1808.

3. ELECTRIC LIGHTING BEFORE THE INCANDESCENT LAMP

Introduction

Some of the earliest experiments with electricity involved lighting. In 1802, only two years after Alessandro Volta's revolutionary discovery of the first practical source of electric current, the voltaic pile, Humphry Davy in England brought strips of several metals to incandescence by sending a current through them. Probably in the same year he also discovered the principle of the electric arc, and in 1808 he staged, together with William Pepys, a large-scale demonstration of a continuous luminous electric arc between two pieces of charcoal before the Royal Institution in London. For this experiment he used no less than two thousand voltaic cells. Practical application of electric lighting, however, had to wait until the coming of the first steam-driven generators, after 1850.

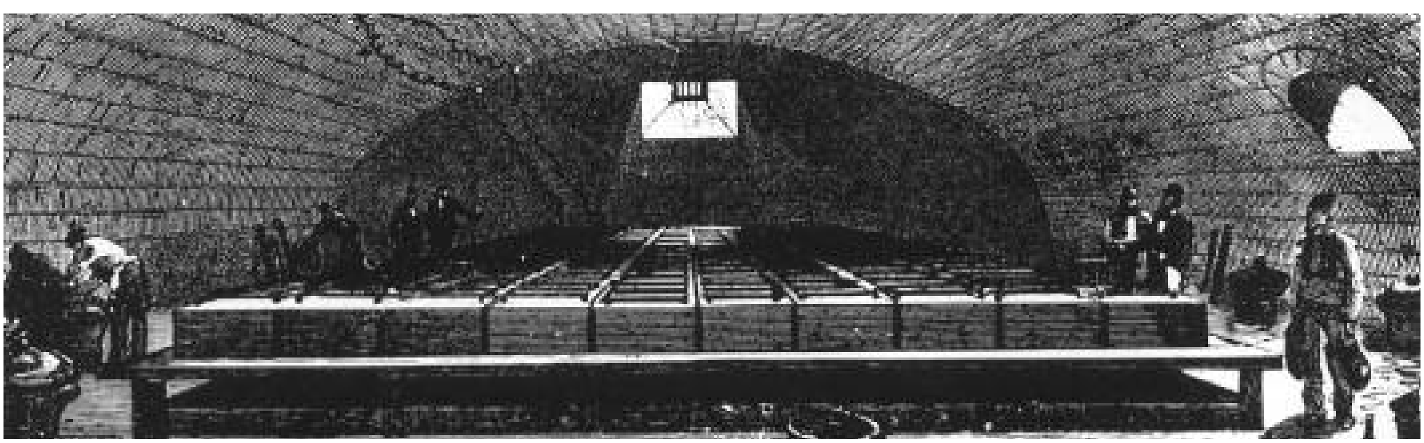
Electric lamp development took place along three different main lines. The carbon-arc lamp received its practical form around 1850, but further development took place until well into the nineties, when this lamp type reached a stage of near-perfection.

After numerous false starts, the first practical incandescent lamps came into being in 1879, and development continued at a rapid rate until about 1930, after which no further significant improvements can be recorded—with the notable exception of the halogen incandescent lamp.

Systematic investigation into electric discharges in rarified gases started as early as 1856, but it was not until the end of the nineteenth century that these could be used for practical lighting purposes. Development of discharge lamps has been taking place along various lines, and is still far from concluded.

Parallel to lamp development, electricity generating and distribution systems grew to perfection, thus paving the way for the wide-spread introduction of electric lighting.

Fig. 3.2. The bank of 2000 voltaic cells Humphry Davy used for his arc light demonstrations.



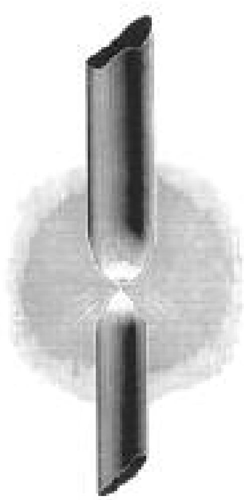


Fig. 3.3. Principle of the d.c. carbon arc. The thicker carbon is the anode.

Fig. 3.4. Hand-regulated arc lamp, as favored for projection purposes.

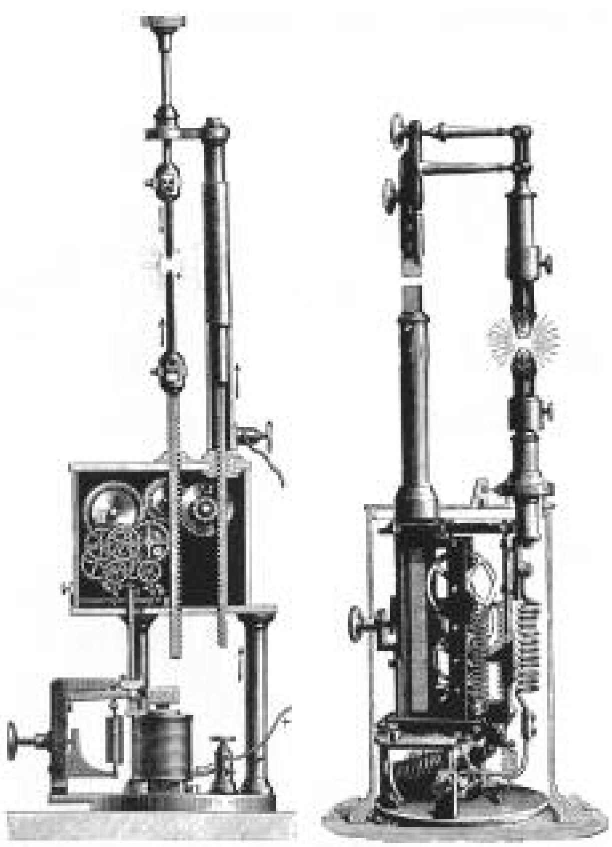


Fig. 3.5. Two early types of self-regulating arc lamp. Foucault and Dukosq (left); Serrin (right).

Principal of the arc lamp

Fundamentally, an arc lamp consists of two rods of carbon connected to the terminals of a current source. When the carbon rods are brought together and then separated to form a gap of a few millimeters, a brilliant light is created. It is not so much the arc itself that emits the light, but rather the ends of the carbon rods, which are brought to incandescence. The first investigators used charcoal rods for their experiments. These burned away very quickly, and the harder retort carbon—a by-product of the gas-works—was soon found to be a better alternative.

Either d.c. or a.c. can be used to supply the arc, but d.c. was generally preferred, because of the higher arc stability. As with the gas-mantle, it took a considerable time before the underlying processes were properly understood. With the d.c. arc, it is the positive carbon tip (anode) that has the highest temperature, and therefore emits most of the light. It is also the one which burns away most rapidly.*

The chief advantage of the electric arc was its brilliant, highly intense light, which never ceased to amaze nineteenth-century spectators. Its drawbacks, however, were many. The carbon rods burn away with time, and therefore require constant attention to keep then at the right spacing, otherwise the arc will extinguish. For the same reasons the carbon rods (or electrodes, as they are also called) have to be renewed at regular intervals. With d.c. supply, consumption of the positive carbon is about three times as fast as the negative one—given they have the same thickness and composition—because of the higher temperature. When burning, a carbon arc hisses and fumes. Even the lowest practicable light intensity is still far too high for domestic use.

Irregularities in the arc current, combines with the negative voltage-current characteristic of the arc, for a long time ruled out the possibility of connecting more lamps in parallel to one and the same power supply. In the beginning, each arc lamp even needed its own battery or generator. Later, to a limited extent, series supply became possible.

In the course of the nineteenth century inventors managed to reduce or eliminate most of these drawbacks, but nevertheless the arc lamp remained an expensive, temperamental and cumbersome light source.

** As with the gas-mantle, it took considerable time before the underlying processes were properly understood. That the positive carbon has the highest temperature is because a large part of the electrical energy of the discharge is concentrated there. Near the anode the fast moving electrons carrying the electric current meet a layer of carbon vapor surrounding it. This forms a poor conductor, because the carbon atoms are not ionized. The resulting large voltage drop causes the heat generation.*

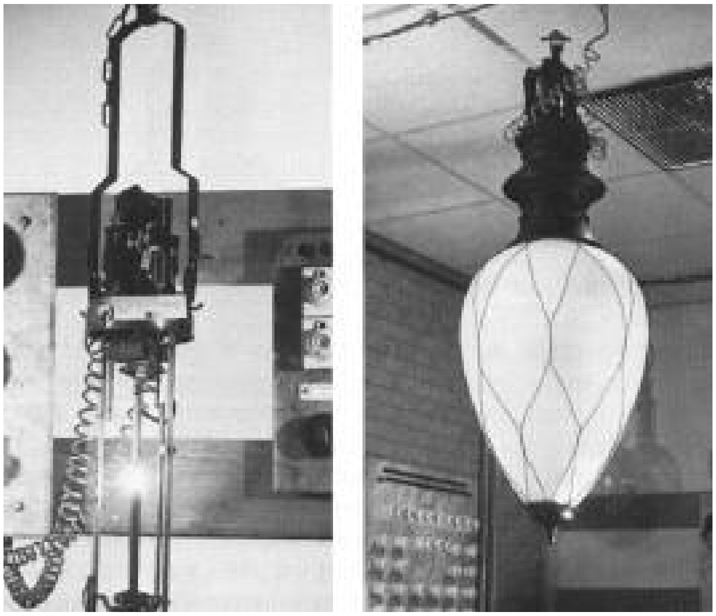


Fig. 3.6. A "Hefner-Alteneck" differential lamp, shown both opened and closed.

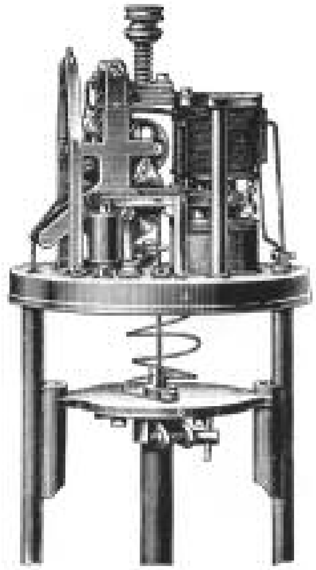


Fig. 3.7. The complicated regulating mechanism used in the "Hefner-Alteneck" differential lamp.

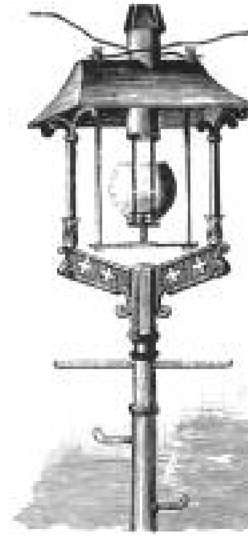


Fig. 3.8. A "Brush" type self-regulating arc lamp, as used for street lighting in the United States.

Further development of the arc lamp

After its discovery, which, as we have seen, took place shortly after 1800, development of the arc lamp stagnated for a considerable period through lack of a suitable source of electric power. In 1846 the theme was picked up again by William Edwards Staite. He patented a lot of improvements, the most important being a device to maintain the carbon rods at the proper distance during burning by means of an electromagnet through which the lamp current flowed. The magnet kept the carbon rods apart against gravity, but its force would weaken as the carbons burned away and the arc lengthened, as this caused the lamp current to fall. The idea was further worked out by Foucault and Dubosq and put into practice by Serrin in 1859, who also found a method of maintaining the position of the arc, despite unequal burning of the positive and negative carbons.

Current-regulated lamps of this type could not be connected in series to the current supply, as every regulator in the circuit would respond to a current variation, whichever lamp required regulating. To overcome this problem Crompton in England and Brush and Wallace-Farmer in the USA devised a system whereby the voltage across the arc was monitored, instead of the arc current, and regulation was performed by a shunt electromagnet of comparatively high resistance. A series electromagnet was still necessary to start the lamp.

Finally, around 1880, Compton and Pochin in England and Friedrich von Hefner-Alteneck in Germany developed the differential carbon-arc lamp. Here the lamp power was kept constant by monitoring both the arc voltage and arc current, and the regulating mechanism was considerably refined by means of a clockwork-type escapement.

Fig. 3.9. A "Jablochkoff-candle", shown separate and in its typical globular luminaire.

Fig. 3.10. Automatic replacement mechansim for Jablochkoff-candles.

Fig. 3.11. Long-burning, all enclosed arc lamp, as produced by the General Electric Co. around the turn of the century.

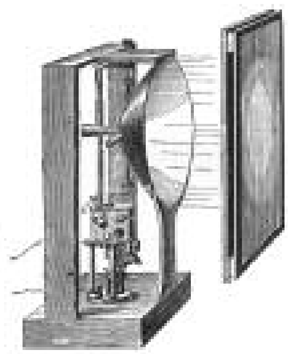


Fig. 3.12. The arc lamp Foucault built in 1849 to simulate the rising sun in Meyerbeer's opera "Le Prophète".

A completely different solution to the self-regulating lamp was contributed by the Russian engineer Paul Jablochkoff. His "Jablochkoff-candle", introduced in 1878, used two thin parallel carbon rods, separated by a layer of kaolin or plaster of Paris. This restricted the arc to the tips of the carbons and crumbled away as the carbons burned down. As the carbon rods were of equal thickness, Jablochkoff-candles had to be operated on a.c. circuits. A thin piece of graphite connecting the two carbons at the top facilitated ignition. Once extinguished, a Jablochkoff-candle could not be restarted and had to be replaced. The average life was only ninety minutes, and devices for automatically replacing the candle were soon introduced.

If air can enter freely, as is the case with open-arc lamps, carbon rods burn away at an average rate of 20 millimeters per hour. In 1893 William Jandus and Louis B. Marks introduced the enclosed arc, whereby the arc was contained in a glass balloon. This reduced carbon consumption to about one fifth, and allowed burning times of up to 150 hours without carbon replacement.

Another important improvement was the flame-arc lamp, invented by Hugo Bremer in 1889. By adding fluorides of certain metals to the carbon rods, the luminous output of the arc could be considerably increased, without increasing the electricity consumption. Also, the color of the light could be influenced by the type of salt added. Typical flame compounds are rare earths for white light, calcium for yellow, strontium for red and iron for ultraviolet.

Applications of the arc lamp

The oldest practical application of the arc lamp was on the theater stage. After a successful debut in the premiere of Giacomo Meyerbeer's grand opera "Le Prophéte" in 1849 in Paris, for which Foucault built an arc light to simulate the sun, there followed a period when no opera or ballet performance was complete without arc-light effects.

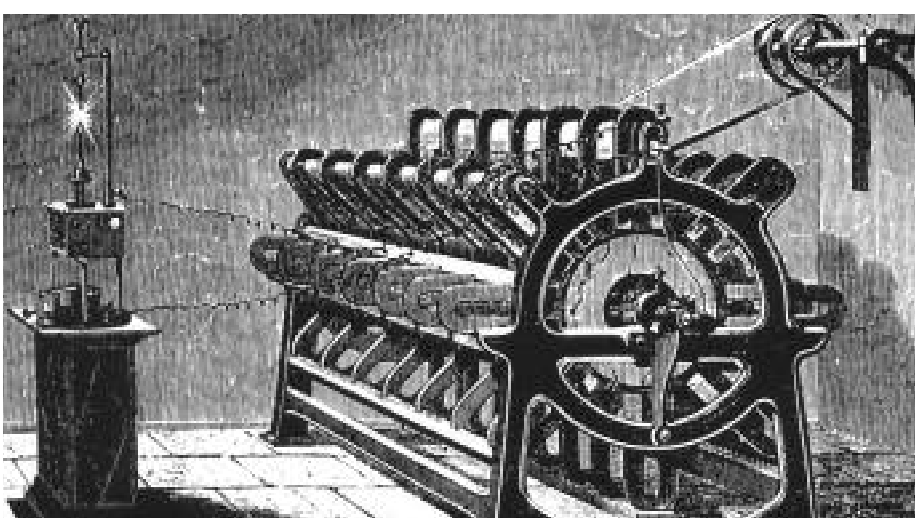


Fig. 3.13. Set-up of an arc light coupled to an "Alliance" magneto-electric generator, as first applied in lighthouses along the French Channel coast.

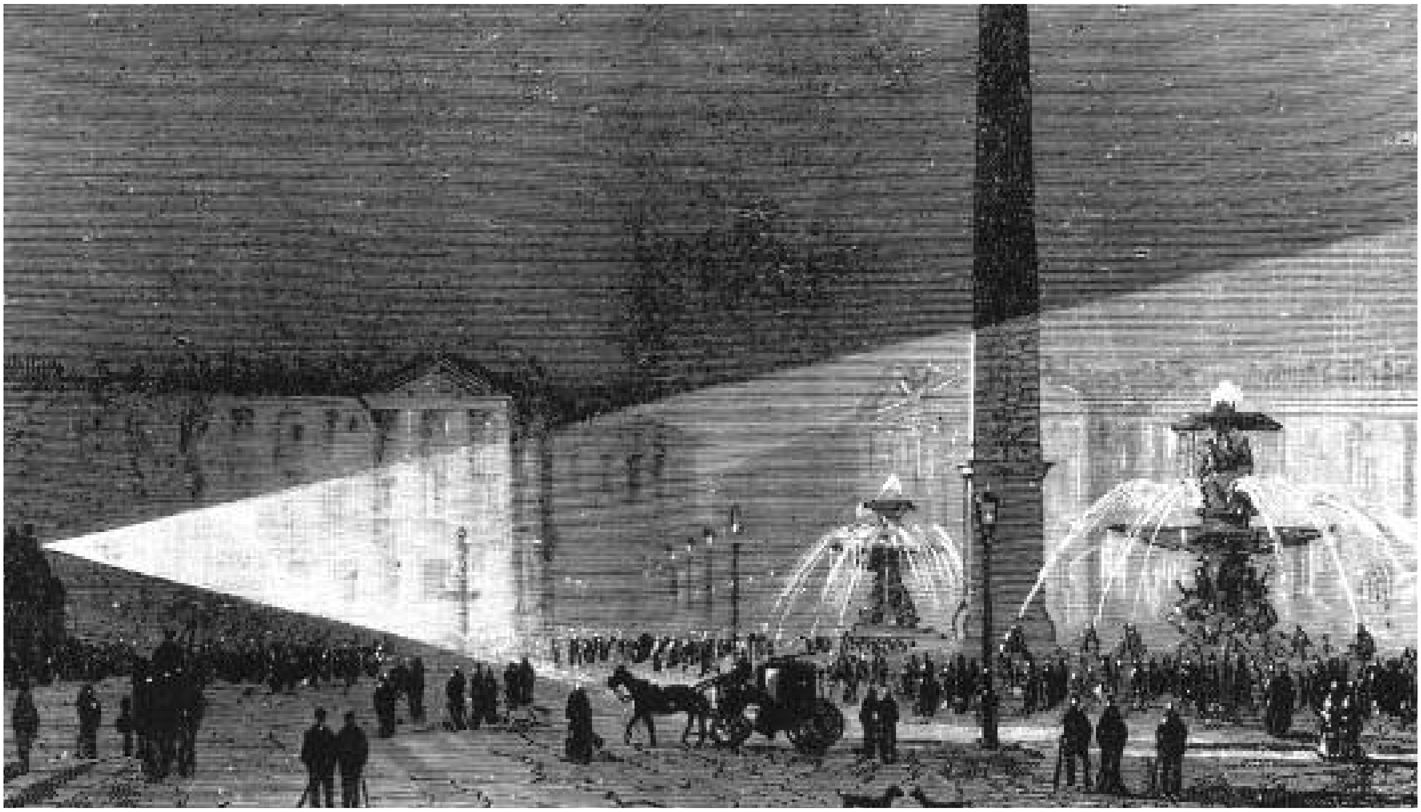
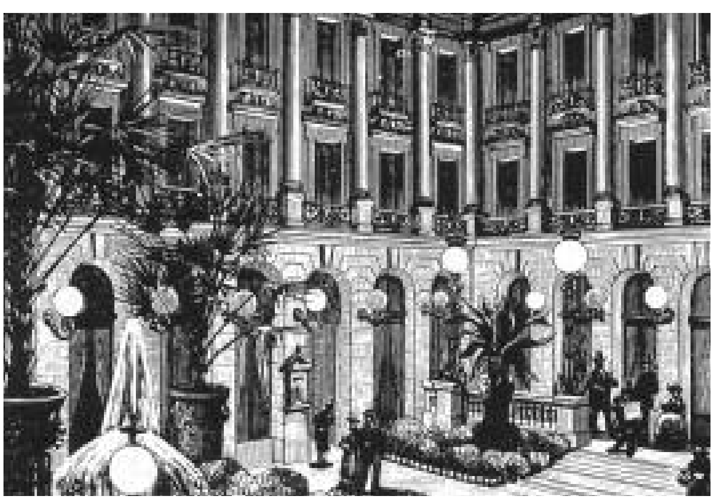


Fig. 3.14. Deleuil's demonstration of the arc lamp for street lighting on the Place de la Concorde in Paris, 1844.

Fig. 3.15. Jablochkoff-candles were soon used in large numbers to light the street and public places of Paris.



In 1858, the South Foreland lighthouse near Dover, England, was the first in the world to be equipped with electric-arc lighting, using two Holmes generators with permanent field magnets for the power supply. After its success, other lighthouses along both Channel coasts quickly followed.

Although the first experimental street lighting using carbon-arc lamps had already been demonstrated in 1844 by Joseph Deleuil on the Place de la Concorde in Paris, general introduction had to wait for a self-regulating lamp that could be employed in series-circuits. From 1878 on, starting with the Avenue de l'Opéra, the main squares and thoroughfares of Paris were lighted by Jablochkoff-candles, the city for that reason perhaps gaining its epithet "Ville Lumière". The other major cities in Europe followed only a few years later. With the introduction of the Hefner-Alteneck differential lamp, however, the Jablochkoff-candle soon became obsolete.

Because of the drawbacks already mentioned, the arc lamp was hardly ever employed for domestic lighting, but it saw use in large indoor areas such as factory halls, department stores and railway stations, sometimes in the form of indirect lighting.

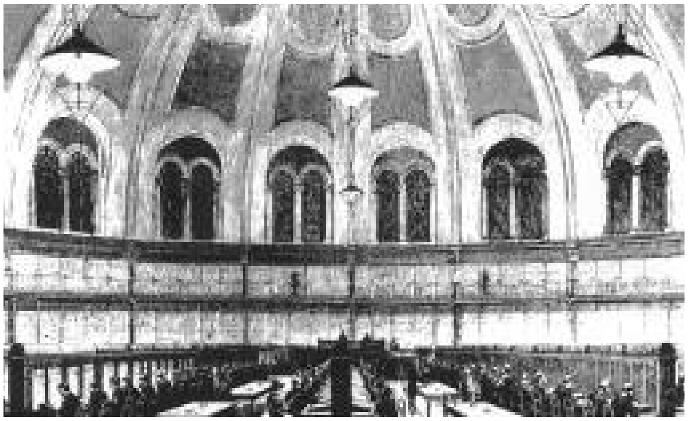


Fig. 3.16. The reading room of the British Museum in London, lit by "Hefner-Alteneck" differential arc lamps.

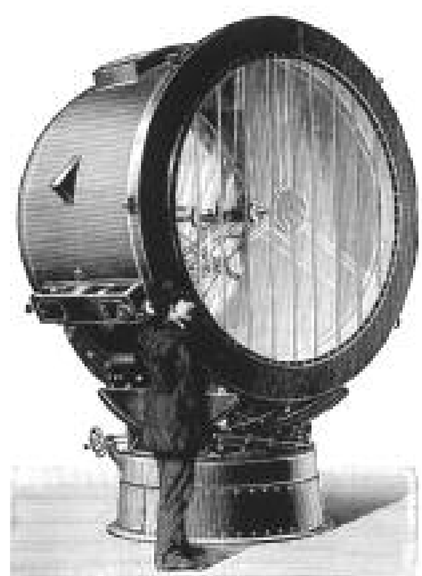


Fig. 3.18. Carbon-arc searchlight, constructed by the German firm of Schuckert for the World Exhibition held in Paris in 1900. It had a parabolic mirror of two metres diameter, and was regarded as the strongest artificial light source then in existence.

The heyday of the carbon-arc lamp came in the closing years of the last century, after which it was quickly superseded by the incandescent electric lamp for general applications. Nevertheless, in London for example, some street arc lights lasted until the 1950's.

A stronghold for the carbon-arc lamp remained those special applications where a highly concentrated light source of extremely high intensity was required. Typical examples included theater-stage lighting, light in photo and film studios, cinema projectors, aircraft searchlights, and reproduction cameras in the graphic industry. With the advent of the short-arc xenon lamp, introduced in 1951, its role in these fields of application has also all but ended.

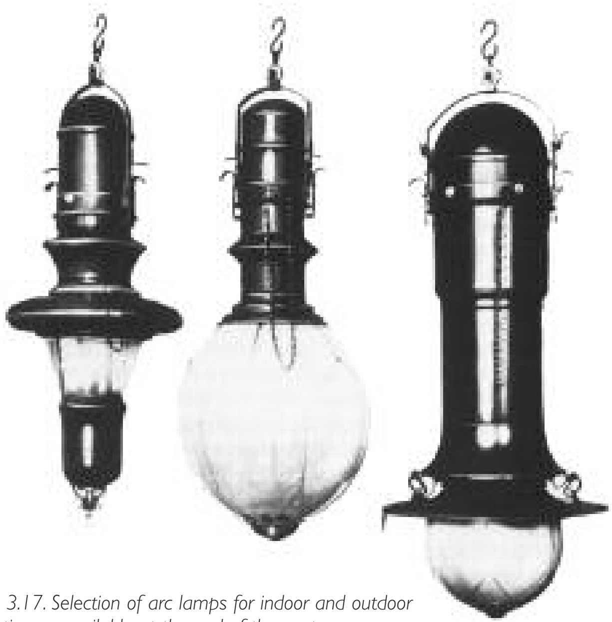


Fig. 3.17. Selection of arc lamps for indoor and outdoor lighting, as available at the end of the century.

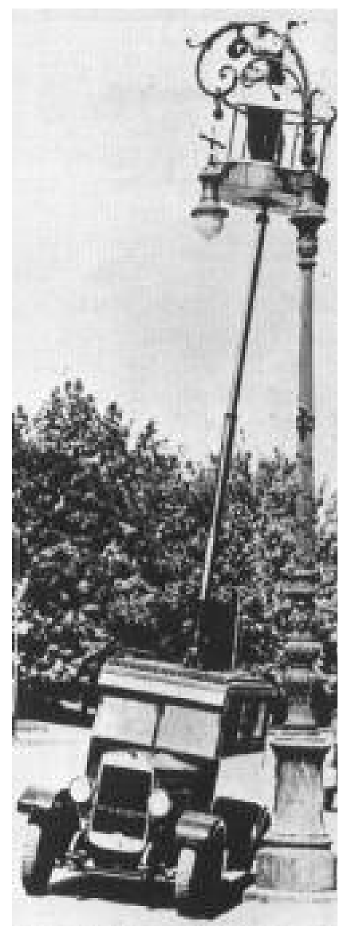


Fig. 3.19. Maintenance carried out on street arc lights in a Dutch town in the thirties.

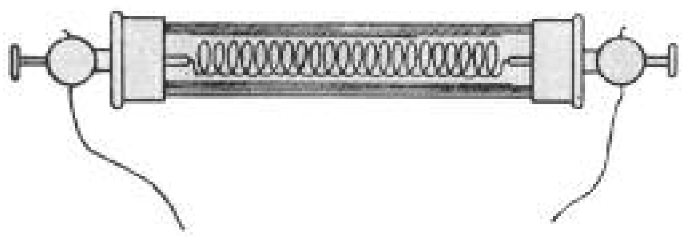


Fig. 4.1. The first attempt to make a practicable incandescent lamp was probably that made by Arthur de la Rive, in 1820. He used a platinum fillament in a partial vacuum.

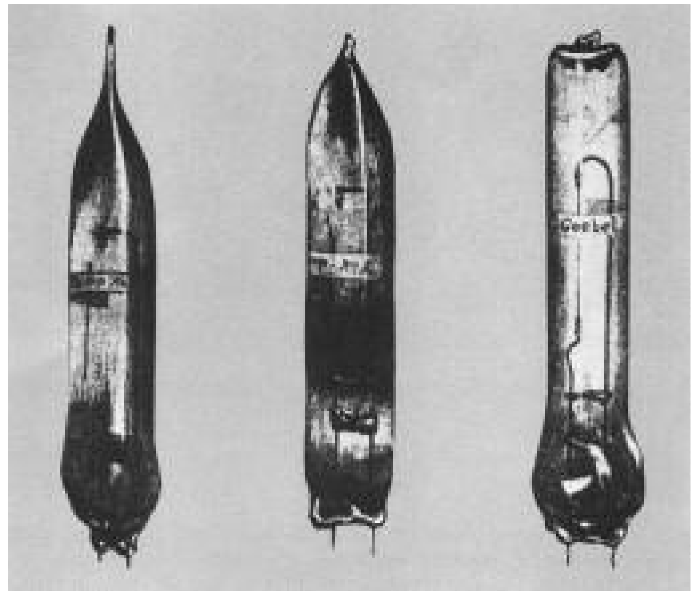


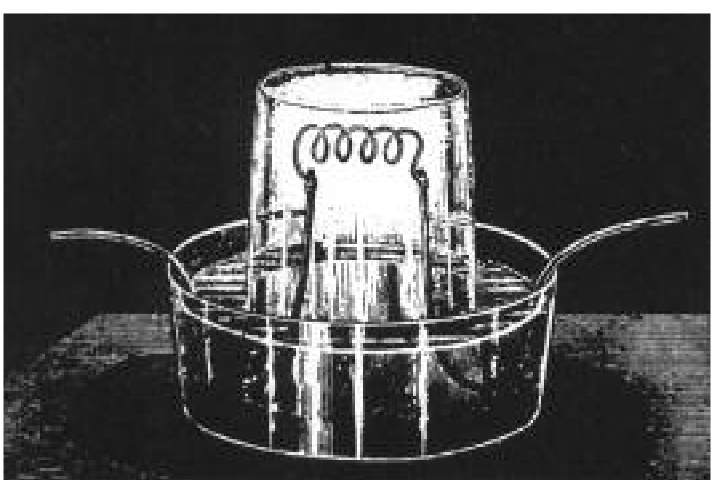
Fig. 4.3. Some of the carbon-filament incandescent lamps made by Heinrich Goebel.

4. THE INCANDESCENT LAMP

The forerunners

The development of the incandescent lamp took place during roughly the same period as did the carbon-arc lamp, and many inventors were involved in both types of electric lighting, and sometimes in gas lighting as well. However, initial results were far less spectacular with incandescent electric lamps than with carbon-arc lamps, and the list of unsuccessful experimenters is indeed impressive.

Fig. 4.2. The Platinum "lamp" William Grove used in demonstrating his battery.



The first one to discover that a metal strip or wire could be brought to incandescence by passing an electric current through it was probably Louis Jacques de Thenard in 1801. Better documented, however, is the research carried out by Sir Humphry Davy between 1802 and 1808, who discovered that, while most materials readily burned away, platinum would emit light for a considerable time. Unfortunately, nobody then saw the potential of this for use in constructing a practical light source, partly because of the lack of a suitable current source.

Nevertheless, investigators tried to extend the life of the incandescent strip, rod or wire by placing it in a vacuum. The Swiss Auguste Arthur de la Rive in 1820 was probably the first to use a coiled platinum filament in a partly evacuated glass tube. The Belgian Jobart, in 1838, found that carbon would not burn away if brought to incandescence in an air-free environment. When demonstrating his newly invented battery in 1840, William Grove used a platinum filament in a glass beaker, placed upside-down in a dish filled with water. This "lamp" burned for a considerable time, but its main purpose was to demonstrate the quality of the battery.

Many other investigators experimented with electric incandescent light in the period between 1840 and 1854. William Edwards Staite—who also constructed the first self-regulating arc lamp—and Petrie, for example, used strips of platinum-iridium, while J.W. Starr experimented with a platinum strip of adjustable length. He, as well as M.J. Roberts, also tried a carbon rod placed in a vacuum. In 1841, Frederic de Moleyn took out a patent on a lamp in which carbon powder dispersed between two platinum coils was brought to incandescence, and in 1850 E.C. Shepard, in a similar way, used the contact resistance between two pieces of carbon.

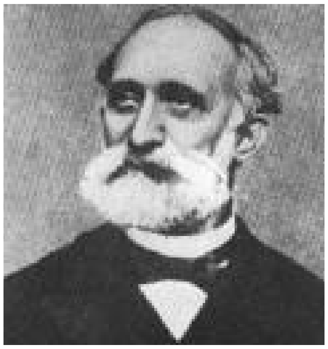


Fig. 4.4. Heinrich Goebel

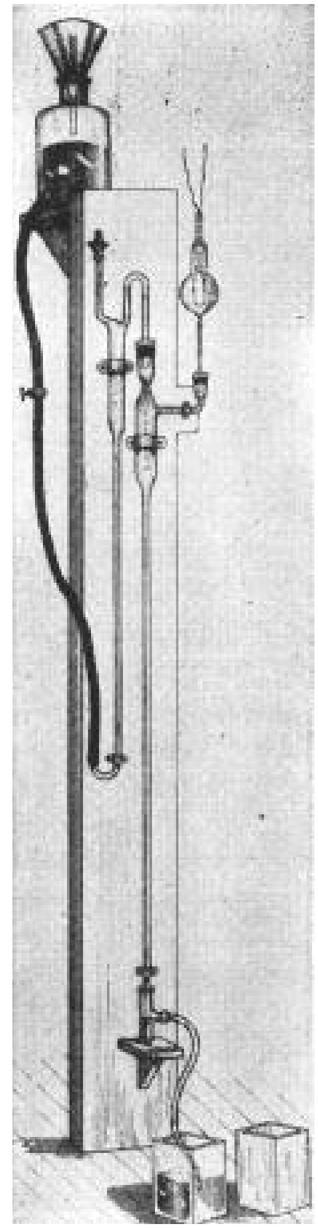
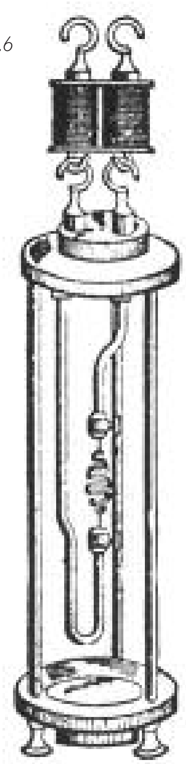


Fig. 4.7. Sprengel's mercury-drop vacuum pump.

The first to make practical use of electric incandescent light was Heinrich Goebel in 1854, although a less convincing claim is sometimes made for the Scot James Bowman Lindsay in 1835. Goebel, a German who had emigrated to the United States, made electric lamps of carbonized bamboo filaments, sealed in evacuated perfume bottles. He used these lamps to illuminate the show-window of his watch-shop in New York, but failed to pursue his invention further for lack of a suitable current source. In 1893, however, his priority claim over Edison was recognized before the court.

4.6



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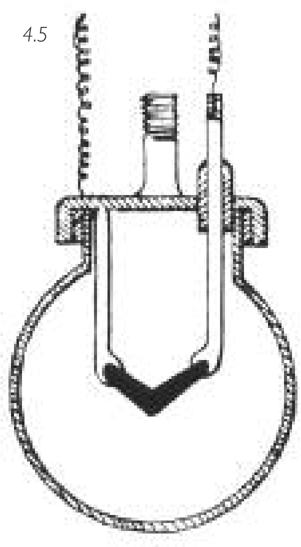


Fig. 4.5. The lamp of Lodyguine used a graphite rod as incandescent body and was filled with nitrogen.

Fig. 4.6. De Changy's open-filament platinum lamp for use in mines.

Other inventors who met with at least partial success were the Frenchman de Changy, who in 1856 devised an open platinum filament lamp for use in mines, which actually seems to have been used as such; the American Joseph Farmer, who also used open platinum strip lamps to light his living room; and the Russian scientist Lodyguine, who constructed lamps with an incandescent body of graphite in a glass balloon filled with nitrogen. In 1872 he used no less than 200 of these lamps to illuminate the naval harbor of St. Petersburg (now Leningrad).

Fig. 4.8. Thomas Alva Edison

Fig. 4.10. The first of Edison's unsuccessful platinum lamps.

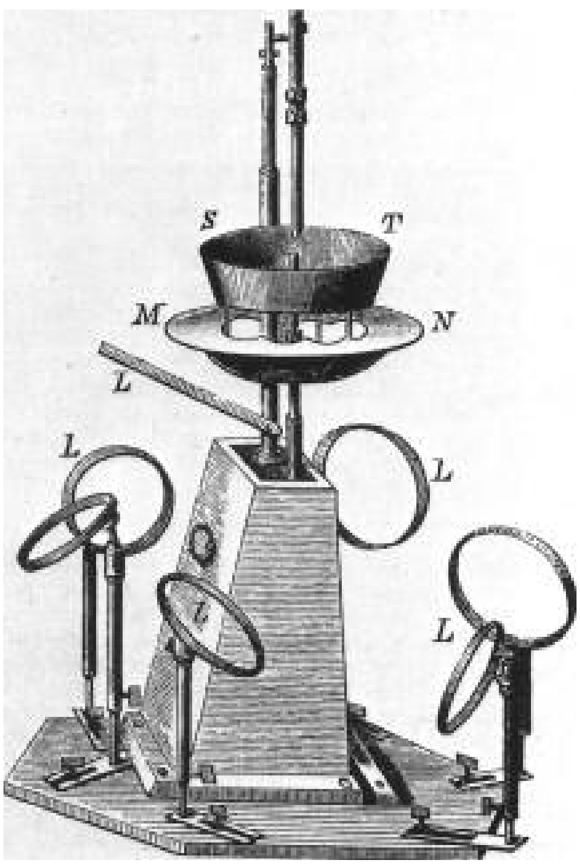


Fig. 4.9. Attempts were made to spread the light of a carbon-arc lamp in various directions using mirrors and lenses.

The birth of the carbon-filament lamps

At the end of the 1870s, most of the problems underlying the construction of a successful incandescent lamp were understood, although not necessarily solved. It was realized that a material with high melting and vaporizing temperatures was required for the incandescent filament. Also, it was correctly believed that a lamp of fairly high resistance had advantages over one of low resistance, but that the former called for very thin filaments, which would only last sufficiently long if a high vacuum was maintained in the surrounding bulb. Many experiments failed to achieve the latter, but with the invention of the mercury-drop vacuum pump by Wilhelm Sprengel in 1865 this problem could at last be properly tackled—although pumping times of ten hours and more hardly encouraged the commercial production of lamps. Around 1875 experimenters also discovered that by heating the bulb and filament, occluded (i.e. absorbed) gases were freed, and so would not act to spoil the vacuum.

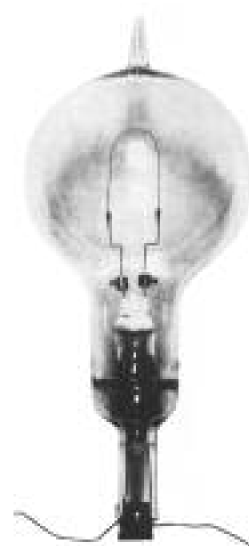


Fig. 4.11. The oldest type of carbon-filament lamp made by Edison.

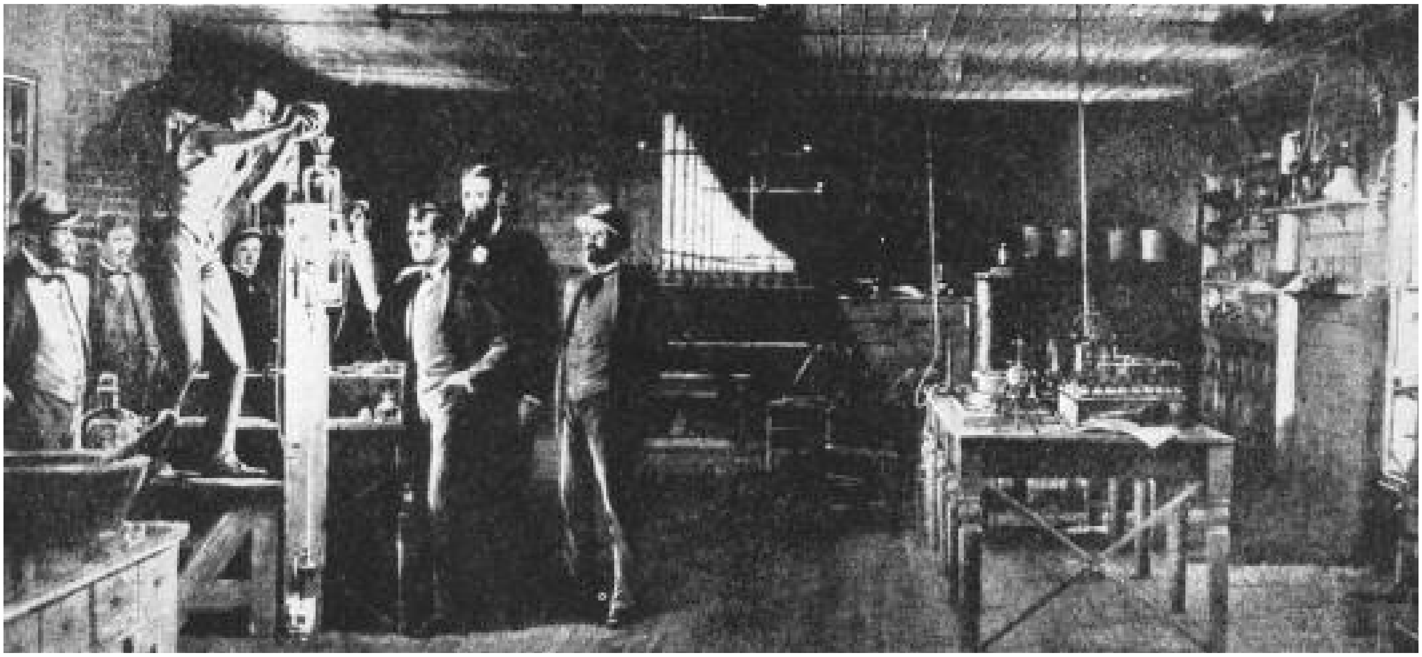


Fig. 4.12. Edison in his laboratory, with his first successful carbon-filament incandescent lamp.

The reason why great priority was given to the development of a high-resistance lamp was that there was a problem raging through the scientific world at the time involving the so-called "subdivision of electric light". As has been described in the previous chapter, it had long been impossible to connect more than one arc lamp to an electric power source; even when series connection became possible with the Jablochkoff-candle and the differential lamp, it remained limited to a few lamps at a time, and the failure of one lamp would automatically break the circuit. Individual switching of lamps was also hardly possible. Indeed, the problem became so pressing that some inventors sought an optical solution by directing the light of a single arc lamp into several directions by means of lenses and mirrors.

With low-resistance incandescent lamps much the same sort of problems arose. Parallel connection was ruled out because of the heavy currents in the supply leads and considerable differences in lamp resistance. And, of course, series connection presented the same problems as with arc lamps in that proper working of one lamp depended on all other lamps in the circuit. In addition there were the losses in the supply leads to contend with, which increased if low-resistance (and therefore high-current) lamps were used; and the situation was not improved by the use of poor-quality copper. (Pure, electrolytic copper was first produced in 1866, but only became widely available several years later.)

It was Thomas Alva Edison who suggested that a definite solution to the problem of how to subdivide electric light could only be found in the use of high-resistance lamps in parallel circuits. But this put all the weight of the problem on the finding of a suitable material for the necessarily very thin filament and the creation of a permanently high vacuum.

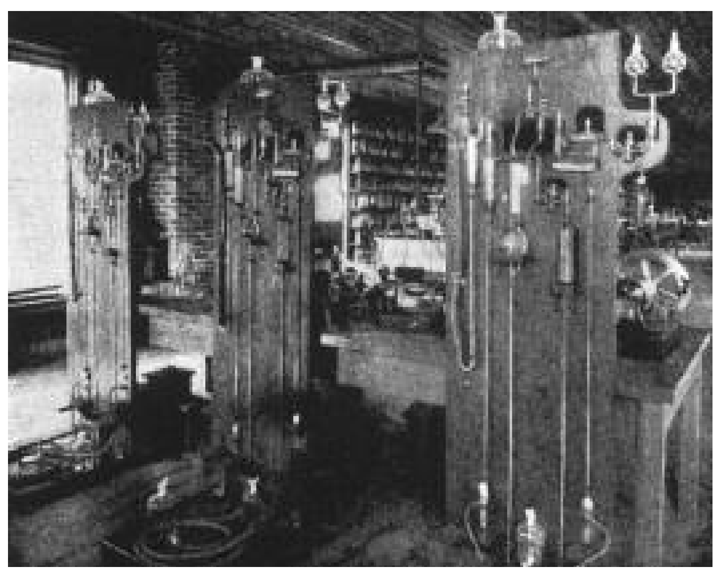


Fig. 4.13. The array of vacuum pumps Edison used for the construction of his first lamps.

Fig. 4.14. Joseph Wilson Swan

Fig. 4.15. Early type of Swan lamp, with a graphite rod as the incandesant element.

Fig. 4.16. A later type of carbon-filament lamp, with a filament of squirted, carbonized cellulose.

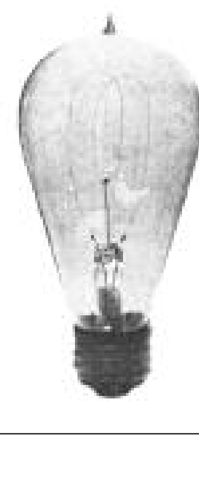


Fig. 4.17. The "metallized" carbon-filament lamp invented by Willis Whitney.

Edison started his investigations into the construction of incandescent lamps in 1878, in his laboratory in Menlo Park, New Jersey. He first used filaments of platinum wire, and tried, unsuccessfully, various thermostatic devices to prevent these from over-heating and melting. And then it suddenly dawned on him that a commercially successful platinum lamp would exhaust the world's supply of the metal in a few years, so he turned to carbon as a possible filament material. During August of 1879, fibers of a large number of organic materials were carbonized and tried as filaments. On October 21 of the same year he met with some success—a lamp with a carbonized cotton thread as filament had burned for forty hours. One of his assistants, William Moore, was immediately sent to travel the world in search of the most suitable raw material to serve as a filament, and this eventually turned out to be a Japanese species of bamboo. In the meantime, Edison had also turned to the problem of obtaining and maintaining a high vacuum in the bulb. He achieved this by first thoroughly annealing the balloon and the filament, and then using a combination of a Geissler and a Sprengel vacuum pump—the former being faster, but the latter giving a better vacuum.

Several other inventors were also working toward the construction of a successful incandescent lamp, the most important being Joseph Wilson Swan of Newcastle-on-Tyne, England. Swan had started experimenting with incandescent lamps some 30 years previously, in 1848, using strips of carbonized paper. But these early efforts had met with little success because of the imperfect vacuum then employed. In 1877 he took up the problem again, this time in cooperation with the vacuum specialist Charles H. Stearn. He first tried a graphite rod, as he—like many contemporary scientists—disagreed with Edison on the necessity and feasibility of producing a high-resistance lamp. In 1880, however, he found a suitable thin filament material in carbonized cotton thread, which was first parchmentized to harden and smooth it by immersing it in sulfuric acid. There is firm evidence that Swan demonstrated a working incandescent lamp at a lecture he gave before the Royal Society in Newcastle in February 1878, thus beating Edison to the discovery by six months. The resulting controversy that arose seems rather academic now; more important is that both Edison and Swan paved the way for future developments and were successful in exploiting their invention commercially.

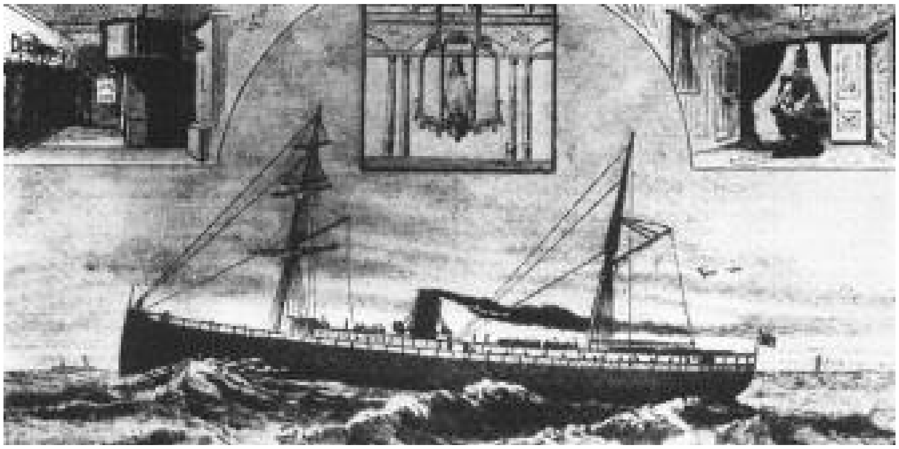


Fig. 4.18. The first commercial lighting installation with Edison incandescent lamps was in 1880 on the steamship "Columbia".

Further development of the carbon-filament lamp

But the carbon-filament lamp was still far from ideal. The specific light output was barely 3 to 4 lumens per watt (compared with 16 lm/W for a standard incandescent lamp of today), and lamp life was just a few hundred hours. Many inventors, however, worked in those years toward perfecting the carbon-filament lamp. Among these were St. George Lane-Fox, Moses F. Farmer, William E. Sawyer, Alban Mann and Hiram S. Maxim, to mention just a few. Sawyer, Mann and Maxim, for example, devised and perfected a method of preheating the filament in hydrocarbon (benzine) vapor, depositing a thin layer of graphite on it. This treatment improved the light output. By varying the length of the process, the first lamps having a predetermined light output could be produced.

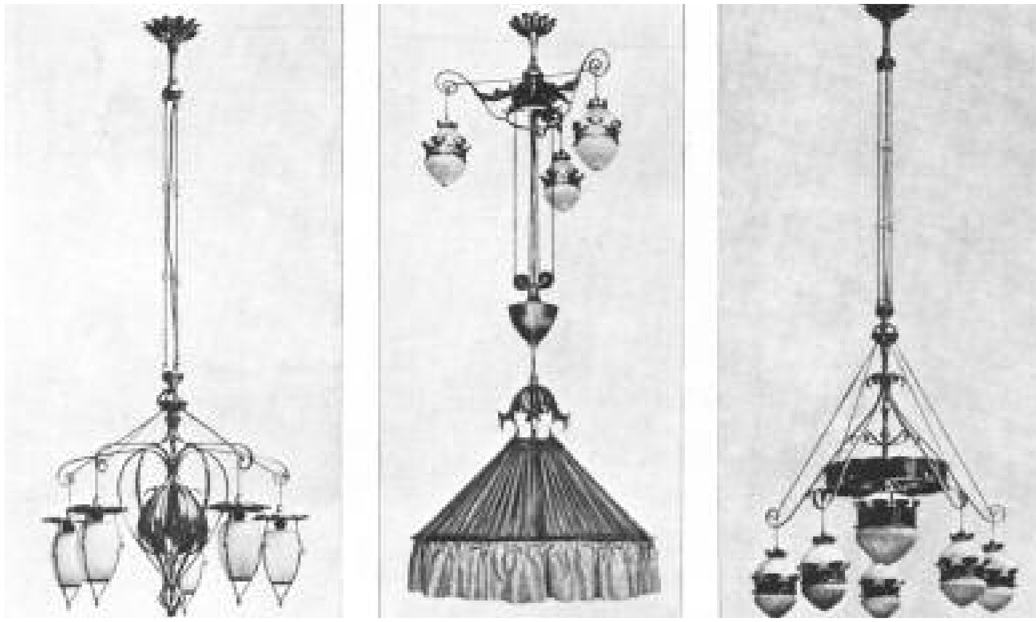
An important step in improving the incandescent lamp was made in 1883, when Swan discovered a way of making a better filament. This involved converting cotton into nitrocellulose, which is soluble in acetic acid. By squirting the solution into a suitable coagulant—alcohol, for example—he obtained a thin and very uniform thread of reconstituted cellulose, which could be carbonized to form an improved lamp filament. Almost the same process would later be employed for the production of rayon or artificial silk. Gerard Philips used it for his first lamps.

Around the turn of the century, many attempts were made to improve the luminous efficacy of the carbon-filament lamp by coating or impregnating the filament with a substance intended to reduce the evaporation rate. Among materials tried were silicon, boron, chromium, molydenum and tungsten. The results, however, remained far from convincing.

The last major improvement of the carbon-filament lamp came in 1905, when the American Willis Whitney found a method to anneal carbon filaments at very high temperatures (3500° C). Thus treated, the light output per watt rose by 25 percent and the lamp exhibited a positive temperature-resistance characteristic—like metal filaments—instead of a negative one. The lamps so produced by General Electric were referred to as having "metallized carbon filaments", a term that gave rise to many misunderstandings.

Fig. 4.19. Typical of the first years of incandescent lamp manufacturing was a lack of standardization, as witnessed by this selection of lamp caps.

Fig. 4.20. Industrial artists soon directed their attention to the design of luminaires for electric lighting. These delightful chandeliers date from the turn of the century.



Both Edison and Swan hastened to start commercial production of their carbon-filament lamps. Edison's first order was one for 250 pieces, secured on September 20, 1880, for the lighting of the steamship Columbia. The first lighting installation realized with Swan lamps was in January 1881, in Cragside Mansion, the property of the industrialist William Armstrong. In 1883 his company was already claiming to have lighted more than one hundred buildings. On October 26, 1883, after several years of intense competition and litigation in connection with breach of patent, the Edison and Swan Companies in England merged to form The Edison & Swan United Electric Light Co. Ltd., trading under the name EdiSwan.

On the European continent Siemens had taken the lead, starting production of incandescent lamps in 1882. Later in the same year he used these in an experimental street lighting system in Berlin.

The many lamp manufacturing companies that sprang up after 1880 had a hard struggle selling their products, and most of them succumbed after a few years. Strong competition was especially experienced from Auer von Welsbach's gas mantle, which was introduced in 1887. It was in these hard times when an enterprising young engineer named Gerard Philips in 1891 started production of carbon-filament lamps in Eindhoven, a tentative beginning to what eventually would become one of the largest lighting manufacturing companies worldwide.

Fig. 4.21. Gerard Philips at the time when he started lamp manufacturing, shown together with the oldest type of Philips carbon-filament lamp and the factory where they were produced.

Fig. 4.22. Lamp manufacturing at the Philips "Emmasingel" factory in the twenties.

Early metal-filament lamps

Although a century of experiments with platinum had left no practical results, the idea of using metal filaments had not been given up. In 1893, for example, the Russian scientist de Lodyguine, mentioned earlier, tried platinum wire plated with rhodium, ruthenium, osmium, chromium, molybdenum and tungsten. It was the first time that tungsten had been considered for use in incandescent lamps.

Ironically, the first successful metal filament lamp was made in 1897 by Carl Auer von Welsbach (of gas mantle fame). The lamp went into production in 1902. It had a filament of osmium, which was made by squirting a mixture of osmium powder and a carbon-containing binder. Because of the high price of osmium, burned out lamps were much sought after for recycling purposes, a trade-in price even being offered. In 1905 the production of osmium lamps was discontinued in favor of tungsten lamps.

In 1902 the Russian chemist Werner von Bolton succeeded in drawing the metal tantalum into fine wires, and used these to construct a lamp with a tantalum filament. This lamp was produced by Siemens from 1906 to 1913. Because of tantalum's low resistivity, very long filaments had to be used. A drawback was that tantalum lamps could only be successfully operated on a d.c. supply, as a.c. made the filament brittle. Between 1902 and 1905 Hollefreund of Berlin produced a lamp having a filament of zirconium carbide, but this material too was very brittle.

Fig. 4.23. The first successful metal-filament lamp was the "Auer" osmium lamp.

Fig. 4.24. The tantalum lamp. Because of the length of the filament a double set of supports had to be used.

The Nernst lamp

An interesting parallel development was a lamp introduced by Walter Nernst in 1897 that could perhaps best be described as a cross-breed between an incandescent electric lamp and a gas mantle. The squirted incandescent filament was composed of a mixture of zirconia and several rare earths. This material is a near insulator at low temperatures, but becomes reasonably conductive at high temperatures. The lamp therefore had to be preheated originally by a match, but later by a preheating filament of platinum, which was switched off automatically after the lamp became conductive. Because of the pronounced negative temperature coefficient, a current-limiting device in the form of a resistor in series with the lamp was necessary—much the same as is done with the modern fluorescent tube. The lamp burned in air, a glass globe only being provided for protection, and this had to be cleaned regularly. The Nernst lamp was expensive and appeared prone to breakdown, but once burning it boasted a luminous efficacy two to three times higher than that of a contemporary carbon-filament lamp. In 1902 the German firm of AEG took up production, but after ten years the Nernst lamp was finally ousted by the tungsten-filament lamp.

Fig. 4.26. One of the earliest squirted-filament tungsten lamps, dating from 1907. Because of the brittleness of the material, the filament consists of seperate short wires.

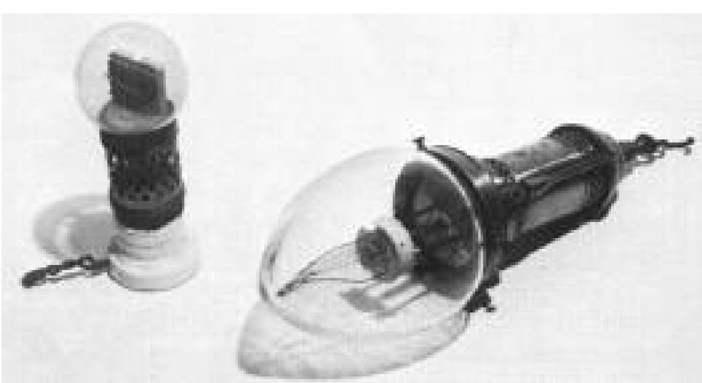


Fig. 4.25. Two "Nernst" lamps of different sizes, both with a preheating filament.

Fig. 4.27. "Wotan" lamp from 1914, of the type fitted with a reflector.

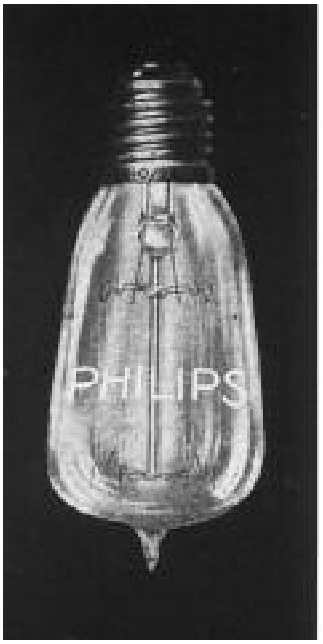


Fig. 4.28. The first type of vacuum lamp with a drawn tungsten filament, manufactured by Philips in 1912.

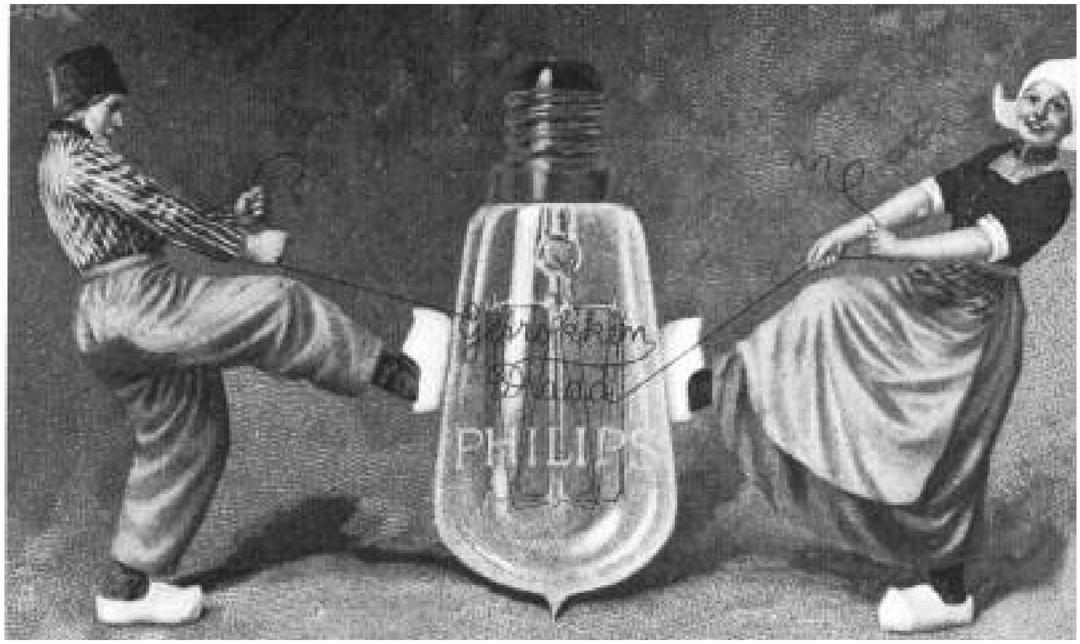


Fig. 4.29. Contemporary advertisement, from about 1913, accentuating the strength of the drawn tungsten filament.

The birth of the tungsten-filament lamp

Although tungsten had already been discovered in 1783, it took a long time before its unique properties were recognized as being ideal for lamp filaments. It has the highest melting point of all the metals, and even close to the melting point the evaporation rate is still very low. On the other hand, its metallurgical properties were far from ideal, for at the time it could be neither smelted nor worked. In fact it was only available as a powder or in the form of compounds.

The first to make a working tungsten lamp were the Austrian scientists Alexander Just and Franz Hanamann in 1903. They produced a tungsten filament by heating a carbon filament in an atmosphere of tungsten oxytetrachloride, whereby an exchange takes place between carbon and tungsten. A more practical method, worked out in 1905 by Hans Kuzel, used the same principles as already described for the osmium lamp. Fine tungsten powder was mixed with a binder, extruded through a very small opening, and the resulting wire heated to remove the binder and sinter the powder.

Commercial production of these squirted tungsten-filament lamps started in 1907, the then still small Philips company following only one year later. The light output per watt was twice that of the carbon-filament lamp, but the long fine tungsten wires needed were extremely brittle and research was continued to find a way to draw tungsten wires from the solid metal. The first to be successful was

Fig. 4.30. Forerunner of the present reflector lamp is this "Projector" lamp, launched by Philips in 1917. It had detachable reflector of opal glass.

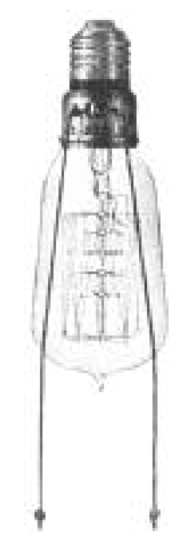


Fig. 4.31. Also dating from 1917, this double-filament lamp could be switched to full and dim light.

Fig. 4.32. the first gas-filled coiled-filament lamps marketed by Philips were the "Half-watt" lamp and the "Arga" lamp. The former was intended to replace the carbon-arc lamp in outdoor applications, the latter especially for use indoors.

the Siemens & Halske Company, who found that an alloy of tungsten and nickel could be drawn to fine wires at room temperatures. The filament was mounted on a system of support wires derived from the tantalum lamp, then the only lamp type with a drawn filament, and therefore the lamps were called Wotan lamps—from wolfram (i.e. tungsten) and tantalum. Before evacuating and sealing, the nickel had to be evaporated by annealing the filament. Wotan lamps were marketed for the first time in 1910.

Drawn tungsten filaments

Meanwhile, in the United States, William D. Coolidge had developed a process for making a ductile tungsten. Course tungsten powder was pressed into a bar, which was sintered at very high temperature by passing an electric current through it. Its cross section was reduced by a hot-hammering process (swaging), followed by hot drawing through many dies to produce thin filaments of pure tungsten. He constructed his first lamp at the end of 1910.

Lamp manufacturers were quick to pick up the new process, Philips entering in 1912. Because of the higher mechanical strength of the filament, the working temperature could be further increased by some 100°C, increasing the efficacy to about 10 lumens per watt.

Coiled filaments

The next big step in lamp development was made soon afterwards. In 1912, the American Irving Langmuir found that evaporation of the filament could be considerably reduced by filling the lamp with an inert gas. He first used nitrogen for this purpose, but subsequently adopted a mixture of 90 percent argon and 10 percent nitrogen because of its lower thermal conductivity. Filling the lamp with gas in fact increased the heat loss from the filament compared with a vacuum, and to counteract this Langmuir wound the filament into the coil. These gas-filled, coiled-filament lamps were somewhat optimistically advertised as "Half-watt" lamps, as it was claimed that they dissipated only half a watt of electricity per candle of luminous intensity. Theoretically, this corresponds to a luminous efficacy of 25 lm/W, but in practice only some 12 lm/W was reached—although this was still an increase of twenty percent compared with straight-filament vacuum lamps.

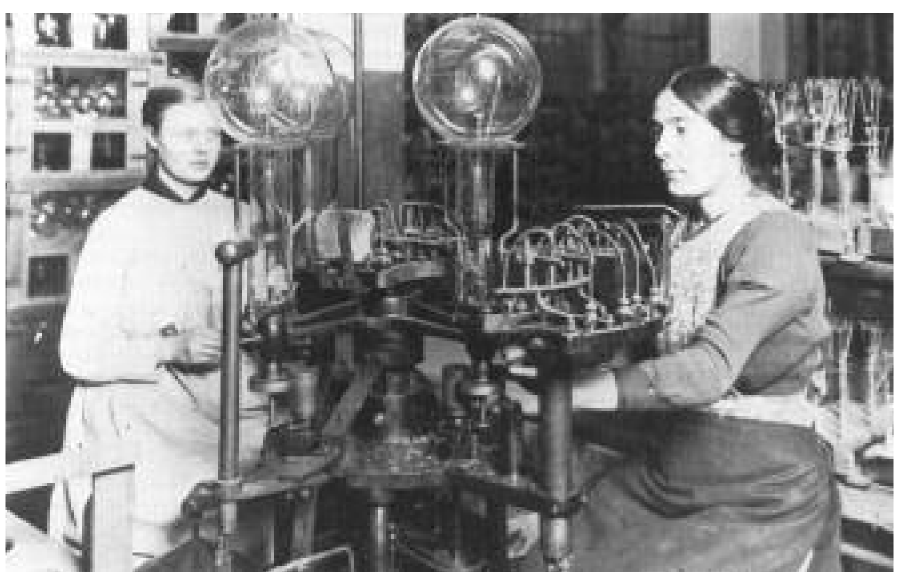


Fig. 4.33. Lamp assembly carousel for "Half-watt" lamps

Fig. 4.34. Contemporary advertisement for "Half-watt" and "Arga" lamps, displaying a typical Dutch flavor.

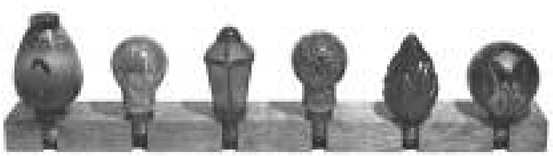


Fig. 4.35. Set of decorated lamps to meet the taste of the thirties.

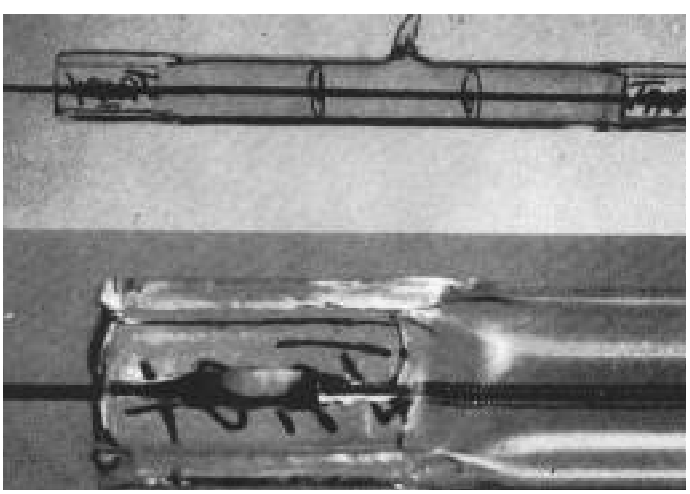


Fig. 4.36. Zuber and Mosby's first experimental 500 watt halogen incandescent lamp of 1959.

The new lamps became commercially available in 1913 and were so successful that they virtually swept carbon-filament and other lamp types from the market. They were responsible for the widespread introduction of electric lighting in the home. Again, Philips was among the first manufacturers to introduce these lamps, starting with the production of nitrogen-filled lamps in 1913 and going over to argon-filled lamps a year later. After 1913 the pace of development of the incandescent lamp slowed, no significant improvements being introduced until the early thirties, although the range of available types was considerably extended.

The 1933 the double-coiled, or coiled-coil, filament was introduced for general-purpose lamps, although the idea had been used some time earlier for special lamp types, such as those used for projection purposes. The introduction of the coiled-coil lamp resulted in a further increase in luminous efficacy of between 10 and 15 percent.

The halogen incandescent lamp

The latest important development took place in 1959, when E.G. Zuber and F.A. Mosby, both from the United States, succeeded in making the first practicable halogen lamp. By adding a small quantity of a halogen (normally bromine or iodine) to the filling gas, tungsten evaporating from the filament is made to combine with the halogen and stay gaseous instead of settling on the glass bulb. If a tungsten-halide molecule strays near the hot filament, decomposition follows and the tungsten is deposited on the filament. The result is that the filament temperature can be increased without shortening the life of the lamp. The luminous efficacy of a halogen lamp is in the order of 20 lm/W.

The idea was not entirely new, for in 1882 Edwin A. Scribner in the United States had already patented the idea of adding chlorine to carbon-filament lamps in order to reduce lamp blackening.

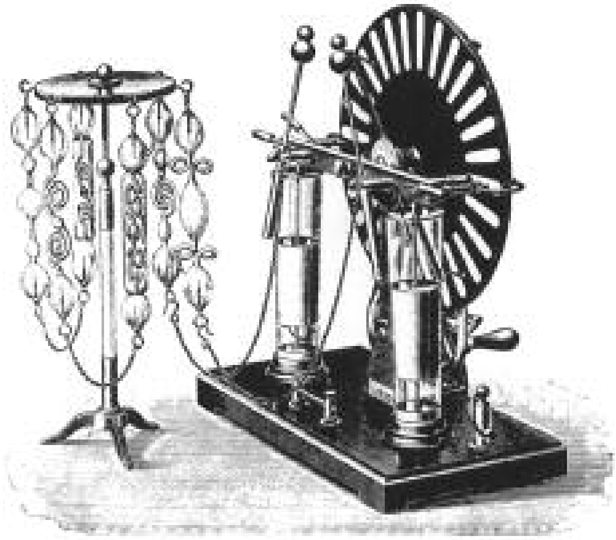


Fig. 5.1. An array of "Geissler" tubes of various shapes activated by an influence machine.

Fig. 5.2. Theater entrance lobby in the thirties, lighted by Moore tubes.

5. DISCHARGE LAMPS

Introduction

By the end of the nineteenth century, three rapidly developing methods of light generation—the gas mantle, the carbon-arc lamp and the incandescent electric lamp—were courting the public's favor. In this situation it was understandable that interest in still other light sources was not overwhelming. This explains how a most promising way of light generation, the electric gaseous discharge, could remain a physical curiosity for a full half-century after it had been seriously studied for the first time.

Only in around 1900 did gas-discharge lamps make a tentative entry in the market as a practical light source in the form of the now almost forgotten Moore tube. A wide-spread introduction, however, had to wait until after 1940, when the tubular fluorescent lamp had grown to maturity. It was in that time that the gas-discharge lamp made a definite breakthrough.

With the introduction of the compact fluorescent lamp in various forms, now some five years ago, the gas-discharge lamp has begun to challenge the incandescent lamp in its last strong hold, the private home.

The beginning

Strictly speaking, the carbon-arc lamp also belongs to the category of gas-discharge lamps, but because of the special place it occupies in the history of electric lighting and the fact that—at least in the original carbon-arc lamp—the incandescent positive electrode is the true light emitter, this lamp type has been described separately in an earlier chapter.

The oldest observations of electric discharges in rarified gases date back to the seventeenth century. Beginning in 1676—shortly after Torricelli's invention of the mercury barometer—scientists time and again reported the appearance of light-producing phenomena in the vacuum above the mercury. In the following century, experiments with light effects in evacuated glass globes, produced by influence machines, became popular.

Systematic research into the phenomena can be said to have started in 1856, when the German physician Julius Plücker, assisted by the glass blower Heinrich Geissler, experimented with electric discharges in evacuated glass tubes. He found that at a certain pressure these would emit a bright violet light. For the high voltage necessary to create the effect, he used the induction coil invented a few years earlier by Rühmkorff. Subsequently, investigators like Hittorff, Crookes and Goldstein found that the light phenomena changed by further reducing the pressure in the tubes or by adding other gases or vapors to the rarified air.

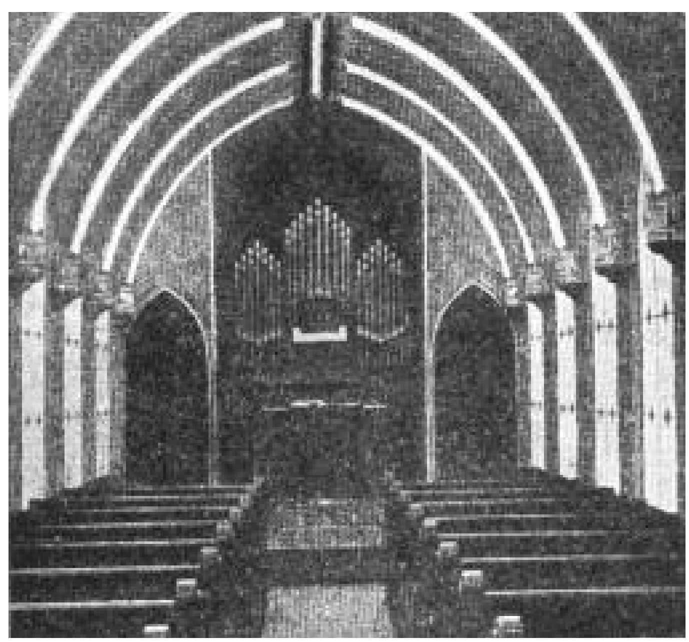


Fig. 5.3. To demonstrate his lighting system, Moore in 1898 illuminated a chapel in Madison Square Garden, New York. This "Moore Chapel" became world-famous.

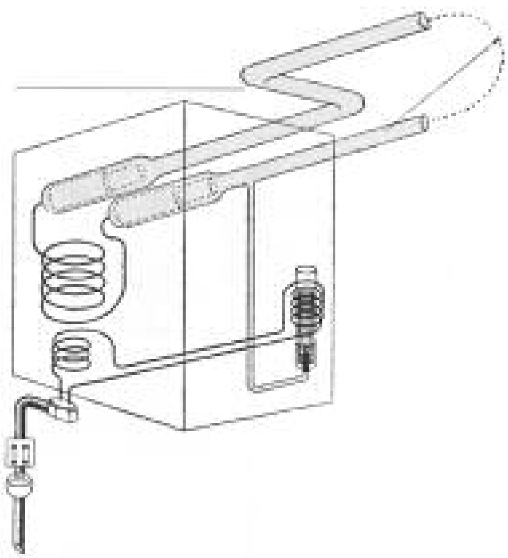


Fig. 5.4. Moore developed an automatic system for replenishing the carbon dioxide absorbed by the glass tube of his lamp. A shortage of CO_2 would cause the lamp current to increase, which was used to actuate a solenoid which, in turn, opened a valve admitting more of the gas.

Fig. 5.5. Typical small neon advertising sign from the fifties.

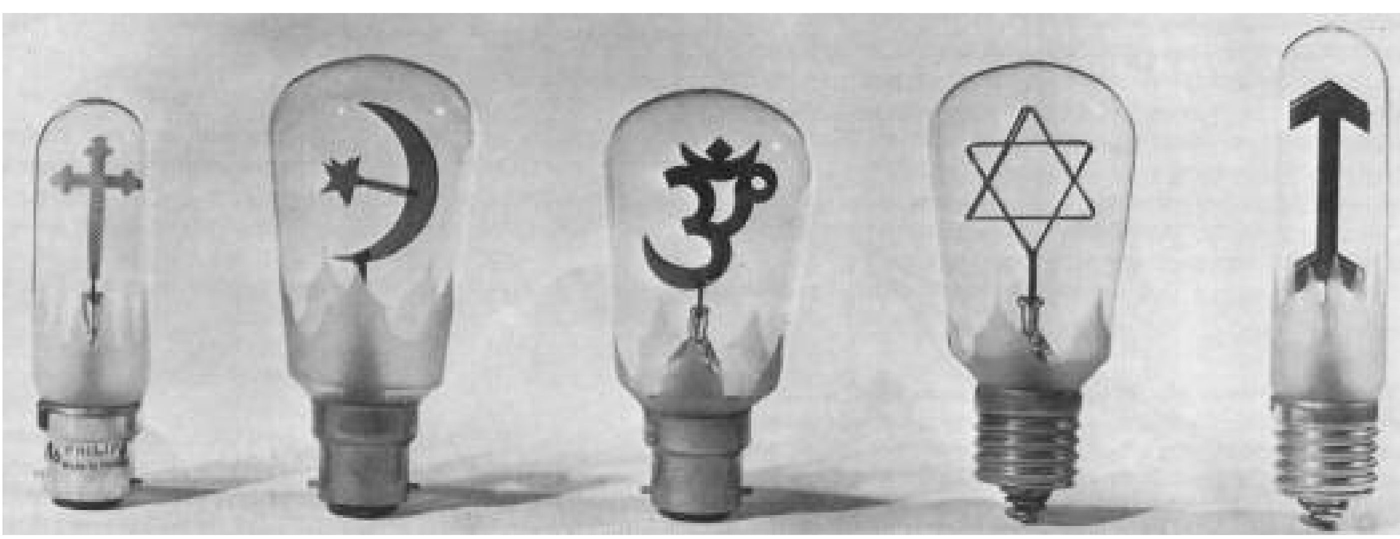
High-voltage lamps

The first attempts to use the phenomenon of gas discharge for lighting purposes took place at the end of the nineteenth century. In 1894 D. McFarlan Moore began experimenting with tubes filled with nitrogen or carbon dioxide at low pressure. With nitrogen a pinkish light was obtained, while with carbon dioxide the color came very close to that of daylight. Initially Moore used external electrodes in the form of metal foil wound round the tube ends.

From 1902 on, however, he employed internal graphite electrodes. The supply voltage of several kilovolts was obtained from a transformer. A drawback was that the light output per unit of surface was rather low, about one tenth of that of a modern "TL" D/84 fluorescent lamp. Moore tubes therefore tended to be very long, up to sixty meters. Also, from time to time, carbon dioxide had to be added, as this was absorbed by the tube wall.

The first lighting installations with Moore tubes date back to 1898, and they maintained a modest position in electric lighting until

Fig. 5.6. Selection of neon "devotion" and "logo" lamps, marketed by Philips from about 1930 on.



superseded by the fluorescent lamp in the late thirties. For color matching they remained in use even longer.

After the Moore lamp, and rather similar to it in working principle, came the neon tube, invented by the French physicist George Claude and displayed for the first time in Paris in 1910. Claude's experiments were originally aimed at producing a lamp for normal lighting purposes, but he soon found that the brilliant red light was better suited to advertising signs. Claude, too, found that he could change the color by adding other gases or vapors. Mercury, for example, produced blue light. Neon tubes are still widely used today, but are now usually given a fluorescent coating to increase the light output and provide for a greater choice of colors.

More modest applications of the neon lamp include those for signalling and devotion purposes. The former rank among the longest living of all commercial lamp types, with a lifetime of up to 80,000 hours, or ten years!

Early low-pressure mercury lamps

The first experiments with discharges in low-pressure mercury vapor were carried out by J.T. Way around 1860, but never went beyond the laboratory stage. The first practical lamps were constructed by Peter Cooper-Hewitt in 1901. He employed a one-meter long tube, with an electrode of iron or graphite at one side. A pool of mercury formed the other electrode and the lamp was started by tilting the tube, allowing the mercury to make the initial contact. Because of the negative-voltage characteristic, a series resistor, or ballast, was necessary to limit the lamp current.

Fig. 5.8. Free-standing Cooper-Hewitt lamp, fitted with carbon-filament lamps in series to act as a ballast.

Fig. 5.7. Pendant-mounted Cooper-Hewitt low-pressure mercury lamp, clearly showing the tilting mechanism.

The chief drawbacks of the Cooper-Hewitt lamp were the unfavorable light color (greenish blue) and poor color rendering. It was, however, popular in medicine, as the high proportion of ultraviolet radiation it emitted was considered beneficial in the treatment of diseases.

To improve the color characteristics for normal lighting applications, carbon-filament lamps were sometimes used as a ballast—an early form of blended light lamp. With the advent of gas-filled tungsten filament incandescent lamps, the Cooper-Hewitt lamp quickly became obsolete, only to return in the thirties, much improved, as the tubular fluorescent lamp.

Fig. 5.9. Reflector luminaire with resistor ballast for a Cooper-Hewitt low-pressure mercury lamp.

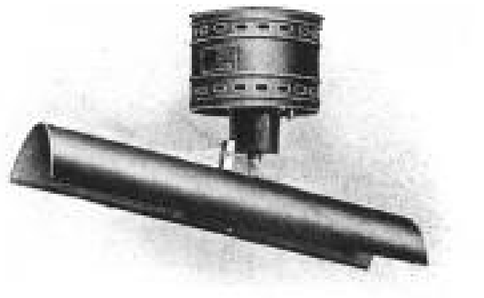


Fig. 5.10. A pair of Osram 20 watt flourescent lamps from 1936, sharing a common ballast.

The fluorescent lamp

From 1924 on, in several parts of the world, lamp developers worked toward producing a practicable low-pressure mercury discharge lamp. Two important discoveries—attributed to a team of German scientists, formed by Friedrich Meyer, Hans Spanner and Edmund Germer—were largely responsible for the eventual success achieved in this undertaking. In a report published in 1926, these workers described how the electrodes could be preheated to facilitate ignition at lower voltages, and the tube wall coated with fluorescent material to convert the strong ultraviolet radiation of the mercury discharge into visible light, the coating serving to increase the luminous efficacy and improve the color characteristics of the light.

The appearance in 1932 of oxide-coated electrodes having a much higher electron-emission rate permitted the operating voltage to be further reduced to the standard mains voltage of 220 V. But even so, it took three more years before the first tubular fluorescent lamp could be demonstrated at the Annual Convention of the Illuminating Engineering Society of North America, held in Cincinnati in September, 1935. This was largely the work of André Claude—a cousin of the inventor of the neon tube, Georges Claude—who worked in Paris and took out a patent on a hot-cathode fluorescent lamp in 1932. His patent rights had been taken over by the General Electric Co.

The light color of these first tubes was still unsatisfactory, but by the following year the first practical applications of fluorescent lighting could be shown to the public, both in the United States and in Europe. In the United States, General Electric fluorescent lamps were used for the first time to illuminate the banqueting hall in Washington where the centenary of the United Sates Patent office was celebrated on November 23, 1936, and in Europe, the firm of Osram showed its first fluorescent lamps at the world exhibition held in Paris in the same year.

The lamp first appeared on the market in the United States on April 1, 1938. Philips started the same year with the production of high-voltage fluorescent tubes for series supply, and the following year with tubular fluorescent lamps with heated cathodes for connection to the 220 volt mains. But with the outbreak of the World War II, the production of fluorescent lamps in Europe soon came to an end, and was not resumed until after 1945.

The first fluorescent powders used were calcium tungstate and zinc silicate. These gave the lamp an efficacy of about 30 lm/W, but color rendering was only moderate. In 1942, A.H. McKeag in Great Britain found that activated halophosphates of calcium and strontium had very good fluorescent properties. These were introduced in 1946, resulting in a doubling of the luminous efficacy. In 1973 Philips introduced the now familiar three-band fluorescent lamp, based upon ideas of M. Koedam, J. J. Opstelten and William A. Thornton. This employs fluorescent powders derived from color TV technology, which emit light in only three narrow spectral zones: videlicet red, green and blue. The result was a 50 percent increase in efficacy, with no loss in color rendering properties.

The last important development that should be mentioned here is the introduction in 1980 of the compact fluorescent lamp in various forms and by various firms, Philips SL and PL lamps being probably the most advanced among these.

Fig. 5.11. The first lighting installation with flourescent lamps realized by Philips was in 1938 in one of the HEMA department stores in Amsterdam. High-voltage tubes of two metres long were used in this installation.

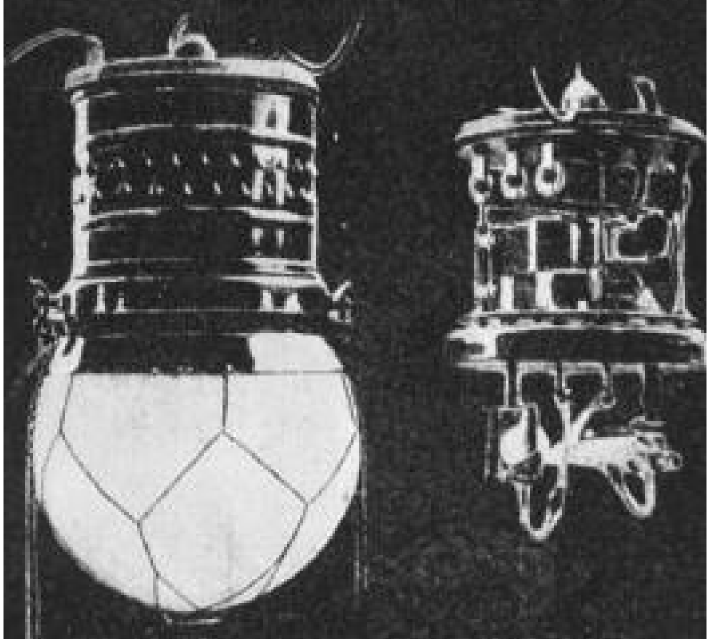


Fig. 5.12. Küch and Retschinsky's high-pressure mercury lamp in the form it was commercially introduced by Westinghouse in 1908, shown both closed and open.

High-pressure mercury lamps

Let's return to the Cooper-Hewitt mercury-vapor discharge lamp of 1901, with its very poor color rendering. Improvement was sought in two directions: in the use of fluorescent coatings, and in increasing the mercury vapor pressure. Research in the latter direction was carried out by R. Küch and T. Retschinsky, who produced the first high-pressure mercury lamp in 1906. Because of the high temperature and pressure inside the discharge tube, this was made of quartz. The lamp was commercially introduced by Westinghouse in the United States in 1908 under the name "Silica" lamp, and shortly afterwards by Brush Electrical Co. of London under the name "Quartzlite". Both were for d.c. use and (like the Cooper-Hewitt lamp) could be ignited by tilting, thus creating a temporary short-circuit between the liquid-mercury electrodes. The success of the lamp was only modest, a problem being that quartz readily transmits ultraviolet radiation, which was still present in considerable quantities. Also, mass production of the lamp was problematic, because no satisfactory solution had been found for making a gas-tight seal between the lead-in wires and the quartz discharge tube. The result was that interest in the high-pressure mercury lamp soon faded.

This interest was reawakened in the early thirties, when several firms came out with improved high-pressure mercury lamps. These had a discharge tube of hard-glass, instead of quartz, which avoided sealing problems. In 1935, however, Philips found a way to seal tungsten wires in quartz. Also, the working pressure inside the discharge tube was increased from approximately one atmosphere to about ten, thus achieving a far better spectral distribution of the emitted light. A fluorescent powder that could withstand the intense ultraviolet radiation of the high-pressure mercury lamp was discovered around 1934 in the form of cadmium sulphide. The corrective effect was only moderate, however, and after World War II several other fluorescents were tried. Yttrium phosphate vanadate, introduced in 1967, eventually became the most successful.

Two offsprings of the high-pressure mercury lamp should be mentioned: the blended-light lamp and the metal halide lamp. The former is in fact a combination of an incandescent filament and a high-pressure mercury discharge tube, connected in series and mounted in a common bulb. The filament acts both as a current stabilizer and provides some color correction toward the red end of the spectrum. The idea goes back to the beginning of the century (cf. the Cooper-Hewitt lamp), but in its present form it was first manufactured around 1935.

In 1961 G.H. Reiling took out a patent on a high-pressure mercury lamp that had halogen compounds of certain metals added to the mercury-vapor filling. Typical compounds used were: indium, thallium and sodium; scandium and sodium; or dysprosium and thallium. The metal halide lamp, as it was named, was put on the market in 1964. It represented a considerable improvement over the traditional high-pressure mercury lamp, both in terms of increased efficacy and better color rendering.

The idea was not entirely new. The flame-arc lamp, invented in 1889, worked on more or less the same principle. In 1912 M. Wolke tried to improve the color properties of the high-pressure mercury lamp by adding cadmium and zinc, but the arc temperature of the discharge was insufficient for these additives to become really effective, and they also attacked the quartz tube.

Fig. 5.13. The first high-pressure mercury lamp made by Philips was this HO lamp, dating from 1935.

Fig. 5.14. In 1936 Philips introduced a high-pressure mercury lamp for lower wattage ratings in the form of this HP 300 of 75 watt.

Fig. 5.15. Early Philips blended-light lamp from 1941.

Sodium lamps

That mercury was an obvious choice as filling gas for metal-vapor discharge lamps had to do with the fact that of all the metals, it is the only one with an appreciable vapor pressure at normal temperatures. Furthermore, it emits a fair proportion of its radiation in the visible part of the spectrum. Another promising metal was sodium, which had a melting point of only 98° C, and emits almost all of its radiation in two closely separated lines in the yellow part of the spectrum, close to the region of maximum eye sensitivity. Therefore, theoretically at least, a very efficient lamp could be built on the sodium-discharge principle.

Fig. 5.16. The d.c. low-pressure sodium lamp with vacuum mantel used in the Beek-Geleen installation.

Fig. 5.17. The first road-lighting installation using low-pressure sodium lamps was between Beek and Geleen in the south of the Netherlands in 1932.

The first experiments with low-pressure sodium discharges, carried out in 1922 by M. Pirani and E. Lax in Germany and in 1923 by A.H. Compton and C.C. van Voorhis in the United States, clearly showed that a very high efficacy could be achieved. Also, preliminary investigations by Compton in 1920 had led to the discovery of a sodium-resistant borate glass needed for the discharge tube.

The first practicable low-pressure sodium lamps were constructed in 1931 by Philips and Osram, and the first lighting installation equipped with the new lamps was realized one year later by Philips on a stretch of road in the south of the Netherlands. These first lamps were for use on a d.c. supply, but in 1933 an a.c. version came on the market. This was used to light the Scheldt tunnel in Antwerp, Belgium. Later in the same year, the heated electrodes were replaced by cold ones, and the low-pressure sodium lamp acquired the shape it was to keep for more than twenty years.

The heat generated by the low-pressure sodium discharge is only marginally sufficient to keep the lamp at its optimum working temperature. Consequently, in the early lamps, the discharge tube was encapsulated in a double-walled, evacuated glass mantle. From 1955 on, a single-evacuated bulb was employed, and this was coated with a heat-reflecting material, initially tin oxide, and now, indium oxide. Virtually all the research done on this lamp type was and still is carried out in Philips' laboratories.

The low-pressure sodium lamp has by far the highest efficacy of all lamp types. This has been increased from 50 lm/W in 1931 to 220 lm/W today for certain types, which is twelve times that of a modern incandescent lamp. The only real drawback of the low-pressure sodium lamp is the monochromatic yellow light, which makes it impossible to distinguish colors and therefore restricts its use to certain applications, such as road lighting.

As was the case with the mercury-discharge lamp, an attempt was made to improve its color characteristics by increasing the vapor pressure. Unfortunately, it was found that the aggressive sodium vapor would then attack all types of glass, including quartz. Research started in 1955 by R.L. Coble led to the discovery that a gas-tight, sodium-resistant, translucent discharge tube could be made of highly-purified, sintered aluminum oxide. The first practicable high-pressure sodium lamps employing this principle were made in 1964 by Bill London and Kurt Schmidt, both from the United States. Full-scale production started the following year. The feasibility of further increasing the sodium-vapor pressure with a view to improving the color characteristics of the light are currently being examined.

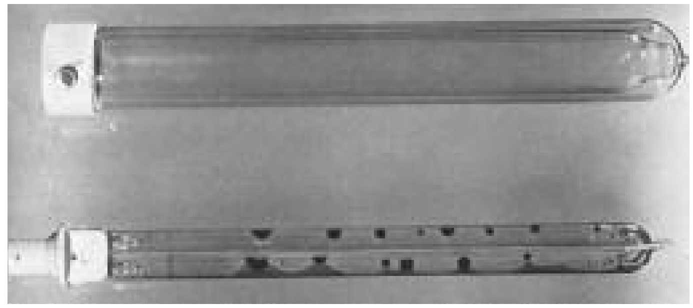


Fig. 5.18. The low-pressure sodium lamp with cold electrodes and a detachable vacuum mantle, which remained in production for over twenty years.

The xenon lamp

The last lamp type worthy of mention in this chapter is in fact the high-pressure version of the Moore and Neon tube. In 1944, P. Schultz in Germany found that discharges in high-pressure xenon produced an intense white light with color characteristics close to those of daylight. It could therefore form an ideal replacement for the cumbersome carbon-arc lamp. Commercial production of the xenon lamp, however, had to wait until after the war; it was first produced in 1951 by the Osram company.

Fig. 5.19. The a.c low-pressure sodium lamp with heated electrodes used in the Scheldt tunnel installation.

Fig. 5.20. In 1933, the Scheldt tunnel in Antwerp, Belgium, was the first to be lighted with a.c. low-pressure sodium lamps.

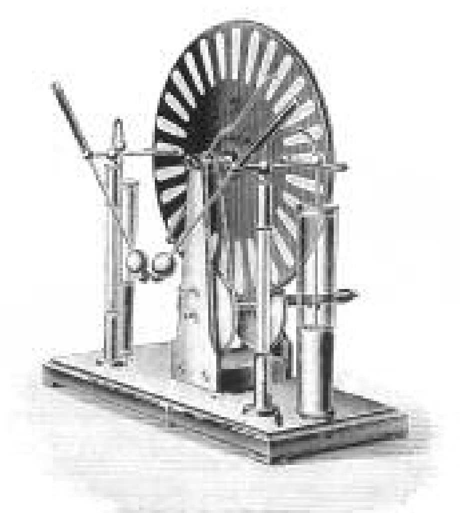


Fig. 6.1. The "Wimshurst" influence machine was the only source of man-made electricity before the nineteenth century.

6. ELECTRICITY PRODUCTION AND DISTRIBUTION

Introduction

The history of electric lighting is closely linked to that of electricity generation. Indeed, many important developments in electric lighting have been stimulated by equally important improvements in electricity generation and distribution, and vice versa.

The oldest generators were only sufficient to supply current for a single or just a few arc lamps, which restricted their use to lighthouses and the like. It was Thomas Alva Edison, however, who realized that the incandescent electric lamp could only be made a commercial success if electricity was supplied to the public from a central generating station.

As a result, shortly after 1880 electric power stations of ever-greater capacity sprang up in all parts of the world, to the convenience of the fast-expanding lighting industry.

Fig. 6.2. The "Leyden Jar" was nothing more than an early form of capacitor.

Influence machines and batteries

The oldest form of man-made electricity is the electrostatic charge. Even the ancient Greeks knew that after rubbing a piece of amber (which they called "elektron"), it would attract light-weight particles. Although seventeenth century methods existed for multiplying these electrostatic charges, using so-called "influence machines", and storing them in "Leyden Jars", the only light effects that could be produced using this form of electricity were sparks and very transient discharges in evacuated glass vessels.

The first continuous electric current was produced in 1800 when Alessandro Volta constructed his famous voltaic pile, a wet battery built of alternate copper and zinc plates placed in a conductive liquid, such as salt water or dilute acid.

Less than two years after its appearance, the battery played an essential role in two of the most important discoveries in the history of electric lighting—the phenomena of the electric arc and electric incandescence. The electric arc appeared especially promising as a light source at the time, but this practical application was severely limited so long as batteries were the only current source available. These used zinc as "fuel", which was then a very expensive metal. Also, the early batteries could not be used continuously for very long before becoming polarized, a state in which hydrogen bubbles formed on the positive plate caused the battery to cease working. However, this problem was largely overcome by the work of Daniell, Grove and Bunsen in the years 1836 to 1842.

Fig. 6.3. The oldest form of battery is this voltaic pile.

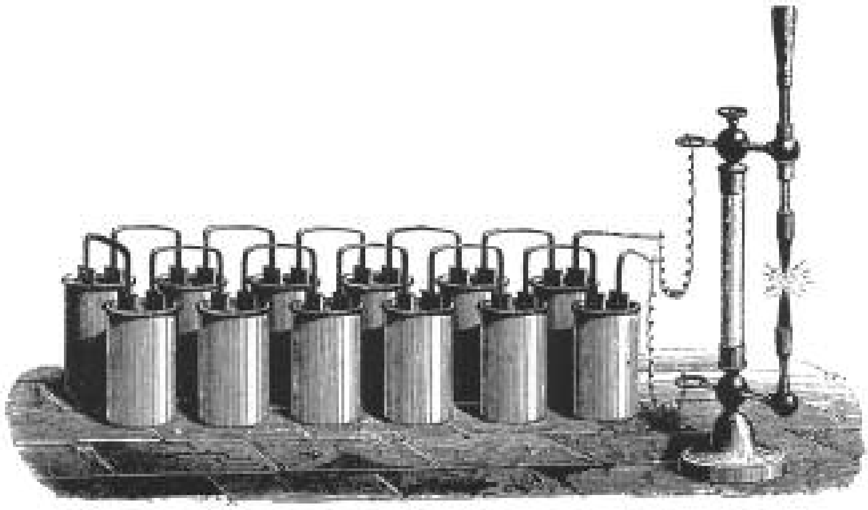


Fig. 6.4. Primitive arc lamp connected to a battery of "Bunsen" elements.

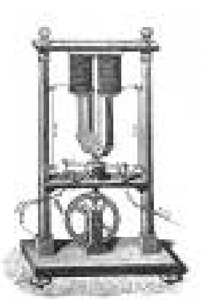


Fig. 6.5. Pixii's first hand-driven dynamo of 1832.

The Anglo-French "Société de l'Alliance", founded in 1852 by the Belgian physicist Floris Nollet, was the first to produce these machines commercially. They were closely followed by the generators built by the Englishman Frederic Hale Holmes who, in 1858, supplied these to power the world's first electric lighthouses.

Although extremely heavy and cumbersome for their modest output, these early machines were sturdy and reliable, a few even lasting until the beginning of the present century. They consisted of a large number of coils (a hundred or more), arranged on discs, rotating in the field of an equally large number or permanent magnets. Magneto-electric generators of this type were used for electroplating and for extracting metals by electrolysis, but their primary function was to power the arc lights used in lighthouses, in the construction of railway tunnels and the like, in theaters, and on the battlefield.

Magneto-electric generators

In 1820, H.C. Oerstedt had discovered that an electric current creates a magnetic field. In 1831, Michael Faraday and Joseph Henry found that the opposite is true as well—that is, an electric current is generated in a wire when this is passed through a magnetic field. A year later, in 1832, the French instrument maker Antoine Hyppolite Pixii used the principle to build the first hand-driven generator, in which a magnet was made to rotate between static field coils. This so-called magneto was subsequently developed in various forms to supply current for early telegraphs and for detonating mines. Our humble bicycle dynamo also still works along the same principles.

The oldest steam-driven magneto-electric power generators date from about 1844. Initially, these were intended for use in the electro-chemical industry (electroplating), but attention soon turned to electric lighting, using the already well-known carbon-arc principle.

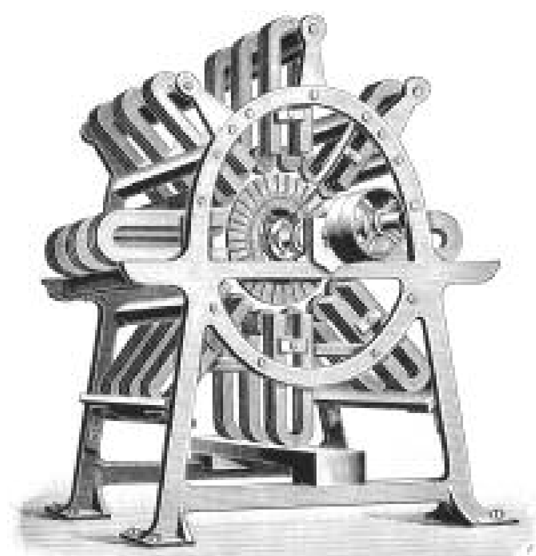


Fig. 6.6. An "Alliance" magneto-electric power generator circa 1860.

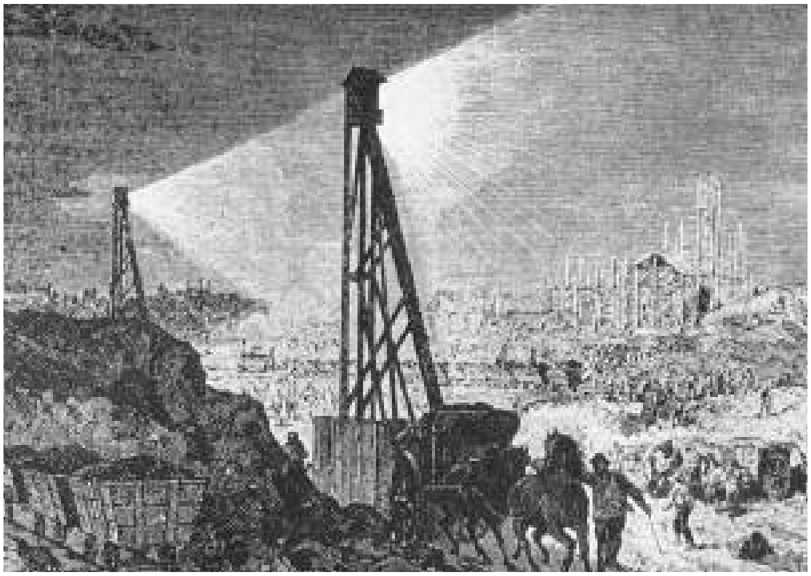


Fig. 6.7. Construction site lighting in Paris, 1854, using arc lamps powered by "Alliance" generators.

Self-exciting generators

The idea of using powerful electro-magnets instead of permanent magnets and to energize these by the output current of the generator itself or by a small auxiliary magneto-electric machine occurred to several workers simultaneously. Among them were the brothers Werner and William von Siemens and Charles Wheatstone, who built their first prototypes in 1866.

The first practical generators based on the principle of self-excitation were constructed around 1870 by the Belgian engineer Zénobe Théophile Gramme and soon became very popular for lighting purposes. Gramme was the first to make practical use of the compact ring armature, invented some ten years earlier by the Italian Antonio Pacinotti. In the same period, the first practicable d.c. electric motors became available, so that the need for electricity steeply increased and generators were soon being built by many firms in a wide range of sizes.

The oldest public electricity supply systems

Important as the invention of the first reliable high-voltage incandescent lamps by Edison and Swan in 1879 had been, both inventors were convinced that proliferation of electric lighting was only viable if electricity was generated at a central point and distributed to the public through a cable network, much in the same way as gas supply had started seventy years earlier.

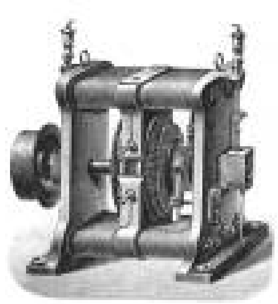
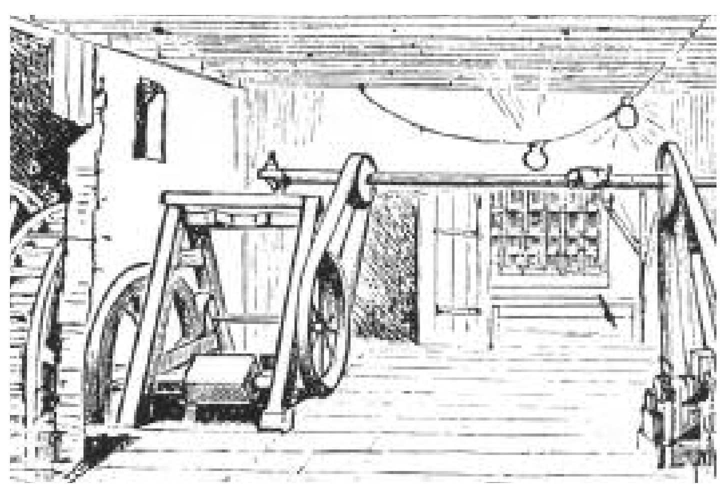


Fig. 6.8. Early type of "Gramme" generator used for lighting purposes.

Initially, electric lighting installations used electricity generated on the site by a waterwheel or by a steam or gas engine. The first public electricity supply system in the world, be it by a very small margin, was probably that set up in the market town of Godalming in Surrey, England, in October of 1881. Originally supplying electricity for street arc-lamps only, shortly afterwards the first private customers started to burn Swan incandescent lamps in their homes. However, there were never more than a few dozen private customers, which was insufficient to make the system economic, and the company was wound up in 1884, Godalming reverting to gas lighting.

Fig. 6.9. An existing water mill was employed to drive the Godalming generator.



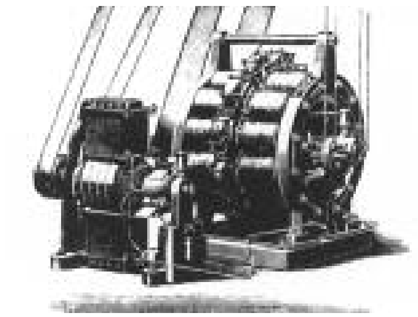


Fig. 6.10. Siemens a.c. generator of the type used in Godalming. The smaller d.c. dynamo in the foreground supplies the exciting current for the field coils.

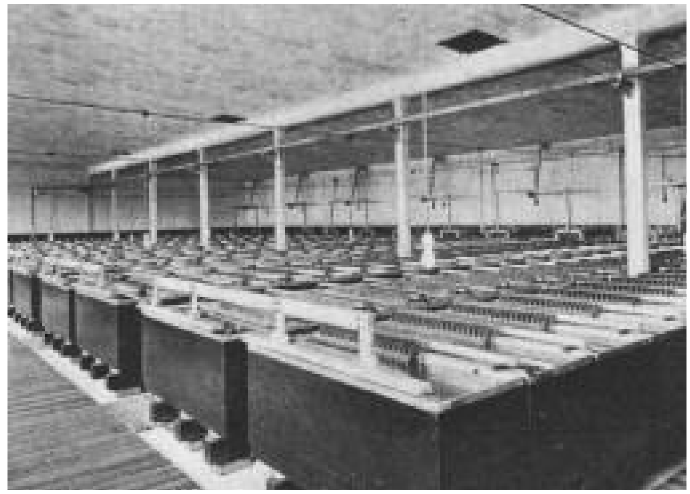


Fig. 6.12. This bank of batteries was installed in Buffalo USA. It had a storage capacity of 1500 kWh.

On January 12, 1882, a few months after the Godalming project had started (which was a Siemens venture), the Edison Lamp Company opened an electricity generating station at High Holborn, London. This was the first electricity plant in the world for supply to the public which used steam power, as the Godalming generator was initially driven by a waterwheel. On September 4, 1882, Edison started with public electricity supply in the United States. This was from the Pearl Street power station in New York, which in 1884 already served 10,000 lamps. Other firms quickly followed, and in a few years electricity companies had sprung up in all parts of the then civilized world. One of the largest of these early installations was completed in 1886 and served the Opera House and theaters in Vienna, Austria. The nominal generating capacity of 700 kilowatts could, if necessary, be temporarily boosted to one megawatt by means of banks of batteries.

Fig. 6.11. Early view of Edison's Pearl Street power station in New York.

The battle of systems

Still in the eighties, a controversy arose between advocates of direct current and those favoring alternating current. This controversy was to rage for years. The existence of alternating current had been known since the earliest experiments with magneto-electric machines, and practical a.c. generators had been built from the early sixties of the nineteenth century. But there was little point in generating a.c. at a time when neither power transformers were available to step the voltage up for transmission over large distances, nor rectifiers to convert the a.c. to d.c. Direct current was generally regarded as far more useful in most applications, and therefore all early power stations—with the exception of the Godalming one—supplied direct current.

Advantages claimed for d.c. supply were that arc lamps worked better on d.c.—for incandescent lamps the system used did not matter, as long as the mains voltage was kept constant—and that only satisfactory d.c. motors were available. D.c. generators were also easier to connect in parallel. Another strong point in favor of d.c. supply was that banks of rechargeable batteries could be employed to assist at peak loads or to take over from the generators during the night. This was particularly important at a time when 95 percent or more of the electricity generated was used for lighting, and load distribution throughout the day was therefore very uneven.

The chief drawback of d.c. was, of course, that it could not conveniently be stepped-up to a higher voltage, and stepped-down again at the distribution points. Because of the heavy losses involved, this made long-distance transmission of electricity next to impossible.

Early d.c. supply companies tried to get around this problem by generating current at the highest voltage possible with the state of the art in insulation technology, which was about 2000 volts. This was supplied to a system of substations, where banks of batteries were charged in series. By tapping these batteries in parallel groups, consumers in the area could be supplied with 100 volts d.c. The coming of rotary converters around 1890 made this cumbersome system soon obsolete.

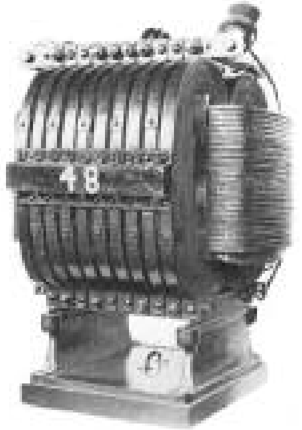
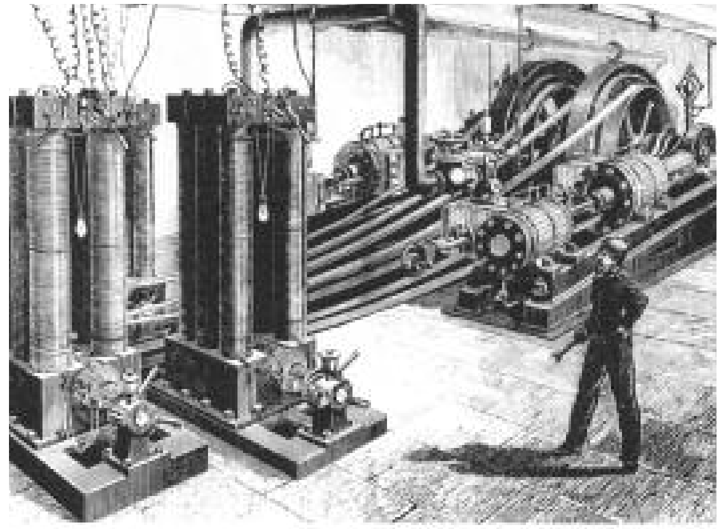


Fig. 6.13. One of Ferranti's 10,000 volt power transformers used for the Deptford–London high-voltage transmission line.



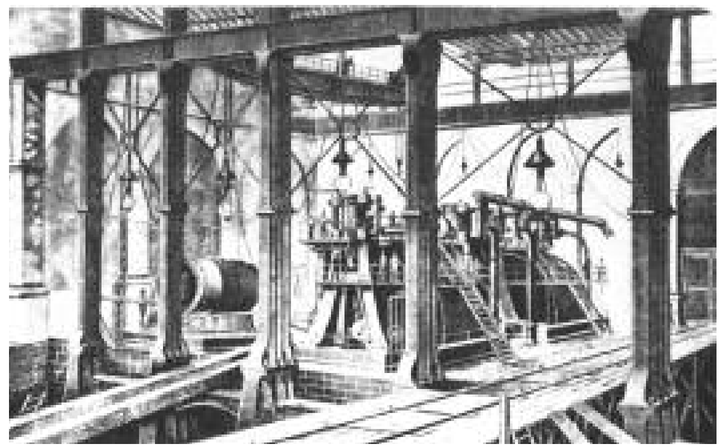


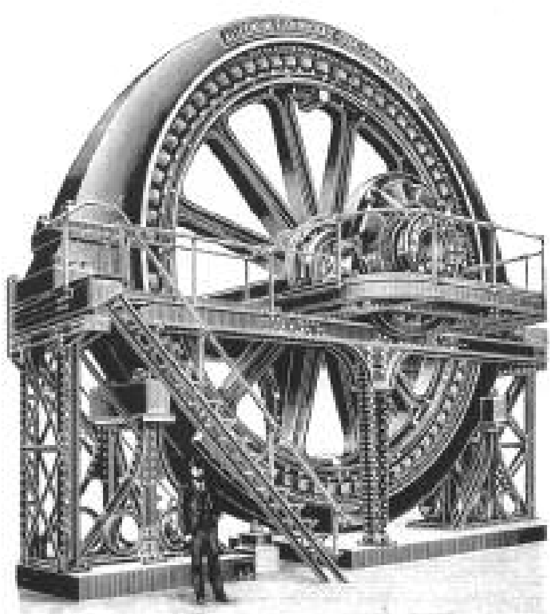
Fig. 6.15. The rapid improvement in power plant technology is clearly illustrated by the contrast between the Manchester power station of 1884, with belt-driven Edison generators of the type "long-legged Mary Ann", and the Hartford power station of 1889, using Crompton generators directly coupled to fast-running triple-expansion engines.

The advent of modern a.c. networks

Edison was a strong advocate of direct current and such was his influence that d.c. supply met little argument for several years. In 1888, however, two events occurred that finally served to tip the balance in favor of a.c. First, the British engineer Sebastian Ziani de Ferranti perfected the power transformer, invented five years earlier by L. Gaulard and J.D. Gibbs from France. Second, Nicola Tesla, a former assistant to Edison, presented the first successful a.c. motors, a year later obtaining patents for a range of single- and three-phase induction and synchronous motors.

Two of the strongest arguments against a.c. had thereby been eliminated. A.c. could now be conveniently stepped up (and down) for transmission purposes, and there were suitable a.c. motors available, which, by coupling to a d.c. generator, could also be used to convert the a.c. to d.c. where needed. The first high-voltage transmission line (at an unprecedented 10,000 volts), built by Ferranti between Deptford power station and the City of London, was put into use in 1890.

Fig. 6.14. Three-phase a.c. generator of three megawatts shown at the World Exhibition held in Paris in 1900.



The next logical step was to move from single-phase to three-phase a.c. for generating and distribution purposes. After a successful demonstration on the World Electricity Fair held in Frankfurt, Germany, in 1891, the first three-phase distribution systems were installed in 1892 in the United States under Tesla's patent. At the same time, the ponderous reciprocating steam engines, which drove the generators, were being replaced by steam turbines. Charles Parsons had built his first experimental turbo-generator in 1884, and the first power-station to be equipped with steam turbines was Forth Banks in Scotland in 1890.

An alternative for steam to drive the generators was water power. Sometimes, as in Godalming, a conventional, vertical waterwheel was used, but soon afterwards the first commercial hydroelectric power station using horizontal water turbines was built in 1882 by René Thury in Brotzingen near Bienne, Switzerland.

Since about 1903, the history of electricity supply has been marked by minor improvements rather than by radical changes in the principles employed. Even a nuclear power station is in fact nothing more than a steam plant burning a different fuel.

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