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A BRIEF HISTORY OF ELECTRIC LIGHTING

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Mark Wood-Robinson before retirement was SWEB's expert on lighting and therefore it is very rewarding to gain his services for this article.

INTRODUCTION

The 3rd of February 1879 is the most significant date in the history of electric lighting. Before that date virtually all the light enabling mankind to see *was produced by combustion*. So called "natural light" is emitted by the burning sun with a surface temperature of about 5,800K and all early sources of manmade light also relied on something being burned. One of the few exceptions, in the Far East, was the use of fireflies in small cages with their bioluminescent glow, although they can hardly be said to be manmade!

However, on the date mentioned, Sir Joseph Wilson Swan demonstrated to over 700 people in Newcastle that light could be produced by conducting electricity through a filament of carbon in a near vacuum. It must be admitted that he, and others, had achieved short life performances with platinum strips and other devices which were made to glow by the passage of electricity but this lamp made by Swan was the *first practical example to be demonstrated in public*. This event marked the breaking of the mould. The filaments did not last long in these early lamps, but *combustion was not an essential component* of the light production. Edison's contribution will be mentioned later.

Before this significant date the early materials from which light was produced by combustion were either in liquid form, oils of various types, or solid, as in candles. The one thing that they had in common was that they were all fairly expensive, so that artificial light tended to be the prerogative of the well to do. Indeed there are many references in literature to the need for extinguishing candles at the earliest opportunity to save expense. However notwithstanding the cost, the security value of light during the hours of darkness was demonstrated by early legislation requiring householders to provide light outside their premises.

The first breakthrough towards cheaper light came after a considerable period of the development of gas lighting. Many experimenters were involved during the 18th century but Richard Murdoch is usually agreed to have developed the first practical installation to illuminate his house and office in Redruth in 1792. An example of the pioneering spirit of the South West! The gas was produced by heating coal, thereby making coke as a bye product. Gas, Light and Coke companies sprang up all over the country and by the middle of the 19th century there were about a thousand of them in England. It has been estimated that there were about 40,000 gas lamps in the streets of London by 1823. The light produced by gas was about one quarter of the cost of earlier light sources. At the end of the century the invention of the incandescent Welsbach mantle for gas lamps greatly increased the light output compared to that of a simple flame. Meanwhile the use of oil instead of gas was making a comeback, with the availability of cheap mineral oil, and many attractive examples of portable oil lamps can still be seen in antique shops. They did however require maintenance and refilling as they were self-contained.

Finally, in the introduction, it would be useful to mention some of the terms used in connection with light sources. The temperature of the sun's surface mentioned above is on the Kelvin scale, which is written K, without the ° symbol. This scale, whose zero point is "Absolute Zero" at -273°C, is used to define the warm/cool appearance of light sources. Thus a normal filament lamp emits light at around 3,000K whilst candlelight is about 1,800K. Overcast daylight, without direct sunshine, is about 6,500K and electric lamps of various types are available to match this and the 3,000K mentioned above. Strictly speaking Colour Temperatures only apply to light sources with a continuous spectrum, known as "black body" sources, but approximate values can be assigned to other lamp types such as discharge and fluorescent, which have discontinuous and spiky spectral distributions.

The *intensity* of light in a specific direction is quantified in *candelas*, which were formerly called candlepower. The *total light output*, in all directions, from a light source is defined in *lumens* and a theoretical candle therefore emits 4π or about 12 lumens. A 100W tungsten filament lamp (now banned for sale, but not for use!) emits about 1300 lumens. It should be remembered in this connection that the light emitted by a lamp declines in quantity with hours of use. This rate of decline varies considerably between lamp types and this aspect will be referred to later. When considering the amount of light arriving on a surface, known as the *illuminance*, the unit used is the *lux* and this is defined as one lumen per square metre. Let us now review the different categories of electric light sources.

ARC LAMPS

At the very beginning of the 19th century Sir Humphry Davy (another West Countryman who worked in Bristol for a time) was experimenting with carbon arc lamps, amongst many other endeavours, and in 1808 he demonstrated one to a meeting at The Royal Institution in London. The lamp consisted of two carbon rods which were connected to a 2000 cell battery. The 10 cm gap was bridged, after initial contact, by the resulting discharge which arched upwards with the warm air; hence the term "arc" lamp. The majority of the light was emitted by the incandescent tips of the carbon rods which gradually burnt away. The temperature of the carbon tips was of the order of 3,700K. . Davy's use of batteries for the DC electricity supply restricted the wider application of the invention at this stage. The DC supply meant that one rod burnt away more quickly than the other but the advent of AC generating stations overcame both these problems. Nevertheless, as the carbons burnt away devices were needed to maintain the ideal separation, and many ingenious mechanical techniques were developed. One unusual approach was the so-called Electric Candle invented by Paul Jablochoff in 1870, which consisted of two parallel carbon rods separated by a layer of Plaster of Paris of appropriate thickness. The rods gradually burnt away during a period of operation of about eight hours. It is interesting to note that Joseph Swan, who took a great interest in all lighting matters, observed these Electric Candles on a visit to Paris for the International Exhibition in 1878.

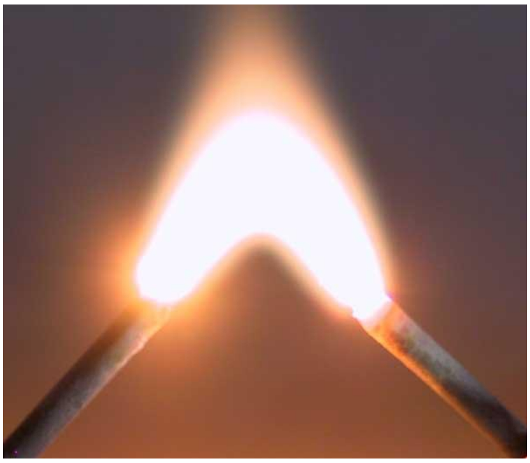

Figure 1. A Simple Electric Arc.

As generating stations multiplied rapidly in the second half of the 19th century the use of these lamps increased and many thousands were used for street lighting in this country, until, during the 1920s and 30s, they were gradually replaced by filament lamps or early forms of discharge lamp. (Further details on this subject are covered in the article by Peter Lamb on this website, entitled "Electric Arc Lamps in Bristol).

Carbon arc lamps were also used in searchlights during World War 2 and, with large reflectors of 1.5m diameter, were capable of producing amazing intensities, up to 800 million candelas. The beams were visible for 35 miles in optimum conditions, and were most effective at revealing the location of unfriendly aircraft. Indeed by using two at a known distance apart they enabled triangulation calculations to reveal the height of the invader in order to achieve more accurate gunfire.

FILAMENT LAMPS

Part 1. The Early Story

Like Sir Humphry Davy, Sir Joseph Wilson Swan was extremely versatile and is credited with being the first to discover that silver bromide coated paper was capable of storing black and white images, the basis of monochrome photography to this day. He also devised a means of squirting nitro-cellulose into acid which solidified it and this technique has developed into the manmade fibre industry. Indeed many of his early filaments for incandescent lamps were made of carbonised versions of these threads. Swan was born in 1828 and at the age of 20 he was already trying to make carbon filaments by processing strips of various kinds of paper and card. In 1860 he managed to make a carbon strip glow in an evacuated jar but he was limited by two main factors; firstly, the absence of a constant and cheap supply of electricity, and, secondly the achievement of an effective vacuum. The latter was overcome by the development of the Sprengel pump which was used by his colleague Charles Stearn in Birkenhead to achieve a much more complete evacuation than had been possible before. The final stroke was to pass a strong current through the filament just as the evacuation process reached its climax and this mopped up the last remains of air. This vital technique enabled the demonstration referred to in the introduction to take place on 3rd February 1879, and Swan did eventually patent the process on 2nd January 1880. He had actually produced a working lamp in December 1878 but the filament had failed before the meeting on the 18th of that month. The filaments in these early lamps were not made from paper or card but were a new material which started off as cotton and was coagulated with sulphuric acid to become like cat-gut. This particular development was patented by Swan in November 1880, but he was of the opinion that so many people were working on the general subject of the filament lamp and he himself had made earlier, but not so successful, versions, that it was not worth trying to patent the general principle. This was to prove a costly error, as far as his reputation was concerned.

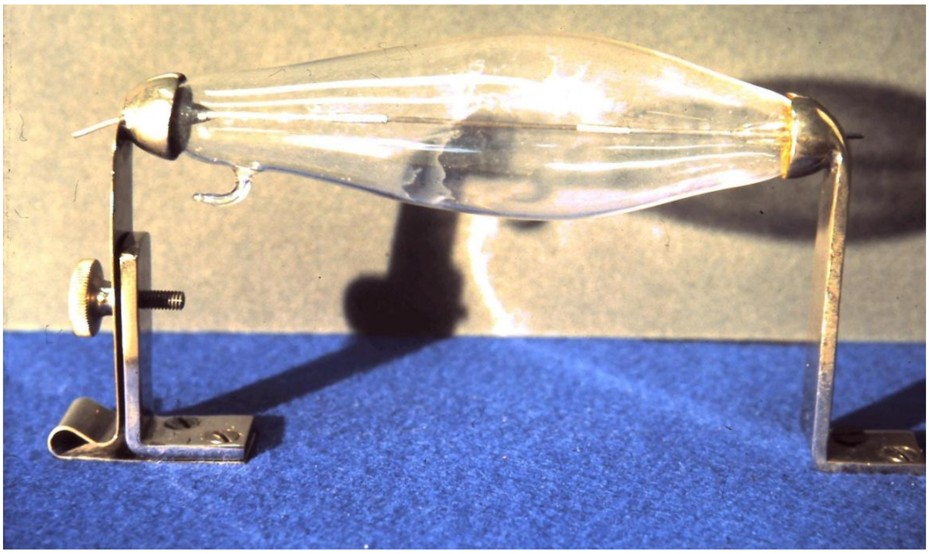

Figure 2. A facsimile of Joseph Swan's original incandescent filament lamp, as demonstrated in Newcastle on 3rd February 1879.

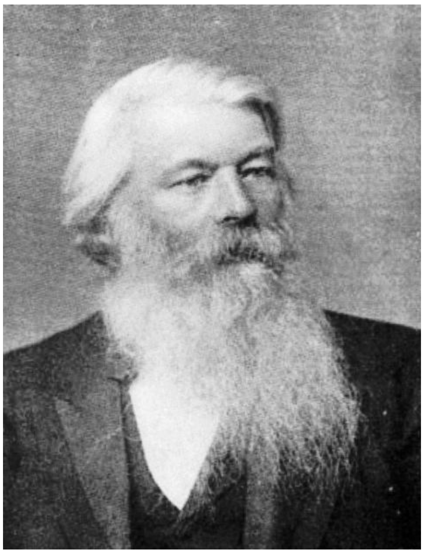

Figure 3. Joseph Wilson Swan, aged 54 in 1882.

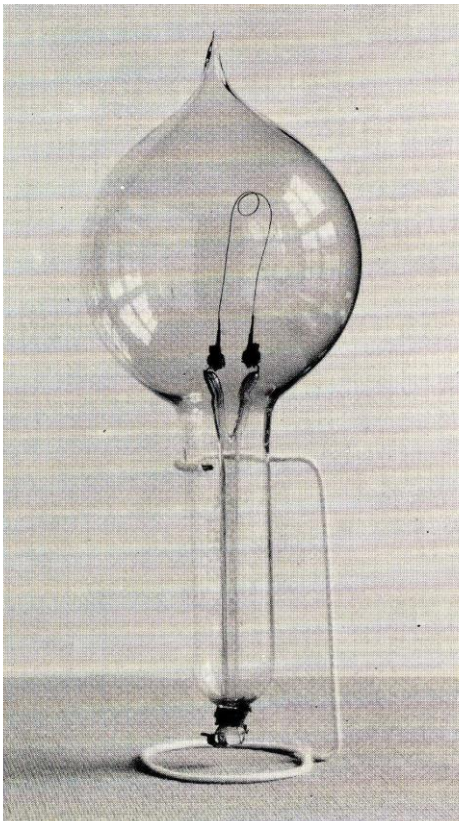

Figure 4. An example of the first commercial Swan lamp made in Newcastle in 1881.

By the summer of 1880 Swan's lamps had been sufficiently developed for them to be produced in quantity and Colonel Crompton was appointed as Chief Engineer for the Swan Electric Lamp Company in Newcastle.

Swan illuminated his own house with the new lamps and in December 1880 he supervised the installation at "Cragside", the home of his friend Sir William Armstrong which is now owned by the National Trust. The electricity there was generated by water power, so it became the first house in the world to be lit by hydroelectric means. The light output of each lamp was of the order of 700 lumens.

In June 1881 a trial installation of Swan lamps took place in the House of Commons and many other significant buildings followed suit, including, famously, the Savoy Theatre, home of the Gilbert and Sullivan operas.

Meanwhile, across the Atlantic, Thomas Alva Edison, who was born in 1847, and who had a very different set-up compared to Swan, as he had a team of about 100 people in all, was also working on the same subject, quite independently of Swan. He was more commercially minded and very aware of the value of patents. The incontrovertible fact is that it was not until 22nd October 1879 that Edison first carried out a successful test of his carbon filament lamp.

The first public demonstration of the lamp took place on 31st December 1879, eleven months after that of Joseph Swan. Unlike Swan, Edison anticipated this demonstration and applied for a British patent on 10th November 1879 which, for reasons best known to the patent office, was granted. He had already filed for a US patent on 4th November which was granted on 27th January 1880. The patents describe several ways of making the carbon filament, including cotton threads, wood splints and paper but it was not until several months later that he discovered that bamboo strands could be carbonised to make more durable filaments.

It is interesting to note that when Edison's achievements were published in Britain, Swan wrote to the magazine "Nature" in a letter dated 29th December 1879, pointing out that he had done similar experiments fifteen years previously and that he had now produced a "perfectly durable lamp by means of incandescent carbon". This surely throws into considerable doubt the legality of granting the patents to Edison. The latter was, however, a great pioneer in many ways, especially in the setting up of generating plants and electricity supply networks that enabled the widespread use of the new light sources.

Swan and Edison now both held significant patents in the field of incandescent lamps and instead of undertaking a lengthy and costly legal battle they sensibly agreed to join forces and form the Edison and Swan United Electric Light Company in 1883. The headquarters and principal factories were in London and the filament production followed the technique developed by Swan. In order to preserve their joint patents, for the sake of the company profits, it was necessary to establish that Swan's earlier work in some way differed from that of Edison and the argument concocted was that Swan's filaments were not really filaments as they were too thick, with a diameter of 1mm. By this subtle means the patents were upheld in law but Swan's place in history in the public view was lost forever! The commercial success of the combined company was, however, assured.

Part 2. Later Developments

After the amalgamation mentioned above, Edison continued his research into the use of bamboo and other natural materials which eventually led to little of permanent value. Swan, on the other hand, proceeded with his squirted filament research and in 1883 used nitro-cellulose coagulated in acetic acid to make a continuous fibre which was carbonised and thus formed filaments, some of which lasted more than 30 years. Growth was rapid and in that year production in the North London factory exceeded 10,000 lamps per week. The American factory adopted the same technique.

The lamp cap developed by Edison proved to be of more lasting benefit and the ES, or Edison Screw cap is used in great numbers in various sizes today. The UK has tended to use the bayonet cap (BC) which is quicker to insert and remove but slightly less firm and perhaps more prone to difficulties arising from indentation of the solder pads.

Carbon filaments continued to be the mainstay of the incandescent lamp until the turn of the century but in 1904 Franjo Hanaman and Aleksander Just in Budapest developed a technique for coating the carbon with tungsten which has the highest melting point of all pure metals at 3,695K. The carbon burnt away leaving the tungsten to emit a whiter light with a higher Kelvin rating. Some years later, in 1913, William Coolidge in the USA developed a technique with tungsten oxide powder which enabled pure tungsten filaments to be drawn, and this became the standard method of making filaments, some of which are only 0.01 mm diameter. The early lamps used frameworks of support wires to make so-called "squirrel cage" lamps, but the benefits of reducing the overall envelope of the filament became apparent and so coiled and then, in 1936, coiled coils became the standard method, with fewer supports. The original Swan lamp with its carbon filament had an efficacy of about 1.7 lumens per watt and the use of tungsten raised this to at least 10 lumens/watt. In all considerations of filament lamp life it must be remembered that the life is very dependent on the voltage applied. For voltages within 25% of that for which the lamp was designed the lamp life is inversely proportional to the nth power of the voltage, where n=14 for normal GLS lamps. Thus a 5% increase in voltage will halve the lamp life. The increasing use of domestic dimmers demonstrates the opposite change as a side effect.

Figure 5. The Chapter House at Wells Cathedral, demonstrating the use of narrow beam tungsten halogen spotlamps, from concealed locations.

The evaporation of the tungsten at a high temperature in a vacuum can be much reduced by the presence of inert gases, typically nitrogen and argon, and the normal GLS (General Lighting Service) lamp is so filled. The life of the filament can be further extended by using the results of a discovery made in 1953 by a group of American scientists who added halogens, iodine or bromine, to the filling. This has the effect of causing the "halogen cycle", whereby the tungsten which evaporates from the filament and would normally be deposited on the inner surface of the lamp is absorbed by the halogen and returned to the filament. The temperature at which this process takes place is such that the enclosure is made of silica, or quartz, hence the term "quartz iodine" lamps. In addition to the higher temperature of operation, leading to higher efficacies, the compact nature of the filament enables more accurate beam control for directional lighting.

DISCHARGE LAMPS

The earlier section on arc lamps did not mention that the carbon arcs were eventually enclosed in glass envelopes. This reduced the available oxygen and led to longer lives for the carbons, in addition to protecting the arc from draughts. The introduction of various gases to this discharge enclosure causes the arc to take on colours relevant to the individual gases, and now the discharge itself becomes the source of the great majority of the light and the electrodes can be made of more durable metals. The earliest demonstration of this phenomenon was made by one Francis Hauksbee, an English scientist, as early as 1705, but this was only of scientific interest. Heinrich Geissler, a German physicist, was the first to develop this lamp, in 1857, but it was still used largely for decorative purposes. Further developments of this lamp by William Crookes in the 1870s led to the production of X-ray tubes and cathode ray tubes. These devices operated with cold cathodes and the same description is applied to the long glass tubes which are formed into advertising signs etc. Again, the colour emitted depends on the gas enclosed, neon for red, argon for blue and carbon dioxide for white. Cold cathode lamps are often about 3m long with a diameter of 20mm and can be shaped to fit architectural situations.

If sodium vapour is used in the discharge, operating at low pressure (c.1% atmospheric) with relatively large lamps, the light emitted is the familiar monochromatic yellow used for street lighting in the past, and still, unfortunately, not entirely replaced today. By raising the pressure (up to 20% atmospheric) in smaller lamps the colour rendering can be improved dramatically. Indeed superior versions of these high pressure sodium lamps have been installed in many churches in the South West of England.

The presence of mercury in the discharge produces a blue light together with a large amount of ultra-violet radiation. Much development of this lamp took place in the 1940s, the early MA type operating at a pressure of about 1 atmosphere. The very blue appearance and poor colour rendering made them rather unpopular and a rapid development of the MB type with a silica/quartz discharge tube and pressure increased to 5/10 atmospheres led to a much wider spectrum and greater efficacy.

Reference must be made now to the phenomenon of fluorescence. In 1852 Sir George Stokes presented a paper describing the change in the wavelength of received radiation achieved by certain substances. He noted that the wavelength was always increased, known as the Stokes' Shift (also sometimes referred to as Stokes' Law, although this title really relates to his work in fluid mechanics).

Figure 6. Holy Trinity Church in Salcombe using de luxe high pressure sodium lamps with their warm and welcoming colour rendering properties.

Thus the ultra-violet radiation from the mercury discharge can be converted to visible light by phosphors such as halophosphates applied to the inside of the lamp glass. This technique was used to greatly improve the colour of the light emitted by the MB lamps, and led to the MBF/U lamp, the U indicating a universal mounting option. These lamps do however suffer from considerable lumen depreciation through life and are now being phased out as the arc tube improvements resulting from the use of metal halides have been developed since the 1960s. The addition of rare earth (such as thallium and dysprosium) halides to the mix in the discharge tube can double the lumen output and improve the colour properties. Improvements in this field are ongoing and lamps are now available in a very wide range of sizes and ratings, from 20W up to 3.5kW, with excellent colour rendering properties and high efficacies.

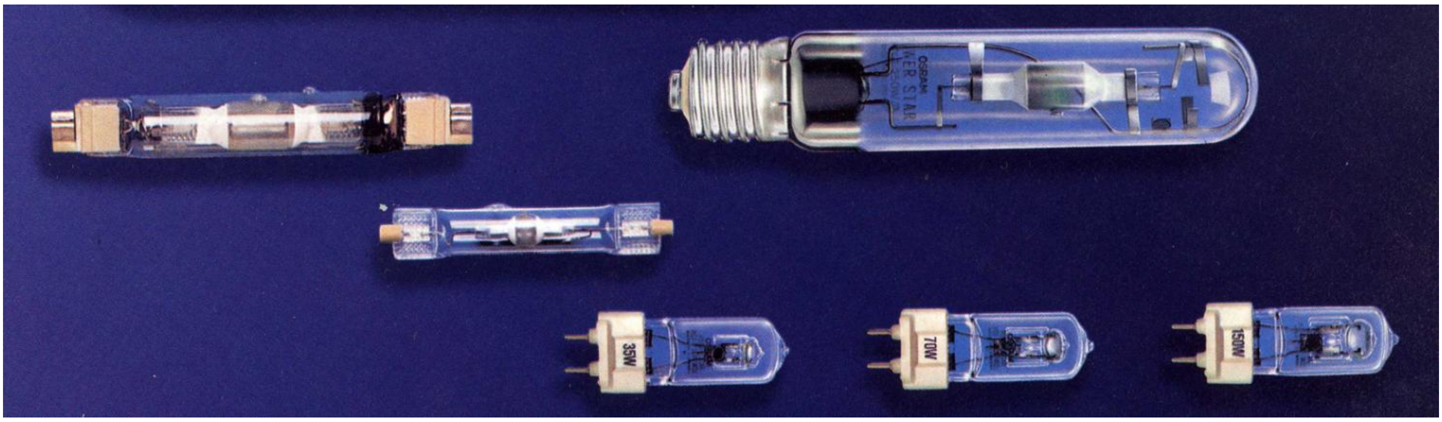

Figure 7. Some examples of Metal Halide lamps, showing some of the variations in lamp cap. These lamps emit a lot of light from a small volume source and need careful directional control.

Before going on to the final category of discharge lamps, namely fluorescent tubular lamps, it should be pointed out that virtually all electrical discharges have what is known as negative resistance characteristics, such that the resistance falls as the current rises. This is the complete opposite of the filament lamp, where the inrush current in the cold filament can be typically 14 times that of the steady state current for a very short duration. For discharge lamps therefore a current limiting device is always required in the circuit, in addition to starting devices which can take various forms.

FLUORESCENT LAMPS

Several researchers in the ‘20s and ‘30s were developing the idea of employing the phenomenon of fluorescence to produce light sources but the General Electric Company in the USA probably produced the first practical lamp in 1934. These lamps have the designation MCF and the C indicates a very low internal pressure. They are equipped with hot cathodes which are preheated during the starting operation in order to emit electrons to initiate the discharge. These cathodes are in fact tungsten filaments, of the coiled coil type, coated with emissive material. Many varieties of circuit have been used to operate these lamps, from the traditional "starter switch" type to the present electronic versions. The latter are more efficient than the earlier ones with wire wound chokes and recent energy conservation regulations preclude the early types. The early lamps mostly had a diameter of 38mm but this was reduced to 25mm and now many are down to 16mm. The field of phosphor research has provided much improved varieties with excellent colour rendering and higher light outputs with the reduced tube diameters. Indeed the latest 1.5m X 16mm tube, which has reverted to the traditional loading of 80W, emits 6,650 lumens at a temperature of 35°C. Lower temperatures reduce the output, so luminaire design plays a significant role in achieving maximum overall efficiency. Lumen maintenance through life has been considerably improved so that after 15,000 hours the output is still 90% of the initial value.

The reductions in tube diameter have been of paramount importance in the development of the Compact Fluorescent Lamp or CFL. These were developed in the 1970s and fall into two distinct categories; lamps with and without integral ballasts. The former are the more familiar and can be used to replace GLS lamps in domestic and commercial properties. The early versions of these used magnetic chokes and so were somewhat heavy and bulky. The use of electronic ballasts reduced the weight and size and, by generating a high frequency supply at, typically, 20,000Hz they overcame the 50Hz flicker problems associated with the normal supply. The high frequency also improves the efficacy of the lamp but unfortunately their acceptance by the general public has been hampered by exaggerated claims in relation to the equivalent GLS lamps. Not only are the *effective* light outputs initially lower than the so-called "equivalents" but the lumen maintenance is poor in comparison. So called *average* light outputs are often taken after 1500 hours for a lamp claimed to last 10,000 hours. The result has been a steep decline in the illuminance values achieved in many domestic situations. The problem of the disposal of many millions of lamps with an albeit small individual mercury content has also not been fully taken care of. From a technical point of view they do operate at a very low Power Factor and introduce a very high proportion of harmonic currents which can cause problems at power stations. However they do undoubtedly reduce the power requirements of the average home to a small extent, some of which must, however, be made up by the heating system and they will certainly be with us for some years to come.

The other variety of CFL comes in many shapes and forms and requires separate ballasts. They are used in many buildings and are available from 5W to 70W. Their relatively small size enables a good degree of directional control and they are usually operated with high frequency electronic ballasts to achieve high efficacy and complete absence of flicker.

NEW DEVELOPMENTS

However in the long term the CFL will inevitably be seen to have been but a temporary phenomenon as they will almost certainly be overtaken by the development of the Light Emitting Diode. Nick Holonyak, in the USA, is credited with the invention of the first red LEDs in 1962 and these were widely used as indicator lamps. These early LEDs used gallium arsenide to produce the long wavelength radiation but other chemicals were able to reduce the wavelength and a yellow version and then the familiar bright blue one appeared, and in the mid 90s this was combined with a phosphor to produce white light. The latest white light LEDs are achieving over 100 lumens/watt and development is so rapid that this figure will soon become commonplace.

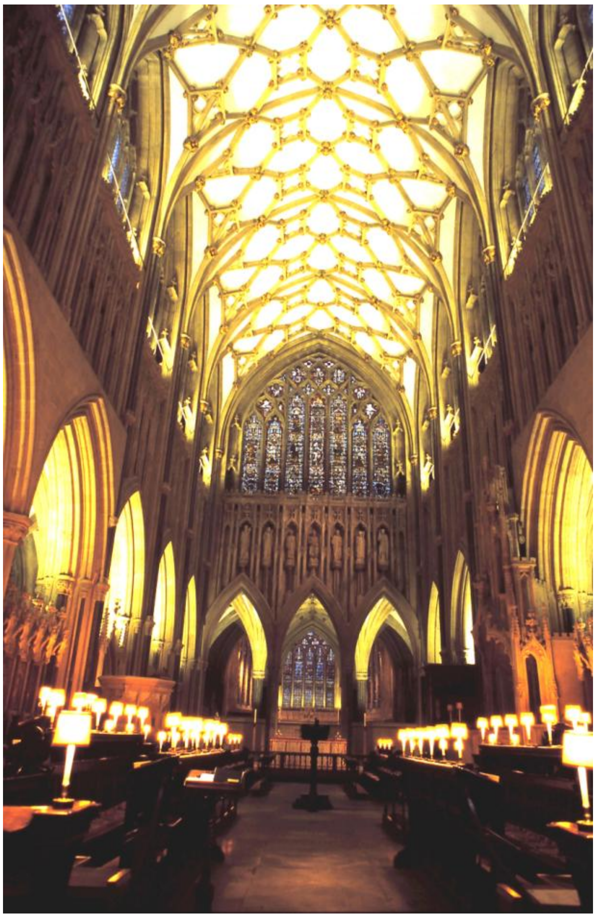

Figure 8. The Quire at Wells Cathedral, which, like the rest of the building, is mostly lit by 36W compact fluorescent lamps operating at high frequency with dimmable electronic ballasts in purpose made luminaires with efficient reflectors. The desk lighting is achieved by small crown silvered incandescent lamps.

THE FUTURE

It is difficult to see what can stop the march of the Light Emitting Diode, unless it is the induction lamp which has no electrodes to wear out and which uses a magnetron or electronic ballast to produce high frequency radiation directed into a plasma filled globe causing it to generate light and ultra violet radiation. The UV is fluoresced by a phosphor coating to produce more light and the overall efficiency can be very high. The principle was first established by Nikola Tesla in the 1890s. He was a Croatian, who for a short time worked with Thomas Edison, and who made valuable contributions in many fields, including alternating and direct current motors and generators. The unit of magnetic induction, the tesla, is named after him. Numerous researchers have contributed to the technique since then and production of the lamps is growing rapidly today. These lamps are used, for example, to illuminate the faces of the Big Ben clock and with their long life of around 60,000 hours or more are especially useful in situations with difficult access. They are also known as High Efficiency Plasma or HEP lamps. With these and the LEDs gaining ground so rapidly we can be certain that nothing will stand still in the field of light production and it will be fascinating to see what the future brings.

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