THE PRINCIPLES OF LIGHTING

PART 1: LAMP TYPES

Dr Alan Smith discusses lighting and its relevance to optical practice

An understanding of the principles of lighting is relevant to the everyday work of a dispensing optician. If lighting levels are inappropriate, even the finest lenses and most accurate lens powers will be inadequate. Vision correction through the prescribing and fitting of spectacles can be optimised through discussion and advice concerning the conditions in which the correction will be used. Light can be a hindrance to good vision as well as an aid, for example for VDU operators, or those with low vision. It can facilitate the correct perception of colours and detail. Its consideration is an integral part of the dispensing of spectacles for occupational activities and hobbies.

The Principles of Lighting **consists of four articles to be published over the next few months and gives a chance to study lighting in greater depth, in order to supplement dispensing skills and obtain a greater understanding of lighting and its various applications. Each article carries one CET credit, so up to four are available for the series, which has been produced in response to requests for more in-depth study topics, and are provided as part of your ABDO membership fee.**

Dr Alan Smith is a leading authority on lighting and its relevance to optical practice, and I am delighted to commend this series to you.

Paula Stevens

For many years man relied heavily upon the use of oil lamps, wax candles and subsequently coal gas for the production of artificial light. It wasn't until Michael Faraday discovered the principles of electromagnetism in 1831, that safer, cleaner, and more efficient light sources, based upon the conversion of electrical energy, could be contemplated. In 1879 Joseph Swann in the United Kingdom and Thomas Edison in the United States, working separately from each other, produced and exhibited a practical electric lamp, the incandescent lamp. Subsequent developments have seen the introduction of discharge lamps and, more latterly, semiconductor lamps.

Lamp classification

Table 1 shows the principal lamp types.

Incandescent lamps

Tungsten filament lamps include the general lighting service (GLS) lamp and the tungsten halogen lamp. Both types rely upon the flow of an electrical current through a filament, which will raise its temperature. Ultimately the filament reaches incandescence thereby emitting radiation, some of which (typically in the region of 6 per cent for practical lamps) lies within the visible spectrum.

The tungsten halogen lamp is a development from the basic tungsten filament lamp, and relies upon the halogen cycle for its light output. A small amount of one of the halogen group of elements, which includes bromine, chlorine and iodine, is added to the normal gas filling of the lamp. The halogen will combine with the evaporated tungsten thereby forming a tungsten halogen. When the tungsten halogen comes into contact with the filament the tungsten is re-deposited on the filament and the halogen is released.

One precaution that must be observed when handling a tungsten halogen lamp is that the lamp envelope must not come into contact with the human skin. The acids and grease that are present on the skin will be transferred to the quartz envelope and will cause blistering of the quartz leading to premature failure of the lamp.

Figure 1 shows the typical construction of the tungsten halogen lamp.

Tungsten halogen light sources are of particular significance to the optometric professional as they are used:

a In instrumentation, and

b In conjunction with dichroic reflectors in installations where it is necessary to prevent excess heat impinging onto the object that is being illuminated, eg frame displays.

Figure 2 shows the simplified principal of the dichroic reflector lamp [1].

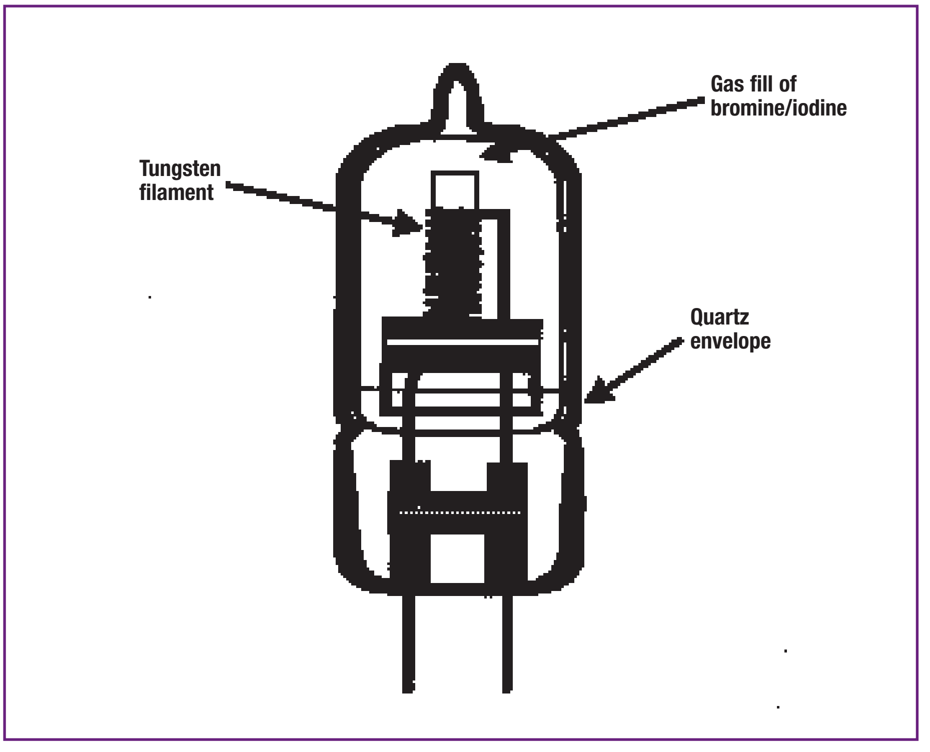
Discharge lamps

If a voltage is applied to the electrodes located in a discharge tube the energy will be transferred to the gas or vapour. The electrons that are orbiting the atoms of the gas within the discharge tube will be raised to a higher energy level. They remain in this higher energy level orbit for a very short time, typically nanoseconds, before falling back to the lower energy level orbit from which they had originally been raised. In falling back to the lower energy level, the electrons will emit their newly acquired excess energy in the form of photons of light, the wavelength of which depends upon the difference in energy level between the two orbits. See **Figure 3**.

Discharge lamps will not attain their

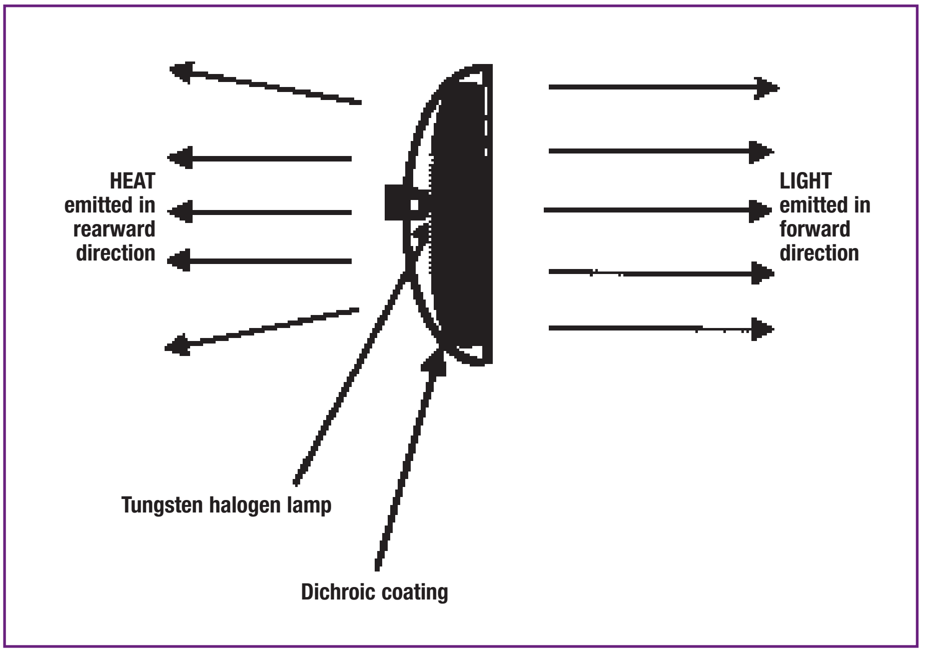
Incandescent	Discharge	Semiconductor
Tungsten filament or general lighting service (GLS)	**Mercury**	Light emitting diodes
Tungsten halogen	Low pressure (fluorescent)	
	High pressure	
	Metal halide	
	Sodium	
	Low pressure	
	High pressure	
	Xenon	

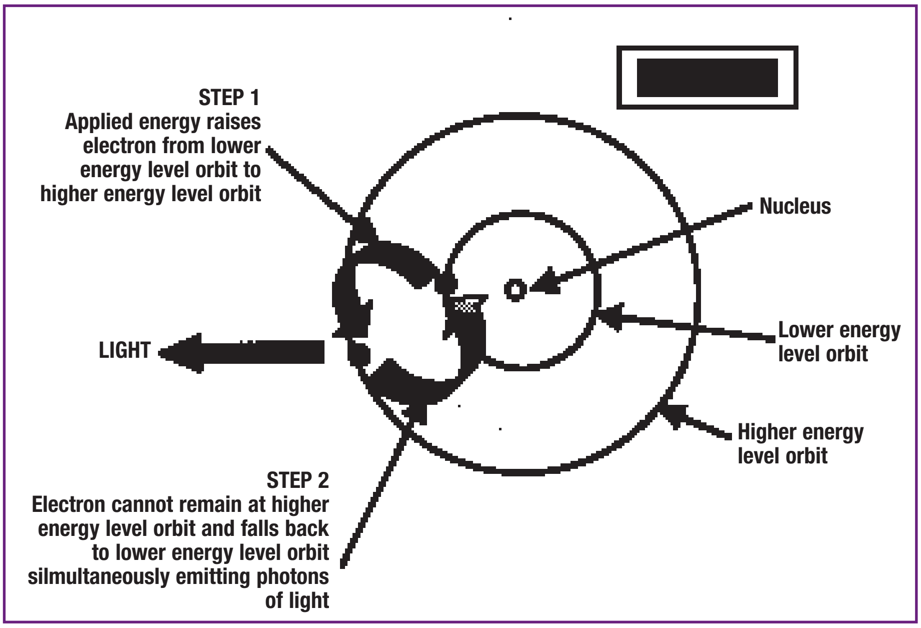
▲ **Table 1:** principal lamp types



▲ **Figure 1:** construction of capsule-type tungsten halogen lamp

▼ **Figure 2:** construction of dichroic reflector lamp





▲ **Figure 3:** light production by gas discharges

steady-state luminous output instantaneously following switch on but take time before the output reaches its maximum obtainable value, a condition that also applies to fluorescent lamps [2], although not to the same level as with other discharge lamps.

Mercury vapour lamps

In the low pressure (fluorescent) mercury vapour lamp the discharge consists primarily of ultraviolet radiation. In order to produce a lamp output in the visible spectrum the inner wall of the glass tubing, from which the lamp is constructed, is coated with phosphors. The phosphors absorb incident radiation and re-emit at wavelengths that fall within the visible spectrum.

Fluorescent lamps can be subdivided into:

a Hot cathode lamps, where the original striking of the arc is achieved after the lamp electrodes have been pre-heated, and

b Cold cathode lamps, where the arc is established with the aid of a relatively high voltage. These lamps are used typically in advertising signs. Cold cathode lamps have a much higher lamp life than that obtained with hot cathode lamps.

Fluorescent lamps can be either tubular, compact or of the induction type. The light output of tubular and compact lamps can be effectively dimmed when high frequency supplies are used. The induction lamp is a comparatively recent innovation that involves energy transfer relying on electromagnetism.

The induction lamp is ‘electrode-free’ which is in contrast to conventional fluorescent lamps that rely upon electron emitting oxides, coated onto the electrodes, to assist with lamp starting. A quantity of of this electron emitting material is ‘pulled away’ from the electrodes each time the conventional lamp is started, from which it is apparent that the life of a fluorescent lamp will be influenced by the number of times the lamp is started. It is clear that a situation will eventually be reached when no electron emitting material remains on one or both electrodes. Under such conditions the lamp will not start. Due to the absence of conventional electrodes, induction lamps have a long lamp life.

The prevailing ambient temperature radically affects the light output from conventional fluorescent lamps. Low external temperatures reduce the temperature of the mercury vapour within the lamp with the consequence that light output will be correspondingly reduced. Fluorescent lamps provide their optimum light output when the surrounding ambient temperature lies between 20°C and 25°C. The luminous output of the lamp will be attenuated with deviation away from this temperature range as shown in **Figure 4**.

High Intensity Discharge (HID) lamps, often referred to as high pressure discharge lamps include mercury vapour and metal halide lamps.

High pressure mercury vapour lamps were used in various outdoor applications including street lighting but such installations are now being largely replaced with high-pressure sodium lamps that produce a ‘warmer’ light output and which tend to be more agreeable to the eye.

Metal halide lamps are based upon the same modus operandi as the basic high pressure mercury vapour lamp. If metal additives in halide form are used in the discharge tube the colour properties of the lamp are much improved from that applying with the basic high pressure mercury vapour lamp.

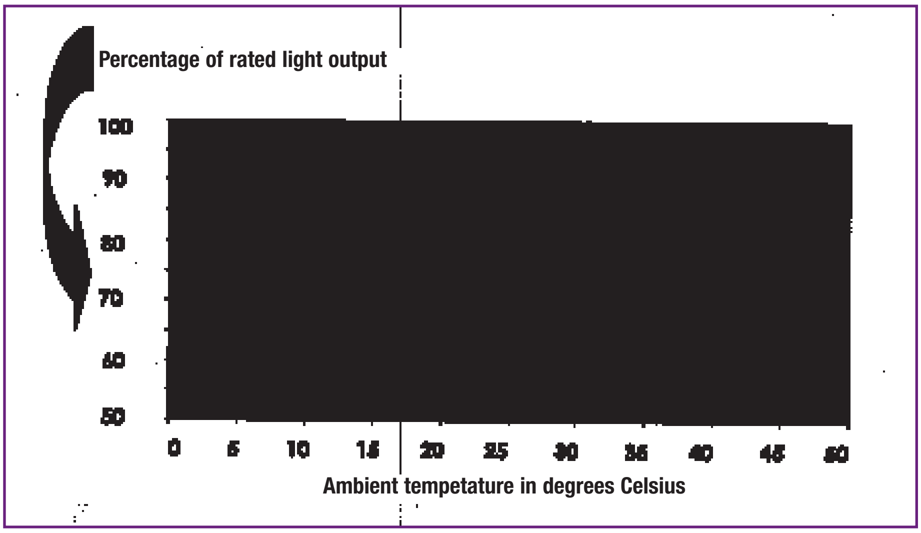
Sodium vapour lamps

The low pressure sodium lamp emits radiation that is referred to as monochromatic although strictly with spectral output lines at 589 nm (95 per cent) and 589.6 nm (5 per cent). Since the output wavelengths are near to the wavelengths of peak sensitivity of the photopic eye, the low pressure sodium lamp has a relatively high luminous efficacy value when compared to other artificial light sources currently available.

In addition to their high luminous efficacy values, low pressure sodium lamps are particularly useful in foggy and steamy atmospheres. If the incident radiation were to be provided by ‘white light’ then water droplets in suspension in the foggy atmosphere will produce the ‘rainbow dispersion effect’. However, as the incident radiation from a low pressure sodium lamp is considered to be monochromatic, such dispersion does not occur [3]. Unfortunately since the output from the low pressure sodium lamp is monochromatic, the lamp has very poor colour rendering properties.

High pressure sodium lamps have

▼ **Figure 4:** effects of ambient temperature on lumen output of tubular fluorescent lamp



much-improved colour rendering properties when compared to the low pressure sodium lamp. Unfortunately this improvement in colour rendering is offset by a corresponding reduction in lamp efficacy.

Conventional electric lamps are assigned letter designations in accordance with ILCOS [4], which was introduced in 1993 by the International Electrotechnical Commission and is detailed in BS IEC 1231:1993 [5].

Xenon lamps

A xenon lamp is a miniature discharge lamp that contains a combination of noble gases that include xenon. The lamp does not have a filament and the light output from the lamp, in the form of an arc, is created between two electrodes. In common with other gas discharge lamps, the xenon lamp requires other electrical equipment in the circuit, ie an electronic starter that assists in providing rapid ignition together with an electronic ballast.

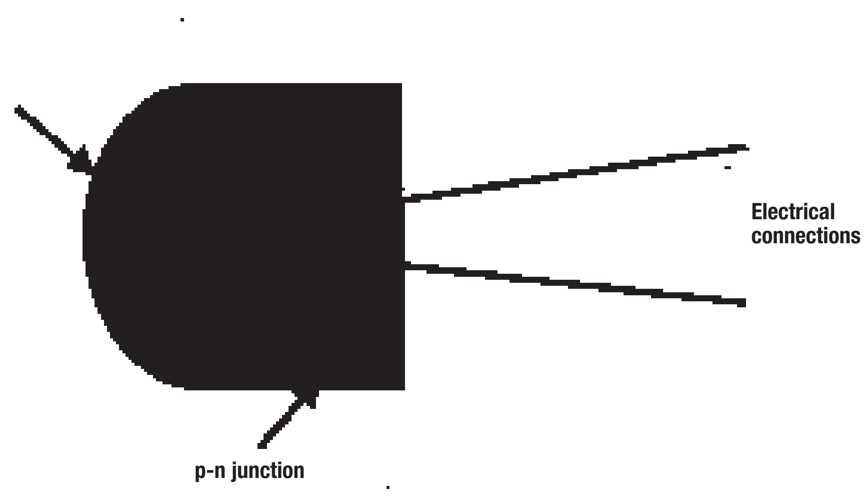
The xenon lamp, increasingly used in automobile headlights, has a luminous efficacy of typically four times that of a tungsten halogen lamp, ie up to 100 lumens per watt. The light output produced by a xenon lamp is not blue but is strictly white light although it appears blue when compared to the warmer light output of the tungsten halogen lamp and is claimed to be similar to daylight thereby enabling drivers to concentrate more effectively [6].

Lamp control gear

Discharge lamps, unlike incandescent lamps that can be connected directly to the mains electrical supply, require some form of control gear. The function of the control gear is twofold. Initially it provides a high voltage pulse in order to initiate the discharge and thereby establish the arc in the discharge tube and once the arc has been established, the control gear takes on the role of a current limiting device keeping the lamp current to a safe value and preventing the lamp from destroying itself. The control gear will consume electrical energy from the mains supply that has to be paid for by the consumer. By way of an example a 35Watt low pressure sodium lamp may consume typically 50 watts, 15 watts of which is consumed by the control gear.

Semiconductor lamps

Light emitting diodes (LEDs) are a form of semiconductor lamp. Essentially they are constructed of a substrate material that is doped with other selected materials. In so doing, a p-n (positive-negative) junction is formed, as shown in **Figure 5**. When a voltage is applied across the junction, charge carriers inject across the junction where they recombine. The corresponding excess energy is converted into visible radiation, the wavelength of which will be influenced by the properties of the materials used in the junction.



▲ **Figure 5:** construction of a typical light emitting diode

The luminous efficacy of a white LED is claimed to be in the region of 100 lumens per watt, which represents an increase over the conventional fluorescent light source. The Colour Rendering Index (CRI) value of the white LED is typically 85, which compares favourably with that of the conventional fluorescent lamp [7].

There are, however, some very beneficial advantages attributable to LEDs including robustness, extended lamp life and low heat production. The production of little heat during the normal operation of the lamp is particularly important when used with those who suffer from low vision, which is considered in CIE Report 123 [8]. Conventional lamps, eg the tungsten filament lamp, emit high amounts of infrared radiation. When used in situations where individuals require high illuminance levels in order to carry out a particular visual task, eg reading print, it is often impossible to locate the lamp in the preferred position due to the heat emission. The use of a cluster of LEDs in a luminaire, so as to give the required light output, should not pose a problem in respect of excess heat.

Ultraviolet radiation emitted by lamps

The tungsten halogen lamp is constructed with an outer envelope made of quartz, which is a good transmitter of ultraviolet radiation. This combined with the heat generated in a tungsten halogen lamp leads to an increased emission of ultraviolet when compared with that of a GLS lamp.

Some high intensity discharge (HID) lamps emit ultraviolet radiation during normal operation and it is essential that such lamps are installed and operated in luminaires fitted with appropriate safety shields.

High pressure mercury vapour and metal halide lamps present a UV hazard if they operate with the outer envelope fractured but with the inner discharge tube still intact. The inner discharge tube in these lamps is constructed of quartz whilst the outer envelope is usually made of borosilicate glass, which under normal operating conditions will absorb the UV radiation [9].

Disposal of spent lamps

Lamps contain many materials, some of which are toxic in nature, and it is therefore necessary to take appropriate precautions, in accordance with current legislation, when disposing of such lamps after they have reached the end of their useful life.

The materials referred to include cadmium, lead and mercury. Cadmium will not degrade and is insalubrious. If cadmium is not disposed of in an appropriate manner it may become absorbed by the general mass of earth. From there it can be taken up by plant life and in so doing enter the food chain.

Broken mercury lamps release both mercury vapour and liquid mercury, albeit in small quantities. In certain situations the mercury may be converted into methyl mercury, which is extremely toxic. The mercury-contaminated powders released when fluorescent lamps are broken should not be inhaled.

Sodium lamps also present problems, as sodium is hygroscopic. In damp environments sodium can absorb moisture and in some cases in sufficient quantities for the lamp to become hot and eventually ignite. The storage of sodium lamps should be in accordance with the recommendations of the local Fire Department.

Conclusion

Optometrists and dispensing opticians

Glossary of terms

Colour rendering: The ability of a light source to reveal the "real" or "expected" colour of an object. The Colour Rendering Index has a maximum value of 100. A value of 20 would be poor.
Dichroic filter: consists of a glass base plus thin layers of varying refractive index. Interference causes absorption of some wavelengths and transmission of others.
Hygroscopic: tending to absorb moisture
Lumen: the measurement of luminous flux
Luminaire: the "housing" for a lamp, or lamp fitting. The luminaire includes the equipment containing the lamp, the control gear, the component controlling the appearance of the lamp and the protection of the lamp.
Luminous efficacy: the ratio of light output to the input power (lumens/watt)
Photopic vision: vision mediated largely by cone receptors. The maximum sensitivity is at a wavelength of 555nm ■

should ideally have an appreciation of lamps, as sources of artificial light, and the lighting conditions perceived, as a consequence of the operation of the lamps.

It is also necessary for them to have an awareness of the potential hazards that may occur from the use of such lamps, eg ultraviolet radiation, and to be able to suggest appropriate corrective action.

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