LIGHTING INSTALLATION

BUILDING LIGHTING SYSTEMS

LIGHT

Artificial light is constant and controllable, whereas daylight is continually varying with the same time of year, time of day and weather conditions. The amount of light needed is directly related to the nature of the task, and higher the level of illumination the better can small details be seen and the quicker the task carried out without mistakes.

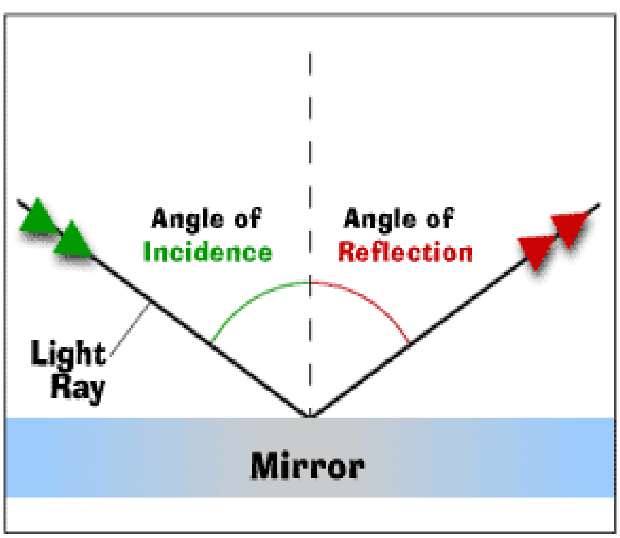
Factors which affect the choice of illumination level include the size of the object, the degrees of contrast which assists vision and whether or not the eyes or the object have movement. The reflective characteristics of the mains surfaces, furnishings and content of a room contribute to the illumination and may have a marked effect on visual comfort, and therefore should be considered at an early stage in the lighting design.

Glare may also be caused be the reflection of the light sources from polished surfaces such as table-tops and floors: matt surfaces are generally preferable where there is a risk of this occurring, and for the same reason matt finishes may be used for walls and ceilings.

In order to create an interior that has a lively and stimulating appearance, variety in the visual scene is required with contrasts in light and dark, highlight and shadow – as well as variations in texture and colour.

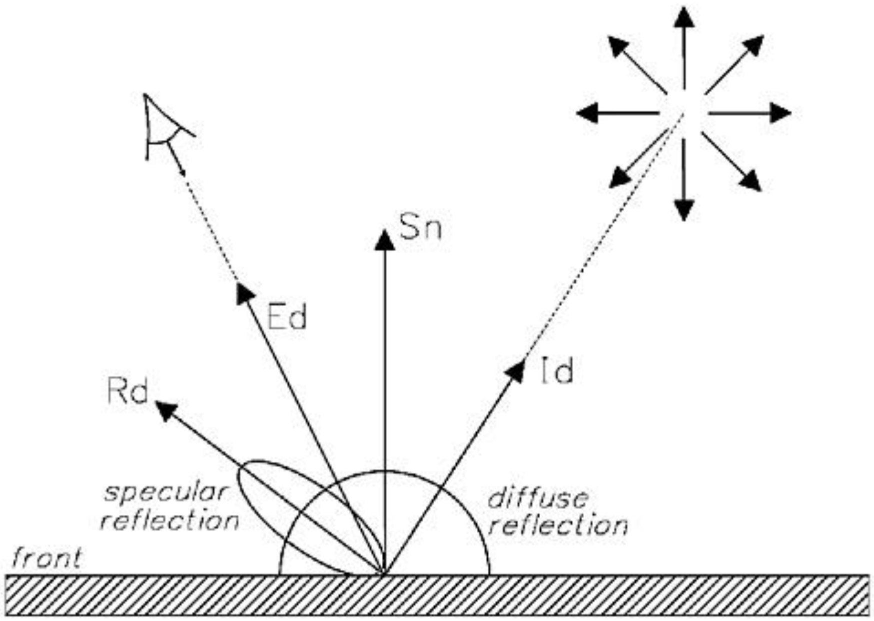
Light is a form of electromagnetic radiation (EMR). It is similar in nature and behaviour to radio waves at one end of the frequency spectrum and X-ray at the other.

The light reflected from a polished (specular) surface at the same angle that strikes it. A matt surface reflects in a number of directions and a semi-matt surface responds somewhere between a polished and a matt surface.



Angle of incidence = Angle of reflection

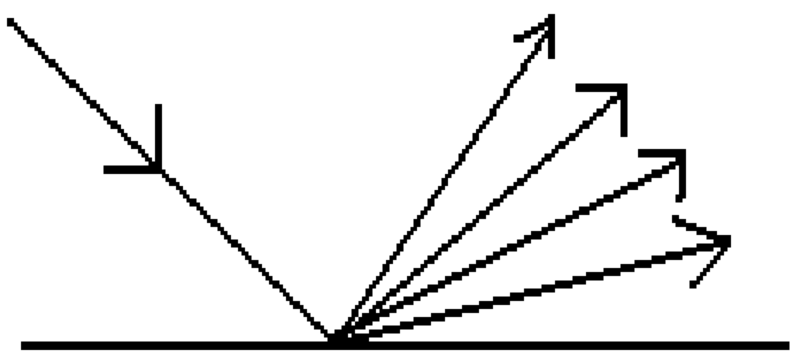
Figure 1: Light reflected from a polished surface



Light reflected from a matt surface

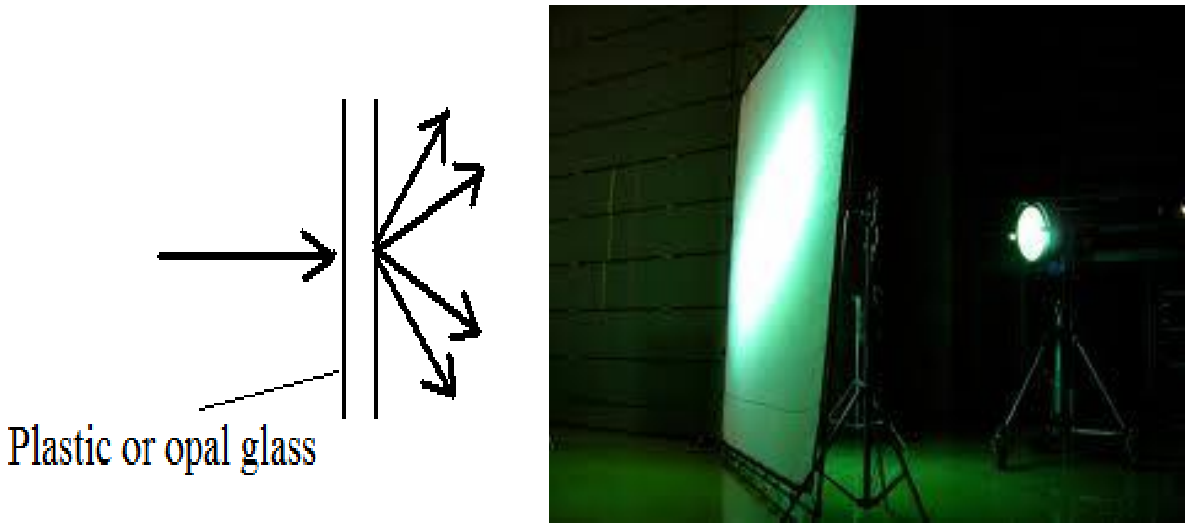
Figure 2: Light is reflected in all directions

Some light is scattered and some light is reflected directionally



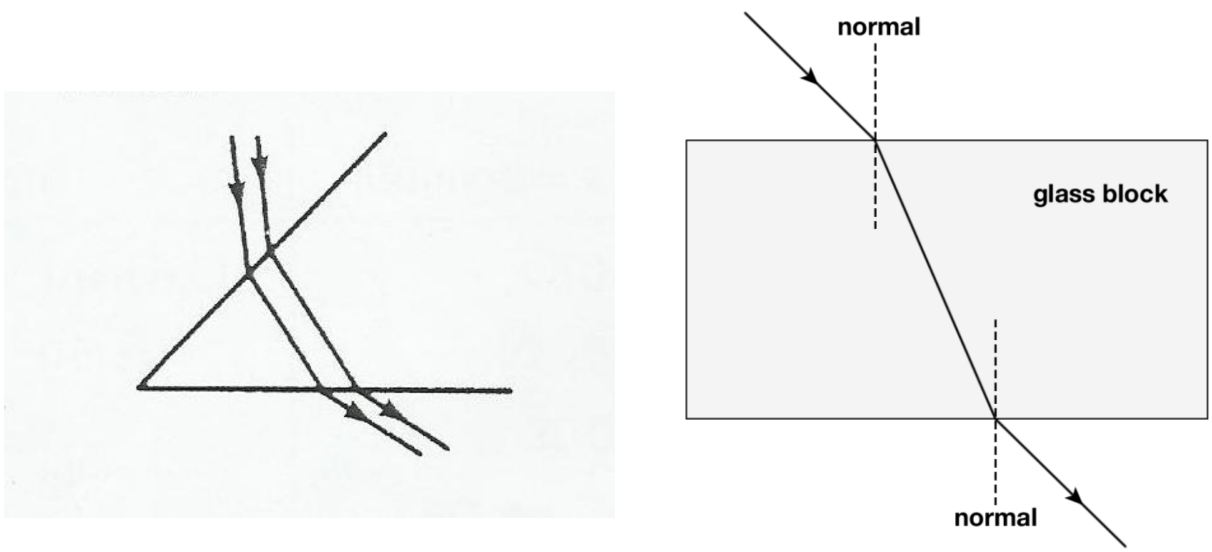
Light scattered and reflected from a semi-matt surface

Figure 3: Light is scattered and reflected directionally



Lighting passing through a diffusing screen

Figure 4: Light is scattered in all directions (diffusion)



Light is bent or refracted when passing through a surface between two media

Figure 5: Light passing through between two media

LUMINOUS INTENSITY

A measurement of the magnitude of luminance or light reflected from a surface. The quantity of visible light emitted in unit time per unit solid angle. The unit for the quantity of light flowing from a source in any one second (the luminous power or luminous flux) is called the ***LUMEN***.

The lumen is evaluated with reference to visual sensation. The sensitivity of the human eye is greatest for light having a wavelength of 555 nanometres (10^{-9} metre); at this wavelength there are 685 lumens per watt of radiant power, or radiant flux (the luminous efficiency), whereas at other wavelengths the luminous efficiency is less.

The unit of luminous intensity is *one lumen per steradian*, which is the unit of solid angle—there are 4π steradians about a point enclosed by a spherical surface. This unit of luminous intensity is also called the standard candle, or ***candela*** (cd/m^2)

ILLUMINATION

It produced from a light source perpendicular to the surface.

By reference to figure 6 shown below, it will be seen that area over which the luminous energy, from the light source, will be spread increases with the square of the distance from the source. The illumination produced on a surface area in m^2 from a light source perpendicular to the surface at a distance *d* from the luminous intensity may be found the following expression:

$$E = \frac{I}{d^2}$$

E = Illumination on surface (lux)
I = Illumination intensity from source (cd)
d = distance from light source to source (m)

THE INVERSE-SQUARE LAW

The intensity of illumination from a point source varies inversely as the square of the distance from the source.

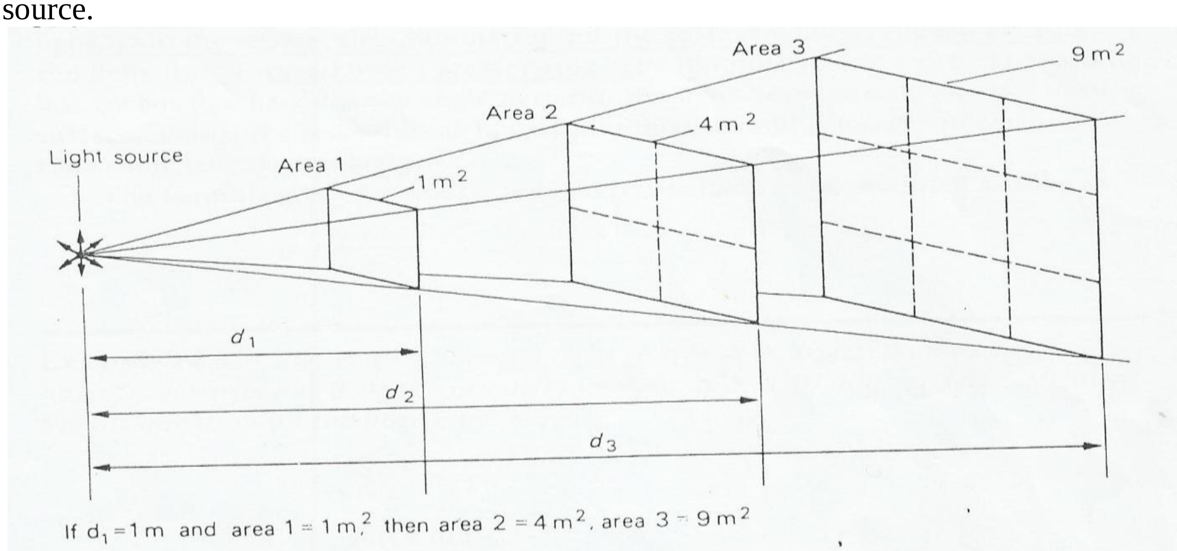


Figure 6: The inverse-square law

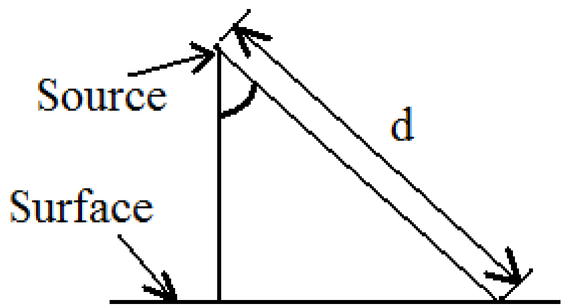
Example 1:
A spotlight having a light intensity along its beam 16000 candelas is directed on to a horizontal surface 4m from the light source. If the beam of light is normal to the surface, calculate the maximum illumination level on the surface in lux.

$$E = \frac{I}{d^2}$$

$$E = \frac{16000}{4^2} = \underline{\textbf{\textit{1000 lux}}}$$

COSINE LAW OF ILLUMINATION

If the surface is not normal, i.e., perpendicular to the direction of the emitted light from the source, the illumination on the surface will be reduced because the light flux is source, the illumination on the surface will be reduced because the light flux is spread over greater area. The illumination surface will be less by cos θ, where θ is the angle between the light beam and the normal to the surface. This is the second basic law of illumination and usually referred to as *the cosine law of illumination*.

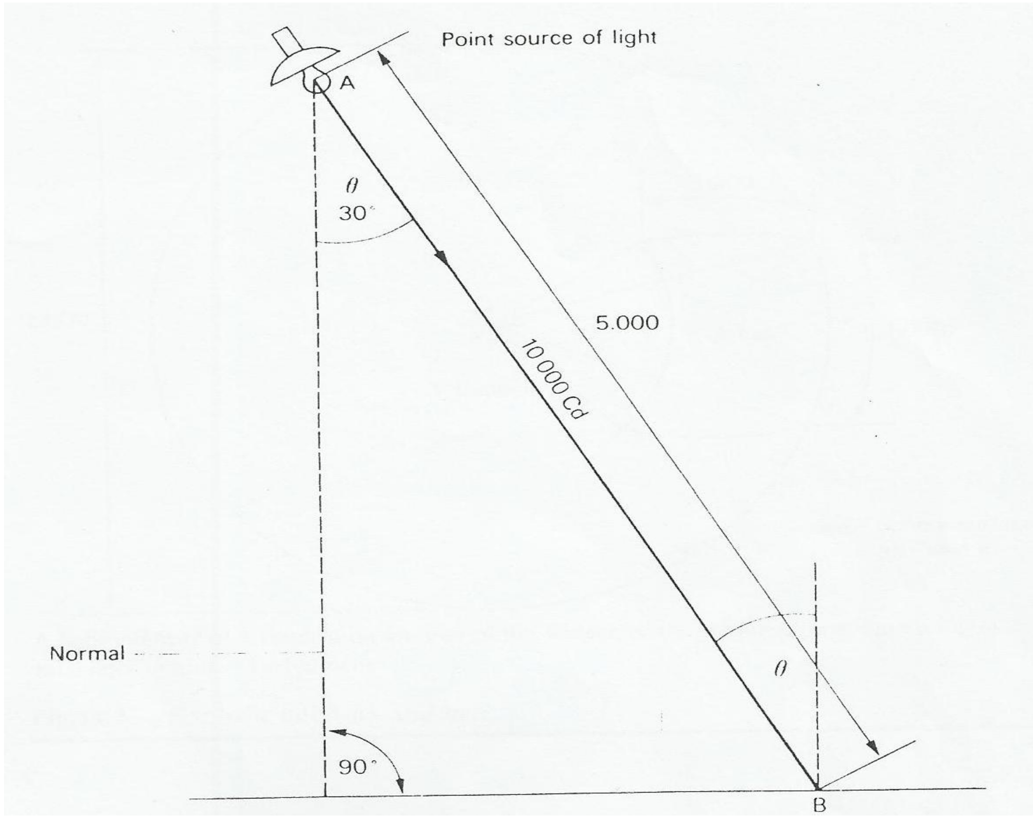


Illumination produces from a light not perpendicular to the surface

The formula given previously will therefore have to be modified as follows:

$$E = \frac{I \cos\theta}{d^2}$$

Example 2:
Figure 7



a) Illumination on a surface when the beam of light is at 90 to the surface $= \frac{I}{d^2}$

b) Illumination on a surface when the beam of light is at another angle θ to the surface $= \frac{I \cos \theta}{d^2}$

Figure 7 above shows a light source at A directed on to a horizontal surface at B. If the intensity of light at A is 10000 candelas, calculate the illumination on the horizontal surface.

$$E = \frac{I \cos \theta}{d^2}$$

$$E = \frac{10000 \cos 30°}{5^2}$$ ***= 346.4 lux***

THE LUMEN

The lumen may be defined as the flow of light through an area of $1m^2$ on the surface of a sphere of 1 m radius with a uniform point source of 1 candela at its centre. The total number of lumens emitted in all the space around this source is equal to the area in square metres in the surface of a sphere having a radius of 1 m.

The surface area of a sphere may be found the formula $4\pi R^2$ and since the radius of the sphere is 1 m, its surface area will be 4π, or $12.57m^2$ approximately.

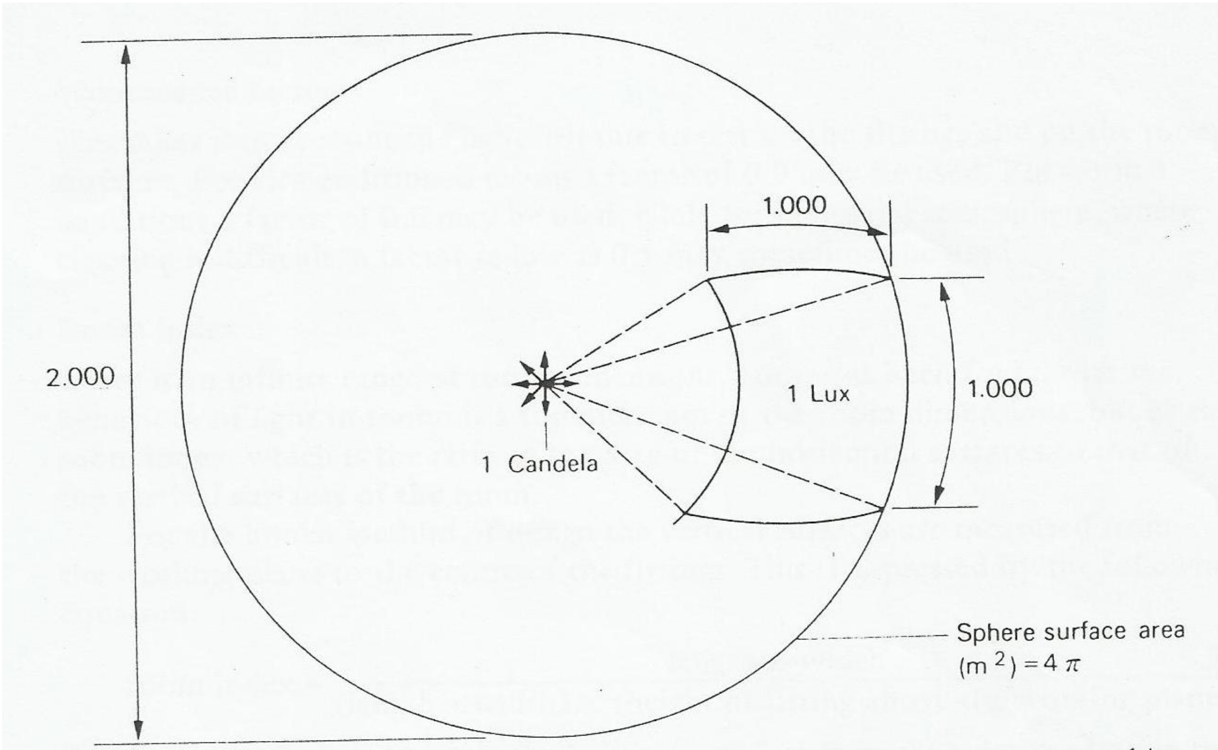


Figure 8: The light intensity and lux.

A light intensity of 1 candela on an area of the surface of the sphere of one square metre= 1 Lux total light output = 4π 1 lumen.

Since the luminous energy decreases with the square of the distance from the light source, the intensity of illumination may be found from the following expression:

$$E = \frac{F}{4\pi \times d^2}$$

Where, F = flux in lumens
d = the distance from light source to the surface in metres (m)

LUX
This is the unit of the level of illumination. An illumination of 1 lumen per square metre is equal to 1 lux

Luminous flux
A measurement of the visible light energy emitted.

Luminous intensity
A measurement of the magnitude of luminance or light reflected from a surface.

Example 3:
A diffusing spherical light-fitting is suspended so that its centre is 2 m above the work plane. If the fitting emits 1500 lumens uniformly in all directions, calculate the intensity of illumination on the working plane.

$$\text{intensity of illumination} = \frac{F}{4\pi \times d^2}$$

$$\text{intensity of illumination} = \frac{1500}{12.57 \times 2^2} = 29.83 \text{ lux}$$

Examples of illumination levels and limiting glare indices for different activities:-

Activity / location	Illumination (lux)	Limiting glare index
Assembly work: (General)	250	25
: (fine)	1000	22
Computer room	300	16
House	50 to 300*	n/a
Laboratory	500	16
Lecture / classroom	300	16
Office : (General)	500	19
: (Drawing)	750	16
Public house bar	150	22
Shops / supermarkets	500	22
Restaurant	100	22

* Varies from 50 in bedrooms to 300 in kitchen and study

The Building Regulations, approved Document L2 requires that non domestic buildings have reasonably efficient lighting systems and make use of daylight where appropriate.

ELECTRIC LIGHTING

Types of Lamps and Lighting

A lamp is an energy converter. Although it may carry out secondary functions, its prime purpose is the transformation of electrical energy into visible electromagnetic radiation. There are many ways to create light. The standard method for creating general lighting is the conversion of electrical energy into light.

The two main families of electric light are:-

1. ***Incandescent lamps,*** which produce light by a filament heated white-hot by electric current, When solids and liquids are heated, they emit visible radiation at temperatures above 1,000 K; this is known as incandescence. Such heating is the basis of light generation in filament lamps: an electrical current passes through a thin tungsten wire, whose temperature rises to around 2,500 to 3,200 K, depending upon the type of lamp and its application.

2. ***Electrical discharge lamps,*** which produce light by an electric arc through a gas. *Electrical* discharge is a technique used in modern light sources for commerce and industry because of the more efficient production of light. An electric current passed through a gas will excite the atoms and molecules to emit radiation of a spectrum which is characteristic of the elements present. Two metals are commonly used, sodium and mercury, because their characteristics give useful radiations within the visible spectrum. Discharge lamps are often classed as high pressure or low pressure, although these terms are only relative, and a high-pressure sodium lamp operates at below one atmosphere.

Performance Criteria

Performance criteria vary by application. In general, there is no particular hierarchy of importance of these criteria:-

***Light output*:**
The lumen output of a lamp will determine its suitability in relation to the scale of the installation and the quantity of illumination required.

***Colour appearance and colour rendering*:**
Separate scales and numerical values apply to colour appearance and colour rendering. It is important to remember that the figures provide guidance only, and some are only approximations. Whenever possible, assessments of suitability should be made with actual lamps and with the colours or materials that apply to the situation.

***Lamp life*:**
Most lamps will require replacement several times during the life of the lighting installation, and designers should minimize the inconvenience to the occupants of odd failures and maintenance. Lamps are used in a wide variety of applications. The anticipated average life is often a compromise between cost and performance. For example, the lamp for a slide projector will have a life of a few hundred hours because the maximum light output is important to the quality of the image. By contrast, some roadway lighting lamps may be changed every two years, and this represents some 8,000 burning hours.
Further, lamp life is affected by operating conditions, and thus there is no simple figure that will apply in all conditions. Also, the effective lamp life may be determined by different failure modes.

Physical failure such as filament or lamp rupture may be preceded by reduction in light output or changes in colour appearance. Lamp life is affected by external environmental conditions such as temperature, vibration, frequency of starting, supply voltage fluctuations, orientation and so on.
It should be noted that the average life quoted for a lamp type is the time for 50% failures from a batch of test lamps. This definition of life is not likely to be applicable to many commercial or industrial installations; thus practical lamp life is usually less than published values, which should be used for comparison only.

***Efficiency*:**
As a general rule the efficiency of a given type of lamp improves as the power rating increases, because most lamps have some fixed loss. However, different types of lamps have marked variation in efficiency. Lamps of the highest efficiency should be used, provided that the criteria of size, colour and lifetime are also met. Energy savings should not be at the expense of the visual comfort or the performance ability of the occupants. Some typical efficacies are given in table 1.

Table 1. Typical lamp efficacies

Lamp efficacies	Efficacy
100 W filament lamp	14 lumens/watt
58 W fluorescent tube	89 lumens/watt
400 W high-pressure sodium	125 lumens/watt
131 W low-pressure sodium	198 lumens/watt

Types of Luminescence

Photoluminescence occurs when radiation is absorbed by a solid and is then re-emitted at a different wavelength. When the re-emitted radiation is within the visible spectrum the process is called *fluorescence* or *phosphorescence*.

Electroluminescence occurs when light is generated by an electric current passed through certain solids, such as phosphor materials. It is used for self-illuminated signs and instrument panels but has not proved to be a practical light source for the lighting of buildings or exteriors.

The fluorescent tubular lamp became the dominant light source because it made possible the shadow-free and comparatively heat-free lighting of factories and offices, allowing maximum use of the space. The light output and wattage requirements for a typical 1,500 mm fluorescent tubular lamp is given in table 2.

Table 2. Improved light output and wattage requirements of some typical 1,500 mm fluorescent tube lamps

Rating (W)	Diameter (mm)	Gas fill	Light output (lumens)
80	38	argon	4,800
65	38	argon	4,900
58	25	krypton	5,100
50	25	argon	5,100 (high frequency gear)

Table 3: Main lamp types

Type (code)	Common ratings (watts)	Colour rendering	Colour temperature (K)	Life (hours)
Compact fluorescent lamps (FS)	5–55	good	2,700–5,000	5,000–10,000
High-pressure mercury lamps (QE)	80–750	fair	3,300–3,800	20,000
High-pressure sodium lamps (S-)	50–1,000	poor to good	2,000–2,500	6,000–24,000
Incandescent lamps (I)	5–500	good	2,700	1,000–3,000
Induction lamps (XF)	23–85	good	3,000–4,000	10,000–60,000
Low-pressure sodium lamps (LS)	26–180	monochromatic yellow colour	1,800	16,000
Low-voltage tungsten halogen lamps (HS)	12–100	good	3,000	2,000–5,000
Metal halide lamps (M-)	35–2,000	good to excellent	3,000–5,000	6,000–20,000
Tubular fluorescent lamps (FD)	4–100	fair to good	2,700–6,500	10,000–15,000
Tungsten halogen lamps (HS)	100–2,000	good	3,000	2,000–4,000

The most efficient source of electric light is the low-pressure sodium lamp. It produces, for all practical purposes, a monochromatic orange/yellow light, which gives a similarly monochromatic perception of any illuminated scene. For this reason, it is generally reserved for outdoor public lighting usages. Low-pressure sodium lights are favored for public lighting by astronomers, since the light pollution that they generate can be easily filtered, contrary to broadband or continuous spectra.

INCANDESCENT LAMPS

These lamps use a tungsten filament in an inert gas or vacuum with a glass envelope. The inert gas suppresses tungsten evaporation and lessens the envelope blackening. There is a large variety of lamp shapes, which are largely decorative in appearance.

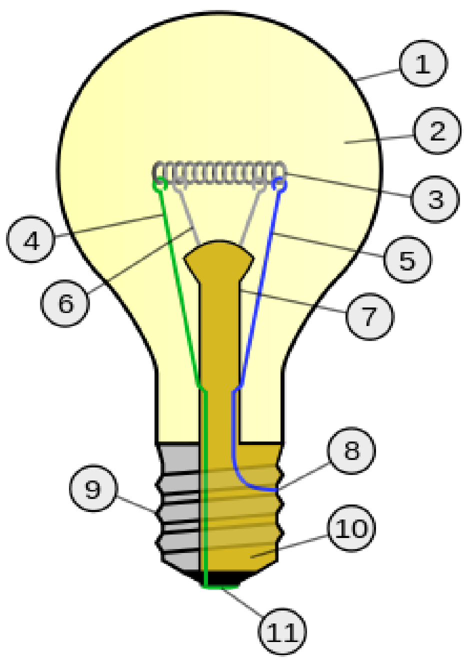
Incandescent light bulbs consist of an air-tight glass enclosure (the envelope, or bulb) with a filament of tungsten wire inside the bulb, through which an electric current is passed. Contact wires and a base with two (or more) conductors provide electrical connections to the filament. Incandescent light bulbs usually contain a stem or glass mount anchored to the bulb's base that allows the electrical contacts to run through the envelope without air or gas leaks. Small wires embedded in the stem in turn support the filament and its lead wires.

The bulb is filled with an inert gas such as argon (93%) and nitrogen (7%) to reduce evaporation of the filament and prevent its oxidation at a pressure of about 70 kPa (0.7 atm).

An electric current heats the filament to typically 2,000 to 3,300 K (3,140 to 5,480 °F), well below tungsten's melting point of 3,695 K (6,191 °F). Filament temperatures depend on the filament type, shape, size, and amount of current drawn. The heated filament emits light that approximates a continuous spectrum. The useful part of the emitted energy is visible light, but most energy is given off as heat in the near-infrared wavelengths.

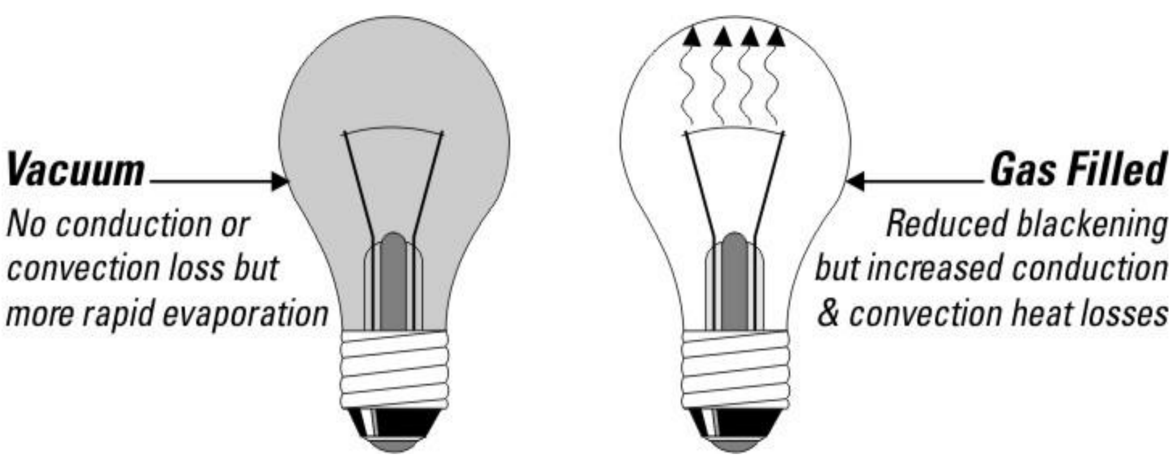
Three-way light bulbs have two filaments and three conducting contacts in their bases. The filaments share a common ground, and can be lit separately or together. Common wattages include 30–70–100, 50–100–150, and 100–200–300, with the first two numbers referring to the individual filaments, and the third giving the combined wattage.

Figure 9:



1. Outline of Glass bulb
2. Low pressure inert gas (argon, nitrogen, krypton, xenon)
3. Tungsten filament
4. Contact wire (goes out of stem)
5. Contact wire (goes into stem)
6. Support wires (one end embedded in stem; conduct no current)
7. Stem (glass mount)
8. Contact wire (goes out of stem)
9. Cap (sleeve)
10. Insulation
11. Electrical contact

Figure10: The different between vacuum and gas filled bulb



Incandescent lamps are also available with a wide range of colours and finishes. The ILCOS codes and some typical shapes include those shown in table 4.

Table 4. Common colours and shapes of incandescent lamps

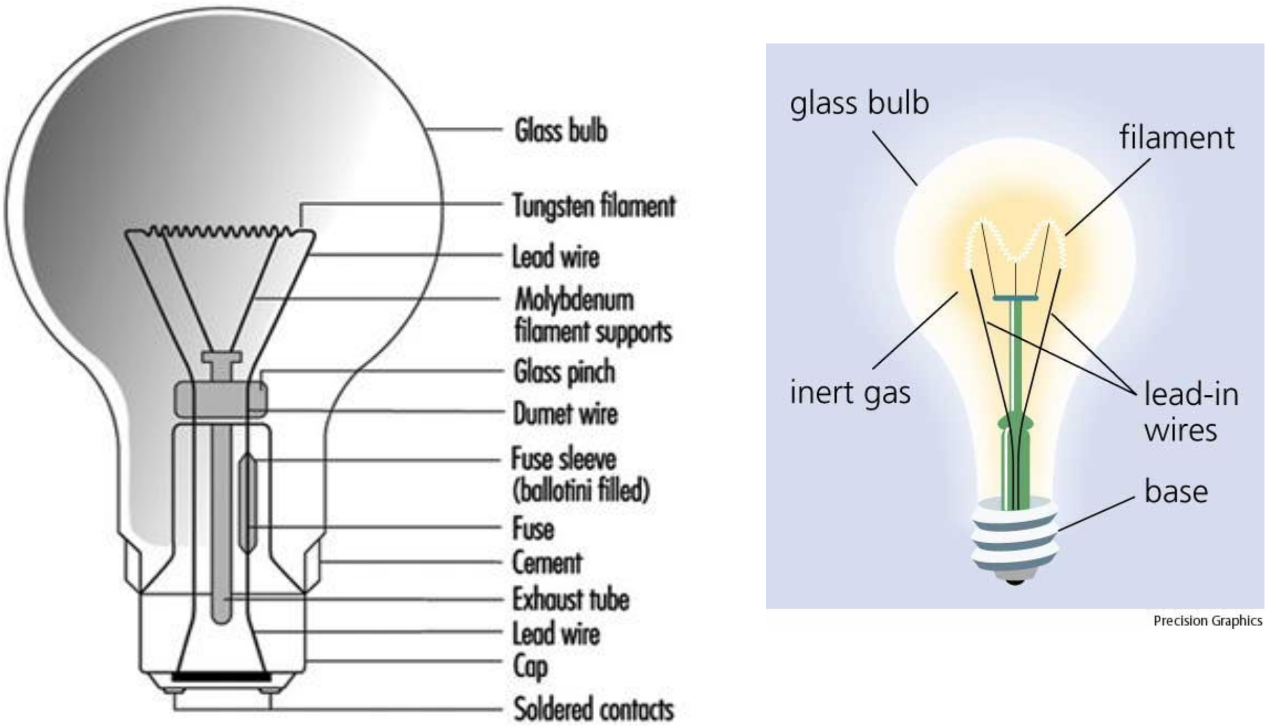
Colour/Shape	Code
Clear	/C
Frosted	/F
White	/W
Red	/R
Blue	/B
Green	/G
Yellow	/Y
Pear shaped (GLS)	IA
Candle	IB
Conical	IC
Globular	IG
Mushroom	IM

Incandescent lamps are still popular for domestic lighting because of their low cost and compact size. However, for commercial and industrial lighting the low efficacy generates very high operating costs, so discharge lamps are the normal choice. A 100 W lamp has a typical efficacy of 14 lumens/watt compared with 96 lumens/watt for a 36 W fluorescent lamp.
Incandescent lamps are simple to dim by reducing the supply voltage, and are still used where dimming is a desired control feature.
The tungsten filament is a compact light source, easily focused by reflectors or lenses. Incandescent lamps are useful for display lighting where directional control is needed.

Filament Lamps
The tungsten iodine lamp is used for floodlighting. Evaporation from the filament is controlled by the pressure of iodine vapour. The gas-filled, general-purpose filament lamp has a fine tungsten wire seated within a glass bulb. The wire is heated to incandescence (while heat) by the passage of an electric current.

Discharge lamps
These do not have a filament but produce light by excitation of a gas. When voltage is applied to the two electrodes, ionsation occurs until a criticl value is reached when current flow between them. As the temperature rises, the mercury vaporizes and electrical discharge between the main electrodes causes light to be emitted.

Figure 11: Tungsten lamps



Tungsten halogen lamps

These are similar to incandescent lamps and produce light in the same manner from a tungsten filament. However the bulb contains halogen gas (bromine or iodine) which is active in controlling tungsten evaporation

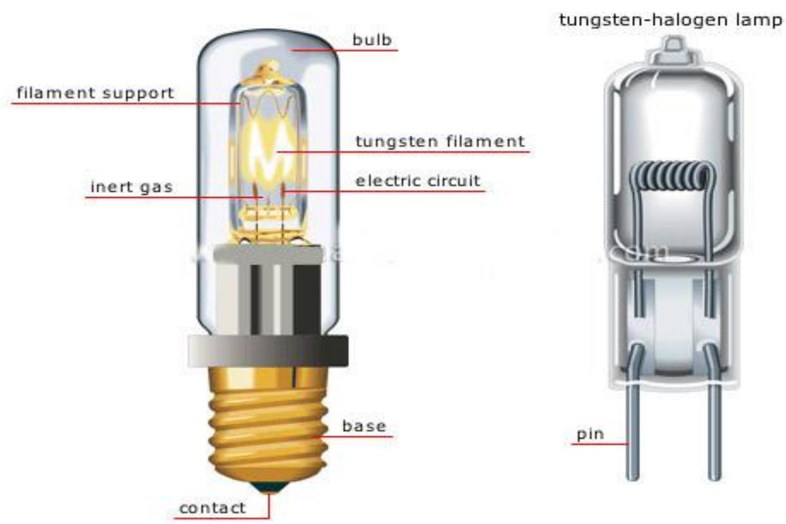


Figure 12: Tungsten-halogen lamp

Fundamental to the halogen cycle is a minimum bulb wall temperature of 250 °C to ensure that the tungsten halide remains in a gaseous state and does not condense on the bulb wall. This temperature means bulbs made from quartz in place of glass. With quartz it is possible to reduce the bulb size.

Most tungsten halogen lamps have an improved life over incandescent equivalents and the filament is at a higher temperature, creating more light and whiter colour.
Tungsten halogen lamps have become popular where small size and high performance are the main requirement. Typical examples are stage lighting, including film and TV, where directional control and dimming are common requirements.

Low-voltage tungsten halogen lamps
These were originally designed for slide and film projectors. At 12 V the filament for the same wattage as 230 V becomes smaller and thicker. This can be more efficiently focused, and the larger filament mass allows a higher operating temperature, increasing light output. The thick filament is more robust. These benefits were realized as being useful for the commercial display market, and even though it is necessary to have a step-down transformer, these lamps now dominate shop-window lighting. See figure 3.

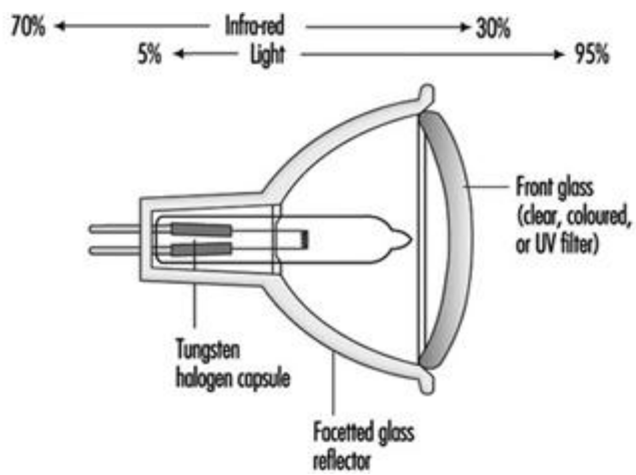


Figure 13: Low-voltage diachronic reflector lamp

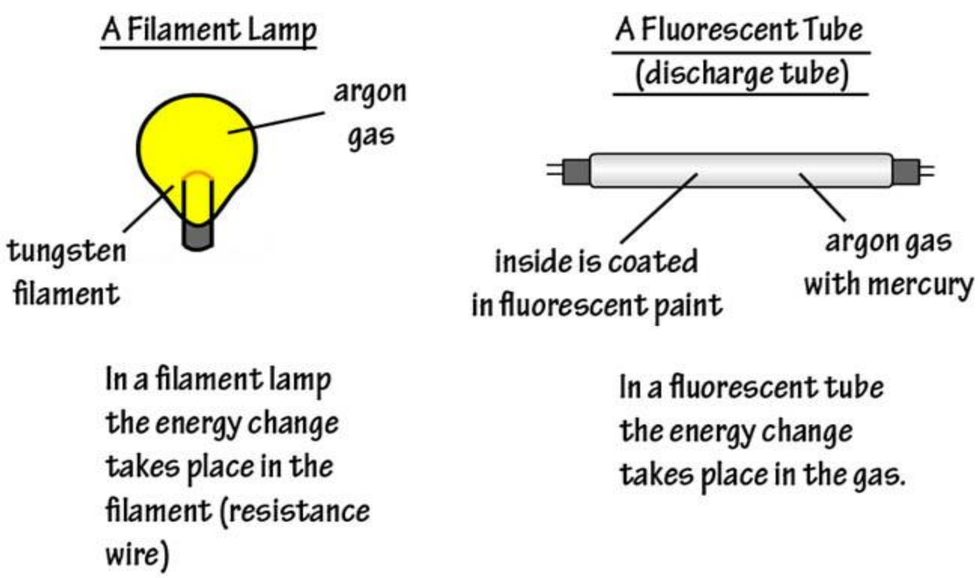
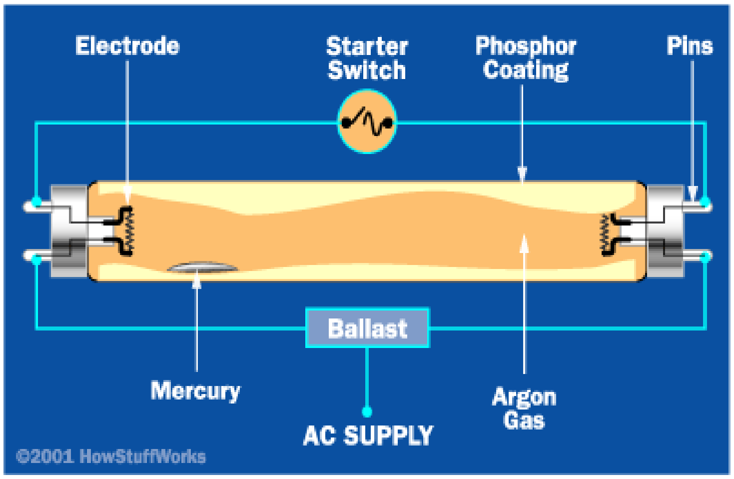
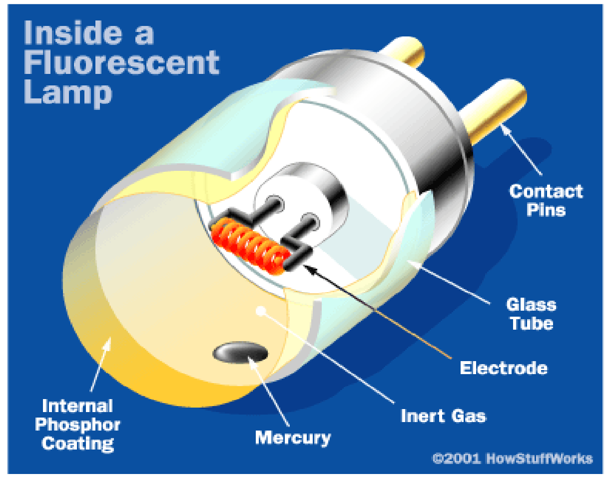


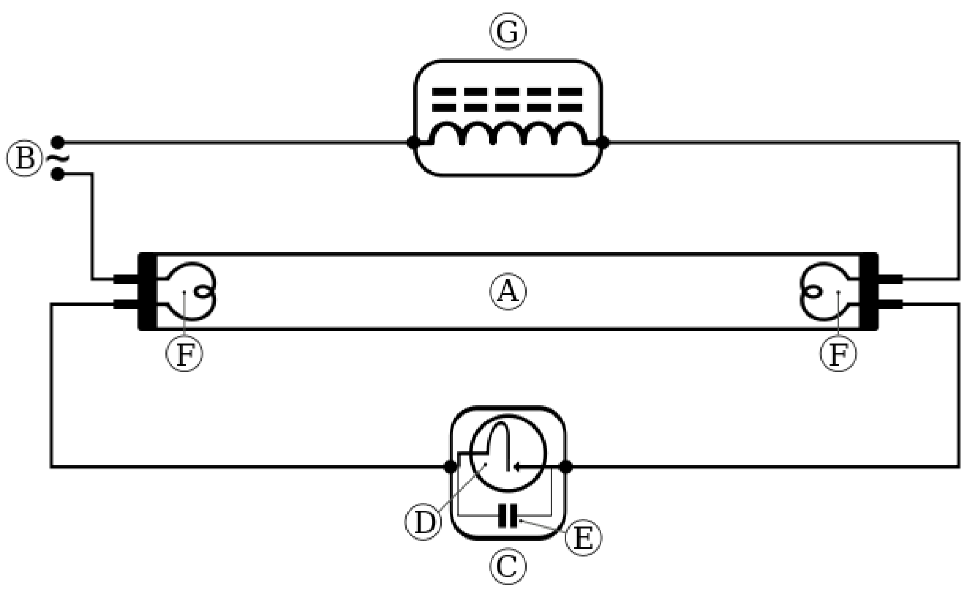
Figure 14: The different between a filament lamp and a fluorescent tube

FLUORESCENT LAMP

This is a low pressure mercury-vapor gas-discharge lamp that uses fluorescence to produce visible light. An electric current in the gas excites mercury vapor which produces short-wave ultraviolet light that then causes a phosphor coating on the inside of the bulb to fluoresce, producing light.. Energized mercury atoms emit ultra-violet radiation and a blue/green light. The tube is coated internally with a fluorescent powder which absorbs the ultra-violet light and re-radiates it as visible light.







A: Fluorescent tube, B: Power (+220 volts), C: Starter, D: Switch (bi-metallic thermostat), E: Capacitor, F: Filaments, G: Ballast

Figure 15: Operation of Fluorescent light

Fluorescent strip lamps have many applications. The fitting reflectors shown are appropriate for use in industrial locations with a variation which creates an illuminated ceiling more suited to shops and offices. A false ceiling of thermal scent panels provides well diffused illumination without glare and contributes to the insulation of the ceiling. Other services should not be installed in the void as they will cast shadows on the ceiling. Tubes are mounted on batten fittings and the inside of the void should be painted white maximize effect.

A fluorescent lamp converts electrical power into useful light much more efficiently than incandescent lamps. The luminous efficacy of a fluorescent light bulb can exceed 100 lumens per watt, several times the efficacy of an incandescent bulb with comparable light output.

Fluorescent lamp fixtures are more costly than incandescent lamps because they require a ballast to regulate the current through the lamp, but the lower energy cost typically offsets the higher initial cost.

The compact fluorescent lamp is now available in the same popular sizes as incandescent and is used as an energy-saving alternative in homes. Because they contain mercury, many fluorescent lamps are classified as hazardous waste.

Compact fluorescent lamps
The fluorescent tube is not a practical replacement for the incandescent lamp because of its linear shape. Small, narrow-bore tubes can be configured to approximately the same size as the incandescent lamp, but this imposes a much higher electrical loading on the phosphor material. The use of tri-phosphors is essential to achieve acceptable lamp life.

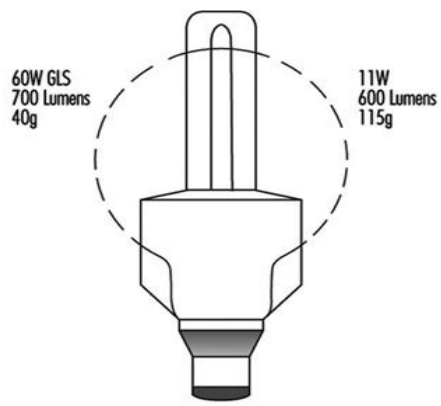
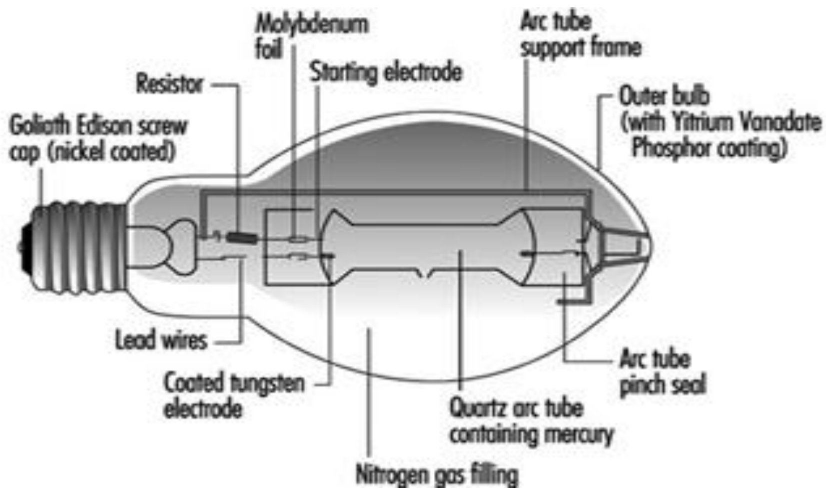


Figure 16: Four-leg compact fluorescent

All compact fluorescent lamps use tri-phosphors, so, when they are used together with linear fluorescent lamps, the latter should also be tri-phosphor to ensure colour consistency.
Some compact lamps include the operating control gear to form retro-fit devices for incandescent lamps. The range is increasing and enables easy upgrading of existing installations to more energy-efficient lighting. These integral units are not suitable for dimming where that was part of the original controls.

Induction lamps
Lamps using the principle of induction have recently appeared on the market. They are low-pressure mercury lamps with tri-phosphor coating and as light producers are similar to fluorescent lamps. The energy is transferred to the lamp by high-frequency radiation, at approximately 2.5 MHz from an antenna positioned centrally within the lamp. There is no physical connection between the lamp bulb and the coil. Without electrodes or other wire connections the construction of the discharge vessel is simpler and more durable. Lamp life is mainly determined by the reliability of the electronic components and the lumen maintenance of the phosphor coating.

High-pressure mercury lamps
High-pressure discharges are more compact and have higher electrical loads; therefore, they require quartz arc tubes to withstand the pressure and temperature. The arc tube is contained in an outer glass envelope with a nitrogen or argon-nitrogen atmosphere to reduce oxidation and arcing. The bulb effectively filters the UV radiation from the arc tube.



Mercury-vapour discharge lamp (efficacy = 50 lumen/W)

Figure 17: Mercury lamp construction

At high pressure, the mercury discharge is mainly blue and green radiation. To improve the colour a phosphor coating of the outer bulb adds red light. There are deluxe versions with an increased red content, which give higher light output and improved colour rendering.

All high-pressure discharge lamps take time to reach full output. The initial discharge is via the conducting gas fill, and the metal evaporates as the lamp temperature increases.
At the stable pressure the lamp will not immediately restart without special control gear. There is a delay while the lamp cools sufficiently and the pressure reduces, so that the normal supply voltage or ignitor circuit is adequate to re-establish the arc.

Discharge lamps have a negative resistance characteristic, and so the external control gear is necessary to control the current. There are losses due to these control gear components so the user should consider total watts when considering operating costs and electrical installation. There is an exception for high-pressure mercury lamps, and one type contains a tungsten filament which both acts as the current limiting device and adds warm colours to the blue/green discharge. This enables the direct replacement of incandescent lamps.

Although mercury lamps have a long life of about 20,000 hours, the light output will fall to about 55% of the initial output at the end of this period, and therefore the economic life can be shorter.

Low-pressure sodium lamps
The arc tube is similar in size to the fluorescent tube but is made of special ply glass with an inner sodium resistant coating. The arc tube is formed in a narrow “U” shape and is contained in an outer vacuum jacket to ensure thermal stability.

During starting, the lamps have a strong red glow from the neon gas fill. The characteristic radiation from low-pressure sodium vapour is a monochromatic yellow. This is close to the peak sensitivity of the human eye, and low-pressure sodium lamps are the most efficient lamps available at nearly 200 lumens/watt. However the applications are limited to where colour discrimination is of no visual importance, such as trunk roads and underpasses, and residential streets.

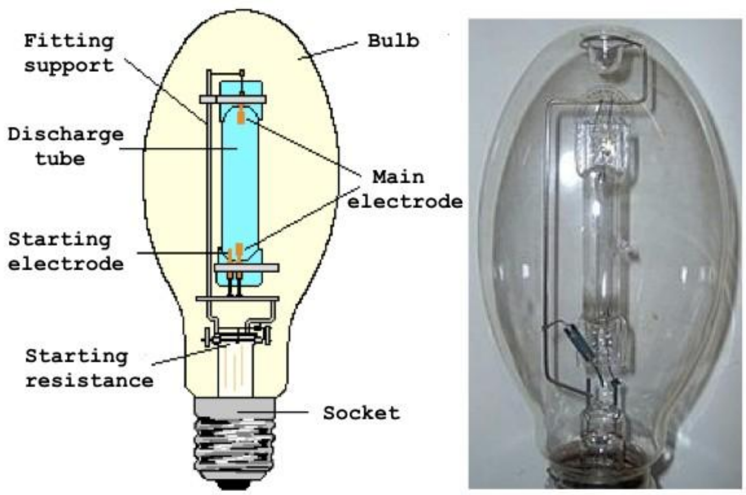


Figure 18: Low pressure sodium lamp

In many situations these lamps are being replaced by high-pressure sodium lamps. Their smaller size offers better optical control, particularly for roadway lighting where there is growing concern over excessive sky glow.

High-pressure sodium lamps
These lamps produce a consistent golden white light in which it is possible to distinguish colours. They are suitable for floodlighting, commercial and industrial lighting and illumination of highways. The low pressure variant produces light that is virtually monochromatic. The colour rendering poor when compared to the high pressure lamp. Sodium vapour pressure for high and low pressure lamps is 0.5Pa and 33kPa and tpical efficacy is 125 and 180 lumen/W respectively.

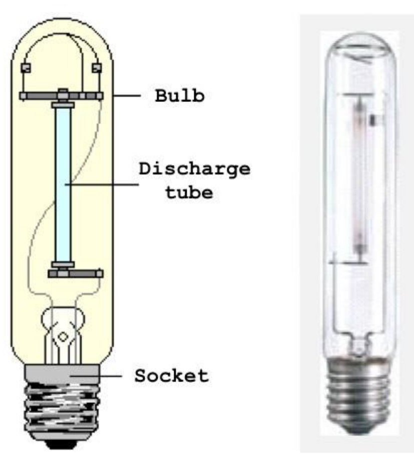


Figure 19: High-pressure sodium lamp

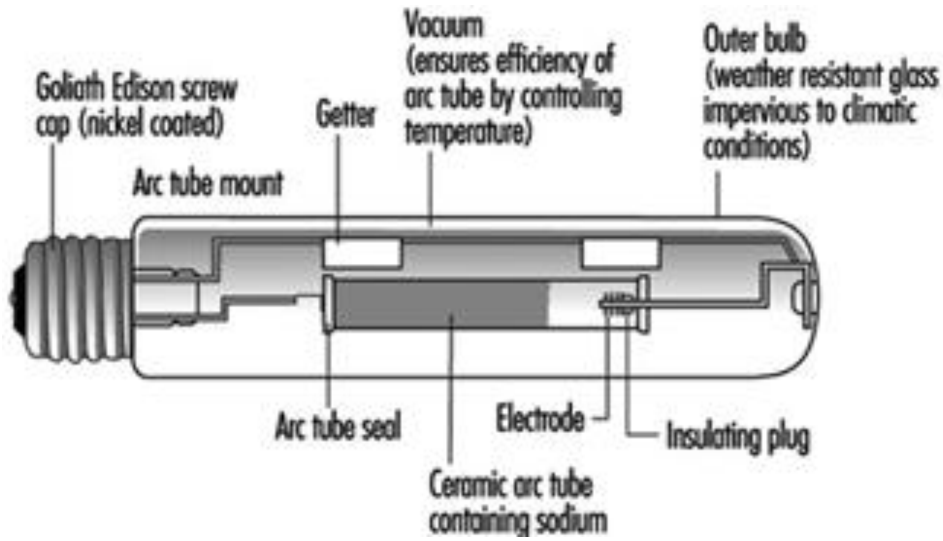


Figure 20: High-pressure sodium lamp construction

As the sodium pressure is increased, the radiation becomes a broad band around the yellow peak, and the appearance is golden white. However, as the pressure increases, the efficiency decreases. There are currently three separate types of high-pressure sodium lamps available, as shown in table 5.

Table 5. Types of high-pressure sodium lamp

Lamp type (code)	Colour (K)	Efficacy (lumens/watt)	Life (hours)
Standard	2,000	110	24,000
Deluxe	2,200	80	14,000
White (SON)	2,500	50	

Generally the standard lamps are used for exterior lighting, deluxe lamps for industrial interiors, and White SON for commercial/display applications.

Dimming of Discharge Lamps

The high-pressure lamps cannot be satisfactorily dimmed, as changing the lamp power changes the pressure and thus the fundamental characteristics of the lamp.

Fluorescent lamps can be dimmed using high-frequency supplies generated typically within the electronic control gear. The colour appearance remains very constant. In addition, the light output is approximately proportional to the lamp power, with consequent saving in electrical power when the light output is reduced. By integrating the light output from the lamp with the prevailing level of natural daylight, a near constant level of luminance can be provided in an interior.