Illumination terms - Laws

Objectives: At the end of this lesson you shall be able to
- **explain the nature of light**
- **state and explain different terms used in illumination**
- **state properties and advantages of good illumination**
- **state and explain laws of illumination.**

The nature of light

Light is a form of electromagnetic radiation. It is basically the same thing as the radiations used in radio, television, X-rays, gamma rays etc. Visible light is the radiation in that part of the spectrum between 380 and 760 (nm) nanometre (10^{-9}M) to which the human eye is sensitive. A nanometre (nm) is a wavelength of one millionth (10^{-6} mm) of a millimetre.

Within these limits, differences in the wavelength produce the effect of colour, blue light being at the short-wave and red at the long-wave ends of the visible spectrum. Because the human eye is more sensitive to the yellow and green light in the middle of the spectrum, more power must be expended to produce the same effect from colours at the end of the spectrum.

Standared safety norms:

Trainees may be instructed to refer the Internation Electrotechnic Commission (IEC - 60598 part 2 section 3) web site for standard safety norms related with electrical illumination system for further details

Definitions

A few principle terms in connection with illumination are defined below.

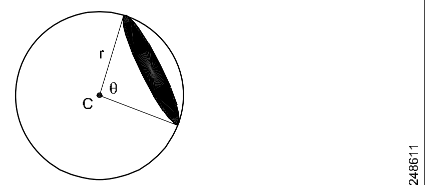
Luminous flux (F or Φ)**:** The flux of light emitted from a luminous body is the energy radiated per second in the form of light waves. The unit of luminous flux is `lumen'(lm).

Luminous intensity(I): The luminous intensity of a light source in a given direction is the luminous flux given out by the light source per unit solid angle. The angle subtended by an area r^2 on the surface of sphere of radius r, at the centre of sphere is unit solid angle. In SI, the unit of luminous intensity is the candela.

Candela: This is the amount of light emitted in a given direction by a source of one candle power. SI base unit is candela (cd). 1 candela = 0.982 international candles.

Lumen (lm)**:** It is the unit of luminous flux. This is defined as the amount of light contained in one steradian from a source of one candela at its focus. (Fig 1)

Fig 1



If the shaded area = r^2 and a source of one candela is at the centre C, the light contained within the solid angle is one lumen.

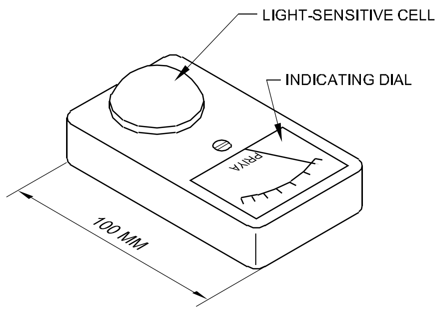
The light output of electric lamp is measured in lumens and their luminous efficiency (efficacy) is expressed in lumens per watt (lm/w).

Illuminance or Illumination (E): Illuminance of a surface is defined as the luminous flux reaching it perpendicularly per unit area. The metric unit is the lumen / m^2 or lux (lx).

Lux: This is the total output of light. Lumen per square meter (1m/m^2) or lux is the intensity of illumination produced in the inner surface of a hollow sphere of radius one meter by a standard candle at the centre. Sometimes this is also known as metre-candle.

Lighting engineers use a pocket-size instrument called a `lightmeter' to measure illuminance; and the reading in lux is read off the scale (Fig 2). This is not the same sort of instrument as a photographic exposure meter, which measures brightness, not illuminance.

Fig 2



TYPICAL POCKET-SIZE LIGHT-METER FOR MEASURING ILLUMINANCE.

Measured brightness is termed `luminance', and it should not be confused with `illuminance'. Luminance is the lumens emitted by a luminous surface of one square metre.

Two other terms that are easily confused with each other are `luminance' and `luminosity'. The first is measured brightness expressed in apostlibs or candelas per square metre, the second the apparent brightness as seen by the eye.

A simple example is the appearance of a motor car head lamps by day and by night. Their luminance is the same in both conditions but their luminosity is far greater at night than when it is seen in daylight.

Factors to be viewed for correct illumination

The following are the important factors which should be considered while planning correct and a good illumination:

Nature of work : Considering the nature of work , sufficient and suitable lighting sould be maintained. For example, a delicate work like radio and TV assembling, etc. requires good illumination to increase the production of work where as for rough work like storage, garages, etc needs very small illumination.

Design of Apartment : The design of apartment must be kept in view while planning scheme for illumination. It means that the light emitted by the illumination source should not strike the eyes of the occupants or workers.

Cost : It is an important factor which should be considered while designing an illumination scheme for particular purpose.

Maintenance Factor : While planning illumination, it should also be kept in view the amount of reduction of light due to accumulation of dust or smoke on the source of light and after how much period cleanliness is required. Where there is a possibility of heavy loss of light due to the adherence of smoke, arrangement for the extra light is to be made from the very beginning.

Properties of good illumination

An illumination source should, have the following properties.

i It should have sufficient light.

ii It should not strike the eyes.

iii It should not produce glareness in the eyes.

iv It should be installed at such a place that it gives uniform light.

v It should be of correct type as needed.

vi It should have suitable shades and refelectors.

Advantages of good illumination

i It increases production in the workshop.

ii It reduces the chances of accidents.

iii It does not strain the eyes.

iv It reduces the wastage or loss of material.

v It increases the interior decoration of the building.

vi It gives smoothing effect to mind.

Laws of illumination

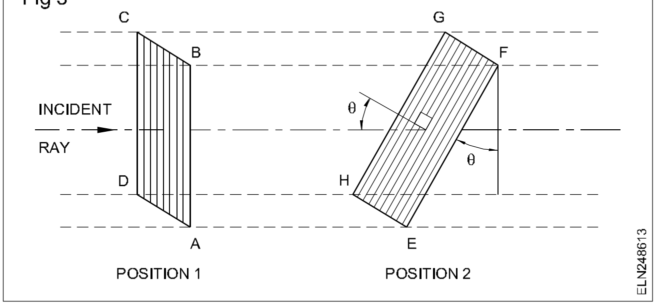
Inverse square law: If the internal radius of a sphere is increased from 1 metre to r metres, the surface area of it is increased from 4π to $4\pi r^2$ square metres. With a uniform point source of light of one candela at the centre, the number of lumen per square metre on the sphere of radius r metres.

$$= \frac{4\pi}{4\pi r^2} = \frac{1}{r^2}$$

Hence the illumination of a surface is inversely proportional to the square of its distance from the source. This is called the **Inverse Square Law of Illumination.**

Lambert's cosine law: According to this law, illumination (E) is directly proportional to the cosine of the angle made by the normal to illuminated surface with the direction of the incident flux. (Fig 3) Let Φ be the flux incident on the surface of area ABCD when in position 1. When this surface is so placed that the angle between the incident ray and the perpendicular to the surface EFGH is θ. The luminous flux falling on area EFGH is Φ.

Fig 3



Hence the illumination on the surface in position 1 is

$$E_1 = \frac{\Phi}{\text{Area ABCD}}$$

But in position 2, the illumination is

$$E_2 = \frac{\Phi}{\text{Area EFGH}}$$

(Area ABCD = AB x BC,

Area EFGH = EF x GF

$$= \frac{AB}{\cos\theta} \times BC$$

because, $\cos\theta = \frac{AB}{EF}$

Therefore, $E_2 = \frac{\Phi \times \cos\theta}{\text{Area ABCD}} = E_1 \cos\theta$

So illumination on EFGH

$$= \frac{1}{d^2} \times \cos\theta$$

where `d' is the distance of the surface from a source having a luminous intensity of one candela.

Filament lamps

Objectives : At the end of this lesson you shall be able to
- **list out the types of lamps**
- **explain the different types of lamps**
- **explain the construction and working of tungsten filament lamp.**

Types of lamps

There are many types of electric lamps now available. They differ in construction and in the principle of operation. The lamps can be grouped on the principle of operation as follows.

Filament lamps fall into a group of light producing devices called `incandescents'. They give light as a result of heating the filament to a very high temperature. The definitions of the terms are given below.

Electric lamps
- Filament lamps
  - Carbon
  - Metal
- Arc lamps
- Discharge lamps
  - Cold cathode
  - Hot cathode

Filament lamp: A lamp in which a metal, carbon or other filament is rendered incandescent by the passage of electric current.

Vacuum lamp: A filament lamp in which the filament operates in a vacuum.

Gas-filled lamp: A filament lamp in which the filament operates in an inert gas.

Halogen lamp: A tungsten filament lamp in which the tungsten filament operates in a relatively small space filled with an inert gas and halogen of iodine or bromine.

Arc lamp: An electric lamp in which the light is emitted by an arc.

Discharge lamp: An electric lamp in which the light is obtained by a discharge of electricity between two electrodes in gas or vapour.

Carbon filament lamp: The carbon filaments made today have limited application as resistance lamps (battery charging) and radiant heat apparatus. This lamp gives a reddish light and operates at a temperature about 2000°C. Above this limit, the carbon evaporates rapidly and blackens the glass bulb or envelope. The output from a carbon filament lamp is abot 3 lm/W (lumens per watt).

Tungsten filament lamp: This lamp consists essentially of a fine wire of the metal, tungsten (the filament) supported in a glass envelope and the air evacuated from the glass bulb - hence called a **vacuum lamp**.

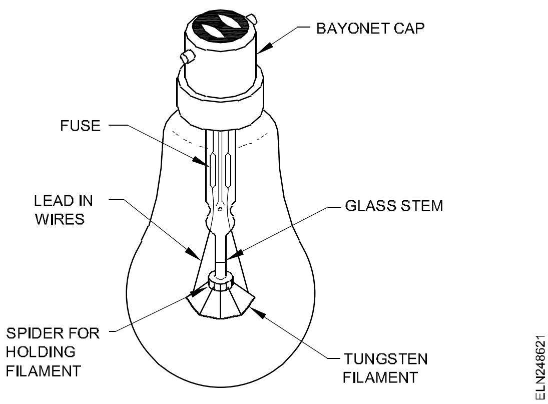
Filaments are now constructed of tungsten due to its exceptionally high melting point. It operates at a temperature of 2300° C and has an output of about 8 lm/W.

At temperatures above 2000°C, whilst the filament does not melt, it begins to break up and particles fly to the side of the lamp. This causes the glass bulb to become blackened. (Frequently observable in torch light bulbs.) The evaporation causes weak spots in the filament resulting in uneven resistance, which sets up hot spots and the filament burns out and breaks, i.e. fuses.

Filling up the bulb with an inert gas reduces the rate of evaporation. Argon and nitrogen are inert gases which do not support combustion. The operating temperature of a gas-filled lamp is about 2700°C. The output is in the region of 12 lm/W.

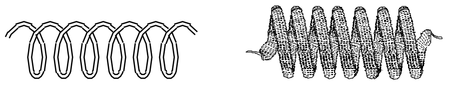
Fig 1 shows the parts of tungsten filament lamp

Fig 1



The two types of filaments (Fig 2) are

Fig 2



- single coil filament
- coiled coil filament.

The main advantage of a coiled coil lamp is the higher light output.

Most general lighting service (GLS) filament lamps used in homes have a bayonet cap (BC). Some small lamps used in special fittings have a `small' bayonet cap (SBC). Some GLS lamps have an Edison screw (ES) cap. There are also `small' Edison screw (SES) and `giant' Edison screw (GES) caps.

ES Caps are favoured for spot lights in which the lamp must be accurately positioned. Each type of lamp can be used only in an appropriate design of a lamp holder.

The rated life of GLS lamps is 1000 hours. This means that in any batch of lamps, 50 percent will have failed after 1000 hours of use. The life of an individual lamp in any batch may be greater or less than this average. The rated life is achieved in `normal conditions of use'. The normal conditions of use are

- operated cap up
- free from vibration
- not subjected to a voltage in excess of the rated voltage
- suitable light fittings.

Operating a filament lamp at a voltage higher than its rated voltage will reduce its life. Lower operating voltage will extend its life. At higher voltage, the filament gives a whiter and a more bluish light and operates at brighter and higher efficiency.

Lights and light fittings

Objectives: At the end of this lesson you shall be able to
- **name the types of bulbs for illumination**
- **explain direct and indirect lighting.**

Types of lamps used for illumination: The lamps used are:

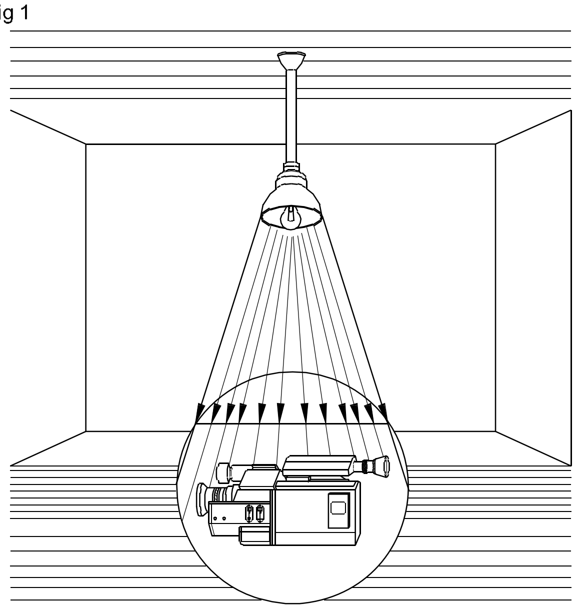
- incandescent lamps
- tube lights

Types of bulbs/incandescent lamps

- Glow lamps
- Moonlight lamps
- Luminous lamps
- Daylight lamps
- Tree light lamps
- Photo flood lamps
- Movie flood lamps
- Photo flash lamps
- Silvered bowl lamps
- Projector lamps
- Reflector lamps
- Halogen lamps.

Points to remember while designing illumination direct lighting and indirect lighting: Lighting for commercial purposes is divided into many parts such as built in direct lighting (Fig 1), indirect lighting (Fig 2), core lighting, spot lighting etc.

Fig 1



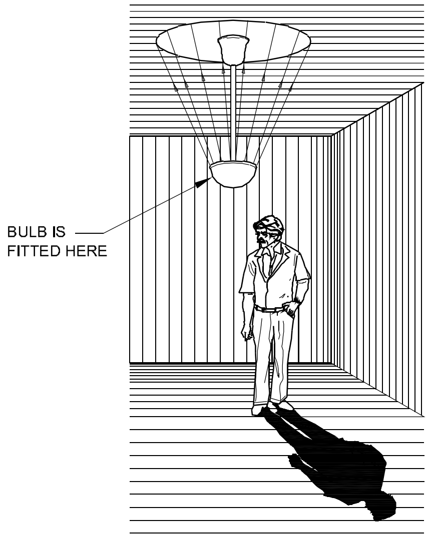
DIRECT LIGHTING

To achieve the above lighting there are ceiling fixtures, side wall fixtures, portable fixtures and other luminaries available.

The number of lumens required for the working place is 150 lumens/m^2. The lumens provided by the lamp must however be greater than this figure to allow for depreciation of the installation owing to dust and dirt on the lamps and their fittings.

Atleast 150 lumens per square metre should be provided for

Fig 2



INDIRECT LIGHTING

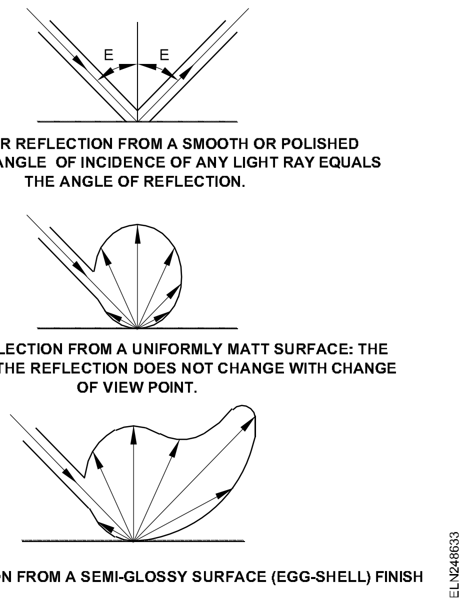
adequate visual performance on rough or unskilled work. Up to 1500 lumens per square metre should be provided for difficult or fine works.

Most sources radiate light in all direction and are too bright to be viewed comfortably. The light must therefore be controlled to direct it where it is required and to soften its brilliance.

Reflection of light may be of three kinds.

- Specular reflection Fig 3(a)
- Diffuse reflection Fig 3(b)
- Spread reflection Fig 3(c)

Fig 3



a) SPECULAR REFLECTION FROM A SMOOTH OR POLISHED SURFACE THE ANGLE OF INCIDENCE OF ANY LIGHT RAY EQUALS THE ANGLE OF REFLECTION.

b) DIFFUSE REFLECTION FROM A UNIFORMLY MATT SURFACE: THE BRIGHTNESS OF THE REFLECTION DOES NOT CHANGE WITH CHANGE OF VIEW POINT.

c) SPREAD REFLECTION FROM A SEMI-GLOSSY SURFACE (EGG-SHELL) FINISH

Specular reflection: When light strikes a mirror like surface it is reflected at the same angle and in the same plane as it strikes, for example a car lamp.

Diffuse reflection: Diffuse reflection is useless for the precise control of light, but it can be used to reflect light in a general direction.

Spread reflection: Unpolished metals and satin-finish mirrored surfaces have reflection characteristics between specular and diffuse. Vitreous and synthetic enamels are widely used for reflecting surfaces of light fittings. Vitreous enamels is the more hard working.

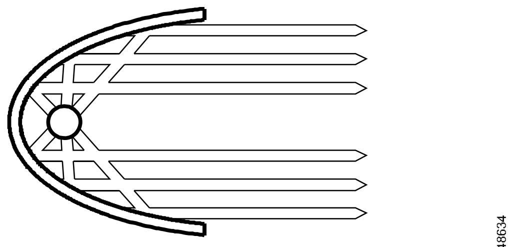
Types of reflectors: A lamp without any kind of reflector will radiate light in every direction. By placing the lamp within a reflector, you can control the light and direct it where you want it.

Dispersive type: The reflecting surface is either white enamelled or vitreous enamelled. The Viterous enamelled type is more expensive and less efficient optically but are more suitable for use in damp and corrosive atmosphere.

Mirror type reflector: These have highly polished surface for specular reflection. Silvered glass, Chromium plated; copper sheet anodized aluminium shades are typical example of this. This type is used in yard lighting

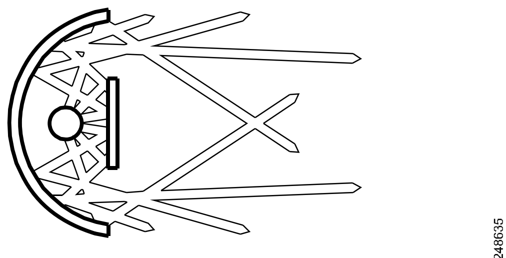
Parabolic and softlight reflector (Fig 4 & Fig 5): A parabolic reflector produces a hard light and is most commonly used with tungsten lamps. A softlight reflector has shield in front of the bulb and so produces a diffused light. A spotlight enables you to vary the light beam. In each case, the light will be softer if the reflector surface is matted or dimpled rather than highly polished.

Fig 4



PARABOLIC REFLECTOR

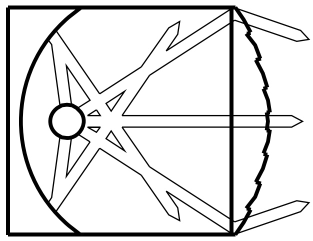
Fig 5



SOFTLIGHT REFLECTOR

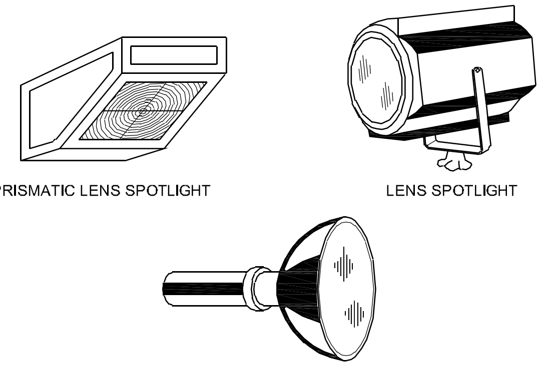
Spotlighting (Figs 6 & 7)**:** Spotlighting is one way lighting, usually employed projectors with lenses but sometimes with reflectors only, and is used to give special illumination to a limited area as in theatre practice. The spotlights must be so located as to be out of the direct line of vision and produce no troublesome reflections or glare.

Fig 6



SPOTLIGHT

Fig 7



TYPE OF SPOTLIGHT FIXTURES

Supplementary lighting: Supplementary lighting as the name implies, should be employed in conjunction with a general lighting system, when necessary or desirable.

Light fitting, types and performance (Fig 8)

Direct lighting type has largest efficiency from energy utilization point of view but glare is always present. Such systems are used for flood and Industrial lighting.(Fig 8a)

Indirect lighting type designed to avoid glare and recommended for specific purposes.(Fig 8b)

Semi direct type designed to avoid glare and recommended for offices and other specific purposes. (Fig 8c)

Semi indirect type designed to avoid glare and recommended for specific purposes.(Fig 8d)

General diffusing type system has got low efficiency but are free from glare and has got uniform distribution of light.

Details of reflector's and their %age of light distribution is given in Table 1 for your reference.

Fig 8

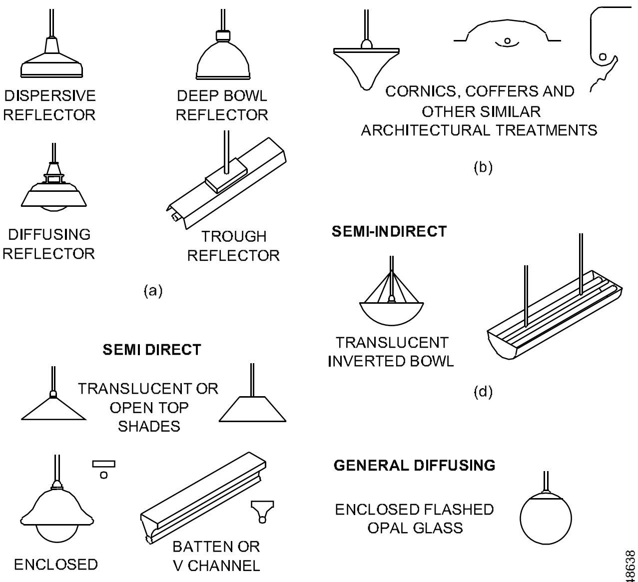


Table 1

Lighting systems

Types of system	**Amount of emergent light**	
	Downward	**Upward**
Shaded or reflector system		
1 Direct	90 to 100%	0 to 10%
2 Semi direct	60 to 90%	10 to 40%
3 Semi indirect	10 to 40%	60 to 90%
4 Indirect	0 to 10%	90 to 100%
Diffused system		
1 General diffused	50%	50%

Above table is in line with CIE classification of general indoor lighting luminaries

Low voltage lamps - different wattage lamps in series

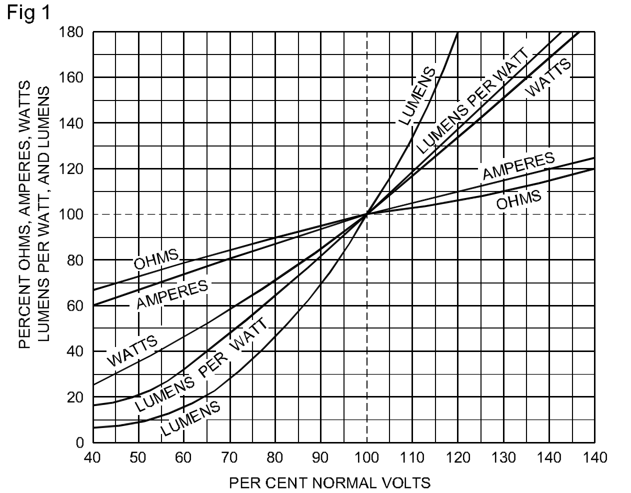
Objectives: At the end of this lesson you shall be able to
- **state the purpose of differtent voltage lamps**
- **calculate and compare the hot resistance of the same voltage but of different wattage/current lamps**
- **describe the method of measuring and calculating the 'hot resistance'**
- **state the effects of different wattage lamps in series.**

Purpose: In quite a few places we use low voltage supply i.e. 6V, 12V or 24V, such as in automobile vehicles. Automobile vehicles are equipped with many lights to provide an efficient lighting system for both day and night driving conditions. The various lights require the use of different wattage and types of light lamps to provide the amount of illumination desired.

Glow conditions of low wattage lamps with current flow through it: An electric lamp changes electrical energy into heat and light, when current flows through its filament and causes it to become incandescent. The filament is made of tungsten wire. The low voltage lamps are generally of low wattage because at a low voltage, the current taken by the filament for a given wattage is much more as compared to the domestic light.

The performance characteristics of tungsten-filament lamp is affected by voltage. The effect of operating a lamp at other than its rated voltage is shown in Fig 1. The decrease in voltage across the lamp lowers the current flow thus lowering the filament temperature. At 50% of the rated voltage, current decreases to about 68% and the resistance of the filament to 75%. The temperature of the filament lowers to an extent to give a light out of less than 10% lumens.

Fig 1



CHARACTERISTIC CURVES FOR INCANDESCENT LAMPS SHOWING THE EFFECT OF OPERATING A LAMP AT OTHER THAN ITS RATED VOLTAGE. THESE CHARACTERISTICS ARE AVERAGES OF MANY LAMPS.

Calculating the hot resistance: The lamp filament operates at a very high temperature, 1800°C to 2200°C. Therefore, there is a very big difference between 'cold resistance' and 'hot resistance'. Hot resistance (when the lamp is ON) is nearly 12 times more than the cold resistance (when the lamp is OFF).

Hot resistance

a Wattage = 12W

Voltage = 12V

$$\text{Current} = \frac{W}{V} = \frac{12}{12} = 1 \text{ amp.}$$

$$\text{Resistance} = \frac{V}{I} = \frac{12}{1} = 12 \text{ ohm(hot)}$$

b Wattage = 40W

Voltage = 24V

$$\text{Current} = \frac{W}{V} = \frac{40}{24} = 1.667 \text{ amps.}$$

$$\text{Resistance} = \frac{V}{I} = \frac{24}{1.667} = 14.4 \text{ ohm (hot)}$$

c

(i) Voltage = 6V

Current = 0.1 ampere

$$\text{Resistance} = \frac{V}{I} = \frac{6}{0.1} = 60 \text{ ohm (hot)}$$

(ii) Voltage = 6V

Current = 0.15 ampere

$$\text{Resistance} = \frac{V}{I} = \frac{6}{0.15} = 40 \text{ ohm (hot)}$$

(iii) Voltage = 6V

Current = 1 ampere

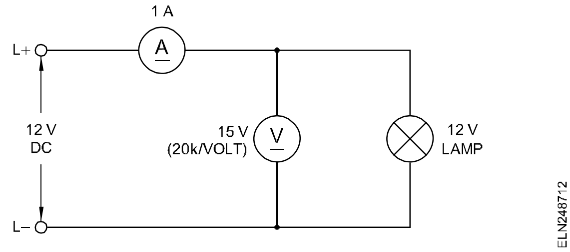
$$\text{Resistance} = \frac{V}{I} = \frac{6}{1} = 6 \text{ ohm (hot)}$$

The resistances calculated above are always hot resistance. To find out the cold resistance, it is measured with the ohmmeter when the lamp is OFF and at room temperature.

Measuring 'hot resistance': The hot resistance of a low voltage lamp could be measured by connecting the lamp as per the circuit given, Fig 2. The lamp must operate at its rated voltage. A voltmeter of high sensitivity not less than 20 k ohms per volt is used such that the current taken by the voltmeter is negligible. The reading of the ammeter and voltmeter must be taken accurately.

$$\text{Hot resistance} = \frac{\text{Voltmeter reading}}{\text{Ammeter reading}}$$

Fig 2



Different wattage lamps in series: If the two lamps of different wattage in parallel across in A.C. circuit, it should be same voltage for proper operation. But, if they are connected in series they should have the same current ratings.

All the bulbs in house are probably connected in parallel and they will draw the current it requires, and all the lamps will glow bright.

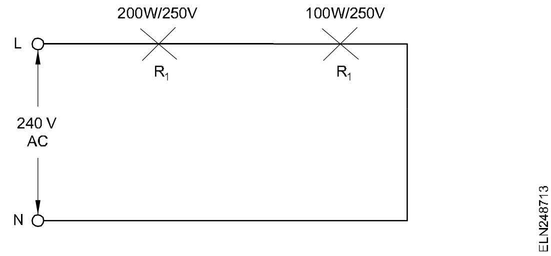
If two lamps with unequal wattages and same voltage ratings are connected in series they will divide up the available voltage between them.

Low wattage lamp will glow bright, due to high resistance and high voltage drop. High voltage lamp will glow dim, due to low resistance and low voltage drop.

Example

In a circuit the two lamps rated as 200W/ 250V, and 100W/250V are connected in series across 240 volt A.C. supply. (Fig 3)

Fig 3



200W (higher wattage) lamp will glow dim and

100W (low wattage) lamp will glow bright.

because,

The resistance of 200W/ 250V lamp,

$$R_1 = \frac{V^2}{W_1} = \frac{250 \times 250}{200} = 312.5\ \Omega$$

The resistance of 100W/250V lamp,

$$R_2 = \frac{V^2}{W_2} = \frac{250 \times 250}{100} = 625\ \Omega$$

Total resistance $R_T = 312.5 + 625 = 937.5\ \Omega$

$$\text{current I} = \frac{V}{R_T} = \frac{240}{937.5} = 0.256\text{A}$$

voltage drop in 200W lamp, $= IR_1 = 0.256 \times 312.5 = 80V$

Voltage drop in 100W lamp, $= IR_2 = 0.256 \times 625 = 160V$

Power V X I = 240 X 0.256 = 61.4 W

Hence,

The 100W lamp having high voltage drop due to high resistance it will glow bright than high wattge lamp 200W which is having low voltage drop and low resistance.