# TTE Training Ltd.

## Phase 1
## Electrical Course Notes

# E-CN-002


http://www.tteltd.co.uk

# *Industrial Lighting*

# Lighting

**Health & Safety ***

Two specific aspects of health and safety are relevant in relation to lighting ;

(a) a gradual deterioration in an individual's visual acuity and performance.

(b) the increased likelihood of accident brought about by a worker's failing or incorrect perception.

The purpose of the lighting section of the health and safety legislation is to consider lighting deficiencies which can result in the inability of people to perceive danger and cause deterioration in visual performance. In turn, this involves an examination of lighting in terms of ;

(a) the quantity and quality of light required for a given task as well as the relationship of lighting to the general environment of the workplace.

(b) The basis for lighting design and specific applications, as in the case of visual display units (VDUs).

**Present Legal Requirements ***

Legal requirements relating to lighting of workplaces are dealt with in Regulation 8 of the Workplace (Health, Safety & Workplace) Regulations. "***Every workplace shall have suitable and sufficient lighting which, so far as is reasonably practicable, shall be by natural light.*** *Further-more, suitable and sufficient emergency lighting shall be provided and maintained in any room in circumstances in which persons are specially exposed to danger in the event of failure of artificial lighting".*

The provisions relating to **emergency lighting** in the Regulations are mainly directed at situations where sudden loss of light would present a serious risk, for example, if process plant needs to be shut down under manual control or a potentially hazardous process needs to be made safe, and this cannot be done safely without lighting.

* Taken from "The Handbook of Health and Safety Practice", Third edition, by J.Stranks, 1994.

## Emergency Lighting

In the event of a power failure, **emergency lighting** should be powered by a source independent from that of normal lighting, e.g. batteries, and should be immediately effective in the event of failure of the normal lighting, without need for action by anyone. It should provide sufficient lighting to enable persons at work to take any action necessary to ensure their, and others, health and safety (Approved Code Of Practice).

## The Design Of Lighting.

In the design of lighting, many factors need consideration. These may include the following ;

- **Illuminance levels** for the principle operations within the premises and for specific parts of the premises, both externally and internally.
- **Availability of natural lighting.** Whilst it is the best form of illuminance, it must often be considered a secondary option in lighting design owing to its unreliability.
- **Specific areas and processes.** The type of lighting and lighting needs of specific areas and/or processes should be considered e.g. access points, corridors, internal traffic lanes.
- **Colour rendition aspects.** Correct positioning and perception of colour is very important in certain areas, e.g. safety signs and notices.
- **Glare and dazzle.** Potentially hazardous where machinery is installed.
- **Structural aspects.** Items such as screens, pillars and plant may obstruct light flow reducing the illuminance levels.
- **Atmospheric influences.** The presence of steam, fumes and mists may impair vision and reduce the lighting levels.
- **Lamp and window cleaning.** The need for frequent cleaning, replacement and maintenance of lamps will depend upon the types of process being undertaken in the area. Suitable access and equipment must be provided.
- **High risk areas.** The potential for fire and explosion in certain areas may indicate the need for specialised light fittings.

- **Emergency lighting**. Necessary in most activities.
- **Energy considerations.** The use of time-switches or photo-electric switching devices should be considered.

Finally, the physiological effects of poor lighting, such as reduced visability and performance, and the psychological effect on perception and attitudes of workers, must be considered.

**It has been proven that the quality of lighting has a direct effect on worker performance, and, more importantly, the accident potential.Quantitative Aspects Of Lighting.**

The quantity of light flowing from a source such as a light bulb or fluorescent lamp is the luminous flux or light flow . This is generally termed as "illuminance". The units of measurement of luminous flux were formerly foot-candles or lumens per square foot, however more recently, the unit has become the lux, which is the metric unit of measurement. Thus ;

| | | |
|---|---|---|
| Foot candles | = | lumens per square foot. |
| Lux | = | lumens per square metre |
| 10.76 lux | = | 1 lumen per square metre |
| 1 lux | = | 0.093 lumens per square metre |

On this basis, a conversion factor of 10 or 11 is used for converting from lumens per square foot to lux, i.e. 20 lumens per square foot = 200 lux.

**The lux, therefore, is the unit of illuminance, (<u>not</u> "illumination"), which can be measured with a standard photometer, or light meter. This will give an indication of the quantity of light present at any particular point.**

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## Lighting

The table below gives an indication of the average illuminance and minimum measured illuminance for different types of work.

| General Activity. | Typical locations / types of work. | Average Illuminance Lux (Lx). | Minimum Measured Illuminance Lux (Lx). |
|---|---|---|---|
| Movement of people, machines and vehicles (see note 1). | Lorry parks, corridors, circulation routes. | 20 | 5 |
| Movement of people, machines and vehicles in hazardous areas ; rough work not requiring any perception of detail (see note 1). | Construction site clearance, excavation and soil work, docks, loading bays, bottling and canning plants. | 50 | 20 |
| Work requiring limited perception of detail (see note 2). | Kitchens, factories assembling large components, potteries. | 100 | 50 |
| Work requiring perception of detail (see note 2). | Offices, sheet metal work, bookbinding. | 200 | 100 |
| Work requiring perception of detail (see note 2). | Drawing offices, factories assembling electronic components, textile production. | 500 | 200 |

Note.

(1) Only safety has been considered because no perception of detail is needed and visual fatigue is unlikely. Where it is necessary to see detail, to recognise a hazard or where error in performing the task could put someone else at risk, for safety purposes as well as to avoid visual fatigue, the figure should be increased to that for work requiring the perception of detail.

(2) The purpose is to avoid visual fatigue : the illuminance will be adequate for safety purposes.

### Light Output Comparison

The light output can vary enormously according to which type and wattage is selected. The histogram shown below, (Fig. 1), compares the initial light outputs from lamp types in general use. It can be seen that there are wide differences in the lamp rating to provide a given light output. This is because different lamp types have differing abilities to convert electrical power into light.

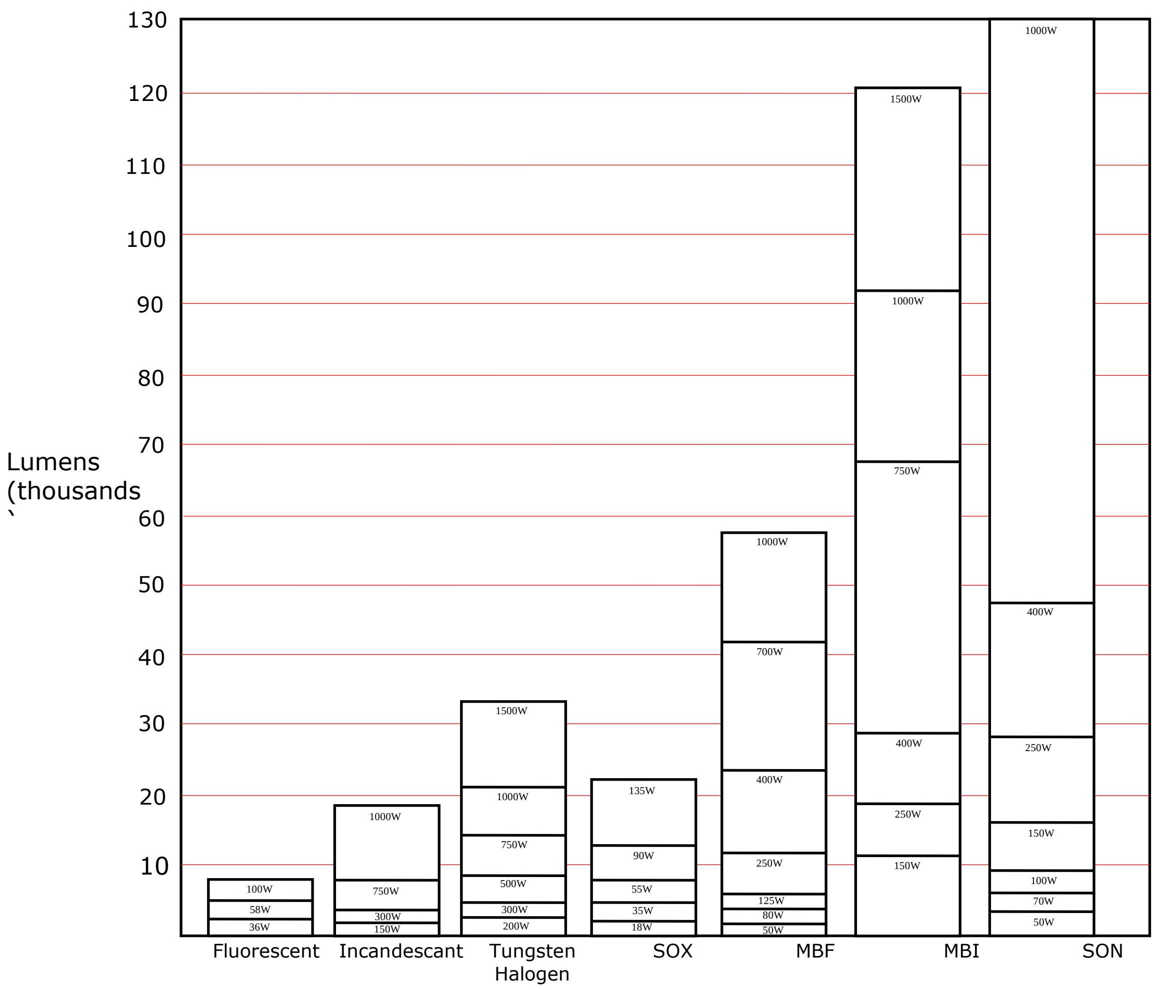



**Fig.1**

**The quantity of light emitted, often the initial lumens, divided by the power input in watts, is known as efficacy and is measured in <u>lumens per watt (lm/W)</u>. This is instead of the term efficiency which can only truly be applied when two quantities of the same units are compared.**

When no control gear is essential, for example to operate a fluorescent tube, the input power to the circuit is greater due to some power losses in the circuit. Efficacy is, therefore, more realistically expressed in terms of the input power to a lamp circuit since the consumer has to pay for all the power that is used.

The diagram below, (Fig. 2), shows the efficacies of the lamp types shown in the histogram above using the <u>total</u> circuit power.

### Luminous Efficacy Comparison

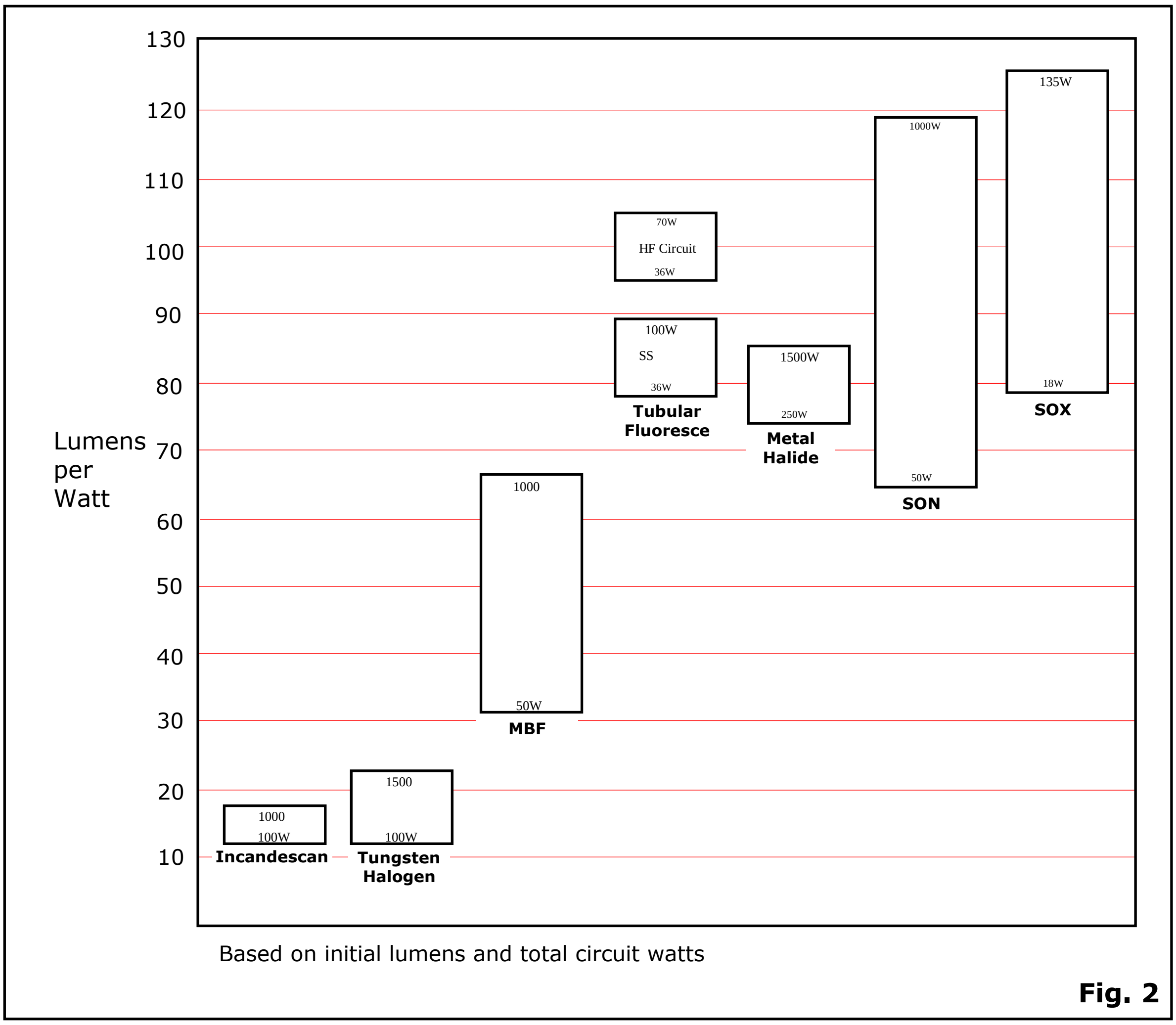



**Fig. 2**

# Lighting

**Lamp Designations**

The following list gives abbreviations used in the U.K. to define lamp types and their operating position.

Incandescant Lamps

GLS - General Lighting Service

PAR- Pressed glass filament (internal reflector coating)

TH - Tungsten Halogen

Tubular Fluorescent Lamps

MCF - Tubular Fluorescent Lamp

MCFA - Tubular Fluorescent Lamps with external earth strip (restricted range : mainly for cold environments).

T12 : T8 : T5 - tube diameter (38mm : 26mm : 15mm respectively).

Low Pressure Sodium Lamps

SOX - Single-ended, U-shaped arc tube

High Pressure Sodium Lamps

SON-E - Diffused ellipsoidal outer bulb, single ended.

SON-T - Clear tubular outer bulb, single ended.

SON-TD - Clear tubular outer bulb, double ended.

SON-R - SON with internal reflector

SON DL-E - SON with improved colour rendering

SON DL-T - SON-T with improved colour rendering

E For use with external starting device

I Contains internal starting device

High Pressure Mercury Lamps

MBF - High Pressure Mercury with phosphor coating

MBFR - MBF with internal reflector

MBTF - Combination of MBF and filament lamp

Lamp Operating Positions

/U - Universal (usually not marked)

/V - Vertical, cap up.

/D - Vertical, cap down

/H - Horizontal

/BD - Base down

/BU - Base up

**Gas Discharge Lamps.**

When the potential difference between two electrodes in a tube containing gas and a minute amount of metal exceeds a critical value, ionisation occurs, (see description overleaf), and the current has to be limited by connecting an external resistor or inductor in series. The ionised gas emits radiation which may be in the visible ultraviolet or infra-red regions of the spectrum. All discharge lamps must, therefore, have the following properties :-

- an envelope containing gas and metal which can be ionised by the voltage available and which is capable of emitting visible radiation, directly or indirectly ;
- an external inductor or resistor to limit the current ;
- an arrangement for initiating the discharge.

Discharge lamps operate on most gases, given the right conditions, however pure gases do not give sufficient light output to be used for general lighting purposes. When lamps are required to give good space illumination, those using metal vapour (normally mercury or sodium due to their low boiling point), are far more satisfactory. In such lamps, the arc first strikes using neon or argon gas as the medium and the resulting temperature causes the metal to heat and vaporise. The resulting metal vapour then becomes the arc carrier and emits much more luminous energy.

These lamps come in a variety of shapes and sizes however the most common types are listed below.

- Low Pressure Mercury Vapour.
- High Pressure Mercury Vapour.
- Low Pressure Sodium Vapour.
- High Pressure Sodium Vapour.

Discharge lamps can also be classified as "**Cold Cathode**" and "**Hot Cathode**". In the former, the two electrodes enable the discharge process to start without any prior external heating whereas the latter relies upon the electrodes being independently heated by the external, or control, circuit in order that the arc may strike. In both cases, once the lamp is in operation, the electrodes are kept hot by the discharge itself. Examples of both types are the sodium vapour lamp (cold cathode) and the mercury vapour lamp (hot cathode).

### Efficacy

It has been proven that these lamps are, in general, much more efficient than the incandescent type. The efficiency of a lamp is related to the quantity of visible light emitted per watt of electrical energy consumed and is known as the **efficacy**. For example, if a 100W. incandescent lamp had a total light output of 1200 lumens, its efficacy would be 12 lumens per watt (lm/W.). Of the various types of discharge lamp, the sodium-vapour type is the most efficient, which is why it is favoured by the County Councils responsible for road lighting.

Typical lighting efficacies are as follows :-

| | | |
|---|---|---|
| Incandescent : | 100W Tungsten (coiled-coil). | 12 lm/W |
| Discharge : | 250W Mercury Vapour (low pressure) | 45 lm/W |
| | 250W Sodium Vapour (low pressure) | 100 lm/W |
| | 250W Sodium Vapour (high pressure) | 90 lm/W |

**Gas Ionisation.**

When a voltage is applied to a discharge lamp the positive and negative ions begin to move towards their respective electrodes (cathode and anode). The speed of the ions is dependant upon the applied voltage. Whilst moving along the lamp the ions will collide with the neutral atoms and, if the speed and collision is severe enough, will break an electron away from the atom leaving behind a positively-charged ion. This atom is then said to be in an excited condition and the displaced electron can then do one of the following ;

- collide with the wall of the tube and dissipate its energy as heat.
- excite other atoms and increase their velocity.
- if neither of the above occurs, the energy is dissipated as electromagnetic radiation which may, or may not, be in the visible range.

If the applied voltage is high enough, single ions will collide with single atoms resulting in two new ions (positive charged ion and negative charged electron). These new ions are affected by the voltage and move along the lamp and collide with other neutral atoms resulting in the expulsion of other electrons. The effect is cumulative and whilst it in this state, the gas is said to be "ionised".

This mixture of electrons and ions is called **plasma**, and if the process was left uncontrolled, the resistance across the tube would fall to a very low value giving rise to a dangerously high current flow which would eventually destroy the lamp. It is, therefore, necessary to limit the current by using an impedance in the external (control) circuit. This takes the form of an external ballast in the form of a choke, for the mercury vapour lamp, or a high leakage (reactance) transformer for the sodium vapour lamp.

**Stroboscopic Effect.**

The light output of all discharge lamps fluctuates at twice the supply frequency however the fluctuation within fluorescent lamps is considerably reduced by the persistence of the glow of the fluorescent powder coating in the tube. This fluctuation, or flicker, is known as the **stroboscopic effect** and it can produce undesirable effects, particularly with rotating machinery. If the machine is rotating in multiples of the speed of flicker it may appear to be rotating in reverse or, more dangerously, may appear to be stationary however it can be practically eliminated by doing one of the following ;

- using groups of three lamps distributed between the three phases of a three-phase supply.
- using twin lamps on a single-phase supply, one being connected in series with an inductor and the other in series with an inductor and a capacitor of such capacitance that the current leads the supply voltage by 60°. The result is the currents in the two lamps differ in phase by 120° the power factor of the combined circuits is practically unity.
- introducing a full-wave rectifier between the inductor and the lamp so that the current through the lamp is uni-directional and approximately constant.

**Power Factor.**

The current in a circuit consists of two main components ; (i) the current contributing to the power being absorbed and, (ii) the magnetising current (sometimes referred to as the "idle" or "wattless" current). The power factor is the relationship between these two components and is commonly shown as ;

$$\text{Power Factor} = \frac{\text{Load in Watts (power absorbed or power input)}}{\text{Supply voltage} \times \text{Total circuit current}}$$

Typically, full load power factors are in the range 0.65 to 0.95.

A low power factor is to everyone’s' disadvantage, particularly the Supply Authority, since it limits the capacity of their generating equipment and mains network. In order to operate at their designed output, circuits should, ideally, have a power factor of unity, or 1, (see Fig. 1), since ;

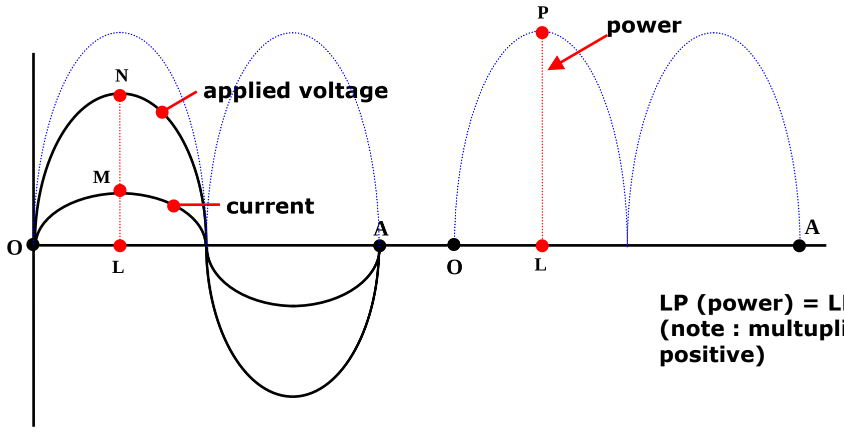
$$\textbf{Active Power} = \textbf{Volts} \times \textbf{Amps} \times \textbf{Cos.}\theta$$

It is, therefore, evident that the lower the power factor of a load, the lower the active power. This may be stated in another way by saying that, for a given power, the lower the power factor, the larger the cross-sectional area of the conductor required to supply that power.

### Power Factor Correction.

In an inductive circuit the current lags the voltage and in a capacitive circuit the reverse is true (see Fig's. 4 and 5). A combination of inductance and capacitance can be arranged so that these effects at least partially cancel each other out to produce a small phase angle difference and, consequently, a high power factor. In order to achieve this in a discharge lighting fitting, a capacitor is included by connecting it across the circuit supply (between "live" and "neutral") in, what is, a low power factor inductive circuit. This will have the desired effect of reducing the supply current and thus improving the power factor closer to unity (see Fig. 3).

**Unity Power Factor - current is in phase with the voltage (zero degree angle of difference).**




**LP (power) = LN (voltage) x LM (current)**
**(note : multuplication of two negatives is a positive)**

**Fig. 3**

## Power in a purely inductive circuit.

**Lagging Power Factor (current lags the voltage)**

**LP (power) = LN (voltage) x LM (current)**

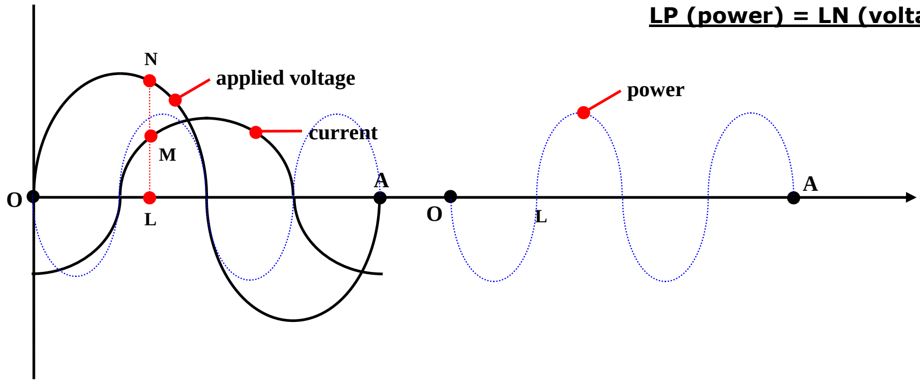



**Fig. 4**

## Power in a purely capacitive circuit.

**Leading Power Factor (current leads the voltage)**

**LP (power) = LN (voltage) x LM (current)**

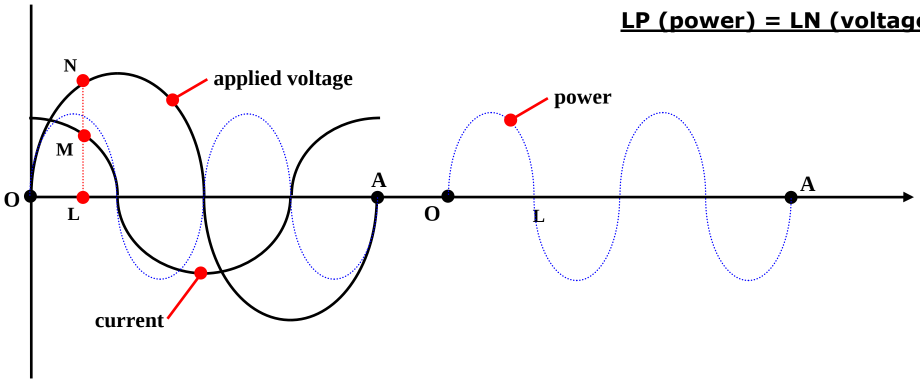



**Fig. 5**

### The Photoelectric Cell.

These units can control a lighting circuit by sensing the fall (and rise) of the surrounding lighting levels. The unit consists of three main parts ;

- the light sensitive semiconductor (which generates a minute current when exposed to light).
- an amplifier (to amplify the current from the transistor).
- the relay (which is triggered at a pre-determined value of the amplified current).

### Recommended Lighting Levels (Chemical Plant).

| Area | Measurement (Lux) | Position Of Measurement. |
|---|---|---|
| Exterior walkways & platforms. | 50 | Walkway level. |
| Exterior stairs & ladders. | 100 | Treads. |
| Exterior pumps & valves. | 100 | Floor level. |
| Pumps & compressor houses. | 150 | Floor level. |
| Interior plant areas. | 399 | Working plane. |
| Control room desks. | 300 | Desk level. |
| Vertical panels. | 300 | On panel. |
| Rear of control panels. | 150 | Floor level. |
| Fitting workshop. | 300 | Working plane. |
| Machine workshop (medium | 500 | Working plane. |
| Machine workshop (fine work). | 1,000 | Working plane. |

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## Filament Lamps.

If a material is made white hot it emits light. This is the principle of operation of the lamp which uses a tungsten filament. Tungsten has both a high melting temperature (3,380°C) and the ability to be drawn into a fine wire. To prevent it oxidising and failing prematurely, all oxygen must be removed from the enclosing glass bulb. Whilst the smaller lamps are evacuated, the larger lamps are filled with argon which reduces filament evaporation at high temperatures.

The efficacy of filament lamps is relatively low but increases with the output ratings (8.0 lm/W for a 25W. up to 11.6 lm/W. for a 100W. lamp). By coiling the already coiled filament, the lamp retains heat and its efficiency increases to 12.6 lm/W. for the 100W. size. The construction of a g.l.s. (general lighting service) lamp is shown in Fig. 14 below. The nominal rated life of a tungsten filament lamp is 1,000 hours.

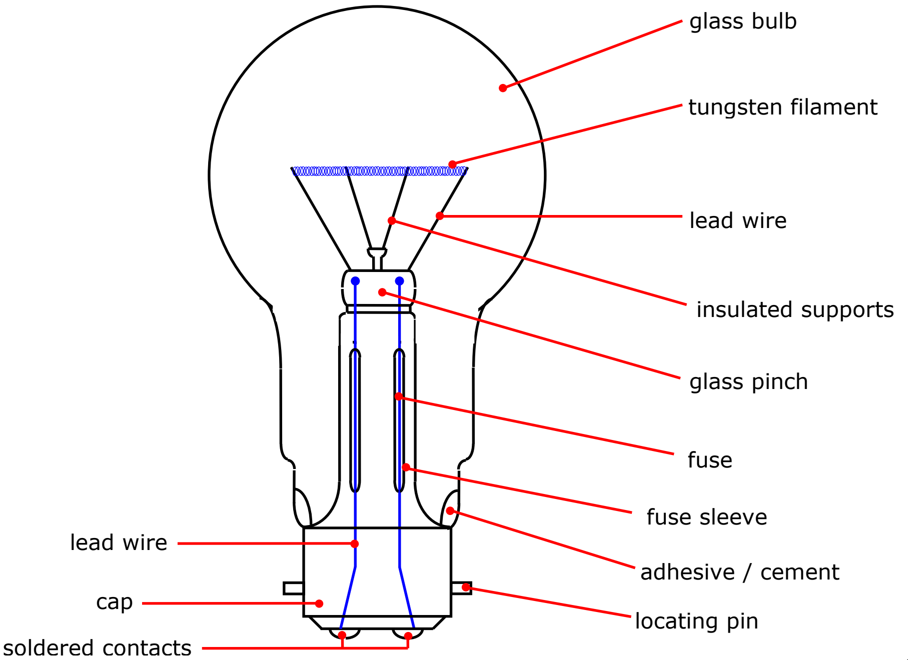


**Fig. 14**

Filament lamps are made in a bewildering variety of sizes, colours and shapes. References should always be made to a manufacturers catalogue if specific details are required. Lamps are frequently used in fittings called luminaries which are designed to provide the required light control. If the luminaire is enclosed, it will be marked to indicate the maximum rating of the lamp for which it was designed ; using a higher power lamp will cause overheating and fire may result.

Incandescent lamps with integral reflectors are often used for display work and result in a great deal of heat as well as light reaching the subject. To reduce this effect, some lamps have dichoric reflectors which reflect the visible light but absorb a high proportion of the heat. Luminaires for use with such lamps must be specially designed because of the additional energy retained by the lamp.

### Effect of Voltage Variation

The efficiency of an incandescent lamp is related to the quality of visible light emitted per watt of electrical energy consumed. Thus, if a 100W incandescant lamp had a total light output of 1200 lumens, its efficacy would be 12 lumens per watt (lm/W).

The efficacy of an incandescant lamp is largely dependant upon two factors, filament temperature and supply voltage. An increase in filament temperature will result in an increase in lamp efficacy however, the temperature of the filament cannot be increased indefinitely since it will melt as the lamp efficacy approaches 40 lumens per watt.

Tungsten evaporation from the filament is more rapid at higher temperatures therefore the life of the lamp is reduced as the efficacy is increased.

**Variations in voltage supply have the effect of varying the the filament temperature and therefore the efficacy of the lamp.**

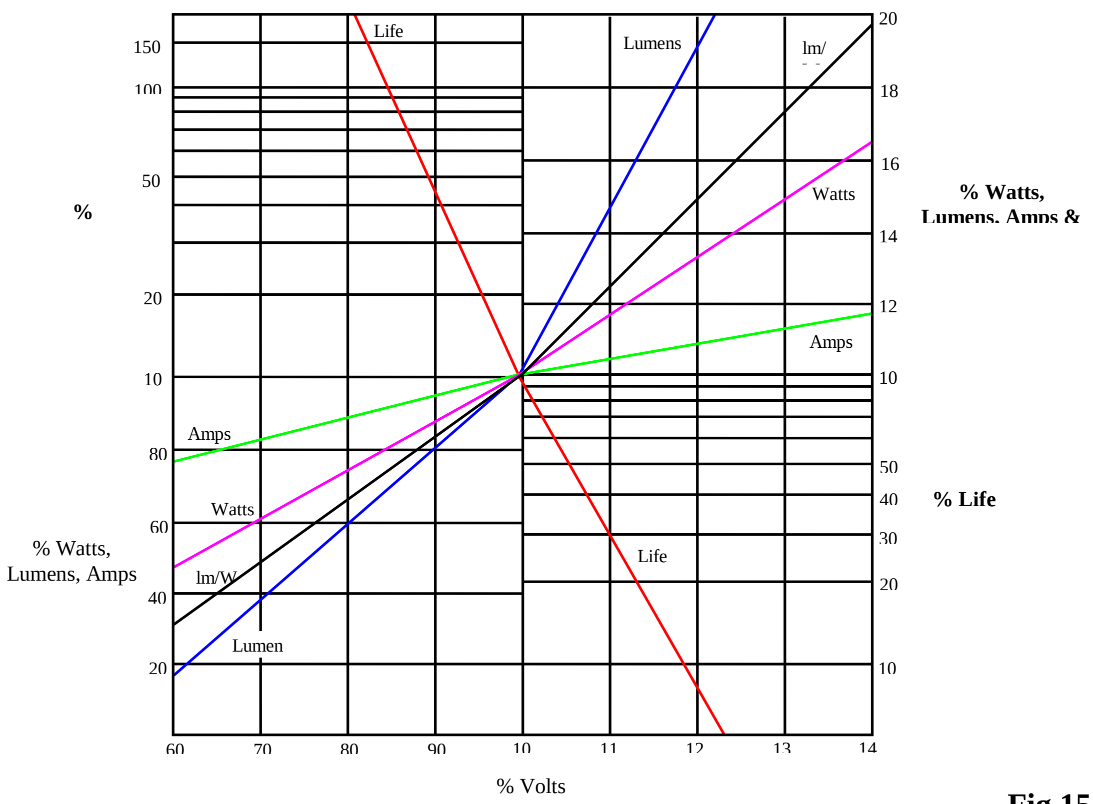


Fig.15

The diagram above, (Fig. 15), shows how the lamp efficacy, life, light output and electrical energy consumed vary with changes in the supply voltage.

For example :

if the supply voltage to an incandescant lamp is reduced by a 5%,(below its rated voltage)

- its life will be nearly doubled.
- the lamp watts would be reduced to approximately 90% of the rated lamp watts.
- the light output is reduced to less than 85% of the designed light lumens.

It is permissable for the electricity supply authorities to vary their declared voltage by plus 10% or minus 6% so the limits on a nominal 230V supply are 253V maximum and 216V minimum. These extremes give very different lives when using a rated 230V lamp. Such variations of voltage frequently occur and are dependent upon the distance the electricity consumer is from the high voltage sub-stations and the type of cable distribution.

As can be seen in the graph, (Fig. 15), a lamp with a rated life of 1500 hours at its correct 230V rating will only last 500 hours on a 250V supply but will last 3000 hours on a 220V supply.

**Tungsten-Halogen Lamp.**

If the envelope of a tungsten lamp is made of quartz instead of glass, it can be made much smaller because quartz can safely operate at a higher temperature and therefore, the gas pressure inside the quartz envelope can also be increased. this has the effect of reducing the evaporation of tungsten from the filament so increasing the efficiency and life of the lamp.

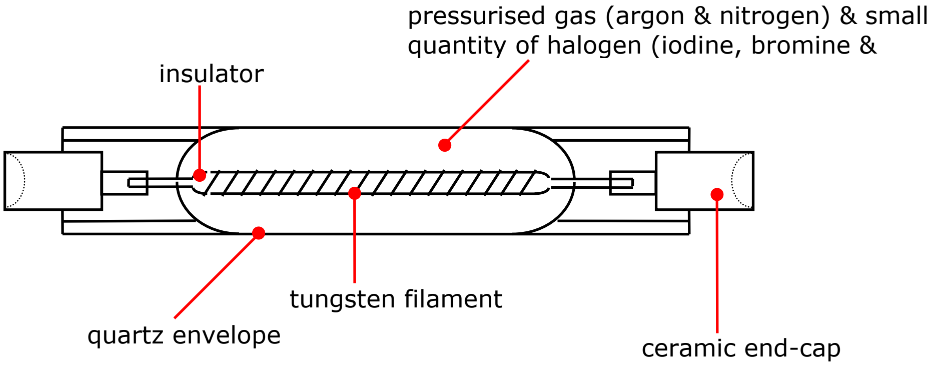


**Fig. 16**

By introducing a small quantity of a halogen into the gas filling, a process called the tungsten halogen cycle occurs. Halogen elements used in this type of lamp include iodine, bromine and chlorine, and under the right conditions their atoms can combine with atoms of other elements without altering their characteristic.

When the temperature of the quartz envelope reaches approximately 250°C the halogen will combine with any evaporated tungsten near the filament to form tungsten halide. As these atoms approach the filament the tungsten is deposited back onto the filament and the halogen is released. This "cleaning cycle" repeats itself however the tungsten is not necessarily deposited back onto the area of the filament that it came from therefore parts of the filament will eventually become so weak that it will break.

Because the lamp bulb is made from quartz glass it should not be handled or the sodium from the skin will form white opaque patches on the glass when it becomes hot. Tungsten halogen lamps are widely used for floodlighting and vehicle lighting applications. A typical lamp of this type is shown in Fig. 16 above.

These lamps are provided with either a bi-pin or small bayonet-cap connections and have a rated life of 2,000 hours. Whilst this type of lamp has an excellent light output, it is not recommended to be connected to a dimming circuit. If the lamp temperature is reduced by lowering the voltage, it is possible that the bulb temperature will fall low enough to cause halogen condensation and hence reduce the life of the lamp.

# Gas Discharge Lighting

### Low-Pressure Mercury Vapour (Fluorescent) Lamps.

The fluorescent lamp usually consists of a long glass tube (**T**), internally coated with a fluorescent powder. The tube contains a small amount of argon together with a little mercury. At each end of the tube there is an electrode (**E**) consisting of a coiled tungsten filament coated with a mixture of barium and strontium oxides. Each electrode has attached to it two small metal plates, one at each end of the filament. These plates act as nodes for withstanding bombardment by electrons during the half-cycles when the electrode is positive. During the other half cycles, the adjacent hot filament acts as the cathode, emitting electrons.

Circuits for the control of fluorescent tubes can be divided into two main groups, namely **switch-start circuits** and **quick-start** circuits.

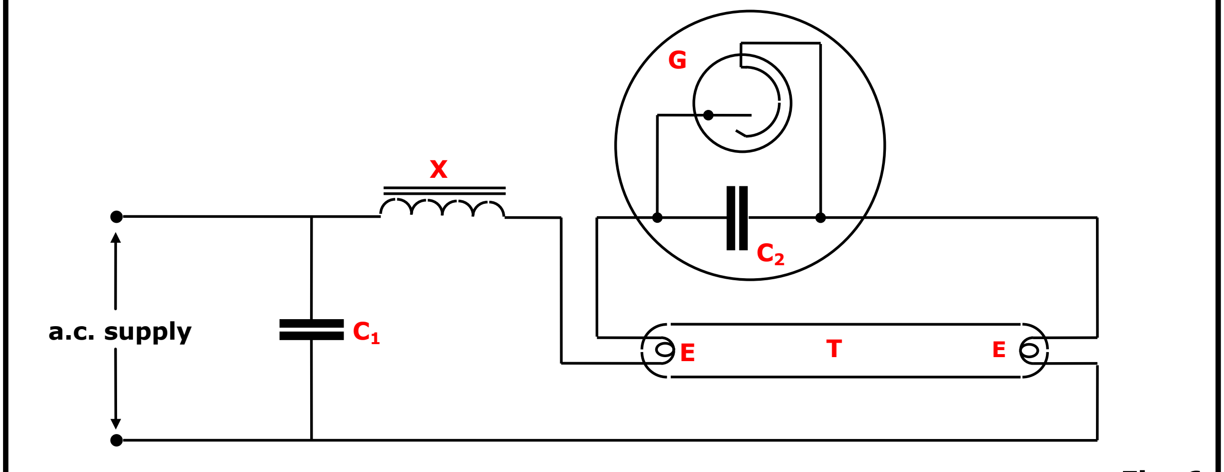

Fig. 6

### The Switch-Start Circuit

The switch-start circuit in general use is a voltage-operated device referred to as a **glow switch** (**G**) (see Fig. 6 above). This consists of two bi-metallic strip electrodes in a glass bulb filled with a mixture of helium, hydrogen and argon at low pressure. The contacts are normally open but the application of the supply voltage starts a glow discharge between the electrodes of **G** and the heat is sufficient to bend the bi-metallic strips until they make contact, thereby closing the circuit. A relatively large current flows through the electrodes **EE** raising them to incandescence and the gas in their immediate vicinity is ionised. After a second or two, the bi-metallic strips cool sufficiently to break contact and the sudden reduction of current induces in choking coil **X** an e.m.f. in the order of 800-1,000V (re. Lenz's Law). This surge is sufficient to ionise the argon in the space between electrodes **EE** and the heat generated in the tube then vaporises the mercury. The potential difference across the tube then falls to about 100-110V which is insufficient to restart the glow in the starter switch **G**.

The capacitor, $\mathbf{C_2}$, is connected across the glow switch in order to suppress radio interference. Without **C2**, high frequency voltage oscillations may occur across the starter contacts.

The power factor of the lamp circuit, including choke **X**, is about 0.5 and a capacitor, $C_1$, is introduced to raise the power factor to about 0.9 (lagging).

### Low-Pressure Mercury Vapour (Fluorescent) Lamps (cont).

The **quick-start** circuit is referred to in various ways e.g. switchless, instant start etc., and one arrangement is shown in the diagram below (Fig. 7).

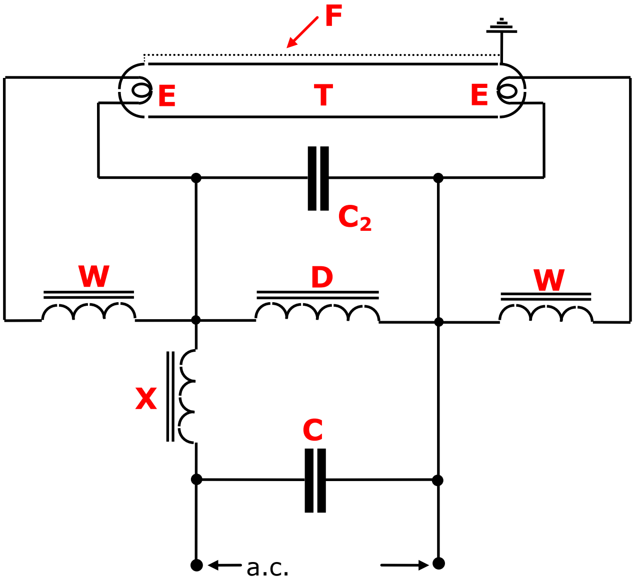


Fig.

The electrode pre-heating is provided by a small auto-transformer, the primary winding **D** being connected across the lamp electrodes **EE**. A thin metallic strip **F** is attached to the outer surface of the tube and is connected to earth via the lamp caps.

When the lamp is switched on the whole of the supply voltage is applied across the tube electrodes **EE** and the potential difference applied to the filaments from the windings **WW** raises them to incandescence. The combination of this pre-heating and of the relatively high potential difference between each electrode and the earth strip **F**, is sufficient to start ionisation in the immediate vicinity of the electrodes **EE**, and this ionisation then spreads to the whole tube. This immediately causes the potential difference across the primary winding **D** to fall to about 100-110V., hence the voltage across the filaments **EE** is effectively halved, and the temperature of the filaments will be maintained partly by the reduced current and partly by the heat of the discharge.

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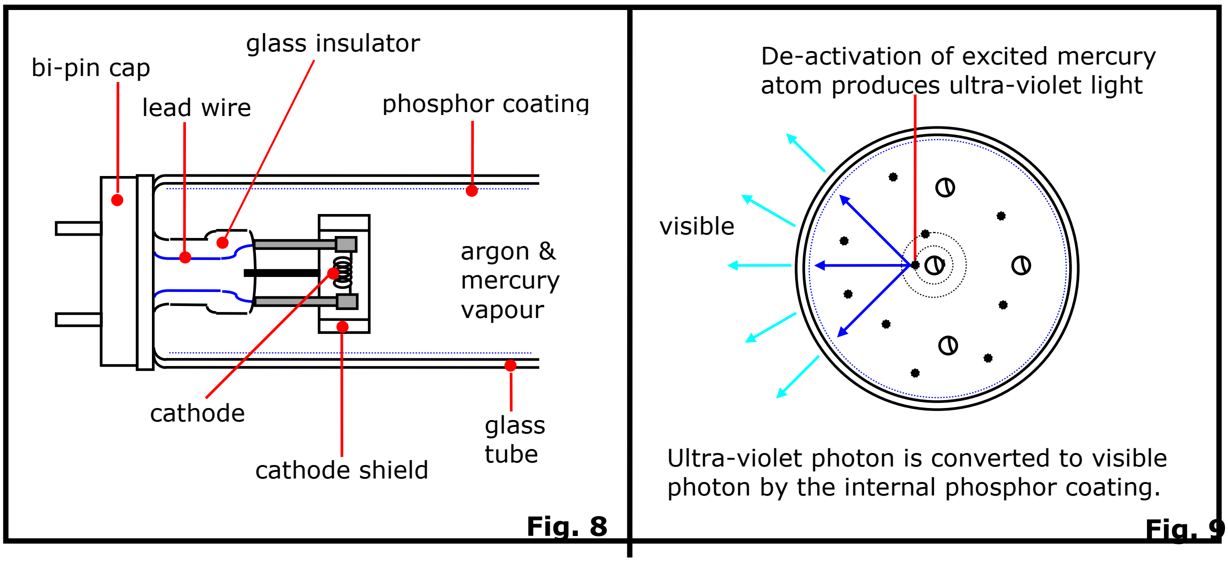
**Lamp Construction.**

The diagrams above shows how a fluorescent lamp is constructed and how visible light is emitted by the lamp.




Fluorescent lamps are constructed with a coiled filament at each end of the glass tube (see Fig. 8). A cathode shield, in the form of a metal strip bent into an oval shape, surrounds the cathode and has a number of purposes :-

- it acts as an anode, trapping any material given off by the cathode during its life
- it reduces the flicker that is associated with fluorescent lights
- it limits the black marks that form at the end of the tube
- it acts as a conductor protecting the delicate filament

The base of the filament supports are gripped in a glass insulator, through which the lead wires pass, forming a vacuum tight glass metal seal.

When the cathode filaments are heated a "cloud" of negatively charged electrons are emitted which are immediately accelerated by the voltage being applied across the lamp. This produces ionisation and the excitation of the mercury atoms. As the mercury and gas atoms collide the energy from the collision is converted into visable ultra-violet ultra-violet light via the phosor coating on the inside of the tube (see Fig. 9).

**Lamp Failure.**

The ultimate failure of a fluorescent lamp is caused by the exhaustion of the oxides with which the filaments are coated. These materials gradually disintegrate during the life of the lamp, particularly each time the lamp is switched on. The average life of the fluorescent tube is approximately 5,000 hours compared with approximately 1,000 hours for the tungsten-filament lamp.

### High-Pressure Mercury Vapour (MBF) Lamp.

The diagram below shows one arrangement of this type of lamp. For simplicity, some of the constructional features have been omitted, such as the lamp cap.

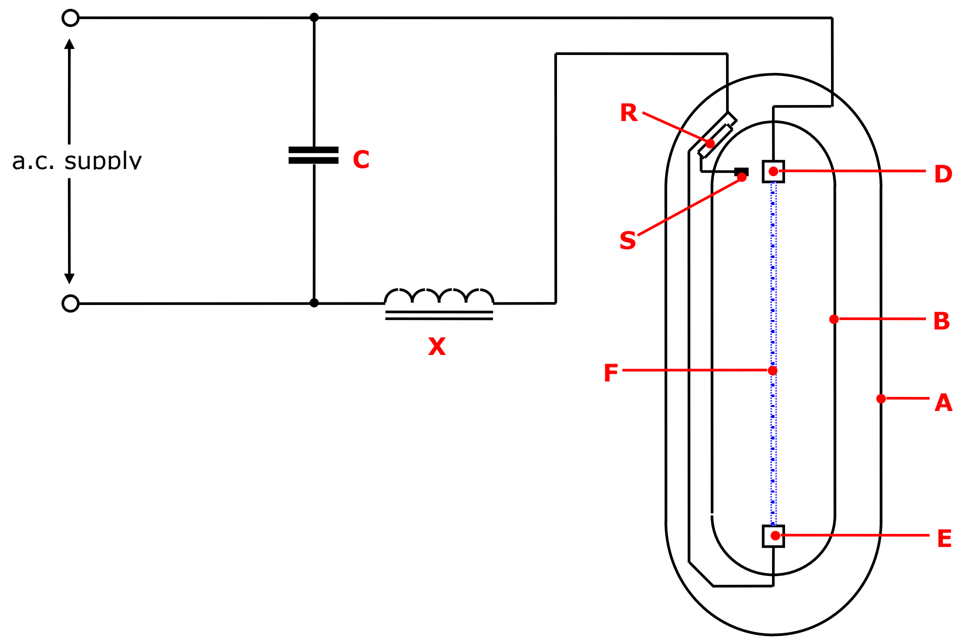



**Fig. 10**

The lamp consists of an inner bulb, **B**, which is generally made of fused silica rather than glass because of the high temperatures involved. It contains a small quantity of mercury and argon and is protected by a outer glass bulb, **A**, which may be cylindrical (as in Fig. 10 above), or elliptical (egg-shaped). This latter shape is being more commonly adopted as it enables the temperature of the middle of the envelope to be limited to about 270°C compared with 500°C. with the cylindrical type. The space between the bulbs **A** and **B** contains nitrogen at a pressure of about half an atmosphere (or bar).

The discharge tube **B** has three electrodes, namely the main electrodes, **D** and **E**, and a starting electrode **S**, which is connected through a resistor **R** of about 10 to 30 kΩ, and to the main electrode **E** situated at the other end of the tube. Electrodes **D** and **E** consist of tungsten-wire helices coated with electron-emissive materials (usually barium and strontium carbonates mixed with thoria).

When the lamp is switched on the high voltage between electrodes **D** and **S** ionises the argon in the tube and enables the arc **F** to strike between the main electrodes **D** and **E**. The potential difference between **D** and **E** gradually increases from about 20V. up to approximately 100-120V. During this period, the output colour of the lamp changes and increases in intensity.

The function of the inductor **X** is to limit the current to a safe value however, since the presence of the inductor produces a lagging power factor, a capacitor, **C**, is connected in parallel to the supply to improve it to approximately 0.9 lagging.

If the lamp is switched off, it cannot be restarted immediately because the vapour pressure is too high to continue ionisation. It must, therefore, be allowed time to cool sufficiently for the vapour pressure to fall to the value at which ionisation can take place between the electrodes **D** and **S**.

### Low Pressure Sodium Vapour (SOX) Lamp.

The low pressure sodium vapour lamp, (shown in Fig. 11 below), consists of a U-tube, **A**, which contains a small amount of sodium, which is solid at room temperature, together with a mixture of the gases neon (app. 99%) and argon (app. 1%). The effect of this gas mixture is to reduce the starting voltage by over 30% and, in some cases, 50%, which makes the starting voltage almost independent of ambient temperature.

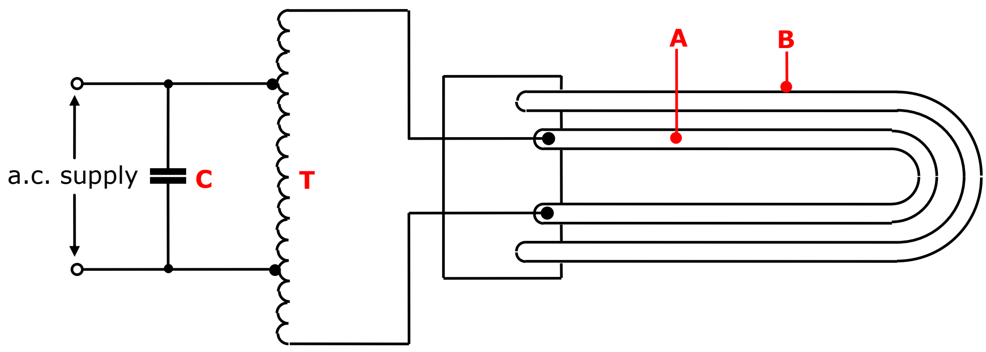



**Fig. 11**

The oxide-coated tungsten electrodes are connected to a step-up auto-transformer, **T**, designed to have a relatively large leakage reactance. When this transformer is on open-circuit, its output voltage is approximately 500V., and this is sufficient to initiate a discharge through the gas. This discharge has a reddish colour however, as the gas discharge increases the temperature, the sodium is vaporised and the discharge changes to monochromatic light.

Since the presence of the transformer produces a lagging power factor, a capacitor, **C**, is connected in parallel with the supply to improve it to approximately 0.9 lagging.

To ensure continuous maximum light output, the temperature of the discharge tube has to be approximately 270°C. In order to maintain this temperature it is necessary to thermally insulate the tube by enclosing the discharge tube in a double-walled vacuum jacket, **B** (similar to that of the domestic vacuum flask) and, in addition, the outer envelope is coated with an infrared reflecting film which will transmit light but reflects heat back onto the lamp.

Hot sodium vapour is very chemically active and the U-tube **A** has, therefore, to be made of ply-glass. The inner layer is a special sodium resisting glass and the outer layer is ordinary soda glass. Since the sodium solidifies when the tube cools it is necessary to ensure that it is deposited reasonably uniformly along the whole length of the tube and not concentrated at one end, consequently, the lamp **must** be used in a horizontal position.

**High Pressure Sodium Vapour (SON) Lamp.**

The high pressure sodium vapour lamp, (shown in Fig.'s 12 and 13 below), emits radiation over a wider range of wavelengths than its low-pressure counterpart giving the lamp improved colour rendering properties, the output being a golden colour.

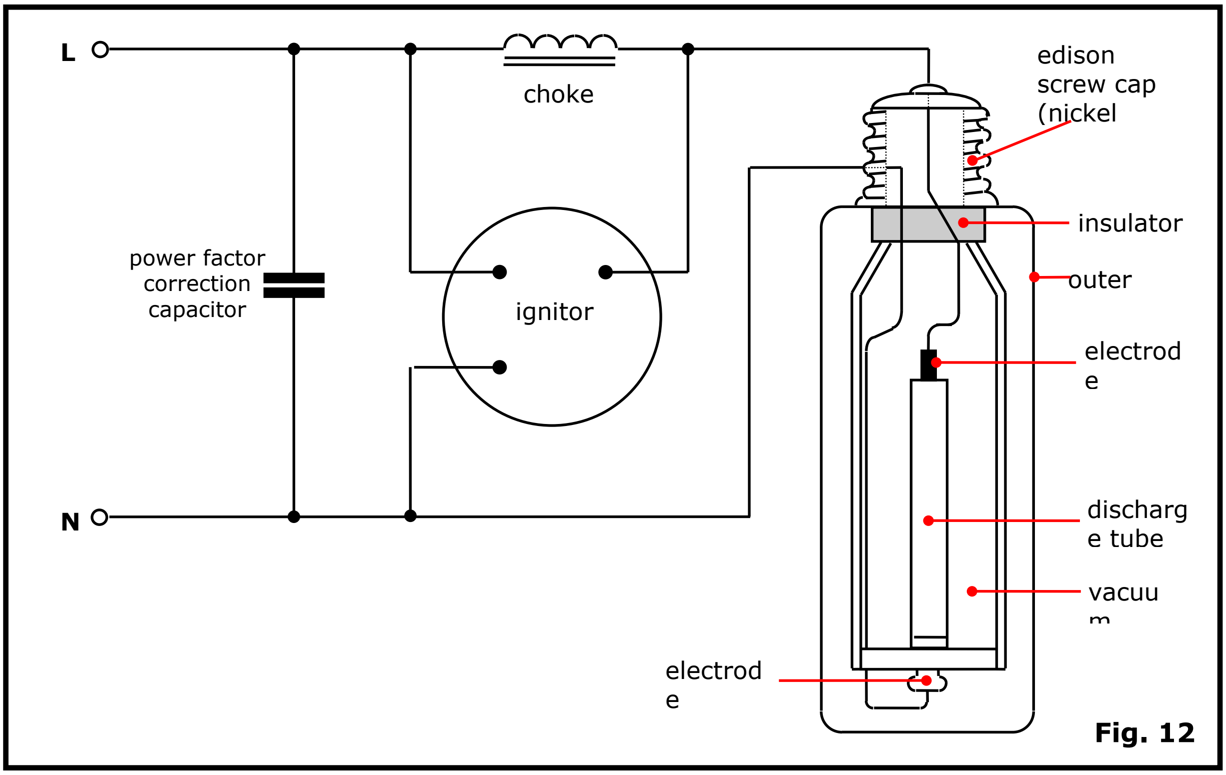


Fig. 12

Hot sodium-vapour is highly reactive and would attack conventional arc-tube materials eventually discolouring or destroying them. Also, in order to achieve the high vapour pressure, the coolest section of the arc-tube must be at 750°C therefore the arc-tube is made of sintered aluminium-oxide which is the only material known that is capable of withstanding a sodium-vapour attack. Most high-pressure sodium lamps contain sodium dosed with mercury (to increase the impedance of the lamp) and argon or xenon gas as the "pre-heating" substance. Starting is effected by the ionisation of the xenon (or argon) gas by high voltage pulses (2kV. to 4.5kV.) from the ignitor in the external control circuit. The ionised gas heats the lamp and the sodium-vapour discharge takes over.

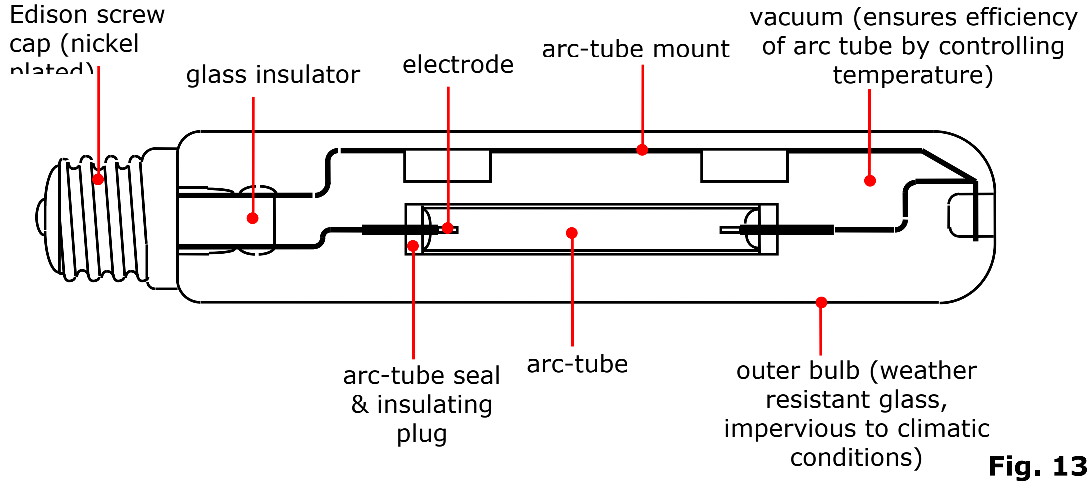



**Fig. 13**