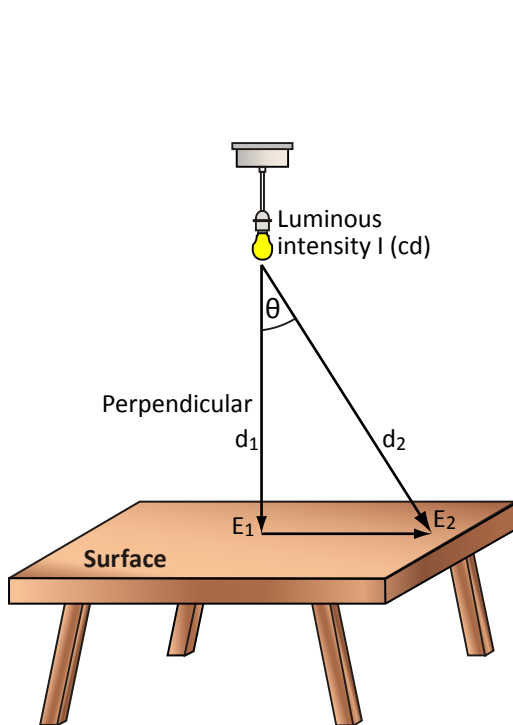


Level 3 Diploma in Installing Electrotechnical Systems & Equipment

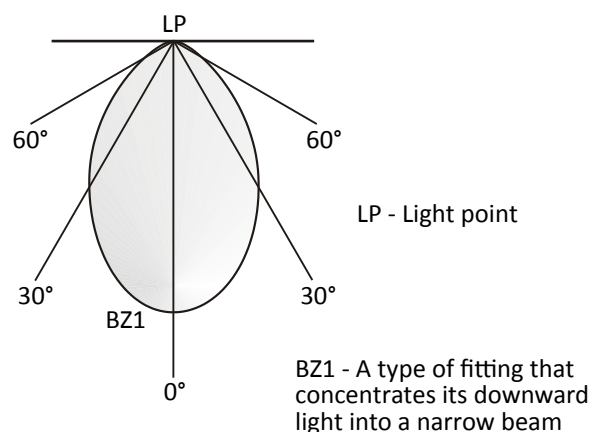
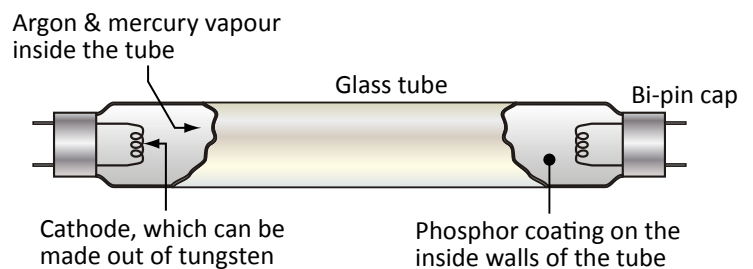
C&G 2357

Unit 309-10 Understand the principles and applications of electrical lighting systems



$$E_1 = \frac{I}{d_1^2}$$

$$E_2 = \frac{I \times \cos \theta}{d_2^2}$$



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Aims and objectives

By the end of this study book you will have be able to:

- Explain the basic principles of illumination and state the applications of:
 - Inverse square law.
 - Cosine law.
 - Lumen method.
- Explain the operating principles, types, limitations and applications of luminaires.
 - General Lighting Service (GLS).
 - Tungsten
 - Halogen
 - Mercury vapour.
 - Low pressure.
 - High pressure.
 - Metal halide.
 - Sodium vapour
 - Low pressure.
 - High pressure.
 - Energy saving (such as compact fluorescent lamps).
 - LED.

1: Basic terminology

In this session the student will:

- Gain an understanding of the following terms:
 - Luminous intensity
 - Luminous flux.
 - Illuminance.
 - Efficacy.

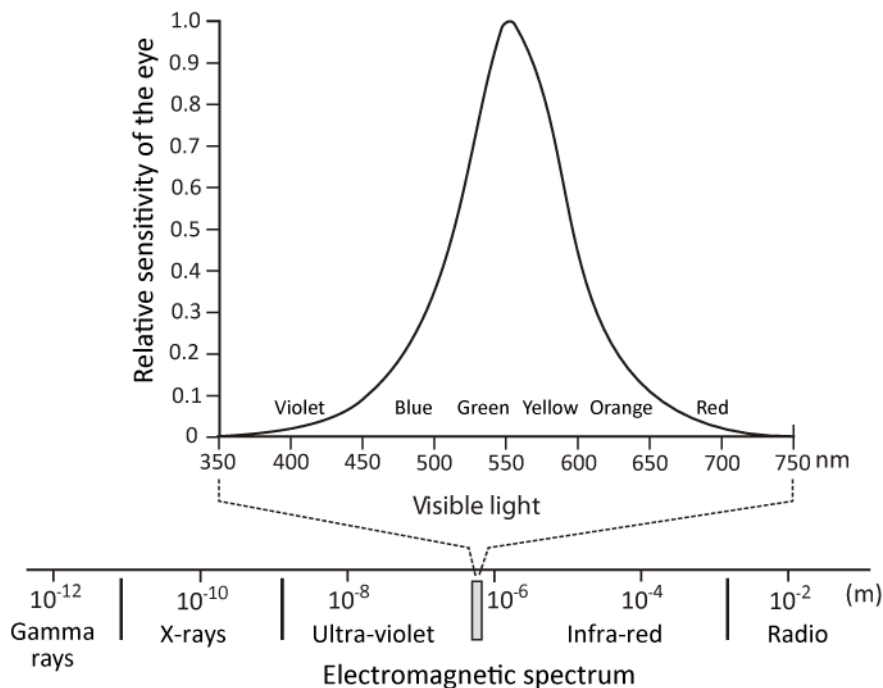
Terminology and units

Light is energy!

It is energy in the form of electro-magnetic radiation in waves.

The visible light spectrum spans from approximately 350 nm to 750 nm with the long wavelengths at the red end of the spectrum and the short wavelengths at the blue end.

This range of radiation can be seen when light passes through a prism or a raindrop and a whole range of colours can be seen. The electromagnetic spectrum is seen below.

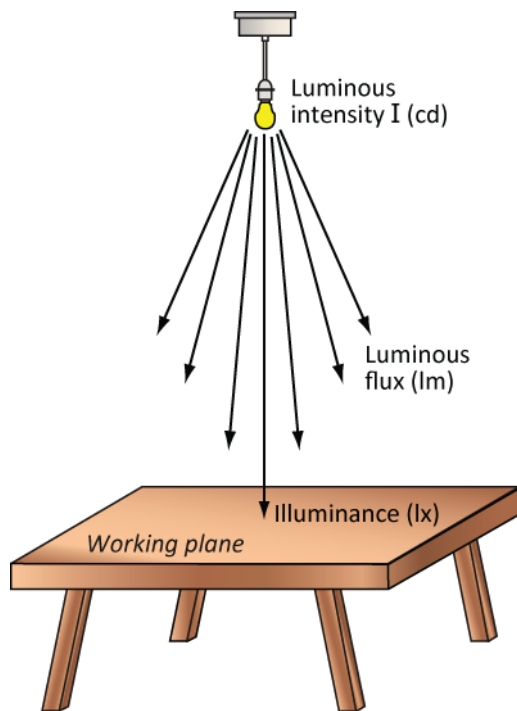


We can see that the light we use only occupies a very narrow band of the electromagnetic spectrum. This spectrum is true for the sunlight but artificial light sources such as electrical lamps typically have a differently composed spectrum.

However, it is not the aim of this study book to look in any detail at the theory and principles of the electromagnetic spectrum. It is interesting to know the range that the visible spectrum of light falls within to set things in context. Lamps are specifically chosen to use their colours to the best effects. For instance; you will not see sodium lamps above a meat counter as it will make the meat look 'off'. Nor would you use incandescent lamps for street lighting.

This unit will consider all the common lamp types and suggest typical applications for them. We will also consider how the illumination required is calculated based on room dimensions and mounting height of the lamp.

Firstly, it is necessary to state some things about light and their associated technical terms and how it behaves before we look at anything else.



Luminous intensity

This is the power of the light source to emit light flux in a particular direction.

Its unit is the candela (cd) [pronounced can dee la] and its symbol is I.

Luminous flux

Is the rate of flow of light energy from a source.

Its unit is the Lumen (lm) and its symbol is ϕ or F.

Illuminance

Illuminance is the amount of light energy reaching the working plane. In doing so it lights up that surface. So illuminance is the density of luminous flux reaching a surface.

Its unit is Lux (lx) or Lm/m^2 . Its symbol is E.

As you would expect there is a formula attached to this.

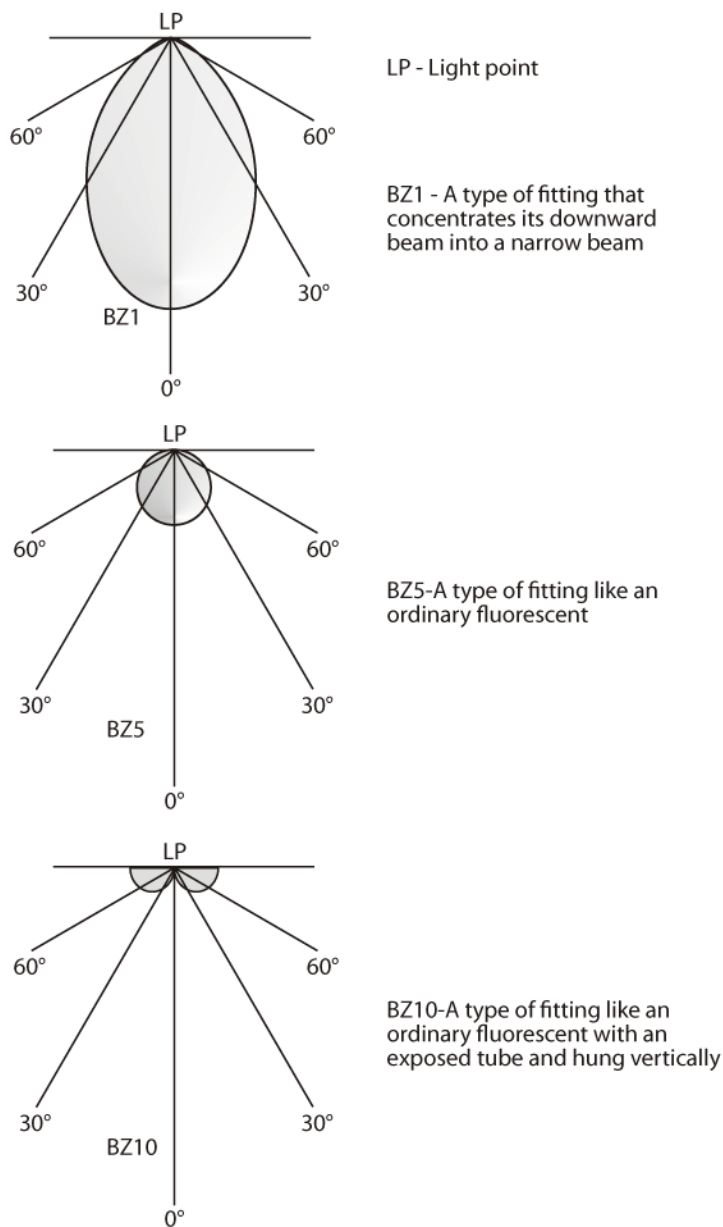
$$\text{Illuminance} = \frac{\text{luminous flux}}{\text{area}}$$

$$E = \frac{F(\phi)}{A}$$

To give you some idea of the range of illuminance levels. Emergency lighting is usually rated at a minimum of 0.2 lux, whereas bright sunlight is rated at approximately 50 000 lux.

Illuminance is a better measure of light than luminous flux, particularly when it is related to the light falling on the surface. This is because luminous flux measures the flow of light from a source, whereas the illuminance measures the actual light at the surface that you happen to be working on.

You should be aware that a light source does not spread its light evenly in every direction. The information for each type of lamp can be gained from the manufacturers. Polar curves show the quality of light in particular directions from a luminaire.



The polar curves show the luminous intensity, measured in candelas, at a variety of distances from a source. Have a look at the diagram shown on the left.

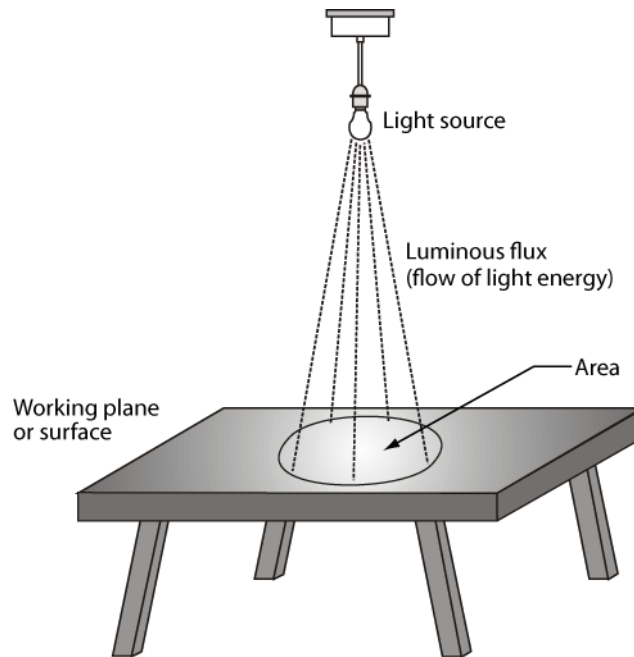
These curves help the designer select a lamp for particular function.

These diagrams tell you immediately if most of the flux (the lumens, the “flow of light”) goes upwards downwards or sideways.

Which of the polar curves shown is the one for a spotlight?

Let us go back to our diagram.

Here we have a light source shining down on a table or it could be a bench in a college workshop.



The level of illuminance is measured on the surface of the work top. The assumption here however is that light falls on to the surface directly; that is at right angles. This is not what would normally happen. Light would fall on a surface from any number of other directions. We will look at this a little later on.

We'll try a couple of examples.

1. A source of light has a luminous flux of 1 500 lm. The worktop on which the light falls is 2.5 m×2.5 m. What is the illuminance?

Firstly determine the area; $A = lb = 2.5 \times 2.5 = 6.25 m^2$

Now to determine the illuminance; $E = \frac{F}{A} = \frac{1500}{6.25} = 240 lux$

2. The light falling on the workbench is required to be 300 lux. If the area of the bench is 3 m×2.75 m, what luminous flux is required?

The area is; $A = lb = 3 \times 2.75 = 8.25 m^2$

Using; $E = \frac{F}{A}$ transpose for F , this gives; $F = EA = 300 \times 8.25 = 2475 lm$

From this you can see that the light source would need to give out nearly 2 500 lumens. Remember that luminous flux is the rate of flow of light energy from a source!

Efficacy

There is an additional measure of the ability of a lamp to convert electrical energy into light energy. This is called the '**luminous efficacy**' or more simply '**efficacy**'. You can think of it as being similar to the efficiency of a system, although efficacy is not measured in terms of 'per-centage' or 'per-unit'.

$$\text{luminous efficacy} = \frac{\text{luminous flux output}}{\text{electrical power input}}$$

$$\text{lm/W} = \frac{\text{lumens}}{\text{power}}$$

$$\text{efficacy} = \frac{F}{P}$$

Its probably worthwhile working through an example so that you have some idea of how it works.

1. A room has a total luminous flux of 9 250 lumens. The fittings have an efficacy of 24 lm/W. What is the total power required, and the number of 100 W fluorescent fittings needed?

Remember to take things systematically.

$$\text{efficacy} = \frac{F}{P} \quad \text{transpose for } P$$

$$\text{Determine the total number of wattage required; } P = \frac{F}{\text{efficacy}} = \frac{9250}{24} = 385.4 \text{ W}$$

Each fitting is rated at 100 W, therefore No. of fittings required;

$$\text{No. of lamps} = \frac{385.4}{100} = 3.85 \text{ lamps} \therefore 4 \text{ lamps are required}$$

Notice that you have to increase the number of fittings to give you the minimum of what is required.

Exercise 1.

1. What three factors can affect the direction of light?
2. Define luminous intensity, and name its unit and symbol.
3. Define luminous flux, and name its unit and symbol.
4. The illuminance on a surface is 0.5 lux. If the area covered is 4 m x 3 m, what is the luminous flux?
5. A source of light has a luminous intensity of 135 cd. 20 % of the total luminous flux emitted from the source falls at right angles on to a surface of area 2 m x 1.75 m. If the total luminous flux is 1696 lumens, calculate the illuminance falling on the surface.
6. The total luminous flux in a hall is 74 000 lumens. If the efficacy of tungsten lamps is 14 lm/W, and that of fluorescent tubes, is 38 lm/W state how many would be needed of each type of lamp to meet the need.

2: Lighting design principles

In this session the student will:

- Gain an understanding of the inverse square law.
- Describe why the cosine law is used.

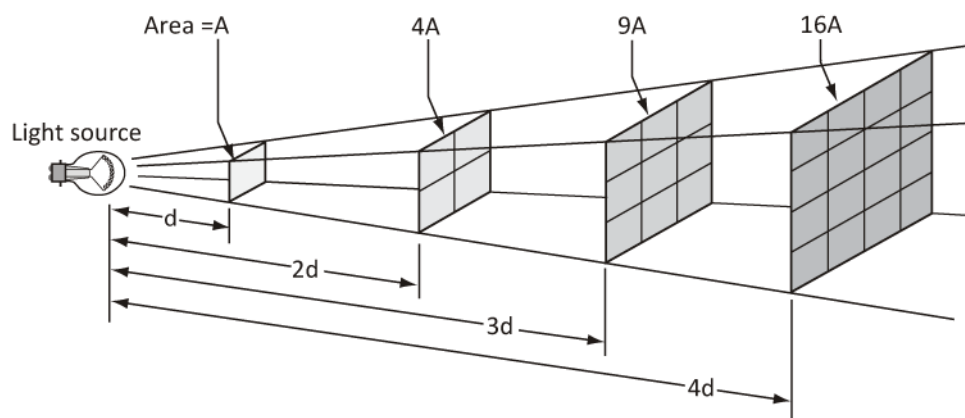
Lighting design is a vast area of study and is mostly beyond the level at which this study book is set. However, over the next few pages you should get some idea of the choices that have to be made as well as the calculations.

As per normal, we'll look at different aspects independently of each other and then see how they come together.

You are already aware that when light travels out from a source then the light energy reaching a point diminishes. You only have to look up at the stars in the sky to see that this is true. The rule that is used as a measure of this fall in light energy is called the '**inverse square law**'.

Inverse square law

Have a look at the diagram below.



You can see in the diagram above that when light travels, for example one metre, then the area that light falls on could be said to fall on an area of 1 m^2 .

As the light travels a further metre from the source, the area that the light falls on also increases. It doesn't just double however, but it increases fourfold, or the square of the distance travelled, for example; $2^2 = 4$.

As the light travels a little bit further, say another metre, so that it has travelled 3 m from the source of light, the light now falls on an area of $3^2 = 9$. This process continues *ad infinitum*.

As you would expect there is a formula attached to this idea.

$$\text{Illuminance} = \frac{\text{luminous intensity (cd)}}{\text{distance}^2 (m)}, \quad \text{giving } E = \frac{I}{d^2}$$

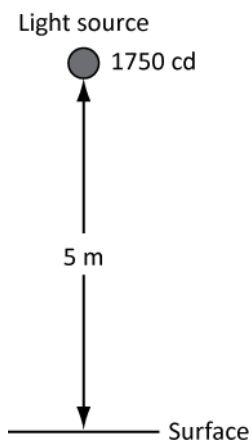
Where:

- E** illuminance or the density of luminous flux reaching a surface.
- I** the luminous intensity of the light energy source and is measured in candelas.
- d** the distance travelled from the light source to the surface which is being illuminated.

Example

- Calculate the level of illumination falling on a surface 5 m away from a light source of 1 750 cd.

Before you begin, do a sketch and put in what information you already have, this helps you solve problems.



Notice that the light falls directly below the source.

Amount of illuminance reaching the working plane or surface is,

$$E = \frac{I}{d^2} = \frac{1750}{5^2} = 70 \text{ lx}$$

- If we still required a level of illuminance of 70 lux, what luminous intensity would be required if it was moved 8.5 m away?

Transpose the equation for I giving; $I = E \times d^2$

The intensity of the light source needs increasing to; $I = 70 \times 8.5^2 = 5057.5 \text{ cd}$

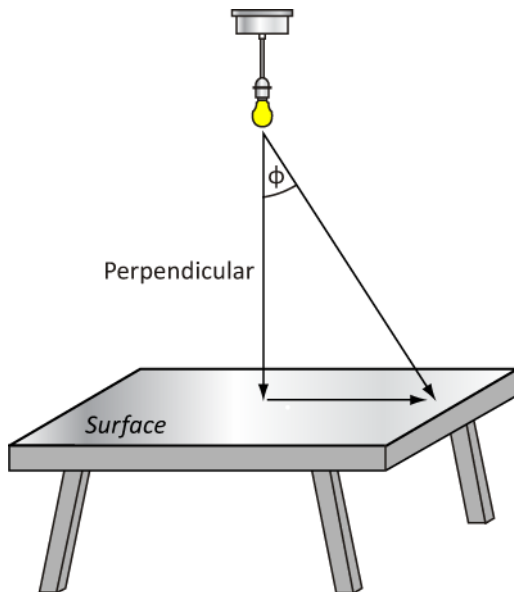
Notice the large increase in luminous intensity required just by a move of 3.5 m to get the same illumination.

You should be able to start seeing the need for the variety of types of fitting now. The greater the light output the further away the fitting can be placed.

So far so good, we can now find the level of light falling onto a surface directly below the fitting. What happens however when the light doesn't fall at right angles but indirectly?

The cosine law

This is the answer to the problem of light not falling directly below the fitting.

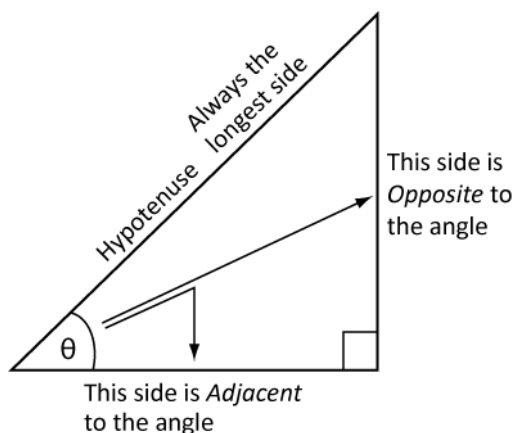


The diagram on the left shows a light source falling onto a surface. We know that the light falls onto the surface directly below it, but we are also aware that this same source illuminates the surface further away.

If we draw the light falling as straight lines, there is one line drawn directly below the source. This is called the **perpendicular**. Another line is drawn at an angle from the source down to the surface. These two lines form an angle ϕ .

The perpendicular forms a right angle between itself and the surface on which it falls. As I'm sure you are aware, this allows us to make use of **Pythagoras' theorem**.

Trigonometry and Pythagoras



Pythagoras

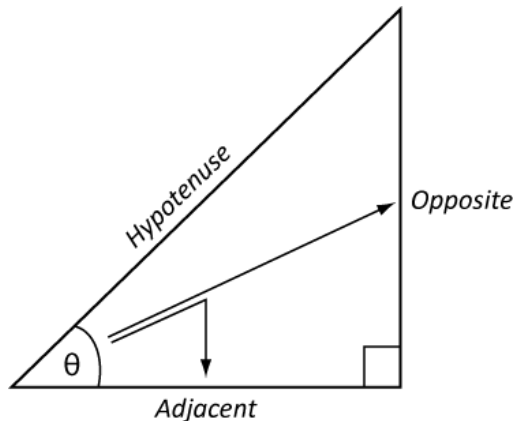
From earlier lessons, I am sure you will remember that the square on the hypotenuse is equal to the adjacent squared plus the opposite squared.

This gives;

$$a^2 = b^2 + c^2 \quad \text{transposed to} \quad a = \sqrt{b^2 + c^2}$$

Where a is the hypotenuse.

The second set of qualities that we can make use of, are the relationships between the sides and the angles of a right-angled triangle. You met these before in the maths unit.



Trigonometry

In any right-angled triangle, we can describe any angle in terms of a ratio of two other sides.

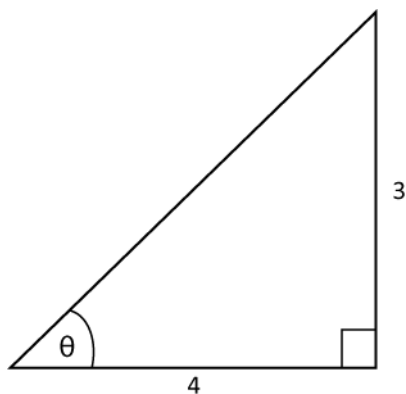
Assume that we are looking for the angle, θ (theta). We can find out this angle in any one of three ways.

$$\cos \theta = \frac{\text{adj}}{\text{hyp}} = \frac{A}{H}, \quad \sin \theta = \frac{\text{opp}}{\text{hyp}} = \frac{O}{H}, \quad \tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{O}{A}$$

A few points need to be noticed. Firstly, it doesn't matter which relationship is used. I can use **sin** or **cos** or **tan**. The angles will still come out the same.

Examples

1.



Based on this triangle determine the values of all the angles and all the sides.

Follow the working out.

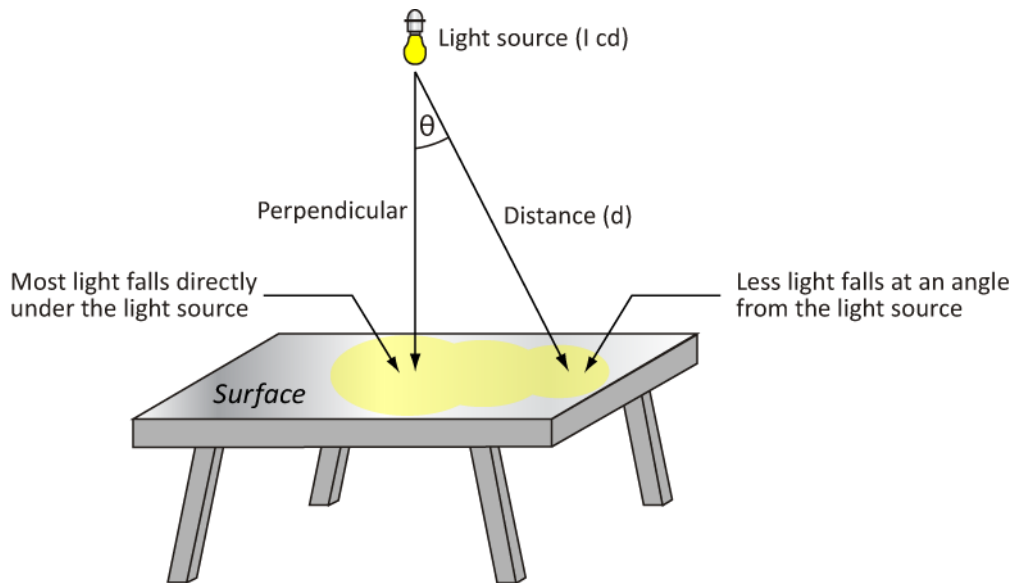
Firstly, determine the length of the hypotenuse; $a = \sqrt{b^2 + c^2} = \sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = \underline{\underline{5}}$

Using the cosine ratio; $\cos \theta = \frac{A}{H} = \frac{4}{5} = \underline{\underline{0.8}} \quad \therefore \theta = \cos^{-1} 0.8 = \underline{\underline{36.87^\circ}}$

Using the sine ratio; $\sin \theta = \frac{O}{H} = \frac{3}{5} = \underline{\underline{0.6}} \quad \therefore \theta = \sin^{-1} 0.6 = \underline{\underline{36.87^\circ}}$

Using the tangent ratio; $\tan \theta = \frac{O}{A} = \frac{3}{4} = \underline{\underline{0.75}} \quad \therefore \theta = \tan^{-1} 0.75 = \underline{\underline{36.87^\circ}}$

Because we have a right-angled triangle, you can make use of the skills that you have just learnt. Consider the diagram below.



To calculate the illuminance directly below the light source we use the equation you met earlier.

$$\text{Illuminance} = \frac{\text{luminous intensity (cd)}}{\text{perpendicular distance}^2 \text{ (m)}}, \text{ giving } E = \frac{I}{p^2}$$

To calculate the level of illuminance at say the edge of the table, the distance has now become what we call the hypotenuse, and we also need to consider the angle that the light has moved through.

Because we know the hypotenuse and the perpendicular, the angle that we are looking at can be found using cosine rather than sine or tangent.

Moving back to looking at the equation: when we put things together, we get a variation on the inverse square law.

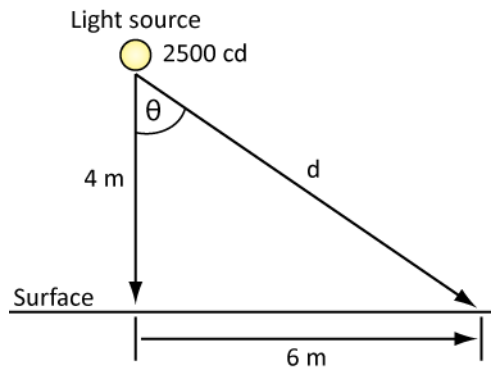
$$E = \frac{I \times \cos \theta}{d^2}$$

E, **I**, and **d** all remain the same; the only difference is the addition of an angle. You should also remember that the distance is the length of the hypotenuse and not the perpendicular.

We'll work through a couple of examples to give you a feel of what you should do.

1. A light source provides a luminous intensity of 2500 cd and is placed 4 m from a worktop. The light is also measured at a point 6m along the workbench. What will be the levels of illuminance directly under the light source and at the point 6 m away?

Remember to draw a diagram first. This will give you an idea of what you have.



Solution

The length of the hypotenuse; $\text{hyp} = \sqrt{4^2 + 6^2} = \sqrt{16 + 36} = \sqrt{52} = 7.21\text{m}$

Illuminance directly below the lamp; $E = \frac{I}{d^2} = \frac{2500}{4^2} = 156.25\text{lux}$

Cosine of the angle; $\cos \phi = \frac{\text{adj}}{\text{hyp}} = \frac{4}{7.21} = 0.555$

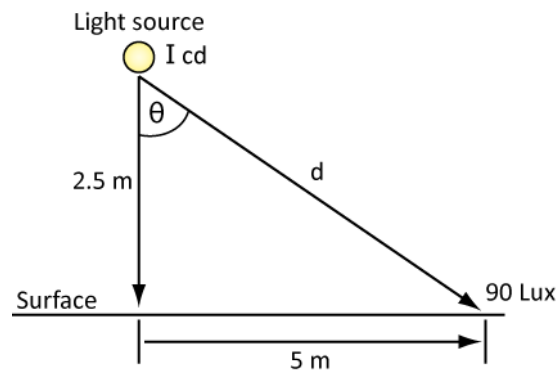
Illuminance 6 m away horizontally; $E = \frac{I \cos \theta}{d^2} = \frac{2500 \times 0.555}{7.21^2} = 26.7\text{lux}$

Notice that there is a large difference between the illuminance at the two points. Again, this has implications for the choice and setting of fittings if light is to be spread evenly over a surface.

Try one more example.

2. An illuminance of 90 lux is required at a point 5m along from a point directly underneath a light source. The distance between the light source and the point directly under it is 2.5 m. What is the luminous intensity?

Again do a drawing.



Solution

The length of the hypotenuse; $\text{hyp} = \sqrt{2.5^2 + 5^2} = \sqrt{6.25 + 25} = \sqrt{31.25} = 5.59 \text{ m}$

Cosine of the angle; $\cos \phi = \frac{\text{adj}}{\text{hyp}} = \frac{2.5}{5.59} = 0.447$

Illuminance 6 m away horizontally; $E = \frac{I \cos \theta}{d^2}$ transpose $I = \frac{E \times d^2}{\cos \theta} = \frac{90 \times 5.59^2}{0.447} = 6292 \text{ cd}$

Exercise 2

1. Determine the level of illuminance on a surface 4.5m away from a light source. Assume that the working surface is directly below the light source of 2350cd.
2. An illuminance level of 275 lux is required. If the source of light is directly over the surface and 3 m away, what luminous intensity would be required?
3. A fluorescent fitting provides a luminous intensity of 1 800 cd and is placed 2.5 m away from a work surface. What will be the level of illuminance directly below the fitting and a further 4 m away on the horizontal?
4. An illuminance level of 300 lux is required at a place 3.5 m along from a point directly underneath a light source. The light source is 1.8 m above the work surface. What will be the required luminous intensity?

3: Lighting arrangement

In this session the student will:

- Gain an understanding of the following terms:
 - Light loss factor.
 - Coefficient of utilisation.
 - Lumen method of arranging lighting.

We're now going to look at how we take account of the other factors that will affect the choice of our types of fitting, the distance they are apart from each other and the heights that they are set at.

When starting to think about designing a lighting system for a room, a number of things have to be taken into account:

- **the type of lamp/fitting to be used.**
- **the type of room that the lamps are to be installed in taking into account, the cleanliness of the room and how the surfaces affect the reflection of light.**

There are two factors that we need to particularly consider. These are the '**light loss factor**', or sometimes called '**maintenance factor**' and the '**utilisation factor**', or '**coefficient of utilisation**'.

Light loss factor

When any lamps are installed, there is a decline in their output from the very first day. There are a number of factors that make up the light loss factor. However, it is basically the relationship between the light output of a lamp when it is clean compared to when it is dirty. The factor is affected by the number of times that the lamp is cleaned, the cleanliness of the walls etc., and is around 0.8 for the average room. This figure will vary and more accurate data can be found from the **CIBSE** (Chartered Institute of Building Service Engineers). The figure quoted will make more sense on the next page or two.

Coefficient of utilisation

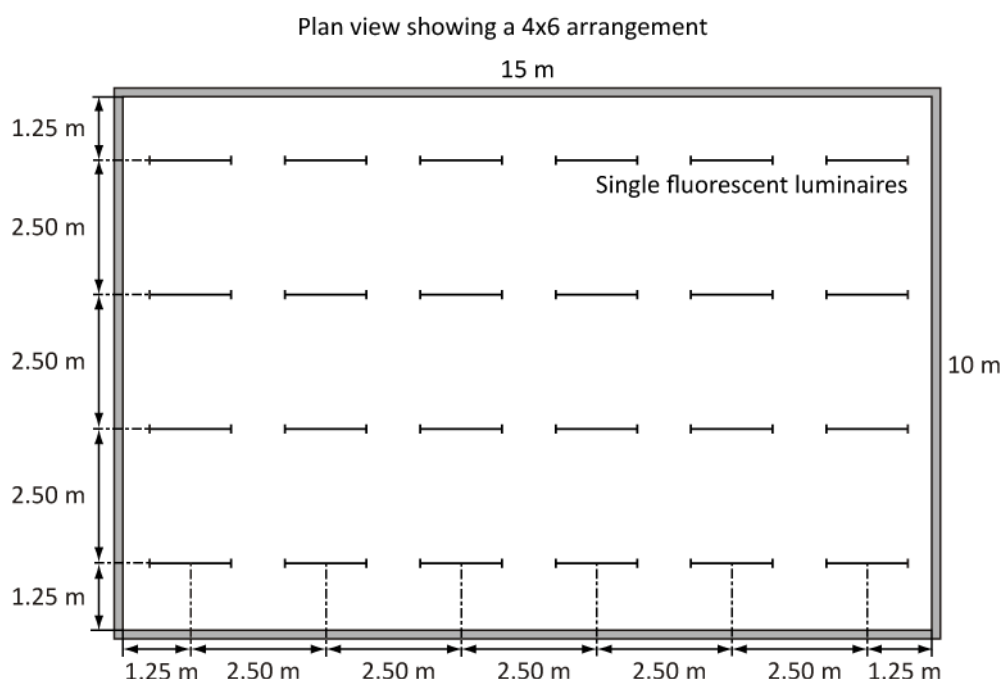
The coefficient of utilisation factor is a measure of the efficiency of the whole lighting system to deliver light to the working surface. This takes into account the colour of the walls, the size of the room and the height of the lamp above the work surface. Again, the value for the utilisation factor is found in lighting tables and is always less than 1.

You already know that the levels of illuminance are affected by the distance of the fitting from the surface as well as the angle that the light travels down. In a normal room, there is often more than one light source and so the calculations can become a little bit more complex.

There is a simplified way of determining the number of lights required in a room and this is called the '***lumen method***'.

Lumen method

If the fittings are mounted overhead and are formed into a regular rectangular pattern then the lumen method can be used. If there is no rectangle/square pattern then there can be no use of this method. Look at the diagram below.



You can see that we have a regular shaped room, and a regular arrangement of luminaires. It is this that is needed for the lumen calculation to work. Notice also the spacing between the fittings and the spacing to the edge of the room.

There are a number of things we need to know before we can determine the number of fittings that are required. These are:

- the illuminance level required (lux).
- the area at the surface on which the light falls (m²).
- the average luminous flux from each lamp (lumen).
- utilisation factor (no units)
- light loss or maintenance factor (no units).

These are all combined into one formula.

$$\text{Number of lamps} = \frac{\text{illuminance} \times \text{area of working surface}}{\text{luminous flux} \times \text{utilisation factor} \times \text{light loss factor}}$$

$$N = \frac{EA}{F \times UF \times LLF}$$

We'll work through a couple of examples to see how this works out.

1. An area of 15 m×10 m is to have a level of 250 lux at the working surface. Each fluorescent lamp delivers a luminous flux of 2 750 lm. If the utilisation factor is 0.5 and the light loss factor is 0.8, calculate the number of lamps required and provide a diagram of the suggested layout.

Solution

Area of the room; $A = lb = 15 \times 10 = 150 \text{ m}^2$

Number of lamps; $N = \frac{EA}{F \times UF \times LLF} = \frac{250 \times 150}{2750 \times 0.5 \times 0.8} = 34.09 \text{ lamps}$

We have a situation here where we have an answer with a decimal point. Obviously you can only get hold of 0.09 of a fluorescent lamp rarely. A compromise has to be reached between getting exactly the right amount of light onto the working surface and the minimum number of fittings that would fit into a rectangular pattern.

The best pattern for this room could involve a five by seven (5x7) pattern giving us thirty-five fittings or a four by eight (4x8) pattern giving us thirty-two fittings.

Very often, it will be the shape of the room that will determine the number of fittings in any particular instance.

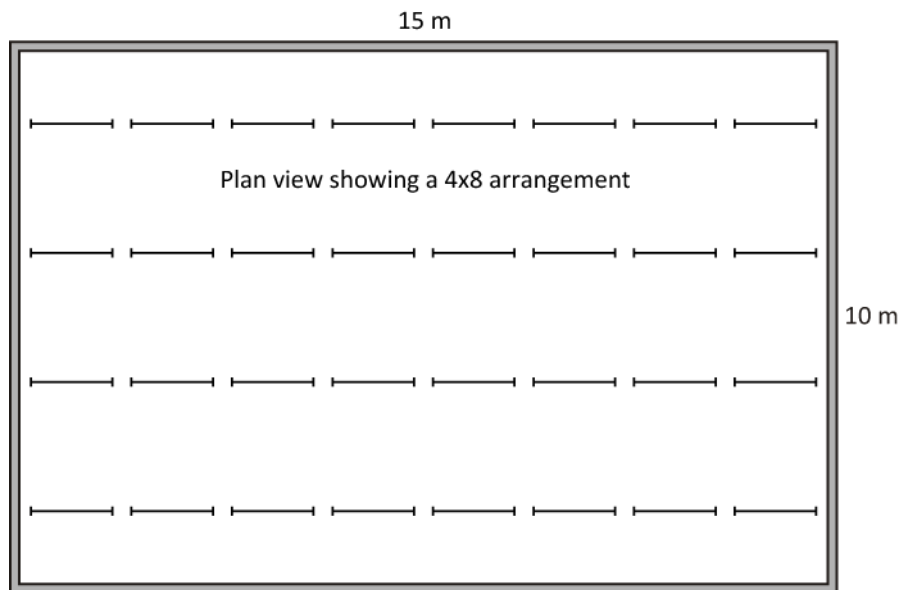
However, you should also be aware of factors such as glare, natural light and the space-to-height ratio:

- *glare can be considered to be excessive brightness in the field of vision. With too much direct light, too strong an image is formed at the back of the eye and can cause damage.*
- *more natural light means that the artificial light may need to be modified.*
- *space-to-height ratio is a measure of the uniformity of light falling on a work surface. It is the spacing between luminaires divided by their height above the horizontal reference plain. This is rather a mouthful. So we'll take a slightly more detailed look at it.*

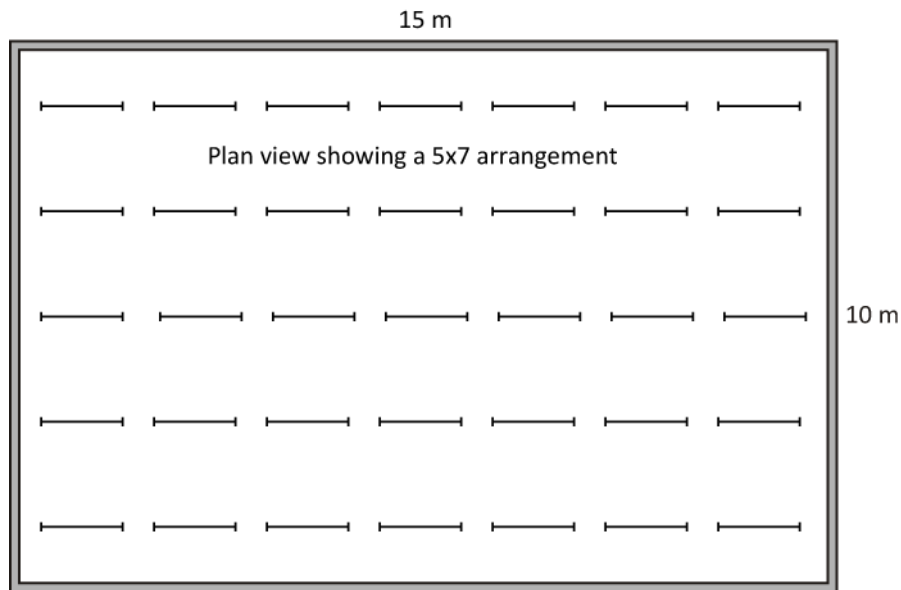
However, back to the question we were involved with.

You will remember that we calculated that we needed a minimum of 34 lamps in a 15mx10m room.

My answer, although not necessarily the only answer, is given below and over the page. I have provided two options.



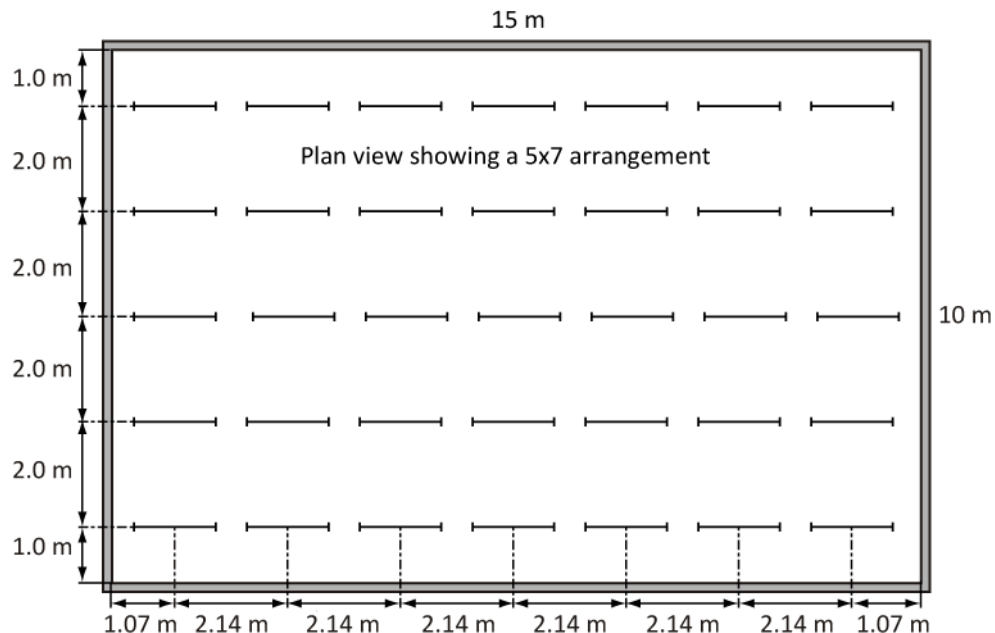
This shows an even arrangement. However, I do not have quite enough fittings. This is not necessarily a problem, but you do need to be aware of the slight fall off in light output.



Here we have slightly too many fittings. There will be a little too much light. Take your pick. It is your choice.

The arrangements of the fittings above are not haphazard. Notice that the gap closest to the walls is half the distance of the gap between the fittings. You should operate this way. It gives an evenness of light throughout the room.

This lighting array should show you what is meant.



Evenness of light is important and you should take great care in choosing your layout. Remember our brief excursion into space-to-height ratios!

We'll have a go at one more example before we review progress and try the next exercise over the page.

2. A general assembly shop, 25 m×12 m requires a general level of illuminance at bench level of 225 lux. There are two possible alternatives under consideration:

- a) 100 W tungsten filament lamps at an efficacy of 12 lm/W
- b) 58 W twin fluorescent fittings at an efficacy of 35 lm/W.

Make a recommendation to the factory owner as to the best option taking into account the current demand required. The light loss factor is 0.6 and the coefficient of utilisation is 0.65. The luminous flux of tungsten filament lamps is 1 250 lumens and the luminous flux from the fluorescent lamps is 2 350 lumens. Assume the supply voltage is 230 V.

Solution

Area of the room; $A = lb = 25 \times 12 = 300 m^2$

Number of tungsten lamps; $N = \frac{EA}{F \times UF \times LLF} = \frac{225 \times 300}{1250 \times 0.65 \times 0.6} = 138.5 = 140 lamps$

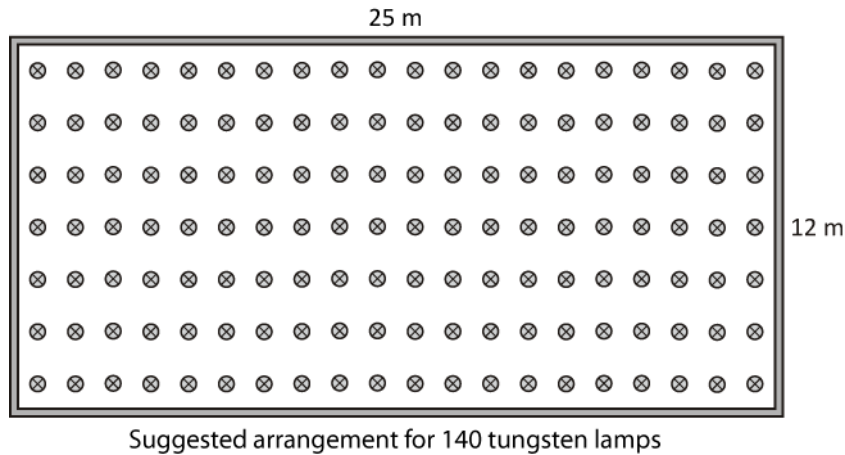
Current drawn; $I = \frac{P}{U} = \frac{100 \times 140}{230} \approx 61 A$

Number of fluorescents; $N = \frac{EA}{F \times UF \times LLF} = \frac{225 \times 300}{2350 \times 0.65 \times 0.6} = 73.6 = 74 lamps$

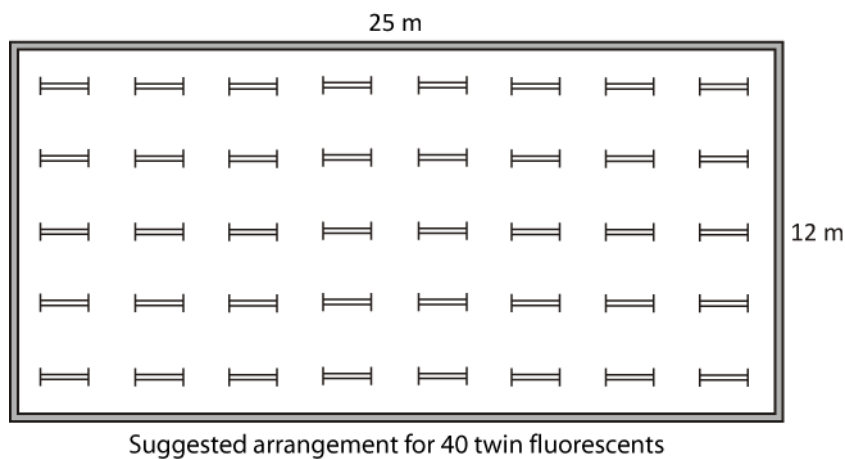
Current drawn; $I = \frac{P}{U} = \frac{58 \times 74 \times 1.8}{230} \approx 34 A$

In this example, nearly 140 tungsten lamps are required (the room would get very hot as 90% of the power supplied to each lamp is given out as heat), compared to only 74 lamps needed for the fluorescent.

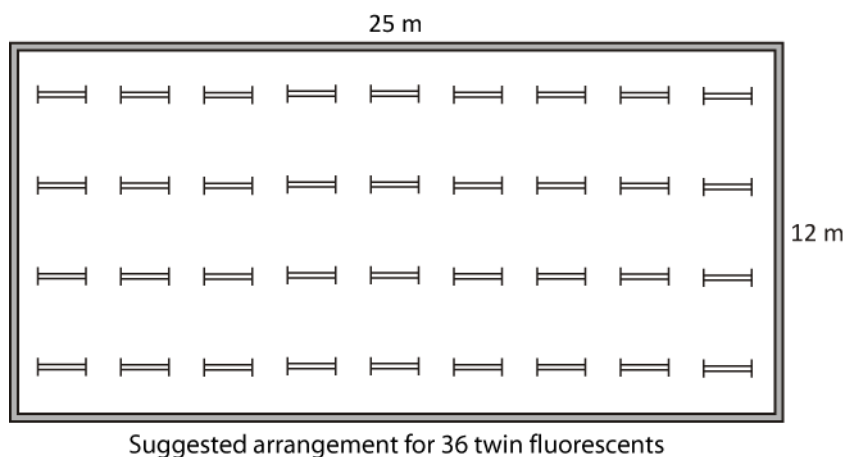
The diagrams below and over the page show the possible arrays for the tungsten lamps and the fluorescent lamps.



As the fluorescent fittings also contain two lamps then there are only 37 fluorescent fittings needed. With this in mind a reasonable pattern would be either 4×9 or 5×8.



This arrangement shows a forty fluorescent arrangement. Again, care should be taken with any consideration with glare.



This arrangement shows a thirty-six fitting arrangement.

On the earlier page, you will see that the tungsten fitting arrangement is ridiculous, and would lead to people having to wander around naked just to keep cool!

However, either the thirty-six- or forty-fitting twin fluorescent arrangements would work well enough.

Exercise 3.

1. Describe coefficient of utilisation and light loss factor.
2. An office 8 mx10 m is to be lit to a level of 350 lux. If each fitting contributes to a luminous flux level of 2 600 lumens and the light loss factor is 0.85 and the utilisation factor is 0.7, what will be the required number of fittings? Show how you might fit them if they are 1 500 mm long.
3. A drawing office measures 50 mx40 m and is to be illuminated with 20 1 000 W high pressure mercury vapour luminaires each having an efficacy of 59 lm/W. If the utilisation factor is 0.6 and the light loss factor is 0.8, calculate the illuminance. Show how you might fit them in the room. If the space-to-height ratio is 1.25:1 determine the mounting height.
4. A luminaire having a luminous intensity of 1 700 cd in all directions below the horizontal is suspended 7 m above a bench. Determine the illuminance on the surface:
 - i) directly below the luminaire
 - ii) at a point 4 m along the bench from (i).
5. A 30 mx15 m workshop is to be illuminated to a level of 350 lux using 100 W low pressure mercury vapour lamps having an efficacy of 33 lm/W. Assuming a utilisation factor of 0.5 and a light loss factor of 0.8 determine:
 - i) total power required
 - ii) number of lamps required.

4: Lamps and the purpose of artificial lighting

In this session the student will:

- Explain what the purpose of artificial lighting is.
- Describe the nature of colour rendering.
- Describe what is meant by glare.
- Gain an understanding of how tungsten filament lamps operate.
- Gain an understanding of how discharge lighting operates.

There will always be times when it is necessary for some form of artificial lighting to be used within an installation. Artificial lighting is provided for three main purposes:

- I. to provide enough light for people to carry out an activity.
- II. to provide enough light for people to move about with ease and in safety.
- III. to display the features of a building in a manner suitable for its character and purpose.

To achieve each of these goals we need to assess the relative merits of the lamps that are commonly used today.

A number of terms will be used throughout this study book that you may not have come across before, so we'll just take a moment to list and define some of them.

Colour rendering

Some kinds of light, such as daylight, are often regarded as being more natural than the light from the majority of lamps. For example, a low-pressure sodium lamp is very yellow in its appearance.

Colour rendering, therefore, is the ability of a light source to reveal the colour appearance of a surface. This is related to a reference source of daylight.

Lamps are divided into classes related to ranges of values of the colour rendering index (CRI).

I've talked a bit about colour rendering and stated that it can be good, or reasonable etc. these terms are not particularly accurate however and there are set figures provided.

The table below gives you some idea of what these are.

Colour rendering groups	CIE general colour rendering index (Ra) 100=Reference	Typical applications
1A	$R_a \leq 90$	Where accurate colour matching is required such as in paint mixing and colour print inspection.
1B	$80 \leq R_a < 90$	Where accurate colour judgements are necessary such as in shop fronts etc.
2	$60 \leq R_a < 80$	Where moderate colour rendering is required.
3	$40 \leq R_a < 60$	Where colour rendering is not that important but too much colour distortion is unacceptable.
4	$20 \leq R_a < 40$	Where colour rendering is unimportant.

Colour rendering index for different light sources

Light source	Colour rendering group
Incandescent	1A
Metal halide	1A ... 2
Fluorescent	1A ... 3
High pressure sodium	1B ... 4
Low pressure sodium	4

Glare

Glare covers a number of situations in which extremes of illuminance in the field of view reduce one's ability to perceive detail in less well illuminated areas and may even cause discomfort.

This depends on the brightness and contrast of light sources and surfaces and the angle that they are viewed from.

Glare is differentiated into a number of types:

- disability glare
- successive glare
- reflected glare
- veiling glare
- discomfort glare.

Efficacy

As we have already seen, efficacy is a measure of the light output compared to the power input to the lamp. It is not a percentage value, although you may consider it a measure of the efficiency with which a lamp can convert power to light.

We will now look at a number of lamp types and see what they can and can't do.

Production of light

Lamps produce their light in one of three ways. The first is by way of '*incandescence*'. Incandescence occurs when a coil or element is heated up and the light that is given off is just a by-product of the heating. The GLS and the tungsten halogen lamp operate on this principle.

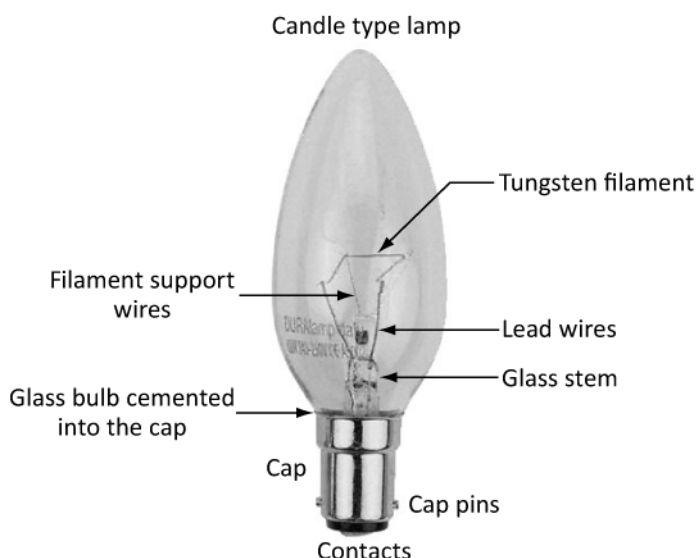
The second method of giving off light is via '*fluorescence*'. In this type of lamp a material that gives off light (fluoresces) is coated onto the inside of a glass tube or envelope. The material fluoresces when ultraviolet light is produced near it. The low pressure mercury vapour, or fluorescent lamp, is an example.

The third way in which light is produced is via *electrical discharge*. In this instance, an electric current is passed through a particular gas and this gas gives off light.

Tungsten filament lamps

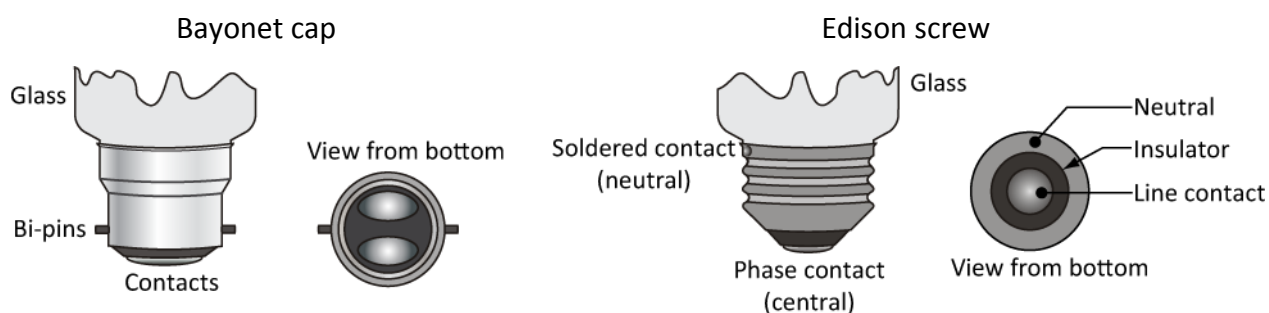
Tungsten filament lamps produce their light via incandescence. This means that putting a current through a tungsten element makes it glow white hot, i.e. it becomes incandescent and gives off light. The problem with this lamp is that it also gets very hot in use, and gives off more heat energy than light energy. The efficacy of this type of lamp is typically less than 12 lm/W which is very poor indeed.

This lamp is called a GLS (General Lighting Service) lamp. Its construction is shown below.



GLS lamps are made up of a coiled filament. The coiling of the filament allows internal convection currents to be produced as the lamp heats up, and the filament lamp can be run at a higher temperature because it cools itself. There are also double coiled filaments or coiled-coil filament lamps which increases this cooling effect.

There is a wide variety of sizes of this type of lamp ranging from 25 W to 2 000 W. There are two main ways in which this type of lamp is connected to the supply called **bayonet cap** (BC) or **Edison screw** (ES or GES).



GLS lamps do however have good colour rendering qualities. This means that they reflect more accurately the true colour of an object when compared to natural daylight.

The GLS lamp is cheap, gives good light, and requires no additional circuitry, which are its advantages. Its disadvantages are that it gives off more heat than light and it has a relatively short lifespan.

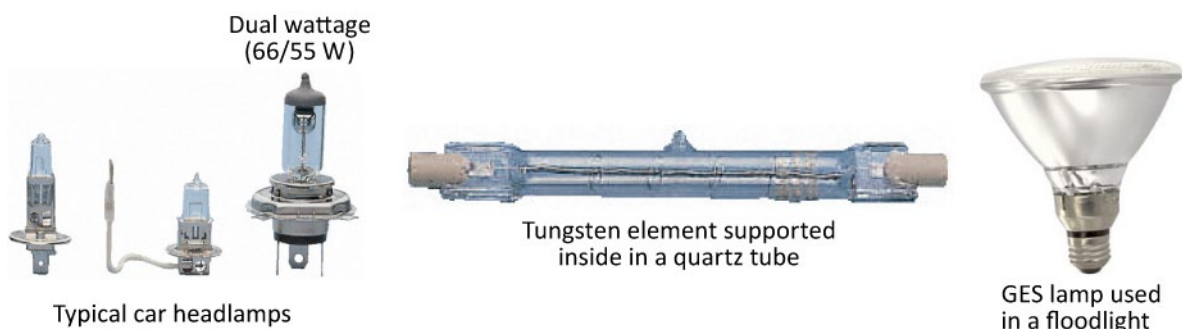
However as previously mentioned, the GLS lamp is incredibly inefficient; it has a very poor efficacy rating and therefore contributes massively to CO₂ emissions. Consequently, this type of lamp is being phased out if not totally banned now. Its direct replacement is the halogen lamp which is available at 230 V with a range of wattages.

Tungsten halogen lamps

With a tungsten filament (GLS) lamp, the temperature at which the lamp operates, and hence the brightness of the light has to be limited to give a reasonable lifespan. If we therefore want to increase the light output, we need to increase the temperature. We also know however, that this will dramatically shorten the life of the GLS lamp.

The tungsten halogen lamp is a variation on the GLS lamp that allows us to increase the temperature, without reducing the lifespan unduly.

The tungsten halogen lamp, as with the GLS lamp, still operates because of incandescence; it glows white-hot! However, the lamp is filled not with an inert gas such as argon/nitrogen, but with a halogen. Typical halogens are fluorine, chlorine, iodine and bromine. These gasses are far from inert and will react with a variety of other elements. Have a look below.



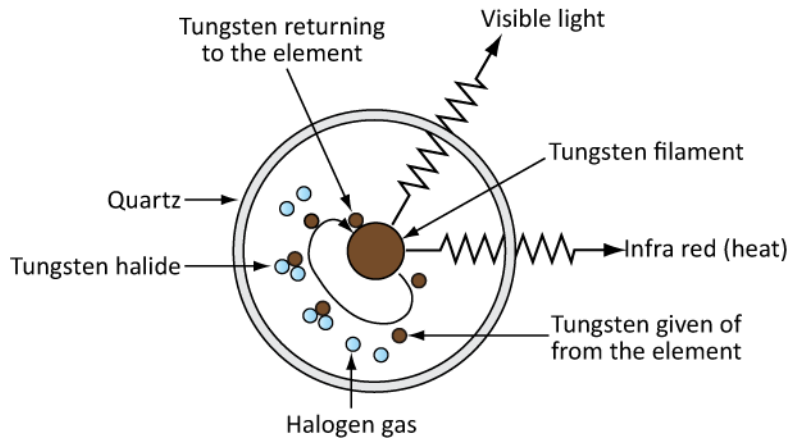
The tungsten halogen lamp has a filament supported along its length and the glass envelope is filled with krypton (an inert gas-doesn't react with other elements) and a trace of a halogen usually iodine.

There are a number of operating conditions that have to be in place for the tungsten halogen lamp to operate properly, the main one being that the outer wall of the lamp must not be contaminated via dirt/grease. This contamination causes 'hot spots' and will change the regenerative cycle of the lamp, reducing its life. So keep your fingers off the lamp wall!

I've mentioned the regenerative cycle of the lamp, so what is it?

As mentioned earlier, this type of lamp is able to operate at a higher temperature, and has a longer life than the normal GLS lamp. Normally with a GLS lamp, the tungsten is slowly driven off the filament and the filament weakens and eventually breaks.

We can alter this process with the use of our halogen gas. Have a look below.



We can see that the tungsten is driven off the surface of the filament, which is at a very high temperature. The tungsten combines with the halogen and forms what is called a halide.

This halide normally condenses at below 250 °C. However because we maintain the wall at above 250 °C, the halide doesn't condense on the wall of the lamp but is driven back towards the tungsten filament by convection currents.

As the halide approaches the filament, it separates out into its constituent parts and the tungsten returns to the surface of the filament and the halogen back to be used in the cycle again. It is this process that increases the life of the lamp and increases the light output of the lamp.

When we look at the qualities of the lamp, we also need to relate those qualities to the GLS lamp.

The range of the tungsten halogen lamp is normally from 150 W to 2 000 W. It has an efficacy of between 15 lm/W and 25 lm/W and gives good colour rendering. It is often used in display and security lighting.

Some of the more inefficient tungsten halogen lamps will be phased out starting September 2013 and be replaced with LEDs and CFLs (compact fluorescent lamps).

Energy efficient lamps

To follow EU directives to save energy and reduces CO₂ emissions, inefficient lamps such as incandescent and some halogen lamps are being phased out. They are being replaced with LEDs and CFLs. Both of these types of lamps offer a large saving in energy costs.

Compact fluorescent lighting (CFL)

How do CFLs work?

They work in very much the same way as for the normal fluorescent which will be discussed in some detail later on.

CFLs have an electric current which is driven through a tube containing a gas called Argon mixed with a small amount of mercury vapour. This mixture generates invisible ultra violet light, this then excites the fluorescent coating (phosphor) on the inside of the tube. This is emitted as visible light.

CFLs require a little more energy when they are first turned on to activate the gases, but once running they use about 75% less energy than conventional bulbs.

The ballast in the CFL helps to kick start the process and then regulates the current once the electricity is flowing. This process can take up to 3 mins to complete which is why they take longer to become fully lit. Most modern CFLs use electronic ballast to eliminate the buzzing noise which used to be emitted.

Advantages of CFLs

- Cheaper to run

Disadvantages

- Not all lamps are able to be used on dimmer switches
- Can take a long time to become fully light
- Emit heat so need ventilation
- Need extra protection if used outside.

LEDs

LED stands for Light Emitting Diode.

In the early days of development there were problems in getting the quality of light to match that of incandescent lamps. This has now been achieved and they are rapidly becoming the choice of the domestic and commercial market.

LED lamps are available to be interchangeable with ordinary incandescent lamps and the MR 16 with a bi-pin base shape which is typical of the halogen downlighter.



100 W Tungsten
£0.85 (dimmable)

Not available

2,000 hrs



20 W CLF Lamp
£3.95 (non

dimmable)

16, 000 hrs



5 W LED
£11.98 (non

dimmable)

35,000 hrs



50 W Halogen
£6.99 for ten.

(dimmable)

2,000 hrs



1.2 W LED
£6.29 (non

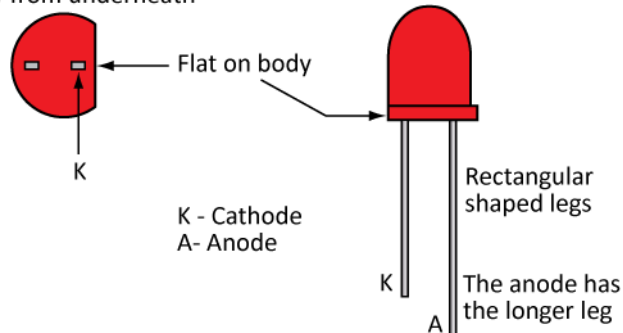
dimmable)

30, 000 hrs

Notice the low wattage of the LED range of lamps and their longevity!

Construction of an LED

View from underneath



The diode is a semi conducting material which when electrons move through them become they illuminated.

They have endless uses such as torches, light bulbs and light fittings.

Low powered LEDs

Low powered LEDs are used for items which are used constantly such as standby indicators on DVD players or the blinking light to show recording device is on.

High powered LEDs

High powered LEDs are used when a larger area of light is needed

Advantages of LEDs

- LEDs emit light in a specific direction whereas an incandescent or fluorescent bulb not only emits light but it emits heat in all directions
- Using LEDs reduces energy cost by up to 75%.
- As the LED also lasts around 10 times longer than an incandescent light there is a reduction in maintenance costs.

Disadvantage

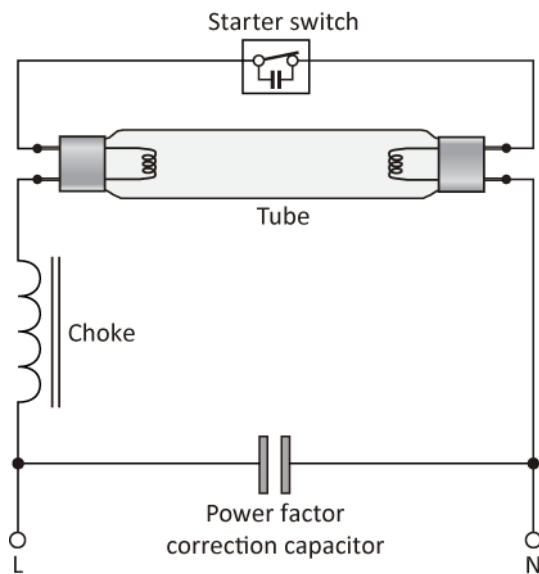
- Expensive
- Not all lamps are dimmable

Low pressure mercury vapour lamps (fluorescent)

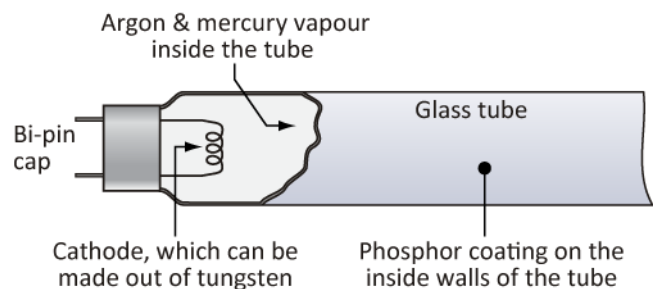
Low pressure mercury vapour lamps or more commonly termed fluorescent lamps, are a very common means of artificial lighting, and are found in many settings. Low pressure mercury vapour lamps don't operate on the principle of incandescence but on that of **fluorescence**. It is therefore necessary to look at how light can be produced from this method before we look at the particular circuits.

Filament lamps produce light by allowing electricity to flow through the filament, which is solid. When we look at fluorescence, we are dealing with electricity passing through a gas.

We shall use the classic fluorescent circuit which incidentally has fallen by the wayside, as a model for describing how we get our light.



Circuit diagram



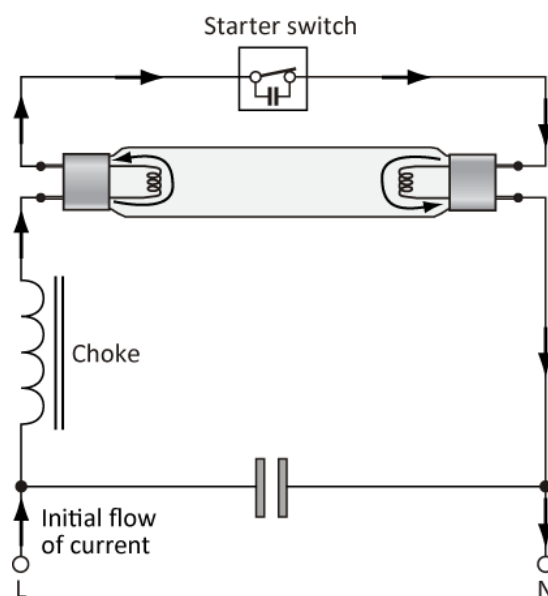
Fluorescent tube

A gas in its normal state is not a particularly good conductor. To overcome this we need to be able to **ionise** the gas. This is the process where the gas atoms have electrons removed from their orbit around a nucleus and the gas atom becomes electrically charged. We call this particular state an **ion**. When we get a state where the gas in the lamp is ionised then we can get conduction of electricity.

How do we get this?

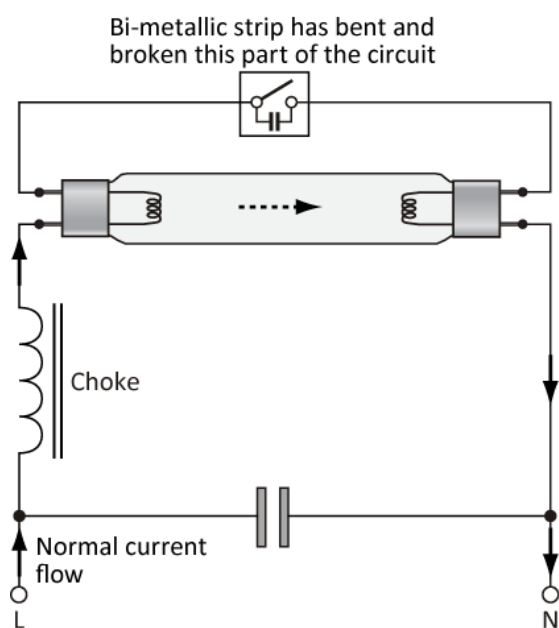
When the lamp is first switched on, the path of least resistance is through the bypass circuit shown by the bold arrows. As can be seen the current flows through both electrodes. These electrodes are just like simple filaments. The current flow heats up the filaments and boils off electrons from the metal surface. These warm electrons flow into the tube ionizing the gas. At the same time current flows through the starter switch which incorporates a bi-metallic strip which is warmed by the current, and eventually opens.

Now, we have an ionized gas in the tube, it just needs a voltage kick to establish the discharge between the electrodes.



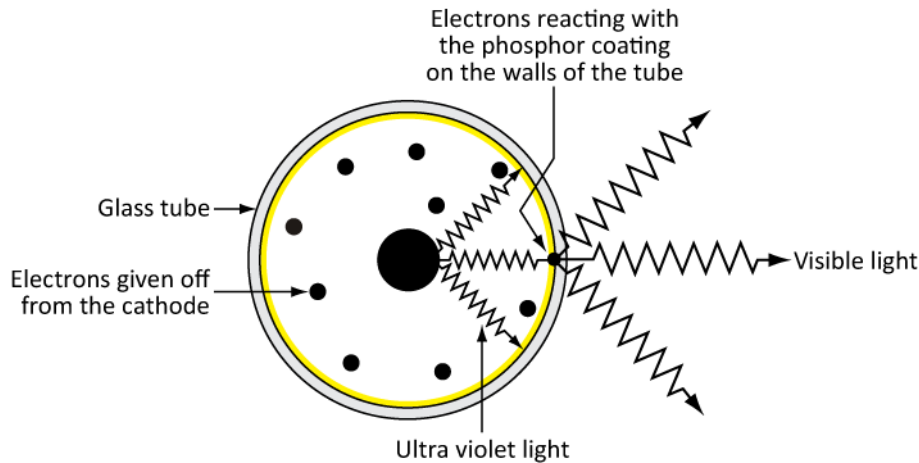
As the current is flowing through the choke energy is being created. When the starter switch opens the current flow through the choke is briefly interrupted, the stored energy creates a large voltage (of about 600 V). This large voltage is enough to establish the electrical arc through the gas. The current now flows through the gas and not the bypass circuit.

The action of free electrons colliding with atoms of argon and mercury creates more free electrons which is a flow of current. See the bold arrows. The choke now “chokes” back the current flow to a sustainable amount.



That is how we can get electricity to flow in a gas, but how is the light produced?

If we apply energy to a gas and we get our ionised state. We also get an amount, of what is called excitation. This excitation is the moving of electrons from one energy level in an atom to another energy level. As the electron moves from one energy level to another, a **photon** of light is released. Consider the diagram below.



With a fluorescent lamp, this photon of light is emitted in the ultra-violet range and this reacts with the fluorescing material which has been coated on the inside of the tube. This material reacts with the ultra-violet radiation and emits light (it glows).

The colour of light given off therefore doesn't depend on the process but on the coating on the wall of the tube:

Colour Temp	Effects on Colours	Typical Applications
Daylight White 5000K +	Strongly enhances blues Flattens reds Bluish tint to whites and greens	Anywhere that requires sharp lighting
Cool White 4000 – 5000 K	Enhances blues Flattens reds Bluish tint to whites and greens	Offices Hospitals Manufacturing
Mid Range 3500-4000 K	Neutral Appearance Enhances most colours equally Does not favour yellow or blue	Retail stores Supermarkets Hotel lobbies
Extra Warm 2000-2500K	Strongly enhances red & orange Blues appear almost black White appears strongly orange	Bread and meat displays Not used for general lighting

To summarise, before a fluorescent lamp can start, we need to have a number of things in place:

- **the gas inside the tube ionised so that the gas will conduct**
- **a large enough starting voltage to ensure that the ionised gas will begin conducting**
- **some means of limiting the current flowing in the tube because once the gas has begun to conduct, its resistance will continue to fall, leading to a rapidly rising current until protective devices begin to operate.**

The normal fluorescent circuit has a natural power factor of about 0.5. In a domestic setting where there are only one or two such fittings, then this is not too much of a problem. However, in a large industrial setting this can lead to paying more for power than is necessary and having to put in larger supply cables. With this in mind, fluorescent fittings have a pf improvement capacitor added which improves the pf to about 0.85.

Fluorescent lamps come in a variety of shapes and sizes. They have a higher lighting efficiency than either GLS or tungsten halogen lamps. Their lifespan ranges from 3 000 hours to 10 000 hours.

There are other ways of starting fluorescent lamps, which we will look at shortly, but the one described here is the most common.

There are a few problems associated with any type of fitting that has a large inductive load: which a low-pressure mercury vapour lamp has:

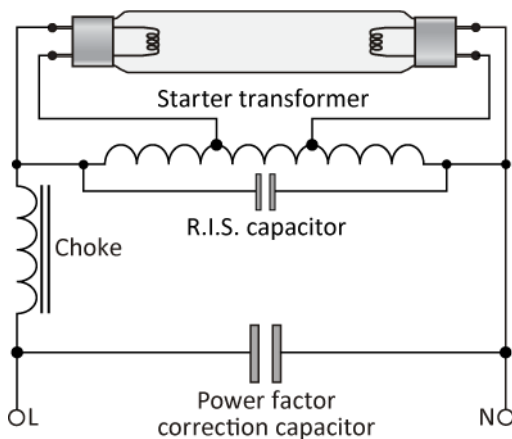
- because there is a large inductor within the circuit then harmonic currents are set up. These currents add to the overall supply current and affect the choice of cable size. Details of the harmonic current can be found by looking in manufacturers' catalogues. If this information can't be found then it has to be assumed that the rating of the fluorescent must be increased by a factor of 1.8x wattage rating of the lamp.
- if mineral insulated cable is used in the control gear, then care has to be taken concerning the breakdown of the insulation with the large induced voltages. Holes can begin to appear in the armouring and allow in moisture. This is not good as MI is very hydroscopic.
- lamps can begin to flicker at the same frequency as rotating machinery (50 Hz) and when this happens the machinery may appear to be standing still. This is called the stroboscopic effect

The ways of removing this effect are to use a lead-lag twin fluorescent luminaires; or an electronic control circuit or to put two fittings close together, but make sure that they are connected to different phases on the supply. This means that they flicker at different times and the effect is removed.

There are a variety of other ways in which a fluorescent lamp can be started other than with the switch starter mechanism. We'll take a brief look at some of the other ways available.

Starterless circuit

When there are enough free electrons in the gas, the lamp strikes with only the supply voltage across the lamp. After the arc has been struck the current in the choke increases and so the voltage across the transformer falls. This fall in voltage across the transformer reduces the current flowing through the lamp.



The problem with this circuit is that it is expensive, however, unlike the starter circuit; it does allow the lamp to be used in a dimmer circuit.

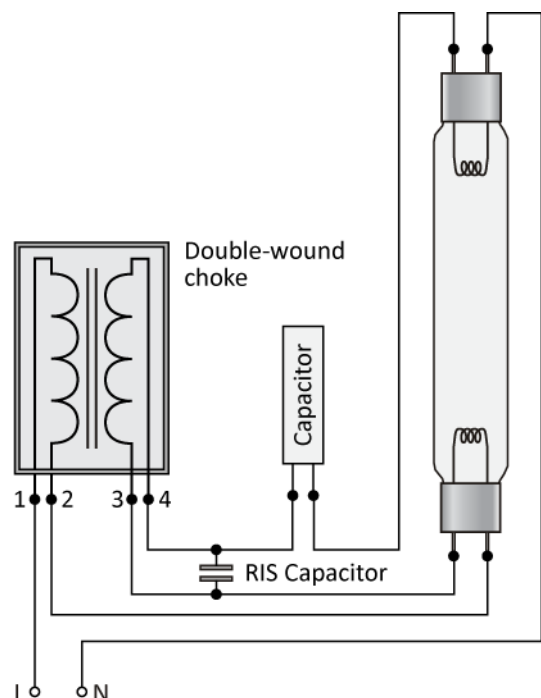
Semi-resonant circuit

In this circuit, there is a double wound choke with two coils wound in opposition to each other. Notice also that there is a capacitor connected in series with one of the coils.

On starting the coil connected in series with the capacitor produces a large voltage across the lamp. Sufficient current also flows for the electrodes to heat up.

After the lamp has started the part of the circuit with the coil and capacitor in series are no longer needed.

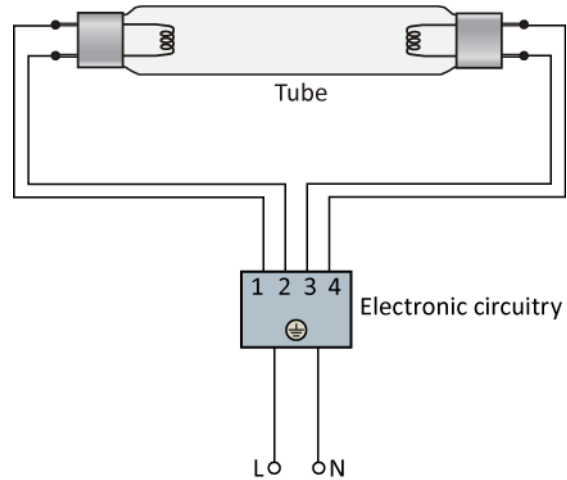
This circuit is good for starting at low temperatures.



Electronic control circuit

There are advantages to increasing the frequency of the lamp.

With a frequency of 30 kHz, there is a reduction in control gear size and losses. There is also the removal of lamp flicker, an increased efficacy and lifespan. It also gives an instant start to the lamp. This type will be found in most of the new low energy lamps that are finding their way into domestic installations. The diagram above shows the control gear. This control gear is set to change the frequency.



The significant problem with such luminaires is that the electronic circuitry will generate a small amount of earth leakage current. Where there are large numbers of fittings this leakage current can be quite large and create problems with harmonic currents.

Exercise 4

1. Why is the EU keen to ban all types of tungsten filament lamps?
2. How does the tungsten filament lamp produce its light?
3. How does a basic switch-start fluorescent fitting work?
4. What are the advantages and disadvantages of CFLs?
5. A home owner replaces his existing 6 ft fluorescent fitting which housed a 70 W tube, for six 50 W halogen GU10 downlighters for the kitchen lighting. He is intending to eventually replace the halogens for 1.5 W GU10 LEDs.

Determine the annual running cost of all three light forms.

Assumptions

- Every year has 365 days.
- The lights will be switched on for 4 hours per day.
- The cost of electricity is 15p per kWhr.

Ignore the initial cost of purchasing the fittings.

5: Industrial lighting

In this session the student will:

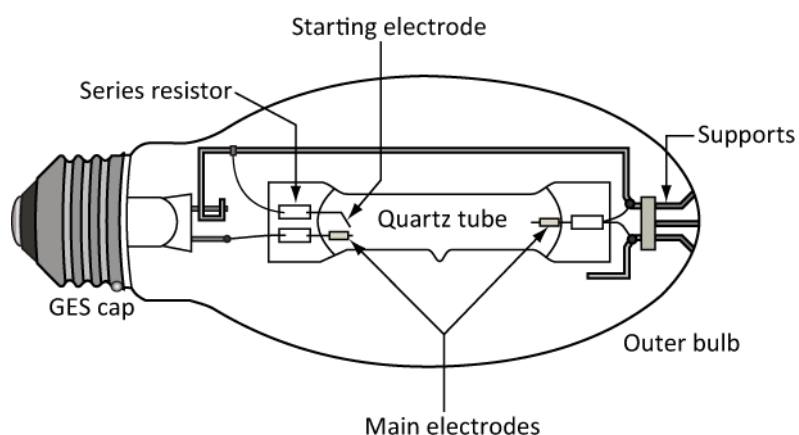
- Be able to describe how the following range of industrial lights function;
 - High pressure mercury vapour.
 - Metal halide.
 - Low pressure sodium vapour.
 - High pressure sodium vapour.
- Understand the circuitry required for the lamps listed above.

High-pressure mercury vapour lamp

We now come to the third way in which light can be produced. We have seen that the GLS and tungsten halogen operate on the principle of incandescence: that is they glow white-hot and so give their light. We have also seen that the low-pressure mercury vapour, or fluorescent lamp, operates on the principle of fluorescence.

The next four lamps that we will look at all operate on the principle of discharge.

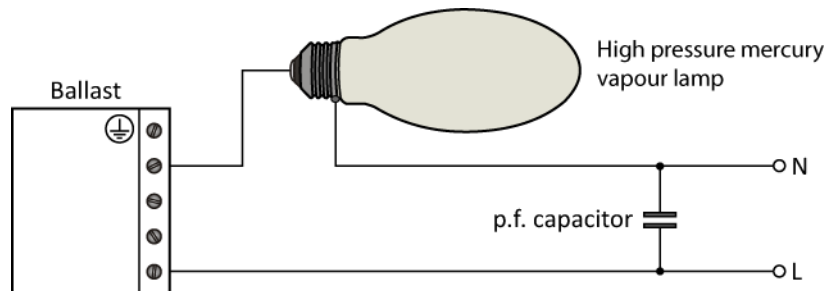
First, consider the internal workings of the high-pressure mercury vapour lamp.



The lamp has an outer glass envelope that contains nitrogen. The nitrogen keeps the arc tube at the correct temperature.

The quartz discharge tube contains the inert gas, argon and a small amount of mercury in liquid form. There are also two main electrodes at either end of the discharge tube and a secondary electrode that begins the discharge.

There is also a resistor (10 k Ω -30 k Ω) connected in series with the secondary electrode and the main electrode at the opposite end of the lamp.



When the supply to the lamp is first switched on there is no current flow.

The mains voltage appears across the main electrodes and between one of the main electrodes and the secondary electrode through the series resistor.

This voltage produces an arc between the secondary and main electrode in the argon gas. Ionisation begins to occur when the arc has been struck and an arc is struck through the argon gas between the main electrodes.

This arc is at low pressure but after a period, the mercury begins to heat up, vaporise and ionise (have an electric charge). As the heat and the pressure build up, more and more of the mercury is vaporised and a high-pressure arc is formed between the main electrodes. When this main arc is formed, the secondary electrode ceases to operate as the resistance of the main arc has become smaller than the series resistor.

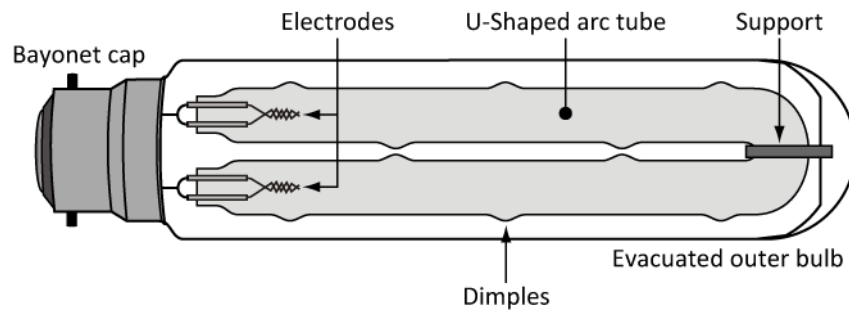
It normally takes between 5 and 7 minutes for the high-pressure mercury vapour lamp to reach full light output. However, if the lamp is turned off it cannot re-strike for quite a period because of the high pressure that exists.

Different elements give off different colours when energy is applied to them. Oxygen gives off a blue light, neon gives off a red light, whilst mercury gives off a bluish light. The light given off is weak in colours such as red and is therefore limited in its application. It is used in areas such as sports halls, warehouses and other industrial applications.

Low-pressure sodium vapour lamps

This type of lamp has two main features. One is that it has a very high efficacy (light out for power in) and secondly that it has a very pronounced orange/yellow colour. It is similar to the high-pressure mercury vapour lamp in that it is also a discharge light, and therefore gives off its light by an electrical discharge through a gas.

We'll look at the general construction of the low-pressure sodium lamp.



This is a single-ended lamp. It has an outer glass envelope which has a double skin which acts a bit like a thermos flask. This double layer is used for heat conservation. The inner discharge tube is made of sodium resistant glass and is coated with a layer of indium oxide. This material acts as an infrared reflector and minimises the amount of power necessary to maintain the correct temperature within the tube.

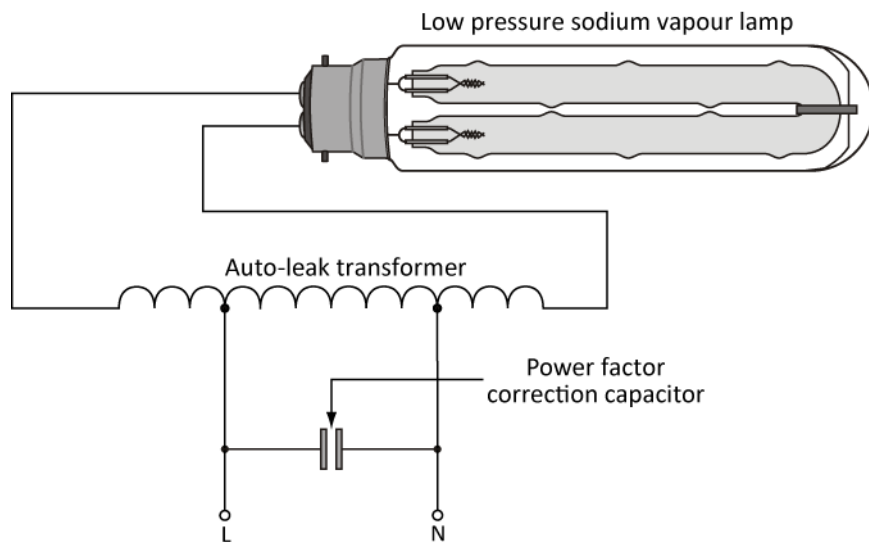
The inner tube also has some dimples or indents on it. These are used as '*cool spots*' and help to contain the sodium when the lamp is cool. This prevents '*mirroring*' on the glass inner tube. There are also two heated electrodes.

The control gear for this lamp needs to produce a larger voltage than the mains. This lamp requires about 500 V for starting, but then settles down to a voltage just above 100 V when it is at full output.

A normal transformer would produce the required initial voltage but would not limit the current when the lamp is at full output, and would therefore require an additional choke to limit the current. This is expensive, so an '*auto-leak*' transformer is used. This is a variation on an auto-transformer, with tap-off points.

So how does it work?

The diagram below is the circuit for a typical low-pressure sodium vapour lamp. The sodium is in a solid form and to vaporise it, argon and neon gasses are included.



When the supply is turned on an arc is struck between the electrodes through the neon gas. This gives off a '**red**' light, which is typical of neon. As the lamp warms up the sodium begins to vaporise and ionise.

This sodium slowly takes over the discharge from the neon, and gives off its characteristic yellow/orange light. It takes between 8 and 15 minutes for it to be at full output.

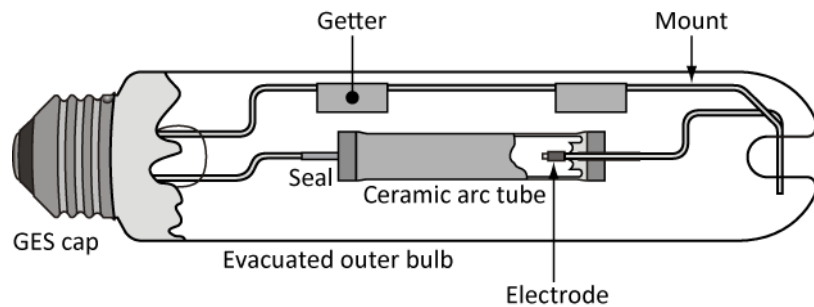
If the outer envelope breaks then the lamp will only give off the characteristic red of the neon discharge as the sodium cannot heat up enough to vaporise and give its light.

As stated earlier, this lamp has a very high efficacy, and yet its real disadvantage is the type of colour that is given off. This poor colour rendering means that it is only useful for street lighting and where colour differentiation is not necessary.

High-pressure sodium vapour lamp

This is the third common type of discharge lamp. It is used to combine the very high efficacy of the low-pressure sodium vapour lamp with an improvement in the colour rendering of the light output.

Have a look at the diagram below for a view of the internal workings.

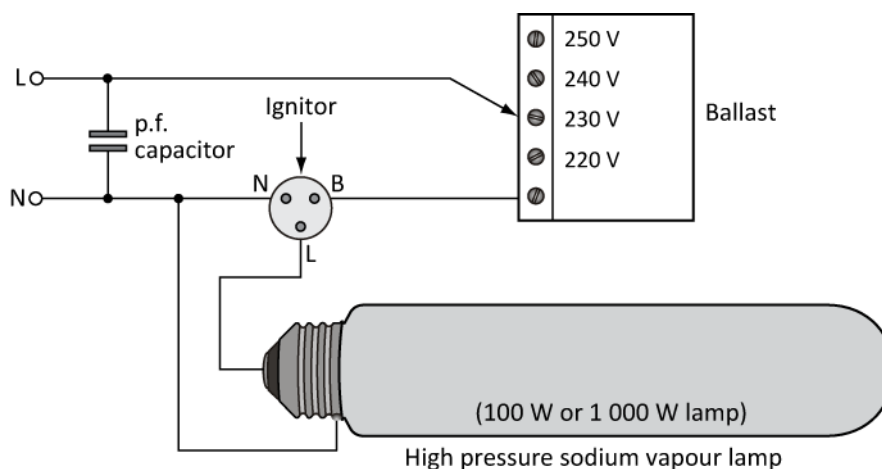


You can see that there is a sintered aluminium oxide tube. (Sintered means that it was produced by combining the material using heat). The tube is supported by two support rods.

The sintered aluminium oxide tube is capable of withstanding the damage done by sodium at high temperatures and pressures. Quartz and glass are very quickly destroyed by the sodium under these conditions.

The lamp glass envelope is coated on the inside with a white material that helps to spread the light that is given off. The outer glass envelope is similar to the low-pressure sodium vapour lamp and has a double skin like a thermos flask.

Inside the lamp, there is a combination of mercury and sodium along with the gas argon or xenon. Have a look below.



A high voltage pulse is applied across the lamp to strike the arc.

An external igniter is used for this and it applies a voltage of a few thousand volts for milliseconds. When the arc has struck then the igniter stops functioning. As with the other discharge lamps, the sodium and mercury slowly vaporise and ionise and take over the discharge from the argon or xenon. It takes about 5 minutes for the lamp to reach full brightness.

Because this lamp operates at high temperatures and pressures, the light output gives better colour rendering than the low pressure sodium vapour lamp, although there is a reduction in the overall efficacy when compared to the low-pressure sodium lamp.

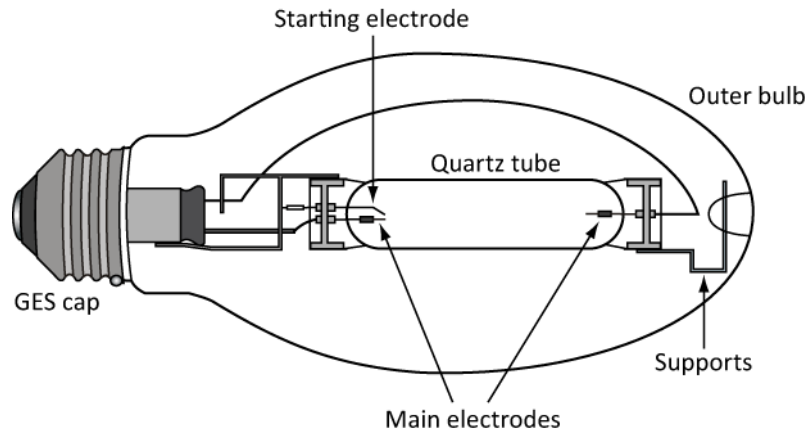
This type of lamp is used in a wider variety of settings than the low-pressure lamps. It is used in high bay lighting for industry, shopping centres, swimming pools etc.

At the end of this session there is a table listing all the advantages and disadvantages of the types of lamps that we have looked at.

The ones we have looked at are the ones that you may see most often. However there is one more general type that we could do with mentioning and that is the **metal halide** lamps.

Metal halide lamp

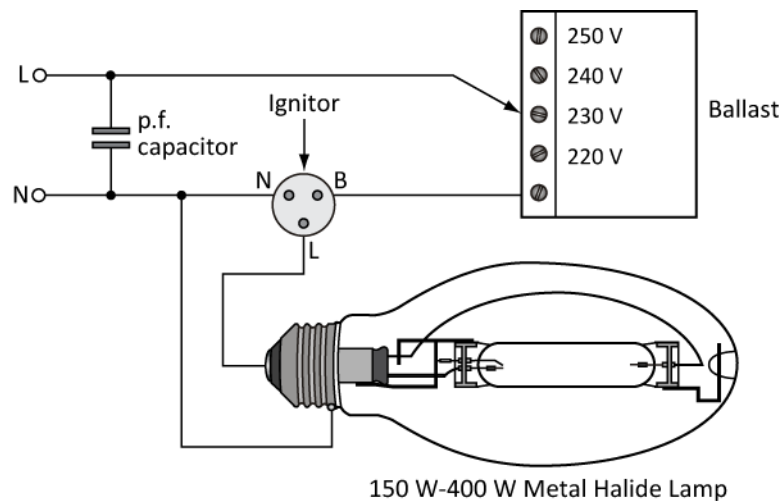
This type of lamp is similar to the high-pressure mercury vapour lamp that we have already looked at, although it does have a much shorter arc tube. Have a look at the set-up of the metal halide lamp below.



This type of lamp uses mercury vapour combined with the halides of a number of other metals such as, dysprosium, thallium, sodium or indium.

The combination of these materials gives a greater range of colour and hence improves the colour rendering properties of the average discharge lamp.

As with the high-pressure sodium vapour lamps, there is a need to have a very high voltage on starting, and this is provided via an igniter. Have a look below.



This type of fitting is used in high bays, floodlighting etc.

The table below should give you some idea of the relative merits of each of these fittings.

Lamps	Letter codes	Wattage range (W)	Efficacy (lm/W)	Colour rendering	Need for ballast	Starter/ignitor	Typical use and average life (hrs)
Low pressure mercury vapour	MCF	4 - 125	37 - 100	Good to very good	Yes	No	Office & shops 9 000 – 16 000
High pressure mercury vapour	MBF	50 - 1 000	35 - 58	Reasonable	Yes	No	Industry 24 0000
Low pressure sodium vapour	SOX	18 - 135	70 - 125	Poor	Yes	Yes	Street lighting 16 000
High pressure sodium vapour	SON	50 - 1 000	55 - 120	Reasonable	Yes	Yes	Industry 24 0000
Metal halide	MBI	150 – 1 500	65 - 75	Reasonable	Yes	Yes	Industry 15 0000

You will have noticed the letter codes that have been applied to the different lamps. Consider the table below.

Code	Meaning	Code	Meaning
Mercury lamps		Sodium lamps	
M	Mercury-the basic filling	SO	Sodium-the basic filling
B	High pressure	LI	Linear
C	Low pressure	X	Standard single ended lamp
E	Very high pressure	N	High pressure filling
F	Fluorescent coating	T	Tubular lamp-single ended
I	Iodide additive-metal halide lamps	TD	Tubular lamp-double ended
L	Linear	<p>Common lamp names for both mercury vapour and sodium lamps are:-</p> <p>MCF-Tubular fluorescent;</p> <p>SOX-Single ended U-shaped arc tube-low pressure sodium lamp;</p> <p>SON-High pressure sodium lamp;</p> <p>Other high pressure sodium lamps could be-SON-E; SON-T; SON-TD; SON-R; SON-DL-E; SON-DL-T;</p> <p>High pressure sodium lamps may also have an I or E suffix-I means that the lamp contains an internal starting device-E means that there is an external starting device;</p> <p>MBF-High pressure mercury vapour with phosphor coating;</p> <p>MBFR-MBF with an internal reflector;</p> <p>MBTF-MBF and filament lamp combination;</p> <p>MBI-High pressure metal halide;</p> <p>Also-MBIL; MBIF; CSI.</p>	
R	Reflector		
T	Tungsten filament		
W	Wood glass bulb		
/U	Universal		
/V	Vertical-cap up		
/D	Vertical-cap down		
/H	Horizontal		
/BU	Base up-cap not more than 15° below the horizontal		
/BD	Base down-cap not more than 15° above the horizontal		

Exercise 5.

1. Describe the terms efficacy, glare and colour rendering.
2. What are the two ways in which light is produced?
3. What material are GLS lamps filaments made of?
4. What are the two types of end cap used with GLS lamps?
5. Why are tungsten halogen lamps brighter than their equivalent GLS lamp?
6. What one change will improve the effectiveness of low-pressure mercury vapour fittings?
7. What is the stroboscopic effect and how can it be dealt with?
8. Why is a resistor placed in series with one of the electrodes in a high-pressure mercury vapour lamp?
9. Why do low-pressure sodium vapour lamps have dimples on their inner tube surface?
10. What type of transformer is needed for the low-pressure sodium vapour lamp?
11. What provides the high voltages necessary for high-pressure sodium and metal halide lamps?
12. What types of fittings would you choose for the following locations and why?
 - Home
 - Shop front
 - Factory
 - Stadium
 - Roundabout.

Formulae

Luminous flux $F = I\omega$

Illuminance $E = \frac{F}{A}$

Inverse square law $E = \frac{I}{d^2}$

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

Luminous efficacy $\text{efficacy} = \frac{\text{lumens}}{\text{power}}$

Lumen calculation $N = \frac{EA}{F \times UF \times LLF}$

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Engineering Learning Materials

Attempt all questions.

All marks are shown in the right-hand margin.

You should aim to pass with an 85 % minimum mark.

1. Explain the following terms:
 - i) Light loss factor 2
 - ii) Utilisation factor 2
 - iii) Glare 2
 - iv) Efficacy 2
 - v) Polar curve 2

2. A spotlight is used to illuminate a sign mounted on a building at a height of 15 m.
If the spotlight is placed at ground level 25 m away from the building determine the illumination on the sign:
 - i) at the centre of the sign [Assume 60 000 cd] 6
 - ii) 20° from the centre line [Assume 40 000 cd]. 6

3. A luminaire has a luminous intensity of 1 800 cd in all directions and is suspended from a ceiling 7.5 m above the working plane. Calculate the illuminance on the surface:
 - i) directly below the luminaire 3
 - ii) at a point 3.9 m along the bench from (i). 3

4. A workshop 28 m×16 m is to be illuminated to a level of 200 lux using 70 W twin fluorescent fittings. Each lamp can be assumed to have an efficacy of 30 lm/W.
Assuming that there is a utilisation factor of 0.45 and a light loss factor of 0.79 determine:
 - i) the total lumens required 4
 - ii) the number of fittings required. 4

Total marks 36