CONSTRUCTION ELECTRICIAN APPRENTICESHIP PROGRAM

Level 2 — Line H: Install Electrical Equipment

LEARNING GUIDE H-1

INSTALL LIGHTING AND LIGHTING CONTROLS

ita
industry training authority

THE RIGHT SKILLS ▶ A PROVEN ADVANTAGE

BRITISH COLUMBIA

Foreword

The Industry Training Authority (ITA) is pleased to release this major update of learning resources to support the delivery of the BC Electrician Apprenticeship Program. It was made possible by the dedicated efforts of the Electrical Articulation Committee of BC (EAC).

The EAC is a working group of electrical instructors from institutions across the province and is one of the key stakeholder groups that supports and strengthens industry training in BC. It was the driving force behind the update of the Electrician Apprenticeship Program Learning Guides, supplying the specialized expertise required to incorporate technological, procedural and industry-driven changes. The EAC plays an important role in the province's post-secondary public institutions. As discipline specialists the committee's members share information and engage in discussions of curriculum matters, particularly those affecting student mobility.

ITA would also like to acknowledge the Construction Industry Training Organization (CITO) which provides direction for improving industry training in the construction sector. CITO is responsible for organizing industry and instructor representatives within BC to consult and provide changes related to the BC Construction Electrician Training Program.

We are grateful to EAC for their contributions to the ongoing development of BC Construction Electrician Training Program Learning Guides (materials whose ownership and copyright are maintained by the Province of British Columbia through ITA).

Industry Training Authority
January 2011

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LEVEL 2, LEARNING GUIDE H-1:

INSTALL LIGHTING AND LIGHTING CONTROLS

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Learning Objectives

- The learner will be able to describe the operation of various lighting equipment.
- The learner will be able to select lighting equipment and controls.
- The learner will be able to connect and maintain lighting equipment and controls.
- The learner will be able to test and maintain lighting equipment.

Activities

- Read and study the topics of Learning Guide H-1: Install Lighting and Lighting Controls.
- Complete Self-Tests 1 through 13. Check your answers with the Answer Key provided at the end of this Learning Guide.

Resources

All resources are provided in this Learning Guide.

BC Trades Modules
www.bctradesmodules.ca

We want your feedback! Please go the BC Trades Modules website to enter comments about specific section(s) that require correction or modification. All submissions will be reviewed and considered for inclusion in the next revision.

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Industry Training Authority
January 2011

Learning Task 1:

Describe basic factors affecting vision

The eye acts as the receiver (encoder) that transmits signals through the optic nerve to the brain (decoder) for interpretation, allowing us to see.

The process of seeing

Figure 1 shows very simple sketch of the human eye. Light enters the eye through the transparent outer membrane surrounding the eye called the *cornea*. It passes through the focusing lens, and strikes the *retina* to form the optical image pattern. The *iris* (coloured portion of the eye) acts as a diaphragm to expand or contract the *pupil,* which controls the amount of light that is allowed to enter the eye.

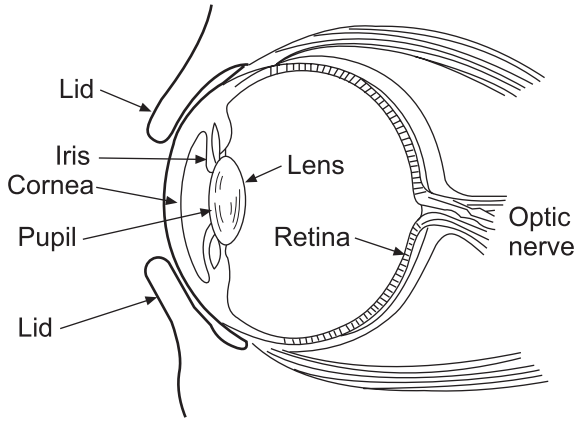


Figure 1—Vertical cross-section of the eye

The retina is the light-sensitive surface at the back of the eye where a delicate film of nerve fibres branches out from the optic nerve. The retina contains two special types of optic nerve receptors that permit vision—the *rods* and the *cones*. The rods provide sensitivity to brightness, allowing us to see at low levels of light, while the cones allow us to perceive finer details and to distinguish colours.

The action of the human eye is often compared to that of a camera. Both use a lens to focus the image at various distances. The iris and pupil compare with the diaphragm and aperture, which control the amount of light. The retina compares with the film in the camera.

Objective factors affecting visibility

There are four fundamental factors governing the visibility of a task: size, brightness, contrast and time. These factors are all interrelated, and often a deficiency in one can be compensated for by an adjustment in one or more of the others.

Size

The larger the object, the more easily it can be seen. As a small object is brought closer to the eye, the visual angle (interpreted as size) is increased, making it easier to see. The familiar eye-test chart utilizes this principle to test vision.

Brightness

The *brightness* or *luminance* of an object depends upon both the intensity of light striking it and the amount of light reflected toward the eye. For example, for the same amount of illumination, a white surface will be much brighter than a black surface. A dark object requires more lighting in order to be more easily seen.

Contrast

Contrast is the difference in brightness between the visual object (task) and its immediate background. For example, it is much easier to read black lettering on a white background than on a dark-coloured background.

Time

It also requires a certain amount of time in order to clearly see an object. The eye can see more detail when the image is present for a longer time. This factor is extremely important when viewing objects that are moving. In this case, high lighting levels are needed to increase visibility.

It is important to recognize that the focusing of the eye is controlled by muscles. Under poor lighting conditions, these muscles become tired, and eye fatigue and discomfort can result. A good lighting system provides both the quantity, and the quality of light to improve the performance of difficult visual tasks.

Now do Self-Test 1 and check your answers.

Self-Test 1

1. Which part of the eye is the:
   a. light-sensitive surface where the image is projected onto at the back of the eye
   b. coloured portion that functions as a diaphragm to control the amount of light entering the eye
   c. opening in the centre of the iris where light enters the eye
   d. transparent capsule behind the iris that is used to focus the image

2. State the four main factors considered to affect visibility.

_____

_____

_____

_____

3. Which one of the preceding factors is most important when viewing moving objects?

_____

4. What two important features does a good lighting system provide?

_____

_____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 2:

Describe light characteristics and measurements

Light is a special form of electromagnetic radiation that produces the sensation of sight. As shown in Figure 1, visible light is a very narrow range of the electromagnetic spectrum.

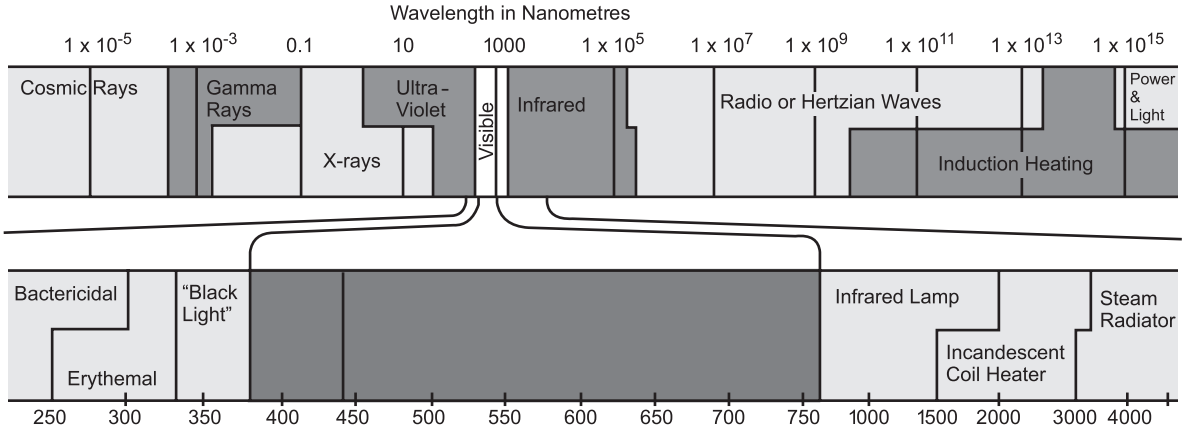


Figure 1—Electromagnetic spectrum

The individual types of radiant energy are identified by either their particular frequency range or their wavelength. The wavelength of visible light ranges from approximately 380 nanometres to 760 nanometres. (A nanometre is one billionth of a metre.) Both the sun and artificial electric lamps emit shorter and longer waves than visible light.

Colour

A light source emitting radiant energy that is relatively balanced in all visible wavelengths will appear white. When a beam of white light passes through a prism, the beam will spread and separate into individual visible wavelengths known as a *colour spectrum*. See Figure 2.

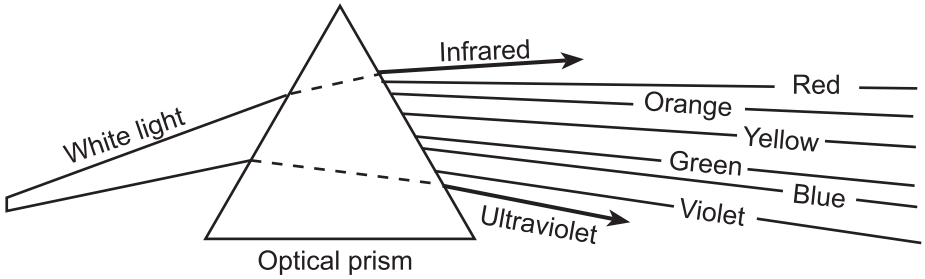


Figure 2—Colour spectrum

The colour spectrum, like a rainbow, is a band of colours ranging from violet through blue, green, yellow, orange to red. The human eye is not equally sensitive to all colours (wavelengths), and tests have shown that the average eye is most responsive to a wavelength of about 555 nanometres, or in the yellow-green colour range.

Red, green and blue are commonly referred to as the *primary colours* since by mixing any combination of these colours, all other colours of light can be produced. The colours that we see in objects are the result of the waves of radiant energy that actually reach the eye. The colour of light that we see can be changed by passing the light through a filtering medium that diffuses or refracts light, or by reflection, where the reflecting surface can diffuse or absorb light rays.

Colour temperature

Colour temperature or *chromaticity* is a term that is used to describe the colour of a light source. It is expressed in degrees Kelvin (°K); however, it is not a measurement of temperature, but rather a measurement of light quality. It is used to define the colour appearance of a light source. For example, sources with low colour temperatures—below 3000°K—have "warm" colour (reddish or yellowish), while sources with high colour temperatures—above 4000°K—have "cool" colour (bluish). Warm colour is more acceptable at low lighting levels, and cool colour at high lighting levels. Table 1 shows the approximate colour temperature of different light sources.

Table 1: Colour temperature of different light sources

Light source	Colour temperature	Description
Sky—extremely blue	25 000	cool
Sky—overcast	6500	cool
Sunlight at noon	5000	cool
Fluorescent—cool white	4300	cool
Metal halide (400 W, clear)	4300	cool
Fluorescent—warm white	3000	warm
Incandescent (100 W)	2900	warm
High-pressure sodium (400 W, clear)	2100	warm
Candle flame	1800	warm
Low-pressure sodium	1740	warm

Colour Rendering Index (CRI)

Colour rendition is the ability of a light source to portray the colour appearance of objects accurately when compared to a standard (reference) light source of the same colour temperature. The CRI has a value from 0 to 100, where 100 indicates a light source that renders colours as good as the reference source. Light sources with a high CRI cause the least emphasis or distortion of colour. Table 2 shows the colour rendering index of different light sources.

Table 2: Colour rendering index of different light sources

Light source	CRI	Colour rendering
Incandescent lamps	97	excellent
Fluorescent, full spectrum 7500	94	excellent
Fluorescent, cool white deluxe	87	excellent
Compact fluorescent	82	excellent
Fluorescent, warm white deluxe	73	good
Metal halide (400 W, clear)	65	good
High-pressure sodium (250 W, deluxe)	65	good
Fluorescent, cool white	62	good
Fluorescent, warm white	52	fair
Mercury vapour (phosphor-coated)	43	poor
High-pressure sodium (400 W, diffuse-coated)	32	poor
Mercury vapour (clear)	22	poor
Low-pressure sodium	—	(undefined)
Colour rendering description		
CRI	**Colour rendering**	
75–100	Excellent	
60–75	Good	
50–60	Fair	
0–50	Poor (not suitable for colour-critical applications)	

Light measurements

Although there are many measurements involved with lighting, the two most fundamental measurements deal with (1) the total quantity of light output from a source, and (2) the illumination or lighting level on a surface.

1. Luminous flux

The quantity of light output from a source is called *luminous flux*, and it defines the time rate flow of light. The unit for luminous flux is the lumen (Lm) and its symbol is ϕV.

2. Luminous flux density

The density of light flux measured on a surface is known as *luminous flux density*, or more simply *illumination*. The unit for illumination is the lux (Lx) and its symbol is Ev.

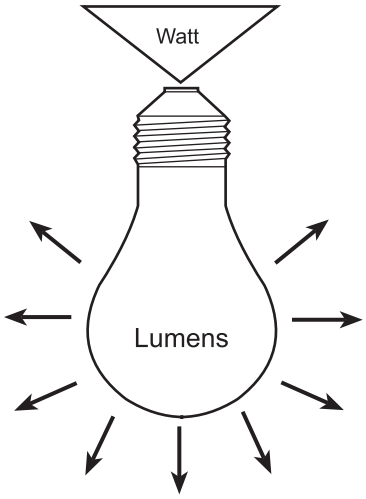


Figure 3—Luminous flux

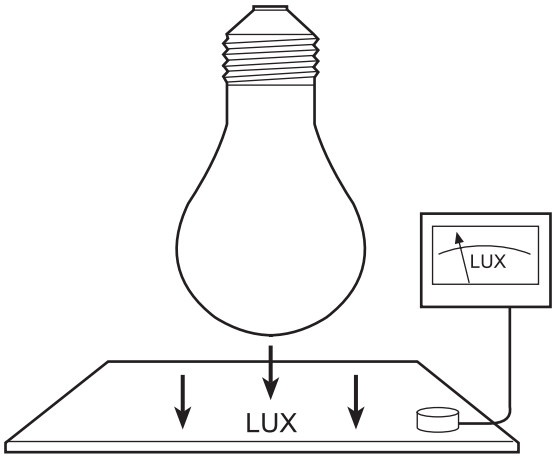


Figure 4—Luminous flux density

A lighting level of 1 lux is equal to 1 lumen per square metre, or 1 Lx = 1 Lm/m^2. (Older measurements used the foot-candle [fc], where 1 fc = 1 Lm/ft^2. The relation between the foot-candle and the Lux is 1 fc = 10.76 Lx.)

The lighting level is commonly measured using a photometer, as illustrated in Figure 4.

Lighting equations

There are two fundamental equations dealing with lighting calculations: inverse square law and the cosine law of incidence.

Inverse square law

The inverse square law states that *illumination is inversely proportional to the square of the distance between the light source and the work surface*. The formula is:

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

Where E = illumination in *lux*
I = light intensity in *candela*
d = distance in *metres*

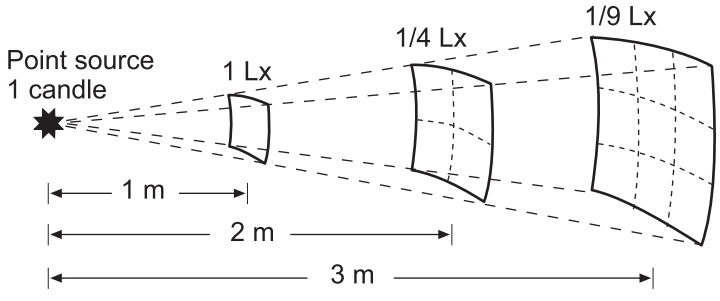


Figure 5—Inverse square law

This basic law simply demonstrates that luminous flux density (lighting level) decreases with the square of the distance from the light source (Figure 5).

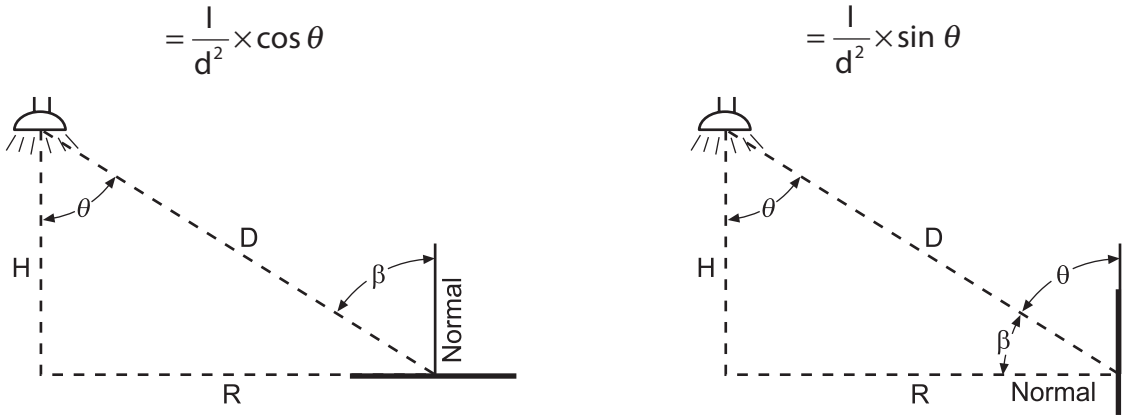
Cosine law of incidence

The cosine law states that the illumination on any surface varies as the cosine of the angle of incidence. The angle of incidence (θ) is the angle between the normal to the surface and the direction of incident light.

The Inverse square law and the cosine law can be combined as follows:

$$E = \frac{I}{d^2} \times \cos\theta \qquad \text{where } \theta = \text{angle of incidence}$$

Figure 6 illustrates the application of this relationship.



(a) Illumination on the horizontal plane (b) Illumination on the vertical plane

Figure 6—Cosine law of incidence

For a horizontal surface such as the floor in Figure 6a, the illumination provided at any point along the floor line R may be determined by using the inverse square law (I/d squared) to find the illumination at the intersection of line H and line R (the shortest distance from the light to the floor surface) and then multiplying that value by the ratio of the measurements line H and line D for any point along line R.

For a vertical surface or wall as in Figure 6b, the illumination provided at any point along line H may be determined by using the inverse square law (I/d squared) to find the illumination at the intersection of line H and Line R (the shortest distance from the light to the wall surface) and then multiplying that value by the ratio of the measurements line H and line D for any point along line H.

Luminous efficacy

A term quite often associated with light sources is *luminous efficacy*. *Efficacy* for a light source is the ratio of the light output (lumens) to the power input (watts). This measurement of lumens per watt (Lm/W) is a manner of expressing the efficiency of a light source in converting electrical energy into light. With no losses (100% efficacy), 1 watt would produce about 683 Lumens. Table 3 gives some approximate values of efficacy for comparison of different light sources.

Table 3: Luminous efficacy comparison of lamp types

Lamp group	Lamp type	Average efficacy
Incandescent	Carbon filament	4 lumens/watt
	Tungsten filament	22 lumens/watt
Discharge	Mercury vapour	56 lumens/watt
	Fluorescent	80 lumens/watt
	Metal halide	100 lumens/watt
	HP sodium	140 lumens/watt

Now do Self-Test 2 and check your answers.

Self-Test 2

1. Using the electromagnetic spectrum, which is the higher frequency light: infrared or ultraviolet?

   _____

2. The actual colour composition of white light can be seen using a _____ .

3. The human eye is considered to be most responsive to colour range of:
   a. purple
   b. red
   c. orange-red
   d. yellow-green _____

4. The "colour" of light is determined by its _____ .

5. The total light output of a lamp is measured in _____ .

6. The unit for illumination is the _____ .

7. What two values does efficacy compare?

   _____

   _____

8. Which of the following types of lamps is considered to provide the best colour rendition?
   a. incandescent
   b. mercury vapour
   c. high-pressure sodium
   d. fluorescent - cool white _____

9. Which of the following light sources is generally considered as having the highest efficacy?
   a. incandescent
   b. fluorescent
   c. mercury vapour
   d. high-pressure sodium _____

10. The lighting level on a work plane is commonly measured using a _____ .

11. In simple terms, state what is meant by the:

    a. Inverse square law

    _____

    _____

    b. Cosine law

    _____

    _____

12. When referring to wavelengths of light, what is a nanometre?

    _____

    _____

    _____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 3:

Describe basic factors in lighting design

The design of any lighting installation usually involves the consideration of many different variables. These may include factors such as:

- Area and type of environment—outdoors or indoors
- Type of task—critical seeing or decoration
- Architectural and decorative requirements—colour rendition and visual comfort
- Costs of installation and maintenance
- Costs of operation
- Availability
- Environmental impact

Once the criteria for the lighting system have been determined, the most appropriate design for light quantity and quality is selected. There are several different methods for calculating and determining illumination levels; these are beyond the scope of this unit of instruction. Nevertheless, the design of any lighting system invariably involves the consideration of light quantity and light quality.

Quantity of light

One of the most significant considerations in any lighting installation is to provide the proper level of illumination. This is quite often determined by the type of visual task and the location that the task is performed in. Since each of us may prefer different levels of light for a specific task, it is sometimes difficult to establish a fixed standard for illumination. Table 1 shows some approximate lighting levels from the IES (Illuminating Engineering Society of North America) *Lighting Handbook*.

Quality of light

An adequate quantity of light does not always provide good illumination. Factors that contribute to the quality of light must also be considered. Some other considerations include:

- Glare
- Diffusion
- Colour

Glare

Glare is a level of brightness that interfers with vision and typically causes discomfort or eye fatigue. Glare may be reduced by decreasing the level of illumination by:

- shielding the light source.
- decreasing the contrast between the source and its surroundings by using light colours on ceilings and walls.
- by repositioning the light source.

Table 1: Recommended lighting levels

Lighting levels by visual task

Type of visual task	Lighting level fc	lux	Comments
Tasks occasionally performed	15	150	General lighting
High contrast or large size	30	300	General lighting
Medium contrast or small size	75	750	Task lighting
Low contrast or very small size	150	1500	Task lighting
Low contrast or very small size — over a prolonged period	300	3000	Combination of general and task lighting
Exacting visual tasks — very prolonged	750	7500	Combination of general and task lighting

Lighting levels by building area and task

Building area and task	Lighting level fc	lux	Comments
Auditoriums	15	150	Include provision for higher levels
Banks — tellers' stations	75	750	
Barbershops	75	750	
Bathrooms	30	300	
Building entrances	5	50	
Cashiers	30	300	
Cleaning	15	150	
Conference rooms	30	300	Plus task lighting
Corridors	15	150	
Dance halls	7.5	75	
Drafting — high contrast	75	750	
Drafting — low contrast	150	1500	
Elevators	15	150	
Exhibition halls	15	150	Include provision for higher levels
Floodlighting — bright surroundings	30	300	Less for light surfaces — more for dark
Floodlighting — dark surroundings	15	150	Less for light surfaces — more for dark
Hospitals — examination rooms	75	750	High colour rendition variable
Hospitals — operating rooms	150	1500	(dimming or switching)
Kitchen	75	750	
Laundry	30	300	
Lobbies	30	300	
Office — general	75	750	
Parking areas — covered	5	50	
Parking areas — open	2	20	
Reading/writing	75	750	
Restaurant — dining	7.5	75	
Restaurant — food display	75	750	
Stairways	15	150	
Stores — sales area	75	750	
Streetlighting — highways	1.5	15	
Streetlighting — roadways	0.5	5	
Utility rooms	30	300	
Video display terminal	7.5	75	

Diffusion

Diffusion is the effect of scattering the light into many different directions. This technique of light disbursement is often used to avoid any annoying reflections of light. Diffusion is achieved

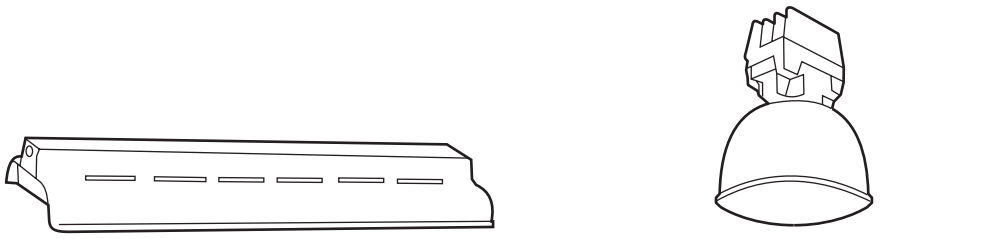
by using indirect light sources, utilizing large-area and low-brightness luminaires, or having a variety of different light sources.

Colour

Light source colour is an important factor for applications that involve colour matching or colour discrimination, as well as certain inspection tasks. For these circumstances, a light source that most closely matches daylight is usually preferred. *Seeability* is a term used to describe the level of peripheral vision and the ability to determine detail. Generally, lower CRI levels will require higher lighting levels to have the same seeability as higher CRI levels of light sources, and it is an important factor in roadway lighting design. Colour has certain psychological effects on people and their emotions. Blues and greens seem to produce a cool effect and create an illusion of increased space; reds, oranges and yellows tend more to produce a feeling of warmth.

Luminaires

A *luminaire* is a complete lighting unit consisting of lamps, wiring channel, reflectors, lens, diffusers and control gear (such as ballasts for gas discharge lamps) where necessary. The purpose of the luminaire is to provide the appropriate distribution of light.



Two-lamp fluorescent luminaire High bay mercury vapour luminair

Figure 1—Industrial luminaires

Luminaires are usually classified on the basis of how they distribute light vertically—either upward or downward. Table 2 lists the different luminaire classifications.

Table 2: Luminaire classifications

Type	Upward component	Downward component
Indirect	90–100%	0–10%
Semi-indirect	60–90%	10–40%
General diffuse (direct-indirect)	40–60%	40–60%
Semi-direct	10–40%	60–90%
Direct	0–10%	90–100%

Luminaires distribute light through the use of diffusers, reflectors, louvers, baffles or a lens, depending on the type of lamp employed and the intended application. The selection of luminaires is usually made based on:

- Luminaire efficiency (percentage of total lumens emitted by the luminaire compared to total lumens generated by the lamp alone)
- Coefficient of utilization (percentage of the initial lamp lumens that reach the task area to produce illumination)
- Spacing-to-mounting height ratio for acceptable uniformity of illumination

Luminaires are usually provided with distribution curves that illustrate the variation in light intensity (usually through a vertical axis). These indicate the pattern of light distribution to show whether it is concentrated, medium spread (as shown in Figure 2) or widespread. The luminaire's intensity distribution is often used as a guide for determining the maximum spacing-to-mounting-height ratio. Designers must also consider a room's cavity ratio, which is a ratio of the room's height to its length and width, as well as its surface reflectivity to minimize shadowing and discomfort causing glare.

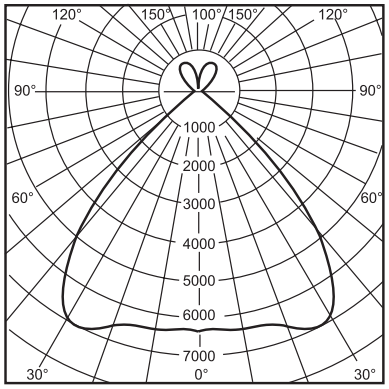


Figure 2—Distribution curve

For general-purpose lighting, the location of the luminaires is based on the room size, the desired level of illumination and the appearance of the finished installation. Even light distribution is usually accomplished through a symmetrical arrangement of the luminaires. When the ceiling area is divided into bays by beams or trusses, it is usually advisable to install the luminaires symmetrically in each bay. Figure 3 illustrates some different layouts used for general lighting.

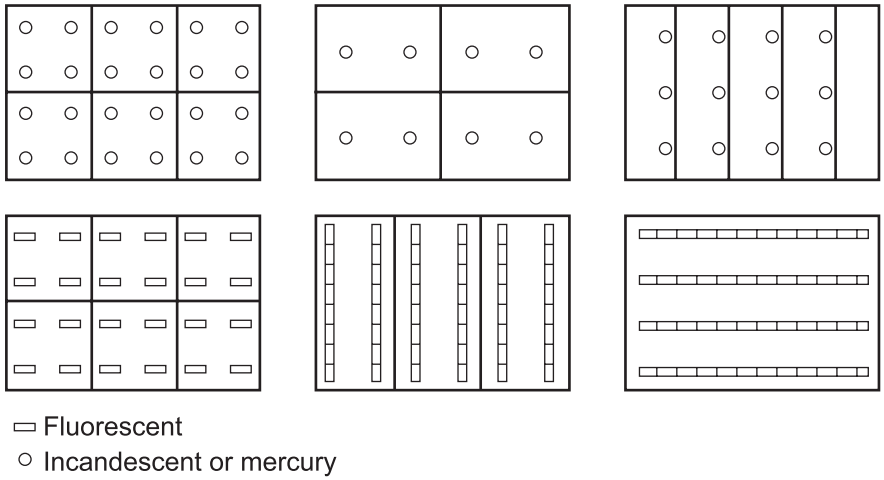


Figure 3—Typical luminaire layouts for general lighting

The choice of the light source for luminaires is:

- Incandescent
- Fluorescent
- High-intensity discharge (HID)
- LED

The lamp type used depends primarily on appearance and economics, although operating characteristics must be considered as well. For example, the life of fluorescent lamps is affected by frequent on/off switching or temperature extremes; HID lamps do not start immediately; and large incandescent loads are inefficient and can add greatly to heat radiation. The added heat of both HID and incandescent loads can burden air-conditioning systems, whereas proper cooling of LED luminaires is important for their longevity. The electrical features must warrant trouble-free operation, and the mechanical construction must allow for easy maintenance.

Lighting maintenance

A good lighting system is designed to provide proper visibility and comfortable seeing conditions. A well-maintained lighting system will continue to produce the illumination levels for which it was originally designed.

Two of the main causes of light loss (up to 50%) with time are:

1. Lamp lumen depreciation. Although the light output of a lamp decreases with age, the wattage input does not. In order to maintain operating efficiency and reduce costs, it is usually advisable to replace lamps in groups when they reach about 70% of rated life. Group relamping is recommended to minimize disruptions and labour costs.

2. Luminaire dirt depreciation. The accumulation of dirt on lamps and fixtures can cause light losses of 30% or more. It is important to maintain proper ventilation and regular cleaning of luminaires.

Periodic cleaning and repainting of walls and ceilings will help to maintain surface reflectance and increase the amount of light reflected rather than absorb, by the surface. To prevent glare, high-gloss surfaces should be avoided.

Now do Self-Test 3 and check your answers.

Self-Test 3

1. The two main factors in the design of a lighting system involve both the _____ of light and the _____ of light.

2. List three variables (factors) involved in the design of a lighting installation.

3. What are three factors that contribute to the quality of light?

4. What two colours are considered to be "cooling"?

5. A complete lighting unit (lamps, reflectors, etc.) is called a _____ .

6. What does a distribution curve illustrate?

7. What are two important considerations for roadway lighting design?

8. What lamp type does not start (light up) immediately?

9. What are the two main causes of light loss over time?

10. Why is group relamping usually recommended?

11. What is meant by the following terms?
    a. Luminaire efficiency

    b. Coefficient of utilization

12. What is the essential difference between direct and indirect classifications of luminaires?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 4:

Select lighting equipment

The oldest and most widely used of all electric lamps is the incandescent lamp invented by Thomas Edison more than 100 years ago. It produces light by passing electric current through a filament and heating it until it glows (incandescence). Although improvements have increased light output to more than ten times that of Edison's original lamp of 1879, the incandescent lamp is still a very inefficient source of light. About 90% of the energy input is wasted as heat. Some jurisdictions are legislating the phasing out of incandescent lamps. However, incandescent lamps are compact, cost little and produce light with warm colour tone. As a result, they are still widely used in residential and commercial applications; however, they are being rapidly replaced with more energy-efficient light sources such as compact fluorescent and LED.

Standard lamp construction

The *filament*, the heart of the incandescent lamp, is enclosed in a sealed envelope called a *bulb*. Filaments made of tungsten are used because tungsten has a high melting point (3419°C) and a low rate of evaporation. The life of an incandescent lamp normally ends when the filament burns open. However, filaments can also break through mechanical shock or vibration. The higher the operating temperature of the filament, the higher the light output, but the shorter the lifespan of the lamp. Low filament temperature has the opposite effect. Standard 120 V/100 W lamps have a light output of about 1650 lumens and last about 1000 hours. Gas inside the bulb reduces the rate of filament evaporation.

The bulbs of most general service lamps are made of soft lime glass. Bulbs designed for exposure to rain, snow or low temperatures are made of heat-resistant glass. Quartz glass is used with tungsten-halogen lamps because it can withstand very high temperatures. The lamp base supports the bulb and provides a means of connecting the filament to the electrical supply.

Figure 1 shows the main construction features of an incandescent lamp with brief descriptions. Not all lamps have all the features shown.

Bulb shapes and sizes

The size and shape of a bulb are designated by a code consisting of one or more letters followed by a number. The letters indicate the shape of the bulb and the number indicates the largest diameter of the bulb in *eighths of an inch*. For example, T10 indicates a tubular bulb having a diameter of 10 × ⅛" or 1¼". In addition to the diameter, most manufacturers' lamp catalogues will also list the overall lamp length. Figure 2 shows some common bulb shapes and letter codes.

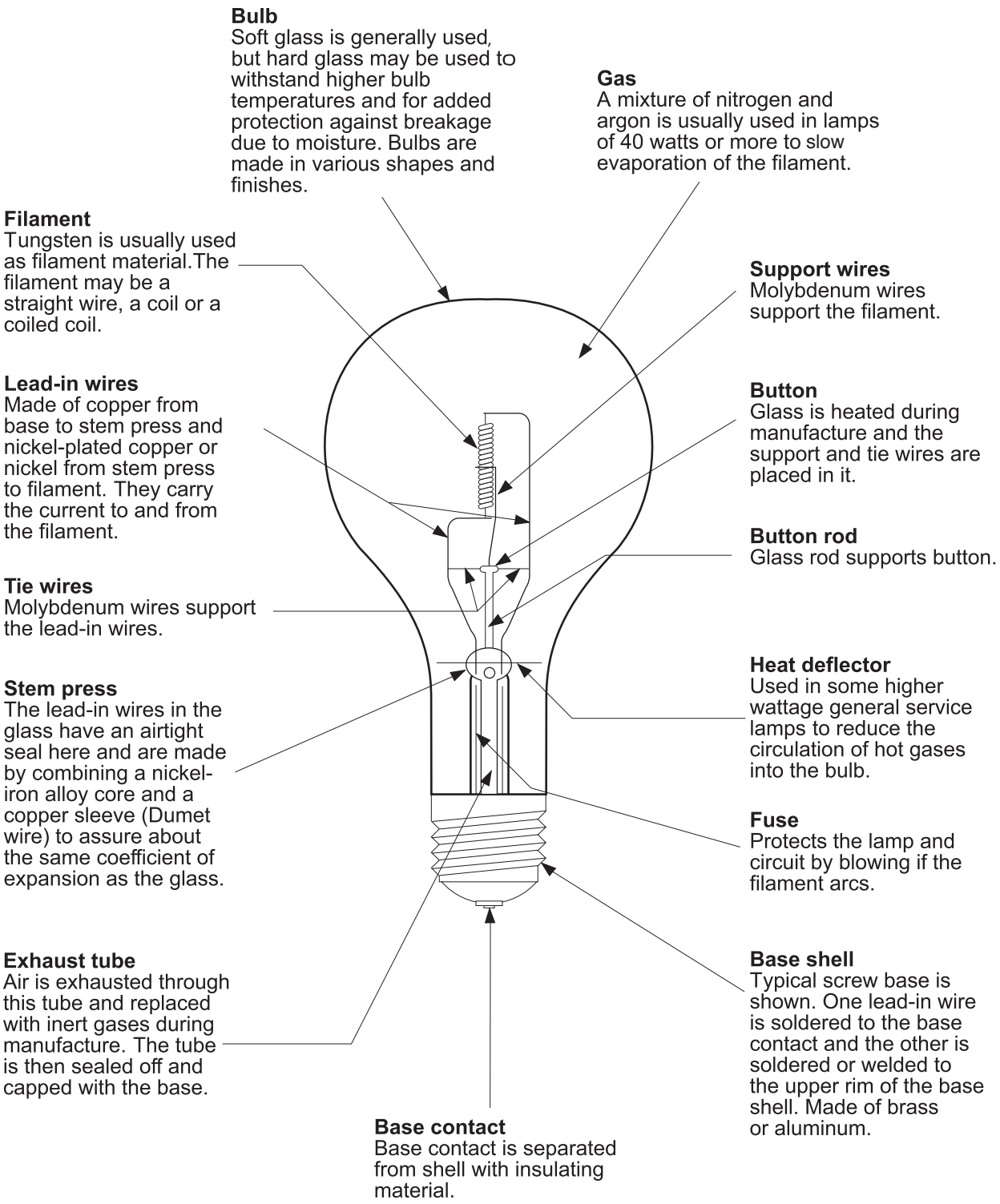


Figure 1—Construction of an incandescent lamp

Shape of bulb	Code letter	Shape of bulb	Code letter
Straight side	S	Tubular	T
Flame-shaped	F	Pear-shaped	PS
Globular	G	Parabolic	PAR
Standard line	A	Reflector	R

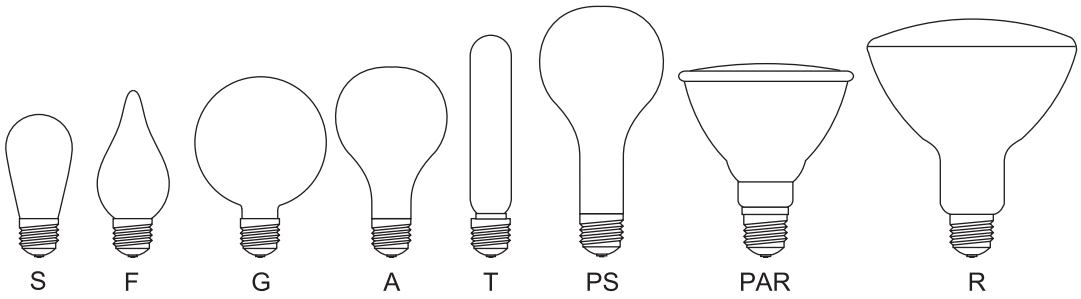


Figure 2—Common bulb shapes and letter codes

Types of bulb glass

The glass used for bulb lamps may be clear, diffuse or coloured. *Clear glass* is ideal where good optical control is required, as in overhead projectors or spotlights. It is also frequently used as chandelier lighting and over jewellery counters because of its decorative effects. But for most tasks involving normal sight conditions, *diffuse glass* is better.

Diffuse glass reduces the brightness of the light source by effectively increasing the surface area of the bulb. To make diffuse glass, acid etching or a coating of fine silica powder is applied to the inner surface of the glass. The resulting diffusing effect is shown in Figure 3. The purpose of diffuse lighting is to reduce brightness and glare that can cause discomfort and eye strain.

Coloured glass bulbs are used to produce different colours of light. The light produced by the filament of a coloured bulb includes all the colours of the visible light spectrum. However, the coloured glass absorbs all but the desired colour, which is transmitted through the glass.

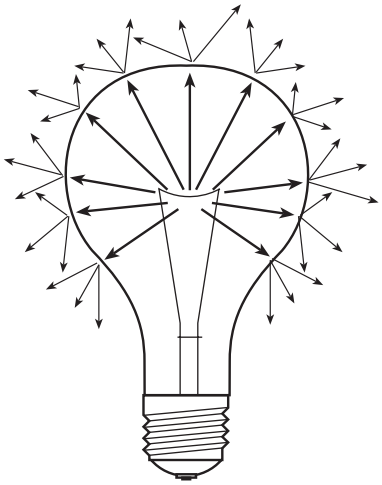


Figure 3—Diffuse lighting is produced by treating the inner surface of the bulb

Lamp bases

Lamp bases are normally made of aluminum or brass and are cemented to the bulb. Bases should always be used as intended. Operating a lamp in a position where it could cause burning or in a location for which it is not designed may cause the base to overheat. This may in turn cause the glass to separate from the base. Some of the more common lamp bases are described in the sections that follow and are illustrated in Figure 4.

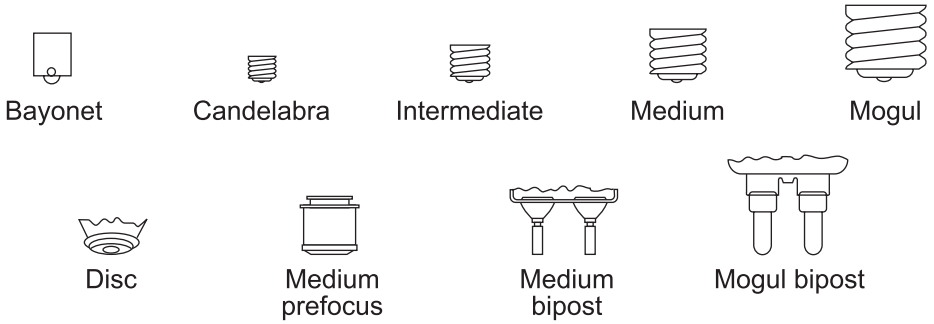


Figure 4—Common bases for incandescent lamps

Edison base

The most commonly used base for a general service lamp is the screw type or Edison base. Typical Edison base sizes (see Figure 4) are mogul, medium, intermediate and candelabra. The most common is the medium base, which accommodates lamps from 7.5 W up to and including 300 W. Bulbs of 300 W are available with both mogul and medium bases. Above 300 W. mogul bases are normally used. Mogul bases can be used with lamps up to 1500 W. Low-wattage indicator lamps and decorative lights use candelabra or intermediate bases.

A person changing an incandescent lamp is much more likely to make finger contact with the screw shell of the lampholder than with the base of the lampholder. Therefore, the screw shell must be connected to the identified conductor; never to the hot wire. The identified conductor will be at ground potential in a grounded system. The term "identified" is covered extensively in previous Learning Tasks and should be a familiar term. The connection shown in Figure 5 is designed to minimize the shock hazard.

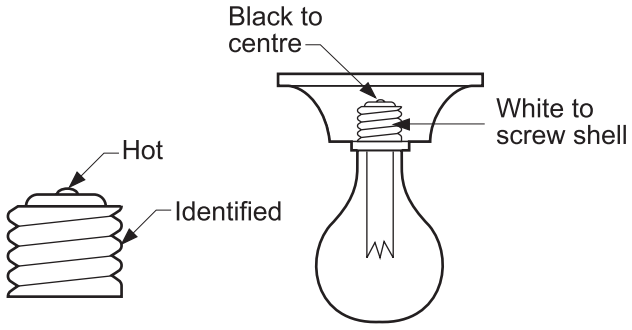


Figure 5—This lampholder connection will minimize shock hazard

Prefocus and bayonet bases

Where accurate filament positioning is required, prefocus or bayonet bases are preferred. Biposts are used for floodlighting where better heat radiation is possible. These lamps generally have wattages of 500 W or more.

Three-contact screw base

Screw bases with three contact positions are available in some medium and mogul sizes. These are used with trilight lamps. The lamps have two filaments and produce three different wattages. A common wire from the two filaments connects to the screw shell and the other two ends go to separate connections on the base.

Operating characteristics

Incandescent lamps have a positive temperature coefficient. When the lamp is cold, it draws more current than when it is warm due to a low initial filament resistance. As the filament heats up, its resistance increases significantly, thereby reducing current flow.

High-wattage lamps have a higher efficacy (lumen output per watt) than low-wattage lamps of the same voltage. One 150 W lamp produces more light than three 50 W lamps. However, low-voltage lamps normally have a longer service life than 120 V lamps.

Higher filament temperatures produce greater efficacy but have a reduced service life. Lamp life may be as short as 10 to 50 hours for projector lamps and as little as three hours for photo-flood lamps where high lumen output is essential. Traffic signal lamps are commonly rated at 6000 hours, while general service 120 V lamps have a rated service life of 750 or 1000 hours.

During the operation of an incandescent lamp, the filament steadily evaporates, causing a slow but continuous reduction in light output. As the filament evaporates, tungsten is deposited on the inside surface of the bulb and blocks the transmission of light. The service life of the lamp ends when the filament becomes fragile and finally breaks. To slow down the rate of filament evaporation, lamps of 40 W and higher are filled with inert gas.

Over-voltage operation results in increased wattage, more light output and reduced life. Under-voltage operation has the opposite effect, producing decreased wattage, less light output and longer service life. Thus, long-life lamps are designed to operate at higher voltages than they would normally receive, thereby extending lamp life. General service lamps may be burned in any position, but are most effective when burned with the base pointing up. Some lamps, notably projection, spotlight and floodlight lamps, are not designed to be used in more than one burning position. These lamps should be installed either base-up or base-down (see Figure 6), as designated by the manufacturer.

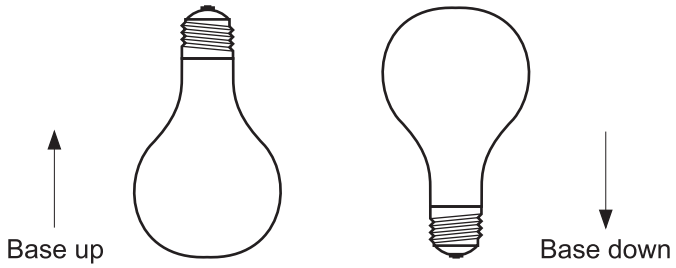


Figure 6—Some lamps must be installed either base-up or base-down

Tungsten wire, when heated to incandescence, becomes somewhat soft and pliable. Filament coils may be distorted or broken when the lamp is subjected to shock or vibration while burning. Where vibration cannot be eliminated, use special vibration-service lamps with special filament supports. Rough-service lamps have shatter-resistant, safety-coated bulbs and should be used on construction sites or where excessive physical abuse is likely.

Tungsten-halogen lamps

The tungsten-halogen lamp is a special type of incandescent lamp. It is a compact, high-intensity light source that provides a *white* light output with high lumen maintenance. These features make it an excellent lamp for projection, automotive uses, reprographic use (photocopying) and floodlight applications. The tungsten-halogen lamp is also called a *quartz-halogen* lamp or *quartz-iodine* lamp.

Construction and operation

In addition to the gases normally found in filament lamps, the tungsten-halogen lamp contains a small quantity of *halogen* gas (iodine or bromine). The halogen gas combines with the evaporated tungsten from the filament at the glass wall. The tungsten-halogen combination drifts back to the lamp filament by convection, where it is broken down and the tungsten is redeposited on the filament. This process, called the *regenerative cycle*, prevents the glass from blackening and results in the high lumen maintenance of the lamp. Figure 7 illustrates the chemical cleaning cycle.

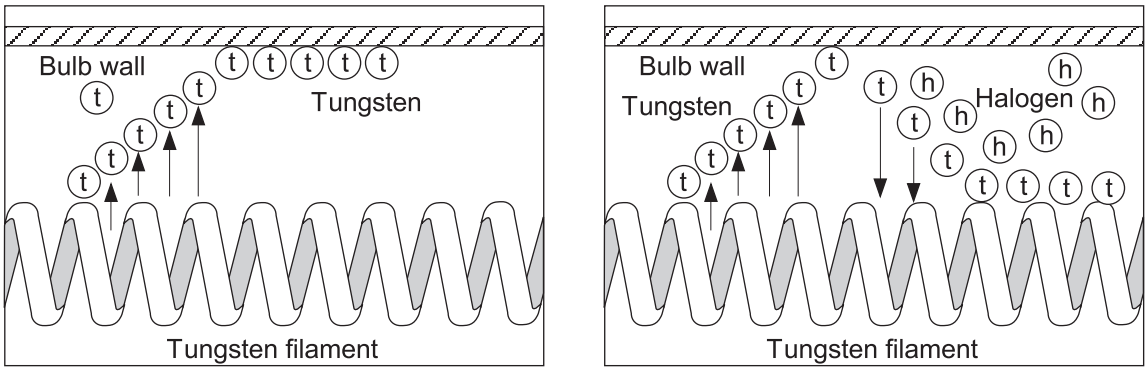


Figure 7—Chemical cleaning cycle of a tungsten-halogen lamp

The filament will last considerably longer than a standard incandescent lamp, but it will not last indefinitely. Tungsten is not redeposited on the filament uniformly and thin spots begin to develop. The typical lamp life is in the region of 2500–3000 hours.

For the regenerative cycle to take place, the temperature at the wall of the glass must be very high. This means the filament must be close to the glass, which accounts for the narrow shape of these lamps and the necessity of using glass resistant to high-temperatures.

Figure 8 shows a typical tungsten-halogen lamp. This lamp has a recessed single-contact (RSC) base at each end and takes a 400 W T4 lamp, 3⅛" long. Lamp wattages of 300 W, 500 W and 1000 W are common with this type of lamp, and the length and diameter of the lamp increase with wattage.

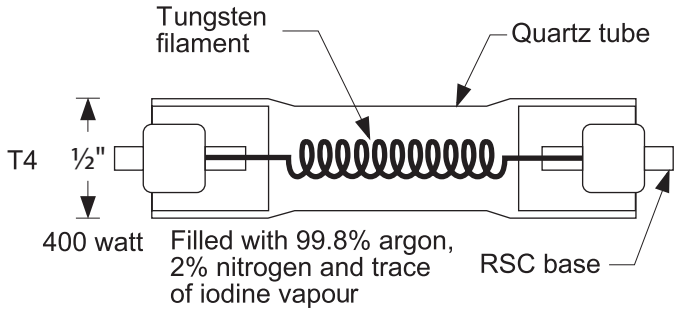
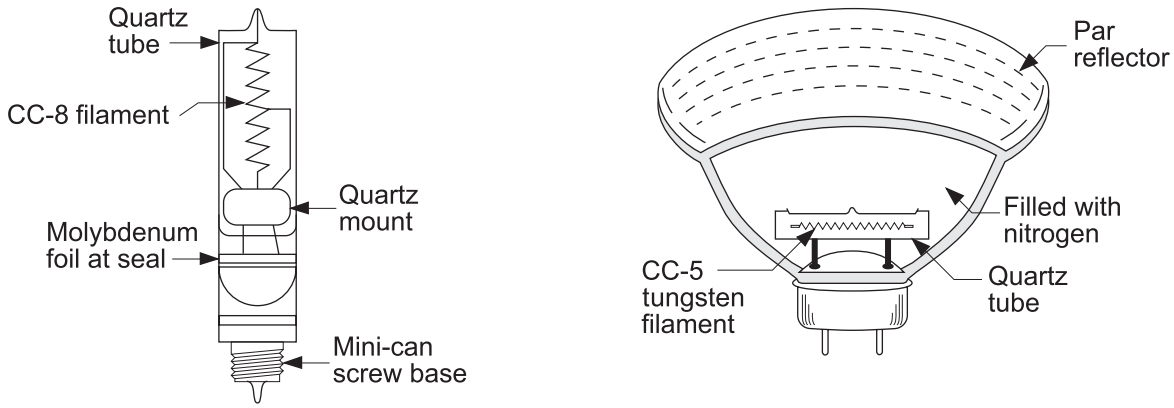


Figure 8—Typical tungsten-halogen lamp

Due to its high bulb-wall operating temperature, quartz glass with a melting temperature of 1650°C is used. For this reason it is sometimes called a *quartz halogen* or *quartz-iodine* lamp. Due to its compact construction, the tungsten-halogen lamp is often combined with a parabolic-shaped reflector, or placed in a suitable luminaire that has its own reflector. This makes it an excellent spotlight, floodlight or automotive headlight, as shown in Figure 9.



9a. Spotlight

9b. Automotive headlight

Figure 9—Tungsten-halogen lamps make excellent spotlights and automotive headlights

This lamp is an excellent *white light* source and is often used for studio lighting, glass-case display lighting and any application where good colour rendition is important. Under-counter and cabinet accent lighting in residential and commercial installations often employ low-

voltage (12 volt) tungsten halogen lamps with an MR16 designation. This means they have a 2-inch multi-faceted reflector that permits precise beam control for narrow spot, spot, narrow flood, flood, or wide flood light applications. Wattage ratings range from 10 to 50 watts, with 20 watts being commonly used. A remote-mounted step-down transformer provides the source, and if dimming is required, a special dimmer installed on the line side must be used to be compatible with the transformer.

Installation and operation

Because of its operating pressure of five or six atmospheres, the tungsten-halogen lamp must be contained within another glass envelope in case the lamp shatters during operation. The envelope also helps to maintain the high wall temperature of the quartz tube. Operating the lamp at reduced voltage reduces lamp-wall temperature and may interfere with the regenerative cycle. For this reason, dimming of standard quartz tubes on a continuous basis is not advised. When dimmers are used with tungsten halogen lamps, they must be occasionally operated at full voltage to permit the regenerative cycle to prevent the lamps from darkening.

When the lamp is operating, the temperature of the outer wall of a quartz tube is 250°C or higher. Therefore, you should not try to install or remove the lamp unless the light is switched off. Skin contact with the glass may result in oily deposits on the glass, which can cause glass breakage and premature failure. Foam wrappers or rubber gloves are usually included in the lamp package to prevent skin contact when handling the lamp.

A cautionary note normally accompanies the lamp packing or is written on the box. A typical note is reproduced below.

> CAUTION—This lamp is pressurized. Protect it from scratches; avoid use over 110% rated voltage. Use screening techniques where appropriate to protect people and surroundings in case of shattering. Prolonged exposure to this lamp operating at 110% rated voltage may cause eye irritation. Be sure power is off before installing or removing lamp.
>
> OPERATING INSTRUCTIONS—Use only in lighting fixture designed for lamps of this type and wattage, because lamp performance depends on keeping lamp seal temperature below 650°F and bulb wall temperature above 500°F.
>
> Finger marks left on bulb during installation may discolour bulb, slightly lowering lamp and fixture output.
>
> General Electric Co. Nela Park, Cleveland Ohio 44112

Infrared heat lamps

Infrared heat lamps emit medium-wave infrared energy for the purpose of creating heat. Incandescent heat lamps are used in shower and bath areas, for brooder lamps in poultry production, and for food warming in restaurant kitchens. These lamps are commonly rated at 250 watts and have an R40 designation. They contain an internal reflector and a red filter to minimize visible light output. Because of the lamps' high operating temperature, plastic lampholders may melt or burn, so ceramic lampholders must be used with them. Installers must also be mindful of the proximity of adjacent combustible surfaces, and placement of heat lamps in bathrooms must not be above the arc of the door swing.

Quartz heat lamps are used in industrial applications such as chemical processing, paint drying and food processing. They have a much quicker response time than incandescent heat lamps and can direct heat much more evenly, with a linear output of up to 40 watts/cm.

Now do Self-Test 4 and check your answers.

Self-Test 4

1. How is light produced in an incandescent lamp?

2. What percentage of the output of an incandescent lamp is in the form of light? What percentage is in the form of heat?

3. As a light-producing device, the incandescent lamp is:
   a. highly efficient
   b. moderately efficient
   c. very inefficient

4. What types of gas are used in incandescent lamps, and for what purpose?

5. A 100 W incandescent lamp is designated as G25 on the box. What is the shape and diameter of this lamp?

6. Where would you likely locate information about the overall length of a lamp?
   a. on the bulb
   b. on the lamp box
   c. in the manufacturer's catalogue

7. What material is the filament normally made of?

_____

8. Why are heat deflectors used in some lamps?

_____

_____

_____

9. The glass in lamps used for general purposes is:
   a. clear
   b. diffuse
   c. coloured _____

10. Why is the glass identified in the previous question used for general purposes?

_____

_____

11. The melting point of tungsten is closest to:
   a. 1000°C
   b. 2500°C
   c. 3000°C
   d. 3500°C
   e. over 5000°C _____

12. How does a green incandescent lamp produce that colour light?

_____

13. The most common lamp base is the _____ .

14. Name a typical application for each of the following lamp bases:
   a. mogul _____
   b. prefocus _____
   c. three-contact screw base _____

15. The higher the temperature of the lamp filament, the _____ the light output and the _____ the lamp life.

16. What normally ends the life of an incandescent lamp?

_____

_____

_____

17. Lumen maintenance or maintained lumens are highest when a general service lamp is operated:
    a. horizontally
    b. with the base up
    c. with the base down _____

18. State a reason why the light output of an incandescent diminishes over the life of the lamp.

_____

19. Which of the following combinations of incandescent lamps produces the most light?
    a. one 150 W
    b. three 50 W
    c. two 75 W
    d. one 100 W and one 50 W _____

20. For the same wattage, which lamp would last longer, a 120 V or a 12 V?

_____

21. Another name for the tungsten-halogen lamp is the _____ lamp.

22. What is the regenerative cycle action in the tungsten-halogen lamp?

_____

23. Explain why a tungsten-halogen lamp has high lumen maintenance compared to a standard incandescent.

_____

24. Typical lamp life of a typical 1500 W tungsten-halogen lamp would be closest to:
    a. 50 hours
    b. 1000 hours
    c. 2500 hours
    d. 5000 hours _____

25. What feature of quartz glass makes it suitable for the tungsten-halogen lamp?

    _____

26. Why must the tungsten-halogen lamp be enclosed in a reflector or similar enclosure?

    _____

27. The dominant colour of the light from a tungsten-halogen source is _____ .

28. Why is continuous dimming not recommended for tungsten-halogen lamps?

    _____

    _____

29. What condition is finger contact with cold quartz glass likely to cause?

    _____

    _____

30. Why must tungsten-halogen lamps be de-energized before installation or replacement?

    _____

    _____

    _____

31. Explain the lamp designation MR16.

    _____

    _____

    _____

32. What are two precautions to observe when using incandescent heat lamps?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 5:

Describe the control of incandescent lamps

Three main types of devices are used to control incandescent lighting. These are snap switches, dimmer switches, and relays and contactors. This Learning Task describes each of these three main types of controllers.

Snap switches

Snap switches are used to control incandescent lighting more frequently than any other method. The three most common types of snap switches are the single-pole switch, the three-way switch and the four-way switch.

Single-pole switch

Of the three snap switches, the single-pole is the most common. In the ON position, the switch toggle (operating handle) is up, and in the OFF position, the toggle is down. Some switches have a dot instead of an ON/OFF designation on the handle. The dot indicates the ON position of the handle.

Figure 1 shows a schematic diagram and a wiring diagram of a single lamp controlled by a single-pole switch. However, more than one lamp could be controlled by the switch.

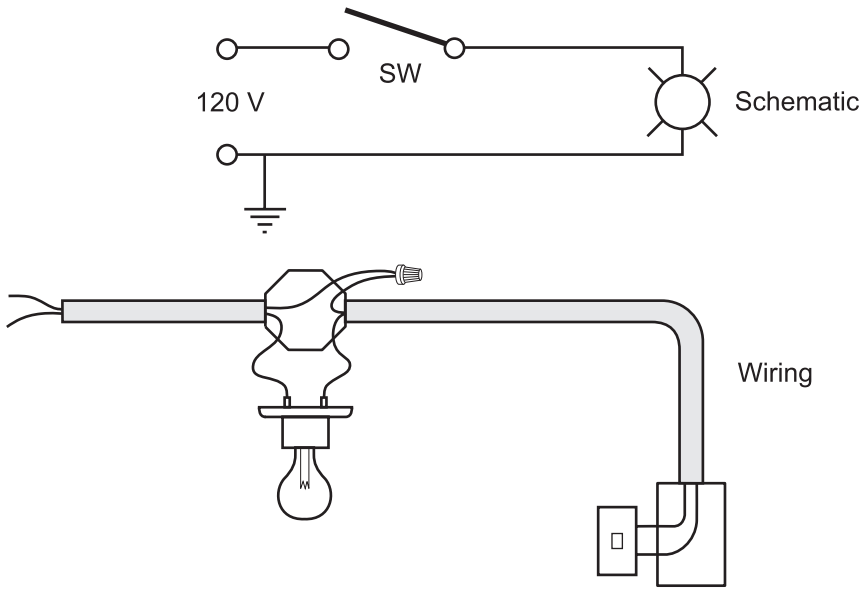


Figure 1—Single-pole switch

The switch must open the hot conductor (not the identified grounded conductor) to ensure the lampholder is *not* energized when the switch is OFF.

Three-way switch

Three-way switches are used to control a light from two locations. A typical example would be a light with switch as at the top and bottom of a stairway. The switch has three terminals, one

of which is the *common*. This terminal is often bronze-coloured for identification purposes. The switch does not have an ON/OFF designation, so there are no "up" or "down" positions as with the single-pole switch. These switches must be used in pairs. Figure 2 shows a schematic diagram and a wiring diagram of this type of switching.

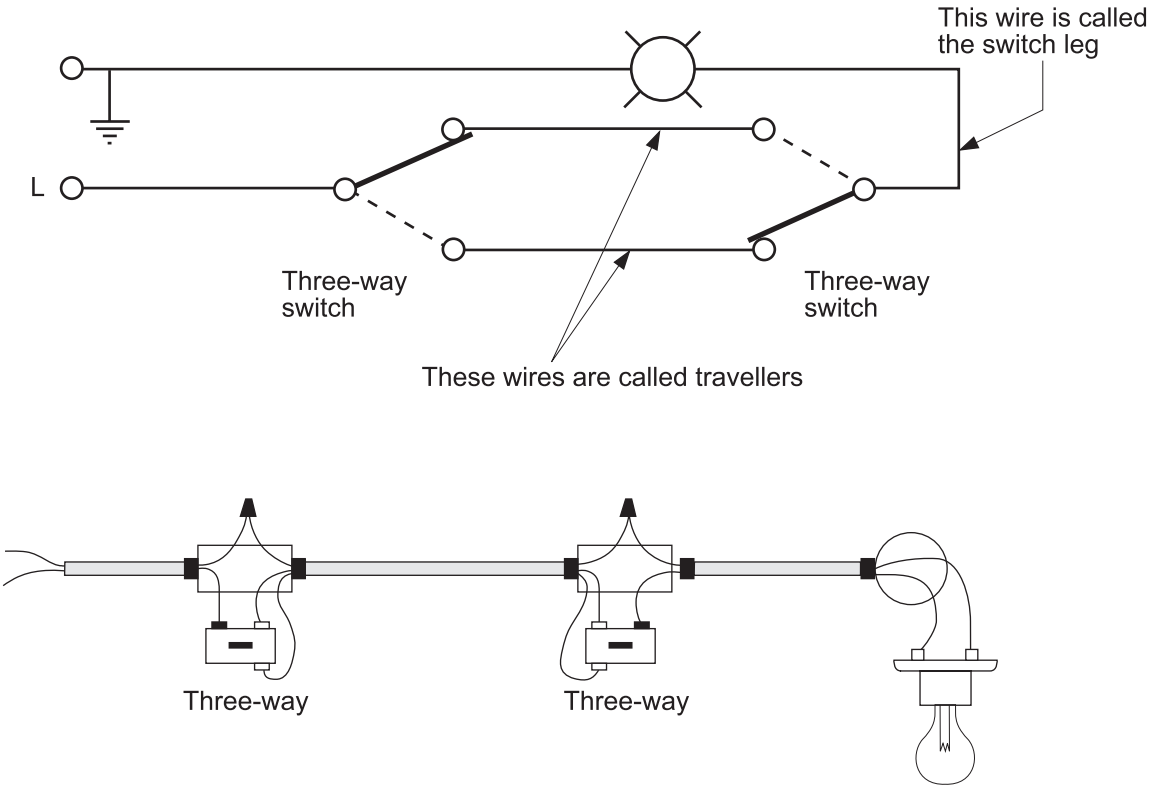


Figure 2—Three-way switching

Four-way switch

Four-way switches are used when one or more lamps are to be controlled from three or more locations. They are used in combination with three-way switches. An example would be a light in a long hallway, when switches may be located at three or more locations. Like the three-way switch, the four-way switch has no ON/OFF markings, so there is no "up" position as such. It has four terminals, two of which are often bronze-coloured to identify a set. To control a light from three or more points, two three-way switches are required and the rest must be four-way. Figure 3 shows both schematic and wiring diagrams for four-way switching.

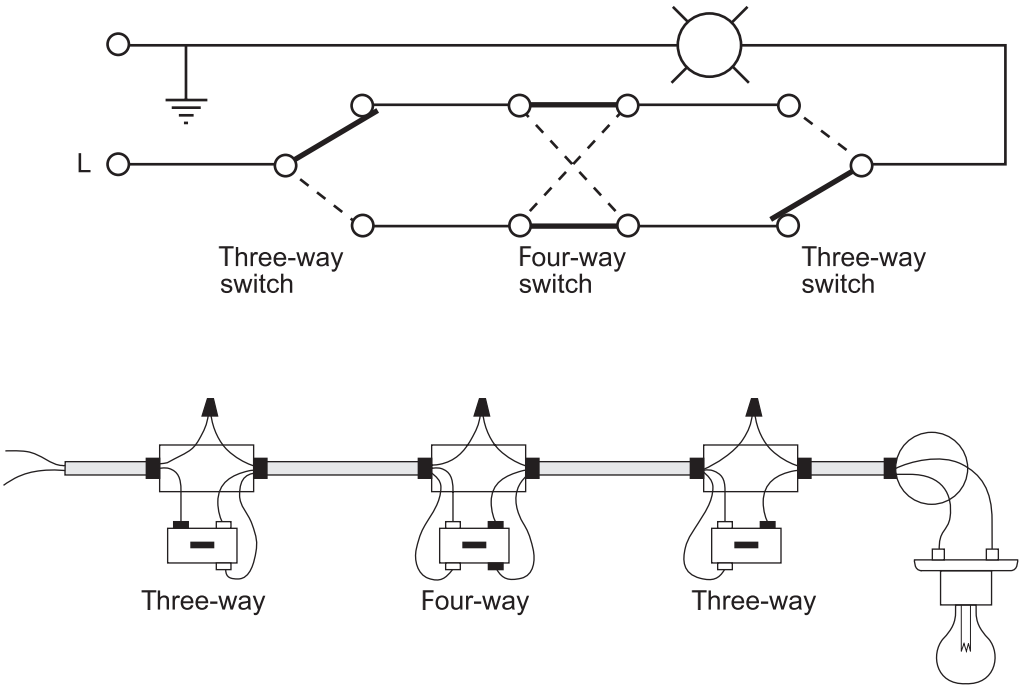


Figure 3—Four-way switching

Pull-type switches

Pull-type switches (Figure 4) are activated by pulling on a cord or chain. The cords or chain links must be constructed of approved insulating material. This is to reduce the possibility of shock in the event of a faulty lampholder. However, non-insulated pull-chains are acceptable with specially designed lampholder switch mechanisms. Always look for the CSA sticker of approval.

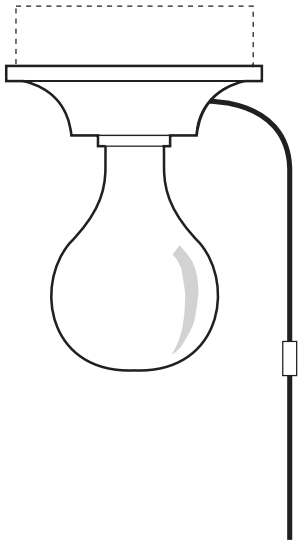


Figure 4—Pull-type switch

Dimmer switches

Dimmer switches are often used with incandescent lamps. The main advantage of the dimmer over other types of control devices is its ability to regulate light output. The dimmer can provide from zero light output to full brightness cheaply and efficiently. There is a wide variety of available dimmers ranging from the common, inexpensive rotary-type dimmers, to heat-sensitive "touch" type dimmers that all mount in standard switch boxes, subject to box fill requirements. The CEC also requires that an on/off disconnecting means is present on all dimmers. The most common type of dimmer is the rotary type, which mounts in a standard switch box. The device controls light output electronically, depending on how far the rotary part is turned. It also incorporates an ON/OFF mechanism that, in many designs, is activated by pressing the rotary knob. Figure 5 illustrates a typical dimmer switch. The switch is connected in the circuit like any single-pole switch.

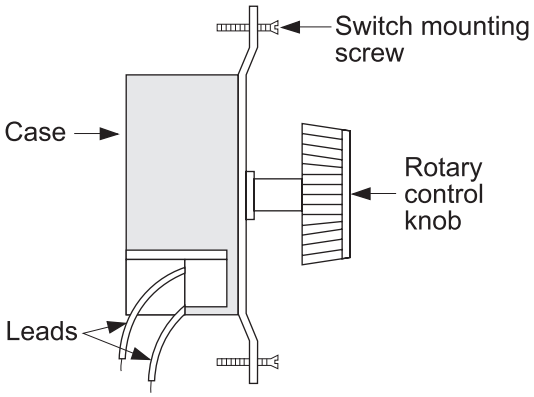


Figure 5—Typical dimmer switch

Incandescent dimmers are commonly rated for 600 W, 120 V but are also available with a 1000 W, 120 V rating. They are strictly for incandescent lamps and are not to be used for dimming fluorescent or other types of gas-discharge lamps. The total lamp wattage must not exceed the watt rating of the dimmer switch. High-wattage dimmers for commercial use incorporate integral cooling fins that also act as the cover plate to safely dissipate heat away from the dimmer. Care must be taken when planning dimming station layouts because these covers are wider than standard switch plates, which prohibits the use of multiple dimmers in ganged outlet boxes.

More and more incandescent lamps are being replaced with energy-efficient compact fluorescent and LED lamps, some of which are marked as being dimmable. These contain special circuitry that makes them compatible with high-efficacy HED dimmers. Standard CFL and LED lamps will not work properly with HED dimmers, nor will dimmable CFL and LED lamps work properly with standard dimmers.

Decora toggle Touch dimmer Toggle touch

Figure 6—Common light switches

Relays and contactors

The third main category of control devices is relays and contactors in which an external control circuit is used to open or close the lighting circuit. The devices in this category include *extra low-voltage relay controls* and *lighting contactors*.

Extra low-voltage relay control

With this type of control, relays located in the lamp outlet boxes perform the actual switching. The relays are controlled by rocker-type switches operating on 24 V or 30 V. When activated, the wipe switches give a momentary pulse of current to the relay, which latches ON or OFF. However, the relay coil does not remain energized. Figure 6 shows a simple relay control circuit.

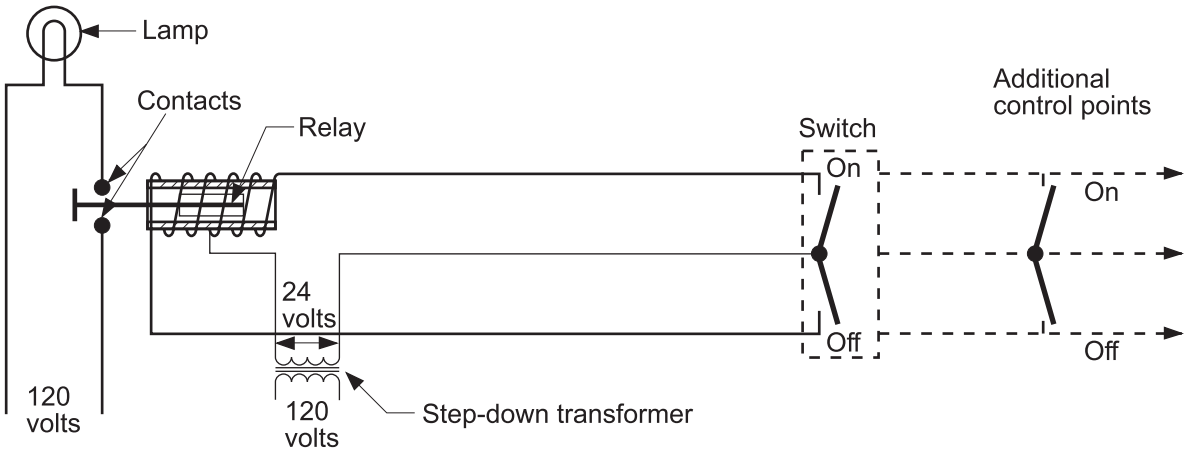


Figure 7—Simple extra low-voltage relay control circuit

The main advantages of extra low-voltage relay controls are that:

- Additional switches can easily be connected, allowing the lamp to be controlled from several different locations.
- Extra low voltage at the switches enhances safety.
- Wiring to these switches can be inexpensive bell wire.
- In commercial and institutional installations, relays are usually grouped in designated LV relay panels for ease of maintenance and energy management.

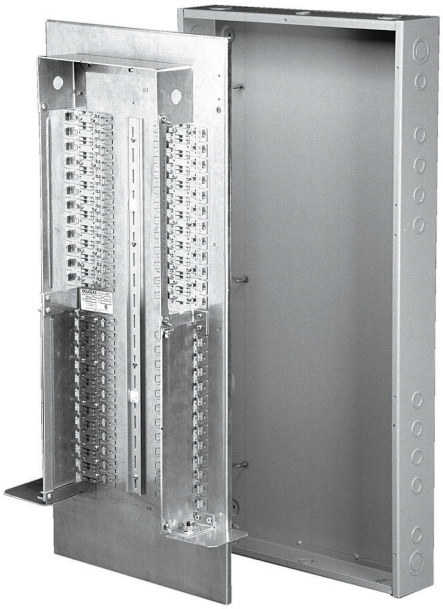


Figure 8—Typical low-voltage relay panel

Figure 9—A programmable low-voltage switch

Lighting contactor

A lighting contactor is used in situations where a large bank of lights is required to come on at the same time. The lighting contactor works on the same principle as a magnetic motor starter. The push-buttons energize and de-energize the coil of the contactor, which in turn switches the bank of lamps on or off. Unlike the motor starter, the contactor does not require overload heaters in the power circuit or overload contacts in the control circuit.

Figure 10 shows a lighting contactor controlled by a time switch, manual switch and photocell working in combination. This type of arrangement would be applicable to security lighting or other area lighting. The contactor usually controls the power to a large lighting load or lighting panel.

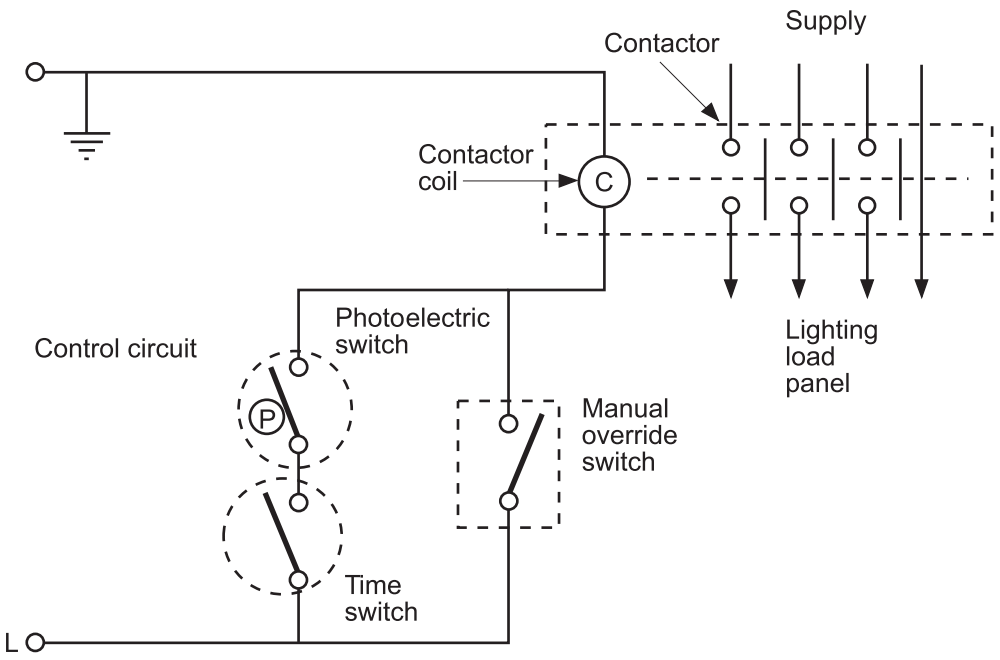


Figure 10—Lighting contactor controlled by a combination time switch, manual switch and photoelectric switch

Now do Self-Test 5 and check your answers.

Self-Test 5

1. Draw the symbol for each of the following switches:
   - Single-pole

   - Three-way

   - Four-way

2. An incandescent light is to be controlled from five separate locations using three-way and four-way switches. How many of each are required?

3. If a single-pole switch is placed in the identified conductor instead of the live (hot) wire, will the light operate? What problem will result?

4. When the toggle (operating handle) of a single-pole switch is down, the light should be _____ . How can you make sure a switch is not mounted upside-down?

5. With the switch positions as shown in Figure 1 below, the lamps would be _____ .

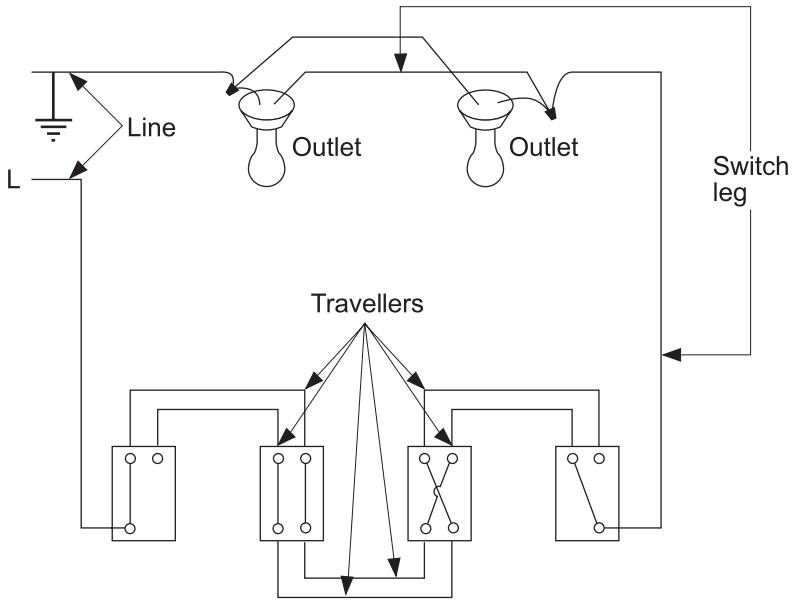


Figure 1

6. For the switching arrangement shown in Figure 2, how many wires would be needed in the cable runs between the:

   a. lamp and each three-way (S_3) switch

   b. lamp and the four-way (S_4) switch

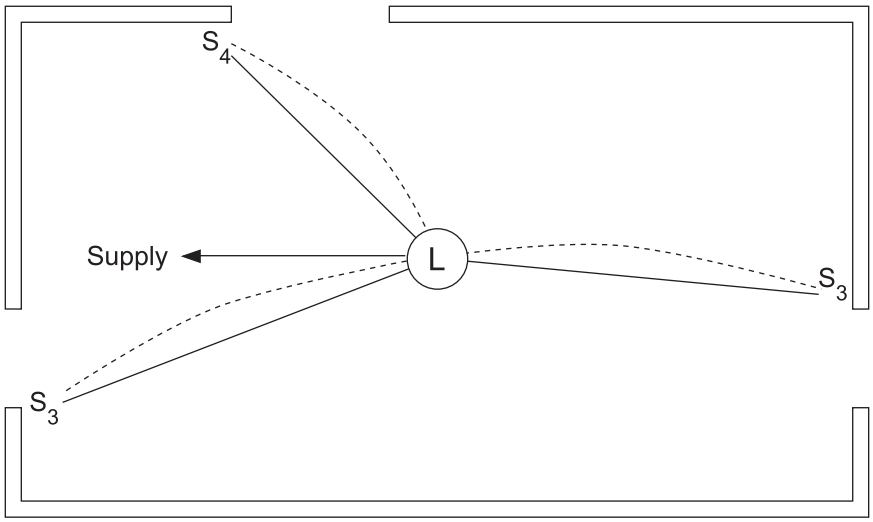


Figure 2

7. The most common wattage rating for a dimmer switch is _____ .

8. Are incandescent dimmers suitable for fluorescent lamps?

9. Why can't commercial high-wattage dimmers be used in ganged outlet boxes?

10. What type of dimmers are required for dimmable CFL lamps?

11. Extra-low voltage relays commonly operate at what voltage?

12. Why is a momentary contact switch used with low-voltage control relays?

13. Name two advantages of the low-voltage-relay switching control.

14. Refer back to Figure 7 of this Learning Task. Why are the time switch and the photocell connected in series?

15. What is the main advantage of using a lighting contactor over a simple switch?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 6:

Describe the construction and features of fluorescent lamps

The main applications for fluorescent lamps are in offices and commercial or industrial buildings. However, they are also frequently used in the kitchens, bathrooms and utility areas of homes and apartments. First developed in 1938, the lamp is available in a variety of sizes, shapes, wattages and colours.

Operation

Fluorescent light is produced by a two-stage process. First, electric current passes through a gas inside a glass tube and produces invisible ultraviolet (UV) radiation. The UV radiation is converted to visible light at the glass by a layer of phosphor powder that coats the inside surface of the fluorescent lamp. Figure 1 illustrates this process.

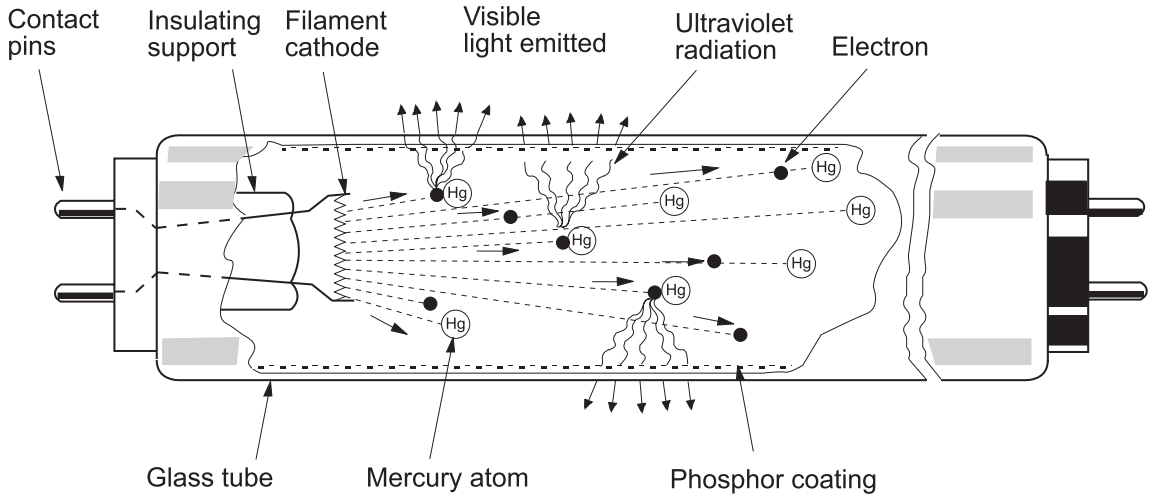


Figure 1—UV radiation is converted to visible light by a layer of phosphor powder on the inside surface of the lamp

The glass tube contains a *starting* gas such as argon or krypton, and a minute quantity of condensed mercury. A high striking voltage between the tube ends ionizes the starting gas and initiates current flow. The resulting heat causes the mercury to vapourise (turn into a gas), and collisions between the moving electrons and the vapourized mercury begin to occur. These collisions produce UV radiation, which in turn produces visible light when it strikes the phosphor powder on the inside surface of lamp. The colour of this light is determined by the type of phosphor used.

A *ballast* is needed in all types of fluorescent lamps. In most cases, the ballast performs two functions: It provides the high starting voltage necessary to ignite the tube; and it limits the current in the tube once the tube lights. In short tubes, it may serve the latter purpose only. The supply voltage is high enough to strike the arc in a short tube.

Bulb shapes

The 4' T12 (1½") diameter fluorescent lamp was at one time the most commonly used type but it has since been replaced by 4' T8 (1") diameter type. Diameters vary from T5 (⅝") to T17 (2⅛"). Nominal lamp lengths for straight tubes vary from 6" to 96". Figure 2 shows a typical fluorescent-lamp construction.

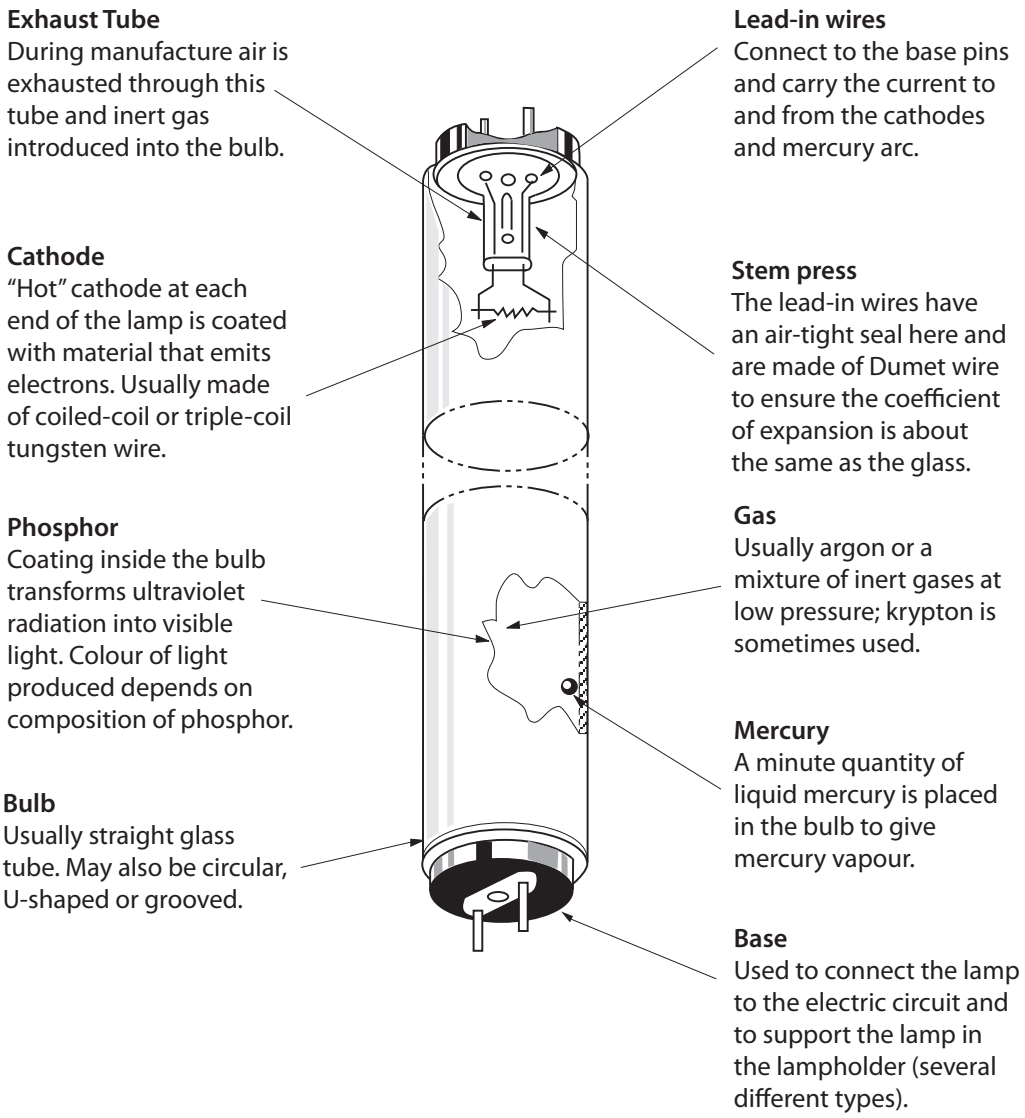


Figure 2—Typical fluorescent-lamp construction

Several other shapes are also available. Figure 3 shows some of the most common. The "U" shape is commonly used in a 2 × 2-foot ceiling cavity and circline shapes (rings) are used in bedside lamps and flat ceiling fixtures. Compact flourescent lamps are commonly used now in applications where only incandescent lamps could be used in the past. These lamps are called *CFLs* and they have two important advantages over incandescent lamps: higher efficacy (more lumens per watt) and longer life. Whereas the standard life span of incandescent lamps is 750 to 1000 hours, it is 6000 to 15 000 hours for CFLs. The following chart compares the light output of CFLs and incandescent lamps.

Power Consumption (watts)		Light output (lumens)
CFL	Incandescent	
9–13	40	450
13–15	60	800
23–30	100	1600
30–52	150	2600

All CFL lamps require an electronic ballast to operate. There are two different types of lamp construction: the integrated type, meaning the ballast is built into the lamp base; and the non-integrated type, which uses a ballast remotely located within the lighting fixture. Integrated bases come with either a standard Edison base or a bayonet-style base. Non-integrated bases are bayonet-style only and may have either a two-pin or four-pin base, depending upon the wattage.

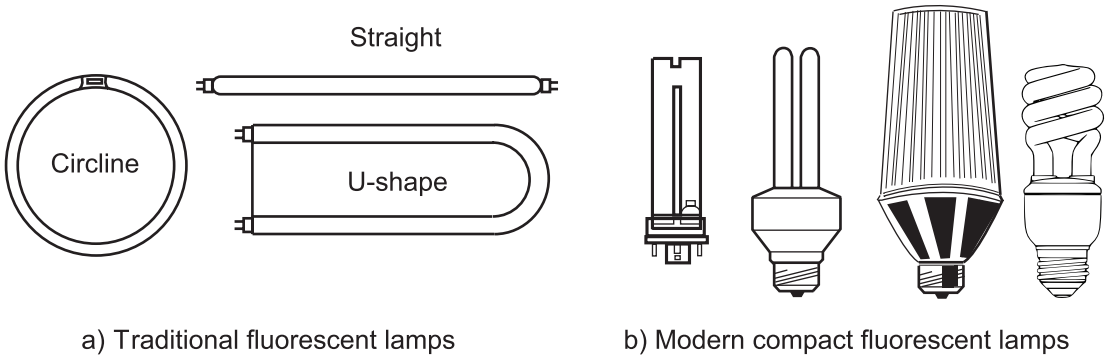


Figure 3—Common lamp shapes

Lamp bases

Different types of bases facilitate different starting classifications. They also prevent indiscriminate interchanging of high- and low-current lamps. The three bases most often used with fluorescent lamps are the bipin, single pin and recessed double-contact bases (Figure 4).

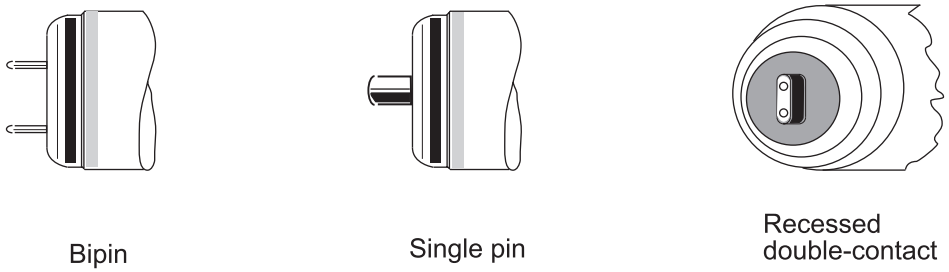


Figure 4—Bipin, single pin and recessed double-contact are the most common bases

Operating characteristics

The rated life for most fluorescent lamps is in the 7500 to 20 000-hour range. The instant-start lamps tend to be at the lower end of the range and rapid-start lamps tend to be at the higher end. The 7500 to 20 000-hour range is based on a burning time of three hours per start. If the lamps are on for 10 hours at a time, they last about 30% longer.

You reduce lamp life by:

- Switching too frequently
- Operating with the wrong type of ballast
- Using excessive supply voltage
- Losing cathode preheat during start-up

Light output decreases rapidly over the first 100 hours. Beyond this, the decrease is much more gradual. The drop in light output is due to phosphor deterioration and tube wall blackening caused by tungsten emissions from the cathodes. The tubes need to run for 100 hours to establish smooth, non-flickering working. This is called *seasoning*.

Standard lamps are designed for an indoor ambient temperature of 20°C. Light output will drop rapidly with a decrease in ambient temperature, and less rapidly if ambient temperature increases. Special *cold weather* ballasts may be required to start a fluorescent lamp if the ambient temperature is too low.

A ballast should last 12 to 15 years under normal operation. High ambient temperature is a major cause of ballast failure. Faulty lamps can also affect ballast life. Lamps that flash on and off should be replaced, as they will reduce the life of the ballast. Ballast hum can also be a problem with fluorescent luminaires. Ballasts are rated for noise with letter codes. A ballast with an "A" rating is quietest and a ballast with an "F" rating is noisiest.

Standard rapid-start lamps, which operate at 430 mA, are the most common type of fluorescent lamp. High-output lamps operate at 800 mA and are called "*HO*." Very-high-output lamps operate at 1500 mA and are called "VHO" or "SHO," for super-high-output. The abbreviation "F" for fluorescent is typically followed by the lamp watts, shape, diameter and colour. For example, if you saw a lamp bearing the code F40T12CW, you would know the lamp is: fluorescent, 40 W, tubular shaped, 1½" in diameter (from $12 \times \frac{1}{8} = 1\frac{1}{2}$), and cool white in colour. While this descriptive code is common, some lamps (such as slimline lamps) can operate at different currents. Table 1 shows a typical fluorescent-lamp data-reference table. Lamps are either preheat start, instant-start or rapid-start, and must match the fixture classification. This is covered in more detail in Learning Task 7. Slimline lamps are instant-start lamps with a single pin at each end.

Special fluorescent lamps

While the filaments of all fluorescent lamps produce light in the ultraviolet (UV) range, most lamps filter out UV at the tube wall and only light in the visible range is radiated through the glass. Special purpose fluorescent lamps, however, emit light mainly in the UV range. *Black-light* tubes use a phosphor that radiates UV in the 350 nm wavelength range, which is invisible to the human eye. The tubes cause a light glow in substances treated with special phosphor powders, which is useful for inspecting cracks and flaws in machine parts. *Sun lamps* and *germicidal lamps* also radiate UV energy and are used for skin-tanning and killing bacteria, respectively.

Energy-efficient lamps

Special energy-efficient lamps are designed for use with standard ballasts and operate at wattage reductions of 10 to 20%. In the original designs, light output was reduced proportionally. The newer 32 W and 34 W tubes have improved phosphors so that there is only slight lumen reduction compared to the standard 40 W lamp.

Stroboscopic effect

With fluorescent lamps, the arc is completely extinguished twice during each AC cycle and the light carryover depends on the phosphorescence of the powder coating on the glass. Rapid fluctuations of light can cause a *stroboscopic effect* in which moving objects are seen in repetitive flashes at successive positions. Under an unusual combination of circumstances, machinery may appear to be stopped, when in fact it is operating. Such a situation can present a safety hazard in an industrial setting. To avoid this problem, use lead-lag ballasts operating in a twin-lamp fixture. The two lamps operate out of phase and reach their maximum light outputs at different times. Connecting lamps on separate phases of a three-phase system also eliminates the stroboscopic effect. With the advent of electronic ballasts, this hazard has mostly become a non-issue. Electronic ballasts change the operating frequency within the lamp from 60 Hz to around 20 000 Hz, thereby eliminating the stroboscopic effect.

Table 1: Fluorescent lamp characteristics—Common 4-foot lamps[1]

Lamp type	Input watts for 2 lamps and ballast	Lumen output for a pair of lamps	Efficacy (lumens per watt)	CRI
F40T12CW (pre-1995)	(Mag Std) 92	5612	61	62
40 watt	(Mag EE) 86	5612	65	
3050 lumens	(Elec RS) 78	5307	68	
F40T12RE70	(Mag Std) 92	5796	63	72[4]
40 watt	(Mag EE) 86	5796	67	
3200 lumens	(Elec RS) 80	5481	70	
F40T12RE80	(Mag Std) 92	5980	65	82
40 watt	(Mag EE) 86	5980	69	
3300 lumens	(Elec RS) 80	5655	72	
F40T12/ES/CW	(Mag Std) 80	4915	61	62
34 watt	(Mag EE) 72	4915	68	
2700 lumens	(Elec RS) 682	4802	71	
F40T12/ES/RE70	(Mag Std) 80	5092	63	72[4]
34 watt	(Mag EE) 72	5092	71	
2800 lumens	(Elec RS) 68	4975	74	
F40T12/ES/RE80	(Mag Std) 80	5272	66	82[4]
34 watt	(Mag EE) 72	5272	73	
2900 lumens	(Elec RS) 682	5151	76	

F40T10/RE80 40 watt (rated) 42 watt (actual) 3700 lumens	(Mag Std) 94 (Mag EE) 88 (Elec RS) 80	6808 6808 6475	72 77 81	85
F40T12/ES+/RE70 32 watt 2650 lumens	(Mag Std) 76 (Mag EE) 86	4888 4888	64 72	72[4]
F32T8/RE70 32 watt 2800 lumens	(Mag EE) 70 (Mag HC) 66 (Elec RS) 62 (Elec IS) 59	5270 5270 5175 5155	75 76 83 87	75
F32T8/RE80 32 watt 2950 lumens	(Mag EE) 70 (Mag HC) 66 (Elec RS) 62 (Elec RS—high output) 84 (Elec RS—low output) 52 (Elec IS) 59	5428 5210 5332 7552[3] 4602 5310	77 79 86 90 89 90	82[4]
F25T12/RE70 (T8 ballast) 25 watt, 2300 lumens	(Elec RS) 48 (Elec IS) 46	4048 4048	84 88	72[4]
FM28LW (HC only) 28 watt, 2475 lumens	(Mag HC) 60	4210	70	49
F28T5 28 watt, 2900 lumens	(Elec RS) 54	5075	94	85

Notes:

1. Laboratory test conditions; actual wattage and lumens are often lower because of thermal effects.
2. The use of 34-watt "energy-saving" lamps on electronic ballasts designed for T12 lamps is not recommended due to lamp life problems and other considerations.
3. Different manufacturers' products utilize various ballast factors and input watts. This is the highest value.
4. Colour rendering varies depending on CCT. Generally values range from 70 to 82.

Table 2: Fluorescent lamp characteristics—Common 8-foot lamps

Lamp type	Input watts for 2 lamps and ballast	Lumen output for a pair of lamps	Efficacy (lumens per watt)	CRI
F96T12CW (pre-1995)	(Mag Std) 172	11 180	65	62
75 watt (Slimline)	(Mag EE) 158	11 180	71	
6250 lumens	(Elec IS) 130	11 050	85	
F96T12RE70	(Mag Std) 172	11 515	67	72
75 watt (Slimline)	(Mag EE) 158	11 515	73	
6500 lumens	(Elec IS) 130	11 382	87	
F96T12RE80	(Mag Std) 172	11 860	69	82
75 watt (Slimline)	(Mag EE) 158	11 860	75	
6800 lumens	(Elec IS) 130	11 723	89	
F96T12/ES/CW	(Mag Std) 135	9135	68	62
60 watt (Slimline)	(Mag EE) 123	9135	74	
5500 lumens	(Elec IS) 105	8925	85	
F96T12/ES/RE70	(Mag Std) 135	9409	70	72
60 watt (Slimline)	(Mag EE) 123	9409	76	
5700 lumens	(Elec IS) 105	9192	87	
F96T12/ES/RE80	(Mag Std) 135	9691	72	82
60 watt (Slimline)	(Mag EE) 123	9691	78	
6000 lumens	(Elec IS) 105	9467	89	
F96T12/HO/CW (pre-1995)	(Mag Std) 252	15 632	62	62
110 watt	(Mag EE) 237	15 632	66	
8800 lumens	(Elec RS) 190	14 365	76	
F96T12/HO/RE70	(Mag Std) 252	16 100	64	72
110 watt	(Mag EE) 237	16 100	68	
9200 lumens	(Elec RS) 190	15 075	78	
F96T12/HO/RE80	(Mag Std) 252	16 585	66	82
110 watt	(Mag EE) 237	16 585	70	
9350 lumens	(Elec RS) 190	15 530	80	
F96T12/HO/ES/CW	(Mag Std) 222	13 746	62	62
95 watt	(Mag EE) 208	13 746	66	
8000 lumens	(Elec RS) 160	12 480	78	
F96T12/HO/ES/RE70	(Mag Std) 222	14 155	64	72
95 watt	(Mag EE) 208	14 155	68	
8350 lumens	(Elec RS) 160	12 860	80	
F96T12/HO/ES/RE80	(Mag Std) 222	14 580	66	82
95 watt	(Mag EE) 208	14 580	70	
8500 lumens	(Elec RS) 160	13 245	82	

F96T8/RE70 59 watt 5800 lumens	(Elec IS) 105	9230	88	75
F96T8/RE80 59 watt 5950 lumens	(Elec IS) 105	9510	91	85
F96T8/HO/RE70 86 watt 8000 lumens	(Elec RS) 160	13 550	85	75
F96T8/HO/RE80 86 watt 8200 lumens	(Elec RS) 160	13 960	87	85

Table 3: Fluorescent-lamp data

Lamp	Ordering code	Base	Approx. amps	Operating voltage	Minimum starting volts	Average preheat amps	Cathode heater voltage nominal
Preheat							
4W T5 6"	F4T5/CW	Min. bipin	0.135	32	110	0.15	–
6W T5 9"	F6T5/CW	Min. bipin	0.147	47	110	0.20	–
8W T5 12"	F8T5/CW	Min. bipin	0.170	56	110	0.22	–
13W T5 21"	F13T5/CW	Min. bipin	0.160	95	176	0.20	–
14W T12 15	F14T12/CW	Med. bipin	0.385	39	110	0.55	7.5
15W T8 18"	F15T8/CW	Med. bipin	0.300	55	110	0.55	7.5
15W T12 18"	F15T12/CW	Med. bipin	0.330	46	110	0.55	7.5
20W T12 24"	F20T12/CW	Med. bipin	0.330	56	110	0.55	7.5
25W T12 33"	F25T12/CW	Med. bipin	0.480	58	110	0.75	–
30W T8 36"	F30T8/CW	Med. bipin	0.355	98	176	0.53	–
90W T17 60"	F90T17/CW	Med. bipin	1.530	63	132	1.80	–
Preheat–rapid start							
40W T12 48"	F40CW	Med. bipin	0.430	105	256	–	3.6
40W T10 48"	F40T10/CW/99	Med. bipin	0.420	108	256	–	3.6
40W T12 22- $^{7}/_{16}$"	FB40CW/6	Med. bipin	0.430	100	256	–	3.6
Rapidstart							
30W T12 36"	F30T12/CW/RS	Med. bipin	0.430	75	250	–	3.6
High output							
24" T12 38W	F24T12/CW/HO	Recessed D.C.	0.800	41	225	–	3.6
48" T12 60W	F48T12/CW/HO	Recessed D.C.	0.800	75	256	–	3.6
72" T12 87W	F72T12/CW/HO	Recessed D.C.	0.800	113	405	–	3.6
96" T12 112W	F96T12/CW/HO	Recessed D.C.	0.800	165	465	–	3.6
Super-hi							
48" T12 110W	F48T12/CW/SHO	Recessed D.C.	1.500	86	250	–	3.6
72" T12 160W	F72T12/CW/SHO	Recessed D.C.	1.500	128	350	–	3.6
96" T12 215W	F96T12/CW/SHO	Recessed D.C.	1.500	172	470	–	3.6
96" T12 219W	F48T12/CW/SHO II	Recessed D.C.	1.500	172	470	–	3.6
Cold weather							
48" T $^{10}/_{14}$ 105W	F48T10J/CW	Recessed D.C.	1.500	–	–	–	3.6
72" T $^{10}/_{14}$ 150W	F72T10J/CW	Recessed D.C.	1.500	–	–	–	3.6
96" T $^{10}/_{14}$ 200W	F96T10J/CW	Recessed D.C.	1.500	–	–	–	3.6
Instant start (base pins shorted inside base)							
40W T12 48"	F40T12/CW/IS	Med. bipin	0.425	104	385	–	–
40W T17 60"	F40T17/CW/IS	Med. bipin	0.425	107	385	–	–
Slimline							
42" T6 25.5W	F42T6/CW	Single pin	0.200	150	405	–	–
64" T6 38.5W	F64T6/CW	Single pin	0.200	233	540	–	–
72" T8.37.5W	F72T8/CW	Single pin	0.200	218	540	–	–
96" T8 50W	F96T8/CW	Single pin	0.200	290	675	–	–
48" T12 39W	F48T12/CW	Single pin	0.425	100	385	–	–
72" T12 56W	F72T12/CW	Single pin	0.425	149	475	–	–
96" T12 73.5W	F96T12/CW	Single pin	0.425	197	565	–	–
Circline							
22W T10 8 $^{1}/_{4}$" Dia	FC8T9/CW	Four pin	0.380	60	185	–	3.6
32W T10 12" Dia	FC12T10/CW	Four pin	0.430	80	205	–	3.6
40W T10 16" Dia	FC16T10/CW	Four pin	0.415	108	205	–	3.6
Abbreviations: D.C. = double contact; J = jacketed							

Low-pressure sodium lamps

Low-pressure sodium (LPS) lamps are not commonly used anymore due to their very poor colour rendering, and to the recent arrival of new alternatives. Some LPS lamps have an efficacy of close to 200 lumens per watt. Though often associated with high-intensity discharge lamps, in some ways the LPS lamp is more like the fluorescent lamp. However, it is really in a class of its own. Figure 5 illustrates a typical LPS lamp.

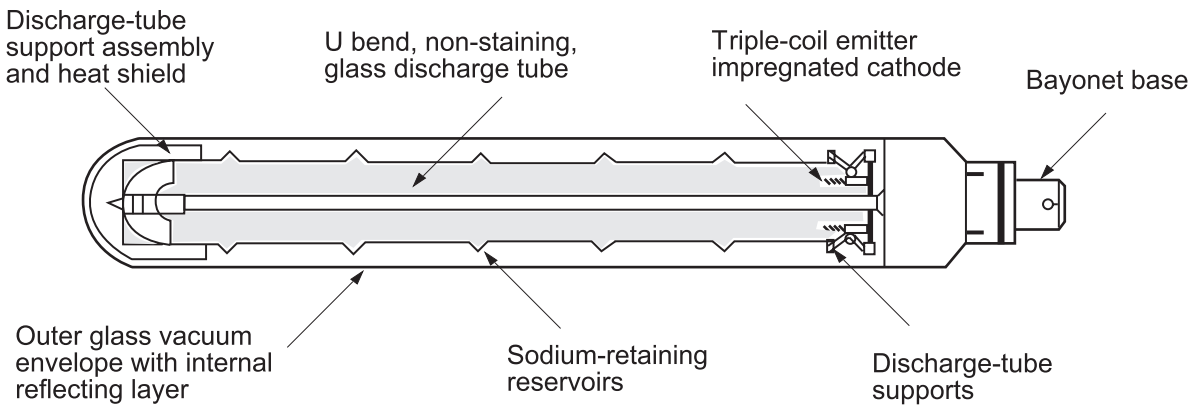


Figure 5—Typical LPS lamp

The U-shaped arc tube is surrounded by an outer glass envelope that keeps the arc tube warm. The arc tube contains a neon starting gas and metallic sodium. Cathodes similar to those used in fluorescent lamps are located at each end of the arc tube. The space between the arc tube and the outer glass is evacuated to minimize heat loss and maintain the arc-tube temperature. The dull appearance of the outer glass envelope is due to an internal heat-reflecting coating that further reduces arc-tube heat loss. The outer glass, like other fluorescents, is warm but not hot like an incandescent lamp. A bayonet base is used for correct lamp positioning. Ballasts serve the same purpose in an LPS lamp as in other discharge lamps: they provide the striking voltage and limit the current flow.

Like fluorescent lamps, LPS lamps require a ballast to provide a high striking voltage for starting. The neon gas gives it the initial orange glow. Heat produced by the starting arc gradually vapourizes the sodium, and light output increases until it reaches full intensity. This process takes 7 to 10 minutes. At full intensity, the light is pure yellow, which is the major shortcoming of the lamp. All colours are rendered yellowish or brownish in tone. Unlike in the fluorescent lamp, visible light comes directly from the arc tube. No phosphor is used on the glass. The LPS lamp restarts almost instantly after a short power outage. It is most suitable for outdoor lighting or for indoor and outdoor security lighting or any other application where the colour of the light is unimportant.

The average life of an LPS lamp is rated at 18 000 hours. Over the life of the lamp, the light output remains constant or may even increase slightly. Although lamp wattage increases, lamp efficacy decreases slightly. The light output is maintained through wide variations in ambient temperatures. In this respect, LPS lamps perform better than fluorescents, which lose light output in low ambient temperatures.

LPS lamps contain high levels of sodium metal, which is a hazardous substance. As a result, you must dispose of burned-out lamps properly in accordance with environmental regulations.

Now do Self-Test 6 and check your answers.

Self-Test 6

1. Briefly explain how light is produced in a fluorescent lamp.

2. How is the colour of light output varied in a fluorescent lamp?

3. What are the two functions of a fluorescent lamp ballast?

4. What is the diameter of a rapid-start, T8 fluorescent lamp?

5. Where are compact fluorescent lamps used?

6. What are the two types of CFL lamps?

7. What two advantages does a fluorescent light source have over an incandescent?

8. What are the three most common fluorescent lamp bases?

9. The average life of a fluorescent lamp is closest to:
   a. 5000 hours
   b. 10 000 hours
   c. 25 000 hours
   d. 50 000 hours

10. What is a major cause of premature ballast failure?

11. Ballast hum is _____ (quietest/loudest) when the sound rating is F.

12. What ambient condition causes the most rapid drop in fluorescent light output?

13. Why is it advisable to replace a fluorescent lamp that is flickering on and off?

14. Identify the three common lamp types according to their current ratings.

15. Which type of lamp is the most common and what is its current rating?

16. Identify the meaning of the following coded information on a 4' glass light tube: F40T12/RS/WW.

Refer to Table 3 in Learning Task 6 to answer questions 17 to 19.

17. What is the cathode heater voltage on a rapid-start lamp?

18. What is the striking voltage of a 4', 40 W, T12, rapid-start lamp?

19. What is the operating voltage of a 4', 40 W, instant-start lamp?

20. Identify three other fluorescent lamps designed for purposes other than area lighting.

21. Modern energy-saving fluorescent lamps:
    a. require special ballasts
    b. use 20% less energy and produce 25% less light
    c. save energy with only slightly reduced light output

22. Which lamp type requires the highest striking voltage?

23. Which lamp type has a single pin at each end?

_____

24. How does the efficacy of an LPS lamp compare to that of a fluorescent?

_____

_____

25. What colour light is produced by an LPS lamp?

_____

26. An LPS lamp has _____ colour rendition.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 7:

Describe the control of fluorescent lamps

Fluorescent lamp fixtures are classified according to their starting methods. There are three classifications: the *preheat start,* first used in the 1930s; the *instant-start,* developed in the 1940s; and the *rapid-start,* developed in the 1950s. All three are still in use, but the rapid-start is the most widely used.

Preheat circuit

When a preheat-circuit fixture is switched on, current flows through the lamp filaments, thermal starter and ballast (see Figure 1). This causes the thermal starter to open. The sudden decay of current in the circuit collapses the magnetic field in the ballast coil, which induces a voltage in the ballast. This adds to the supply voltage and an arc is struck between the two ends of the tube. The ballast then acts like a reactor (choke) to limit the current flow in the lamp. Preheat-circuit fixtures were largely replaced by rapid-start and instant-start fixtures in the 1960s.

Until recently, preheat fixtures were used only for short, low-wattage lamps in EXIT signs and desk lamps. Compact fluorescent lamps often use this method of starting and have given preheat-circuit fixtures a new lease on life. The starter fits into the side of the fixture. A simple reactor is sometimes used in place of a ballast. In small desk lamps, manual rocker switches are often used instead of automatic thermal switches. Preheat lamps come on in 1 or 2 seconds.

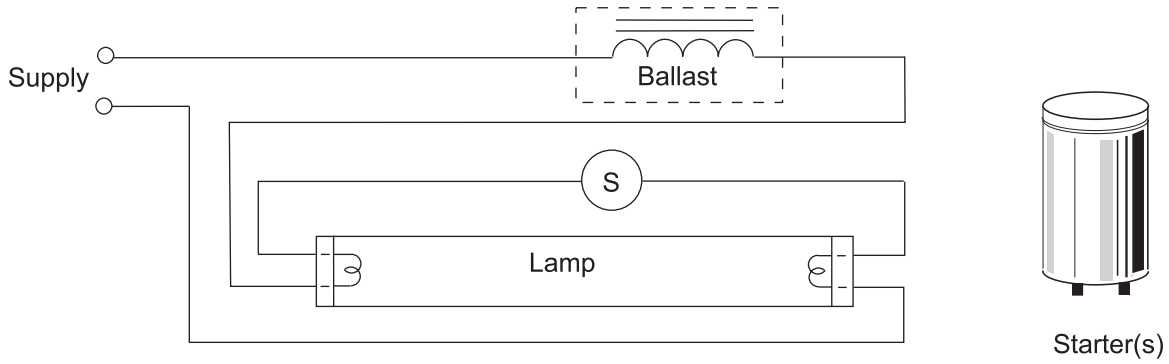


Figure 1—Typical preheat circuit

Instant-start circuit

In an instant-start fixture, the ballast houses an autotransformer that steps up the supply voltage to a magnitude sufficient to strike an arc between the two ends of the tube. Without filament heating, this typically occurs at 400 to 500 volts. Because no cathode preheating is required, the lamp lights, like an incandescent lamp, at the instant the switch is closed. This is referred to as *cold-cathode starting*. Figure 2 shows typical instant-start circuit.

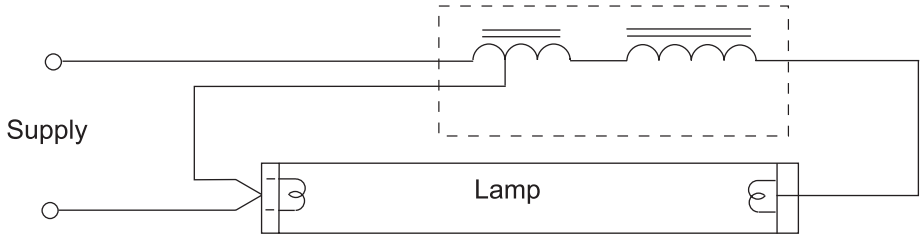


Figure 2—Typical instant-start circuit

The striking voltage for some instant-start fluorescent lamps is in the range of 700 to 800 V, which could represent a safety hazard to someone replacing a lamp. To overcome this, a switch is incorporated in one of the lampholder sockets. This design ensures that the ballast will not be energized (and the high voltage will not be present) until the lamp is fully seated in the fixture. Figure 3 shows this feature.

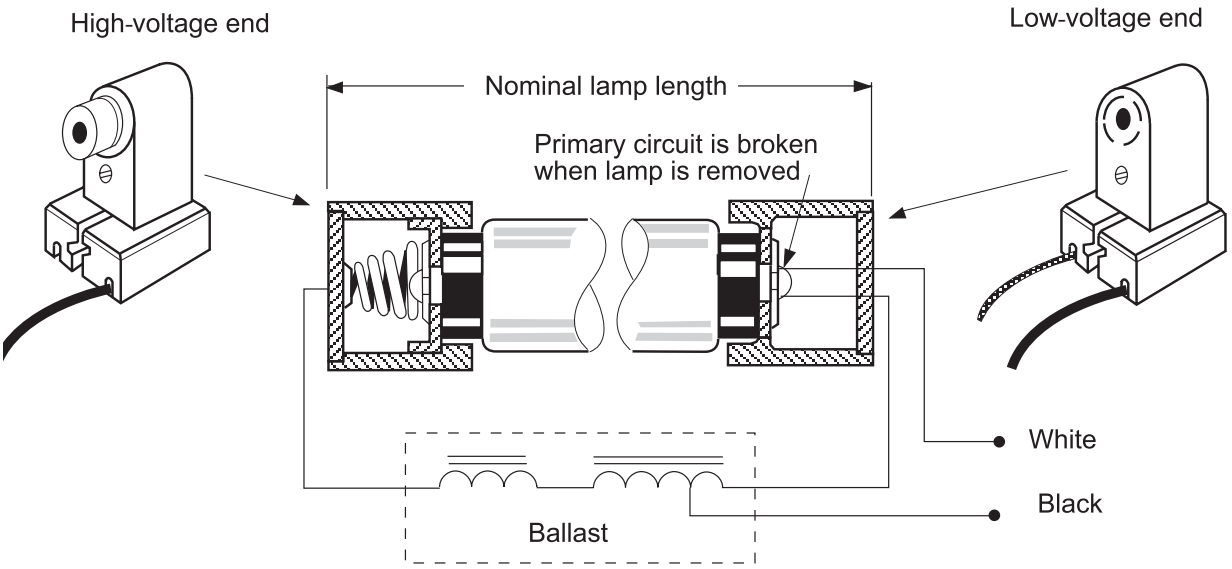


Figure 3—Socket switch design enhances safety

A *slimline* lamp is an instant-start lamp with a single pin on each end. Some instant-start lamps use bipin bases. When installing the lamp, put the single pin into the spring-loaded socket end first, and then put the other end into the socket having the safety switch. When removing the lamp, reverse the procedure: pull the switch end out first. Use this procedure to avoid handling the lamp while it is energized.

Rapid-start circuit

Unlike the instant-start fixtures, the rapid-start fixture takes about a second to start. However, it is the most popular type of fluorescent fixture because it eliminates three major shortcomings of the instant-start fixture: large, heavy ballasts; high striking voltage needed for cold cathode starting; and the resulting reduced lamp life. The rapid-start fixture overcomes these shortcomings. Starters are not required and the striking voltage is 30 to 50% lower than the striking voltage for instant-start lamps.

The operation of the rapid-start fixture depends on a momentary preheating of the cathodes. At the instant the switch is closed, low-voltage windings in the ballast apply 3 to 4 volts to the lamp cathodes, which causes them to heat up. The magnitude of the striking voltage is thus reduced. A further reduction in striking voltage is achieved by the nearby grounded metal plate running the length of the lamp. In most cases the reflector or ballast/wiring channel serves this purpose. This helps to increase the voltage stress on the gas in the lamp and further reduces the magnitude of the striking voltage.

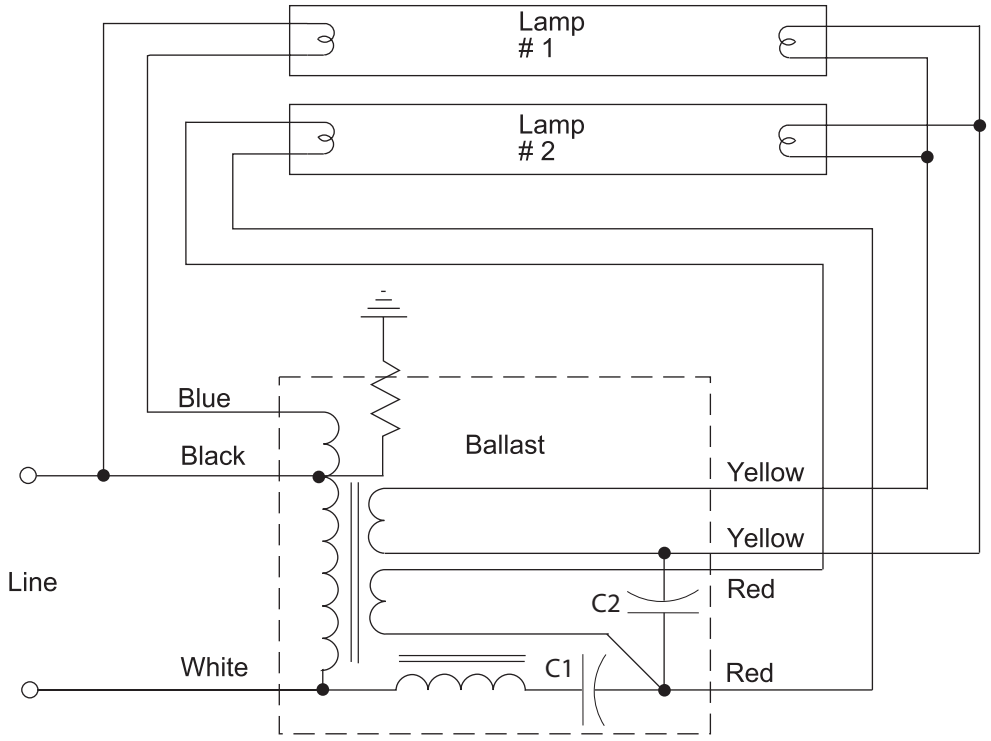


Figure 4—Rapid-start circuit connections

Figure 4 illustrates the rapid-start circuitry for a two-lamp ballast. The starting sequence is such that: full open-circuit voltage first appears across lamp #1 to strike the arc. Then the voltage drop provided by capacitor C2 strikes the arc in lamp #2. The two lamps continue to operate in series.

Electronic ballasts

Recent ballast designs replace the standard core and coil ballasts with solid-state electronic circuitry. Figure 5 shows the basic principle of operation. Electronic ballasts take low-frequency AC line voltage and convert it to DC voltage. The DC voltage is then converted to a very-high-frequency AC voltage. Electronic ballasts usually operate above 20 kHz.

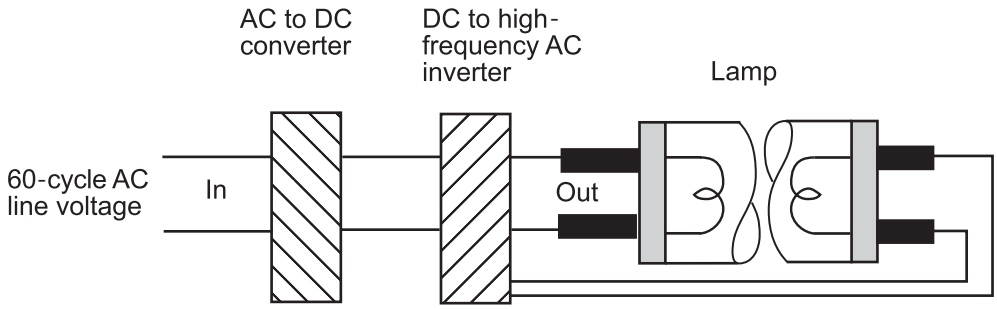


Figure 5—Simple diagram of typical electronic ballast

The high output frequency of an electronic ballast (see Figure 6) increases the efficiency of the lamp's phosphor coating. Therefore, fewer watts are needed to produce the same amount of light. In addition, the ballast circuit operates at a much higher power-conversion efficiency; it saves energy that would otherwise be wasted by producing heat in the magnetic paths of a core and coil ballast. The overall energy savings can exceed 25%, depending on specific lamp-ballast combinations.

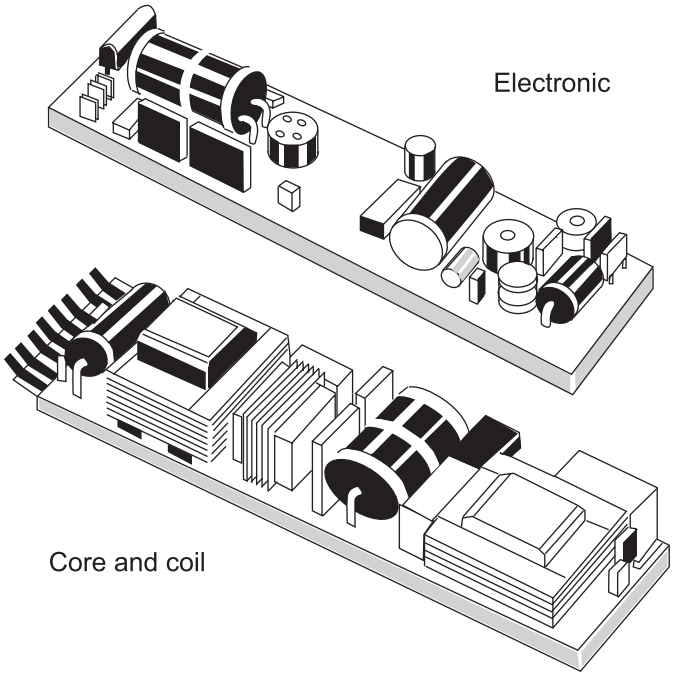


Figure 6—Electronic ballast and core and coil ballasts

A further energy saving can be achieved in applications where air conditioning is used. Due to the cooler operation of the ballast, less cooling is required from air-conditioning equipment. Another advantage is the absence of the audible hum sometimes associated with conventional ballasts. This makes electronic ballasts useful for areas such as libraries and sound studios, where noise is distracting. Some electronic ballasts also provide for lamp-dimming applications.

Electronic ballasts have essentially replaced conventional magnetic ballasts now due to their superiority in every respect. In most parts of North America, government legislation demands

the replacement of magnetic ballasts with electronic ballasts. Despite improvements to early versions, which were expensive and had high failure rates, there are still several drawbacks to electronic ballasts. One is their inherent tendency to produce harmonic distortion, which can have major consequences to the entire electrical system, including overheated neutral conductors, nuisance overcurrent tripping, and disruption of other connected equipment. However steps can be taken to filter harmonic distortion when it is excessive. Another drawback is electromagnetic radiation, which can result in health risks with prolonged exposure. Some electronic ballasts apply dangerously high starting voltages when igniting a fluorescent lamp. This creates a safety hazard and reduces lamp life.

Besides the hazard posed by the high striking voltages produced by some ballasts, many fluorescent fixtures work at supply voltages of 347 V or higher. Electricians have been killed when working on these commercial-industrial fixtures. Make sure circuit protection devices are properly locked out when working on lighting equipment.

Control of fluorescent lamps

Fluorescent lamps must be controlled by an acceptable switch, a circuit breaker or a contactor. This generally prohibits pull-chain switches, small canopy switches or similar switches that are commonly used on incandescent lampholders. Note that:

- Only approved switches may be used with fluorescent lamps.
- Circuit breakers should be approved for switching duty for luminaires rated at 347 V or less and should be marked "SWD" for switching duty.

Large commercial institutions often employ sophisticated control systems as a means of saving energy, saving money, providing convenience and flexibility, and meeting building energy codes.

Manual switching and dimming are the simplest forms of energy saving, but they depend upon occupancy patterns and occupant energy awareness. Occupancy sensors can automatically turn on and off banks of lights as required in areas of intermittent use. Daylight harvesting uses photosensors to turn off banks of lights closest to windows when adequate natural light is present. Timeclocks, high/low ballasts, dimming ballasts, low-voltage relays and lighting contactors can all be used as well with these sensors. Full-building automation systems use computers to monitor and control a building's lighting and heating, ventilating and air conditioning (HVAC) loads; these can be done locally or remotely via modem.

Supply authorities usually impose penalties on large energy users for excessive consumption during times of peak electrical demand. *Load shedding* is a term that refers to the automatic disconnection or reduction of designated loads during the times of peak electrical demand. The use of these controls and strategies allows for lighting and HVAC loads to be reduced as required, with minimal disruption to occupants.

Fluorescent fixtures used as raceways

Sometimes fluorescent fixtures are approved for end-to-end assembly. This type of arrangement is often used for overhead lighting in an office area. Conductors are run from one fixture to the next with the fixture acting like a raceway or conduit. For these installations, the voltage rating of the wiring must be not less than 600 V, and the temperature rating must be not less than 90°C. The purpose of this is to counteract two adverse characteristics of ballasts—they act as heat sources and they sometimes produce high open-circuit voltages.

Now do Self-Test 7 and check your answers.

Self-Test 7

1. What are the three classifications of fluorescent fixtures?

2. Which classification of fixture is most commonly used today?

3. What three features of the ballasts used in instant-start luminaires are considered a disadvantage?

4. What starting principle is used in the new compact fluorescent lamps?

5. Which class of luminaire takes longest to light?

6. Which classification of fixture requires a starter?

7. What safety feature is used in the slimline lamp fixture to reduce the risk of electrical shock while changing lamps?

8. What two features of the rapid-start fixture allow for a reduction in striking voltage?

9. What is the purpose of the capacitor in a single-lamp ballast?

10. In a two-lamp ballast, what is the purpose of the additional capacitor?

11. Why are manual switching and dimming the least effective types of energy-saving controls?

12. What control device is used for daylight harvesting?

13. What does the term *load shedding* mean?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 8:

Describe troubleshooting procedures for fluorescent lamp circuits

Abnormal operation or complete failure of fluorescent lamps can occur for many reasons. Defective lamps, ballasts and starters, poor lamp contact, and excessively high or low supply voltage can all lead to lamp failure. Substituting good parts in a defective luminaire is the most common method of correcting faults. If, for example, a lamp is flickering on and off, try substituting a lamp that you know is working properly.

Troubleshooting

Table 1 provides a list of symptoms, possible causes and remedies that may assist you in troubleshooting fluorescent lamps.

Checking ballasts

Many ballasts are filled with oil, and older ballasts may contain PCBs, which are a health hazard. A ballast should be replaced if it shows any signs of leakage or if it has been severely overheated. A voltmeter may be used to check the open-circuit voltage (striking voltage) and, in the case of a rapid-start ballast, the cathode heater voltage. The latter should be 3 to 4 volts, but the open circuit voltage will vary for different ballast applications. If this voltage is over 300 V, it will be noted on the ballast (for example, OCV - 600 V). Otherwise, check the manufacturer's data sheets. Make sure the voltage selector switch is set sufficiently high on the multimeter or VOM when checking the ballast. Ballast overheating is one of the prime causes of failure. A 10°C rise in ambient temperature will cut the life of a ballast in half.

Checking starters

Standard starters used on preheat fixtures are easily and safely removed from a fixture. Once the lamp lights, the starter is not needed. A simple method of checking a starter fault is to replace the starter with a good starter and insert it into the faulty fixture. If this causes the lamp to light, the faulty starter must be replaced.

Mismatched components

Mismatched lamps and ballasts can be responsible for a variety of problems. The nameplate on the ballast will usually list the lamps that may be used with it. Using other lamps may result in damage, reduced light output or reduced lamp or ballast life.

Table 1: Troubleshooting fluorescent lamps

Symptom	Possible cause	Remedy
Lamps won't come on	Lamp failure	Substitute new lamps, replace both lamps in two-lamp fixture.
	Poor contact in lampholder	Check position of lamp in holder.
	Defective starter	Replace starter (preheat circuits only).
	Ambient temperature too low	Use special fixtures at temperatures below 10°C.
	Defective ballast	Replace with new ballast of same type. Refer to wiring diagram.
Lamps shiver or flicker	New lamps	Should be operated 100 hours for proper seasoning.
	Low ambient temperatures	Striation or swirling can occur if temperature is below 70°C. Don't position near air conditioning ducts or outdoors unless special fixture is used.
	Defective starter	Replace with new starter of proper type.
	Defective lamps	Substitute new lamps.
	Improper voltage (high or low)	Check line voltage.
	Defective ballast	Replace ballast.
Humming noise	Loose assembly of fixture	Check and tighten.
	Loose ballast mount	Check and tighten.
	Defective ballast	Replace with new ballast of proper type.
Very slow starting	Low line voltage	Check line voltage.
	Poor lamp to lampholder contact	Check contact.
	Defective starter	Replace starter (preheat types only).
	Inadequate lamp-starting aid (rapid-start type)	Check starting-aid connections. Check spacing of lamp from reflector. Be sure fixture is grounded.
	Defective lamps	Replace lamp.
	Bulb temperature too low or too high	Check application. Use only special fixtures near air conditioning ducts or outdoors.
Ballast heats excessively (over 90°C case temperature)	High voltage	Check line voltage.
	Defective lamps (instant-start or preheat systems)	Replace starter with one of proper type (preheat system).
Discoloration of lamps, particularly near ends of tubes	Defective starter	Replace starter with one of proper type (preheat system).
	Defective ballast	Replace ballast.
	Mercury accumulation (appears as greyish streaks, usually along lower part of tube)	Rotate tube to different position.
	Cathode emission (appears as dark rings near end of tube)	Indicates tube near end of life.

Now do Self-Test 8 and check your answers.

Self-Test 8

1. What is the most common procedure for troubleshooting a malfunctioning fluorescent fixture?

2. If the ballast is not tightly secured to the fixture, what will be the likely effect?

3. If lamps and ballasts are not matched in a fluorescent fixture, but the lamp lights, what are the possible consequences?

4. Why, apart from the annoyance, should lamps that are flickering on and off be replaced?

5. What causes black discolouration near the ends of the tube in a rapid-start or instant-start lamp?

6. What is the major cause of ballast failure?

7. If a rapid-start fixture is not grounded, what might be the possible consequences from an operational standpoint?

Refer to Table 1 in Learning Task 8 to answer questions 8 to 10.

8. Two newly replaced lamps in a rapid-start fixture shiver or flicker when initially energized. The most likely cause is that the:

   a. ambient temperature is too high

   b. starter is defective

   c. lamps require proper seasoning

   d. ballast has an open circuit _____

9. Which of the following is most likely to occur when a rapid-start fixture is improperly grounded?

   a. The fixture makes a humming noise.

   b. The lamps start slowly.

   c. The ballast overheats.

   d. The tubes quickly develop dark rings at the top. _____

10. A fluorescent lamp will not come on. What is the most likely reason other than the possible causes listed in Table 1?

    _____

    _____

    _____

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 9:

Describe the construction and features of high-intensity discharge lamps

Fluorescent lamp, low-pressure sodium lamps and high-intensity discharge (HID) lamps are all gas-discharge lamps in which light is produced by passing electric current through a gas. The difference between HID lamps and the other two is that HID lamps have much shorter arc tubes and operate at a much higher pressure and temperature. Inside the short HID-arc tube, a highly concentrated and intense arc produces radiation with a wavelength within the visible light spectrum. These compact light sources produce high lumen outputs and are used extensively in industrial, commercial, sports and street-lighting applications. All HID lamps require ballasts.

There are three main types of HID lamps: mercury vapour, metal halide and high-pressure sodium (Figure 1).

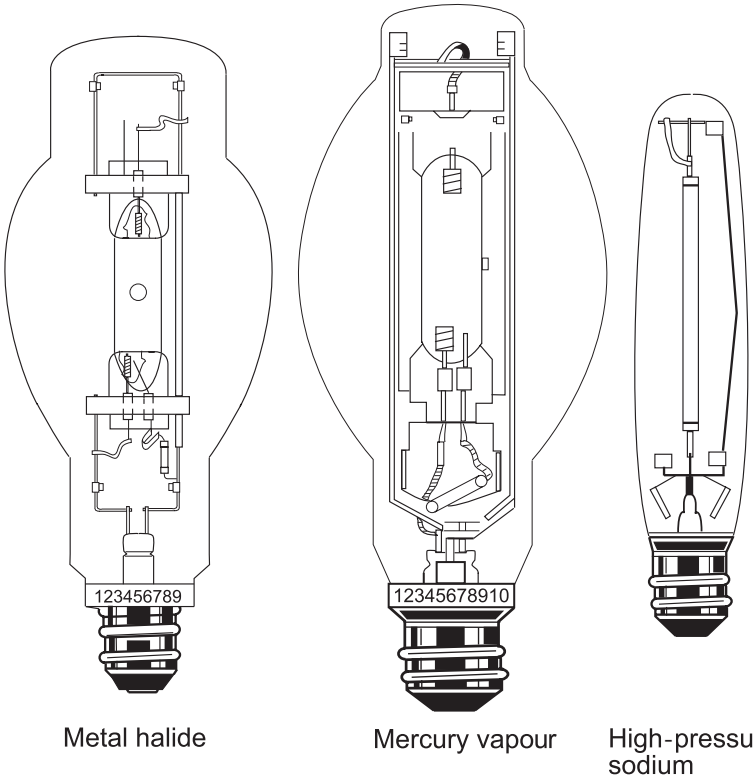


Figure 1—The family of HID lamps

Mercury vapour lamp

Developed in 1934, the mercury vapour lamp was the first of the HID light sources. Though largely replaced by the other two in recent years, it is still widely used in older installations. Figure 2 illustrates the basic construction of the mercury vapour lamp, or mercury lamp, as it is frequently called. A ballast is needed to impress a high starting voltage across the main electrodes, and between the starting and main electrodes.

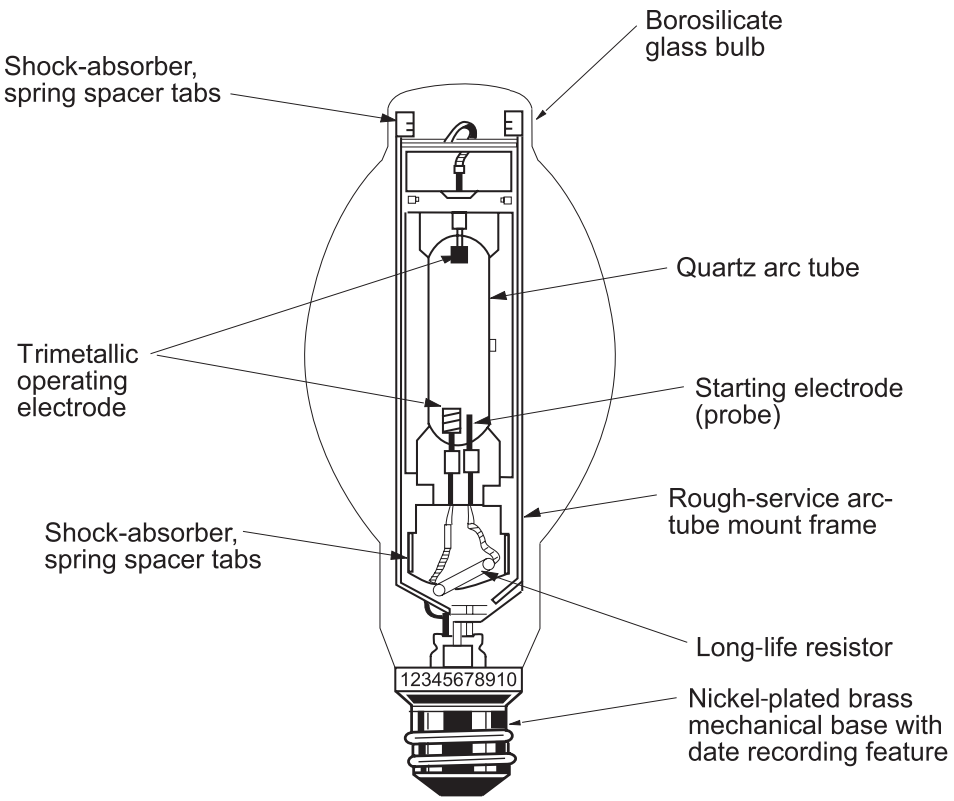


Figure 2—Mercury vapour lamp

The heart of the lamp is the quartz arc tube. When the switch is turned on, a small arc is struck between the lower main electrode and the starting electrode. This vapourizes the mercury gas and permits striking of the main arc. It takes 3 to 7 minutes to reach full light output. If a power outage occurs for even an instant, the arc extinguishes and will not re-strike until the lamp cools and the pressure is reduced. Re-strike time is typically 4 to 6 minutes.

Efficacy of mercury vapour lamps is in the 30 to 65 lumens/watt range, with the higher ratings for lamps with higher wattages. Lamp wattages vary from 40 W to 1000 W and voltages from 120 V to 600 V.

An outstanding feature of the mercury vapour lamp is a rated life of 24 000 hours plus. This is based on 12 hours of burning per start. The lamps are designed for universal burning but are normally more efficient when operated vertically than horizontally.

Unlike the fluorescent, light output may decrease only slightly with low ambient temperature, though the starting voltage of the ballast may have to be higher. A special ballast is required where ambient temperatures are well below the freezing point.

The dominant colour of a clear lamp is bluish white. Many lamps have a phosphor coating that improves the colour by converting some of the ultraviolet radiation to visible light in the red region.

If the outer bulb of a mercury vapour (or a metal halide) lamp is broken, the lamp may continue to operate but UV radiation that is normally filtered by the glass is now free to escape. Severe eye inflammation and serious skin burns can result, depending on how close you are to the lamp and the exposure time. Switch off and replace broken lamps.

Metal halide lamps

Metal halide lamps (Figure 3) are similar in construction to mercury vapour lamps, except that the arc tube is generally a little shorter. It contains an additional compound of metals and halogen gas that improves the efficacy and colour rendition of the lamp. For this reason, metal halide lamps are the first choice among HIDs for good colour rendition.

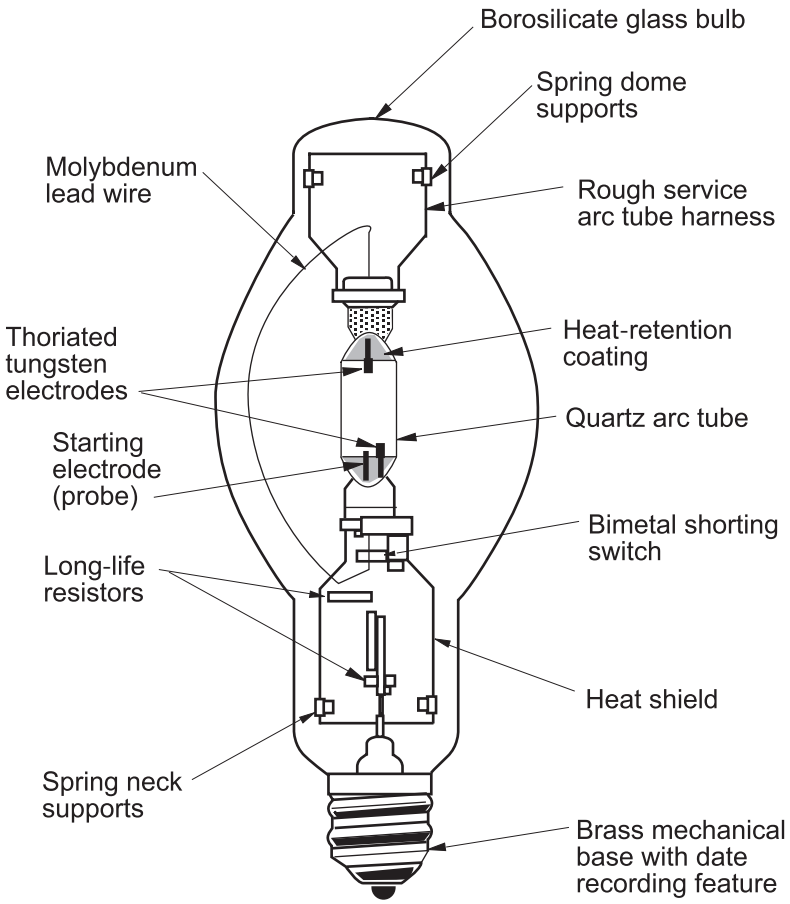


Figure 3—Metal halide lamp

The starting method is essentially the same as for a mercury lamp; however, the metal halide lamp usually has a higher starting voltage than a mercury lamp with an equivalent wattage. The start-up time is also slightly longer, typically 5 to 7 minutes. Because the arc tube of the metal halide lamp operates at a higher temperature than the mercury lamp, it requires a longer cooling period before re-striking. This interval can be as long as 15 minutes.

While the efficacy of metal halide lamps is much higher than mercury lamps, the rated average life is shorter. A metal halide lamp lasts about 15 000 hours. The lamps vary from 175 W to 1500 W and can be used in a variety of operating positions. The correct operating position is normally specified by the manufacturer.

Some manufacturers offer pulse-start metal halide technology that combines a specially designed lamp with a high-voltage pulse igniter to eliminate the starting electrode, and a power-saving hybrid ballast. The lamp contains a specially designed arc tube whose shape allows for maximum flow of the halides within the lamp to distribute heat and light more evenly within the lamp. This provides better colour uniformity and delivers faster warm-up times and improved lumen maintenance. Efficacy and lamp life are also claimed to be up to 50 percent higher than for standard metal halide lamps.

High-pressure sodium lamp

Although the operation of high-pressure sodium (HPS) lamps is similar to those of mercury and metal halide lamps, they are much different in other respects (see Figure 4). For example, an HPS lamp has:

- No starting electrode
- Special circuitry in the ballast that provides an initial high-voltage spike of 2500 volts or more
- An arc tube that contains xenon gas and a small amount of sodium-mercury amalgam

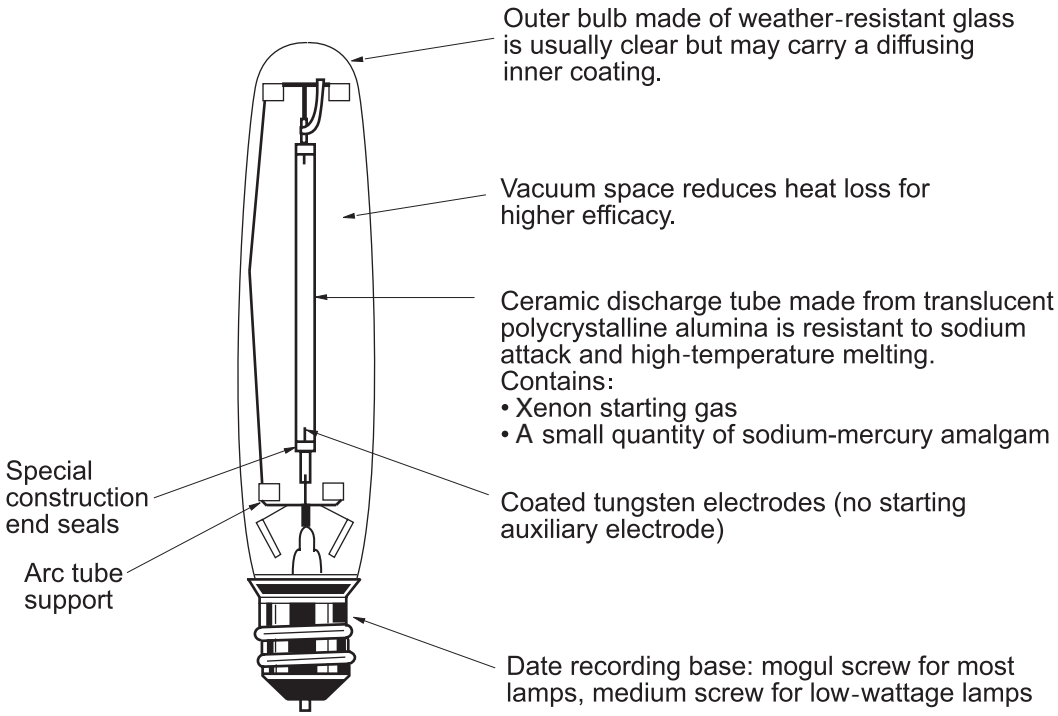


Figure 4—High-pressure sodium lamp

The initial high-voltage spike establishes an arc that travels through the xenon gas between the main electrodes. This heats up the mercury and sodium, which vapourize during the warm-up cycle, and the arc changes to a warm golden white.

The lamp comes to full brilliance in 3 to 4 minutes. Due to its relatively low operating pressure, the lamp re-strike time is usually less than 1 minute, which is much faster than the other HIDs. It has the highest efficacy of all HID sources, providing up to 140 lumens per watt on larger lamps, and a rated life of approximately 24 000 hours. This lamp, unlike the other HIDs, can operate in any burning position with no adverse effects. Lamp wattages vary from 35 W to 1000 W.

HPS lamps are still a widely used light source in new installations for various outdoor applications such as roadway, area and security lighting, and for indoor applications where true colour rendition is not important.

Take special care when working with HID light sources. HID lamps are frequently supplied by commercial-industrial type voltages such as 347 V or 600 V. Remember that a high OCV is produced at the ballast even on 120 V luminaires. Do not work on wiring components while the circuit is energized, regardless of the magnitude of the supply voltage.

Interchangeable HID lamps

Occasionally, there may be a situation where a screw-in replacement for an existing HID lamp is an effective and economical means of upgrading the lighting system. There are a few metal halide lamps designed to directly replace HPS lamps that will work with the existing ballasts, with an immediate improvement to colour rendering. There are also some metal halide lamps designed as a screw-in replacement for mercury vapour lamps. For example, a 325 watt MH retrofit lamp will replace a 400 watt MV lamp using the existing ballast, resulting in improved colour rendering and nearly a 20 percent saving in energy use.

Bulb shapes and sizes

Figure 5 shows some of the more common HID bulbs. Mercury vapour bulbs are available in sizes ranging from 40 W to 1000 W. Metal halide lamps are available from 175 W to 1500 W, and HPS from 35 W to 1000 W. An alphanumeric code is used to designate bulb shape and maximum bulb diameters. Letters indicate the shape of the bulb and numbers indicate the diameter in eighths of an inch. The chart in Figure 5 shows the common letter codes.

Letter code	Bulb name
B	Bullet
BT	Bulged-tubular
E	Elliptical
PAR	Parabolic aluminized reflector
T	Tubular

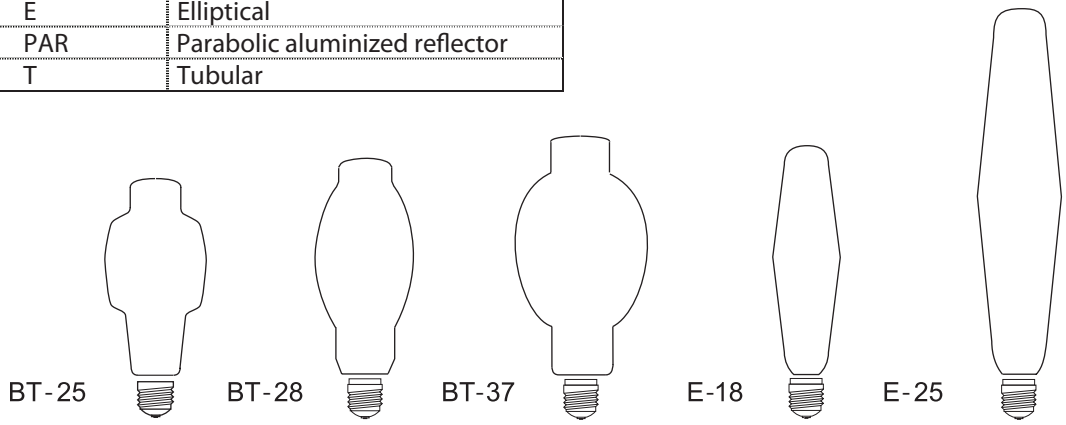


Figure 5—HID bulb shapes

Lamps with larger wattages are normally larger in diameter and longer in overall length. Mercury and metal halide lamps may require a particular operating position such as base-up, base-down or horizontal. This will be indicated on the glass where necessary. The letters "BU" indicate base-up and the letters "BD" indicate base-down.

ANSI code designations

The American National Standards Institute (ANSI) has developed a lamp code description so that common coding can be used to identify similar lamp types from different manufacturers. It should be noted, however, that this coding system is not strictly adhered to by all lamp manufacturers and the information printed on the lamp glass may vary somewhat. An example of ANSI coding on an HID lamp and brief descriptions of how to interpret the code are shown below.

H36BT–1000/DX

H

Indicates mercury vapour (H for Hg, the chemical abbreviation for mercury). M or MH is used for metal halide and S for high-pressure sodium.

36

Ballast type required. Each HID ballast has an ANSI number, which is normally stamped on it. The number 36 ballast has the correct electrical output characteristics to operate this lamp.

BT

These letters identify the physical shape of the lamp, in this case bulged-tubular.

1000

Nominal lamp wattage. Remember there will also be watts (loss) dissipated in the ballast.

DX

Deluxe colour. These are optional letters added by the manufacturer to indicate the bulb finish or colour. DX means deluxe white phosphor-coated; WDX means warm white deluxe phosphor-coated. Clear glass has no code.

Now do Self-Test 9 and check your answers.

Self-Test 9

1. Identify the three main types of HID light sources.

2. Most of the radiation produced in the arc tube of a HID lamp is in the range of the _____ electromagnetic spectrum.

3. Which of the three HID lamps has the lowest efficacy?

4. Name four common applications of HID light sources.

5. Mercury lamps are normally designed for operating:
   a. with the base up
   b. with the base down
   c. in the horizontal position
   d. in any position _____

6. What is the effect of a phosphor coating on the outer glass bulb of a mercury lamp?

7. Which two of the three HID lamps are similar in construction?

8. Which HID lamp is the best for colour rendition?

9. Which HID lamp has the shortest re-ignition time after a power failure?

10. Can pulse-start metal halide lamps be used with regular metal halide ballasts?

11. Which HID lamp is described as having a "golden white" appearance when lighting?

12. Which of the three HID lamps has the longest rated life? Which has the shortest?

13. If a mercury lamp is operating with a broken outer glass bulb, what precautions should be taken and why?

14. Identify one major disadvantage of HID light sources when compared to fluorescent light sources.

15. Which HID lamp takes longest to re-strike after a power outage?

16. A metal halide bulb is identified as BT-37. What does this indicate about the lamp's shape and dimensions?

17. In general, what is the relationship between the wattage of an HPS lamp and its physical dimensions?

18. An HID lamp has the marking MH175WDX. What information is being conveyed by these letters and numbers?

19. What do the letters BU and BD convey when marked on a lamp?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 10:

Describe the control of high-intensity discharge lamps

HID lamps require ballasts for the same reasons as fluorescent lamps—to provide the high striking voltage or OCV needed to ignite the arc tube, and to regulate the current flow once the arc is established. The ballast is normally an integral part of the luminaire, though it can be installed separately from the light fixture if desired. As for fluorescent ballasts, excessive heat and ballast life are closely related. As a general rule, the life of the ballast is reduced by 50% for each 10°C increase above the design temperature. HID ballasts are available for voltages of 120 V, 208 V, 240 V, 277 V, 347 V, 480 V and 600 V. In most instances, a ballast designed for a designated lamp type and wattage (for example, metal halide, 400 W) cannot be used with a different lamp or wattage.

Reactor ballast

The reactor ballast has the simplest design, and is the least expensive. It is used only with mercury vapour lamps, and is sometimes called a *lag reactor* ballast. It is suitable only where the supply voltage is high enough to provide the required striking voltage without the aid of a step-up transformer. The reactor ballast acts only as a choke. Figure 1 illustrates high- and low-power-factor reactor ballasts.

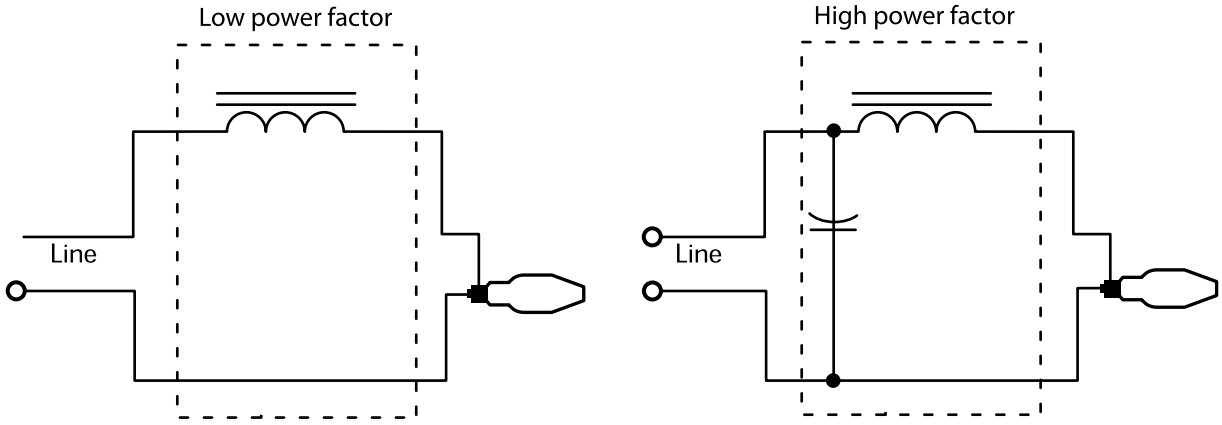


Figure 1—High- and low-power-factor reactor ballasts

The reactor ballast is not suitable for 120 V or 208 V supplies. The supply voltage has to be 240 V or higher, depending on the lamp type and watts. The low-power-factor ballast has a power factor of about 50%, which increases to 90% if the ballast has a capacitor. Reactor ballasts are rarely used in newer installations.

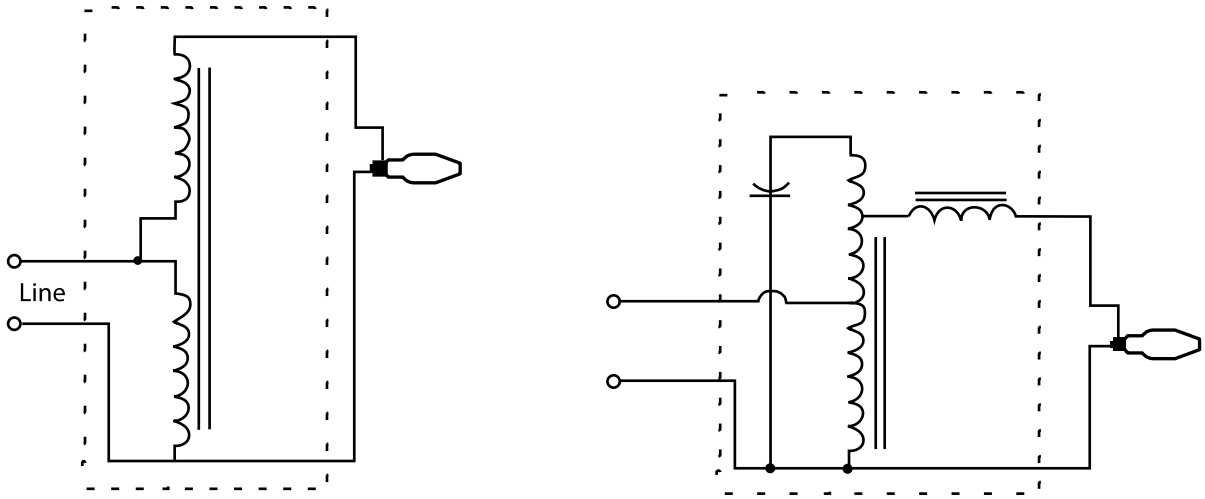
Autotransformer ballast

Also called a *lag autotransformer ballast*, this type of ballast is essentially an autotransformer with or without a series reactor. See Figure 2(a). Its performance is similar to that of the reactor ballast, but it can be used on supply voltages above or below the required lamp starting voltage.

This ballast is larger and more expensive than the simple reactor ballast. It also has greater losses than the reactor ballast. The addition of a capacitor, as shown in Figure 2(b), improves the circuit power factor (PF) to above 90%. The autotransformer ballast is used with mercury lamps.

Both the simple reactor and autotransformer ballasts are limited to situations where the supply voltage does not vary beyond ±5% of nominal supply voltage, and where voltage dips do not exceed 15 to 20%. Variations beyond these limits may prevent lamp starting, alter the rated lamp wattage or extinguish the lamp.

Remember, when a mercury vapour lamp is extinguished it will not re-strike and come back to full light output for several minutes. The primary winding of the autotransformer ballast is commonly provided with taps for two or more line voltages.



(a) Autotransformer without capacitor (b) Autotransformer with capacitor

Figure 2—Autotransformer ballasts

Auto-regulator ballast

This ballast is made up of a high-reactance autotransformer with a series capacitor, as shown in Figure 3. It is also referred to as a *constant wattage autotransformer ballast* (CWA). This design regulates lamp watts by maintaining lamp current at a fixed value regardless of variations in the supply voltage. The combination of the capacitor and the autotransformer (reactor) in this design regulates the lamp current and gives the circuit a PF in the 95% region. In addition, it can handle voltage dips of 40 to 50% without extinguishing the lamp. Primary winding taps allow for two or more supply voltages.

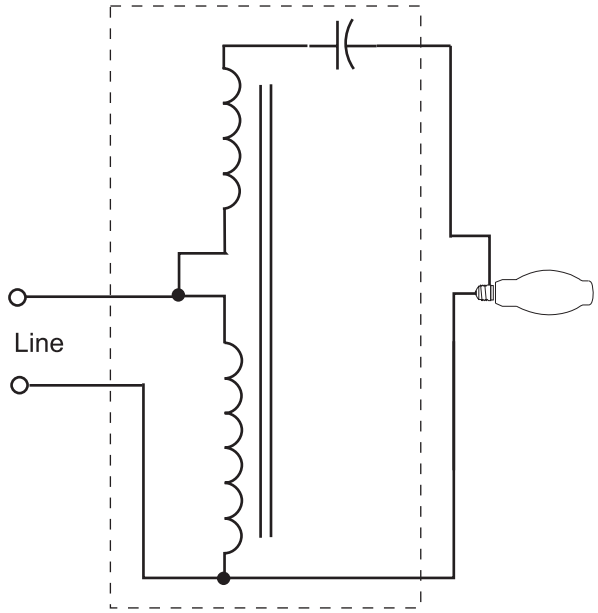


Figure 3—Auto-regulator ballast

Although its design is altered somewhat to fit the specific requirements of particular lamp types and wattages, this ballast is widely used with all HID light sources. It is the most common ballast for metal-halide lamps.

Regulator ballast

As shown in Figure 4, the regulator ballast is made up of two separate windings with a capacitor connected in series with the lamp. Unlike in the autotransformer, the secondary winding is electrically isolated from the supply winding. The regulating action is similar but superior to the autotransformer regulator ballast. The regulator ballast can tolerate supply voltage variations of ±13% and voltage dips of 50 to 60%. As such, it is ideal where large variations in the supply voltage are common. However, the regulator ballast is larger and more expensive than the other types.

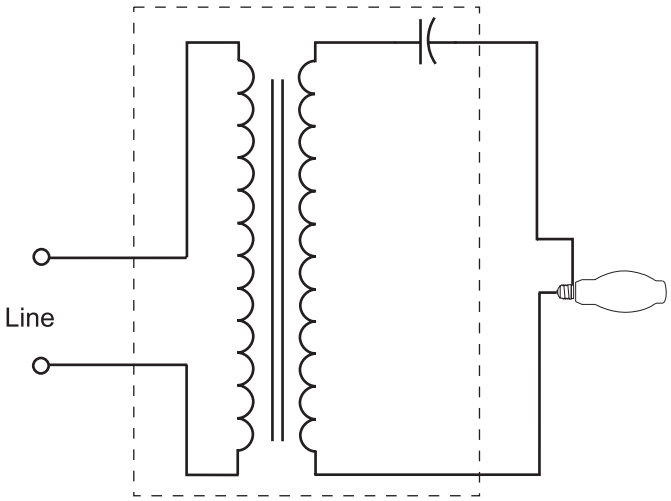


Figure 4—Regulator ballast

Two-lamp ballasts

These are used to reduce ballast costs and cut the size and weight of twin-lamp fixtures. They also minimize the stroboscopic effect. There are two types: lead-lag and series. The lead-lag ballast provides two independent circuits, so if one lamp fails, the other is not affected. The series type is cheaper but has the disadvantage that if one lamp fails both lamps go out.

High-pressure sodium ballasts

The ballast for an HPS lamp serves the same purpose as the ballast for a mercury or metal halide lamp: It regulates the current and lamp wattage. Some of the ballasts previously examined may be used, but they must be specially designed for the unique requirements of the HPS lamp. Unlike the other two HID lamps, the HPS lamp requires a high-voltage spike to augment the starting voltage. This is because the HPS lamp has no starting electrode.

An electronic starting aid provides a voltage pulse with a peak of 2500 to 4000 V for 1 to 4 microseconds. This strikes the arc. When the lamp lights and begins to draw sufficient current, the starting circuit automatically stops. At the end of lamp life, the arc voltage may become too high for the ballast to provide stable operation and the lamp may be extinguished. As it cools, it will restart and may continue to cycle on and off. The lamp should be replaced if this happens. Figure 5 shows a typical high-pressure sodium ballast.

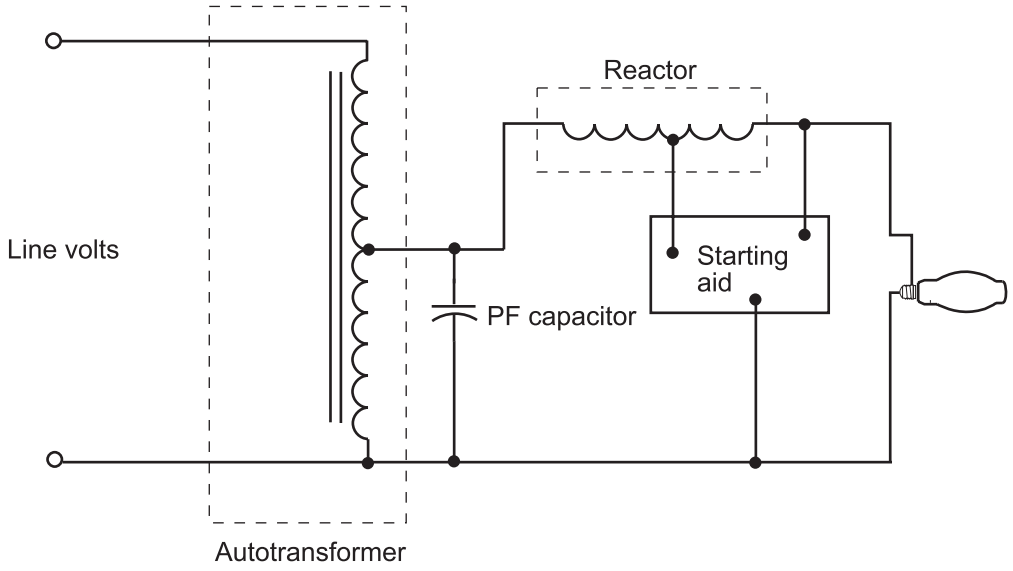


Figure 5—Typical high-pressure sodium ballast

Do not install high-pressure sodium ballasts too far from the fixture because the starting spike attenuates with distance. Check the manufacturer's specifications for the allowable distance.

Polarization of lampholder

The screw-shells of lampholders must be connected to a grounded conductor as shown in Figure 6.

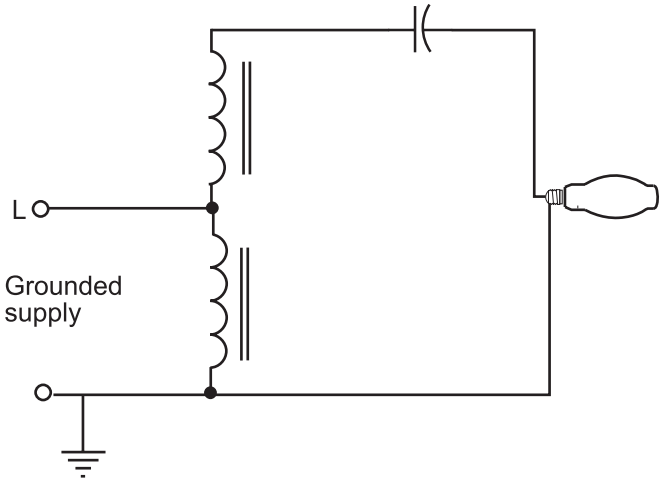


Figure 6—Screw-shells of lampholders must be connected to a grounded conductor

A grounded conductor is readily available on 120 V supplies and also on 277 V and 347 V supplies. However, supply voltages such as 208 V, 240 V and 600 V do not usually have a grounded circuit conductor and would not be able to meet electrical Code requirements. You could overcome this problem by using a two-winding transformer and grounding the screw-shell of the lampholder as shown in Figure 7.

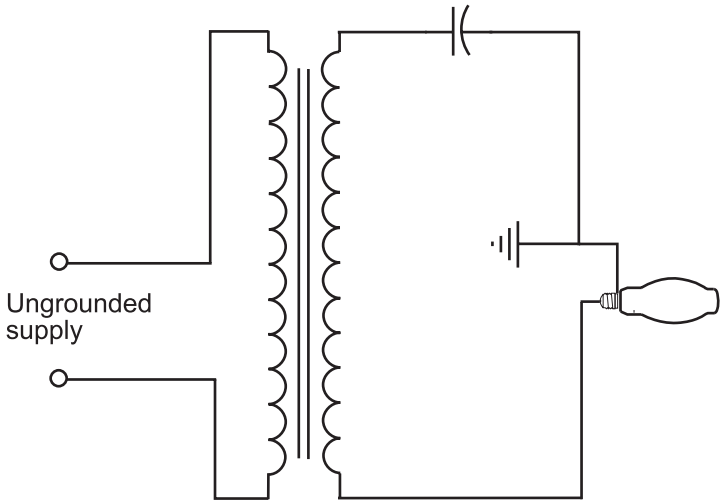


Figure 7—Isolating ballast

An exception to this rule is when the ballast supplies two lamps in series. Only the screw-shell of one lampholder has to be grounded, as long as the removal of that lamp isolates the screw-shell of the second lamp from the hot conductor. Figure 8 illustrates this type of circuit. When lamp A is removed, only the centre contact of the base is hot. When lamp B is removed, the screw-shell is at ground potential.

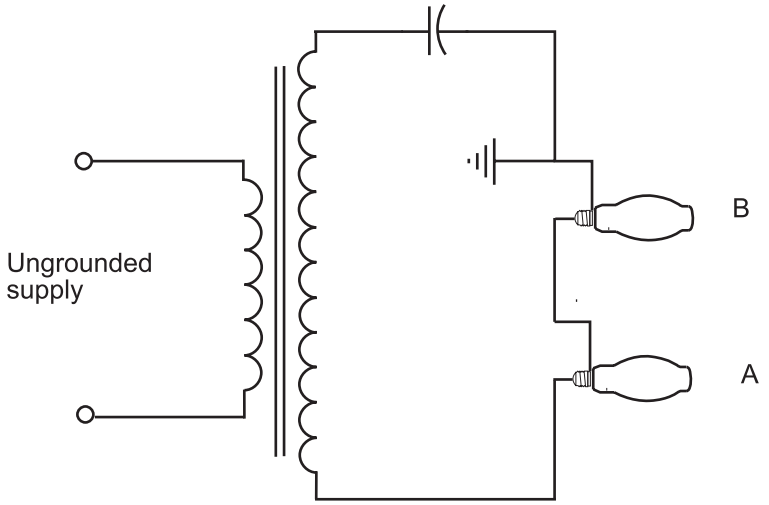


Figure 8—Circuit with double lamps

Ballast location

Normally the lamp and ballast are an integral part of the luminaire, with everything pre-wired by the manufacturer. The electrical Code permits remote ballast mounting, which may be an advantage if there is a high ambient temperature or a need for low ambient noise in a particular location. Distances from remote ballasts to lamps are less critical for mercury vapour and metal halide luminaires than for high-pressure sodium. Follow manufacturers' guidelines carefully. For long runs, you may need to increase conductor AWG size to compensate for excessive voltage drops.

Controls

Generally, HID lamps are not suitable for dimming. While there have been various dimming systems available for HID, they are expensive and do not provide linear energy savings, resulting in the lamp efficacy being greatly reduced with just a small saving of energy. Reduced voltage from the dimmer will affect the proper operation of the arc tube, changing the operating temperature and the resulting colour rendering. Further, most HID lamp manufacturers disallow dimming in their warranties, so they are not widely used.

Because of their long restrike time, HID lamps are not conducive to occupancy sensors and other types of sensors that switch the lamps on and off. HID luminaires installed in public buildings often incorporate a small integral halogen lamp and a photocell for temporary safety lighting. In the event of a power interruption, the halogen light will immediately come on when power is restored while the HID lamp cools down enough to allow its arc to restrike. Once the HID lamp produces enough light to activate the photocell, the halogen lamp turns off.

Large stadiums that televise sporting events often have difficult lighting requirements, with a very broad range of lighting levels needed. For example, a televised basketball game may require as much as 2000 lux, while as little as 200 lux are needed during the half-time show. This cannot be achieved through conventional dimming, so these high-wattage luminaires are equipped with "barn doors" in front of the reflectors to limit the escaping light. These can be operated remotely with the use of servomotors.

Some manufacturers offer high/low ballasts that can be used with timers, occupancy sensors photosensors, etc., to switch the ballast between modes. Sometimes the actual switching of the ballasts is done by a lighting contactor, with the sensor operating the control circuit. Other times the sensor and a relay are integral within each luminaire. Low mode, which may be activated by a timer or photosensor, allows the arc to still be maintained but current is limited by the ballast, causing the lamp output to be very low, which results in an energy saving. When switched to high mode, which may be done by a timer, occupancy sensor or manual switch, the lamp immediately operates at its normal output. Some lamp manufacturers, however, will not warrant their lamps for this application.

Now do Self-Test 10 and check your answers.

Self-Test 10

1. What is the simplest and cheapest mercury vapour ballast?

2. What two functions do most HID ballasts perform?

3. Which HID lamp requires a ballast that produces brief high-voltage spikes to ignite the lamp?

4. What ballast type is commonly used with metal halide lamps?

5. What is the usual function of the capacitor when used in conjunction with the ballast wiring?

6. What is the purpose of the primary winding taps in a ballast?

7. Which ballast is not suitable for a 120 V supply?

8. What advantage does the regulator ballast have over a simple reactor or lag ballast?

9. What advantages does the autotransformer regulator ballast have over the two-winding regulator ballast?

10. What ballast types are limited to applications where the supply voltage stays within ±5% of nominal ratings?

11. What does a regulator ballast regulate?

12. Name two types of two-lamp ballasts.

13. Why are HID lamps not suitable for dimming?

14. Generally, HID luminaires used in public buildings require what special feature for safety?

15. Describe the operation of a high/low dimming system.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 11:

Describe basic troubleshooting for high-intensity discharge lamp circuits

The failure of an HID lamp could be due to many causes. For example, an HID lamp may fail to operate because of:

- A faulty lamp
- A faulty ballast
- The absence of supply voltage
- Low supply voltage
- Defective controls such as lamp photocells
- Poor electrical connections

As with fluorescents, first try substituting a new lamp that is known to be good. While changing the lamp, inspect the socket for any evidence of arcing or a damaged centre contact. If the lamp fails to light, proceed as follows:

1. Read the ballast nameplate to determine the ballast type.
2. Ballasts and lamps must match. An H39 lamp, for example, must have an H39 ballast. Check that this is the case.
3. If the fixture is a mercury vapour or a metal halide, check for voltage at the lamp socket using a voltmeter set on the 600 V scale. A test instrument placed across the lampholder terminals of an HPS fixture will expose the instrument to high-voltage spikes, which may damage the instrument. In any event, the pulse is of such short duration it would not register on the voltmeter.
4. If there is no voltage at the lamp socket, verify that supply voltage is applied to the line side of the ballast. If no voltage is present, check the branch circuit breaker or fuse and then the fixture wiring.
5. If there is voltage at the socket but the voltage is less than the designated OCV for that particular lamp, check the ballast tap to see that it matches the correct line voltage. Many HID ballasts are designed for more than one line voltage. Refer to the manufacturer's specifications to find the designated OCV.
6. If the temperature is abnormally low, the OCV required for starting must be higher. You will need a ballast rated for low-temperature starting.
7. If part of a twin-fixture is operated from a series ballast, the lamps will be series-connected. If either one burns out, the second cannot function.

8. If the line voltage is correct and it is connected to the correct voltage tap of the ballast, it should produce an acceptable OCV. If the OCV is 10% below that listed for the ballast, replace the ballast.
9. Moisture absorbed by insulation can cause ballast failure. Using a 500 V megger, check the insulation levels between the leads and the casing. This should produce a reading of one megohm or higher.
10. Check capacitors for shorts or open circuits. A shorted capacitor may have caused permanent damage to the ballast that cannot be repaired by replacing the capacitor.

Always ensure the lamp is screwed in snugly, but do not over tighten it. Look for evidence of overheating and check for any loose connections.

Now do Self-Test 11 and check your answers.

Self-Test 11

1. Assuming the supply voltage is present, what is the first thing you would normally do if an HID lamp fails to light?

2. When checking the voltage at the lamp socket of a metal halide fixture with the lamp removed, what precaution should be observed with a multimeter?

3. If the voltage at the lamp socket is less than _____ % of the required OCV, the ballast should be replaced.

4. The OCV at a metal halide lamp socket with a new luminaire is 175 V, which is 100 V less than the OCV required for starting the lamp. What is one likely cause?

5. What should the minimum insulation resistance be between the ballast windings and metal frame?

6. In a twin-lamp fixture, what may happen if one of the lamps fails?

7. A HID lamp may not come on if the ambient temperature is exceptionally low. What is the reason, and how may the problem be resolved?

8. Why might a voltmeter be damaged if it is connected across the terminals of an HPS lamp socket with the lamp removed?

9. A capacitor from an HID ballast has its terminals connected across the leads of a multimeter set on the ohms selector switch. If the capacitor is good, how should the instrument respond?

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 12:

Describe basic applications and operation of LED lighting

An LED (light-emitting diode) is an electro-chemical light source. When the diode is forward-biased, light is generated. The light is monochromatic; the colour depends on the materials used in the construction of the LED. LEDs have been around since the 1960s, but LED lighting has just recently begun to appear in the residential, commercial and industrial markets for lighting applications.

There has been much pressure in recent years for the major lamp manufacturers to develop replacement LED lamps for all other lighting types and applications. The challenge has been to try to maintain a similar overall lamp shape and base type where possible for ease of retrofitting, and to avoid the need for fixture manufacturers to have to develop new fixtures to accommodate them. In addition to meeting or exceeding replaced lamp lumen outputs, they must also meet current minimum energy ratings required by building codes and utilities, CRI ratings, reliability requirements and price points. Manufacturers have risen to the challenge and LED lighting is now a viable replacement alternative for most other lighting types.

Efficacy

The efficacy of LED sources is improving continuously; for white LEDs, efficacy, currently ranges from about 75 to 150 lumens per watt, depending on the manufacturer.

Life

Lamp lumen depreciation in a light source is the gradual reduction in light output over time, caused by normal deterioration of phosphors, cathodes, filaments and the other components of the system. LED systems last up to 50 000 hours, based on the fact that when the light output has depreciated to less than 50% of initial output, then the light source has effectively expired. The life of LED systems depends on a number of factors, including the colour; red and green LEDs last significantly longer than blue and white LEDs.

White light LEDs

White LEDs could previously only be created by grouping red, green and blue LEDs and by controlling the current to each to yield an overall white light. This changed with the development of a blue indium gallium chip with a phosphor coating that is used to create the wave shift necessary to emit white light from a single diode. The LED segment of the market is growing and is believed to be the technology of the future for lighting; efficient, long-life white light LEDs in convenient packages, such as a medium screw base lamp module, could replace traditional incandescent lamps.

Advantages of LED lighting

- LEDs have low power consumption.
- LEDs have negligible early installation failures.
- LEDs are resistant to damage from shock and vibration. There is no glass or filament to break.

- LEDs are fully dimmable.
- LEDs are available in all colours.
- LEDs are cool when operating. The efficiency of the semiconductor allows for the production of light without wasted heat.
- LEDs are extra low-voltage devices that require fewer materials and precautions during and after installation.
- LED lighting devices light the surfaces and areas that are required to be illuminated-excess, unwanted light does not bleed off into the environment.
- LED lights deliver directed light for increased system efficiency.
- LED lights have no moving parts, no toxic gases and no filament to burn, break or fail. There's nothing to break, rupture, shatter or leak. There are no dangerous materials to contaminate the environment.
- LED lighting devices are easily mounted or installed in just about any location. Small size allows them to be used in areas not easily accessible, allowing for the optimal illumination of the desired area(s).
- LEDs have an extremely long service life (50 000 hours or more).
- LEDs are instant ON/OFF in their operation.
- LEDs work well in cold weather from –40°C to 185°C.
- LEDs have *an acceptable* Color Rendering Index (CRI) The CRI is widely used to measure how accurately a lighting source renders the color of objects compared to sunlight which is a CRI of 100 most LEDs have a CRI of around 70, which might not be acceptable for widespread use in lighting, particularly indoors.

Disadvantages of LED lighting

- LEDs are currently more expensive than more conventional lighting technologies due to the high cost of manufacturing; there is a limited number of LED fixture manufacturers.
- LEDs are very heat-sensitive. Excessive heat or inappropriate applications dramatically reduce both light output and lifespan.
- LEDs typically cast light in one direction at a narrow angle compared to incandescent or fluorescent lamps, so lenses or reflectors are needed in fixtures to broaden the beam (if desired).

Applications of LED lighting

- Typically used in exposed-source applications such as signage, decorative festive lighting, marketing displays, automotive applications and:
  - Traffic signal lamps
  - Exit signs
  - Road lights
  - Security lighting
  - Seasonal light strings
  - Task and reading lamps
  - Linear strip lighting (under kitchen cabinets)
  - Recessed lighting
  - Porch/outdoor/landscaping lighting
  - Art lighting
  - Night lights
  - Stair and walkway lighting
  - Pendants and overhead
  - Retrofit bulbs for lamps

Figure 1—Typical retrofit LED bulbs for residential applications

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Image provided courtesy of LED Roadway Lighting Ltd. This image may not be used or reproduced without written permission from LED Roadway Lighting Ltd.

Figure 2—LED street Light

Now do Self-Test 12 and check your answers.

Self-Test 12

1. What type of light source is LED lighting?

2. What is the approximate efficacy of LED lighting.

3. List four advantages of LED lighting.

4. List three disadvantages of LED lighting.

5. List four applications for LED lighting.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Learning Task 13:

Describe basic applications and operation of induction lighting

Induction lamps were actually introduced in Europe by Philips, in 1990. Although it is one of the best technologies developed in recent years, many distributors in the lighting industry are still not familiar with the product. The basic technology used in induction lighting relies on the fundamental principles of gas discharge and electromagnetic induction to produce light.

Basic principle of operation

Induced current in the lamp bulb

An electronically controlled high-frequency generator supplies the energy through a power coupler to a primary induction coil inside the induction lamp. The secondary coil of the induction system is represented by the low -pressure gas and metal mercury vapour inside the lamp bulb as shown in Figure 1.

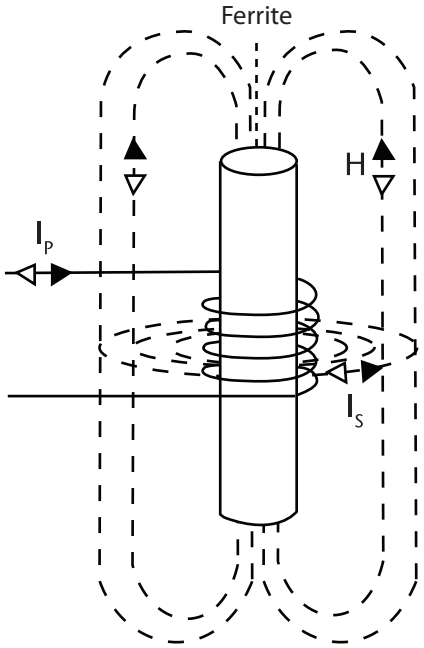


Figure 1—Induction principle

The induced current causes the acceleration of charged particles in the metal mercury vapour. These particles collide, resulting in excitation and ionization of the metal mercury vapour. This produces ultraviolet radiation, which collides with the phosphor coating on the bulb and produces visible light, as shown in Figure 2.

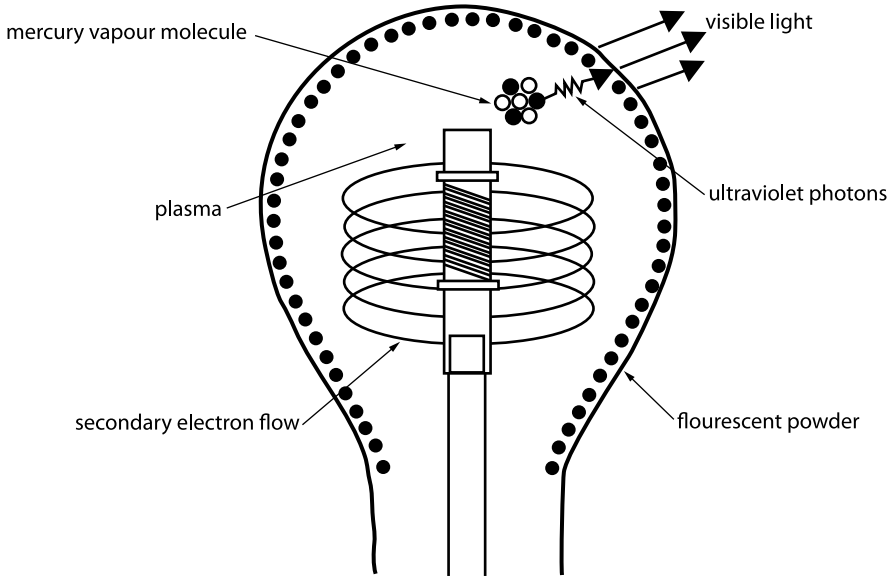


Figure 2—Discharge principle in the QL lamp bulb
Courtesy of Philips Lighting

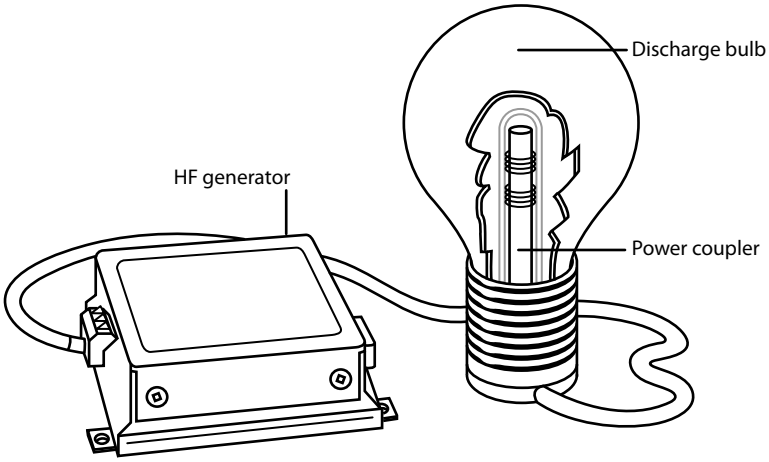


Figure 3—Components of an induction lighting system
Courtesy of Philips Lighting

Efficacy

The typical efficacy of induction lamps is 65 to 70 lumens per watt.

Long lifetime

The long lifetime of the induction lighting system is due to the fact there are no filaments or electrodes as in conventional lamps. The lamp relies on the fundamental principles of gas discharge and electromagnetic induction to produce light. The result of this is a lamp with an unmatched lifespan of 100 000 hours or 25 years. This system can last longer than 100 incandescent, 5 HID or 5 typical fluorescent lamp changes.

Advantages

- Ultra-long life – 100 000 hours rated life based on 50% survival rate
- White light, excellent colour rendering (80+ CRI)
- High reliability – instant start when cold and restarting when hot
- Extremely low maintenance requirement
- No flickering
- Light output is not significantly affected by ambient temperature change
- Vibration-resistant
- Low operating temperature of the components
- No stroboscopic effect with rotating machinery
- No noise

Disadvantages

- At present the cost of the initial system is high.
- Life of the ballast determines the life of the system.
- Proprietary, so parts are not interchangeable between manufacturers.
- Requires special sockets and electronic control equipment.

Applications of induction lighting

- Highway signs, street signs
- Airports, railroads
- Parking lot and garage lighting
- Roadway lighting
- High bay lighting (maximum 6 m [20 feet]
- Indoor lighting for manufacturing and industrial plants
- Security lighting
- Hard-to-reach areas
- Lobbies and front entrances
- Hazardous areas

Now do Self-Test 13 and check your answers.

Self-Test 13

1. What type of light source is induction lighting?

2. What is the approximate efficacy of induction lighting?

3. List four advantages of induction lighting.

4. List three disadvantages of induction lighting.

5. List four applications for induction lighting.

Go to the Answer Key at the end of the Learning Guide to check your answers.

Answer Key

Self-Test 1

1. a. retina
   b. iris
   c. pupil
   d. lens
2. size, brightness, contrast, time
3. time
4. good quantity and quality of light

Self-Test 2

1. ultraviolet
2. prism
3. d. yellow-green
4. wavelength
5. lumens
6. lux
7. lumens to watts
8. a. incandescent
9. d. high-pressure sodium
10. photometer (or light meter)
11. a. The inverse square law states that the luminous flux density (illumination) is inversely proportional to the distance away from the light source; for example, moving twice as far away reduces the luminous flux density to ¼ of previous.
    b. The cosine law states that the luminous flux density (illumination) varies as the cosine of the angle to the normal (straight line) direction of light.
12. one billionth of a metre

Self-Test 3

1. quantity, quality
2. Any three of:
   - Area and type of environment
   - Type of task
   - Architectural/decorative requirements
   - Installation costs
   - Maintenance
3. - Glare
   - Diffusion of light
   - Colour of light
4. - Blue
   - Green
5. luminaire
6. the pattern of light distribution for a particular type of luminaire (light source)
7. CRI and light level
8. HID (high-intensity discharge)
9. lamp lumen depreciation; luminaire dirt depreciation
10. to minimize disruption and labour costs
11. a. The percentage of total lumens emitted by the luminaire compared to the total lumens generated by the lamp alone.
    b. The percentage of the initial lamp lumens that actually reach the task area for lighting.
12. - Direct = The majority of light (90% to 100%) is distributed downward.
    - Indirect = The majority of light (90% to 100%) is directed upward.

Self-Test 4

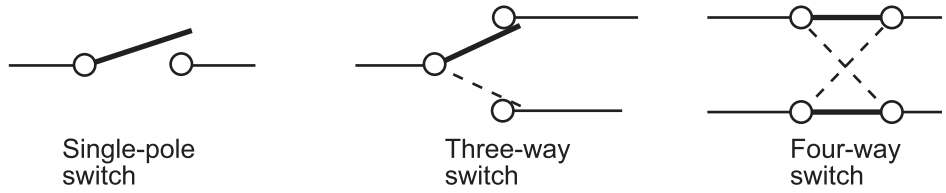
1. Electric current flows through a filament and heats it to incandescence.
2. 90% heat and 10% light
3. c. very inefficient
4. Argon and nitrogen are used to extend lamp life.
5. The letter G indicates the lamp is globular in shape. The 25 indicates that the diameter is 3⅛". $25 \times ⅛ = 3⅛$

6. c. In the manufacturer's catalogue
7. tungsten
8. to deflect heat from the base area, where it may loosen the cement
9. b. diffuse
10. It helps to prevent glare.
11. d. 3500°C
12. Other colours are absorbed by the glass or glass covering and only the green light is let out.
13. screw type or Edison base
14. a. mogul: high-wattage lamps
    b. prefocus: projector lamps
    c. three-contact: trilight lamps
15. higher, shorter
16. Evaporation of the filament reduces the filament diameter to the breaking point. End of life occurs when the filament finally breaks.
17. b. with the base up
18. Tungsten evaporating from the filament sticks to the inside of the glass bulb and blocks a percentage of the light emissions.
19. a. one 150 W
20. 12 V
21. quartz-halogen or quartz-iodine
22. the evaporated tungsten from the filament combining with the halogen gas and then being re-deposited on the filament
23. The regenerative halogen cycle prevents bulb wall blackening. Wall blackening reduces light output. For this reason, lumen maintenance is much higher in a tungsten-halogen incandescent lamp than in a standard incandescent lamp.
24. c. 2500 hours
25. high melting temperature
26. because of the possibility of the lamp shattering at normal end of life, causing personal injury or fire
27. white
28. Reduced temperature may prevent the regenerative cycle action.
29. premature glass breakage and/or glass discolouration

30. Severe burns will result if skin contact is made with glass. Also, this protects against electric shock.
31. multi-faceted reflector, 16/8ths inch or 2-inch diameter
32. Use ceramic lampholders. Do not locate above door swing in bathrooms.

Self-Test 5

1.



2. two three-way switches and three four-way switches
3. The light will operate, but the lampholder will have a 120 V live conductor at one terminal even though the switch is in the OFF position.
4. OFF. Check the operating handle for correct mounting. It will have either a dot (raised indentation) on the operating handle, or an ON/OFF designation.
5. ON
6. a. three wires

   b. four wires
7. 600 W
8. No
9. Oversized cooling fin covers prohibit ganging.
10. HED, or high efficacy dimmers
11. 24 V
12. The design of the relay allows the plunger to latch on, momentarily energizing the coil. If the switch was a maintained contact, the coil of the relay would be energized, needlessly resulting in a waste of energy and reduced coil life.
13. • Additional switches can be easily connected, allowing the lamp to be controlled from several different locations.
    • Low voltage at the switches enhances safety.
14. This arrangement ensures that the lights will come on between different time settings, typically coming on in the evening and going off in the morning. The photocell keeps the lights off if the evening or morning is particularly bright.
15. A switch would be limited to controlling a relatively low-wattage load. The contactor could control a large bank of lights.

Self-Test 6

1. Electrons from the cathodes strike the mercury atoms, producing UV energy. The UV energy is converted to visible light by the phosphor coating on the inner surface of the lamp glass.
2. by varying the composition of the phosphor powder
3. It produces sufficient striking voltage to initiate the arc and it acts as a choke to control the magnitude of the current.
4. 1 inch (8 × ⅛" = 1")
5. as direct replacements for incandescent lamps
6. integrated and non-integrated
7. higher efficacy (meaning more lumens per watt) and longer rated life
8. bipin, single-pin, recessed double-contact
9. b. 10 000 hours
10. excessive ballast temperature
11. loudest
12. low temperature
13. to avoid damaging the ballast
14. standard, high output, super-high-output
15. standard, 430 mA
16. F stands for fluorescent, 40 for 40 watts, T for tubular shaped, and 12 for the diameter, which is 12 × ⅛" = 1½". RS stands for rapid-start lamp, and WW for warm white colour.
17. 3.6 V
18. 256 V
19. 104 V
20. black lamp, sun lamp, germicidal lamp
21. c. save energy with only slightly reduced light output
22. slimline
23. slimline
24. The efficacy of an LPS lamp is much higher than the efficacy of a fluorescent.
25. pure yellow
26. poor

Self-Test 7

1. • Preheat
   • Instant-start
   • Rapid-start
2. rapid-start
3. • Large
   • Heavy ballasts
   • High striking voltage and reduced lamp life
4. preheat
5. preheat
6. preheat
7. A safety switch is incorporated into one of the lampholder sockets to reduce the risk of electric shock. The switch is a spring-loaded lampholder arrangement that keeps the circuit de-energized until the lamp is fully inserted in the lampholder sockets.
8. preheating of cathodes; a grounded metal strip that runs the length of the lamp
9. The capacitor improves the fixture's power factor.
10. to provide a high striking voltage across each tube in turn
11. They depend upon occupancy patterns and occupant energy awareness.
12. photosensor
13. automatic disconnection or reduction of designated loads

Self-Test 8

1. Substitute good parts to see if they correct the problem.
2. excessive hum, and possible overheating due to poor heat transfer
3. • Reduced light output
   • Reduced lamp life
   • Reduced ballast life
4. to avoid shortening ballast life
5. cathode emission, tube nearing end of life, defective ballast, mercury accumulation
6. excessive ballast temperature
7. It may not start or it may be slow in starting.
8. c. lamps require proper seasoning

9. b. The lamps start slowly.
10. absence of supply voltage

Self-Test 9

1. • Mercury vapour
   • Metal halide
   • High-pressure sodium
2. visible
3. mercury vapour
4. • Industrial installations
   • Commercial installations
   • Roadway lighting
   • Sports lighting
5. d. in any position
6. It adds more red to the colour spectrum.
7. mercury vapour and metal halide
8. metal halide
9. high-pressure sodium
10. No, pulse start ballasts are also required.
11. high-pressure sodium
12. Mercury vapour has the longest, metal halide has the shortest.
13. Switch off the lamp and replace it. Harmful ultraviolet radiation is released by operating the broken lamp.
14. time delays on starting and restarting
15. metal halide
16. BT = bulged tubular, which is the lamp's shape. The figure 37 indicates the maximum diameter of the bulb in eighths of an inch: diameter = 37 × ⅛" = 4⅝".
17. The diameter and length increase as the wattage increases.

18. MH stands for metal halide, 175 for 175-watt lamp, and WDX for warm white deluxe.
19. BU indicates the lamp should be installed base-up and BD indicates the lamp should be installed base-down.

Self-Test 10

1. reactor ballast
2. They provide high OCV and limit current flow.
3. high-pressure sodium lamp
4. auto-regulator ballast
5. to improve the power factor
6. to allow for more than one supply voltage
7. reactor ballast
8. It regulates the current better and can withstand higher voltage dips without extinguishing the lamp.
9. It is cheaper and smaller.
10. reactor and autotransformer ballasts
11. the current and lamp wattage
12. • Lead-lag
    • Series
13. Linear dimming does not result in linear energy savings. Also, if dimmed too low the arc will extinguish and have to restrike.
14. an integral halogen lamp and a photocell
15. In low mode, the arc is maintained but current is limited by the ballast. In high mode, the lamp operates normally.

Self-Test 11

1. Try a new lamp or one that is known to be good.
2. Initially set the voltmeter to its highest range.
3. 90
4. The supply voltage is connected to the wrong ballast tap.
5. 1 megohm (106 W)
6. The second lamp won't light either if it is the series-connected type.
7. The lamp requires a higher OCV. A cold-weather ballast that gives out a higher OCV is required.

8. The lamp gets high-voltage spikes when starting and these spikes can damage the meter.
9. The pointer should initially deflect to a low ohmic value and then gradually move back to a higher ohmic value.

Self-Test 12

1. An LED (light-emitting diode) is an electro-chemical light source. When the diode is forward-biased, light is generated.
2. The efficacy of LED sources is about 75–150 lumens per watt.
3. Any of the following:
   - LEDs have low power consumption.
   - LEDs have negligible early installation failures.
   - LEDs are resistant to damage from shock and vibration. There is no glass or filament to break.
   - LEDs are fully dimmable.
   - LEDs are available in all colours.
   - LEDs are cool when operating. The efficiency of the semiconductor allows for the production of light without wasted heat.
   - LEDs are low-voltage devices that require fewer materials and precautions during and after installation.
   - LED lighting devices light the surfaces and areas that are required to be illuminated-excess, directed light for increased system efficiency.
   - LED lights have no moving parts, no toxic gases and no filament to burn, break or fail. There's nothing to break, rupture, shatter or leak. There are no dangerous materials to contaminate the environment.
   - LED lighting devices are easily mounted or installed in just about any location. Small size allows them to be used in areas not easily accessible, allowing for the optimal illumination of the desired area(s).
   - LEDs have an extremely long service life (50 000 hours or more).
   - LEDs are instant ON/OFF in their operation.
   - LEDs work well in cold weather from –40°C to 185°C.
4. Any of the following:
   - LEDs are currently more expensive than more conventional lighting technologies due to the high cost of manufacturing; there is a limited number of LED fixture manufacturers.

- LEDs are very heat-sensitive. Excessive heat or inappropriate applications dramatically reduce both light output and lifespan.
- LEDs typically cast light in one direction at a narrow angle compared to incandescent or fluorescent lamps, so lenses or reflectors are needed in fixtures to broaden the beam (if desired).
- LEDs have a low colour rendering index (CRI). The CRI is widely used to measure how accurately a lighting source renders the colour of objects compared to sunlight, which is a CRI of 100. Most LEDs have a CRI of around 70, which might not be acceptable for widespread use in lighting, particularly indoors.

5. Any of the following:
   - Traffic signal lamps
   - Exit signs
   - Road lights
   - Security lighting
   - Seasonal light strings
   - Task and reading lamps
   - Linear strip lighting (under kitchen cabinets)
   - Recessed lighting
   - Porch/outdoor/landscaping lighting
   - Art lighting
   - Night lights
   - Stair and walkway lighting
   - Pendants and overhead
   - Retrofit bulbs for lamps

Self-Test 13

1. The basic technology used in induction lighting relies on the fundamental principles of gas discharge and electromagnetic induction to produce light.
2. The typical efficacy of induction lamps is 65 to 70 lumens per watt.
3. Any of the following:
   - Ultra-long life – 100 000 hours rated life based on 50% survival rate
   - White light, excellent colour rendering (80+ CRI)

- High reliability – instant start when cold and restarting when hot
- Extremely low maintenance requirement
- No flickering
- Light output is not significantly affected by ambient temperature change
- Vibration-resistant
- Low operating temperature of the components
- No stroboscopic effect with rotating machinery
- No noise

4. Any of the following:
   - At present the cost of the initial system is high.
   - Life of the ballast determines the life of the system.
   - Proprietary, so parts are not interchangeable between manufacturers.
   - Requires special sockets and electronic control equipment.
5. Any of the following:
   - Highway signs, street signs
   - Airports, railroads
   - Parking lot and garage lighting
   - Roadway lighting
   - High bay lighting (maximum 6 m [20 feet]
   - Indoor lighting for manufacturing and industrial plants
   - Security lighting
   - Hard-to-reach areas
   - Lobbies and front entrances
   - Hazardous areas

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