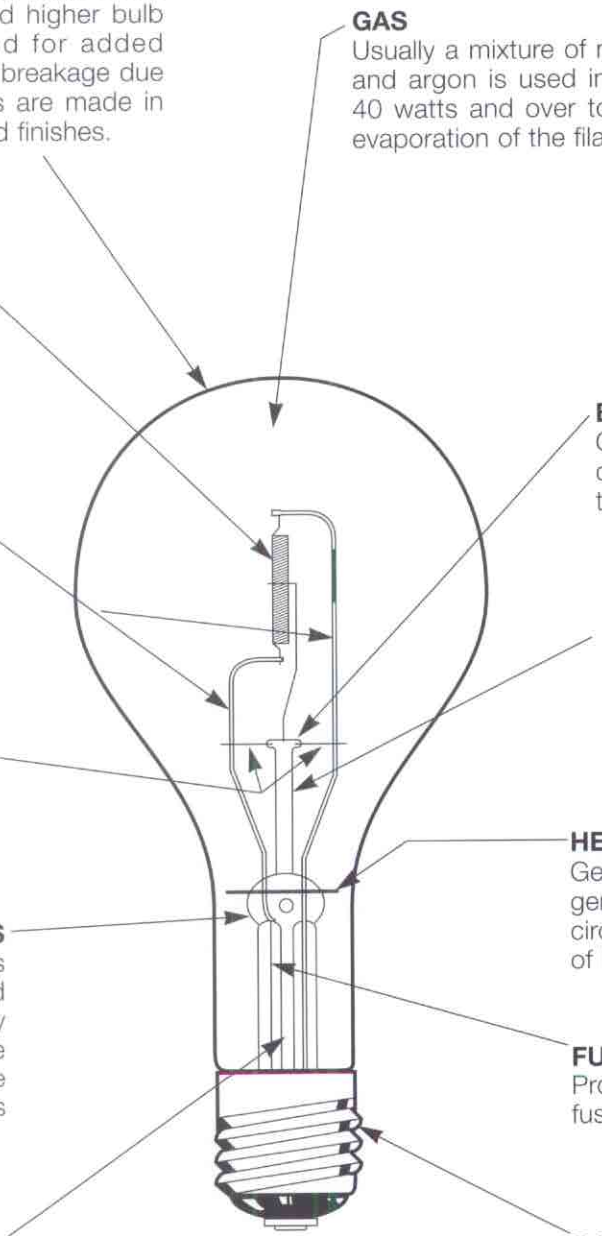

Figure 1. Typical Incandescent Lamp

INCANDESCENT LAMPS

The typical incandescent lamp consists of a conductive filament sealed within a light-transmitting bulb that is either evacuated or filled with an inert gas. Lead-in wires from the ends of the filament pass through a glass seal so that the filament may be connected to a source of electricity. The filament is heated by the electrical power supplied to it and emits electromagnetic energy. If the electrical power is sufficient to raise the filament temperature above approximately 850K, the filament becomes incandescent, i.e., it glows. Technically, above 850K the filament emits sufficient electromagnetic energy in the visible region of the spectrum (380-770nm) to be seen by its own emission. The amount of light produced by incandescence increases with higher temperature, although the life of the filament is reduced. One fundamental problem of incandescent lamp design is achieving high light output while retaining reasonable life. Figure 1 depicts a typical incandescent lamp and its component parts.

Edison's first successful incandescent lamp employed a filament of carbon, which has a higher melting point (3823°K) than any other element. These filaments, however, cannot be operated at temperatures high enough to obtain desirable efficacies (lumens per watt) without rapid evaporation of the carbon. The evaporating filament causes bulb blackening, early filament failure and, thus, greatly shortened lamp life. The efficacy of the carbon filament lamp was limited to the low value of 1.4 lumens per watt (LPW). The efficacy of incandescent lamps was gradually improved through the use of new filament configurations and materials, such as osmium and tantalum. Tungsten, however, replaced all previous filament materials after 1911 when a practical drawing process was perfected.

The first tungsten filament lamps were vacuum lamps which achieved efficacies of 10 LPW. The introduction of coiled filaments and inert gases (1913) permitted efficacies of 14 LPW. Subsequent developments have resulted in efficacies up to 23 LPW in large commercial types and up to 35 LPW in short-life photographic lamps. The value of 35 LPW is the practical upper limit set by losses within the lamp and the melting point of tungsten.

Tungsten Filaments

Tungsten has the lowest vapor pressure at elevated temperatures and the highest melting point (3655K) of all metals. This combination of properties is desirable since low evaporation rates permit extended filament life while high filament temperatures result in high lumen outputs and efficacies (LPW). Relatively, tungsten wire has great strength and is very durable when operated near its melting point. The variation of lumen output and efficacy with filament temperature is shown in Figure 2.

FILAMENT TEMPERATURES AND EFFICACIES OF 120 VOLT INCANDESCENT LAMPS

Lamp Watts	Approx. Initial Lumens	Approx. Efficacies (LPW)	Approx. Color Temp (K)	Approx. Filament (°F)	Life (hrs)
6*	40	6.7	2370	3860	1500
10*	70	7.0	2450	3900	1500
25*	210	8.4	2550	4190	2500
40	460	11.5	2770	4470	1500
60	890	14.8	2800	4530	1000
100	1,690	16.9	2870	4670	750
150	2,780	18.5	2900	4710	750
200	3,900	19.5	2930	4760	750
300	5,850	19.5	2940	4830	750
500	10,000	20.0	2960	4840	1000
1000	23,100	23.1	3030	4980	1000
1500	33,620	22.4	3070	5010	1000

*Vacuum Lamp

Figure 2.

Filament Design

The objective in filament design is to create a light source that economically satisfies the required need. Length, diameter and shape of the filament are determined by consideration of application, watts, volts and life of the lamp. An incandescent lamp filament could be designed to burn almost forever, but only by greatly reducing efficacy (LPW). Conversely, a very short-lived filament could be designed with very high efficacies. The straight wire filament, formerly used in all lamps, requires many supports due to its long length and is employed in very few lamps today. Coiling the filament reduces heat losses and increases the efficacy. The coiled coil construction is formed by again coiling the original coiled filament as shown in Figure 3. This double coiling results in a still higher concentration of heat which leads to about a 10% increase in efficacy for the 60-watt lamp.

A design improvement, originally used in street lamps, is "axial" mounting of the filament along the lamp's vertical axis (Figure 4). In a base-up or base-down burning position, this axial mounting aligns the filament with the stream of circulating gases within the lamp. Several improvements result:

- decrease in bulb blackening
- improved lumen maintenance throughout the life of the lamp
- smaller, more compact bulb
- 6% more light in 100-watt lamps and 15% more light in 300- to 1000-watt lamps (axial-mounted coiled-coil filament)

Figure 3.

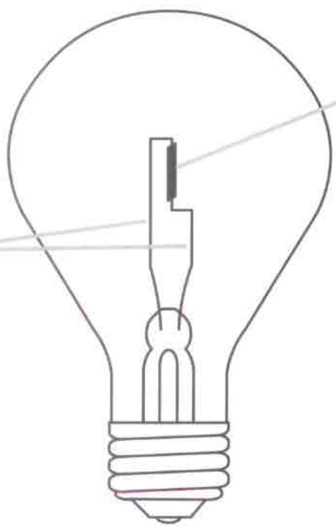

Figure 4. Axial Filament A19 Lamp

Incandescent lamps are designated with a letter to indicate the filament wire construction and an arbitrary number to identify the mount shape. The filament may be a straight wire (S), a coil (C) or a coiled coil (CC). For example, a C-9 filament is a coiled wire of Form 9. Examples of some filament configurations are shown in Figure 5. A more complete listing of filaments can be found in the Large Lamp Catalog.

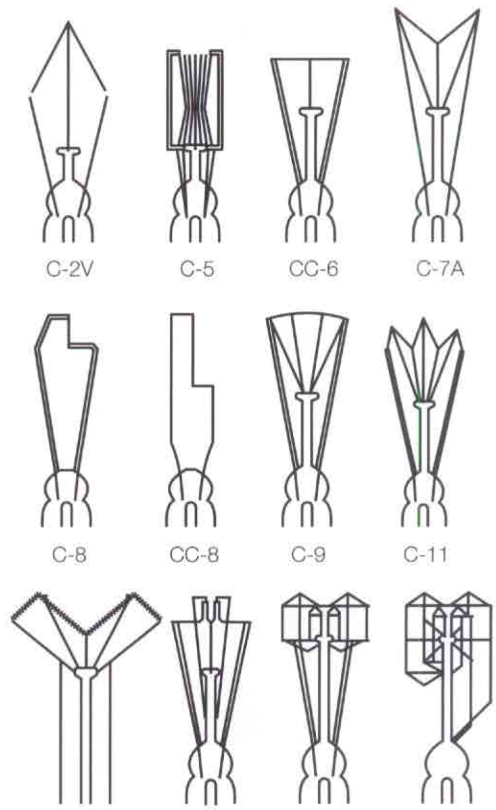

Figure 5. Incandescent Lamp Filament Configuration and Mount Design

BULBS

Bulb Shapes

Figure 6 pictures lamp bulb shapes most commonly used for OSRAM SYLVANIA incandescent lamps. When all lamps were vacuum lamps, the S shape was universal. When gas lamps were developed, however, filaments had to be moved farther from the bulbs and base. Bulb shapes are identified by letters in an easily recognizable system. The numbers following the letter(s) designate the bulb's maximum diameter in eighths of an inch. Thus, a G-30 bulb is a globe-shaped lamp with a diameter of 3 3/4 (30/8) inches. See the Large Lamp Catalog for a complete list of lamps with their bulb shapes.

PAR, ER, BR and R types of lamps are designed with a built-in reflector of pure aluminum or silver that is hermetically sealed inside the lamp. This reflector coating, in conjunction with the filament location and the finish on the bulb face, is capable of providing a variety of light-distribution patterns — from a narrow concentrated beam for spotlighting to a very wide beam for flood-lighting. Because the sealed-in reflecting surface is completely protected from dust and dirt, light output remains high throughout lamp life.

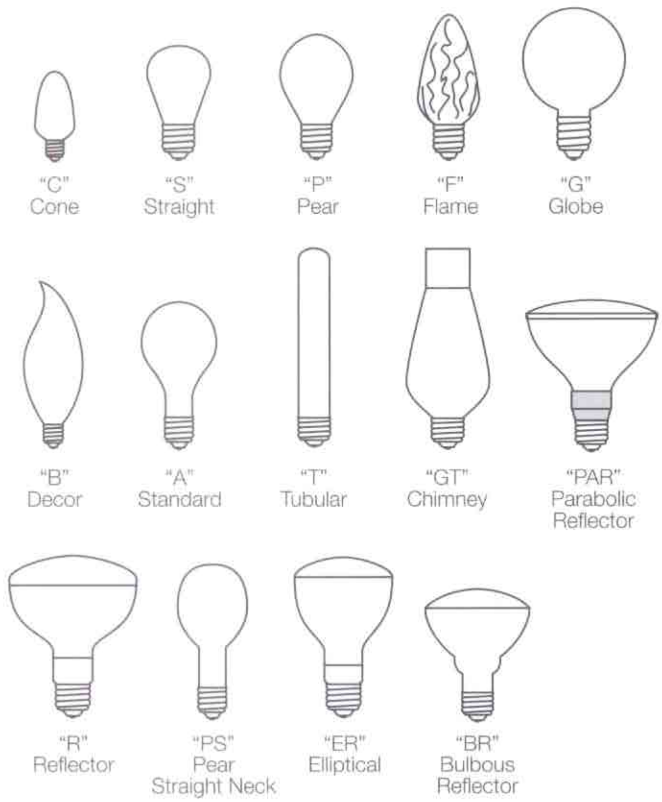

Figure 6. Lamp Bulb Shapes

APPROXIMATE MAXIMUM BARE-BULB TEMPERATURES OF STANDARD INCANDESCENT LAMPS*

Watts	Bulb	°Fahr.
20	A-19	240
40	A-19	260
60	A-19	275
100	A-19	320
150	A-23	310
200	A-23	345
300	PS-30	350
500	PS-35	375
1000	PS-52	400
1500	PS-52	475

*Bare lamp burning vertically, base up.

Figure 7.

Bulb Glass

Most lamp bulbs are made with soda lime (soft) glass which has a maximum safe-operating temperature of about 700°F (370°C). Lamp bulbs using borosilicate (hard) glass, such as projection lamps, have a maximum safe-operating temperature of 885°F (475°C). Pyrex glass bulbs, used for PAR lamps, will safely withstand temperatures up to 975°F (525°C). Hard glass is used for outdoor and smaller-bulb high-wattage lamps.

The spectral transmittance of most clear glass is high over the range from about 325nm to 2500nm, so that visible light is transmitted well but shorter-wavelength ultraviolet and longer-wavelength infrared are absorbed. Note that the spectral transmittance of fused quartz, used for most tungsten halogen bulbs, begins about 200nm, so that ultraviolet, visible and near-infrared are all transmitted well.

Other factors limiting the maximum safe-operating temperature of lamps include the breakdown temperature of the basing cement and the melting point of the solder. Figure 7 shows the maximum bare-bulb temperatures of standard incandescent lamps.

Bulb Finishes and Colors

Common bulb finishes are clear, inside frost (IF), standard coat (a light silica inside coating), soft white (a heavy silica inside coating), daylight and silver bowl. Colors are obtained by using colored glass or by applying colored coatings to the inside or outside surfaces of the bulbs.

- *Inside Frost (IF)* bulbs used to be acid etched on the inner surface to soften the light of the brilliant filament. Today Inside Frost has been replaced by standard coat.

- *Standard Coat (SC)* is an electrostatically-applied thin coating of fine silica powder. The most common of all bulb finishes, standard coat spreads the brilliant filament image and partially diffuses the light.

- *Soft White (SW)* bulbs have a heavy coating of white silica powder which provides almost perfect diffusion of the light, while reducing light output by only one to two percent.

- *Daylight* lamps produce a light that is closer to "daylight" in color by using an external blue ceramic coating which absorbs some of the red and yellow wavelengths. This results in a loss in lamp efficacy (LPW) of approximately 35%.

- *Silver bowl* lamps have a reflector coating of pure silver on the inside half of the bulb, opposite the base. Used in a base up position, almost 100% of the light from the filament goes up to the lighting fixture or ceiling.

- *Colored* lamps are available in many varieties: outside colored (ceramic and transparent), inside colored powder, dichroic and stained. Colored silicone-coated PAR and dichroic colored lens PAR lamps are excellent sources for color floodlighting and display lighting.

VACUUM AND GAS FILLED LAMPS

Previous to the introduction of gas filled lamps in 1913, all lamps were made with an evacuated bulb so that the filament operated in a vacuum with no oxygen present. When oxygen comes in contact with a burning filament, there is rapid oxidation of the tungsten, and the filament literally "burns-up." Today, vacuum lamps are designated as type B and gas-filled lamps as type C.

Many of the problems encountered in evacuated lamps are eliminated by filling the envelope with an *inert* gas of *low thermal conductivity.* Being inert, it does not react with the tungsten filament and, having low thermal conductivity, it minimizes heat losses from the filament. The inert gas greatly reduces evaporation loss of tungsten from the filament, permitting higher filament-operating temperatures and thus higher efficacies (LPW). The usual cold gas pressure is about 80% of atmospheric, rising to about atmospheric when the lamp is operating.

The fill gas now used is usually argon or argon blended with a small amount of nitrogen. The nitrogen is added to reduce the possibility of arcing between filament sections or across lead-in wires. The percentage of nitrogen depends on voltage rating, operating temperature of the filament and mechanical factors, such as filament configuration and the spacing between lead-in wires. Krypton has lower thermal conductivity than argon, so a krypton gas fill further reduces heat losses from the filament. Krypton molecules are also heavier than argon molecules, resulting in lower filament evaporation and thus increased filament life. However, krypton is much more expensive than argon, and it is used only where the increased cost is justified, such as in energy-saving, extended-service, and traffic signal lamps.

Active halogen gas, such as bromine and iodine, is used in Tungsten Halogen lamps to permit higher efficacies without the reduced life associated with high filament temperatures. Refer to the *Tungsten Halogen Engineering Bulletin 0-349* for details.

BASES

Bases provide a means for mechanically fastening lamps to their sockets and electrically conducting current from the sockets to the lamps. Lamp wattage, operating temperature and type of service are important factors in the selection of bases. Most incandescent lamps for general lighting have screw bases. These bases are usually cemented to the bulbs with cement suited to the rated operating temperature. Maximum allowable temperature for the cement is 450°F (230°C). Lamps designed for services in which the bases run extremely hot may employ "mechanical" bases that are clamped to the bulbs. Some typical bases for incandescent lamps are shown in Figure 8. For a complete list of lamps with their standard bases, see the Large Lamp Catalog.

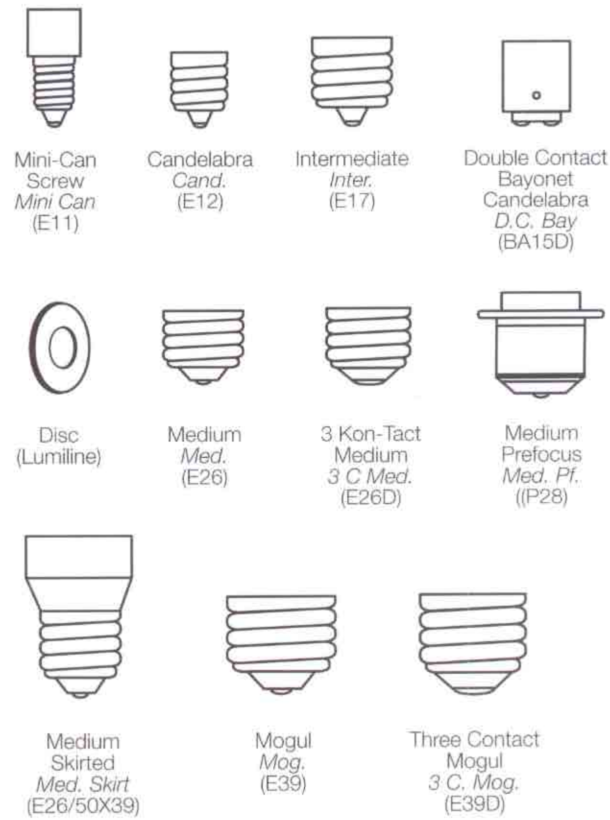

Figure 8. Typical Lamp Bases

SOME MAJOR TYPES OF INCANDESCENT LAMPS

Rough Service and Vibration Lamps

Lamps for rough service and vibration service furnish longer life in installations where standard lamps cannot withstand excessive rough treatment or vibration. Vibration service lamps are not suitable for rough service applications, and rough service lamps are not recommended for vibration service applications.

- *Rough Service* lamps are designed primarily for "high amplitude/low frequency" shocks. The lamps are built to withstand bumping, banging and rough handling, often experienced on the ends of extension cords in garages and machine shops. Rough Service filaments are carefully held in place by many supports, as shown in Figure 9. Although the extra supports add to the cost of the lamp and reduce efficacy, rough service lamps survive under shock conditions.

- *Vibration Service* lamps are intended for applications subject to "low amplitude/high frequency" vibrations like those produced by high-speed machinery or in subway stations. Standard coiled-coil tungsten filaments, used for general service incandescent lamps, have a crystal structure that resists sagging but breaks easily when continuously shaken. Vibration lamp filament wire is made with a specially blended tungsten, which is flexible, sags and will not break when subject to vibration. Since the wire is allowed to sag, more supports are necessary (Figure 10). With these extra supports, heat losses increase, so efficacy decreases. Horizontal burning is not recommended, since the coil segments are likely to sag together which then results in poor lamp life.

Because of their relatively low efficacies, neither Rough Service nor Vibration Service lamps are recommended for general lighting.

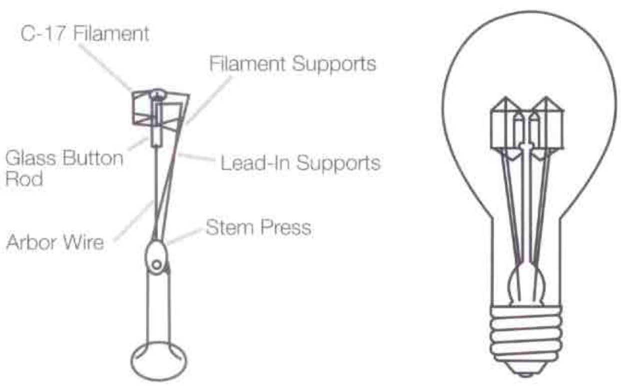

Figure 9. Typical Rough Service Lamp

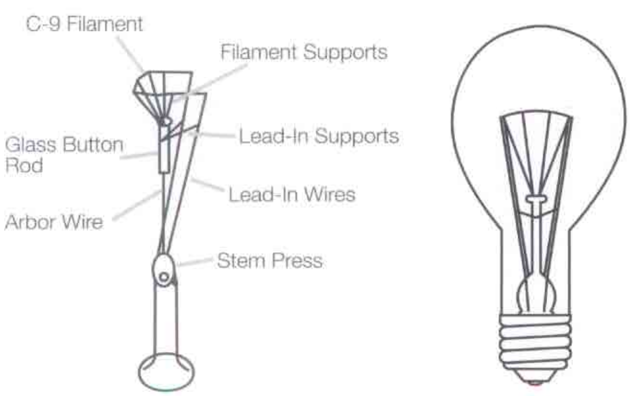

Figure 10. Typical Vibration Service Lamp

Traffic Signal Lamps

Traffic Signal lamps are subject to more severe service conditions than most standard types of incandescent lamps. Additionally, they must conform to the design requirements of normal traffic signal fixtures set forth in a series of Standards by the Institute of Transportation Engineers. The regular line of OSRAM SYLVANIA Traffic Signal lamps is complemented with energy-saving, long-life krypton-filled lamps.

Sign Lamps

Sign lamps are designed for outdoor use. Most are vacuum lamps that operate at lower bulb temperatures, which make them less susceptible to cracking when exposed to rain and snow. Other low wattage lamps are gas filled and designed for flashing signs, operating at bulb temperatures low enough for outdoor applications. Filaments of some types are rhenium doped for vibration service, and most have a plurality of filament supports. Sign lamps are available in a variety of sizes, wattages, shapes and colors.

Long Life Excel Super Saver® Lamps

Long life lamps offer extended-service life at the expense of light output and lamp efficacy. Krypton-filled Excel lamps with 2500-hour life ratings are available, but light output is approximately 15% less than that of standard 750- and 1000-hour lamps. The lamps are usually used in hard-to-get-at installations, like stairwells and high ceilings, where relamping is difficult or expensive.

Decorative Lamps

OSRAM SYLVANIA's product line includes many Decorative lamps in a variety of wattages, bases and bulb shapes. Some long-life versions, with ratings up to 4000 hours, are available. Most bases are either candelabra or medium, and typical bulb shapes include B-10, F-15, G-25, G-30 and G40. Interesting variations are B-10 "bent tip" bulbs that make the lamp look like a real flame and GT-19 bulbs that are shaped like the old-fashioned lamp chimney. In most lighting situations, a Decorative Lamp can be chosen to enhance the decor of any commercial or residential area.

Reflector Lamps

A reflector lamp has a silver or aluminum reflective coating that is vapor deposited directly onto part of the inner bulb surface. "ER", "BR" and "R" lamps are made of one-piece blown glass bulbs and used primarily indoors. A "PAR" lamp consists of two pieces of molded Pyrex glass bonded together and will withstand outdoor use. "BR" ("bulbous reflector") is an "R" lamp with an enlarged bulb in the neck of the reflector to improve lumen output. "BR", "R" and "PAR" lamps are available in a variety of colors, sizes and beam spreads. An "ER" lamp utilizes an elliptical bulb. The ellipsoidal reflector causes the reflected light beams to crossover approximately two inches in front of the lens and then broaden into a flood pattern. This lamp can, therefore, be utilized in a recessed downlight (high hat) fixture to produce a wide beam pattern with minimal glare. See the OSRAM SYLVANIA Large Lamp Catalog for a complete listing of Reflector Lamps.

Safe Line Lamps
OSRAM SYLVANIA's Safe Line and Rhino Coat™ lamps have a clear or diffusing silicone rubber coating that greatly reduces bulb breakage. On sudden impact, the bulb may break but the pieces of glass are contained. The Safe Line and Rhino Coat™ overlay also protects the heated bulb from hot or cold thermal impacts, like weld splatter or cold rain. With the tough silicone coating, Safe Line and Rhino Coat™ lamps can be used safely indoors and outdoors in all kinds of weather.

Dichroic Par Lamps
Dichroic Colored Lens. A dichroic material on a glass surface separates radiant energy into spectral bands, some of which are transmitted while the rest are reflected. Very efficient colored lamps are made by controlling the number of layers and thickness of "thin films" deposited on the lenses of PAR lamps. Five colors of 150W PAR38 Spots are available.

Dichroic Coated Reflector. Dichroic coatings are also layered on the reflector surface of Cool-Lux PAR38 lamp so that the infrared (heat) is transmitted through the back of the lamp and only the visible light is directed forward. Because about 65% of the heat is removed from the beam, Cool-Lux Dichroic Lamps are ideal for lighting groceries and heat sensitive merchandise. These lamps should only be used in fixtures which are designed to allow heat to escape. The full offering of PAR38 Dichroic Lamps is found in the Large Lamp Catalog.

Tungsten Halogen Lamps
Tungsten Halogen Lamps operate on the fundamental principles of a standard incandescent lamp, but the envelope is filled with a blend of inert and halogen gases. This gas fill within the bulb causes a regenerative "tungsten halogen cycle" that allows the filament to operate more efficiently at higher temperatures. Compared to standard incandescent lamps, Tungsten Halogen Lamps can be designed for longer life, higher efficacy, higher color temperature and better beam control. Refer to OSRAM SYLVANIA Engineering Bulletin *O-349, Tungsten Halogen Lamps,* for more information.

Complete information and data on all of the preceding major types of lamps are found in other bulletins and the Large Lamp Catalog.

OPERATING CHARACTERISTICS OF INCANDESCENT LAMPS

Spectral Power Distribution
An incandescent lamp emits only a small percentage of the total energy in the visible part of the spectrum. Most of the energy is in the infrared with a small amount in the ultraviolet. Figure 11 shows the spectral power distribution of a tungsten filament lamp operated at 3000K. As the temperature of the tungsten filament is raised, the visible emission increases more rapidly than the infrared and thus the luminous efficacy (LPW) increases. The curve of Figure 11 may be significantly altered by the spectral transmittance of the bulb material and any coatings applied to the inside or outside of the lamp.

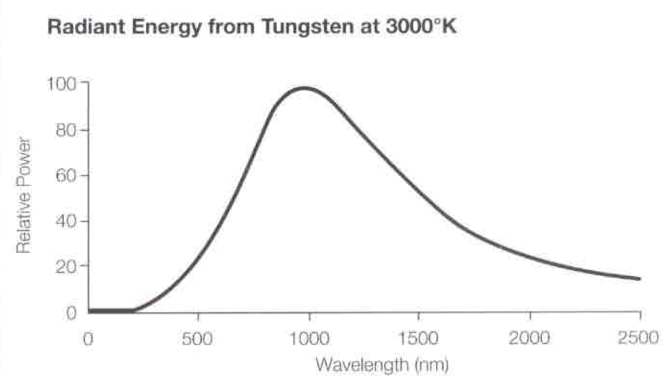

Figure 11.

Characteristics Of Operating Voltage Variation
Most consumers are aware of the importance of buying the proper wattage incandescent lamp to satisfy their lighting needs. Less familiar is the importance of operating the lamp at the design voltage to give the best combination of efficacy and life. Operating an incandescent lamp above or below rated voltage will affect the watts, lumens and life as shown in Figure 12. Increasing voltage to the lamp sets off a series of events:

1. Lamp wattage (W) consumed increases with rising current (I) and increased tungsten wire resistance (R). ($W = I^2R$). The resistance of a hot tungsten filament is about 15 times that of one at room temperature.
2. Filament temperature increases so the filament glows brighter, producing more lumens.
3. At higher filament temperatures, tungsten evaporates more quickly, so life is shortened.

Conversely, a decrease in voltage affects all the characteristics in the opposite way. Temporary line voltage fluctuations, like a momentary power surge or a "brown out" during an electrical storm, should not noticeably affect the life of the lamp.

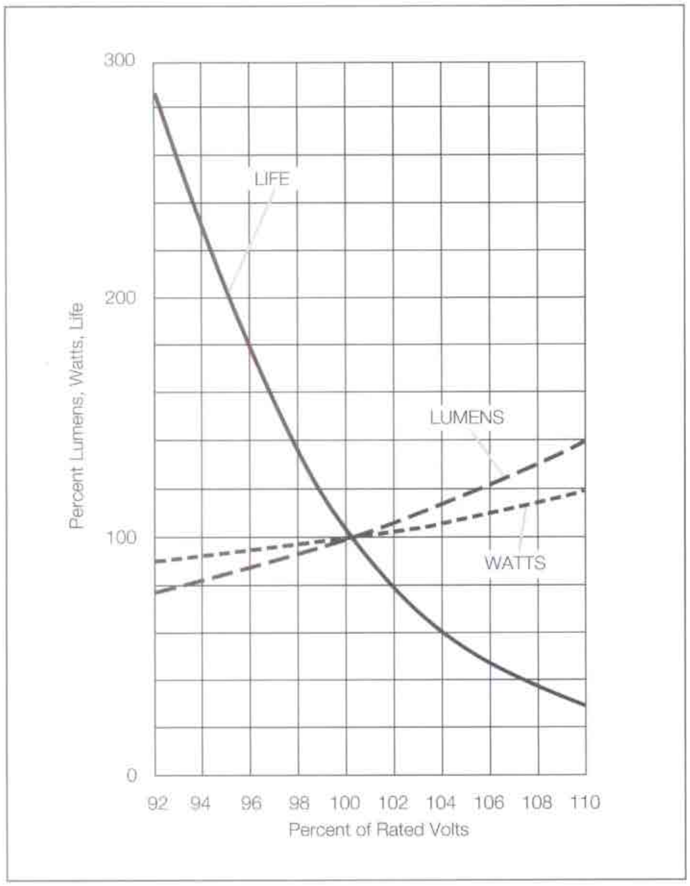

Figure 12. Approximate Incandescent Lamp Characteristics as affected by Voltage

Use of the Characteristic Curves (Figure 12)

The lamp characteristic curves of Figure 12 are in a "Percent of Rated ..." format rather than absolute values so that the chart can be a guide for all incandescent lamps. Be aware that the curves represent an average of many lamps and that the characteristics of individual lamps may vary. In general, however, life and lumen values at various input voltages can be determined by following the six steps below.

Example: What is the light output of a 60 watt, 120 volt lamp when operated at 125 volts?

1. The voltage under consideration should be divided by the rated voltage of the lamp to give "Percent Rated Volts," which in our case leads to:

   125/120 x 100 = 104%

2. The next step is to determine what percentage of rated lumens we should expect from a lamp which is operating at 104% rated volts. This is done by locating 104% on the "Percent Rated Volts" scale, at the bottom of the chart, and then following a vertical line up to the curve marked "Lumens". At the junction of the vertical line and the curve, a horizontal line should be followed to the left across to the "Percent Lumens" scale. The result will be in "Percent of Rated Lumens," which in our case is 116%.
3. Look up, in the Large Lamp Catalog, the rated light output for the lamp under consideration. For a 60 watt standard 120 volt lamp, the rated light output is 890 average lumens.
4. Multiply the rated lumens by the "Percent of Rated Lumens" figured in step 2 to determine the approximate light output. For this example:

   890 average lumens x 116% = 1032 lumens

   Thus, we can expect approximately 1032 lumens from a 60 watt 120 volt lamp when operated at 125 volts.
5. In a like manner, a horizontal line may be carried across from the point where the 104% initial vertical line meets the curve marked "Life". This horizontal line will intersect the scale marked "Percent of Rated Life" at 58%. Since the normal rated life of a 60 watt lamp is 1000 hours, we may expect 58% or approximately 580 hours of life when the lamp is operated at 125 volts.
6. From the junction of the 104% vertical line and the "Watts" curve, a horizontal line drawn to the left intersects the "Percent Watts" axis at 107%. Thus, at 125 volts the lamp will consume approximately 60 x 107% = 64.2 watts.

Lamp Mortality

Because of slight variations in lamp materials and manufacturing operations, lifetimes of individual lamps differ. Rated life, therefore, is the average life of a large group of lamps, defined as:

At the end of *rated life,* approximately 50% of the lamps in the large group will have burned-out and 50% will remain burning.

Figure 13 pictures the Incandescent Life Expectancy Curve.

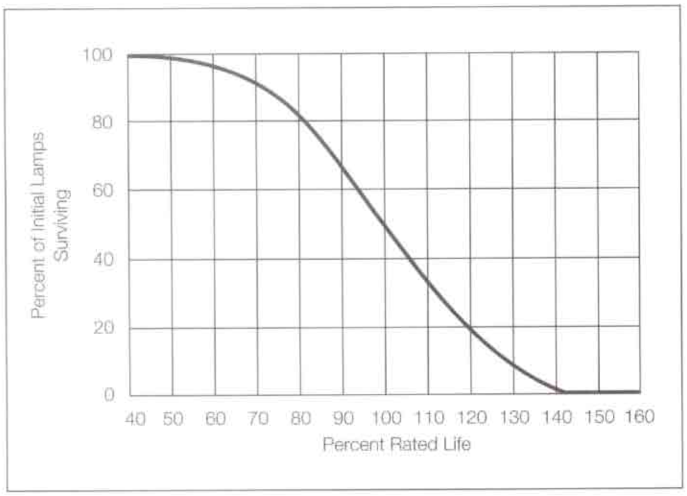

Figure 13. Range of Typical Mortality or Life Expectancy Curves for Incandescent Lamps

Group Relamping

Lamps in a lighting system can be either individually replaced as they burn out or replaced as a group at one time. The life expectancy curve in Figure 14 shows that, within a group of similar lamps with the same burn times, the failure rate will increase as the burn time passes 70% of the rated life of the group. By scheduling group relamping between 70% and 85% of rated life, substantial labor savings may be realized. Lamp and labor costs for each installation should be considered to determine the most economical relamping schedule.

Bulb Blackening

Bulb blackening is the deposition of tungsten particles on the inner bulb surface caused by normal evaporation of the filament. In a vacuum lamp, the blackening occurs rather evenly over the entire inside of the bulb. In a gas filled lamp, the convection currents set-up by the hot gas carry the particles upward to be deposited on the bowl when the lamp is burning base down or on the neck when the lamp is burning base up. An active material called a "getter" is applied to some lamps during manufacturing to reduce residual gas pressure and clean up the atmosphere when the lamp is first lighted. In vacuum lamps, the "getter" material generally causes a slight yellow appearance on the inner bulb surface and minimizes blackening throughout life.

Water Cycle

The "water cycle" may be another factor in lamp life depreciation. The glass and metal inside the lamp may contain absorbed hydrogen and oxygen which are liberated during initial operation. The water vapor which is formed contacts the filament, dissociates, and then forms mobile tungsten oxide molecules, which are deposited on the cooler bulb surface. Here, the tungsten oxide is reduced by the hydrogen, leaving the metallic tungsten on the bulb wall and creating water vapor molecules that are again free to repeat this degeneration process.

Also, in the presence of minute quantities of water, tungsten is removed from the hottest area of the filament and deposited, through the gas phase, to nearby cooler areas of the filament. This causes the hot area to get hotter and leads to early lamp failure. Water cycle effects are greatly reduced by the use of "getters," described above, which combine with oxygen and water vapor that may be liberated during initial operation.

Notching

Notching is the formation of sharp irregularities on the filament surface during operation. The effect is more pronounced with a DC power supply. For small diameter filament wire (0.001 inch), like that used on miniature lamps, the notches may be an appreciable fraction of wire diameter. This causes hot spots and localized reduction in strength, which leads to early failures. Thus, lamps with a very fine filament wire operated on DC may have a life of one half or less than that obtained on AC operation.