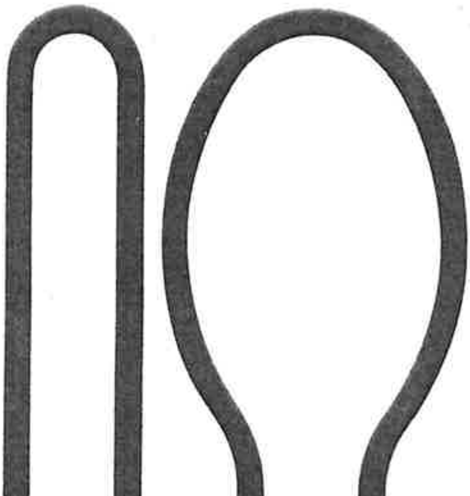
SYLVANIA



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"SOLARARC" HIGH PRESSURE SODIUM LAMPS

PRINCIPLES OF OPERATION

It had been known for many years that operating a sodium discharge at high pressure could provide a lamp of high efficacy and good colour quality. However, complex technological problems had to be overcome. Space research and developments in lamp construction have recently made it possible to produce High Pressure Sodium Lamps in practice.

Low Pressure Sodium Lamp operating characteristics are carefully chosen to ensure optimum resonance radiation ('D' Line). The resulting yellow-coloured light characteristic of Low Pressure Sodium Lamps is almost monochromatic and stems from a double line at a wavelength of 589 nm and 589.6 nm. The low pressure sodium radiation is shown in Fig. 1.

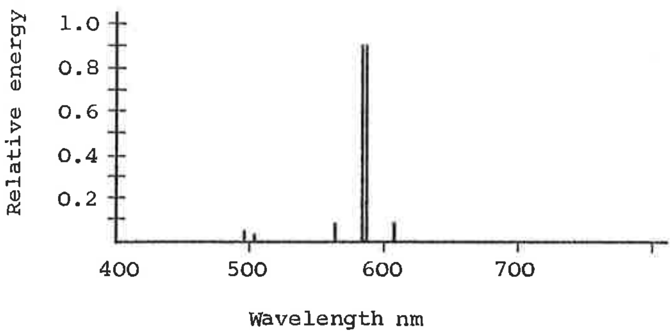
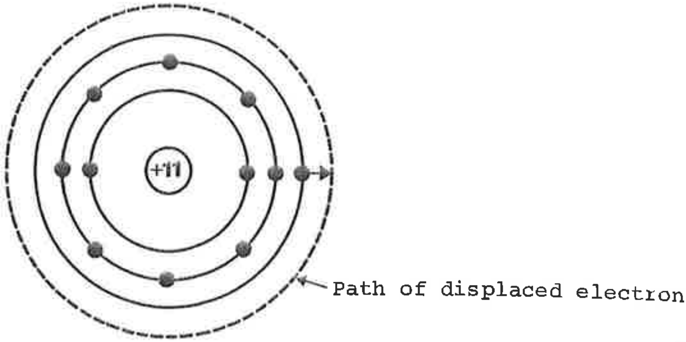
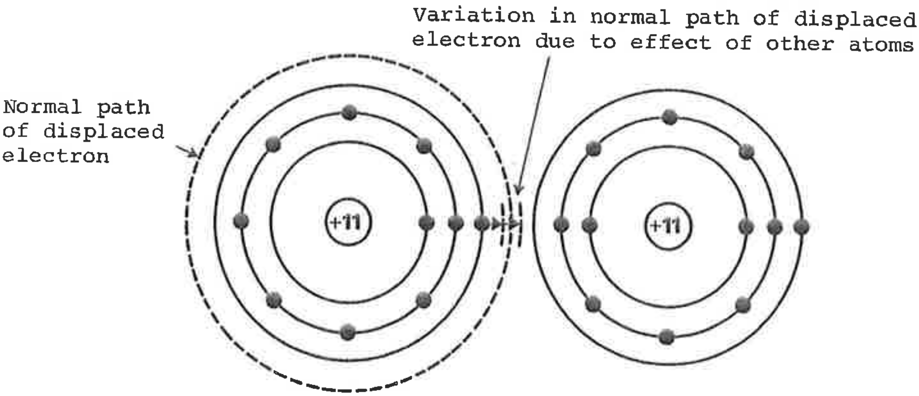


Fig. 1 Spectral Energy Distribution of Low Pressure Sodium Discharge



(a) Excited Atom in Low Pressure Sodium Lamp



(b) Excited Atoms in High Pressure Sodium Lamp

Fig. 2

Low Pressure Sodium Lamps are operated at a vapour pressure of 1/152.000 of an atmosphere. At this pressure the resonance radiation is generated at high efficacy. An important aspect of resonance radiation is that it is readily absorbed by neutral atoms. The number of neutral atoms present in the discharge depends largely upon the vapour pressure. Close control of this pressure is, therefore, critical; any rise would result in most of the radiation being absorbed.

In High Pressure Sodium Lamps, as the vapour pressure increases, other secondary processes become operative. As illustrated in Fig. 2 the density of sodium atoms rises to a point where individual atoms cease to have independent electrical fields. Some electrons in excited atoms are unable to assume their correct excited state owing to the effect of nuclei in close proximity. The radiation from these electrons comprises of wavelengths varying from the resonance radiation by amounts depending upon the sodium vapour pressure.

The broadening of the 'D' Line which occurs as a result of this process is shown in Fig. 3 a). This radiation is subsequently absorbed by other sodium atoms and then re-radiated in other wavelengths which depend upon the vapour pressure. The total radiation which results covers a wide spectral band over the range of visible wavelengths. The development of the spectral energy distribution in a high pressure sodium discharge is shown in Fig. 3 b).

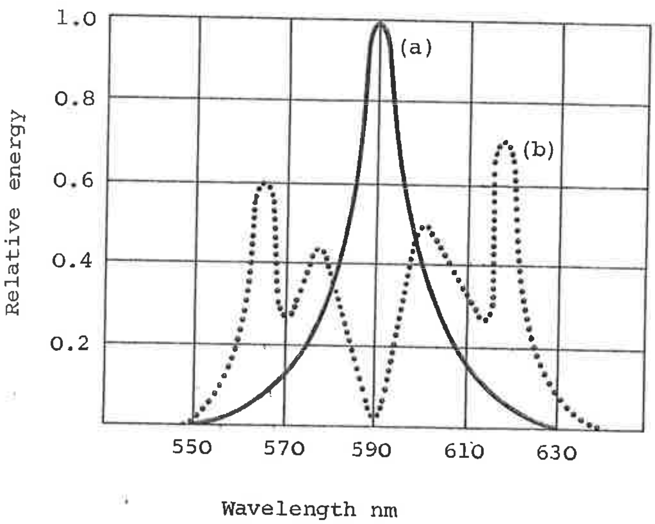


Fig. 3 Development of Spectral Energy Distribution in High Pressure Sodium Discharge

LAMP TECHNOLOGY

Sodium vapour at high pressure and temperature is so corrosive that conventional arc tube materials, such as glass or quartz (fused silica), are very rapidly attacked and rendered unuseable. The successful development of High Pressure Sodium Lamps was, therefore, contingent on the development of entirely new lamp-making materials. In addition to being resistant to the chemical attacks of sodium, an arc tube material with minimum visible radiation absorption properties and suitability in lamp-manufacturing processes was required.

In the event, scientists working on space projects developed a high-purity aluminium oxide ceramic which met these requirements, making possible in practice the operation of a sodium discharge at high pressure.

The number of neutral atoms and, therefore, absorption losses are limited to the minimum by keeping the bore of the ceramic arc tube small. As a result, the tube wall and the very hot central core of the sodium discharge are in close proximity, raising the arc tube temperature to some 1300°C.

For optimum efficacy, the voltage gradient along the arc tube is kept at around 10 volts per centimetre.

Typically, the electrical characteristics of a lamp with sodium content only would have low arc voltage and high current features, calling for undesirably large and costly control gear. This is effectively counteracted by adding a controlled amount of mercury to the discharge, which raises the arc voltage and reduces the current to a level where economical control gear can be used. In addition, the presence of mercury in the discharge has a beneficial effect on lamp run-up characteristics and colour.

To maintain stable lamp operating characteristics, the vapour pressure of the sodium-mercury amalgam must be very accurately controlled. This is effectively achieved by inserting an excess amount of amalgam into the arc tube and locating the cold spot at a point where its temperature corresponds to a sodium vapour pressure of some 250 mm above that of the amalgam. The temperature of the arc tube is highest at the centre and decreases towards the seals, to the point where it interacts with the heat conducted away by the electrode. This point is the cold spot of the arc tube, which in Sylvania SOLARARC Lamps is opposite the centre of the electrode. The actual positioning of the cold spot is controlled by the design features of the electrode.

The temperature of the cold spot is critical to within a few degrees centigrade and to maintain the optimum value, the arc tube is mounted inside an evacuated outer jacket.

LAMP CONSTRUCTION

Arc Tube

The need for advanced arc tube materials, able to withstand the severe chemical attacks of sodium at high pressure, is described in "Lamp Technology". The aluminium oxide ceramic used in SOLARARC High Pressure Sodium Lamps is in polycrystalline form, each crystal having a diameter of about 30 microns. Individual crystals act as refractors with the effect that the arc tube is slightly diffusive. The transmission of visible radiation is as high as 93%.

The arc tube has a diameter of about 10 mm, with a wall thickness of around 0.75 mm. This results in a mechanically strong tube, well-suited to withstand the thermal stresses caused by the heating and cooling cycles of the lamp.

Electrodes

The electrodes located at each end of the arc tube provide the electrical connections and electron emission required for the discharge. The construction of these electrodes is of considerable importance, as it affects the life of the lamp. In SOLARARC Lamps, a tungsten rod core is surrounded by tungsten coils in which an emissive compound is embedded.

Seals

A major technological factor affecting lamp life and lumen maintenance is the construction of the seals positioning the electrodes at the ends of the arc tube.

Unlike the glass or quartz commonly used in lamp manufacturing, the aluminium oxide ceramic material used for the arc tube in High Pressure Sodium Lamps has a very narrow viscous range between the solid and the liquid states. When heated sufficiently, the ceramic rapidly changes from solid to liquid (rather like the change from ice to water), destroying the structure of the alumina crystals in the process. This renders the ceramic liable to attack by the metal vapour in the discharge and leads to cracking of the arc tube. The conventional lamp manufacturing technique of heating and pressing the discharge tube ends to form seals is, therefore, impracticable and a new process had to be developed.

The construction of the seals in Sylvania SOLARARC Lamps is shown in Fig. 4.

Niobium, one of the few refractory metals with a coefficient of thermal expansion similar to that of the alumina ceramic, is being utilized. The electrode is brazed to a niobium tube, through which the arc tube is later exhausted. The niobium tube, in turn, is brazed to a niobium disc whose particular "top hat" shape protects the seal from "arc back" on starting. Brazing, in preference to spot welding, ensures a secure bond between the metal components.

The electrode and niobium end disc seal assembly is then attached to the ceramic arc tube by means of a specially-developed metal braze which, when heated, firmly bonds the disc to the ceramic. The alloy is resistant to attack by

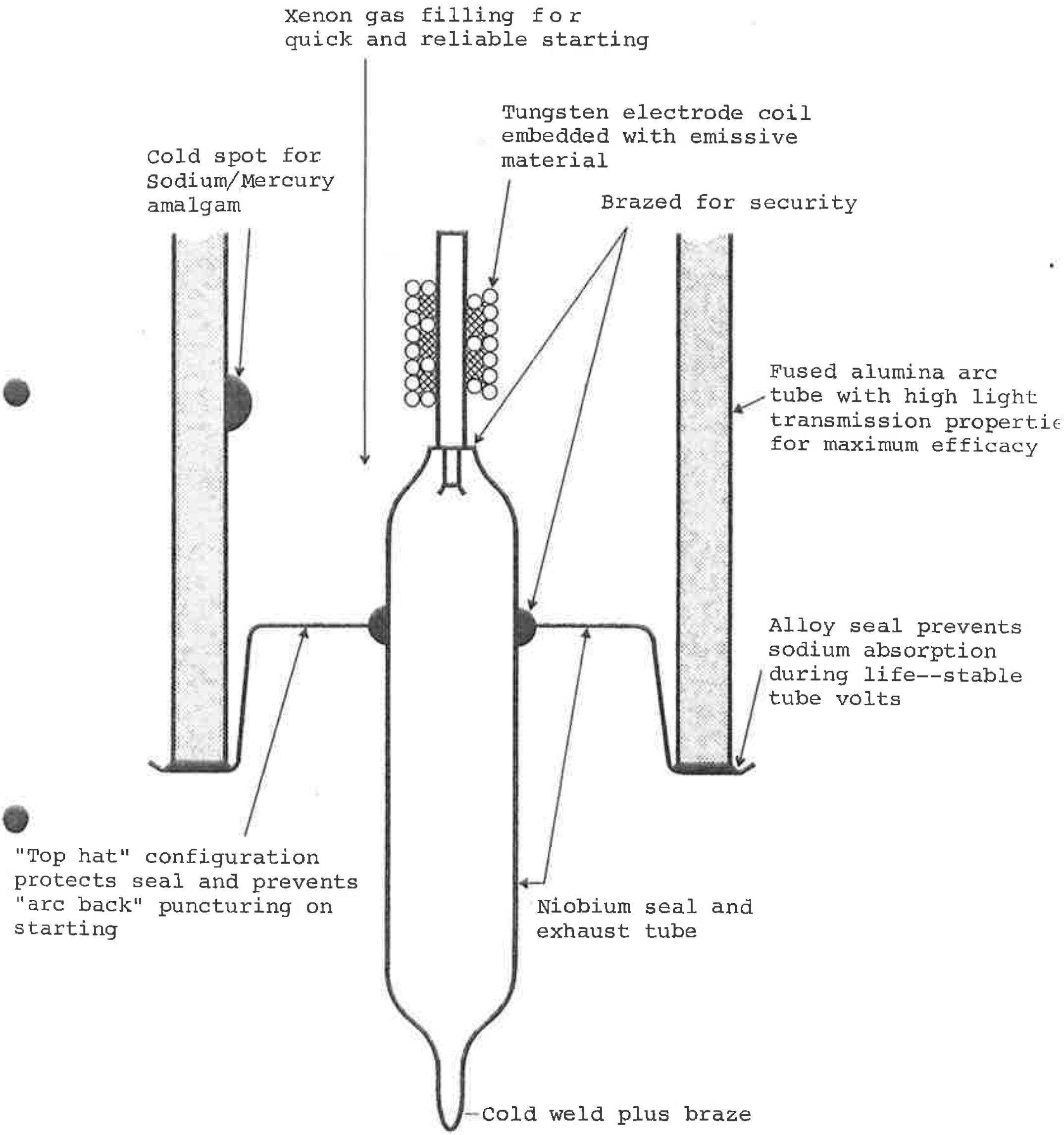


Fig. 4 Section of Seal and Electrode Construction

sodium and mercury vapour. It does not absorb sodium during the life of the lamp, assisting in the stabilization of the arc voltage.

The niobium exhaust tube is mechanically closed after processing and then welded and brazed to form a permanent gas-tight seal.

Gas Filling

In addition to the sodium-mercury amalgam filling described in "Lamp Technology", a quantity of xenon gas at low pressure is introduced into the arc tube to facilitate lamp starting. The pressure of the xenon gas is critical in ensuring optimum lamp performance. It must be low enough to permit an arc to be struck at the voltage available, but sufficiently high to prevent an arc from striking from any point other than the emissive material on the electrode.

Assembly Frame

The assembly frame holds and optically aligns the arc tube within the outer bulb of the lamp. Its strength can significantly affect the overall life of a lamp, as a mechanical failure may render it inoperative. In Sylvania SOLARARC Lamps, special attention has been paid to the design of a sturdy frame which in itself will withstand the shocks and vibrations often encountered in lighting installations and which will avoid the transfer of vibrations to the arc tube.

As illustrated in Fig. 5, the frame takes the form of a complete rectangle. At one end, a metal clip interlocks with an indentation in the outer glass bulb of the lamp, providing mechanical strength and ensuring accurate optical alignment of the arc tube. The arc tube itself is firmly held in place by a rigid support. At the other end, any effects of vibration are absorbed by a floating support and flexible braid connection. The frame is nickel-plated for good light reflection and the number of welded connections is kept to a minimum.

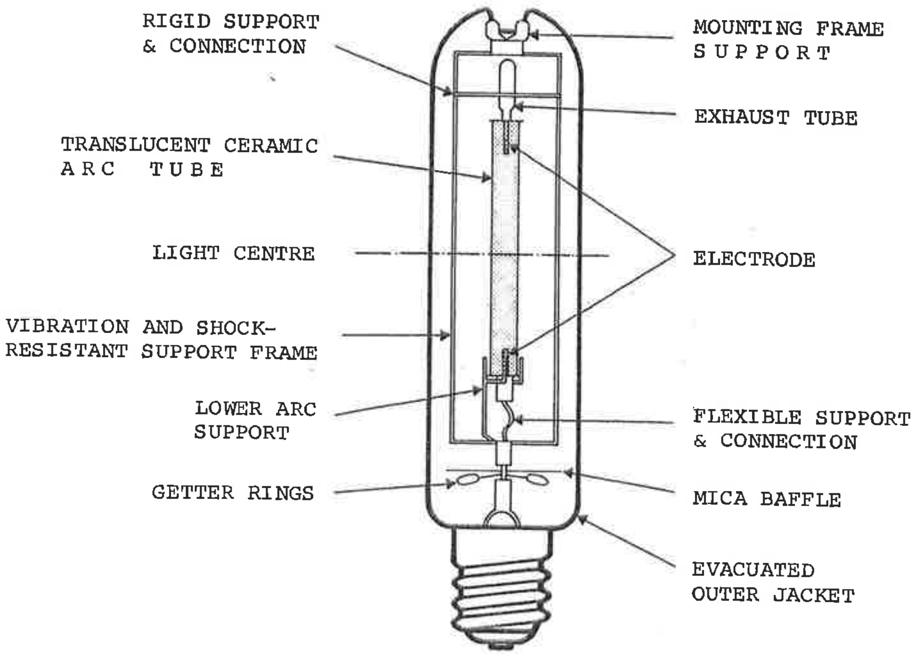


Fig. 5 Construction of SOLARARC Lamp

Outer Bulb

To obtain maximum light output from a High Pressure Sodium Lamp, the arc tube must be maintained at optimum temperature. This is effectively achieved by mounting the arc tube inside an evacuated outer bulb. These bulbs come in a variety of shapes and finishes and are described in "Lamp Types".

The material used for outer bulbs is borosilicate glass, which is resistant to thermal shock. This prevents burning lamps from being shattered if splashed with water.

Cap

Sylvania SOLARARC Lamps are fitted with Goliath Edison Screw Caps (E40). To eliminate the risk of corrosion, which might occur in arduous operating conditions, the caps are nickel-plated. This ensures easy lamp removal from the holder, after thousands of burning hours.

Getter

The maintenance of a high vacuum within the outer bulb is of great importance to optimum lamp performance. Any gases released from the bulb, arc tube or metal components during the life of the lamp could adversely affect its operation and must be absorbed by the getter. The dark film on the inner surface of the outer bulb, just above the cap, is a layer of barium which removes any contamination of the lamp atmosphere.

LAMP TYPES

Ellipsoidal Lamps with Diffusing Finish - 250W and 400W

The ellipsoidal version is a general purpose lamp, primarily for use in fittings with conventional optical systems. The outer bulb has a diffusing internal coating of titania which makes the lamp optically compatible with mercury lamps. Frequently used in streetlighting installations, ellipsoidal lamps are equally suitable for industrial and commercial lighting (Fig. 6).

Clear Tubular Lamps - 250W and 400W

The compact linear light source of the tubular lamp lends itself to accurate optical control. The small dimensions of the arc tube favour the design of relatively small and economical fittings. Incorporated in fittings specifically designed for linear light sources, they are often used for floodlighting, in high-bay industrial installations and streetlighting (Fig. 7).

Reflector Lamps - 250W

The deterioration in levels of illumination in many industrial installations due to dust or soot settling on the lamps and fittings has been overcome by the use of a specially-shaped outer bulb, with an internal reflective coating (Fig. 8).

Fig. 6 Ellipsoidal Diffusing Lamp

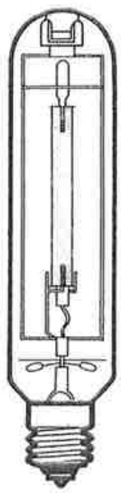


Fig. 7 Clear Tubular Lamp

Fig. 8 Reflector Lamp

APPLICATIONS

The excellent colour rendering properties of Sylvania SOLARARC Lamps and their favourable operating economics make them suitable for most types of lighting installations, such as:-

-- Motorway and Streetlighting

-- Shopping Area and Pedestrian Precinct Lighting

-- High Mast Lighting of Multi-road Intersections

-- Area Floodlighting (Car Parks, Railway Yards, Docks, etc.)

-- Building Site Lighting

-- Floodlighting of Buildings (Churches, Hotels, Castles, Monuments, etc.)

-- Football Stadium Floodlighting

-- Indoor Sports Arena Lighting

-- Interior Lighting of Churches, Railway Stations, Airports, etc.

-- Industrial Lighting

-- Commercial Lighting

-- Cold Store Lighting.

ILLUMINATION CHARACTERISTICS

Light Output and Efficacy

One of the most important advantages of SOLARARC Lamps is their very high light output and efficacy. The 400W clear tubular lamp delivers 47,000 lumens at an efficacy of 118 lm/W. The light outputs and efficacies of the range of SOLARARC Lamps are given in the following table. These figures are measured after 100 burning hours, when the lamps are fully stabilized.

Overall efficacy figures, considering not only the lamp wattage but also the small loss incurred in the ballast, are shown as well. These values should be considered typical only, as the actual ballast losses vary with their design features.

Light Output and Efficacy

Lamp Wattage	Bulb Finish	Efficacy Lumens/Watt Lamp Only	Efficacy Lumens/Watt Lamp & Gear	Light Output Lumens
250	Clear	102.0	92.0	25,500
250	Diffused	92.0	83.0	23,000
250	Reflector	86.0	77.5	21,500
400	Clear	117.5	106.0	47,000
400	Diffused	107.5	97.0	43,000

Spectral Energy Distribution

The spectral energy distribution curve, Fig. 9, illustrates the broad range of the spectrum covered by the radiations produced in the SOLARARC discharge, resulting in the pleasant golden white colour characteristic of SOLARARC Lamps.

The percentage luminosity of SOLARARC Lamps, in eight wavelength bands covering the visible spectrum, are shown in the following table.

Percent Luminosity

Band nm	380-420	420-440	440-460	460-510	510-560	560-610	610-660	660-670
%	0.0002	0.026	0.090	2.3	11.4	72.8	13.0	0.38

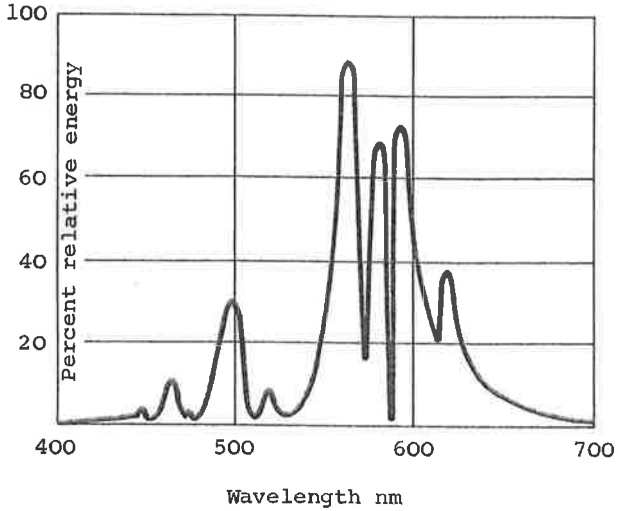


Fig. 9 Typical Spectral Energy Distribution Curve

CIE Chromaticity

The chromaticity coordinates of SOLARARC Lamps are about:-

x = .526 y = .418

Colour Temperature

The colour temperature of SOLARARC Lamps is approximately 2100^{o}K.

Lumen Maintenance

The variations in light output during the life of SOLARARC Lamps are shown in Fig. 10.

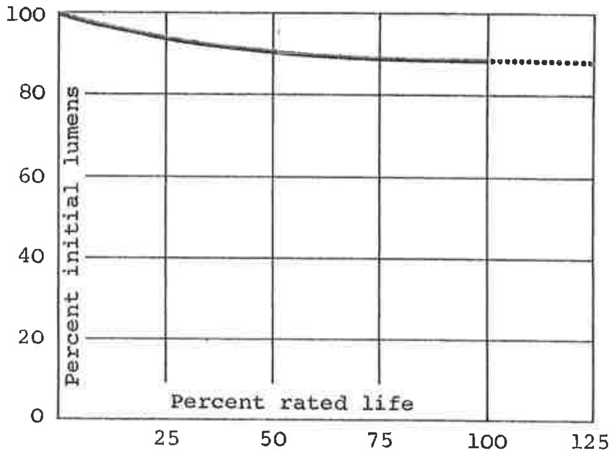


Fig. 10 Typical Lumen Maintenance Curve

Lighting Design Lumens

For the purposes of designing lighting schemes, the inherent fall in light output of the lamps during their life should be anticipated by basing calculations on an average lumen value. For SOLARARC Lamps, this "Lighting Design Lumen Output" rating, measured after 2,000 hours, and the equivalent efficacies of lamps alone and combined with typical control gear are given in the following table.

Lighting Design Lumens and Efficacy

Lamp Wattage	Bulb Finish	Efficacy Lamp Only	Lumens/Watt Lamp & Gear	Light Output Lumens
250	Clear	98.0	88.0	24,500
250	Diffused	88.0	79.0	22,000
250	Reflector	82.0	74.0	20,500
400	Clear	112.5	101.5	45,000
400	Diffused	102.5	92.0	41,000

Polar Distribution

The SOLARARC Reflector Lamp gives a closely-controlled polar distribution, similar to that of a standard lamp with a reflector fitting. The light distribution and comparative intensity of a 250W SOLARARC Reflector and a 400W Mercury Reflector are shown in Fig. 11.

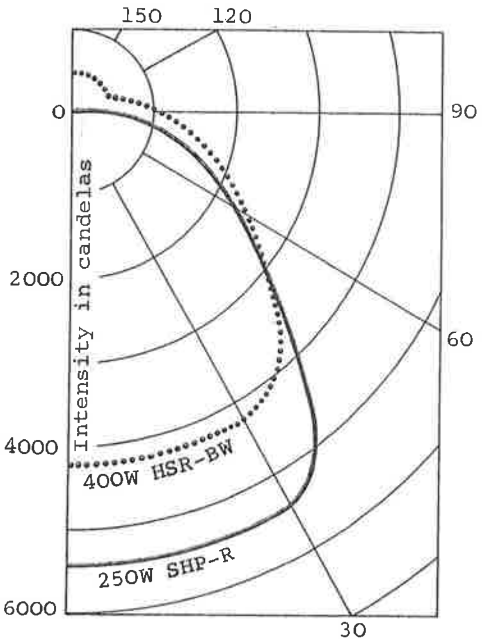


Fig. 11 Polar Intensity Curve

ELECTRICAL CHARACTERISTICS

Reference Data

SOLARARC Lamps of the same wattage have identical electrical characteristics. Typical reference data are listed in the following table. Starting current measurements are taken some ten seconds after the striking of the arc. The performance indicated refers to lamps operating in conjunction with suitable reference control gear, including power factor correction, installed in typical fittings.

Reference Data

Lamp Wattage	Voltage nom	Mains Starting Current Amps	Mains Running Current Amps	Arc Tube Voltage	Arc Tube Starting Current Amps	Arc Tube Running Current Amps
250	220	2.0	1.5	100 ± 15	3.6	3.0
400	220	3.6	2.4	105 ± 15	6.0	4.45

Interchangeability

To safeguard the user's right of choice, Sylvania SOLARARC Lamps incorporate design characteristics which make them interchangeable with other leading European manufacturers' High Pressure Sodium Lamps.

Starting Characteristics

SOLARARC Lamps are cold-started and require a voltage to the order of 1000V to initiate an arc. No starting aids, such as auxiliary cathodes or electrode preheating are incorporated. The normal mains voltage is not sufficiently high to start a lamp and an external device which generates pulses of sufficient voltage and energy is employed to strike the initial arc. This device is described in "Electronic Starters". Once a lamp has been started, the mains supply is adequate to maintain the arc.

During run-up, several changes in the colour of the light can be observed. Initially, there is a very dim, bluish-white glow produced by the ionized xenon. This is quickly replaced by a typical blue, brighter, mercury light. With the increase in brightness, there is a change to monochromatic yellow, which is characteristic of sodium at low pressure and temperature. As the pressure in the arc tube increases, the lamp comes to full brightness with a golden white light. SOLARARC lamps deliver an acceptable light output within two minutes from striking and 80% within four minutes. During this period, the arc tube voltage rises while the tube current diminishes. Typical starting characteristics are illustrated in Fig. 12.

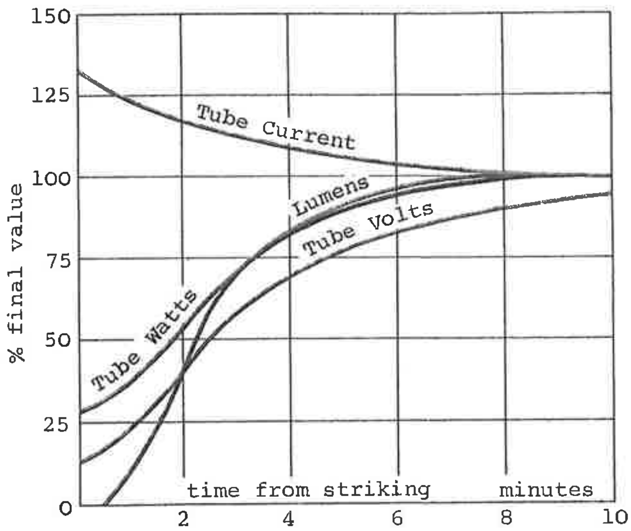


Fig. 12 Typical Starting Characteristics

Re-Starting

If switched off, SOLARARC Lamps cool rapidly and the internal pressure is quickly reduced to a level at which the arc strikes again. After a momentary interruption, the re-strike time is less than one minute.

OPERATING CONDITIONS

Lamp Life

Consistent with the advanced technology and design principles involved, Sylvania SOLARARC Lamps have extended average operating lives. The shape of the life expectancy curve is shown in Fig. 13.

Ultimate lamp failure usually results from de-activation. Actual lamp life depends on many factors, such as external circuit components and operating conditions.

The average rated life is the point at which some 50% of a large group of lamps, tested under controlled laboratory conditions, remain burning.

Low Temperature

Low ambient temperature conditions have no adverse effect on SOLARARC Lamps. The lamps are very suitable for cold store conditions where the temperatures may be as low as -40°C.

High Temperature

Provided the ambient temperature in which SOLARARC Lamps are operated is not over 100°C, the performance of the lamps will not be materially affected.

Lamp operation may, however, be influenced by heat re-radiated back from the fitting. This aspect is described under "Fittings".

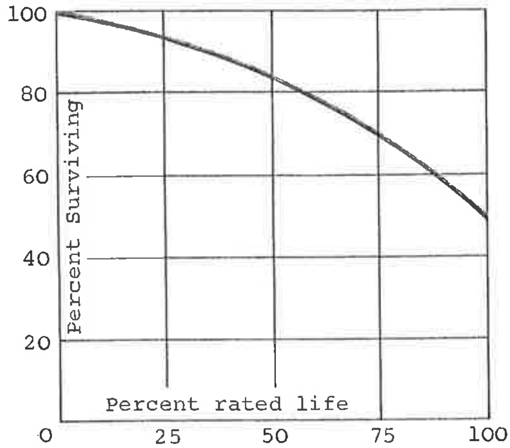


Fig. 13 Typical Life Characteristics

Voltage Variation

SOLARARC Lamps are designed for operation on the standard European supply voltages in the 220-240V range. Mains voltages below 220V nominal are not suitable, but the lamps will function within the normal variations of this figure and will usually accept a drop of 40V provided the actual voltage does not fall below 200V.

High mains voltage conditions exceeding normal variations may cause a lamp to "overwatt" and eventually extinguish. It is important that control gear tappings are adjusted to the actual mains voltage.

The effect on lamp characteristics caused by small variations in mains voltage is shown in Fig. 14.

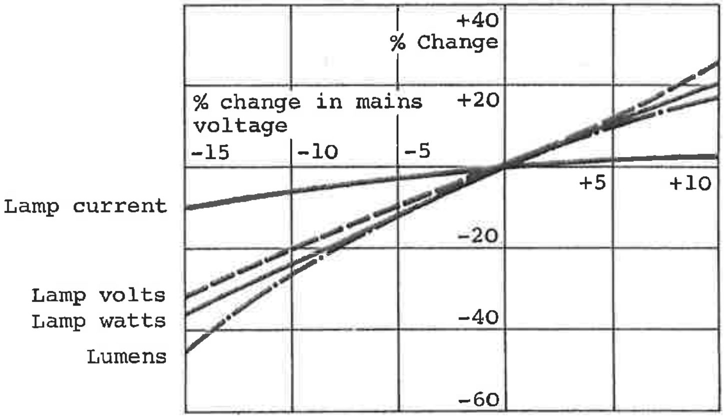


Fig. 14 Effect of Mains Voltage Variations

Vibration

The mechanical design of the frame assembly and arc tube support is the key to SOLARARC's extraordinary capability to operate in arduous conditions of vibration. Flexible leads at one end of the arc tube prevent vibrations from being transmitted to the tube.

Sodium from the niobium tube reservoir, which is located in the arc tube end furthest away from the lamp cap, must not be allowed to get into the arc stream. This could conceivably occur in conditions of exceptional vibration unless prevented by operating the lamps in the cap up position.

Operating Position

Generally, SOLARARC Lamps may be operated in any position. However, as a precaution against sodium from the reservoir entering the arc stream, operation in the positions indicated in the clear portion of the drawing in Fig. 15 is recommended, unless freedom from vibration can be assured.

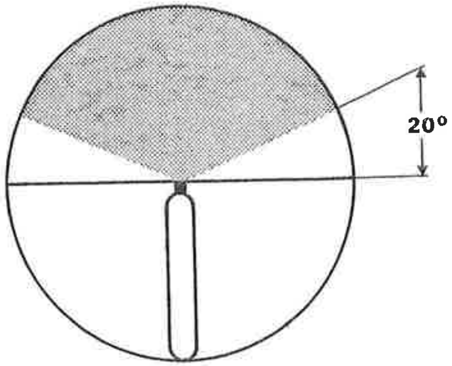


Fig. 15 Recommended Operating Position

Unprotected Lamps

The temperature of the outer bulb rises to some 300-320°C. Bulbs are made of borosilicate glass (hard glass) with a low thermal co-efficient of expansion and can withstand rain splashes. SOLARARC Lamps are, therefore, suitable for operation in open fittings.

DIMENSIONS

The nominal dimensions of SOLARARC Lamps are listed in the following table. As the arc tubes of the lamps with ellipsoidal bulbs are obscured by the diffusive coating, no light centre lengths have been indicated for these lamps.

SOLARARC Lamps are mechanically interchangeable with other leading European manufacturers' High Pressure Sodium Lamps.

Dimensions

Wattage	Diameter mm	Overall Length mm	Light Centre Length mm	Arc Length (Obj.) mm	Cap
250 Tubular	51±2	252±5	158	75	E40
250 Ellipsoidal	90±2	223±5	-	75	E40
250 Reflector	166±2	260	-	75	E40
400 Tubular	51±2	285±5	175	90	E40
400 Ellipsoidal	120±2	285±5	-	90	E40

OPERATING CIRCUITS AND CONTROL GEAR

Circuit

To ensure stable and reliable operation, SOLARARC Lamps must be operated in conjunction with suitable control gear.

The basic circuit for a SOLARARC Lamp, in common with other High Pressure Sodium Lamps, comprises of a series ballast, an external starter and a power factor correction capacitor. The circuit is shown in Fig. 16.

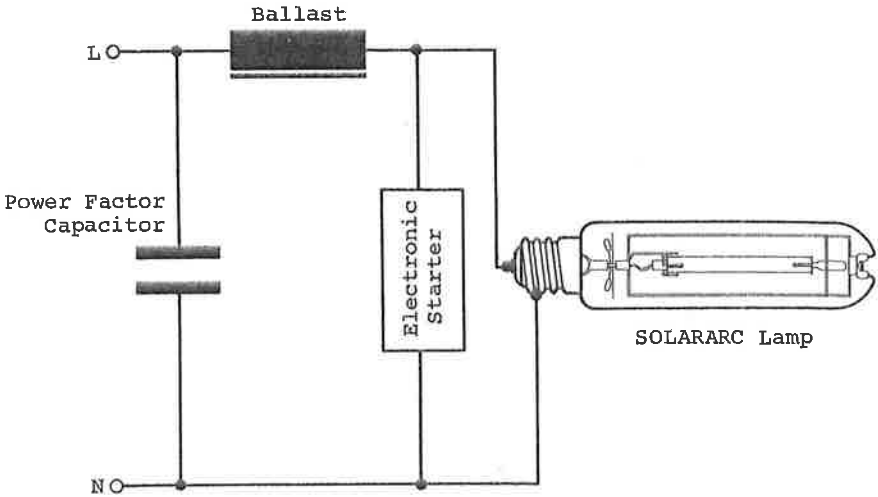


Fig. 16 Operating Circuit

Ballasts

High Pressure Sodium Lamps have a negative resistance characteristic. Lamp current, if not controlled, would rise until a lamp was destroyed. The ballast limits the lamp current to the correct value.

As the pulse delivered by the electronic starter can be as high as 4000V, adequate insulation is an important consideration in the design of suitable ballasts.

In many ballasts, a thermal cut-out is embedded in the windings to prevent over-heating. The cut-out automatically resets when the winding temperature has dropped to a safe value.

Electronic Starters

The Sylvania electronic starter, SHP-1, generates the high-voltage pulses of around 4000V required to strike the arc in SOLARARC Lamps. Employing advanced solid-state circuitry, short, high-voltage bursts of low energy are delivered at a rate of about fifteen pulses per second. This arrangement ensures maximum electrical safety and minimum radio interference.

The starter has the special feature of sensing a faulty or missing lamp. If no arc is struck within two to three minutes, the starter switches itself off automatically.

The SHP-1 will start both 250W and 400W lamps and is compatible with other manufacturers' High Pressure Sodium Lamps. Installation is extremely simple -- only two connections across the lamp are required -- obviating the need for tapped ballasts.

As illustrated in Fig. 17, the SHP-1 starter is supplied in a circular cross-section, aluminium can with two flying connecting leads. The dimensions are approximately 38 mm diameter by 114 mm height.

All electronic components are hermetically sealed into the can and the sturdy construction ensures extended reliable service.

Fig. 17 Electronic Starter

Power Factor Correction

Lamp circuits using choke ballasts such as used with High Pressure Sodium Lamps have a lagging power factor. Unless corrected, this results in increased kVA demand and a need for larger-sized cabling. The power factor must, therefore, be improved to between 0.85 and 0.95 and this is achieved by connecting a suitable capacitor across the mains whose leading current partly compensates for the lagging current of the ballast. The capacitance required depends on the characteristics of the ballast and the final power factor.

INSTALLATION

Cable

In view of the high voltages associated with High Pressure Sodium Lamp circuits, particular attention should be paid to the insulation of the wiring. In some of the cables normally used with other discharge lamps, the insulation may break down when the high-voltage pulses from the electronic starter are applied.

The use of PVC (Polyvinyl Chloride) insulated cable is recommended. In conditions of high temperatures, deformation of the PVC insulation should be prevented with heat-resistant sheathing. Alternatively, special heat-resistant PVC cable may be used.

Cable Lengths

The main factor limiting the distance at which a High Pressure Sodium Lamp may be installed from the control gear is the capacitance of the cables. If cables are extended beyond the recommended length, the capacitance may absorb the starting pulses.

Conductors of appropriate diameter should be utilized to avoid unduly high voltage drops resulting from cable resistance.

Cable lengths up to 20 metres should be satisfactory and this could be extended further provided the conductors are well-separated from each other and from earthed objects.

Insulation Precautions

Care should be taken to ensure that all parts of the circuit are adequately insulated. Particular attention should be paid to:-

- -- cable connections which are close to a terminal fixing bolt:
- -- points of entry of cable into fittings:
- -- back of lamp holders.

FITTINGS

In general, the design of fittings for High Pressure Sodium Lamps follows normal principles, but extra precautions should be taken with respect to insulation.

An important aspect peculiar to High Pressure Sodium Lamps is that heat must not be allowed to be re-radiated back from the reflector onto the sodium reservoir at the end of the arc tube. Such radiation has the effect of raising the sodium vapour pressure in the lamp which, in turn, causes the lamp wattage to increase. This will further raise the temperature of the arc and, therefore, the vapour pressure. Cycling of this nature will continue until the lamp becomes unstable and extinguishes. On cooling down, the lamp will re-strike and go through the same process.

Heat radiation from specific parts of the reflector may be eliminated by cutting away the responsible portion or by rendering the surface non-reflective.

LAMP DISPOSAL

There are few hazards associated with the disposal of SOLARARC Lamps and the prevailing codes of practice and regulations should be adhered to.

The outer bulb, being under vacuum, should be broken by an operator wearing protective goggles and gloves. In the absence of other instructions, a simple procedure for lamp disposal is to put it into a box and pierce the glass just above the cap.

The arc tube and assembly contain traces of metals which may be classed as pollutants.

G. Schoccia 26/4/85

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