

Laboratory 1 ELECTRIC LIGHT SOURCES

1. General Issues

Modern light sources are devices that convert electrical energy into electromagnetic radiation with different *wavelengths*. Energy conversion is performed by *incandescence* and *luminescence* phenomena.

The incandescence consists of visible radiations emission as a result of temperature increase of a body called *radiator*.

The luminescence is the property of matter to emit light when its component particles, atoms or molecules, are excited by processes others than the thermal ones. By the nature of primary energy which produces excitation, luminescence is of several types, lighting technique use especially *electroluminescence* phenomena (excitation produced by an electric field) and *photoluminescence* (excitation produced by electromagnetic radiation). The electroluminescence includes gas discharge, and the photoluminescence includes *fluorescence* and *phosphorescence*.

Gas discharge defines the movement of electrically charged particles in a space filled with gas or metallic vapor, under the action of an external electric field. The type of discharge depends on the electric field, on the chemical composition and on the pressure of the discharge space, on the nature, configuration and distance between electrodes, on the electric circuit parameters, etc.

Fluorescence expresses the property of solid or liquid materials to emit electromagnetic radiation when they are irradiated with fast particles or

electromagnetic radiations.

Phosphorescence is the property of a fluorescent materials to present a post luminescence (persistence of the light emission after the disappearance of the exciting radiation), which may last from a fraction of a second to several hours or even days.

In the case of incandescence and luminescence, the **luminous radiation**, characterized by $\lambda \in [380, 760]$ nm, is generated as a result of the passage of the electrons from higher energy states to low energy states. The difference between the two phenomena lies in the way of

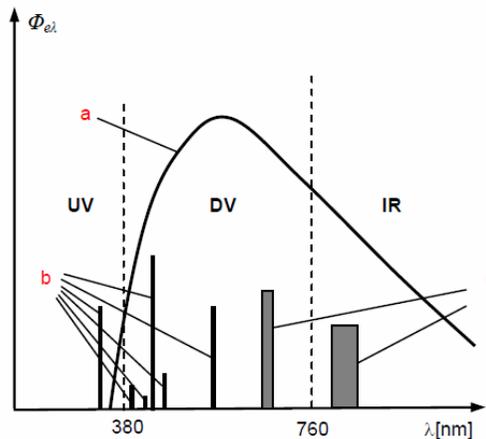


Fig.1.1 Continuous spectrum (a), discrete spectral lines (b), spectral bands (c); UV - ultraviolet radiation field, DV - visible radiation field, IR - infrared radiation field

the substance excitation and, therefore, in the spectral distribution $\Phi_{e\lambda} = f(\lambda)$ of the energy flux Φ_e .

The incandescent light sources have continuous radiation spectrum (Fig. 1.1-a).

In the case of luminescent sources, radiation is a result of the excitation of electrons from the atoms of substances in gaseous or solid state; in the first case are obtained discrete spectral lines (Fig. 1.1-b), while in the second situation will result narrow emission bands covering a specific area of the spectrum (Fig. 1.1-c).

It is to notice that by the psycho-sensitive point of view, depending on the spectral composition, the light emitted by a source can be *cold* (rich in violet, blue, green radiation) or *warm* (rich in yellow, orange, red radiation).

In terms of the spectral composition of the emitted light, the light sources are characterized by color temperature T_c , which is the black body temperature (in Kelvin) for which it is obtained a color similar to that of the considered source. The lower is the color temperature, the warmer is the light perceived (eg.: 2800 K for incandescent lamp). Low temperatures filaments (about 2700K) are rich in red spectral energy, while higher temperatures (about 2900K) are rich in blue wavelength (called paradoxically “cooler”).

In terms of energy, light sources are characterized by the operating time D defined as the time after which the luminous flux drops to 80% of its initial value. After exceeding this time, the lamp operation becomes uneconomical in terms of energy.

2. Incandescent lamps

The incandescent lamp is a transformer of the electrical energy to light energy. The energy conversion is performed based on the Joule-Lenz effect of electric current that brings at incandescence a metallic filament that will emit both heat and light. As a circuit element, the incandescent lamp is a nonlinear resistor, inertial, with a symmetrical volt-ampere characteristic. The incandescent lamps have a wide variety of construction types, but they can be grouped into:

- Classic incandescent lamps (light bulbs);
- Halogen incandescent lamps.

2.1. Classic incandescent lamps (light bulbs)

The main structural elements are the glass bulb, the metallic filament and the socket (Fig.1.2).

The bulb or lamp envelope is designed to avoid contact between the atmosphere and filament and is realized from soda lime glass. It has different forms (standard, spherical, candle, square) depending on the destination of the light source, but in all cases it corresponds to an isothermal area up to 150°C of the lamp filament.

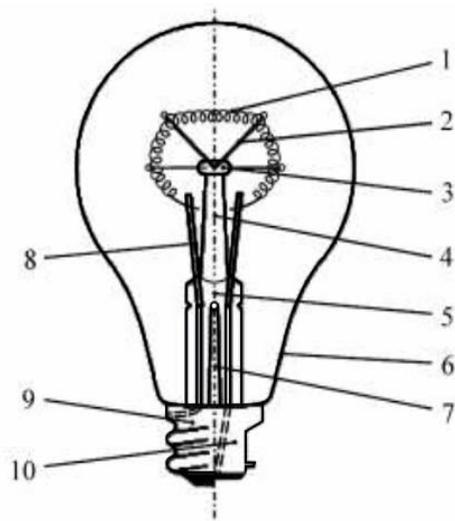


Fig. 1.2 Classic incandescent lamp
 1 - filament, 2 - molybdenum hook, 3 - lens,
 4 - stick, 5 - glass disc, 6 - balloon, 7 - exhaust tube,
 8 - nickel electrodes, 9 - Edison socket, 10 - Swan socket

Clear glass bulbs completely transmit light but have a high, uncomfortable brightness. For this reason are preferred bulbs of:

- Rough mat glass obtained by chemical or mechanical methods;
- Milky glass which is composed of thorium or phosphorus oxide;
- Opal glass obtained by coating the clear glass with a layer of silicate glass, or by including in the glass of a mass of suspension of gypsum, talc, lead oxide, etc.
- Opalized glass obtained by electrostatic processes or by depositing a thin layer of titanium oxide;
- Colored glass and solar type glass with corrected spectrum.

Mat, milky, opal and opalized glasses are designed for lamps with diffuse light that provides a bright comfortable microclimate.

Lamp socket presents various constructive types (screw - Edison type, bayonet - Swan type, smooth - spotlights type with contacts at both ends of the cylindrical lamp) and provides mechanical and electrical connection to the lamp socket. Depending on the application field and construction type of the light source, sockets are made of aluminum, brass or nickel-plated brass.

The lamp filament can be made from various hard fusible metals (tantalum, rhenium, molybdenum, tungsten), but it is preferred tungsten which is characterized by a high melting temperature (3665 K), good mechanical strength, low volatility at high temperatures and considerable ductility, which allows obtaining of wires through wire drawing with a high degree of uniformity.

To avoid oxidation of tungsten, the bulbs of low power lamps - up to 25W including - are voided, and the working temperature of the simple stranded filament is 2400-2600 K. At higher temperatures, the volatilization of the filament is accelerated and the particles that result from it reach on the bulb lamp, blind it and reduce the luminous efficacy, at the same time reducing the cross section of the tungsten wire.

Lamps with power higher than 25W have the bulb filled with inert gases and *wound-coil filament* in order to retain as much thermal energy as possible. These measures have allowed the growth of tungsten working temperature of approx. 2700 ..

3050 K without reducing the lamp's lifetime. Therefore, it increases the luminous efficacy. The presence of inert fill gases has the disadvantage of increased energy losses by the appearance of thermal conduction and convection phenomena. The inert gases commonly used are argon (Ar) and nitrogen (N), in a ratio of 2:1, and the filling pressure is 0.7 atmospheres, value that reaches approx. 1 atmosphere during operation of the lamp. The presence of nitrogen avoids the arcing appearance between current inputs. Replacing argon with krypton (Kr), characterized by higher atomic weight (although more expensive), has the following advantages: lower heat losses, white light, reduced sizes of the glass bulb at the same unitary power of light source.

Current use incandescent lamps are built for voltages of 125/130, 220 and 230 V, have power of 15 ...1000W, luminous efficacy of 10 ...18 lm/W and a lifetime of 1000 hours.

Nowadays it is performed a very wide range of incandescent lamps for indoor or outdoor lighting, from which we quote:

- Opalized, mate or clear bulb lamps, filled with mixtures N+Ar or N+Kr;
 - Candle type bulb lamp from clear or mate glass, with smooth outer surface, twisted or with model;
 - Opalized cylindrical bulb lamp with a variable diameter (25, 37 mm) and variable length (210, 310mm), provided with electrical contacts at the ends (tubular type);
 - High temperature resistant lamps (280, 300°C) used, among others, for the interior lighting of oven stoves;
 - Lamps against insects, designed for lighting for balconies, terraces etc. At this, on the outer surface of the bulb is deposited a special yellow-orange layer that will irradiate a yellow light that does not attract insects. The effect is stronger if in the neighborhood is mounted a lamp with clear bulb, which emits a white light that attracts insects powerfully.
 - Color spherical lamps with 0% cadmium, with filament reinforced construction, resistant at weather and temperature variations, with bayonet socket. The opalized bulb has a live color (white, yellow, red, blue, green, clear) when the lamp is off and preserves the hue when it is on.
- All lamps listed above are provided with *incorporated fuses*, sized for the rated power of the light source. Others sources of incandescent light:
- Low-voltage lamps (12, 24, 36 V) for local lighting or portable lighting;
 - Lamps for vehicles in reinforced construction, *Hang* version with bayonet socket. For the cars headlights are made bulbs with *two phases*, which have two filaments with independent power supply;
 - Lamps with rich infrared spectrum, lamps for projectors etc.

2.2 Halogen incandescent lamps

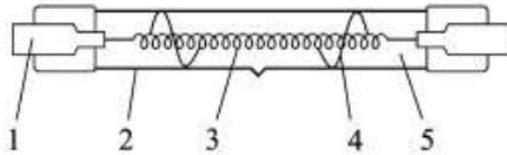


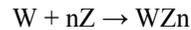
Fig.1.3 Iodine regenerative cycle lamp
1 - current input, 2 - quartz tube, 3 - tungsten filament,
4 - filament support, 5 - filling gas and iodine mixture

The performances of classic incandescent lamps are limited by the intense volatilization of filament at high temperatures. In order to reduce this process, while increasing uptime and unitary power, there were designed and constructed halogen incandescent lamps.

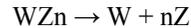
Structurally, halogen lamps are formed from a cylindrical tube of quartz (high temperature resistant material), an axially filament from double stranded tungsten and a fill gas (Ar+N, Kr+N, the last time Kr+Xe) containing a predetermined quantity of halogen (fig. 1.3).

In given temperature conditions, between the halogen substance Z and the vapors of tungsten chemical reactions occur with a cyclic character, which are as follows (the tungsten halide cycle):

- At the relatively low temperatures in the proximity of the walls of the lamp, the halogen atoms are combined with the tungsten particles ejected from the filament with result of a volatile halide



- Tungsten halide molecules, due to thermal agitation, reach to the filament proximity where high temperatures accentuate the decomposition reactions:



Thus, the released tungsten is deposited again on the filament and the halogen substance become chemically free and suitable for a new reaction. The described process is repetitive and light sources that use it are called regenerative cycle lamps.

In most cases, the halogen substance is iodine (I) or bromine (as methyl bromide CH_3Br or methylene bromide CH_2Br_2), hence the name incandescent lamp with iodine regenerative cycle. The chemical reactions described above can be put in the form:

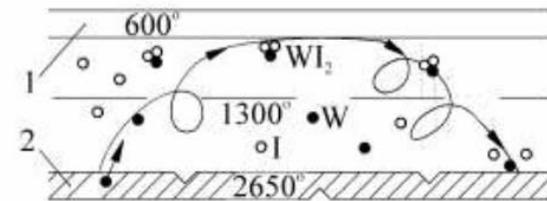
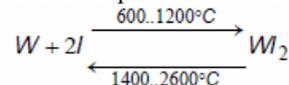


Fig.1.4 Explanation of halogen-tungsten reaction
1 - quartz tube, 2 - tungsten filament,

● - tungsten atom ○ - iodine atom ◐ - WI_2 molecule

indicating that the areas of composition and decomposition of tungsten iodide are separated by an isothermal surface of approx. $1300^\circ C$ (Fig. 1.4).

Unfortunately, the tungsten particles do not return in the same place from which they were expelled. The filament has areas with different temperatures so that, in warmer portions, the material evaporation is more intense and the deposit less pronounced. In the areas with lower temperatures the opposite phenomena occurs and thus appears tungsten axial transfer. Therefore filament deforms over time, it becomes thicker in some area and eventually break. Compared to classical incandescent lamps, the iodine regenerative cycle lamps are characterized by:

- Constant luminous flux for the entire lifetime, which is 2000 hours;
- The absence of *bulb blackening*;
- Luminous efficacy of 18...25 lm/W, at higher unitary powers;
- Color temperature $T_c = 2900$ K provides a good color rendering;
- Reduced overall dimensions at high power, leading to new aesthetic aspects of interior lighting installations in particular;
- Operating temperature of the bulb is $600..900^\circ C$, hence the need for its manufacturing of quartz
- Contacts have operating temperatures of $200..300^\circ C$ and involve porcelain sockets or hardened;
- The mounting position of the lamp - arbitrary or preferential - will be specified by the manufacturer to ensure optimal distribution of iodine during operation time;
- It is prohibited the contact of bulb with skin while manipulating the lamp, otherwise the fatty acids remaining on bulb lead to devitrification of quartz during operation and destruction of the lamp;
- Current inputs are provided with fuses incorporated into the socket, which prevents the occurrence of electric arc in the lamp on filament interruption.

Note: Practical needs impose a variety of types and constructive variants, of which are referred:

- Halogen lamp which their quartz tube is protected by a clear or opalized glass bulb, which facilitates handling of the light source;
- Halogen lamps with pressed glass reflector and zero emission of ultraviolet radiation;
- Lamps with dichroic glass reflector closed in transparent glass, known under the trade name of *spotlights*. These miniprojectors have powers of 20, 35, 50W and are preferably supplied at low voltages (12V) provided by special transformers. We note now that the dichroic mirror has the property to reflect light radiation and to let to pass infrared radiation. The result is a cold light source in terms of the circulating energy by light beam, compared to other lamps. Aluminum reflector spotlights have a temperature of $450^\circ C$, approx. $250^\circ C$ on the closing window of the optical system and about $250^\circ C$ on socket.

- Axial filament lamp for mounting in special reflectors, with or without a protective glass. At these sources the acceptable temperatures are 900°C on the bulb, 350°C on its narrow areas and 300°C on the cylindrical contacts. The high temperature of the bulb requires additional measures in terms of rules for preventing and extinguishing fires in civil and industrial buildings.

- Halogen lamps have become standard in automobile headlamps and projector bulbs and for the photographic use.

3. Fluorescent lamps with low pressure mercury vapor

3.1 Electrical discharges in inert gases and metallic vapors

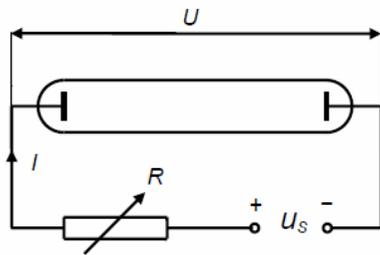


Fig. 1.5 Lamp with discharges supplied in d.c.

The electrical discharge is a process of current crossing through a dielectric in the presence of an external electric field. In gases the phenomenon is possible due to the pre-existence of charge carriers (positive and negative ions, electrons) generated by natural causes (cosmic, telluric, atmospheric radiation). Thus, in a glass cylindrical chamber (fig. 1.5) filled with inert gas at low pressure and provided at its ends with two plane-parallel electrodes, charge carriers have a chaotic movement and into external circuit

doesn't exist electrical power. If at the tube ends is applied a voltage U , the movement of electrical charges becomes ordered, and in the considered circuit current I occurs.

High mobility of electrons leads to electron-atom contacts and, depending on the energy changed at impact, we distinguish elastic and inelastic collisions. *Elastic collisions* only increase the kinetic energy of the atom and, therefore, increase the discharge environment temperature. *Inelastic collisions* increase the internal energy of the atom and it excites (simple or step-up) or ionizes. Excitations last for a short time ($10^{-8} \dots 10^{-9}$ s) and at return of the electron on stable orbit, the emitted radiation will have a wavelength greater than or equal to that of the incident radiation, so it can belong to visible area of the spectrum, hence the gas luminescence.

The degree of luminescence is strongly dependent on pressure and composition of the discharge environment. Thus, a discharge in inert gas and low pressure mercury vapors (0,01 ... 0,1 mm Hg) leads to an emission spectrum rich of mercury resonance radiation $\lambda_1 = 184,9$ nm and $\lambda_2 = 253,7$ nm. If pressure increases the resonance radiations are reduced (are absorbed by gas) and increase the light radiations due to step-up excitation of the mercury atoms. The luminous efficacy η [lm/W] of mercury vapor discharge shows a minimum for the average pressures (Fig. 1.6), being raised at low (LP) and high (HP) pressure. Luminous efficacy of low pressure discharge

increases considerably (dotted line) if on the interior wall of the lamp a luminophore layer is deposited.

If through the discharge tube (fig. 1.5) is applied a continuous, increasing voltage, then it can be obtained a dependence $U=f(I)$ called *static characteristic of discharge in inert gases and metal vapor* (Fig. 1.7) which has several areas, namely:

OA area – the current from circuit complies the Ohm's law and it is generated by the pre-existing charge carriers in the tube;

AB area – when the voltage increases across the tube ends, there appears an excess of charge carriers leading to a saturation current $I_s = I_B$ which does not comply with Ohm's law;

BC area – at the voltage $U > U_B$ inelastic collisions lead to ionization of the gas through shock, the discharge takes an avalanche character and it is called slow (darkened, Townsend), being without emission of light. When $U = U_a = U_C$ the discharge becomes luminescent and this is the ignition voltage or breakthrough voltage of the fill gas;

CD area – in the proximity of the cathode it appears a positive spatial charge, leading to a dependence $U=f(I)$ with negative slope called subnormal in flicker discharge, and in the tube there is observed a sequence of bright and dark areas;

DE area – the voltage between the electrodes remains constant because the cathode current density is conserved and we have a normal luminescent discharge. On this area of the characteristic $U=f(I)$ there are working *cold cathode lamps*, called *flickering lamps*;

EF area – the luminescent discharge becomes abnormal and heavy ion bombardment which is subjected the cathode leads to the thermoelectronic emission of this;

FH area – the gas in the tube is completely ionized and discharge occurs in electric arc, on which the current-voltage dependence is with negative slope. In this area it operates the low pressure warm electrodes lamps (FG) and high pressure lamps (GH ...).

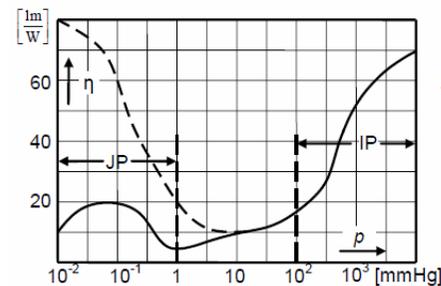


Fig. 1.6 Dependence $\eta = f(p)$ in mercury vapors at constant current $I = 4A$

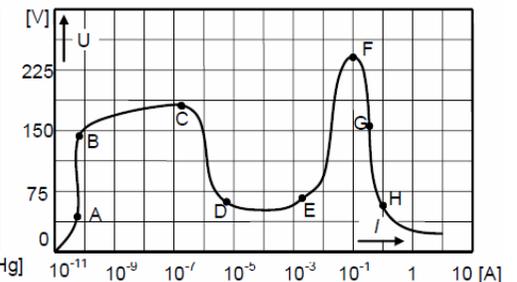


Fig. 1.7 The static characteristic $U = f(I)$ of discharge in inert gases and metal vapors

3.2 Construction of fluorescent lamps

Fluorescent lamps are modern light sources using electro- and photoluminescence phenomena, as a result of electrical discharges in inert gases and low pressure mercury vapors.

Such a light source consists (fig. 1.8) in a glass cylinder shaped (linear, circular, U shape etc.) whose length ($L \approx 100 \dots 2400\text{mm}$) and diameter ($\Phi = 10 \dots 58\text{mm}$) depends on the power of the source light ($P = 4 \dots 200\text{ W}$).

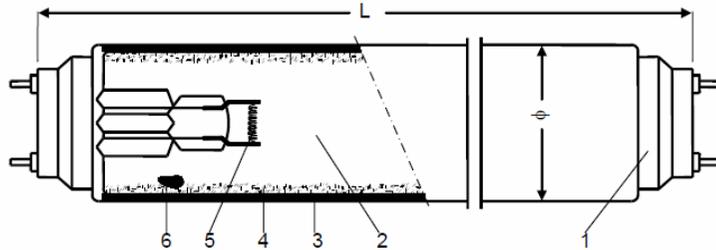


Fig. 1.8 Linear fluorescent lamp
1 – socket, 2 - argon, 3 - glass wall, 4 - fluorescent powder, 5 - filament, 6 – mercury

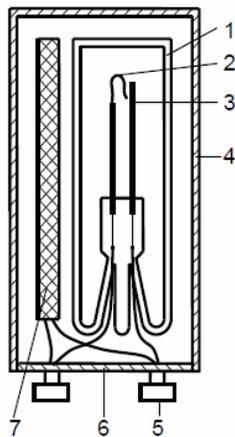


Fig. 1.9 Blinking starter
1 - glass tube, 2 - mobile electrode, 3 - fixed electrode, 4 - PVC box, 5 - terminal, 6 - terminal plate, 7 - capacitor

The walls of the glass cylinder, on the inside, are coated with fluorescent powder (*luminophore*), at the ends there are provided two electrodes, and the tube is filled with inert gas at low pressure and a few milligrams of liquid and vapor mercury.

The preactivated type electrodes are double screwed (wound-coil) tungsten filaments coated with alkaline-earth oxides having a strong thermoelectronic emission at operating temperature ($\approx 900^\circ\text{C}$) of the cathodes.

The fill gas, argon at a pressure of $3 \dots 4\text{ mmHg}$, is intended to facilitate the ignition of the discharge, being easily ionizable. During the normal operation regime of the lamp, at an ambient temperature of $\theta_a = 20^\circ\text{C}$, the partial pressure of mercury atoms is about $0,01\text{ mmHg}$ which favors the emission of mercury resonance radiations with $\lambda_2 = 253,7\text{ nm}$. It is noted that the low pressure mercury vapor are an economic source of ultraviolet radiation that can be converted into visible radiation by a suitable selected luminophore.

The fluorescent powder has in its structure a basic substance (luminophore), a metallic activator and an auxiliary substance. These materials, well mixed, are melted

at high temperatures, and then they are milled, resulting a powdery mixture with crystals of microns order ($2 \dots 4\mu\text{m}$). The fluorescent powder, along with a binder (nitrocellulose) forms a fluid paste which is coated on the inner wall of the lamp.

As luminophores they are used various silicates, with borium and tungsten having different fluorescence (yellow-green, blue, red etc). Halogenophosphates are modern luminophores of high efficiency with a white fluorescence. Luminophores based on rare earth elements (europium) have good thermal stability, high efficiency and emit a warm light from psychosensitive point of view.

The emergence of luminescence on solids is subjected, in general, by the presence of a small amount of a foreign element (heavy metal) called *activator* which has the role to create structural lattices in the luminophore crystal. The metallic activator replaces an atom from crystalline network of the luminophore (similar phenomenon with semiconductor doping) and power level responsible for luminescence originates in activator atoms.

To increase the transmission factor of the metallic luminophore-activator mixture in this is added an auxiliary substance (CaF_2 , NaCl) which aims to favor the emergence of complex microcrystals of luminophore.

Qualitatively, the luminophore must have: high efficiency at ultraviolet-visible conversion, transparency for visible radiation, maximum fluorescence at $+20^\circ\text{C}$, high absorption spectral factor in ultraviolet, chemical stability at the temperature of the lamp and colorimetric properties corresponding to the intended purpose.

3.3 Start-control devices

The starting of fluorescent lamps is done at a higher voltage than the operating one (ignition voltage) and after the arc discharge ignition it is imposed a limitation of the current through the lamp. These ignition and discharge stability conditions are achieved by means of auxiliary circuit components, generally called start-control devices, consisting of starter and ballast.

The starter is designed to provide a pre-heating of the filaments and to break, after a certain time, the current thereof. It is presented in various forms of construction and one of the widely used variants is the flickering starter. This (fig. 1.9) consists of a glass tube filled with inert gas (Ne, Ar) at low pressure and provided with two electrodes, a fixed one (from nickel) and a mobile one (a bimetal). As for the operation principle, the described starter is a lamp with cold electrodes operating under a normal flicker regime and, after the circuit function performed, it is a normally open contact with close time delay.

For the correct operating of the starter assemblies, it is required that between the voltages: U_{st} – the ignition starter voltage, U_l – the lamp regime voltage and U_s – the supply/main voltage, to have the following relation:

$$U_l < U_{st} < U_s$$

The ballast or preconnection device is designed to provide the ignition overvoltage of the lamp at filament circuit interruption by the starter and to maintain the stability of the operating point of the arc discharge. In AC the ballast is an impedance with inductive (BI - inductive ballast) or capacitive characteristic (BC - capacitive ballast), whose main element is a coil with iron core and air gap. The static characteristic $U_b = f(I)$ of ballast is slightly nonlinear (fig. 1.10) and external characteristic $U_{be}^2 = f(I)$ is strongly dropping (fig. 1.11).

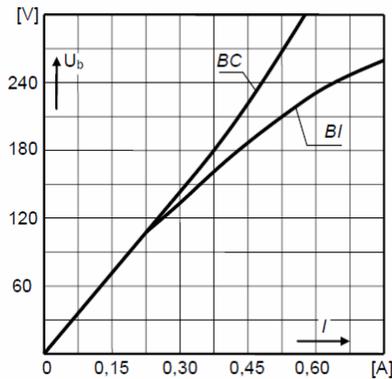


Fig. 1.10 $U_b=f(I)$ characteristics

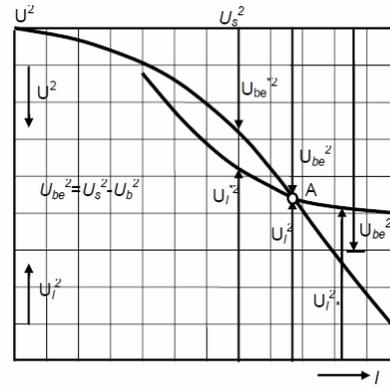


Fig. 1.11 $U_{be}^2=f(I)$ and $U_i^2=f(I)$ characteristics

Stabilization of the arc discharge corresponds to the intersection point of characteristics $U_{be}^2=f(I)$ and $U_i^2=f(I)$ for which the following relationship is valid: $U_i^2 + U_{be}^2 \approx U_s^2$ (point A in fig. 1.11).

3.4. Fluorescent lamps functioning in assemblies with flickering starter

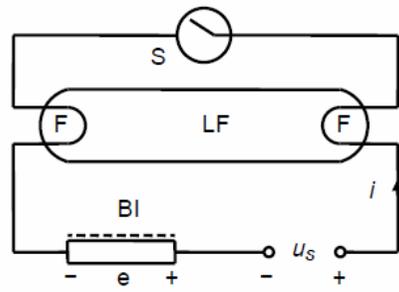


Fig. 1.12 Installation with inductive ballast

Consider (fig. 1.12) an inductive ballast BI in series with a fluorescent lamp LF whose filaments F are interconnected by starter S.

When connecting the assembly to the mains, the supply voltage u_s is found across the starter and in this ignites a normal flickering discharge which heats the inert gas. From this it is heated the bimetal, which expands and, finally, closes the normally open contact. The current from + u_s , F, S, M,

BI - u_s circuit heats powerfully the filaments and prepares the fluorescent lamp for ignition (inert gas is ionized and the mercury is vaporized).

Meanwhile, the gas from the starter cools down, the bimetal returns to the initial position and suddenly interrupts the filaments circuit. Rapid variation di/dt of the current through the ballast generates an induced voltage $e=-d\Phi/dt$ of high value (1000..1200 V). If at the time of filament circuit interruption there are considered for u_s and e quantities the polarities shown in the figure, the voltage applied to the fluorescent tube will be $u_s+e>U_a$ which leads to quasi-instantaneous ignition of the discharge in arc regime.

3.5. Constructive types of low pressure fluorescent lamps

Constructive types of fluorescent lamps can be classified according to different criteria, but one of the most used is the destination of them and, according to this, we distinguish fluorescent lamps of general use and special fluorescent lamps.

a) *Fluorescent lamps of general use* are characterized by high luminous efficacy ($\eta=45 \dots 95$ lm/W), wide range of correlated color temperatures ($T_c=2700 \dots 6500$ K), high rendering color index ($IRC=65 \dots 95$) and an appreciable lifetime ($D=6000 \dots 8000$ hours). The type-dimensions commonly encountered are:

Normal linear lamps with $\Phi 26$ and $\Phi 38$ whose normalized powers are of $P=18, 36$ or 58 W and $P=20, 40$ or 65 W respectively. In Romania there are produced $\Phi 38$ lamps with variants: ignition with starter (LFA symbol for $\theta_a \geq +5^\circ\text{C}$ and LFB if $\theta_a < +5^\circ\text{C}$) and ignition without starter for hazardous environments or low temperatures (LFR symbol, $\theta_a = -15^\circ\text{C}$).

To facilitate the ignition, LFB and LFR lamps are provided on the exterior with a metallic tape deposited by painting which is used to increase and homogenize the electric field along the tube. Also, on the LFR type, to avoid the filaments intense wearing are used the anode rings – ellipsoidal metal sheet screens surrounding the filament and connects to current inputs - which take the electric charge in the alternation in which the electrode acts as an anode.

Local lamp coding is done by attaching to the light source symbol a fraction whose numerator means standardized power P and the denominator means the correlated color temperature in accordance with the recommendations of the ICE (International Commission on Illumination). For example, the notation LFA40/2x states that we have a low voltage mercury fluorescent lamp with ignition with starter assemblies with a power of 40 W and a temperature $T_{cc} = 3800$ K, which corresponds to the white-superior color of emitted light.

- Miniature linear lamps (rod lamps) with $\Phi 7, 15, 16$ and $P = 4 \dots 13$ W;
- U-shaped lamps with $\Phi 38$ and $P = 20, 40, 65$ W;
- Circular (toroidal) lamps with $\Phi 32, P = 18..40$ W and outer diameter of the torus of 100 – 410 mm;
- Monosocket lamps with contacts placed at one end of the light source which consists of 2, 4 rods with $\Phi 10$, two rods with $\Phi 15$ or 2 or 3 U tubes with $\Phi 10$. These

elements have common connection points and behave as a single fluorescent lamp. These are performed in the variants socket with 4 contacts and socket with 2 contacts (starter included in the socket). They are recommended for long-term indoor or outdoor lighting, indicating that emitted luminous flux is less dependent by the ambient temperature.

b) Compact fluorescent lamps called also *economy fluorescent lamps* (Fig.1.13) are actually small diameter fluorescent tubes (8-12 mm), with curved length or composed of several sections connected in series in order to reduce the size. The lamp is supplied at high frequency (10 ... 30 kHz) from an electronic circuit called *electronic ballast* (Figure 1.14).



Fig.1.13 Compact fluorescent lamps

The electronic circuit consisting of a rectifier, electrical filters and an inverter made with two transistors operating back to back contains a ballast inductor L (of small sizes, of ferrite core) which is often included in the lamp. Supplying of the lamp at increased frequency leads to almost instantaneous ignition and disappearance of the flicker effect.

E27 or E14 screw socket takes the advantage of simple connection directly to the mains, like traditional incandescent lamp. In fact this type of lamp can replace any traditional incandescent lamp into the lamp housing related with luminous efficiency of 5...7 times higher.

Some versions come with a protective globe with clear or opal glass.

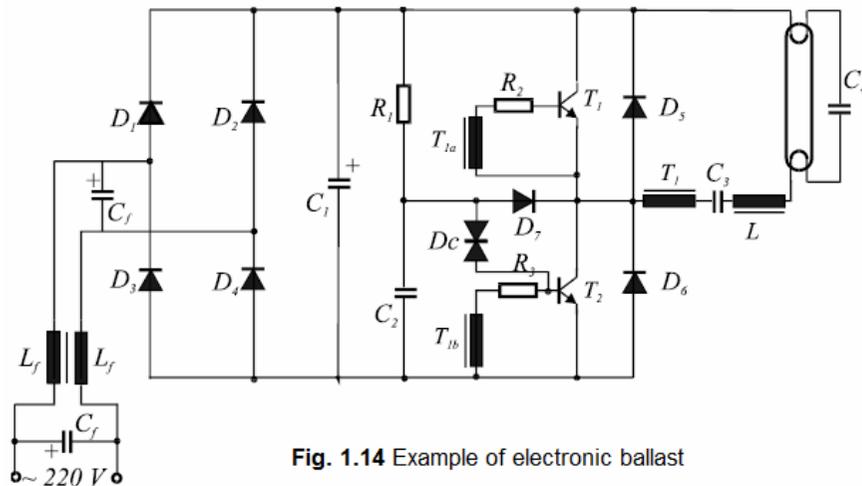


Fig. 1.14 Example of electronic ballast

c) Special fluorescent lamps have distinct manufacturing technology and various fields of use, the most common constructive variants being the following:

- Fluorescent lamps with reflective layer (fig. 1.15-a) on which between the glass tube 1 and the luminophore 3 is interposed a reflective material 2 which has a longitudinal slot of angle α . It is recommended for windows, soffits, direct lighting systems etc.

- Fluorescent lamps with fast ignition (fig. 1.15-b) provided with a metal band 4 on the inner wall connected to one of the electrodes. Inductive ballast can be replaced by an incandescent lamp and it is recommended for environments with a risk of fire and explosion.

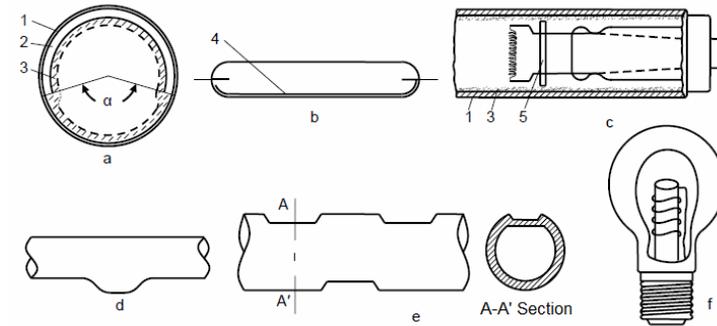


Fig.1.15 Constructive types of special fluorescent lamps
1- glass tube, 2 - reflective layer, 3 - luminophore, 4 - metal band, 5 - screen

- High power fluorescent lamps. Increasing the power of the lamp is possible if it has cooling conditions that lead to the optimal values of pressure (0,01 ... 0,10 mmHg) and temperature (40°C) of mercury vapor. This goal can be achieved by:

✓ forced air cooling of the glass tube, with a fan, such as in the case of HO lamps (high - output) and SHO (super - high - output) with power of 100 W/m;

✓ creating a cold point in the lamp thermodynamic system by shielding the filaments socket (fig. 1.15-c), the realization of a protuberance in the middle of the tube (fig. 1.15-d) or modifying the ratio of cross-section / lateral surface by making small cavities along the tube (fig. 1.15-e).

- *Colored fluorescent lamps* using special luminophores and, possibly, filtering glasses. It is recommended for discos lighting, bars, special effects etc.

- *Actinic fluorescent lamps* with a specific spectral distribution required for heliographic apparatus (spectrum rich in appropriate blue and ultraviolet radiation) or to stimulate the plant growth (spectrum rich in red and blue radiation).

- *Induction lamps* (fig. 1.15-f) are characterized by the fact that ionization of

the discharge medium occurs due to currents induced in the inert gas by a high frequency magnetic field (2,65 MHz) generated by a coil placed at the source of light. The discharge tube is a glass bulb similar to that of incandescent lamps and is coated inside with a normal fluorescent powder. The lamps have the data catalog: instant starting in range of $\theta_a = -20 \dots +55^\circ\text{C}$, $P = 55 \dots 85 \text{ W}$, $\eta = 65 \dots 70 \text{ lm/W}$, $T_c = 3000 \dots 4000\text{K}$, $IRC \geq 90$ and $D = 60000$ hours.

4. Mercury vapours lamps

The classification of these light sources is made after the pressure of the metallic vapors during operation and in accordance with this principle we distinguish:

- Low pressure mercury vapours lamps,
- High pressure mercury vapours lamps.

4.1 Low pressure mercury vapours lamps

Mercury vapours lamp at a pressure about 0.01 torr is a source of ultraviolet radiation ($\lambda = 180 \dots 400 \text{ nm}$) and has a construction similar to the fluorescent low pressure mercury vapours lamps. The difference is the discharge tube made of special glass, transparent to ultraviolet radiation, frosted inside in order to uniform the energy flux.

The grid connection is made using classic or electronic start-control devices (starter, ballast). The application fields are various: luminescent analysis, antiseptic treatments, photochemical processes, polymerization reactions... The lamps have powers of $P = 6 \dots 124\text{W}$ and a lifetime of $D = 2000 \dots 8000$ hours.

Mercury vapour lamp at a pressure of about 0.01 torr is a yellow-green monochromatic radiation source ($\lambda = 557 \dots 577.9 \text{ nm}$) with a blue-green dominant colour.

The lamp (fig. 1.16) is made of a glass cylindrical enclosure 1, wherein a low pressure inert gas is introduced (argon, neon) and a few milligrams of mercury.

At the ends of this discharge tube are placed the main electrodes E_1 and E_2 (wound coiled filament of tungsten) coated with thermo-emissive materials (oxides of barium, strontium, calcium). In the vicinity of one of the main electrodes,

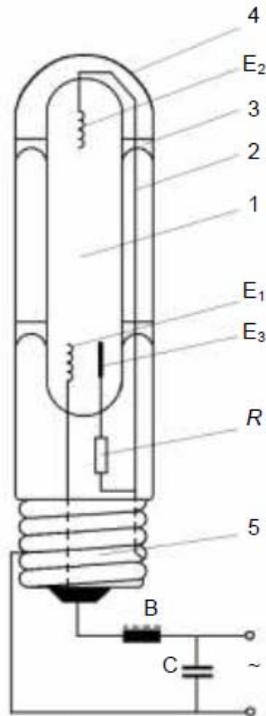


Fig. 1.16 Low pressure mercury vapor lamp

(oxides of barium, strontium, calcium). In the vicinity of one of the main electrodes,

E_1 , is disposed an auxiliary electrode E_3 , connected through the limiting resistance $R = 25 \text{ k}\Omega$ to the other main electrode. The described ensemble, including the current paths 2 and the supporting elements 3, are protected from the destructive action of the environment by the cylindrical bulb 4, of clear glass.

The space between the two enclosures is filled with inert gas (argon, nitrogen) that serves in normal operation to equalize the temperature of the discharge tube and to avoid the appearance of electric arc between the current inputs. The glass bulb has at one end the screwed socket 5.

The network connection is made using the ballast B (coil with iron and air gap core) and eventually a capacitor C which provides a high current power factor. The ignition discharge takes place in two stages:

- At the installation supply it appears a flickering discharge between electrodes E_1 and E_3 , and the circuit current provides both the argon ionization and a strong thermo-electronic emission of the electrode E_1 ;

- Next, because the intense ionization of the environment, the electric arc between the main electrodes appears, the mercury vaporizes and by exciting its vapour in the electric field is emitted a monochromatic yellow-green radiation. The flickering discharge between E_1 and E_3 ceases because the electrical resistance of the space E_1 - E_2 decreases greatly with respect to the limiting resistance R.

The length of transitory processes, which means the time after which the luminous flux of the lamp reaches 80% of the nominal value, is 6...7 minutes. If during operation a voltage drop occurs, the lamp turns off and reigniting is possible after 3...5 minutes (the workspace cools and reaches the appropriate ignition pressure of the flickering discharge).

The source operating position is specified by the manufacturer, and its failure leads to a curved electric arc (under the action of convective thermal currents) and softening the glass in that area.

Low pressure mercury vapour lamps have powers in the range of $P = 80 \dots 1000\text{W}$, luminous efficacy $\eta = 30 \div 40 \text{ lm / W}$, lifetime of $D = 3000$ hours and are only recommended for outdoor lighting because they have a colour rendering index CRI of low value.

4.2 High pressure mercury vapours lamps

The high pressure mercury vapours lamp (Fig. 1.17) has as main constructive element a discharge tube 1 of quartz glass transparent to ultraviolet radiations and resistant to the operating temperature of the electric arc. In the tube is introduced an inert gas (argon) at low pressure (a few torr) and mercury (10..300 mg depending on the lamp power), and the ends are provided with the main electrodes E_1 , E_2 and the secondary electrode E_3 .

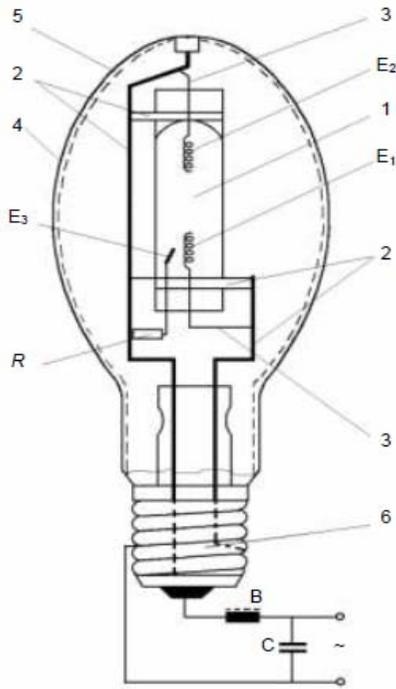


Fig. 1.17 High pressure mercury vapor lamp

The main electrode is formed by a metal rod on which is wound a double-coiled tungsten filament and covered with thermo-emissive material. The secondary electrode is a tungsten or molybdenum wire placed in the vicinity of a main electrode and galvanically connected to the other main electrode through the limiting resistance $R = 25 \text{ k}\Omega$.

The discharge tube, supporting elements 2, the current paths 3 and the limiting resistances are placed into an oval glass bulb 4, which shape corresponds to one of the quartz cylinder isotherms ($\sim 350^\circ\text{C}$). The bulb 4 is filled with inert gas (argon, argon + nitrogen) that reaches the atmospheric pressure during the operation of the lamp.

The glass tire 4 has multiple functions such as: protects the components of the source from the destructive action of environmental factors; ensures thermal balance of arc discharge by homogenize the convective losses, so the independent operation from ambient temperature; absorbs

ultraviolet radiations and allows the modification of the discharge photometric characteristics; decreases, by increasing the inner surface, the discharge tube high luminance (about 600 sb).

The lamp is provided with a metallic socket 6 with E27 or E40 (at high power) which maximum temperature is 200°C and 250°C .

The network connection is made using an inductive ballast B, and the light ignition takes place in two steps, as in the case of low pressure lamps.

The flickering discharge between the electrodes E_1 - E_3 takes place at a voltage of $10 \div 20 \text{ V}$ under a current of about 1,6..1,8 times the rated current, which ensures the ionization of the inert gas and a strong thermo-electronic emission of the main electrode E_1 . When the pressure in the tube is about 20 torr, the electrical resistance of the space E_1 - E_2 becomes smaller than the limiting resistance R, and the discharge switches between the main electrodes E_1 - E_3 and the electric arc appears. After about 5...10 minutes it's reached the stable operating regime characterized by a pressure of $2 \div 15$ atmosphere inside the quartz tube, an arc column temperature of $800 \dots 1200^\circ\text{C}$ and a lamp voltage of 115...135V.

The high pressure mercury vapour lamp and the fluorescent bulb or high pressure fluorescent mercury vapour lamp is obtained by depositing of a fluorescent powder layer 5 in the inner wall of the glass bulb (magnesium fluorogermanate, yttrium orthovanadate) with a strong emission in the red area of spectrum (see fig. 1.16). These radiations are complementary to those of mercury and the lamp has a white light with $T_c = 3300..4300 \text{ K}$ and $\text{CRI} = 40..60$. The lamps are characterized by: $P = 50..1000 \text{ W}$, $\eta = 35..55 \text{ lm/W}$, $D = 16000..24000$ hours and is recommended for public lighting, sport fields, industrial high halls and where is required large luminous flux, relatively concentrated and are not required accurate colour rendering conditions.

The symbolization of the lamps made in the country is done by the group of letters LVF and attaching a number that represents the source standardized power. The range of local products is LVF 80, LVF 125, LVF 250, LVF 400.

The high pressure mercury vapour lamp and the reflector bulb has the envelope of a rotation paraboloid, the front side is of clear glass, and the rest of the bulb is covered, inside, with a reflective layer (titanium dioxide) that is deposited fluorescent powder. The luminous flux is emitted in a steradian angle π with

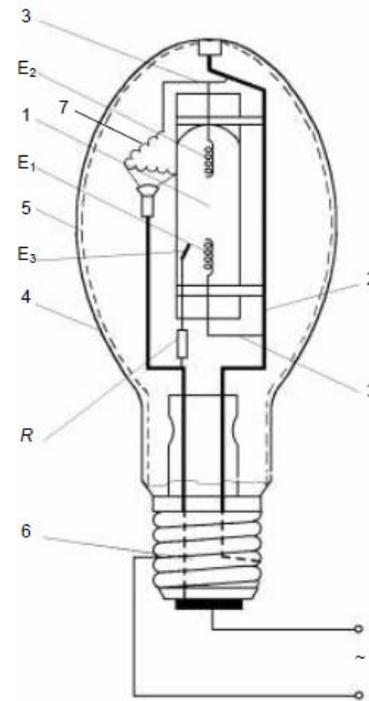


Fig. 1.18 Mixed lamp light

maximum luminous intensity after the solid angle axis and much higher than in standard lamps. Sources are characterized by: $P = 125..1000 \text{ W}$, $\eta = 45..55 \text{ lm/W}$, $T_c = 3900..4200 \text{ K}$, $\text{CRI} = 36..40$, $D = 16000..24000$ hours. It is suitable for installations that commonly use mercury vapour lamps, but where direct lightning is predominant, such as: high industrial halls, agricultural greenhouses, railroad triages, important perimeter areas.

The symbolization is done by the group of letters LVO and attaching a number that represents the source standardized power. The range of local products is LVO 250 and LVO 400.

Mixed light lamp (fig. 1.18) is a high pressure fluorescent mercury vapour lamp in which the ballast has been replaced by a double-coiled tungsten filament 7 mounted in the protective glass bulb. The filament stabilizes the discharge and at the same time is a normal incandescent lamp, which makes the whole ensemble have a better spectral composition than that of high pressure fluorescent mercury vapour lamp.

The light source luminous efficacy is higher when the luminous flux of the tube discharge 1 is equal with the one on the filament 7 and for this is necessary that the incandescent lamp electric power represents about 60% of the total absorbed power, which time is about 3 minutes.

The source is characterized by: $P = 100...500 \text{ W}$, $\eta = 10..26 \text{ lm/W}$, $T_c = 3500..3800 \text{ K}$, $\text{CRI} = 50..60$, $D = 6000 \text{ hours}$, $\cos \varphi = 0.9$. It is recommended for lighting roads, for high industrial halls and other similar spaces with concentrated lighting fluxes and a good colour rendering are required. The higher lifetime than that of standard incandescent lamps is due to the filament lower operating temperature and due to the inert gas increasing pressure in the protective glass bulb.

5. Vapours sodium discharge lamps

The classification of these light sources is made after the pressure of the metallic vapours during operation and in accordance with this principle, we distinguish:

- Low pressure sodium vapours lamp;
- High pressure sodium vapours lamp.

Electric discharge in saturated sodium vapour (metalloid with melting temperature of about 98°C) have maximum luminous efficacy if vapour partial pressure is low (0,005..0,010 torr) or high (100..200 torr).

At low pressure the operating takes place at a discharge environment temperature of $250..270^\circ\text{C}$, and the emitted light is yellow-green and corresponds to resonant radiations (589 and 589,6 nm) of the sodium doublet D. This quasi-monochromatic spectrum is close to the corresponding eye maximum sensibility, leading to a theoretical luminous efficacy of about 520 lm/W.

At high pressure the discharge stabilization is obtained for higher temperatures in the lamp environment ($700..1200^\circ\text{C}$), and the emitted light has an orange colour (yellow-gold, white-gold) because a part of the resonance radiation is self-absorbed and reemitted as a band spectrum that also includes red, green and blue radiation.

In all cases, the sodium vapours at ambient temperature ($+20^\circ\text{C}$) are in small amount and to facilitate the lamp discharge ignition is inserted a mixture of low pressure inert gases (neon, argon, xenon).

5.1 Low pressure sodium vapour lamp

Low pressure sodium vapour lamp has as main element a glass discharge tube, with an U shape or linear shape (fig. 1.19), in whose interior wall is applied a material layer resistant to chemical sodium vapour action. The ends of the tube are provided tungsten electrodes enabled with thermo-emissive materials. In the tube is inserted a saturated quantity of metallic sodium to form saturated vapours and a mixture of neon

and argon at a pressure of 10..15 torr. The discharge chamber thermal isolation is made inserting it into a cylindrical glass bulb (envelope), vacuumed. The radiative heat exchange significantly diminishes if in the inner wall of the envelope is provided a material film (zinc oxide or indium) transparent to visible radiation, but reflecting for the infrared radiation with $\lambda=5,5\mu\text{m}$ produced by the discharge environment found at the optimal temperature of 260°C .

The discharge ignition depends on the light source constructive type:

- Ignition lamps with tungsten double-coiled cold electrodes is made by applying an overvoltage supplied by a large leakage flux autotransformer (fig. 1.19-a);
- Ignition lamps with preheated tungsten double-coiled electrodes are made using an assembly with starter ignition and inductive ballast (Fig. 1.19-b).

When powering up the ensemble a discharge in the inert gases appear at low pressure which heats the lamp environment and leads to sodium gradual vaporization. At first the emitted light is red (neon feature), but in the next 10..15 minutes turns into yellow-green due to sodium atoms excitation found at partially optimum temperature and pressure.

Lamps with higher power than 180W are made with linear shape and the discharge tube has constrictions (fig. 1.19-b) to avoid the sodium movement to higher temperatures in the vicinity of the electrodes. The operating position is horizontal or tilted with 20° , which ensures a good sodium distribution in the discharge tube. Lower power lamps have a U shape and the operating position is vertical or at an angle of 55° to it.

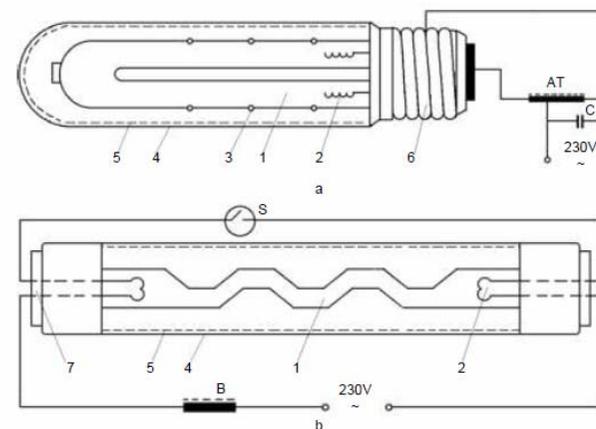


Fig. 1.19 Sodium vapour lamp with U (a) and linear (b) shape. 1-discharge tube; 2-filament; 3-unevennes for sodium condensing in stand mode; 4-glass bulb; 5-iridium oxide film; 6-E27 socket; 7-G13 socket; AT- autotransformer with dispersion; B-inductive ballast; C-capacitor; S-flicker starter.

Low pressure sodium vapour lamps are characterized by: $P = 18..220 \text{ W}$, $\eta = 70..200 \text{ lm / W}$, $D = 6000 \text{ hours}$ and are recommended for outdoor lighting (roads, warehouses, locks, airports, etc.) inside (rooms with dusty or smoky halls and forging, foundries) or for decoration. This wide range of applications is a consequence of the favourable properties of yellow-green monochromatic light on visual acuity and sensitivity in perception of detail, contrasts and shapes. The yellow light emitted by these lamps pass through fog and provides a bold contrast between enlightened and unlightened surfaces, improving visibility. Note that colour rendering is nonexistent because a pure colour, else than yellow, will appear completely black in these light lamps.

5.2. High pressure sodium vapour lamp

High pressure sodium vapour lamp has as main element (fig. 1.20) a cylindrical discharge tube 1 of sintered polycrystalline alumina, translucent (lucalox or PCA), which resists better at the action of chemical sodium vapour at high temperature (about 1000°C). At the ends are mounted the electrodes 2 made of double-coiled tungsten filament covered with heat-emitting material. In the tube is inserted metallic sodium and mercury in amount from 1 to 4, and an inert gas (xenon) or a mixture of inert gases (neon and argon) that allow the discharge initiation. Mercury has the role of buffer gas and ensures, at operating temperature, optimal work pressure and a high potential gradient. The discharge chamber is protected from the influence of the environment by a glass bulb 3, vacuumed, which form may be elliptical or cylindrical.

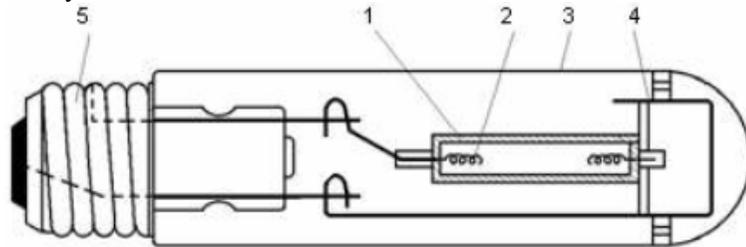


Fig. 1.20 High pressure sodium vapour lamp;

1-discharge tube; 2-filament; 3- protecting glass bulb; 4-support element and current path; 5-socket.

The cylindrical envelopes are from clear glass and have a maximum temperature of 350°C . Ellipsoidal envelopes have frosted inner walls, and their temperature can reach 450°C . The lamp socket 5 is with E27 or E40 thread, the working temperature is 200°C , respectively 250° . The lamp can work in any position at ambient temperatures up to -30°C .

Since the low metallic vapour pressure at ambient temperature, and the distance between electrodes is high enough, the ignition of the lamp discharge is performed using starters (igniters), which have a multitude of sizes. In our country are built igniters with pulse transformers or only with semiconductor elements when the ballast is of special construction (autotransformer type).

Pulse transformer igniter (DAS 05 Fig. 1.21-a) works after the following principle:

- When connecting the application to the network, suppose that the positive alternation of the supply voltage $u_s = U_{sm} \sin(\omega t - \phi)$ is applied to terminal 2 and C_1 capacitor will charge with the polarity from the figure, at maximum value, on the circuit: terminal 2, diode D_1 , primary impulse transformer IT, C_1 capacitor, resistor R_1 , ballast B, terminal 1;

- In the next alternation (with signs in parentheses) takes place the charging of C_2 capacitor with the polarity from the figure, on the circuit: terminal 1, B, R_1 , C_2 , D_2 , D_3 , terminal 2. C_1 capacitor retains its charge $u_{C1} = U_{sm}$ by blocking D_1 , and C_2 charged at $u_{C2} = U_{sm}$ seeks the voltage supply variation.

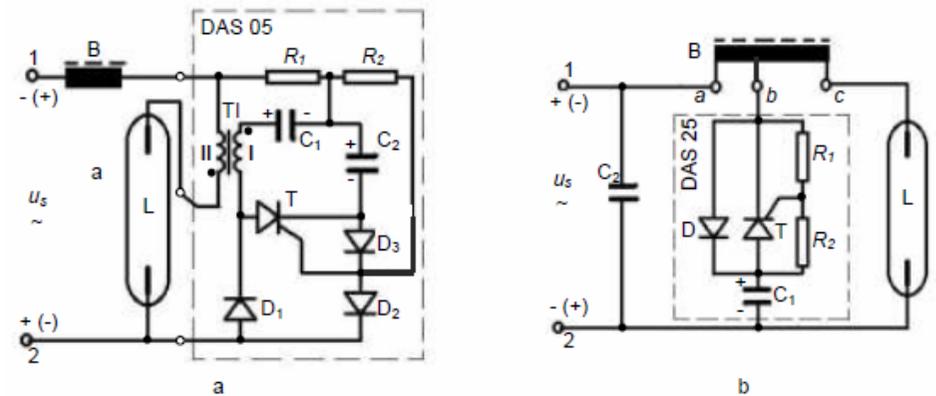


Fig. 1.21 Connecting diagrams of high pressure sodium vapor lamps
B-ballast; L-discharge lamp; DAS05-igniter transformer; DAS25- igniter thyristor

- When $u_s < U_{C2}$ diode D_2 is blocked and the capacitor C_2 generates a gate current $i = U_{C2} / R_2 = U_{sm} / R_2$ which leads to thyristor opening T. From this moment starts the series capacitors discharge $C_1 + C_2$ on the primary I of the pulse transformer IT, which is applied the voltage $2U_{sm}$. The overvoltage $3..4,7 \text{ kV}$ that appears at the windings II endings is found at the lamp electrodes L witch will ignite, and the igniter goes out of service due to low voltage (from the spring terminals) which is applied to the input.

Thyristor igniter (DAS 25 fig. 1.21-b) provides the lamp energizing only if the ballast is of special construction, with sockets, and operates as follows:

- When supplying the installation the source voltage $u_s = U_{sm} \sin(\omega t - \varphi)$ has positive alternating at terminal 1, C_1 capacitor is charging at $u_{C1} = U_{sm}$ with the polarity in the figure, on the circuit: terminal 1, ballast B section a-b, diode D, capacitor C_1 , terminal 2.

- At the next alternation (polarity in parentheses) through the divisor $R_1 + R_2$ it appears a current that leads at a voltage drop on the resistor R_2 , sufficient for opening the thyristor T. From this moment C_1 rapidly discharges on the a-b winding and at the ballast endings a-c a voltage pulse 2,8..4,5 kV that allows energizing the lamp.

The duration of transitional processes corresponding to the lamp entering in normal function regime is 5..10 minutes based on the power source unit. If during the stabilized regime it appears voltage drops, re-ignition the source takes place after 2...3 minutes required for cooling the discharge tube environment.

High pressure sodium vapour lamps are characterized by: $P = 25..1000$ W, $\eta = 35..125$ lm / W, $D = 20,000$ hours, $T_c = 2100..2500$ K, $CRI = 20..80$ and are recommended for street lighting, shipyards and docks, airports, the railroad triages, and industrial plants of considerable height (more than 8..10m). The utilization of these light sources is limited to indoor by the high luminance of the discharge tube, which can reach 900 sb.

This type of light sources are encoded by the group of letters: LPNE- frosted ovoid envelope or LPNT- cylindered clear glass envelope, at which is attached a number corresponding with the standardized power of the lamp and is 15, 250 or 400 W (example: LPNE 150 - high pressure sodium vapour lamp with frosted glass bulb and nominal power of 150 W).