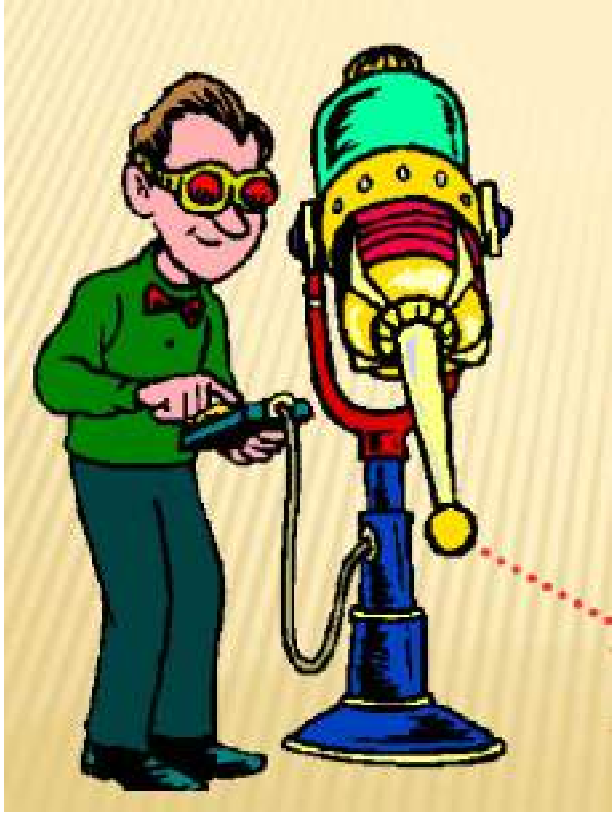
Light Sources



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Sodium-vapor lamp

- A sodium-vapor lamp is a gas-discharge lamp that uses sodium in an excited state to produce light at a characteristic wavelength near 589 nm.

- Two varieties of such lamps exist : *low pressure and high pressure*.

- Low-pressure sodium lamps are highly efficient electrical light sources, but their yellow light restricts applications to outdoor lighting, such as street lamps, where they are widely used.

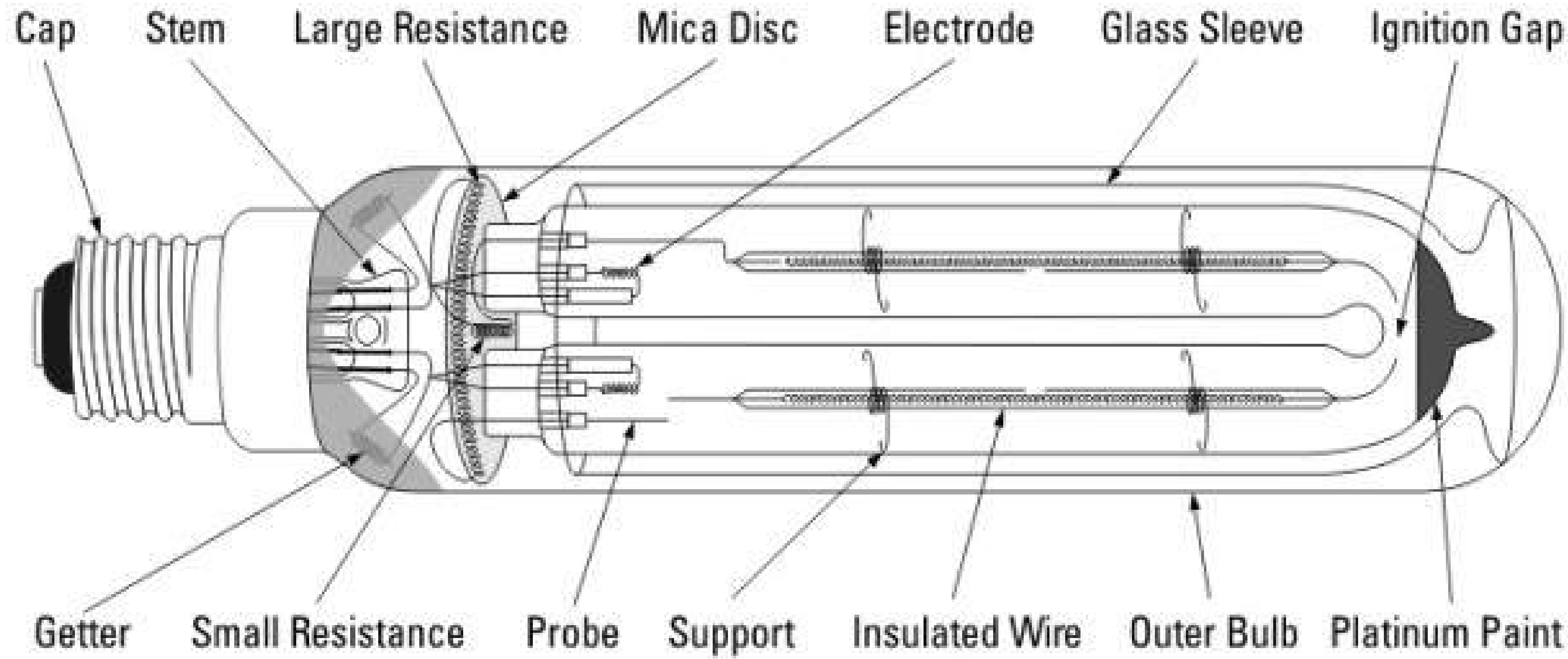
- Low-pressure sodium lamps only give monochromatic yellow light and so inhibit color vision at night.

- These operated at pressures of less than 1 Pa and produced a near monochromatic light spectrum around the sodium emission lines at 589.0 and 589.56 nanometres wavelength.

- High-pressure sodium lamps emit a broader spectrum of light than the low-pressure lamps, but they still have poorer color rendering than other types of lamps.

- Light produced have more energy emitted at wavelengths above and below the 589 nm region.

- A 400 watt lamp would produce around 100 lumens per watt.


Cap
Stem
Large Resistance
Mica Disc
Electrode
Glass Sleeve
Ignition Gap
Getter
Small Resistance
Probe
Support
Insulated Wire
Outer Bulb
Platinum Paint

Low-pressure sodium

- Low-pressure sodium (LPS) lamps have a borosilicate glass gas discharge tube (arc tube) containing solid sodium, a small amount of neon, and argon gas in a Penning mixture to start the gas discharge.

- The discharge tube may be linear (SLI lamp) or U-shaped.

- When the lamp is first started, it emits a dim red/pink light to warm the sodium metal; within a few minutes as the sodium metal vaporizes, the emission becomes the common bright yellow.

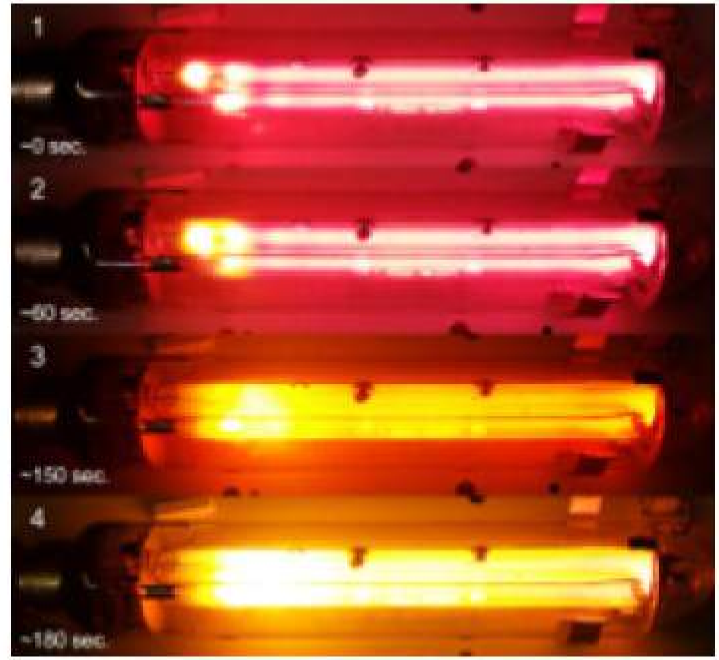
- These lamps produce a virtually monochromatic light averaging a 589.3 nm wavelength (actually two dominant spectral lines very close together at 589.0 and 589.6 nm).

- LPS lamps have an outer glass vacuum envelope around the inner discharge tube for thermal insulation, which improves their efficiency.

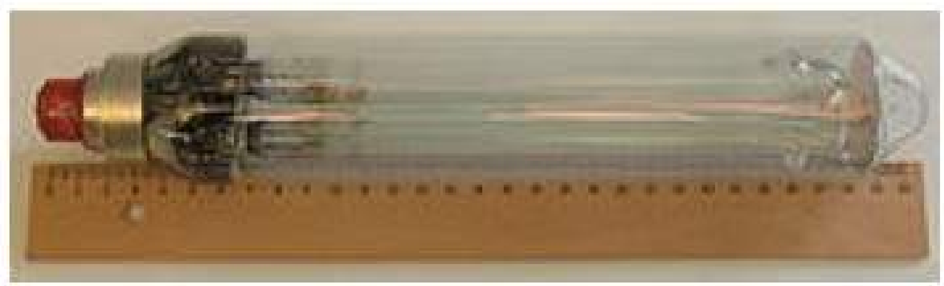
- They are efficient electrical light sources when measured in photopic lighting conditions, producing above 100 and up to 206 lm/W.

- They are used mainly for outdoor lighting (such as street lights and security lighting) where faithful color rendition is not important.

- Modern LPS lamps have a service life of about 18,000 hours and do not decline in lumen output with age, though they do increase in energy consumption by about 10% towards end of life.



Warm-up phases of a LPS lamp. The faint pink light of the Penning mixture is gradually replaced by the bright monochromatic orange light of the metallic sodium vapor.



High-pressure sodium

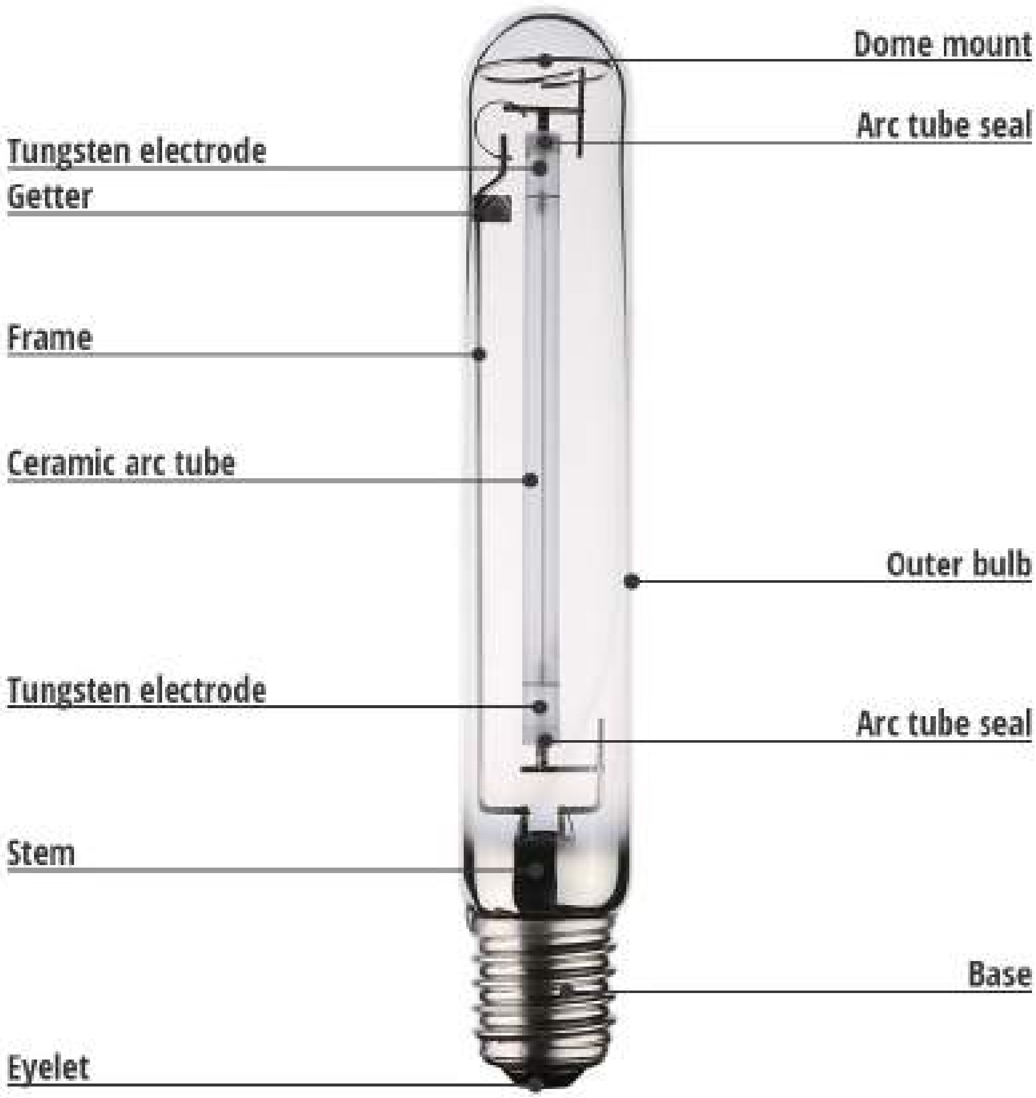
- High-pressure sodium lamps (sometimes called HPS lights) have been widely used in industrial lighting, especially in large manufacturing facilities, and are commonly used as plant grow lights. They have also been widely used for outdoor area lighting, such as on roadways, parking lots, and security areas.

- High-pressure sodium lamps are quite efficient — about 100 lumens per watt.

- Since the high-pressure sodium arc is extremely chemically reactive, the arc tube is typically made of translucent aluminum oxide.

- Xenon at a low pressure is used as a "starter gas" in the HPS lamp. It has the lowest thermal conductivity and lowest ionization potential of all the stable noble gases. The low thermal conductivity minimizes thermal losses in the lamp while in the operating state, and the low ionization potential causes the breakdown voltage of the gas to be relatively low in the cold state, which allows the lamp to be easily started.

HIGH PRESSURE SODIUM LAMP STRUCTURE



• An amalgam of metallic sodium and mercury lies at the coolest part of the lamp and provides the sodium and mercury vapor that is needed to draw an arc.

• The temperature of the amalgam is determined to a great extent by lamp power. The higher the lamp power, the higher will be the amalgam temperature. The higher the temperature of the amalgam, the higher will be the mercury and sodium vapor pressures in the lamp and the higher will be the terminal voltage. As the temperature rises, the constant current and increasing voltage consumes increasing energy until the operating level of power is reached. For a given voltage, there are generally three modes of operation:

1. The lamp is extinguished and no current flows.
2. The lamp is operating with liquid amalgam in the tube.
3. The lamp is operating with all amalgam evaporated.

• The first and last states are stable, because the lamp resistance is weakly related to the voltage, but the second state is unstable.

• Any anomalous increase in current will cause an increase in power, causing an increase in amalgam temperature, which will cause a decrease in resistance, which will cause a further increase in current. This will create a runaway effect, and the lamp will jump to the high current state. As the actual lamps are not designed to handle this much power, this would result in catastrophic failure.

• In practical use, the lamp is powered by an AC voltage source in series with an inductive "ballast" in order to supply a nearly constant current to the lamp, rather than a constant voltage, thus assuring stable operation.

• The light from the lamp consists of atomic emission lines of mercury and sodium, but is dominated by the sodium D-line emission.

• This line is extremely pressure (resonance) broadened and is also self reversed because of absorption in the cooler outer layers of the arc, giving the lamp its improved color rendering characteristics.

• In addition, the red wing of the D-line emission is further pressure broadened by the Van der Waals forces from the mercury atoms in the arc.

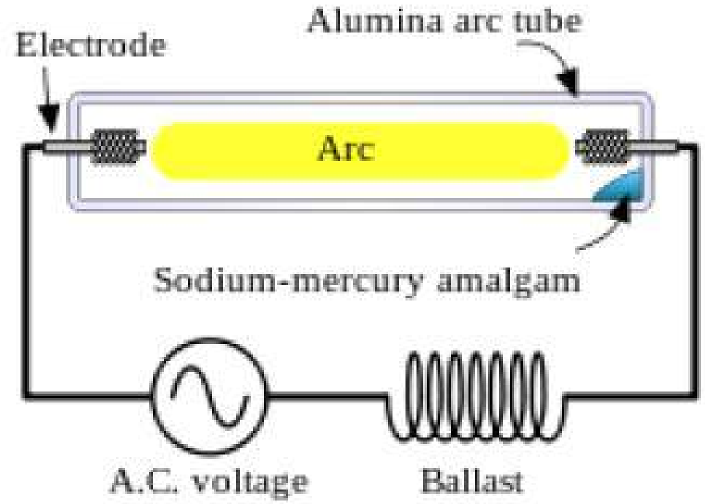


Diagram of a high-pressure sodium lamp.

High-pressure sodium lamp Philips SON-T Master 600 W

Mercury-vapor lamp

• A mercury-vapor lamp is a gas discharge lamp that uses an electric arc through vaporized mercury to produce light.

•The arc discharge is generally confined to a small fused quartz arc tube mounted within a larger borosilicate glass bulb.

• The outer bulb may be clear or coated with a phosphor; in either case, the outer bulb provides thermal insulation, protection from the ultraviolet radiation the light produces, and a convenient mounting for the fused quartz arc tube.

• Mercury vapor lamps are more energy efficient than incandescent and most fluorescent lights, with luminous efficacies of 35 to 65 lumens/watt.

• Their other advantages are a long bulb lifetime in the range of 24,000 hours and a high intensity, clear white light output.

• Clear mercury lamps produce white light with a bluish-green tint due to mercury's combination of spectral lines.

•They operate at an internal pressure of around one atmosphere and require special fixtures, as well as an electrical ballast.

•They also require a warm-up period of 4 – 7 minutes to reach full light output.

A closeup of a 175-W mercury vapor lamp. The small diagonal cylinder at the bottom of the arc tube is a resistor which supplies current to the starter electrode.

Principle of operation

- The mercury in the tube is a liquid at normal temperatures. It needs to be vaporized and ionized before the lamp can produce its full light output.

- To facilitate starting of the lamp, a third electrode is mounted near one of the main electrodes and connected through a resistor to the other main electrode.

- In addition to the mercury, the tube is filled with argon gas at low pressure. When power is applied, if there is sufficient voltage to ionize the argon, the ionized argon gas will strike a small arc between the starting electrode and the adjacent main electrode.

- As the ionized argon conducts, the heat from its arc vaporizes the liquid mercury; next, the voltage between the two main electrodes will ionize the mercury gas.

- An arc initiates between the two main electrodes and the lamp will then radiate mainly in the ultraviolet, violet and blue emission lines.

• Continued vaporization of the liquid mercury increases the arc tube pressure to between 2 and 18 bar, depending on lamp size. The increase in pressure results in further brightening of the lamp.

• The entire warm-up process takes roughly 4 to 7 minutes.

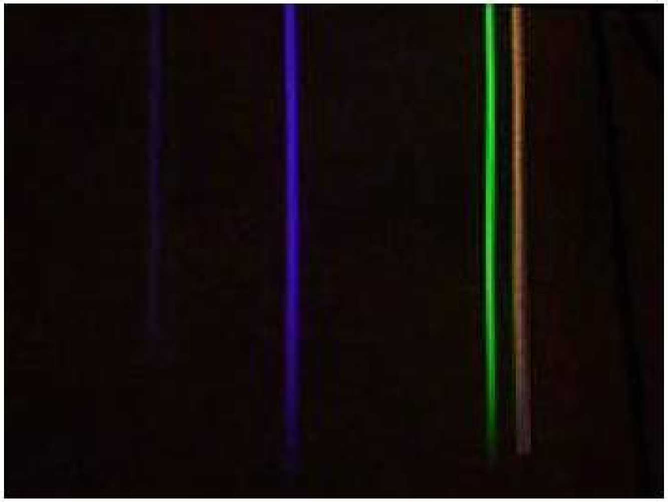
• The mercury vapor lamp is a negative resistance device. This means its resistance decreases as the current through the tube increases. So if the lamp is connected directly to a constant-voltage source like the power lines, the current through it will increase until it destroys itself. Therefore, it requires a ballast to limit the current through it. Mercury vapor lamp ballasts are similar to the ballasts used with fluorescent lamps.

Mercury vapor street light

• To correct the bluish tinge, many mercury vapor lamps are coated on the inside of the outer bulb with a phosphor that converts some portion of the ultraviolet emissions into red light. This helps to fill in the otherwise very-deficient red end of the electromagnetic spectrum. These lamps are generally called "color corrected" lamps.

•Low-pressure mercury-vapor lamps usually have a quartz bulb in order to allow the transmission of short wavelength light. If synthetic quartz is used, then the transparency of the quartz is increased further and an emission line at 185 nm is observed also. Such a lamp can then be used for ultraviolet germicidal irradiation. The 185 nm line will create ozone in an oxygen containing atmosphere, which helps in the cleaning process, but is also a health hazard.

Example of a phosphor-coated 125 W lamp



Line spectrum of mercury vapor. The blue-green tint of mercury vapor lamps is caused by the strong violet and green lines.

LASER

• The term "laser" originated as an acronym for "**light amplification by stimulated emission of radiation“.**

• The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow.

• A laser differs from other sources of light in that it emits light which is *coherent. Spatial coherence allows a laser to be focused to a tight* spot, enabling applications such as laser cutting and lithography.

• Spatial coherence also allows a laser beam to stay narrow over great distances (collimation), enabling applications such as laser pointers and lidar. Lasers can also have high temporal coherence, which allows them to emit light with a very narrow spectrum, i.e., they can emit a single color of light.

• Alternatively, temporal coherence can be used to produce pulses of light with a broad spectrum but durations as short as a femtosecond ("ultrashort pulses").

• Lasers are used in optical disk drives, laser printers, barcode scanners, DNA sequencing instruments, fiber-optic, semiconducting chip manufacturing (photolithography), and free-space optical communication, laser surgery and skin treatments, cutting and welding materials, military and law enforcement devices for marking targets and measuring range and speed, and in laser lighting displays for entertainment. They have been used for car headlamps on luxury cars, by using a blue laser and a phosphor to produce highly directional white light.

Laserlink point to point optical wireless network

The US-Israeli Tactical High Energy weapon has been used to shoot down rockets and artillery shells.

A 5.6 mm 'closed can' commercial laser diode, probably from a CD or DVD player

PROPERTIES OF LASER

- **Monochromatic** (emit only **one wave length**)
- **Coherence** (all in **same phase**-improve focusing)
- **Polarized** (in **one plane**-easy to pass through media)
- **Collimated** (in **one direction** & non spreading)
- **High energy** (Intensity measured by **Watt** J/s)

A laser beam used for welding

Laserlink point to point optical wireless network

TYPES OF LASER HAZARDS

1. *Eye*: Acute exposure of the eye to lasers of certain wavelengths and power can cause corneal or retinal burns (or both). Chronic exposure to excessive levels may cause corneal or lenticular opacities (cataracts) or retinal injury.
2. *Skin*: Acute exposure to high levels of optical radiation may cause skin burns; while carcinogenesis may occur for ultraviolet wavelengths (290-320 nm).
3. *Chemical*: Some lasers require hazardous or toxic substances to operate (i.e., chemical dye, Excimer lasers).
4. *Electrical*: Most lasers utilize high voltages that can be lethal.
5. *Fire*: The solvents used in dye lasers are flammable. High voltage pulse or flash lamps may cause ignition. Flammable materials may be ignited by direct beams or specular reflections from high power continuous wave (CW) infrared lasers.

Design

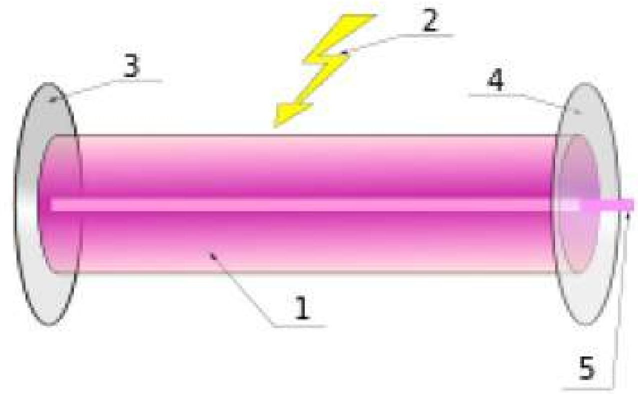
• A laser consists of a gain medium, a mechanism to energize it, and something to provide optical feedback.

• The gain medium is a material with properties that allow it to amplify light by way of stimulated emission.

• Light of a specific wavelength that passes through the gain medium is amplified.

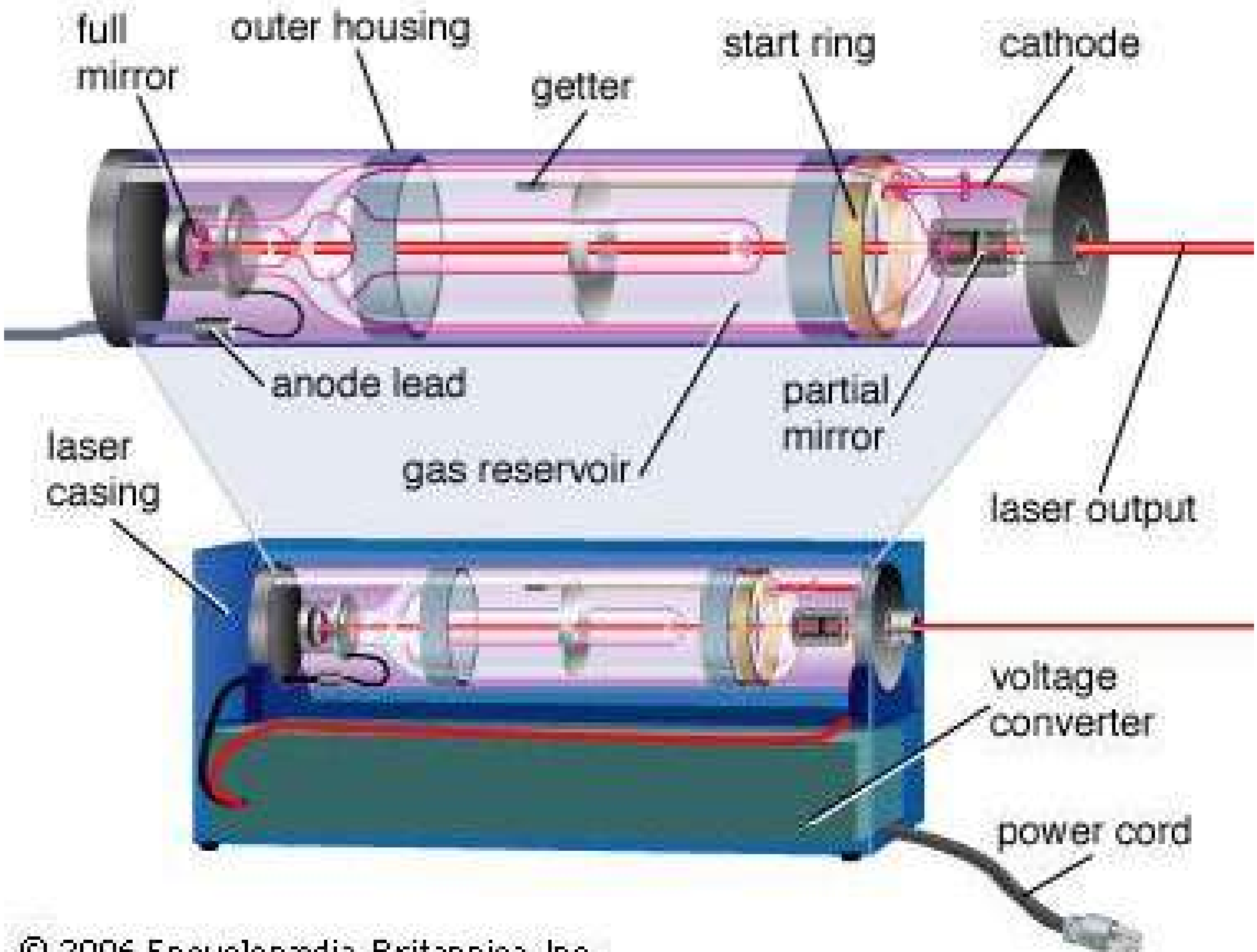
• For the gain medium to amplify light, it needs to be supplied with energy in a process called pumping.

• The energy is typically supplied as an electric current or as light at a different wavelength. Pump light may be provided by a flash lamp or by another laser.



Components of a typical laser:

1. Gain medium
2. Laser pumping energy
3. High reflector
4. Output coupler
5. Laser beam


full mirror
outer housing
getter
start ring
cathode
anode lead
partial mirror
laser casing
gas reservoir
laser output
voltage converter
power cord

Stimulated emission

• An electron in an atom can absorb energy from light (photons) or heat (phonons) only if there is a transition between energy levels that matches the energy carried by the photon or phonon.

• Photons with the correct wavelength can cause an electron to jump from the lower to the higher energy level. The photon is consumed in this process.

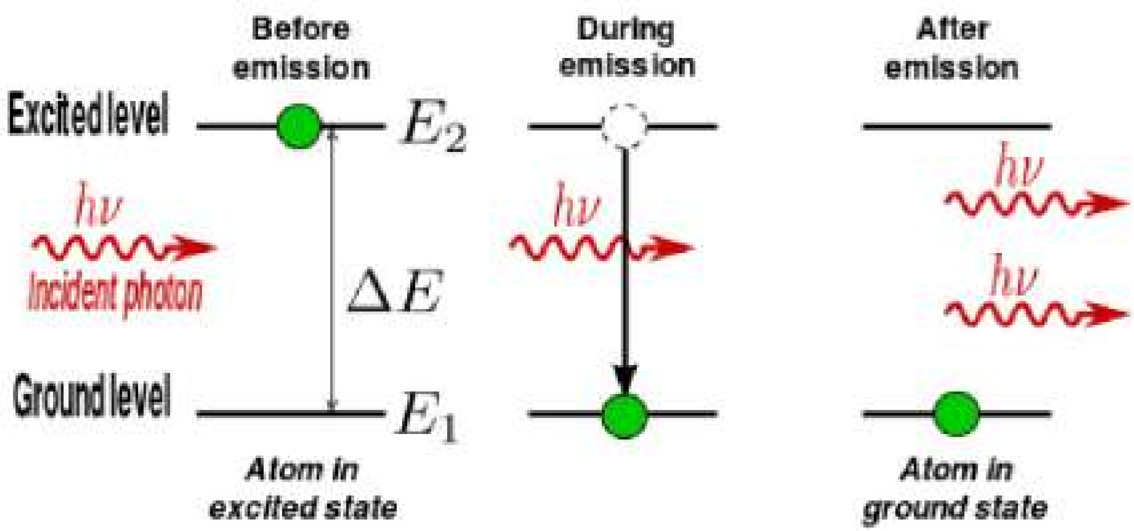
• When an electron is excited to a higher energy level, it will not stay that way forever. Eventually, the electron decays to a lower energy level which is not occupied, with transitions to different levels having different time constants. When such an electron decays without external influence, it emits a photon. This process is called "spontaneous emission".

• The emitted photon has random phase and direction, but its wavelength matches the absorption wavelength of the transitiion. This is the mechanism of fluorescence and thermal emission.

• A photon with the correct wavelength to be absorbed by a transition can also cause an electron to drop from the higher to the lower level, emitting a new photon. The emitted photon exactly matches the original photon in wavelength, phase, and direction. This process is called **stimulated emission**.

• When the number of particles in one excited state exceeds the number of particles in some lower-energy state, **population inversion** is achieved.

• In this state, the rate of stimulated emission is larger than the rate of absorption of light in the medium, and therefore the light is amplified. A system with this property is called an **optical amplifier**.



$$E_2 - E_1 = \Delta E = h\nu$$

• Since the early period of laser history, laser research has produced a variety of improved and specialized laser types, optimized for different performance goals, including :

- ➢ new wavelength bands
- ➢ maximum average output power
- ➢ maximum peak pulse energy
- ➢ maximum peak pulse power
- ➢ minimum output pulse duration
- ➢ minimum linewidth
- ➢ maximum power efficiency
- ➢ minimum cost

and this research continues to this day.


The free-electron laser *FELIX* at the FOM Institute for Plasma Physics Rijnhuizen, Nieuwegein

• In 2015, researchers made a white laser, whose light is modulated by a synthetic nanosheet made out of zinc, cadmium, sulfur, and selenium that can emit red, green, and blue light in varying proportions, with each wavelength spanning 191 nm.

• In 2017, researchers at TU Delft demonstrated an AC Josephson junction microwave laser. Since the laser operates in the superconducting regime, it is more stable than other semiconductor-based lasers. The device has potential for applications in quantum computing.

DIFFERENT TYPES OF LASER

Solid State	Gas	Metal vapour	Dye	Excimer	Diode
Ruby	Ion	Copper	Rhodamine	Argon Fluoride	Gallium-Aluminium Arsenide
Nd YAG	Argon	Gold		Krypton Fluoride	
Erbium YAG	Krypton			Krypton Chloride	
	Helium				
	CO_2				

Uses

• When lasers were invented in 1960, they were called "a solution looking for a problem". Since then, they have become ubiquitous, finding utility in thousands of highly varied applications in every section of modern society, including consumer electronics, information technology, science, medicine, industry, law enforcement, entertainment, and the military. Fiber-optic communication using lasers is a key technology in modern communications, allowing services such as the Internet.

• The first widely noticeable use of lasers was the supermarket barcode scanner, introduced in 1974. The laserdisc player, introduced in 1978, was the first successful consumer product to include a laser but the compact disc player was the first laser-equipped device to become common, beginning in 1982 followed shortly by laser printers.

Communications: besides fiber-optic communication, lasers are used for free-space optical communication, including laser communication in space.

Medicine: Lasers have many uses in medicine, including laser surgery (particularly eye surgery), laser healing, kidney stone treatment, ophthalmoscopy, and cosmetic skin treatments such as acne treatment, cellulite and striae reduction, and hair removal. Lasers are used to treat cancer by shrinking or destroying tumors or precancerous growths. They are most commonly used to treat superficial cancers that are on the surface of the body or the lining of internal organs. They are used to treat basal cell skin cancer and the very early stages of others like cervical, penile, vaginal, vulvar, and non-small cell lung cancer. Laser therapy is often combined with other treatments, such as surgery, chemotherapy, or radiation therapy. Laser-induced interstitial thermotherapy (LITT), or interstitial laser photocoagulation, uses lasers to treat some cancers using hyperthermia, which uses heat to shrink tumors by damaging or killing cancer cells. Lasers are more precise than traditional surgery methods and cause less damage, pain, bleeding, swelling, and scarring. A disadvantage is that surgeons must have specialized training. It may be more expensive than other treatments.

Industry: cutting including converting thin materials, welding, material heat treatment, marking parts (engraving and bonding), additive manufacturing or 3D printing processes such as selective laser sintering and selective laser melting, non-contact measurement of parts and 3D scanning, and Laser cleaning.

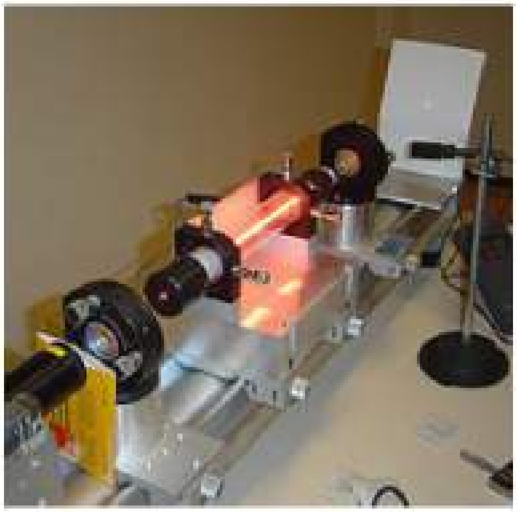
Military: marking targets, guiding munitions, missile defense, electro-optical countermeasures (EOCM), lidar, blinding troops. A laser weapon is a laser that is used as a directed-energy weapon.

Law enforcement: LIDAR traffic enforcement. Lasers are used for latent fingerprint detection in the forensic identification field.

Research: spectroscopy, laser ablation, laser annealing, laser scattering, laser interferometry, lidar, laser capture microdissection, fluorescence microscopy, metrology, laser cooling.

Commercial products: laser printers, barcode scanners, thermometers, laser pointers, holograms, bubblegrams.

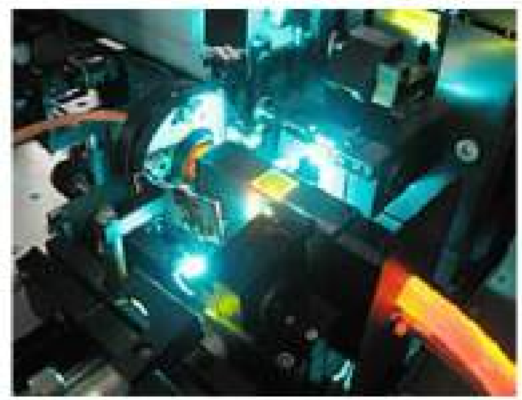
Entertainment: optical discs, laser lighting displays, laser turntables



A helium–neon laser demonstration. The glow running through the center of the tube is an electric discharge. This glowing plasma is the gain medium for the laser. The laser produces a tiny, intense spot on the screen to the right. The center of the spot appears white because the image is overexposed there.

Mercury Laser Altimeter (MLA) of the MESSENGER spacecraft

A 50 W FASOR, based on a Nd:YAG laser, used at the Starfire Optical Range.



Close-up of a table-top dye laser based on Rhodamine 6G