PH 301

ENGINEERING OPTICS

Lecture_Optical Sources_19

Incandescent sources

Thomas Edison, 1878

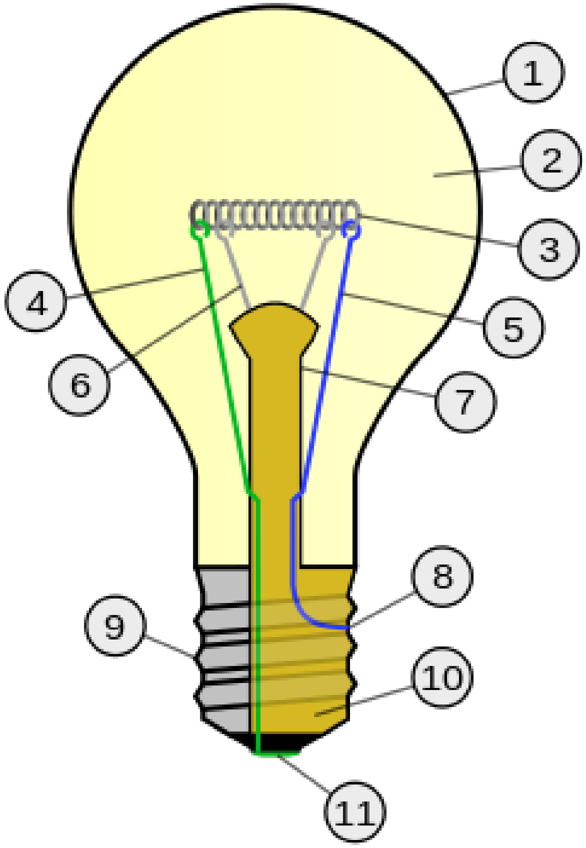
An incandescent light bulb, lamp or globe is an electric light with a wire filament heated to such a high temp. that it glows with visible light (incandescence).

Filament, heated by passing an electric current through it, is protected from oxidation with a glass or fused quartz bulb that is filled with inert gas or evacuated.

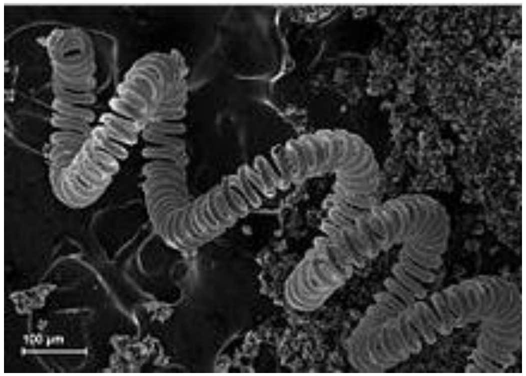
Halogen lamp - filament evaporation is slowed by a chemical process that redeposits metal vapor onto filament, extending its life.

A 230-volt incandescent light bulb

Incandescent light globe



1. Outline of Glass bulb
2. Low pressure inert gas (argon, nitrogen, krypton, xenon)
3. Tungsten filament
4. Contact wire (goes out of stem)
5. Contact wire (goes into stem)
6. Support wires (one end embedded in stem; conduct no current)
7. Stem (glass mount)
8. Contact wire (goes out of stem)
9. Cap (sleeve)
10. Insulation (vitrite)
11. Electrical contact



SEM image of a tungsten incandescent light bulb

Incandescent bulbs are manufactured in a wide range of sizes, light output, & voltage ratings (1.5 – 300 volts). They require no external regulating equipment, have low manufacturing costs, & work equally well on either ac or dc.

Incandescent bulbs are much less efficient than most other types of electric lighting; incandescent bulbs convert less than 5% of energy they use into visible light, with standard light bulbs averaging about 2.2%. Remaining energy is converted into heat.

Luminous efficacy	lumens per watt (lm/W)
Typical incandescent bulb	16 lm/W
Compact fluorescent bulb	60 lm/W
White LED lamps	150 lm/W

Lifetime	Hours
Incandescent bulbs	1000 hours
Compact fluorescent bulb	10,000 hours
LEDs	30,000 hours

Photoluminescence

(Generation of luminescence through excitation of a molecule by UV or visible light photons)

Depending upon electronic configuration of excited state & emission pathway.

Fluorescence

Property of some atoms & molecules to absorb light at a particular wavelength & to subsequently emit light of longer wavelength after a brief interval, termed fluorescence lifetime.

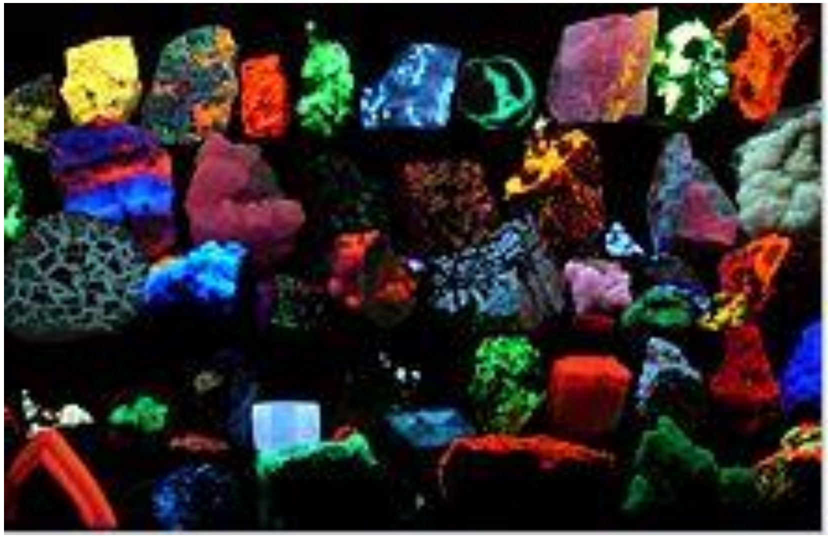
Phosphorescence

It occurs in a manner similar to fluorescence, but with a much longer excited state lifetime.

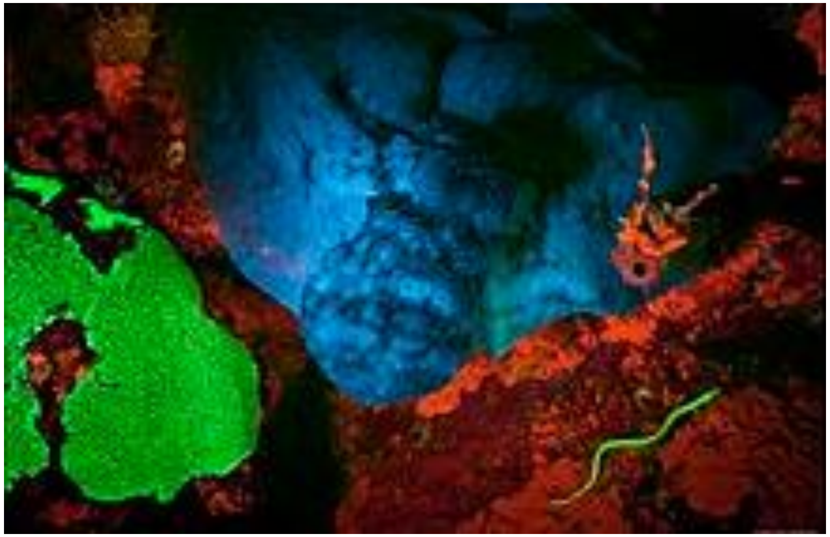
Fluorescent sources

- Fluorescence occurs when absorbed radiation is in UV region, & thus invisible to human eye, while emitted light is in visible region, which gives the fluorescent substance a distinct color that can only be seen when exposed to UV light.

- Fluorescent materials cease to glow immediately when the radiation source stops, unlike phosphorescence, where it continues to emit light for some time after.



Fluorescent minerals emit visible light when exposed to UV light



Biofluorescent marine organisms

In 1852, George Gabriel Stokes described the ability of Fluorspar & Uranium glass to change invisible light beyond violet end of visible spectrum into blue light.

Applications

(Tremendously sensitive emission profiles, spatial resolution, & high specificity)

- **Mineralogy**
- **Gemology**
- **Medicine**
- **Chemical sensor**
- **Fluorescent labelling**
- **Dyes**
- **Biological detectors**
- **Cosmic-ray detection**
- **Fluorescent lamps**

Fluorescence occurs frequently in nature in some minerals & in various biological states in many branches of animal kingdom.

Photochemistry

Fluorescence occurs when an orbital electron of a molecule or atom relaxes to its ground state by emitting a photon from an excited singlet state.

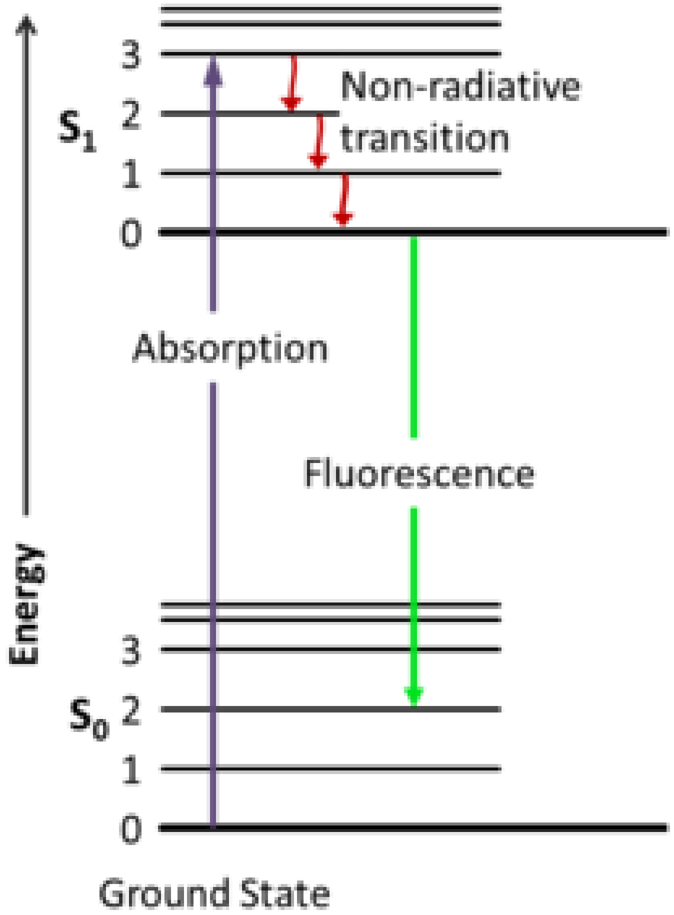
Excitation: $S_0 + h\nu_{ex} \rightarrow S_1$

Fluorescence (Emission): $S_1 \rightarrow S_0 + h\nu_{em} + heat$

Quantum yield: **Efficiency of fluorescence process**

$$\Phi = \frac{\text{Number of photons emitted}}{\text{Number of photons absorbed}}$$

Jablonski Energy Diagram



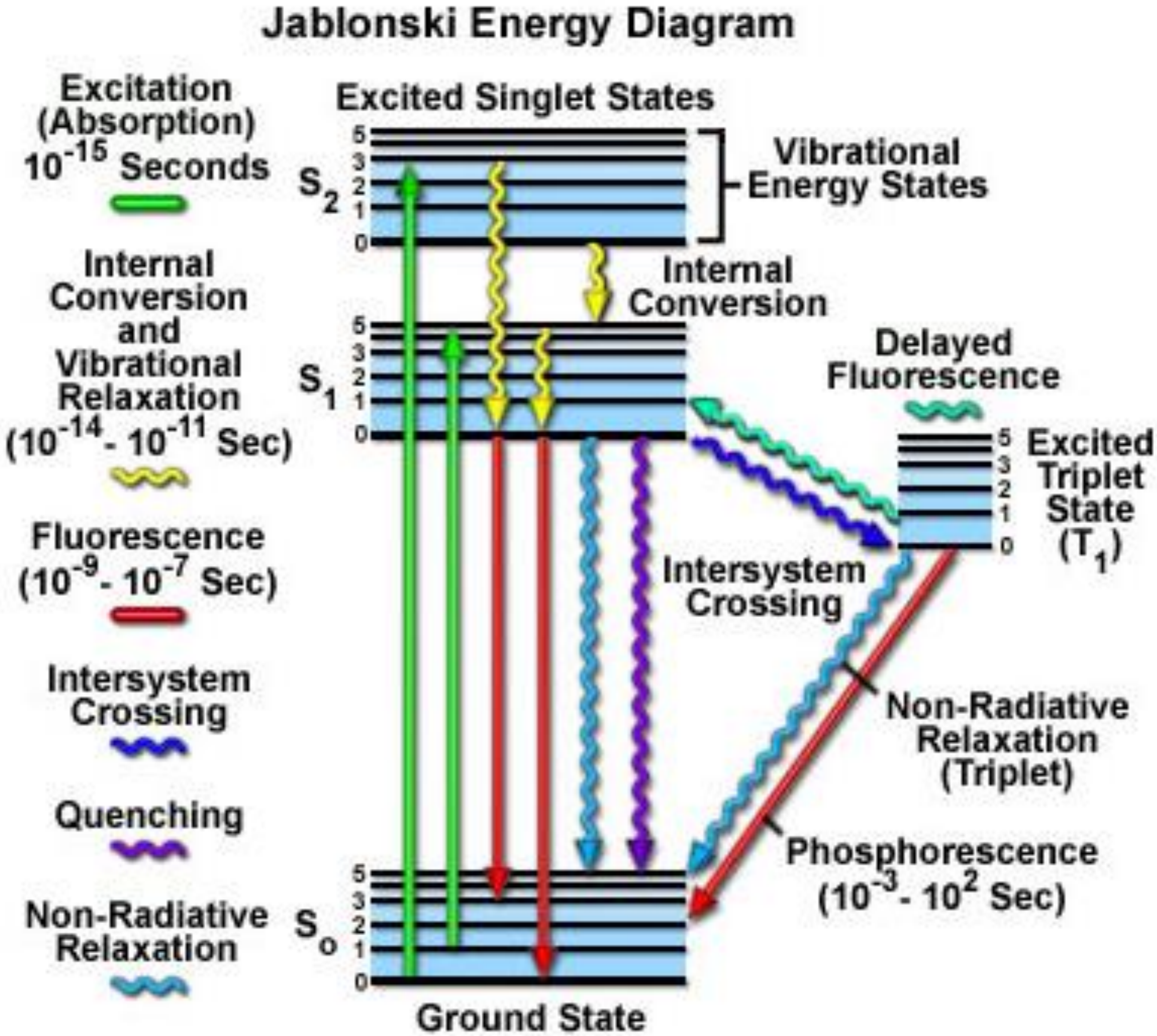
After an electron absorbs a high-energy photon the system is excited electronically & vibrationally. System relaxes vibrationally & eventually fluoresces at a longer wavelength.

Fluorescence process is governed by three important events.

1. **Excitation of a susceptible molecule by an incoming photon happens in femtoseconds (10^{-15} seconds), while vibrational relaxation of excited state electrons to lowest energy level is much slower in picoseconds (10^{-12} seconds).**

2. **Emission of a longer wavelength photon & return of the molecule to ground state, occurs in relatively long time period of nanoseconds (10^{-9} seconds).**

Although entire molecular fluorescence lifetime, from excitation to emission, is measured in only billionths of a second, the phenomenon is a stunning manifestation of interaction between light & matter that forms the basis for expansive fields of steady state & time-resolved fluorescence spectroscopy & microscopy.



Jablonski Energy Diagram
Excitation (Absorption) 10^{-15} Seconds
Internal Conversion and Vibrational Relaxation (10^{-14} - 10^{-11} Sec)
Fluorescence (10^{-9} - 10^{-7} Sec)
Intersystem Crossing
Quenching
Non-Radiative Relaxation
Excited Singlet States
S_2
S_1
S_o
5
3
2
1
0
Vibrational Energy States
Internal Conversion
Delayed Fluorescence
Excited Triplet State (T_1)
Intersystem Crossing
Non-Radiative Relaxation (Triplet)
Phosphorescence (10^{-3} - 10^{2} Sec)
Ground State

Timescale Range for Fluorescence Processes

Transition	Process	Rate Constant	Timescale (Seconds)
S(0) => S(1) or S(n)	Absorption (Excitation)	Instantaneous	10^{-15}
S(n) => S(1)	Internal Conversion	k(ic)	10^{-14} to 10^{-10}
S(1) => S(1)	Vibrational Relaxation	k(vr)	10^{-12} to 10^{-10}
S(1) => S(0)	Fluorescence	k(f) or Γ	10^{-9} to 10^{-7}
S(1) => T(1)	Intersystem Crossing	k(pT)	10^{-10} to 10^{-8}
S(1) => S(0)	Non-Radiative Relaxation Quenching	k(nr), k(q)	10^{-7} to 10^{-5}
T(1) => S(0)	Phosphorescence	k(p)	10^{-3} to 100
T(1) => S(0)	Non-Radiative Relaxation Quenching	k(nr), k(qT)	10^{-3} to 100

Discharge Lamps

German Glassblower - Heinrich Geissler, 1857

Gas-discharge lamps are a family of artificial light sources that generate light by sending an electric discharge through an ionized gas, a plasma.

- **Such lamps use a noble gas (argon, neon, krypton, & xenon) or a mixture of these gases. Some include additional substances, like mercury, sodium, & metal halides, which are vaporized during startup to become part of the gas mixture.**

- **In operation, some of the electrons are forced to leave atoms of gas near anode by electric field applied between two electrodes, leaving these atoms positively ionized. Electrons ejected from these atoms flow onto the anode, while cations thus formed are accelerated by electric field & flow towards the cathode.**

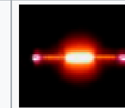
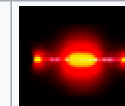
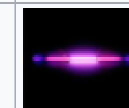
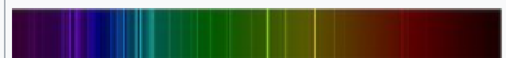
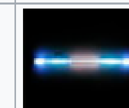
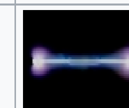
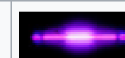
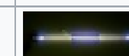
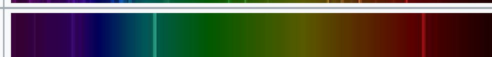
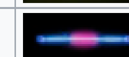
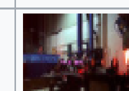
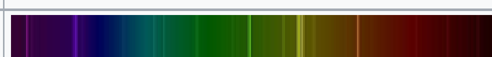
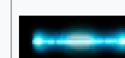
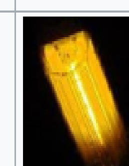
- **After traveling a very short distance, ions collide with neutral gas atoms, which transfer their electrons to ions. Atoms, having lost an electron during collisions, ionize & speed toward the cathode while ions, having gained an electron during collisions, return to a lower energy state while releasing energy as photons.**

Colour depends on emission spectra of atoms making up the gas, as well as pressure of the gas, current density, & other variables.

Gas discharge lamps can produce a wide range of colors. Some lamps produce UV radiation which is converted to visible light by a fluorescent coating on inside of the lamp's glass surface.

Gas-discharge lamps offer higher efficiency, but are more complicated to manufacture & most exhibit negative resistance, causing resistance in the plasma to decrease as the current flow increases. Therefore, they usually require auxiliary electronic equipment such as ballasts to control current flow through the gas, preventing current runaway (arc flash).

Some gas-discharge lamps also have a perceivable start-up time to achieve their full light output.

Gas	Color	Spectrum	Notes	Image
Helium	White to orange; under some conditions may be gray, blue, or green-blue.		Used by artists for special purpose lighting.	
Neon	Red-orange		Intense light. Used frequently in neon signs and neon lamps.	
Argon	Violet to pale lavender blue		Often used together with mercury vapor.	
Krypton	Gray off-white to green. At high peak currents, bright blue-white.		Used by artists for special purpose lighting.	
Xenon	Gray or blue-gray dim white. At high peak currents, very bright green-blue.		Used in flashtubes, xenon HID headlamps, and xenon arc lamps.	
Nitrogen	Similar to argon but duller, more pink; at high peak currents bright blue-white.			
Oxygen	Violet to lavender, dimmer than argon			
Hydrogen	Lavender at low currents, pink to magenta over 10 mA			
Water vapor	Similar to hydrogen, dimmer			
Carbon dioxide	Blue-white to pink, in lower currents brighter than xenon		Used in carbon dioxide lasers.	
Mercury vapor	Light blue, intense ultraviolet	 Ultraviolet not shown	In combination with phosphors used to generate many colors of light. Widely used in mercury-vapor lamps.	
Sodium vapor (low pressure)	Bright orange-yellow		Widely used in sodium vapor lamps.	

High Intensity Discharge Lamp

Nondirectional light sources

HID lamps are similar to fluorescents in that an arc is generated between two electrodes. Arc in a HID source is shorter, yet it generates much more light, heat, & pressure within arc tube.

HID sources in increasing order of efficacy (lumens per watt):

- **Mercury vapor**
- **Metal halide**
- **H-pressure sodium**
- **L-pressure sodium**

Like fluorescent lights, HID also require ballasts, & they take a few seconds to produce light when first turned on because the ballast needs time to establish the electric arc.

Originally developed for outdoor & industrial applications, HID lamps are now used in office, retail, & other indoor applications. Their color rendering characteristics have been improved, & lower wattages have recently become available (as low as 18 watts).

High intensity discharge lamp

Advantages of HID lamps	Disadvantages of HID lamps
Relatively long life (5000 to 24000 hrs)	HID lamps require time to warm up. It varies from lamp to lamp, but the average warm-up time is two to six minutes.
Relatively high lumen output per watt	HID lamps have a "restrike" time, meaning a momentary interruption of current or a voltage drop too low to maintain the arc will extinguish the lamp.
Relatively small in physical size	

- When HID lamps reach "restrike" time, gases inside lamp are too hot to ionize, & time is needed for the gases to cool & pressure to drop before the arc will restrike. This process of restriking takes between 5 & 15 minutes, depending on HID source. Therefore, good applications of HID lamps are areas where lamps are not switched on & off intermittently.

Mercury vapor lamps have phosphor coatings & have better color qualities. Mercury vapor lamps are not as efficacious as most fluorescent lamps or other HID lamps of equivalent light output.

Use: Indoor & outdoor lighting (gymnasiums, factories, departmental stores, banks, highways, parks, sports fields).

Mercury vapor lamps consist of an inner arc discharge tube constructed of quartz surrounded by an outer hard borosilicate glass envelope. Shortwave UV, a result of the decay of mercury atom electrons from an excited to a stable state, is readily transmitted through inner quartz tube but is virtually blocked by the outer glass envelope during normal operation.

Metal halide lamps are more efficacious than mercury vapor lamps. Compact metal halide lamps come in lower wattages. Most metal halide lamps require an enclosed luminaire or other protective measure to guard against possible end-of-life rupture & to filter UV light, although some of the new low-wattage types are available for use in open fixtures.

- Metal Halide lamps are similar to mercury vapor lamps but use metal halide additives inside arc tube along with mercury & argon. These additives enable lamp to produce more visible light per watt with improved color rendition.

- Wattages range from 32 to 2,000, offering a wide range of indoor & outdoor applications. Efficacy of these lamps ranges from 50 to 115 lumens per watt, typically about double that of mercury vapor.

- Because of good color rendition & high lumen output, these lamps are good for sports arenas & stadiums. Indoor uses include large auditoriums & convention halls.

- High-pressure sodium lamps require a ballast with a high-voltage starter because, unlike mercury & metal halide lamps, they do not contain starting electrodes.

- High-pressure sodium lamps produce a yellow-white light & are not appropriate where good color rendering is important; however, there are two types of improved-color high-pressure sodium lamps: white & improved color.

- White high-pressure sodium lamps have correlated color temperature (CCT) ratings that approach those of incandescent lamps. In both types, efficacy is significantly reduced compared to standard high-pressure sodium lamps, but much greater than incandescent lamps.

- Color: Generally poor, although good color rendering is available from some metal halide & improved-color high-pressure sodium lamps. Color appearance may shift over time.

Light Output: High

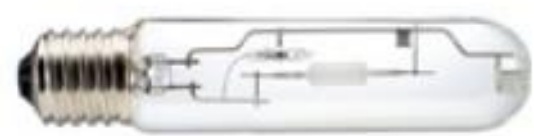
High-pressure sodium lamp: Outdoor & Industrial applications.

- **Such lamps do not contain starting electrodes; ballast circuit includes a high-voltage electronic starter.**

- **Arc tube is made of a ceramic material which can withstand temp. up to 2,372°F. It is filled with xenon to help start the arc, as well as a sodium-mercury gas mixture.**

- **Efficacy of such lamp is very high (140 lumens per watt). Ex., A 400-watt high pressure sodium lamp produces 50,000 initial lumens. Same wattage metal halide lamp produces 40,000 initial lumens, & 400- watt mercury vapor lamp produces only 21,000 initially.**


Supermini Precise™
High intensity discharge lamp



Wattage: High intensity discharge lamps require a compatible ballast, which consumes some power during lamp operation.

Efficacy: High

Life: Very long (up to 24,000 hours)

Cost: Higher than incandescent & fluorescent lamps. Mercury vapor lamps are less expensive than high-pressure sodium or metal halide lamps, but are less efficacious.