IBTM 5680 Lighting Engineering

http://ibse.hk/IBTM5680/

Light Sources & Luminaires

Ir Dr. Sam C. M. Hui

E-mail: sam.cmhui@gmail.com

http://ibse.hk/cmhui/

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- Incandescent
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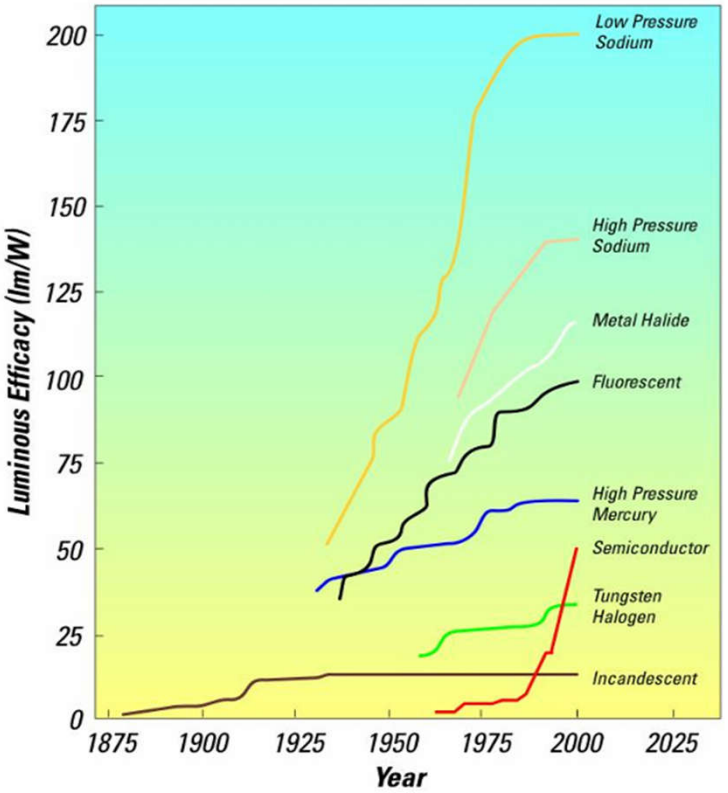
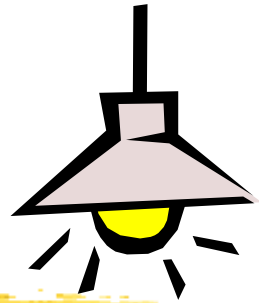
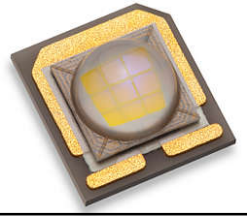


Light sources

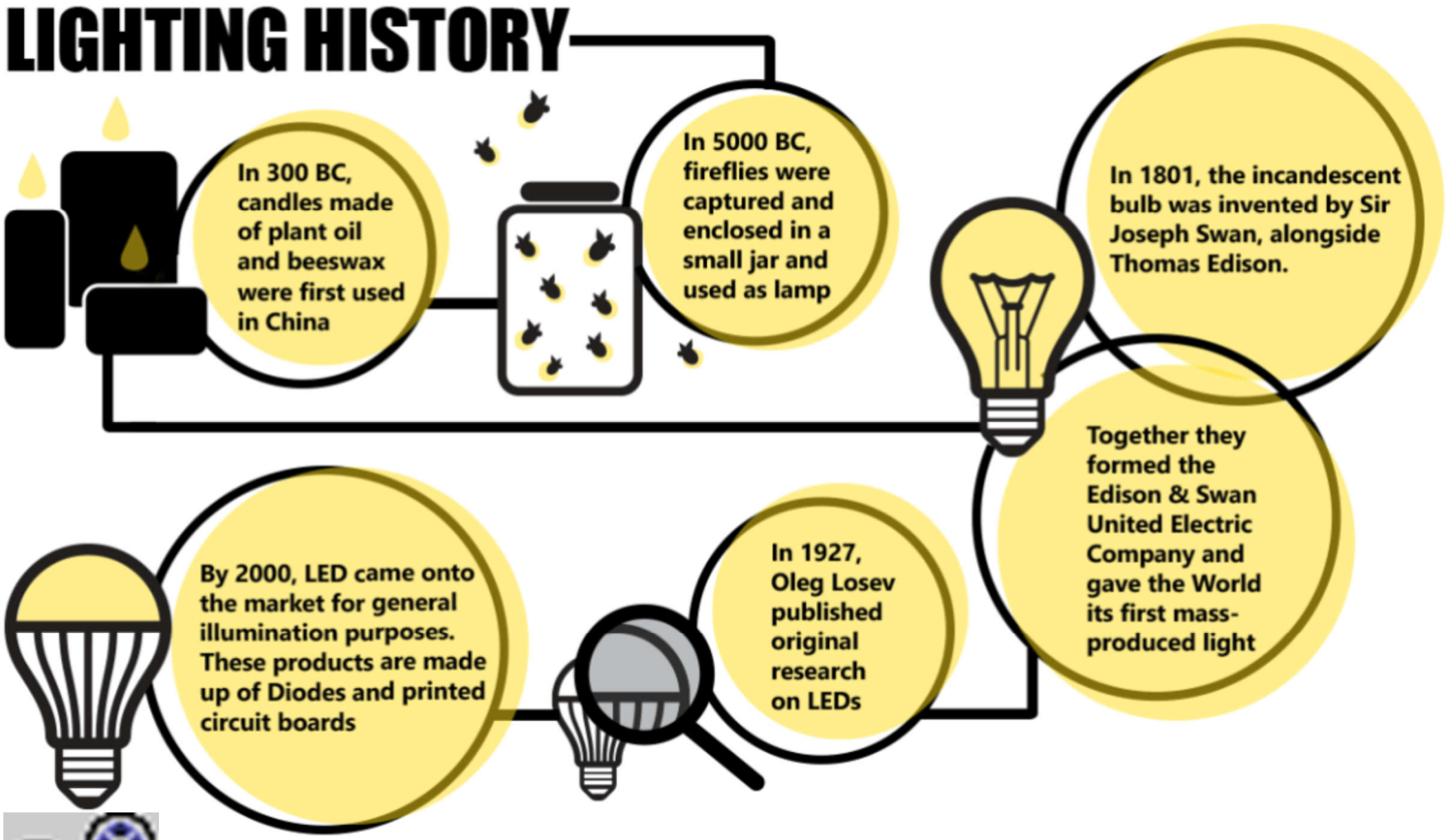


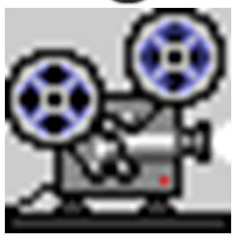
- Historical evolution of lighting
  - Natural light (the sun, daylight)
  - Torches (e.g. fire, wood + animal fat)
  - Candles & the wick
  - Gas lamps (e.g. street lighting)
  - Electric lamps
    - Incandescent light bulbs, fluorescent lights
    - Mercury-vapour & high intensity discharge lamps
    - Light emitting diode (LED) lighting



(Source: The Historical Evolution of Lighting https://www.stouchlighting.com/blog/the-historical-evolution-of-lighting)

Lighting history and light bulbs



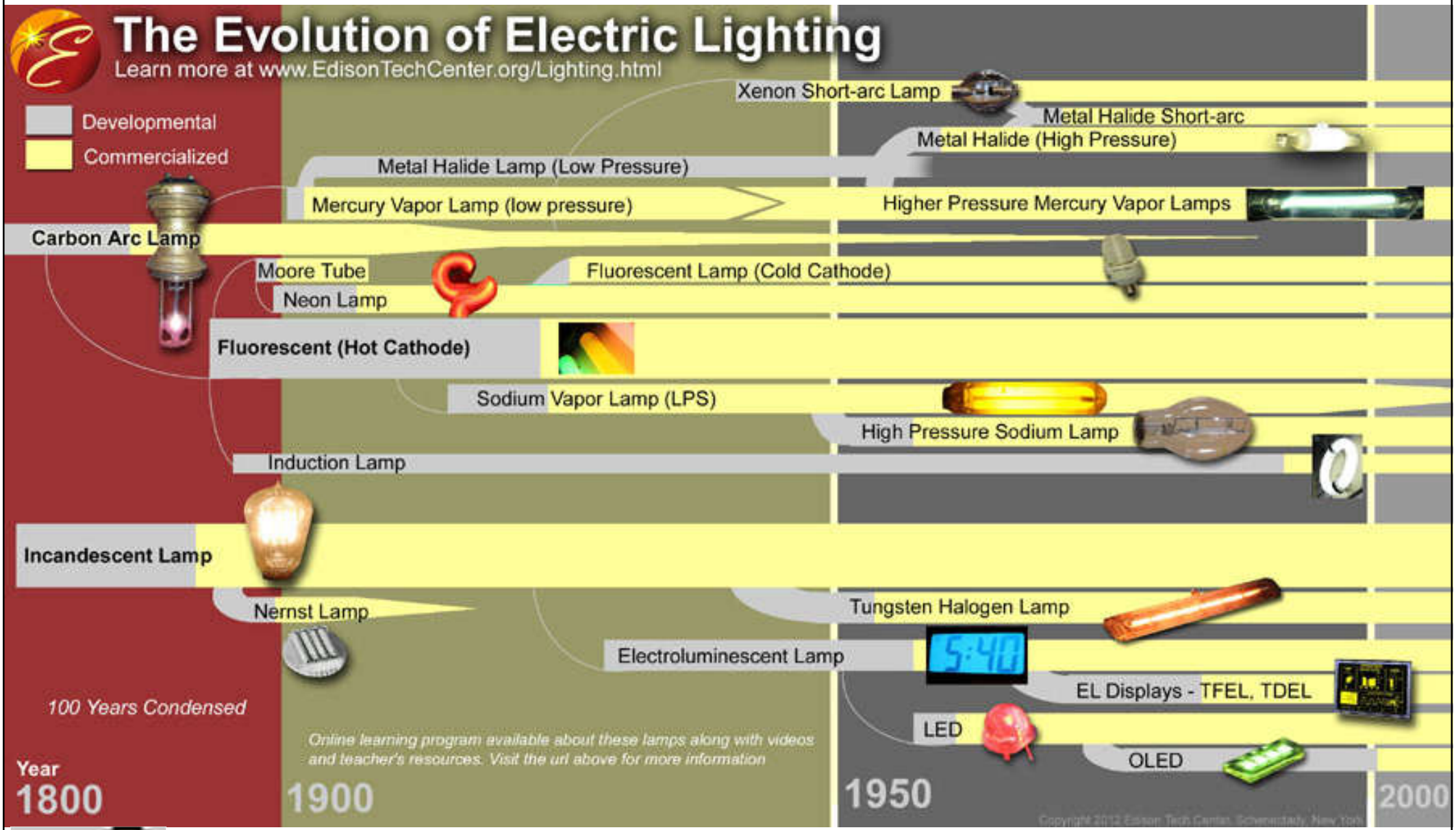


Video: Out of the Dark: The History of Lighting (2:16) https://youtu.be/85wz-jVfa1U

(Source: https://www.standardpro.com/advent-of-the-light-bulb/)


Traditional incandescent
Halogen incandescent
Compact fluorescent (CFL)
Light-emitting diode (LED)
Approximate wattage needed to produce 1,600 lumens
100 watts
77* watts
23 watts
20 watts
INPUT
OUTPUT
Wasted energy
1,600 lumens
1,600 lumens
1,600 lumens
1,600 lumens
Electric current heats an incandescent bulb's tungsten filament until it glows.
Halogen gas such as iodine inside the bulb prevents wear on the filament, allowing it to glow brighter.
Excited gas in a CFL tube emits ultraviolet photons, which coax the bulb's coating to emit visible light.
An LED bulb contains many small semiconductor units; each emits light when a voltage is applied.
LIFE SPAN: 750 hours
1,000 hours
10,000 hours
20,000 hours
PRICE: $0.37 per bulb
$1.59 per bulb
$2.23 per bulb
$45 per bulb

The evolution of electric lighting

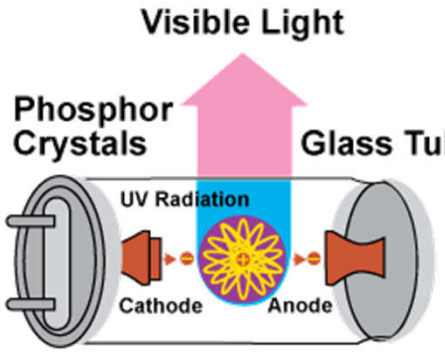


Video: Evolution of Light Bulbs, inventions - 2020 | History of Lighting, Documentary video (7:36) https://youtu.be/uszG5FD1_Uw

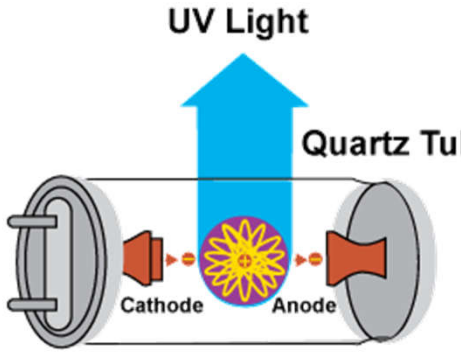
(Source: https://edisontechcenter.org/Lighting.html)

Light sources

- Mechanisms for production of light radiation:
  - Incandescence
  - Electric discharges
  - Electroluminescence
  - Luminescence
  - Radioluminescence
  - Cathodoluminescence
  - Chemiluminescence
  - Thermoluminescence

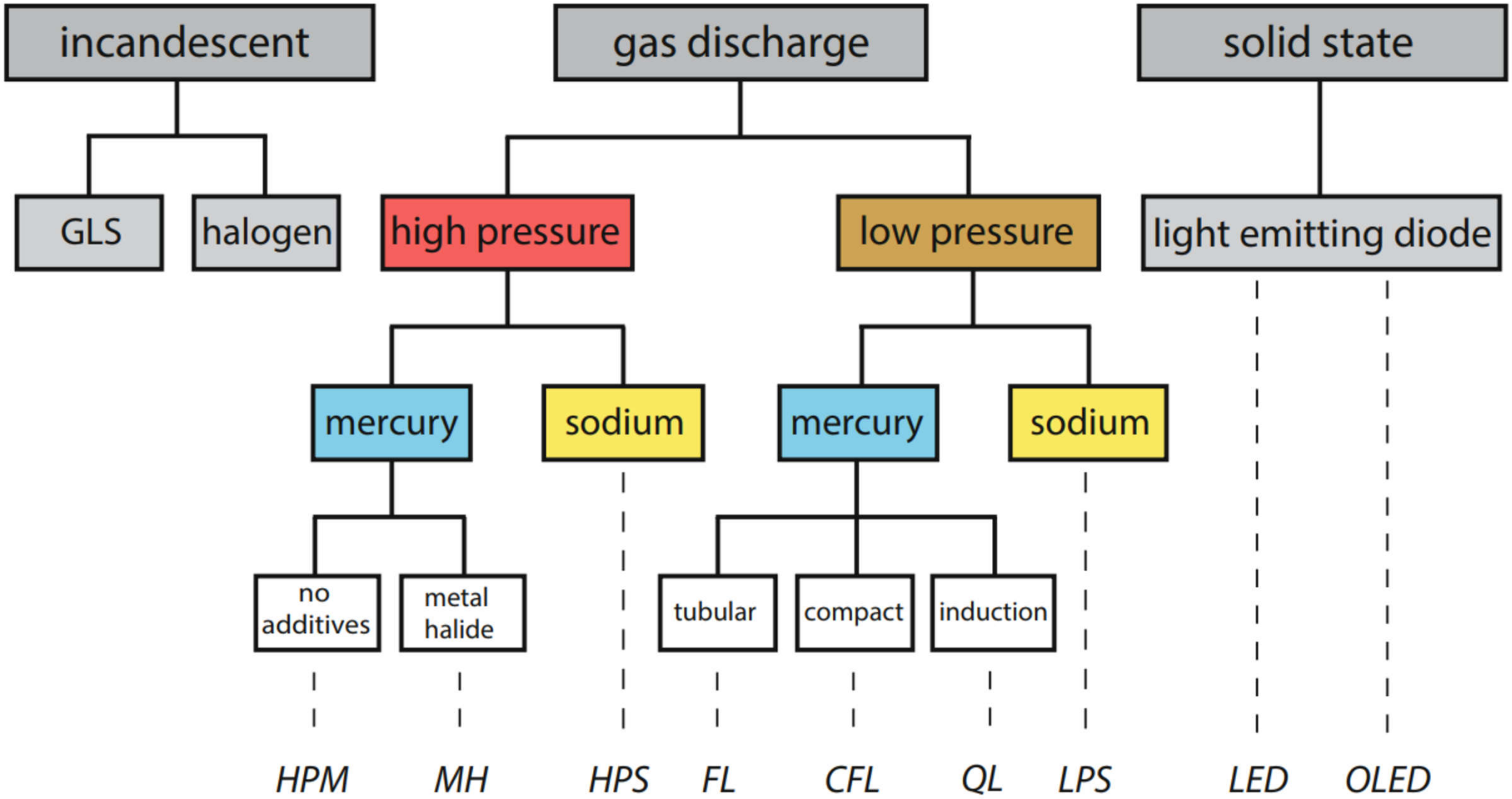


Fluorescent Lamp



Low Pressure Lamp

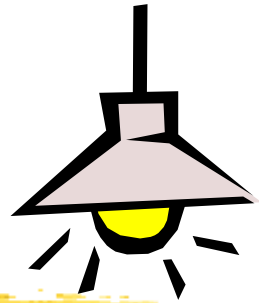
Light sources grouped according to the technology employed



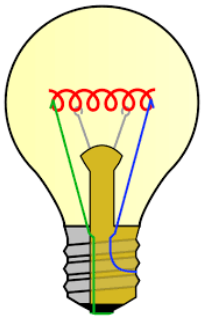
HPM = high-pressure mercury lamp, *MH* = metal-halide lamp, *GLS* = general lighting service incandescent lamp, *HPS* = high-pressure sodium lamp, *FL* = tubular fluorescent lamp, *CFL* = compact fluorescent lamp, *QL* = induction lamp, *LPS* = low-pressure sodium lamp, *LED* = light-emitting diode, *OLED* = organic light emitting diode

(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

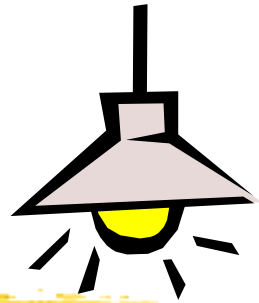
Light sources



- Commonly used light sources (abbrev./code)
  - Incandescent filament (I or GLS = general lighting service)
  - Tungsten-halogen (TH or H)
  - Fluorescent (F)
  - High intensity discharge (HID)
    - Metal halide (MH or MBI or M)
    - Mercury vapour (MBF or HPMV or Q)
    - High pressure sodium (HPS or S or SON)
  - Low pressure sodium (LPS or LS or SOX)



Light sources



- Other light sources
  - Induction lamps
  - Light emitting diodes (LEDs)
  - Electroluminscent lamps
  - Lasers
  - Combustion sources
    - Candle flame
    - Gas light (e.g. using kerosene)

(* See also http://en.wikipedia.org/wiki/List_of_light_sources)

Light sources

- 10 principal families of lamps (according to the manner of light emission) [*CIBSE/SLL Lighting Code*]
  - 1. Tungsten filament
  - 2. Tungsten halogen
  - 3. Metal halide
  - 4. Low pressure mercury (fluorescent)
  - 5. High pressure mercury
  - 6. Compact fluorescent (CFL)
  - 7. Low pressure sodium
  - 8. High pressure sodium
  - 9. Light emitting diodes (LED)
  - 10. Induction (mercury, sodium & sulphur)

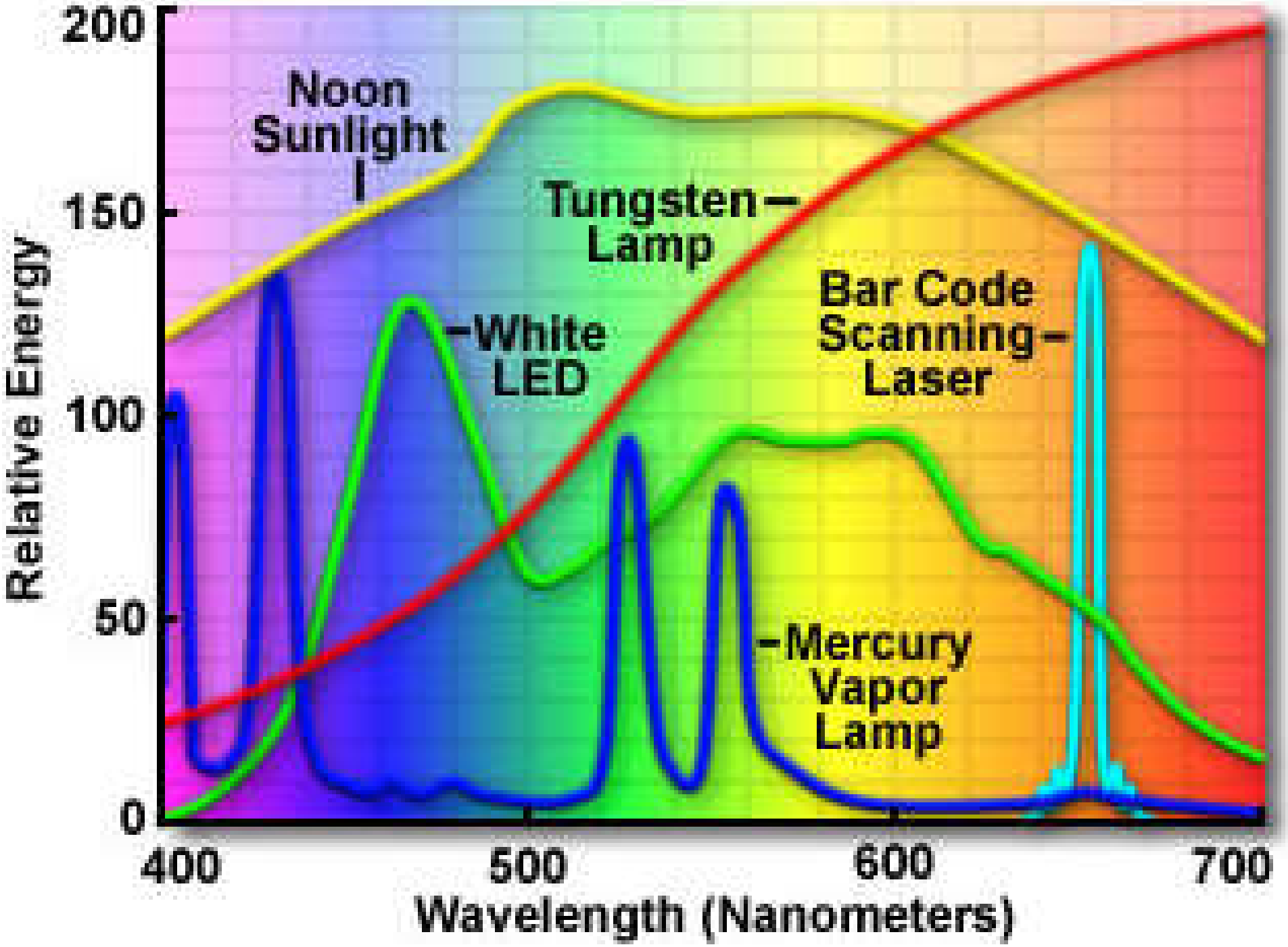
Important characteristics of lamps & light sources in interior lighting

Luminous efficacy (Lm/W)	Colour rendering (Ra)
Lumen package (Lm)	Luminance
Lamp price	Shape and dimensions
Lifetime (h)	Need of gear/driver (yes/no)
Lamp-lumen depreciation (Lx)	Run-up and reignition
Spectrum	Dimmable (yes/no)
Correlated colour temperature (CCT)	Ambient temperature sensitivity
Colour rendering	Environmentally unfriendly material

Lamp type	Lm/W	CCT	R_a	Lifetime (h)	Shape
Incandescent lamp	8–12	2700	100	1000	Compact
Halogen lamp	15–25	3000	100	2000	Very compact
Tubular fluorescent	70–105	2700–17,000	60–90	15,000–20,000	Long linear
Compact fluorescent CFL	70–80	2700–5000	60–90	12,000–20,000	Compact
Induction lamp	65–75	3000–4000	60–90	60,000–75,000	Compact
Compact metal-halide	70–95	2700–4500	70–95	7000–12,000	Compact
Single LED (white)	80–180	2700–10,000	60–95	20,000–100,000	Point source
LED system (white)	70–160	2700–10,000	60–95	20,000–100,000	Many shapes, compact to large
OLED (white)	40–80	2700–6000	60–95	10,000–40,000	Flat, up to 50 × 50 cm

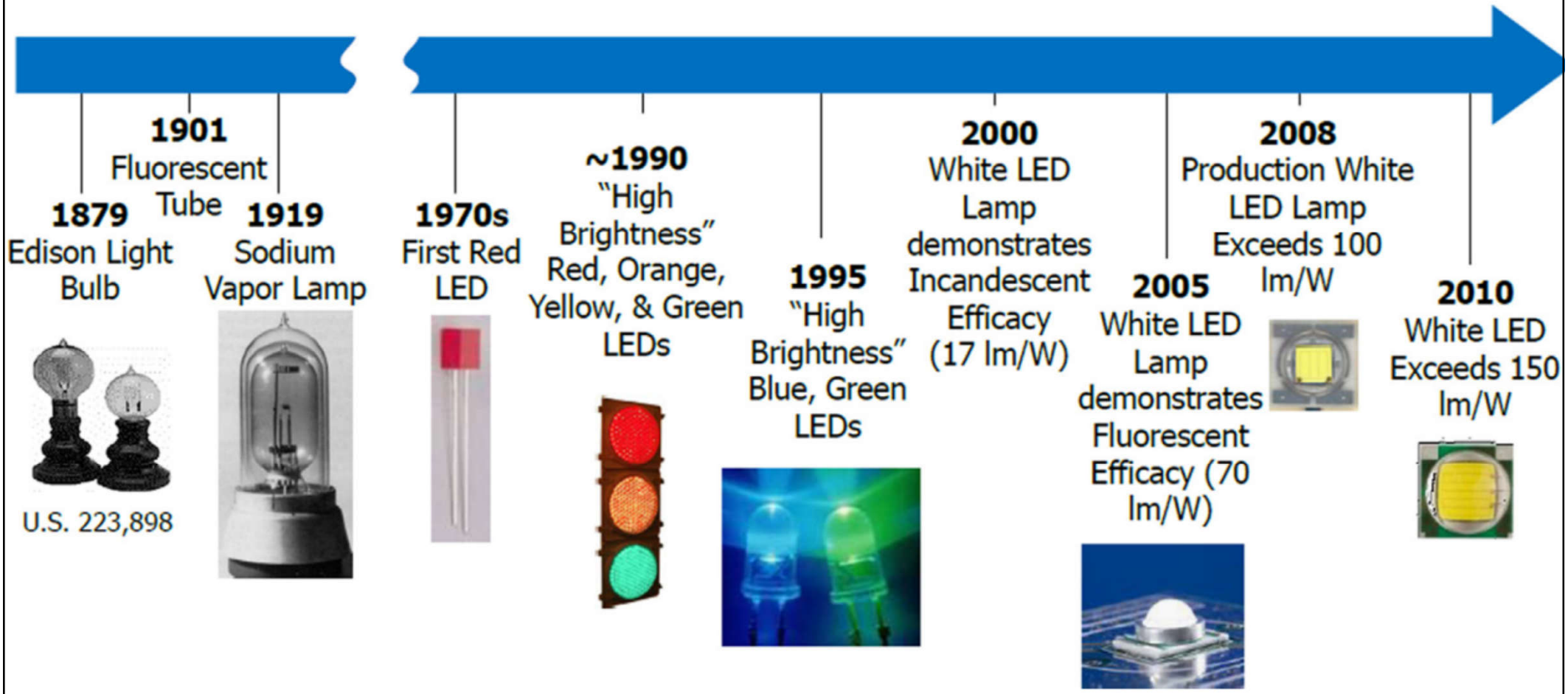
(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

Spectra from common sources of visible light



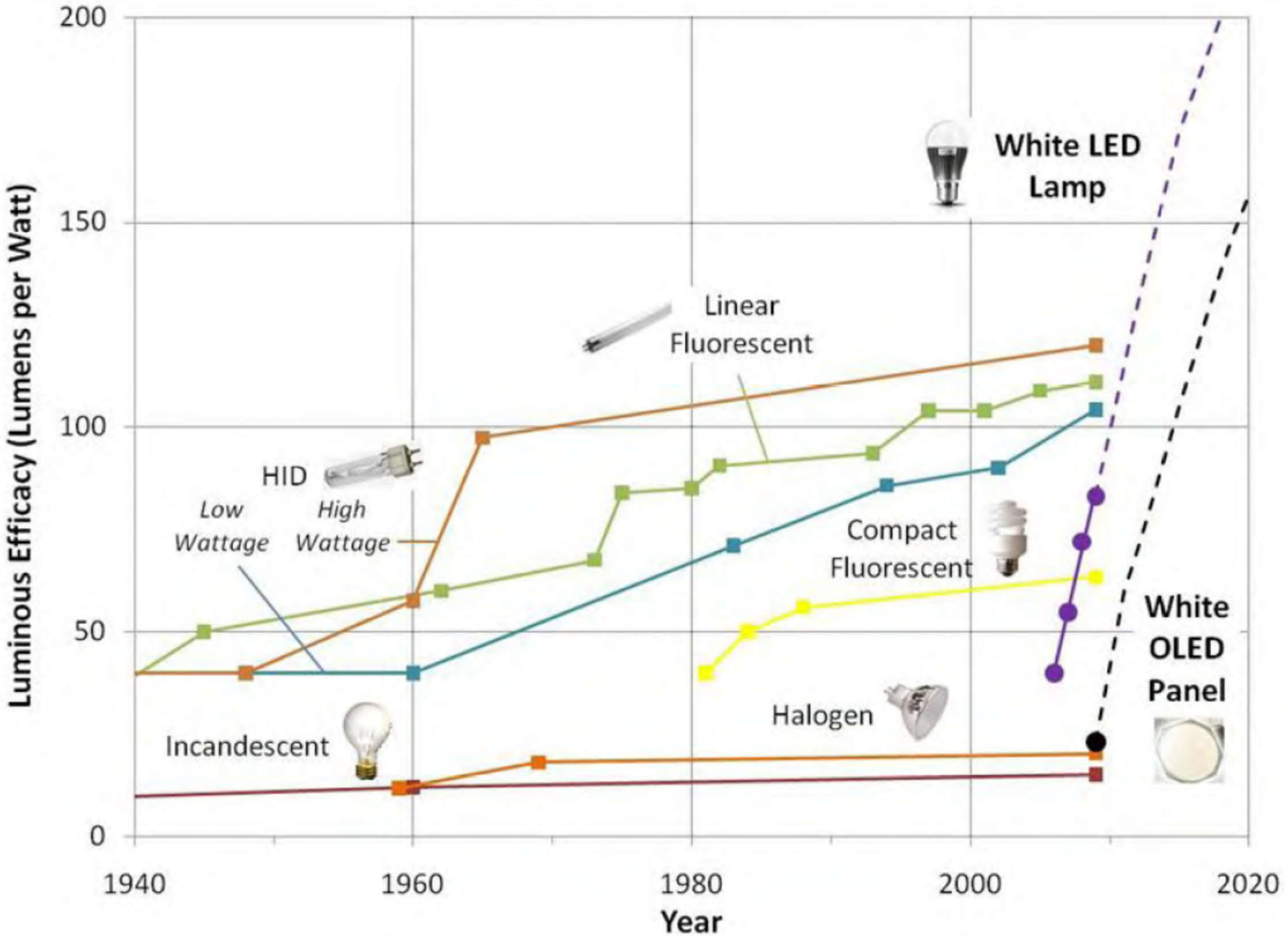
(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/lightsourcesintro/)

Brief history of lighting with some milestones in LED development



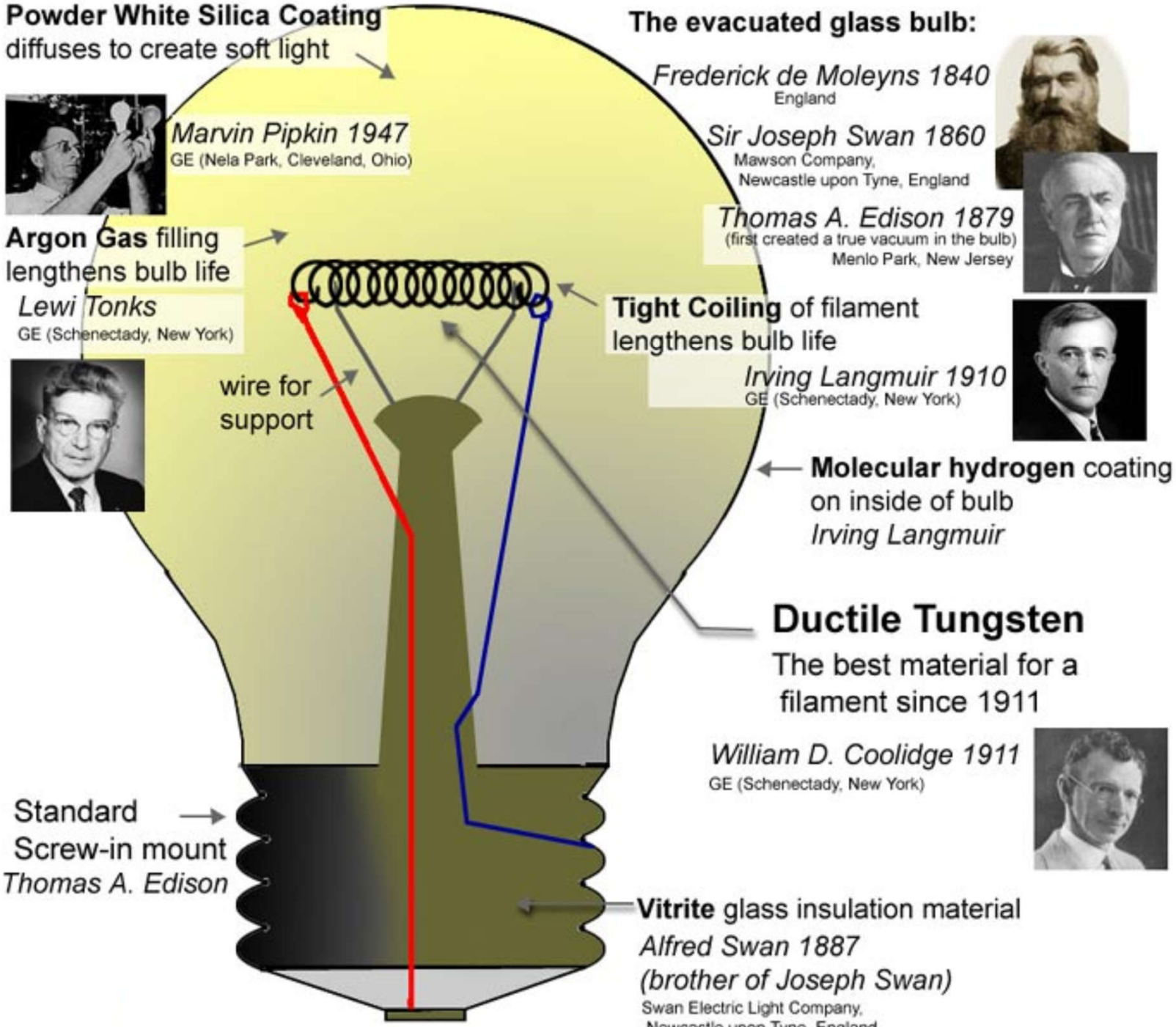
(Source: De Almeida A., Santos B., Paolo B. & Quicheron M., 2014. Solid state lighting review – Potential and challenges in Europe, *Renewable and Sustainable Energy Reviews*, 34: 30-48. http://dx.doi.org/10.1016/j.rser.2014.02.029)

Historical and predicted luminous efficacy of light sources



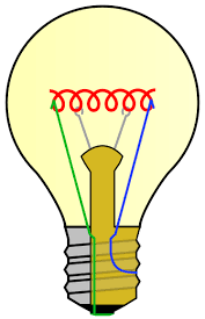
(Source: US Department of Energy)

Inventors of the modern incandescent lamp 白熾燈

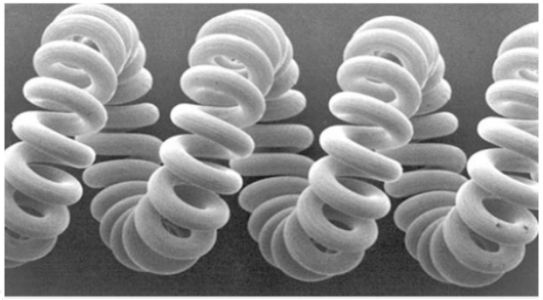


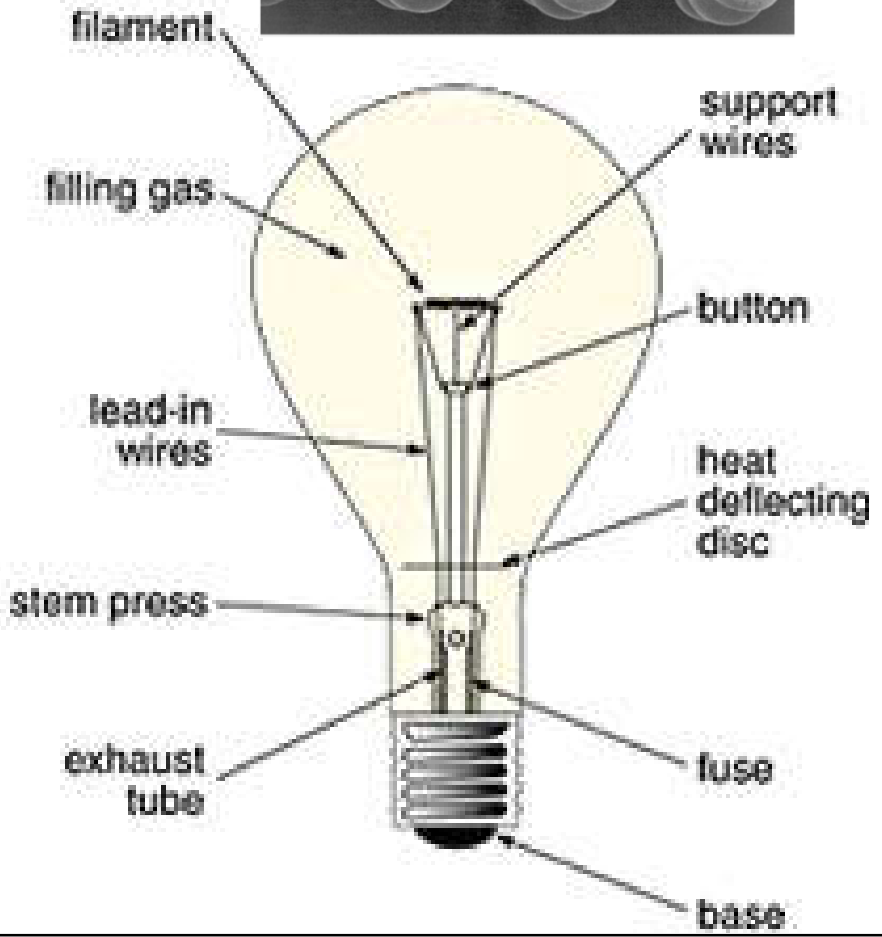
(Source: https://edisontechcenter.org/incandescent.html)

Incandescent

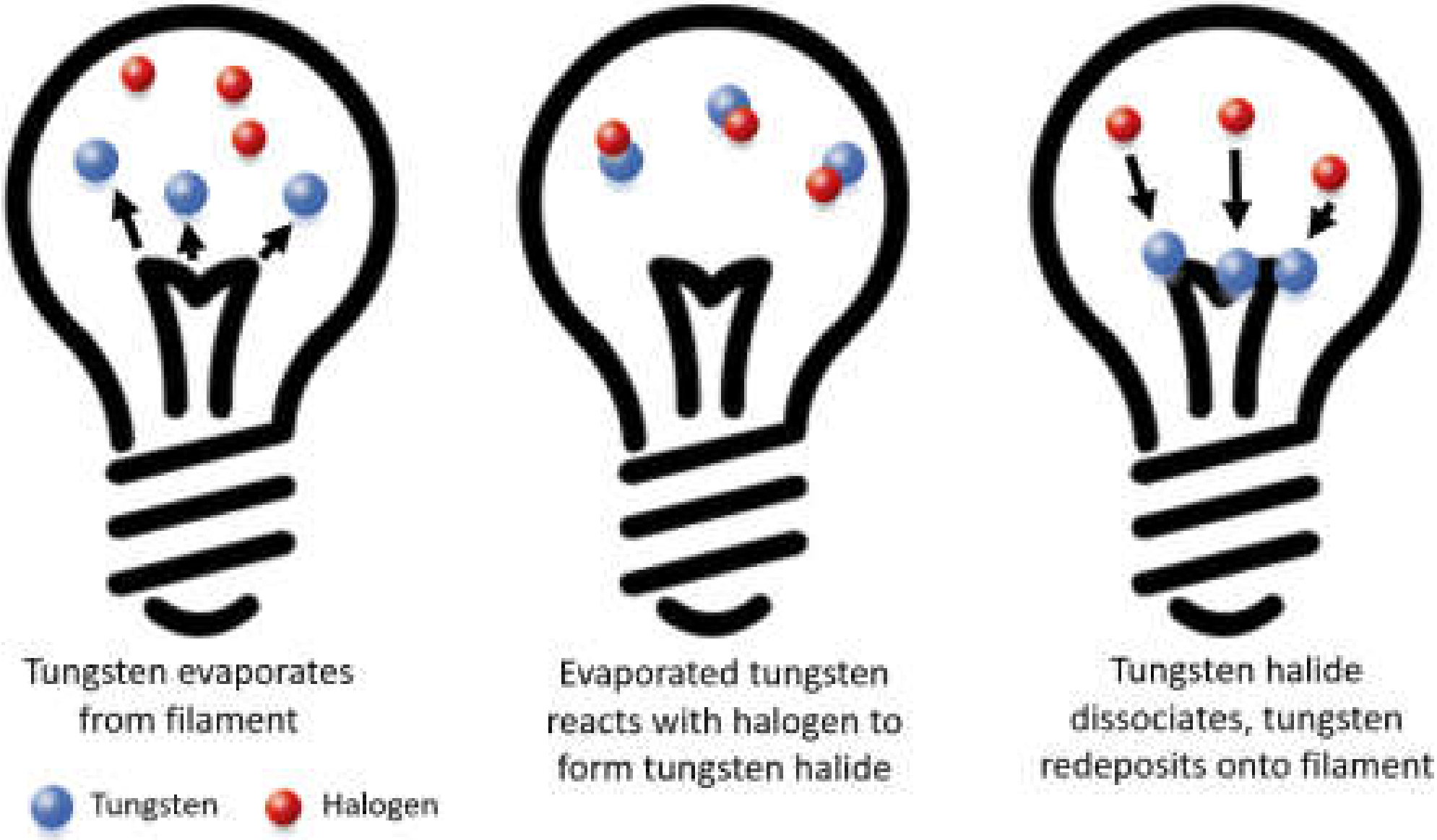


- Advantages
  - Low initial cost
  - Inexpensive to dim
  - High colour rendering
  - Can enhance texture
- Disadvantages
  - Lowest efficacy
  - Voltage sensitive
  - Short life
  - Heat generation

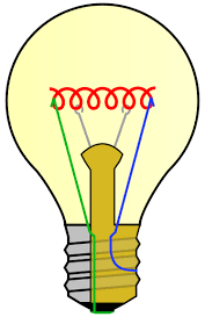




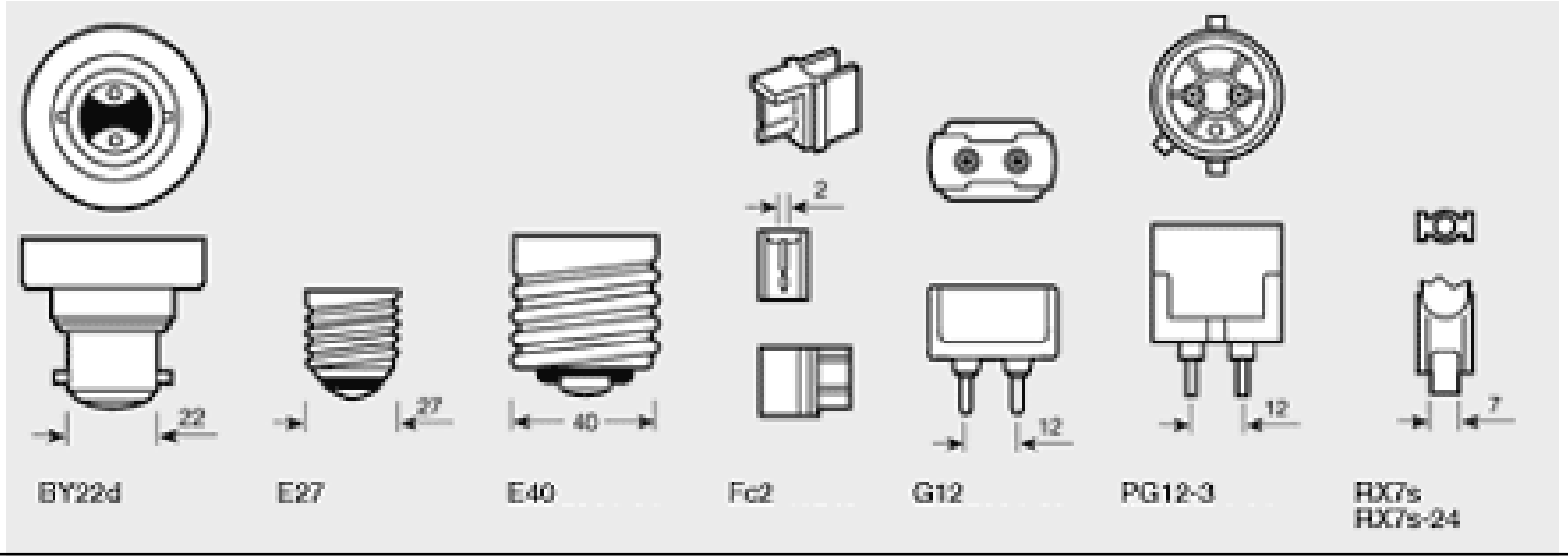
Tungsten halogen cycle for incandescent lamp



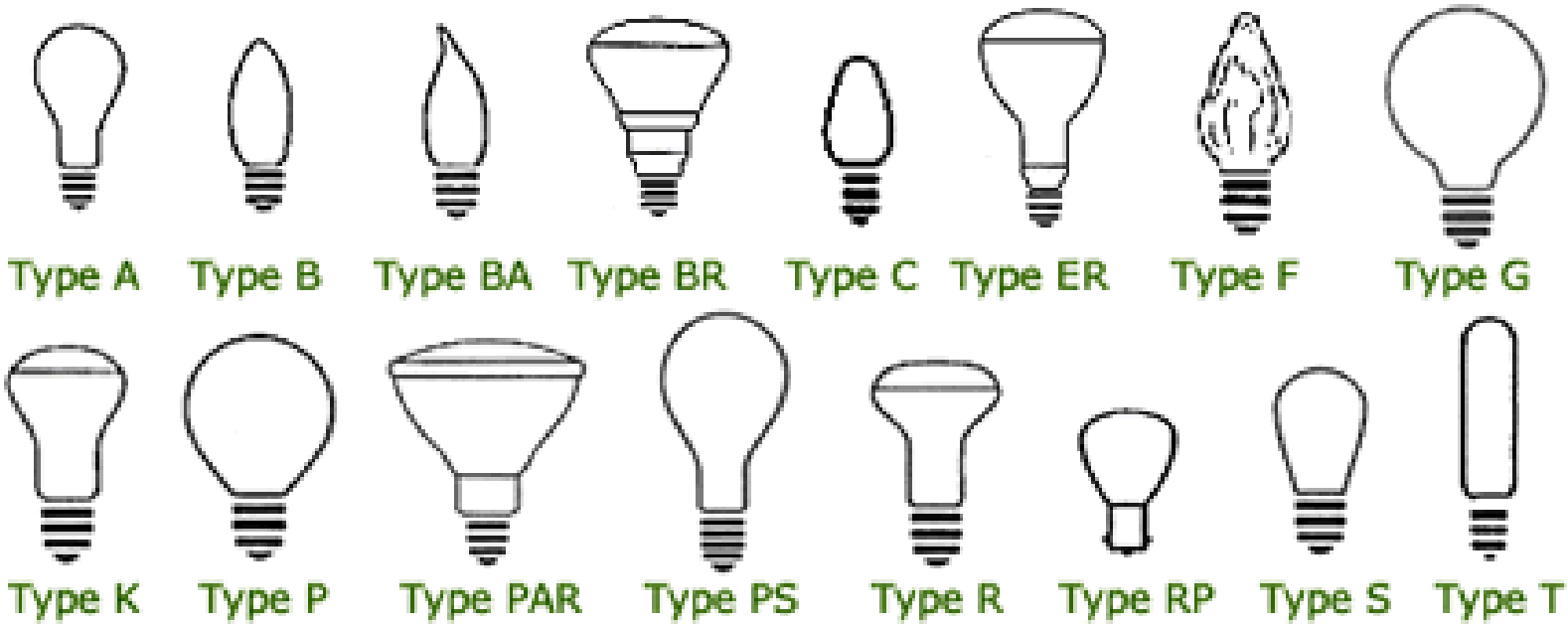
Incandescent

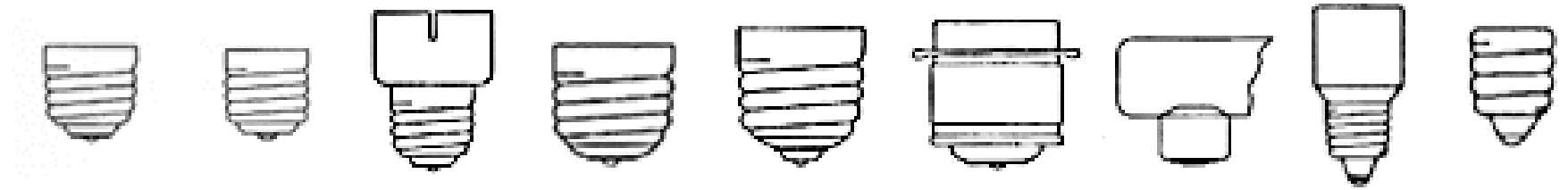


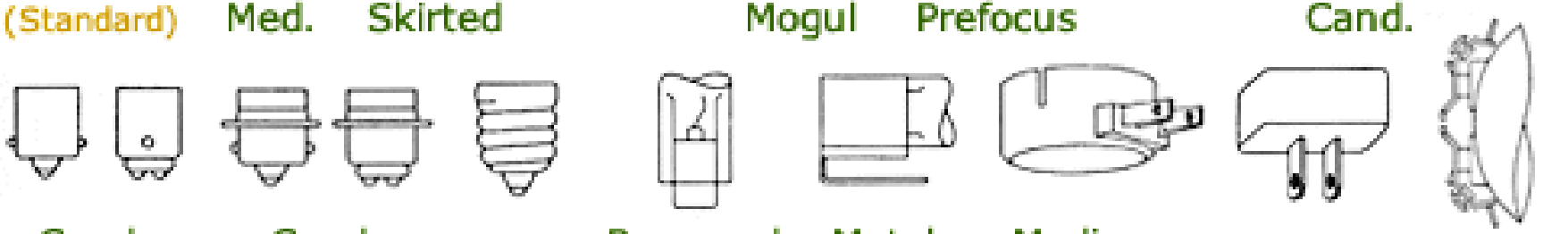
- Specification
  - Lamp/Bulb shape designations
  - Typical filament construction
  - Common lamp bases



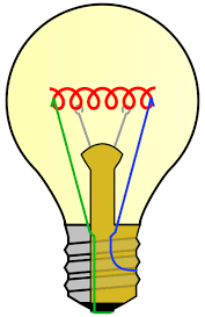
Lamp shapes and bases





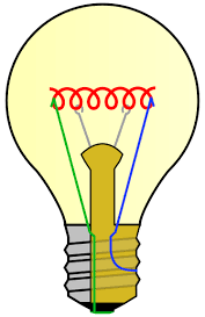


Incandescent

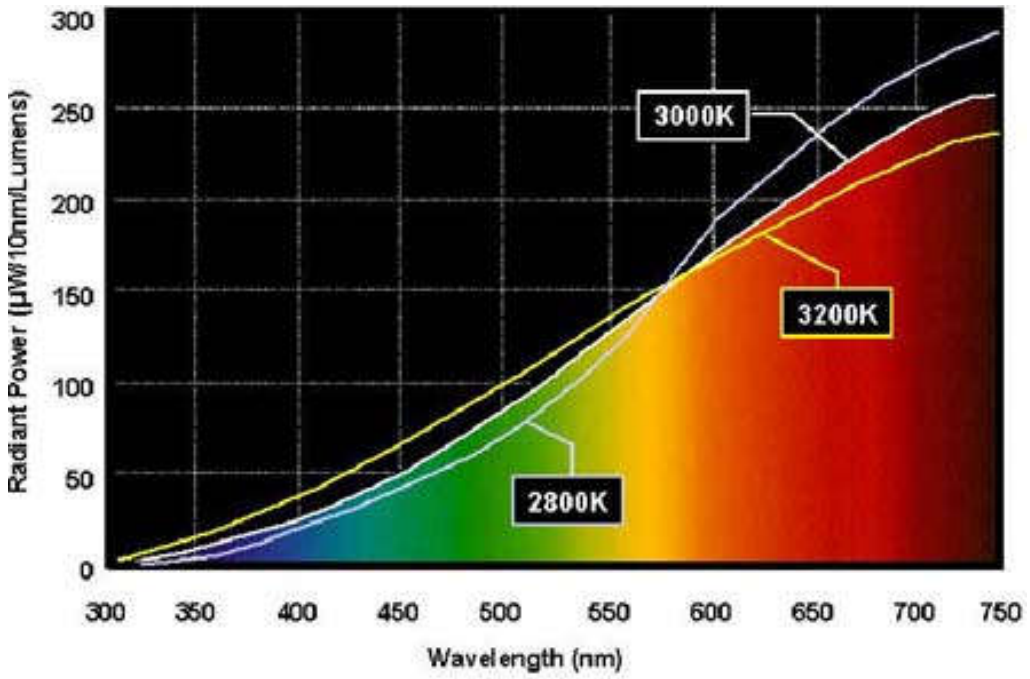


- Construction
  - Glass envelope
    - Lime glass, borosilicate (hard glass)
  - Fills
    - Vacuum, nitrogen, argon, krypton
  - Coatings
    - Acid etch, silica smoke, ceramic, paint
  - Basing
    - Aluminum, brass, nickel plated brass

Incandescent

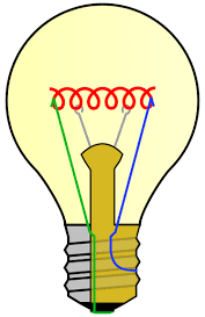


- Lamp characteristics
  - Colour temperature
  - Depreciation
  - Mortality (lifetime)
  - Life / lumens / colour / voltage relationships
  - Bulb & socket temperature



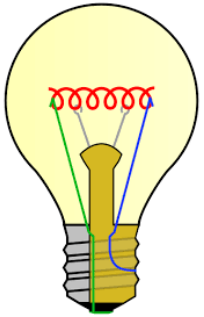
Spectral power distribution (incandescent)

Incandescent



- Major types of incandescent lamps
  - Standard general service (GLS)
  - Decorative
  - Rough service
  - Vibration service
  - Sign lamps
  - Indicator
  - Three way

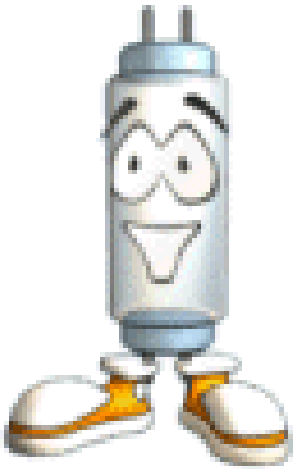
Incandescent



- Tungsten-halogen lamp, or quartz-halogen lamp (line voltage or low voltage)
  - Advantages
    - Compact size
    - Whiter light
    - Excellent lumen maintenance
    - Longer life
  - Disadvantages
    - More costly

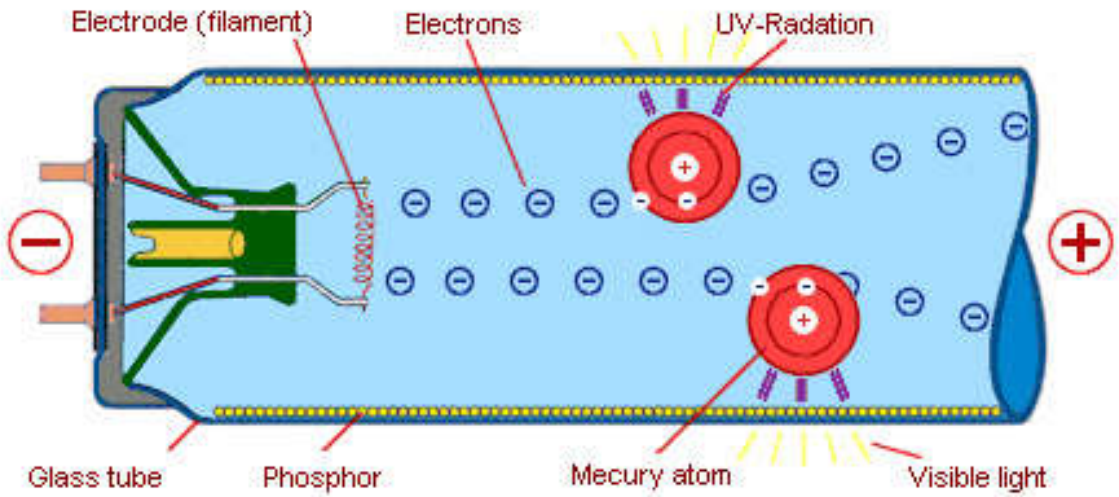
Fluorescent

- Advantages
  - High efficiency
  - Super efficacy at high frequency operatio
  - Wide range of colour choices



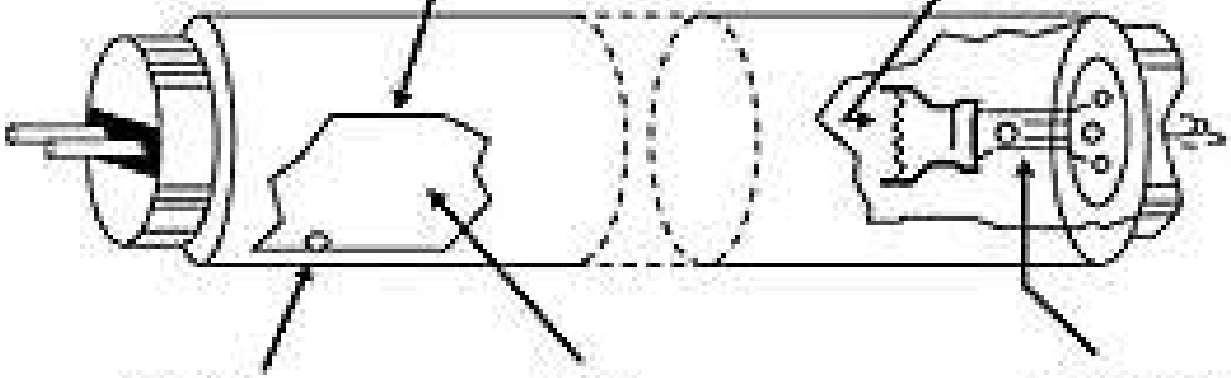
- Disadvantages
  - Require ballast
  - Temperature sensitivity

Construction and operation of fluorescent lamp



Phosphor
Coating inside the bulb transforms ultraviolet radiation into visible light. Light color properties depend on composition of phosphor.

Electrode
Electrodes at each end of lamp emits electrons. Usually made of single-coil tungsten wire.



Mercury
A minute quantity of liquid mercury is placed in the bulb to furnish mercury vapor.

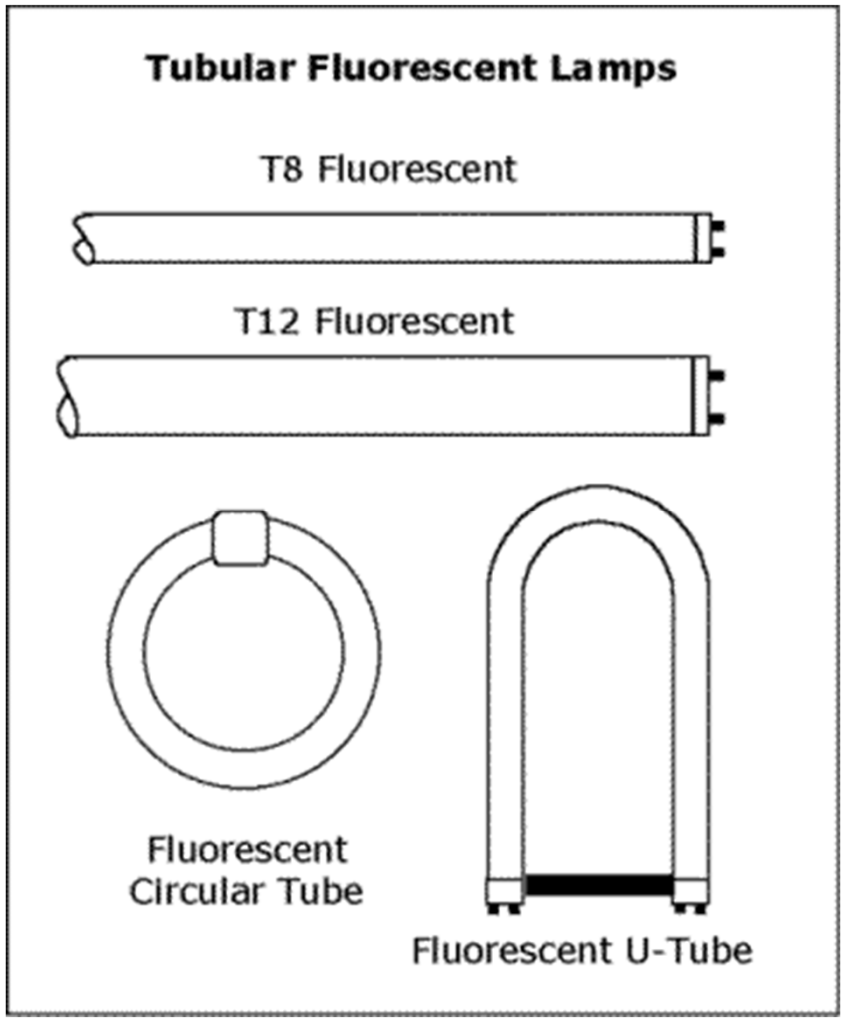
Gas
Usually argon or a mixture of inert gasses at low pressure. Krypton is sometimes used.

Lead-in Wires
Connect to the base pins and carry the current to and from the electrodes and the mercury are.

(Source: LampTech, http://www.lamptech.co.uk/ and http://osram.no)

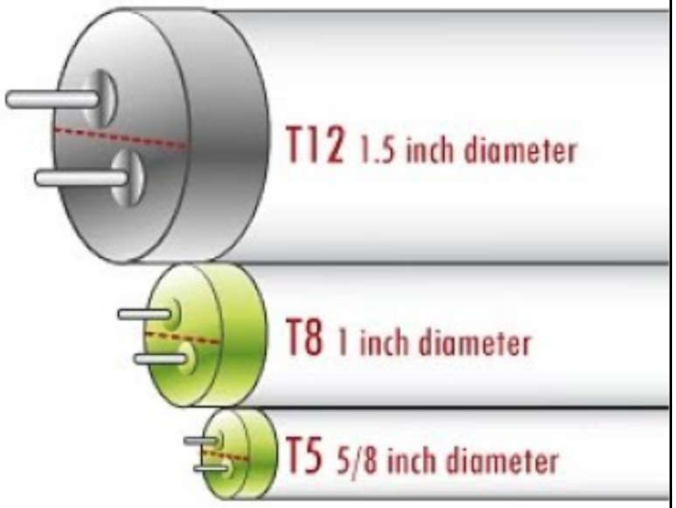
Fluorescent

- Types of fluorescent lamps 螢光燈
  - Linear (tubular)
  - Compact
  - Circline
  - U shape
  - Subminiature
  - Reflector
  - Cold cathode



Fluorescent

- Fluorescent lamp identification
  - Example: F30T12/CW/RS
    - "F" … fluorescent
    - "30" … rated nominal wattage
    - "T" … tubular shape
    - "12" … diameter in eighths of an inch; 12/8 = 1.5 in.
    - "CW" … color; this lamp is a cool white lamp
    - "RS" … mode of starting; rapid-start lamp
  - Linear (tubular) fluorescent lamps typical lengths:
    - 600 mm (2 ft), 900 mm (3 ft), 1200 mm (4 ft), 1500 mm (5 ft), 2400 mm (8 ft)



Fluorescent

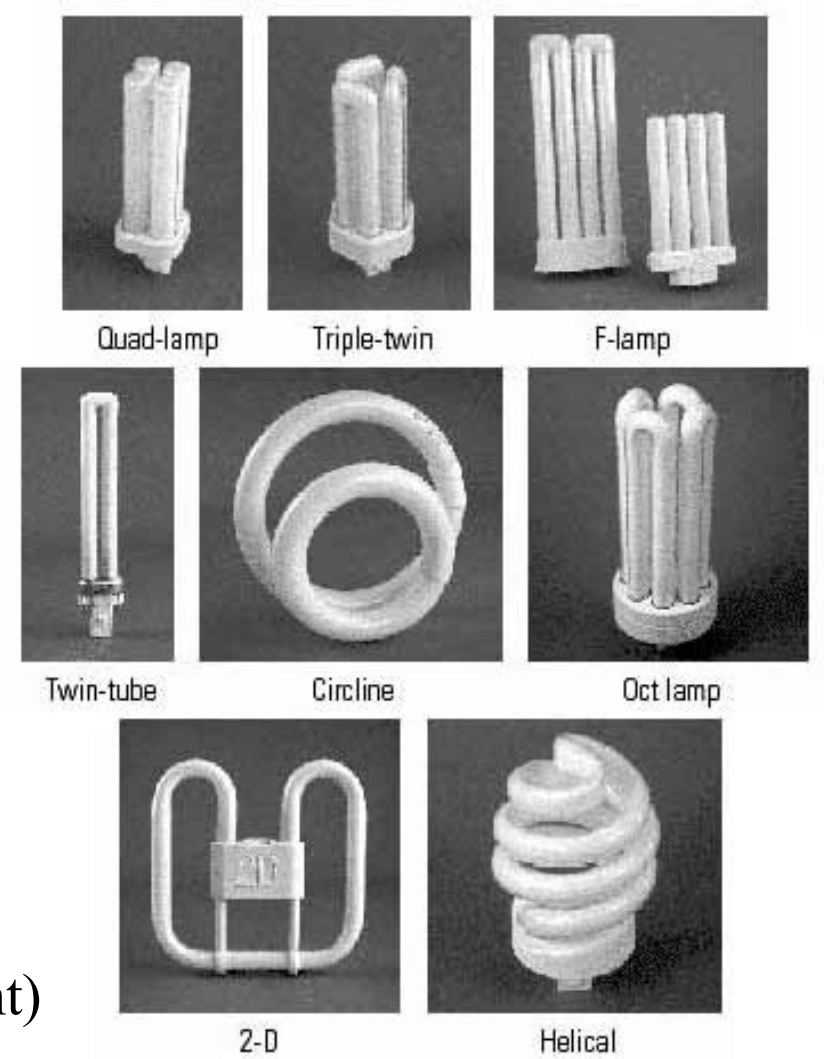
- Classification of fluorescent lamps
  - Lamp shapes
  - Lamp bases
  - Coating technology for (double- & tri-) Phosphor
- Lamp characteristics
  - Efficacy (longer the lamp, higher the efficacy)
  - Temperature effects
  - Strobe effect (flicker)
  - High frequency operation

Fluorescent

- Operating characteristics
  - Light output vs. ambient temperature
    - Optimal at 25 °C (highest lumens per lamp)
    - Also affect the colour of the light produced
  - Lumen maintenance
    - Initial lumens decrease w/ operating hours
  - Effect of starting frequency on lamp life
    - Loss of the electron emissive coasting on electrodes
    - Rated average life = based on 3 hrs operation per start

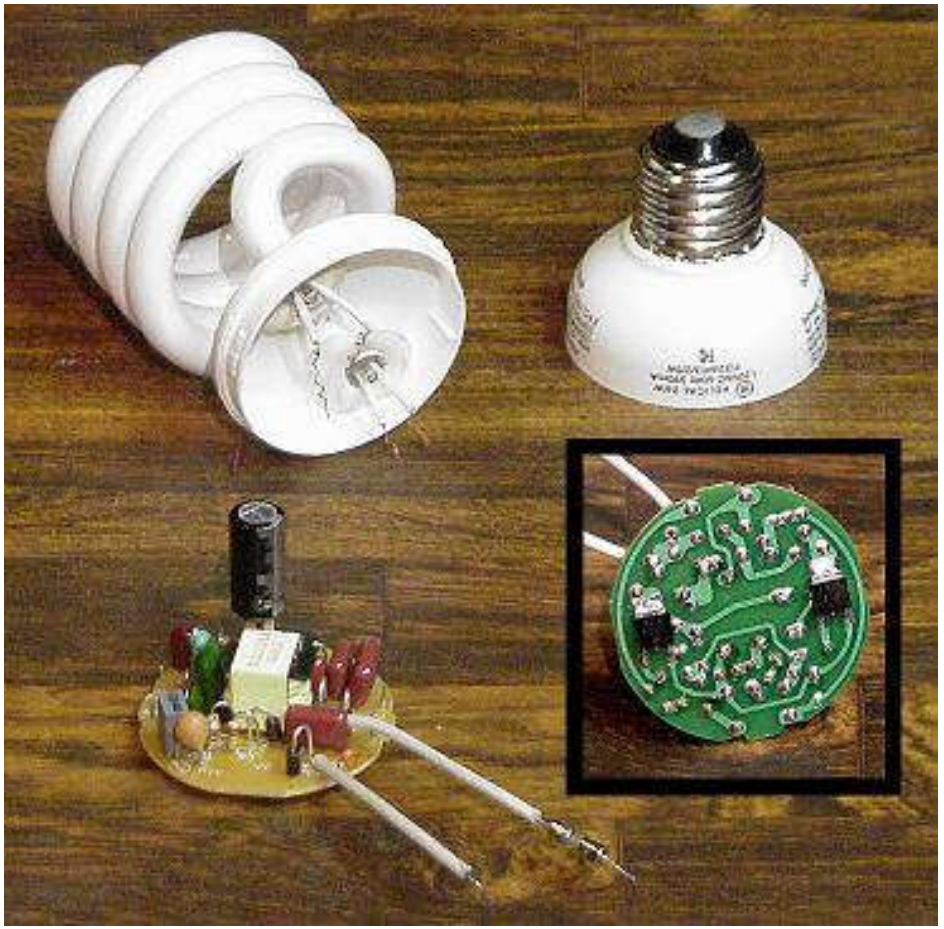
Fluorescent

- Compact fluorescent
  - Advantages
    - Compact size
    - High efficacy
    - High CRI
    - Long life
    - Dimmable (some)
    - High frequency operation
    - Excellent lumen maintenance
  - Disadvantages
    - Position sensitive
    - Thermal sensitivity
    - Require ballast
    - Higher initial cost (over incandescent)



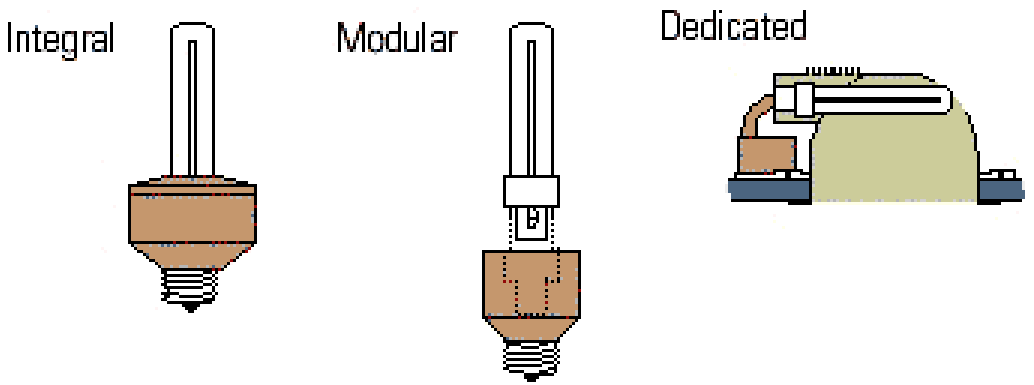
Fluorescent

- Compact fluorescent 一體式螢光燈 / 慳電膽
  - Types
    - Twin tubes
    - Quads
    - Triples
    - Globes
    - Reflectors
  - Adapter ballasts
  - Self-ballasted



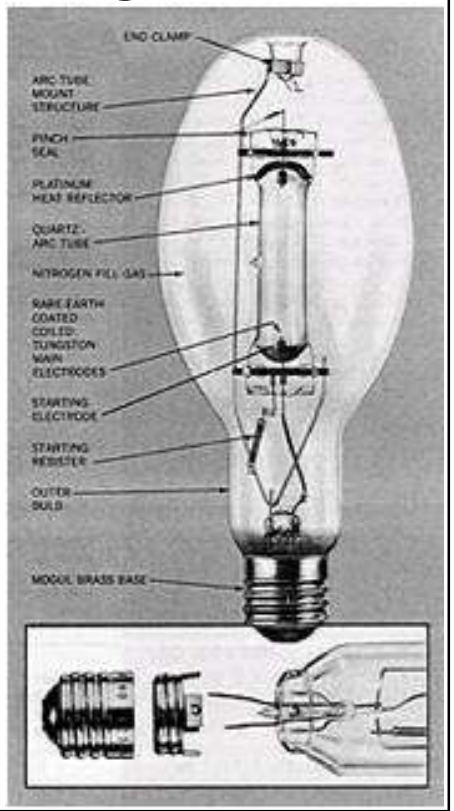
Fluorescent

- Compact fluorescent
  - Thermal factor affecting light output & performance
  - Bulb wall temperature
    - Lamp positioning
    - Luminaire design (e.g. ventilation)
    - Plenum temperature
    - Ambient temperature
    - Amalgam temperature
  - Ballasting



High intensity discharge (HID)

- High intensity discharge (HID) lamps
  - Electrical gas-discharge lamp which produces light by means of an electric arc between tungsten
- Types of HID lamps:
  - Mercury vapour
  - Metal halide
  - High pressure sodium
- * See examples in LampTech website
  - http://www.lamptech.co.uk/

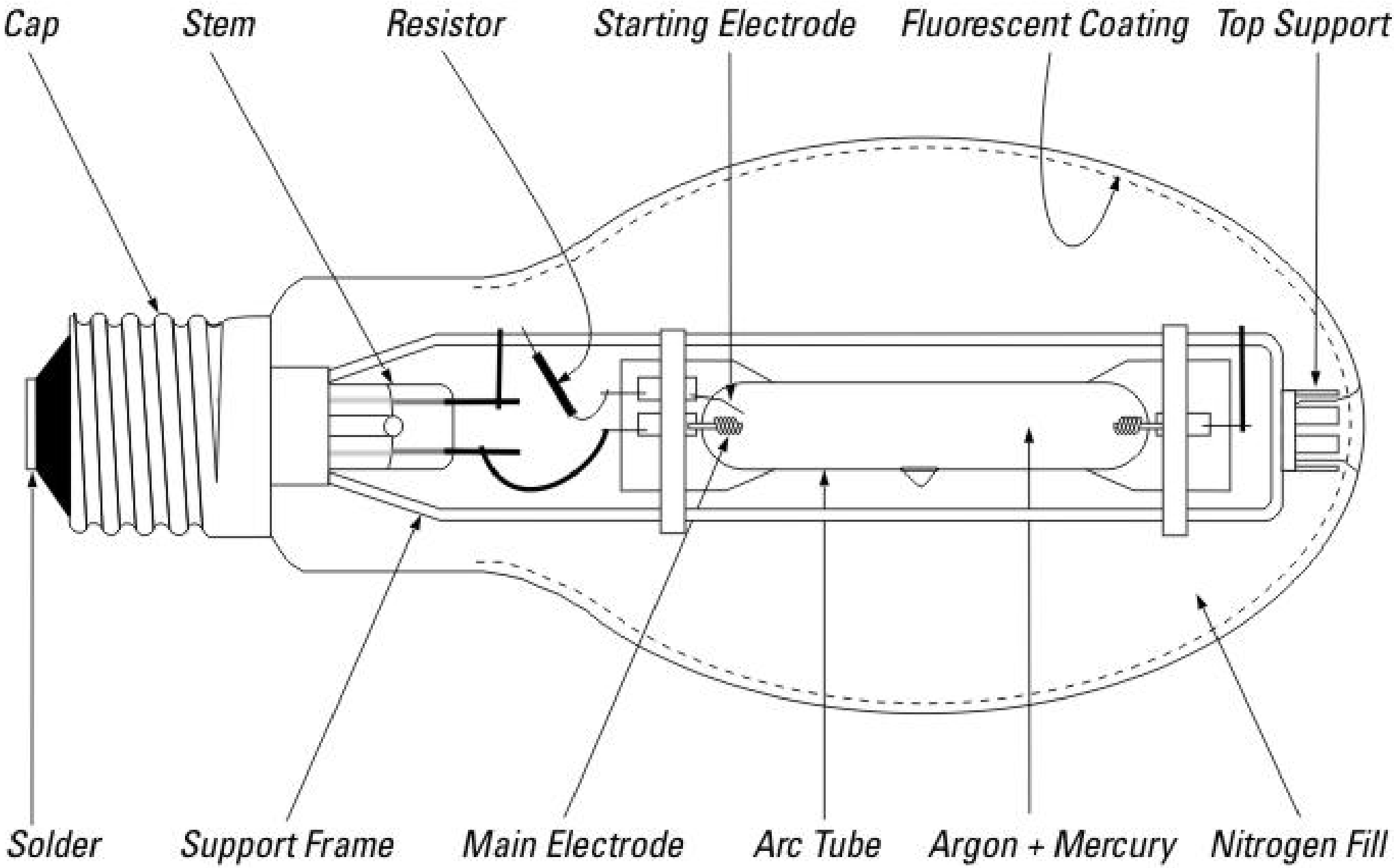


High intensity discharge (HID)

- Video: What is HID? (4:06)
  https://youtu.be/3oHwO-Xu8w4

- Mercury vapour*
  - Advantages
    - Good for landscape lighting
  - Disadvantages
    - Lowest HID efficacy
    - Poor lumen maintenance
    - Poor colour
  - (* historical, use less nowadays)

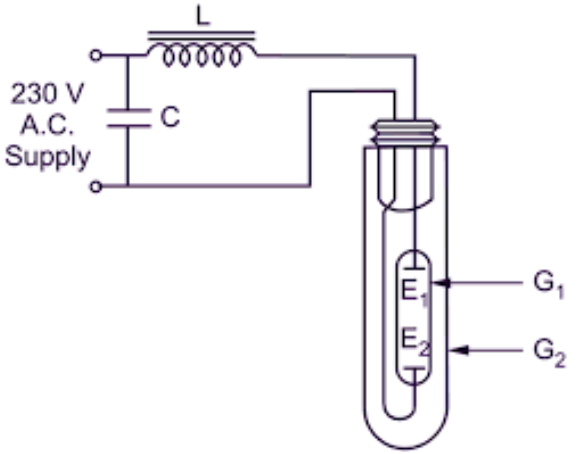
Construction of mercury vapour lamp



(Source: LampTech, http://www.lamptech.co.uk/)

High intensity discharge (HID)

- Mercury vapour
  - Lamp types
    - Standard, PAR (parabolic), R (reflector), Safety
  - Operating characteristics
    - Starting characteristics
    - Lamp operating position (vertical/horizontal)
    - Lamp life & lumen maintenance
    - Temperature effects
    - Flicker & strobe

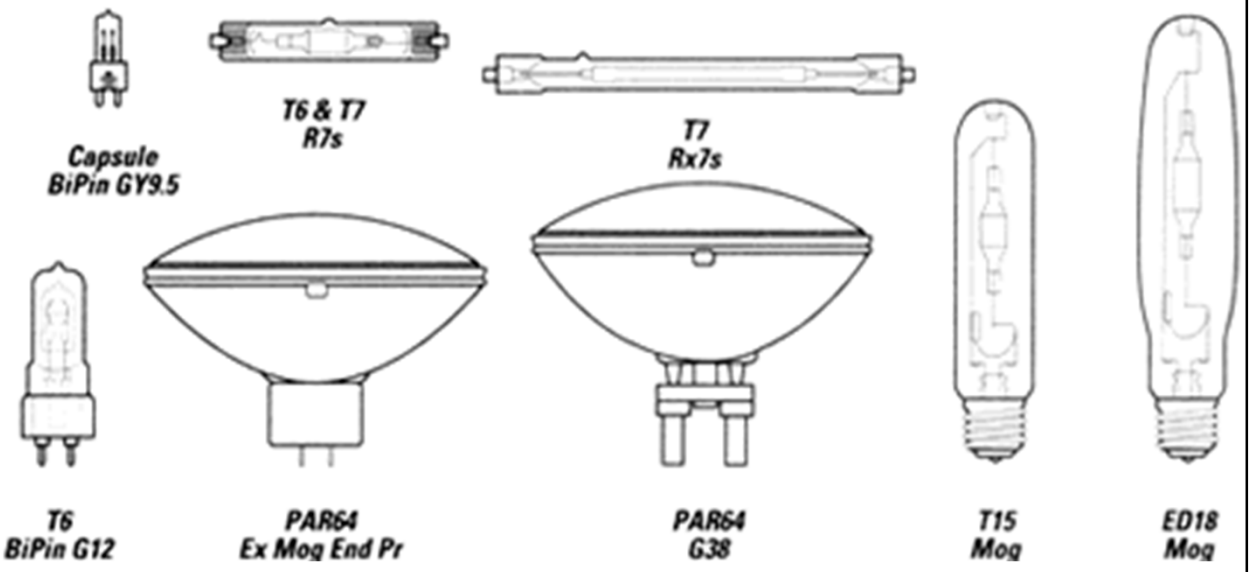


High intensity discharge (HID)

- Metal halide
  - Advantages
    - High efficacy
    - Good to excellent colour
    - Good lumen maintenance
    - Wide range of wattages
  - Disadvantages
    - Colour shift
    - Hot restrike time

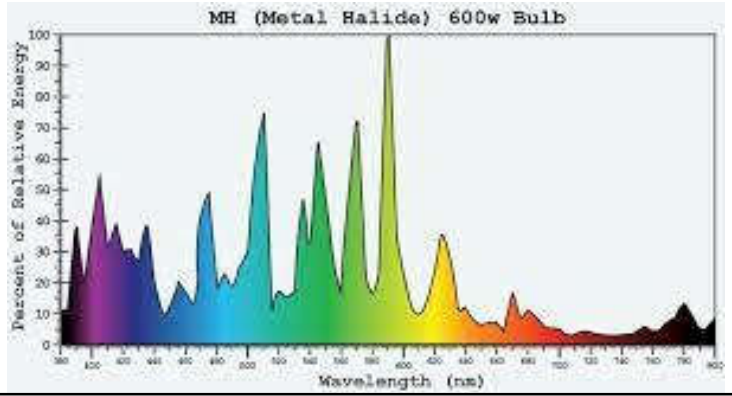
High intensity discharge (HID)

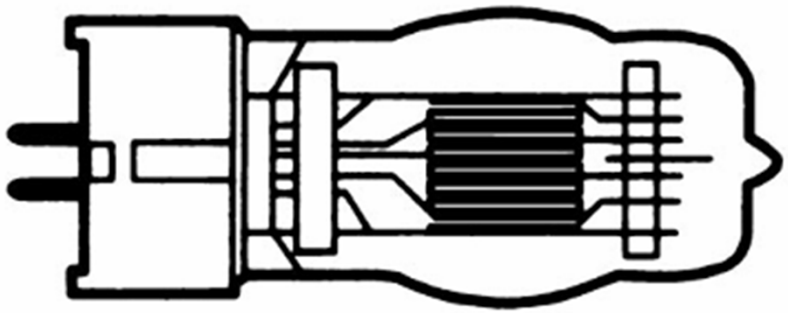
- Metal halide
  - Lamp types
    - Standard
    - High output
    - PAR (parabolic)
    - Open luminaires
    - Safety
    - Double ended



High intensity discharge (HID)

- Metal halide
  - Operating characteristics
    - Starting characteristics
    - Lamp operating position (vertical/horizontal)
    - Lamp life & lumen maintenance
    - Temperature effects
    - Flicker & strobe

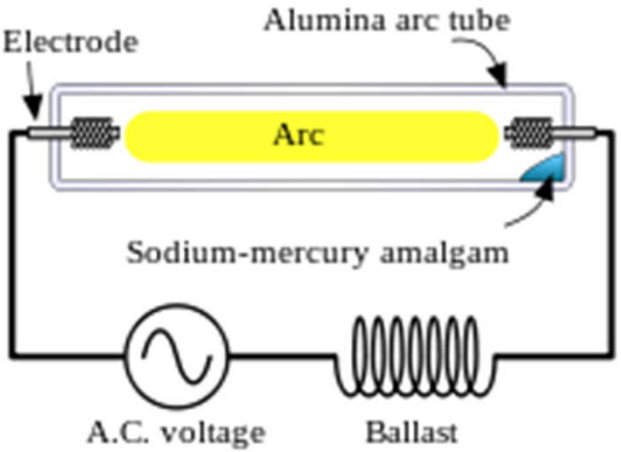


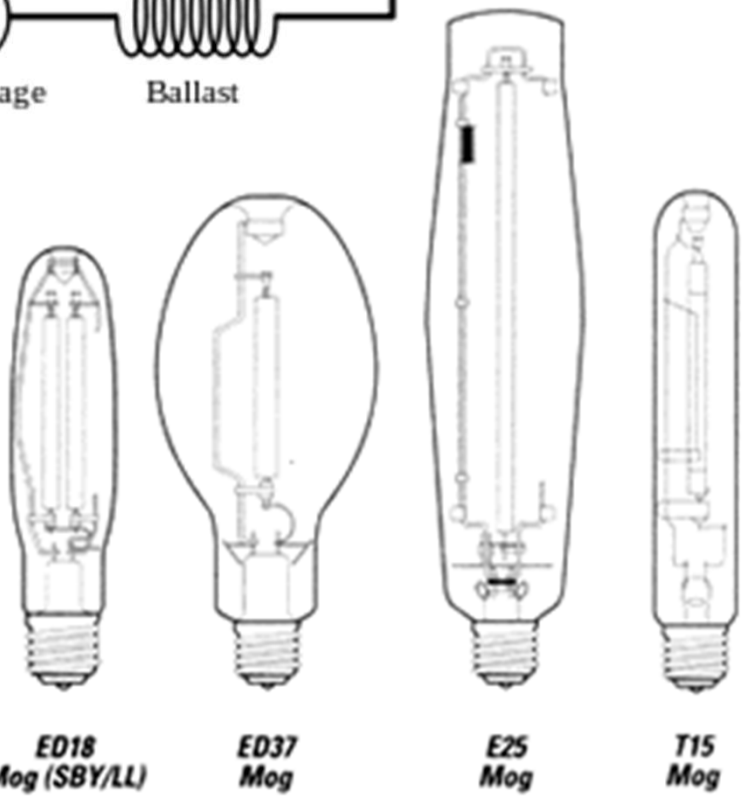


For theatre projection

High intensity discharge (HID)

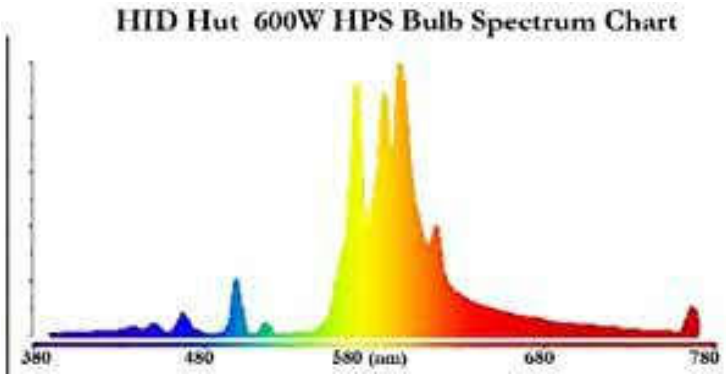
- High pressure sodium
  - Advantages
    - High efficacy
    - Long life
    - Universal burning position
    - Wide range of wattages
    - Good lumen maintenance
  - Disadvantages
    - Colour (standard lamp)
    - Require ballast
    - Cycling (standard lamp)

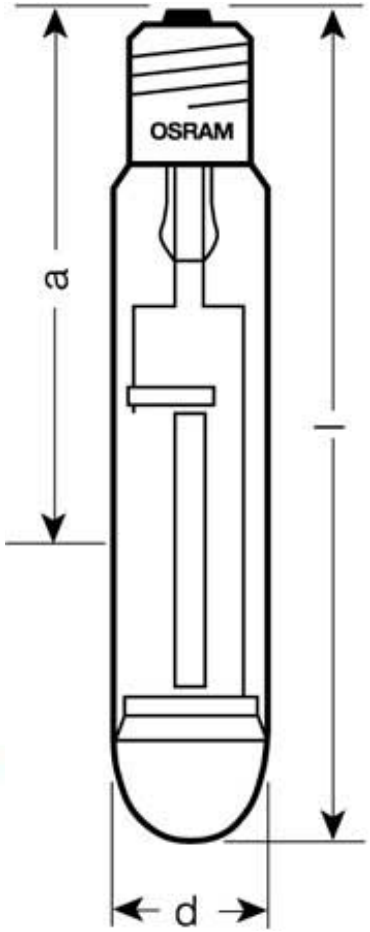




High intensity discharge (HID)

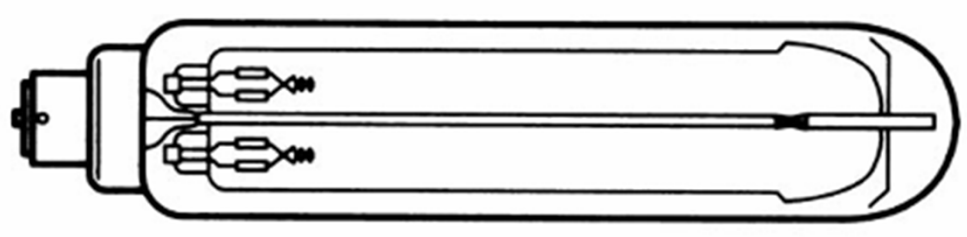
- High pressure sodium
  - Lamp types
    - Standard
    - Standby/instant restrike
    - High output
    - Non-cycling
    - Deluxe colour
    - Double ended
    - Self-ballasted
    - Mercury retrofit
  - Operating characteristics
    - Starting characteristics
    - Lamp operating position (vertical/horizontal)
    - Lamp life & lumen maintenance
    - Temperature effects
    - Cycling

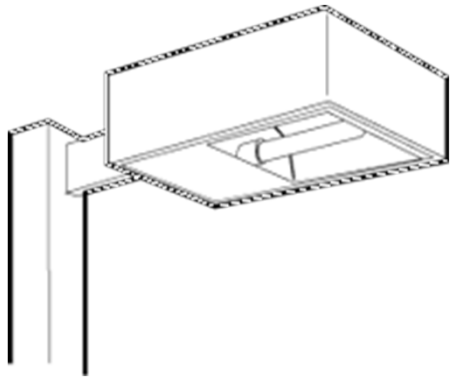


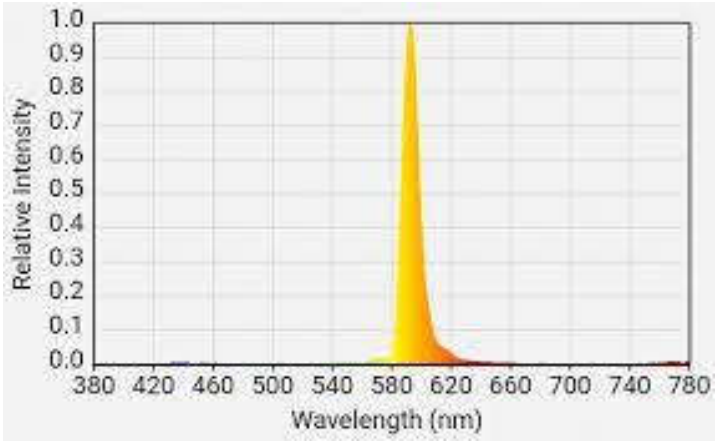


Low pressure sodium

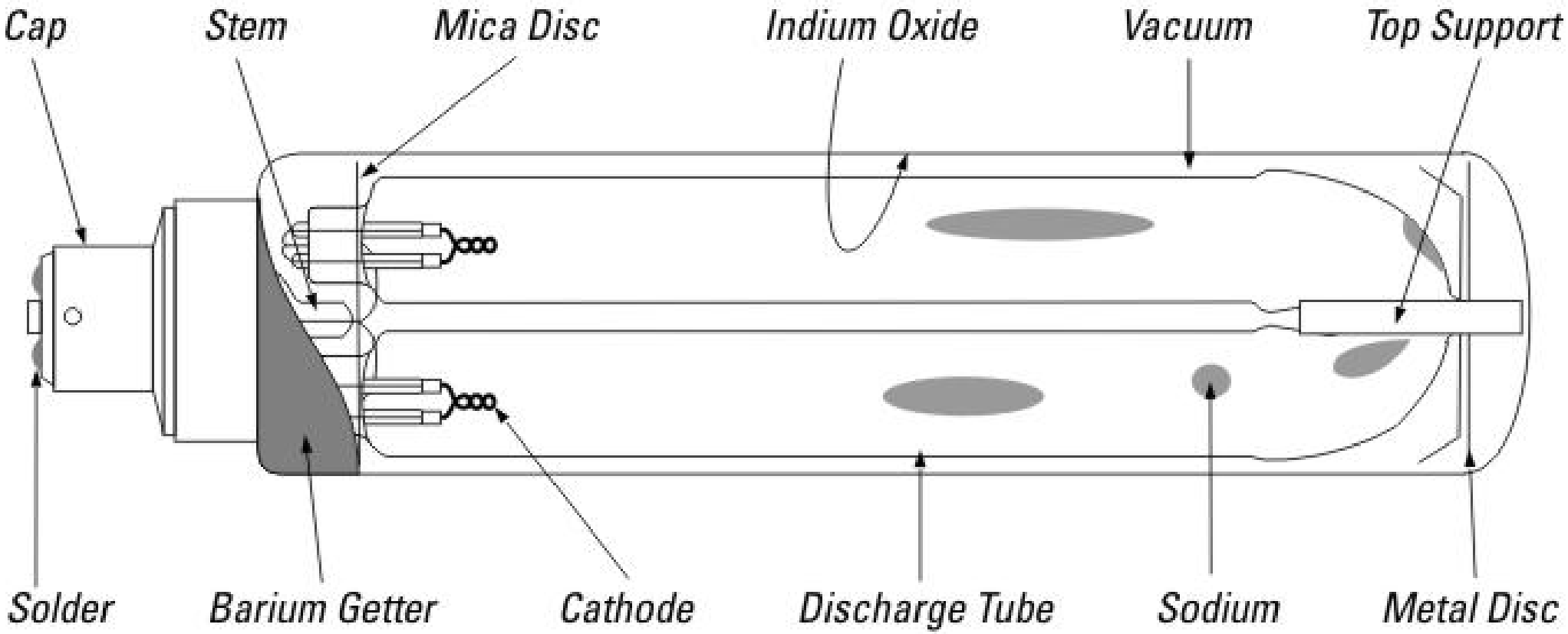
- Low pressure sodium
  - Advantages
    - Highest efficacy
    - Hot restrike
  - Disadvantages
    - Monchromatic
    - Optical control
    - Lamp disposal
    - Increased wattage over life







Low pressure sodium lamp

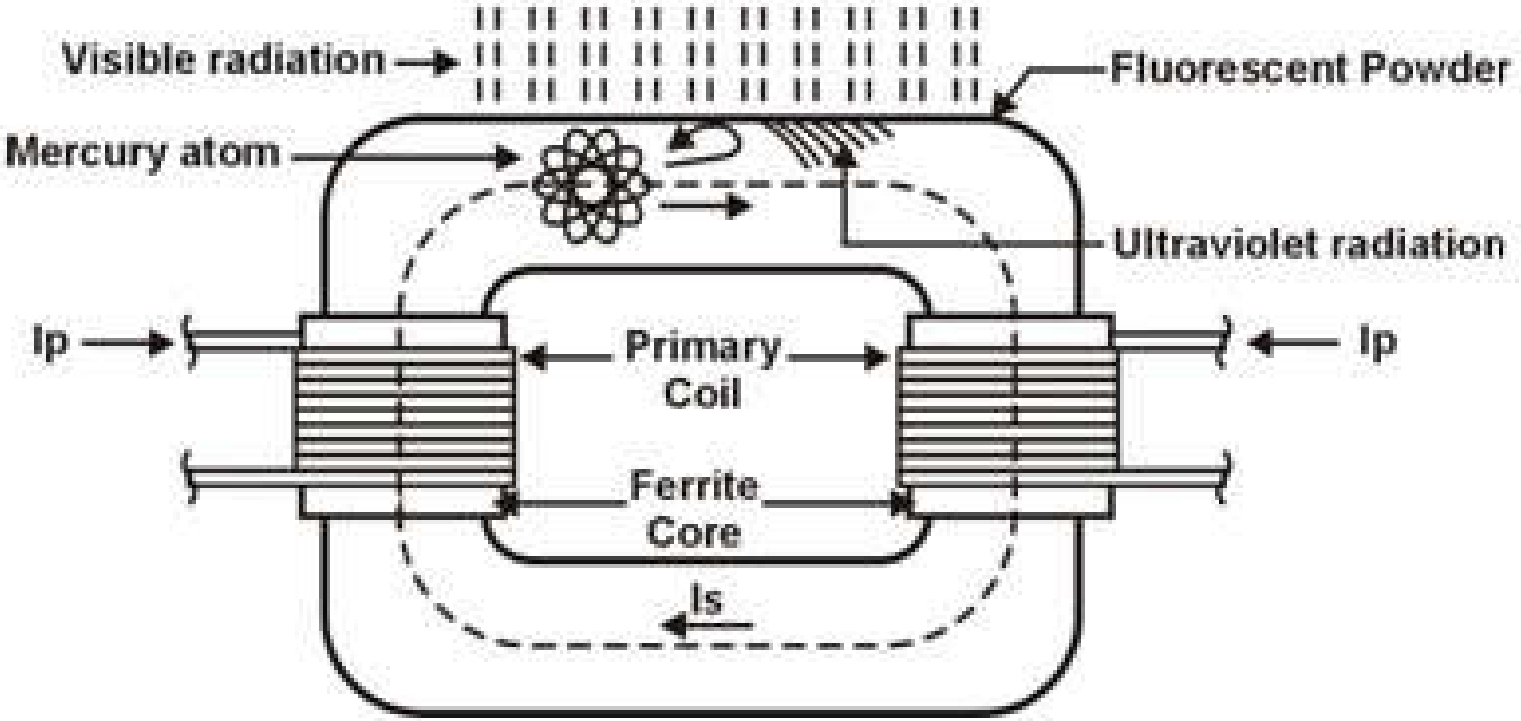


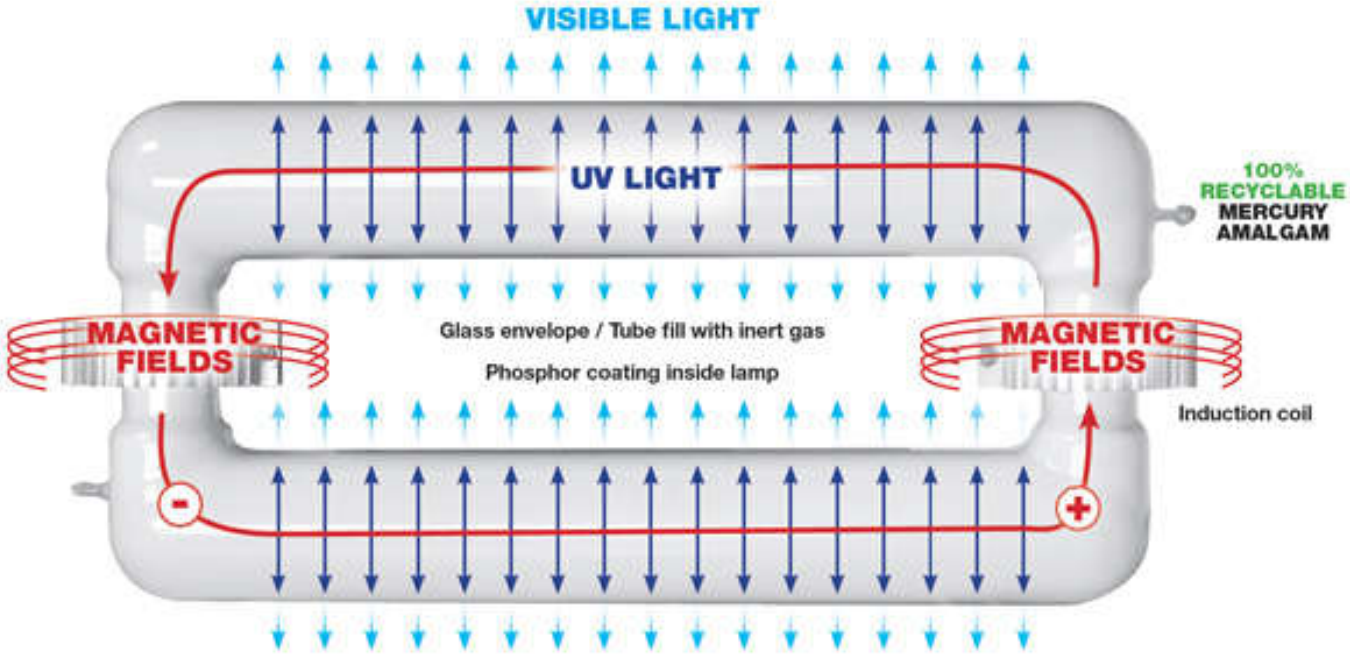
(Source: LampTech, http://www.lamptech.co.uk/)

Induction lamps

- They are gas discharge lamps that do not have electrodes
- The electric field in the lamp is induced by an induction coil that is operating at high frequency

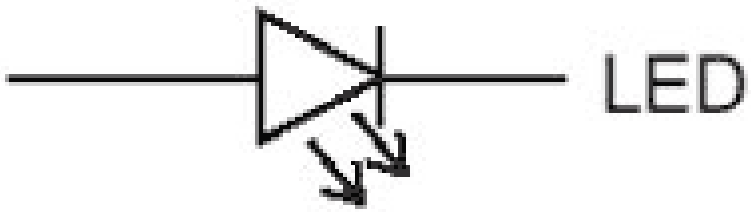
Induction lamps based on fluorescent lamp technology



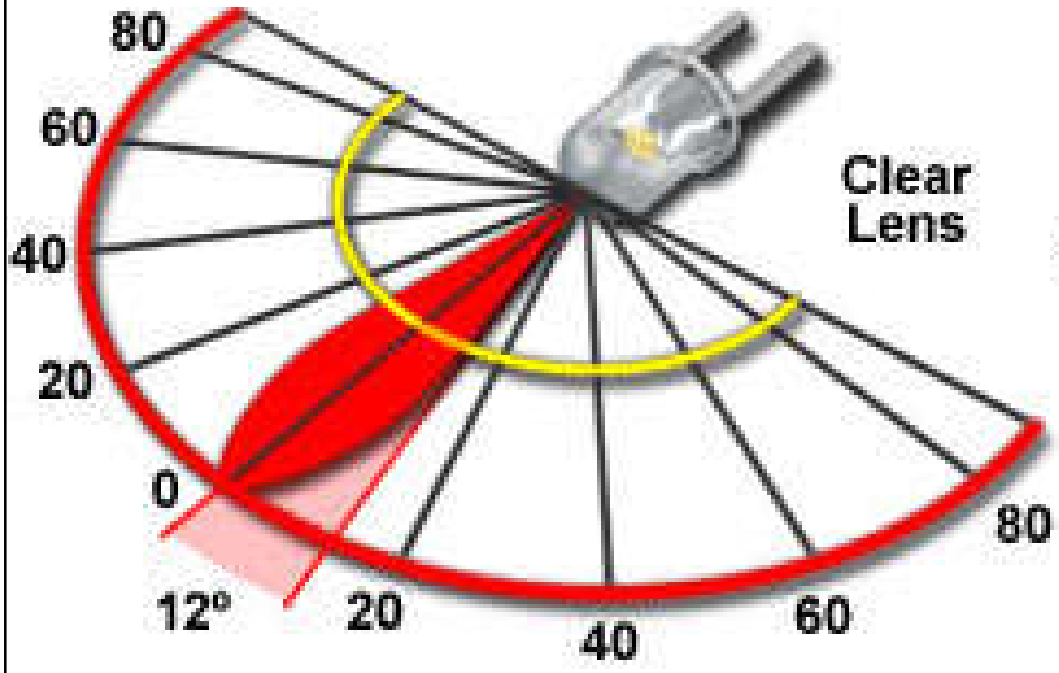


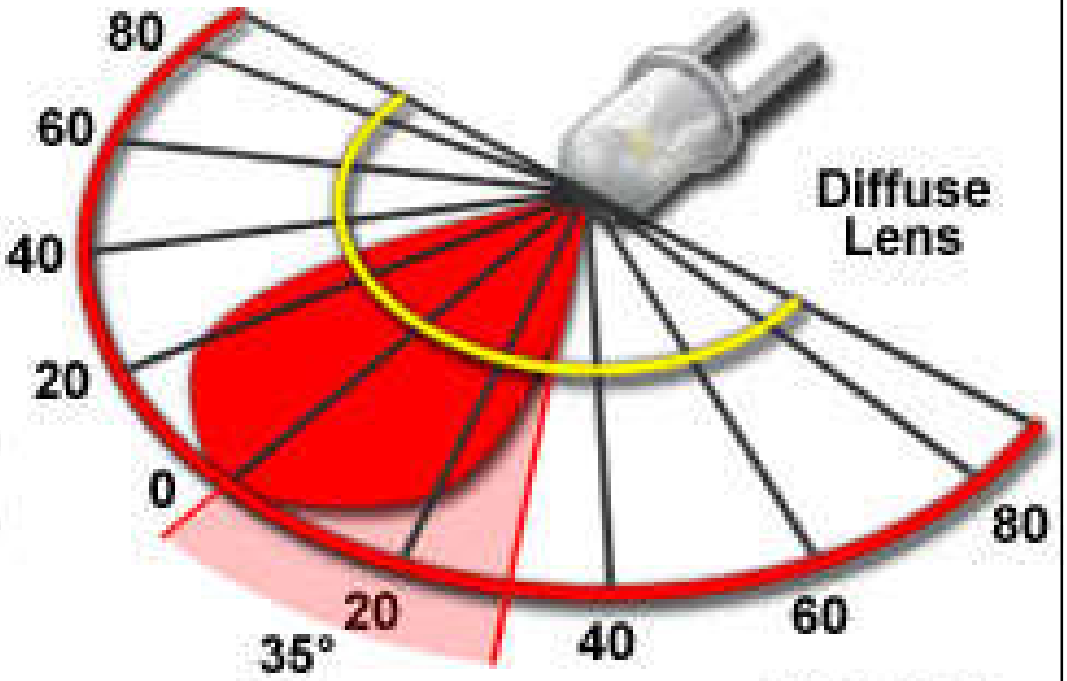
Light emitting diode (LED)

- Light emitting diode (LED)
  - Produces light by electroluminescence at low voltage “p-n” junction (e.g. indicator lights)
  - Development of white light & high output LEDs enables wider use in lighting systems

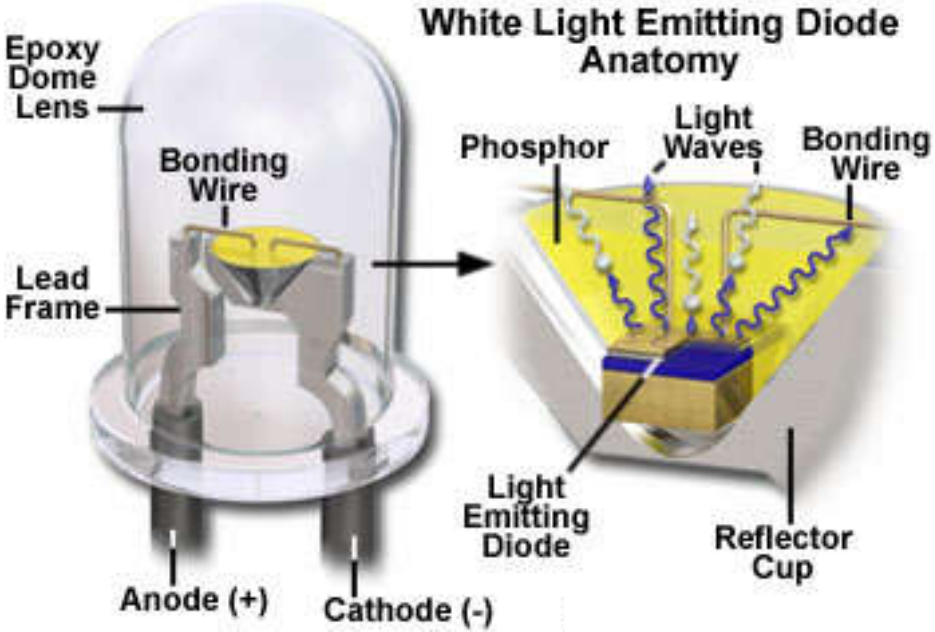


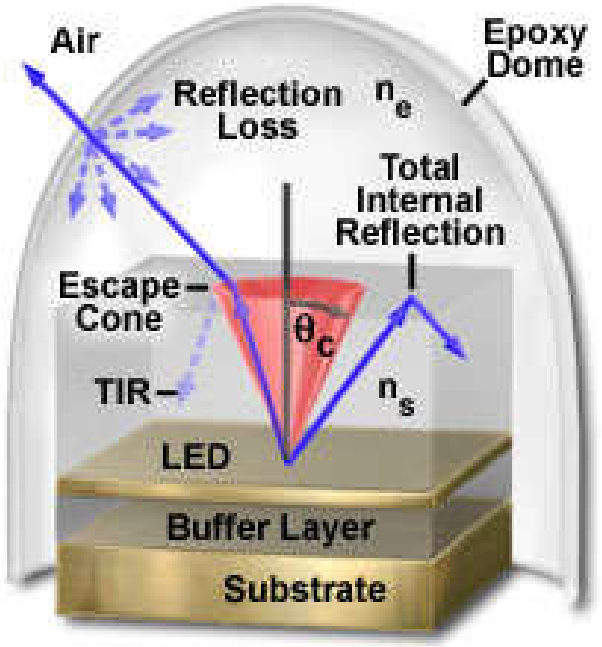
Light cones emitted by clear and diffuse LED lenses





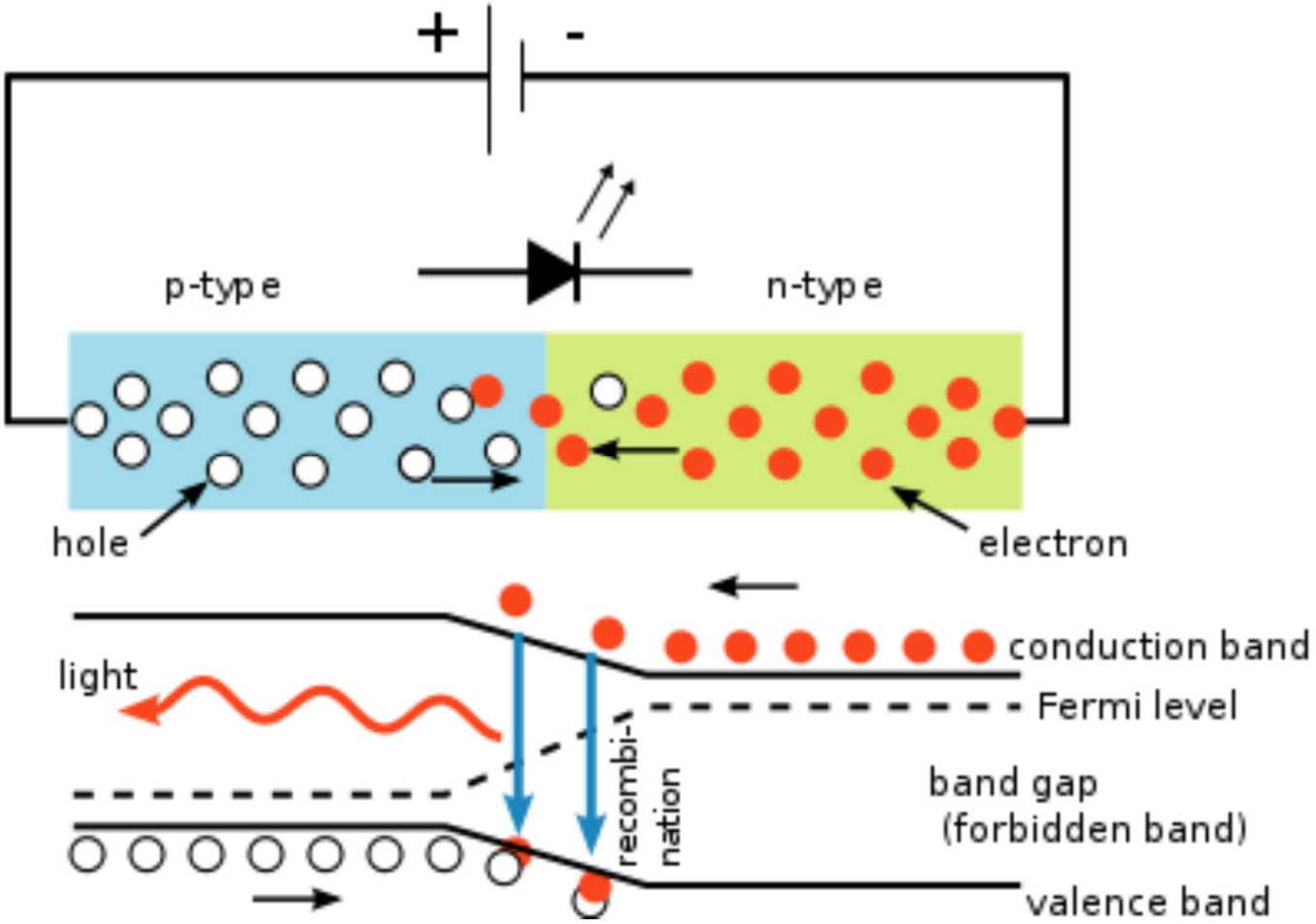
50% Intensity 100% Intensity

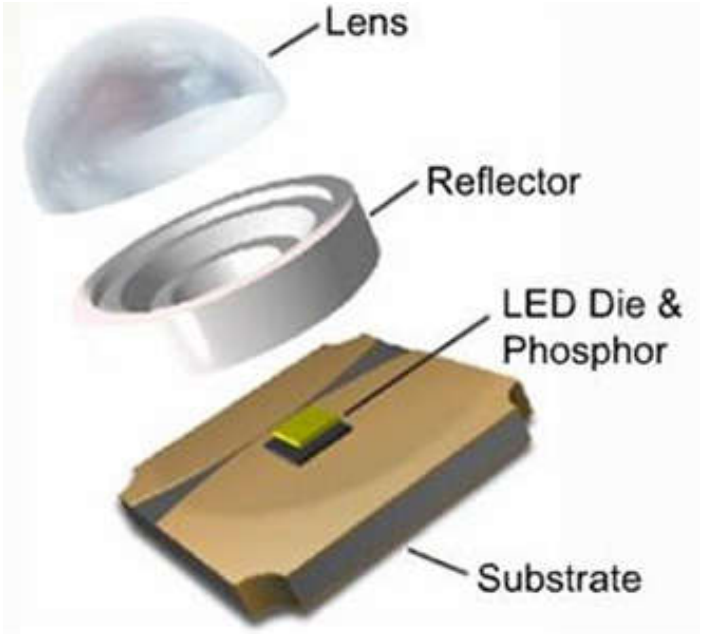




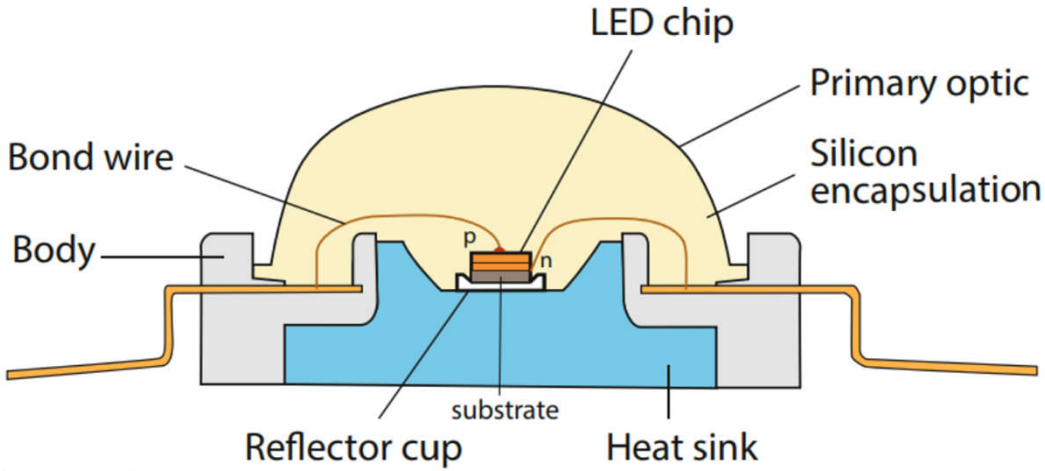
(Source: https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/ledsintro/)

Principle of LED and structure of high power white LED*





Structure of high power white LED



(* See How LED Works, http://www.omslighting.com/ledacademy/)

Light emitting diode (LED)

- Solid state lighting (SSL)
  - Emits light from semi-conductor (solid)
    - Light emitting diode (LED)
    - Organic light-emitting diodes (OLED)
    - Polymer light-emitting diodes (PLED)
  - Advantages:
    - Low power consumption
    - Reduced heat generation
    - Greater resistance to shock, vibration, and wear
  - LED retrofits (not ideal), versus LED luminaires

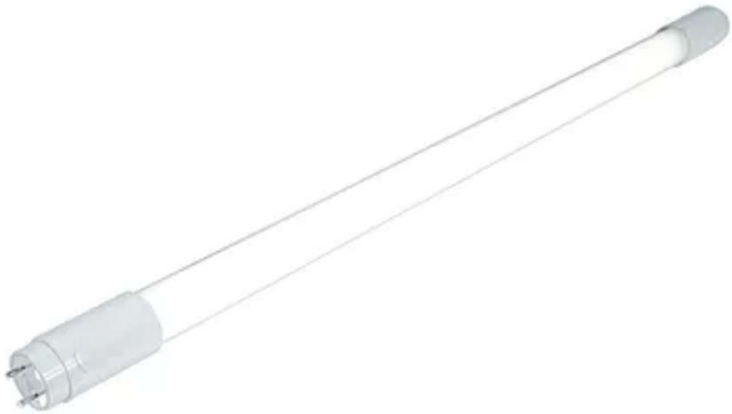
New generation of LED lighting fittings

Linear lights (flexible & rigid)

Recessed luminaires

Recessed downlights

LED panels



LED tubes

LED bulbs

(Source: https://www.lightengine-tech.com/led-general-lighting-solution

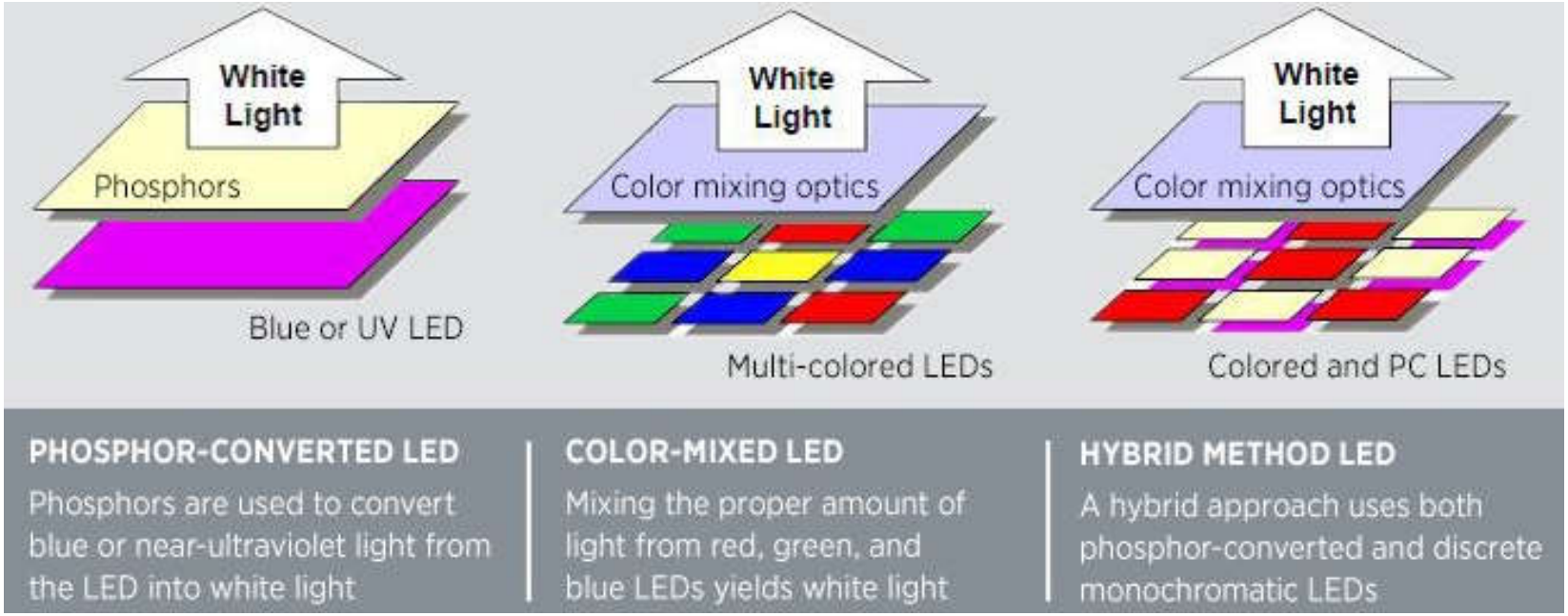
Light emitting diode (LED)

- Light emitting diode (LED)
  - Advantages
    - Low power consumption
    - Long lasting (long useful life)
    - Durable (withstand impact & vibration)
    - Cool (little heat produced)
    - Modular design & compact size
    - Controllability (colour balance & intensity)
    - Instant on, frequent switching
    - No annoying flicker
    - Low cost of manufacture
    - No ultraviolet & infrared radiation
    - Mercury free
  - Disadvantages
    - Focused, directional light
    - Need different optics design
    - May need heat sink (thermal management)

LED candles

Light emitting diode (LED)

- White light LED
  - Mixing light from multiple LEDs of various colours, or using a phosphor to convert some of the light to other colors



(Source: https://www.energy.gov/eere/ssl/led-basics)

Light emitting diode (LED)

- Colour changing LED lighting
  - Tunable lighting systems employ banks of coloured LEDs that can be individually controlled
- LED drivers
  - An appropriate circuit to control electrical power
- Thermal management & heat mitigation
  - The housing of high-power LEDs should be designed to adequately dissipate heat
  - Efficiency decreases with operating temperature

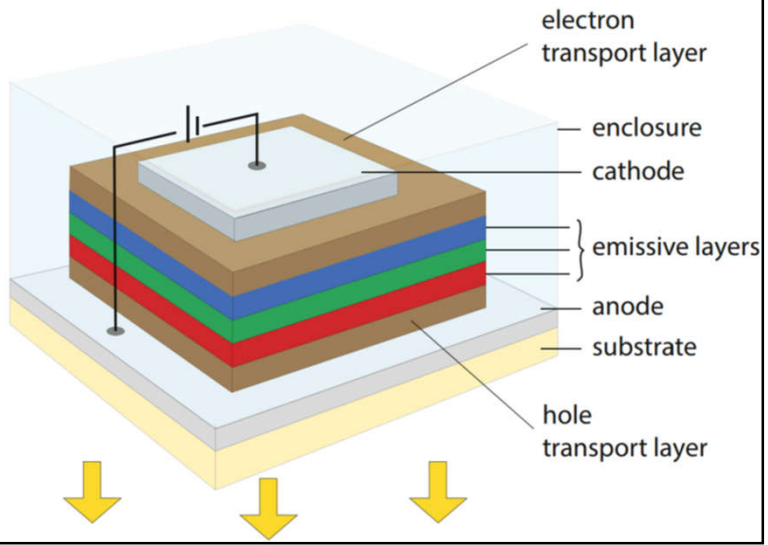
Light emitting diode (LED)

- Video: LEDs and OLEDs - How it Works, Inventors (7:18)

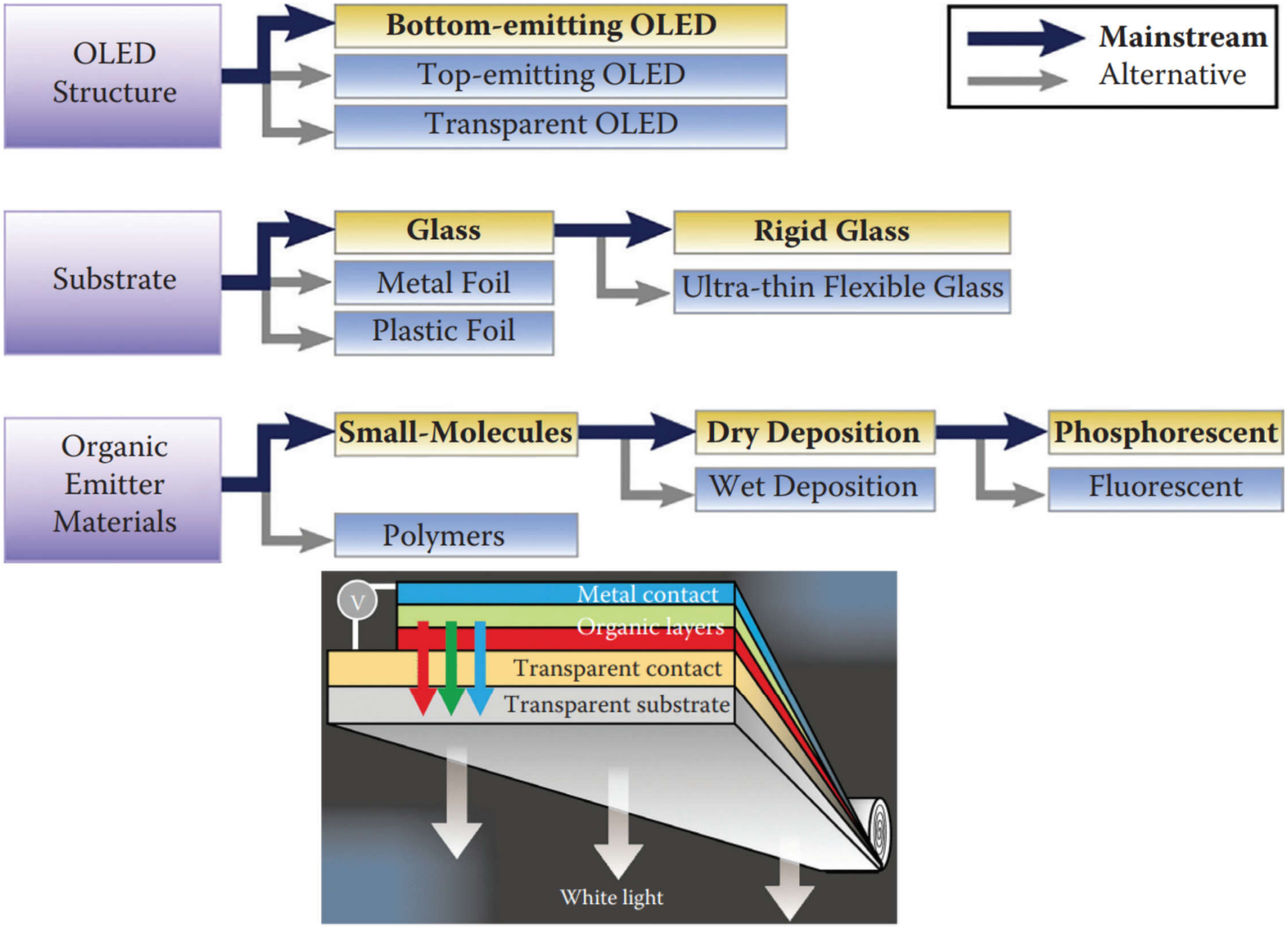
  - https://youtu.be/8quZrUcRFlw
  - All about Light Emitting Diodes and Organic LEDs. How they work, the difference between them.
  - Learn about the inventors of the lights at the end of the program.

Light emitting diode (LED)

- Organic light emitting diode (OLED)
  - LED made of organic semiconductor material
  - Can create large area lighting panels
  - Can be used to make flexible & transparent panels
  - They are expensive & difficult to produce

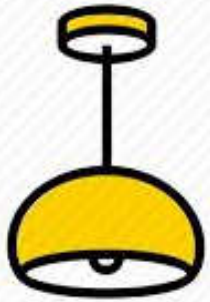


OLED structure and materials

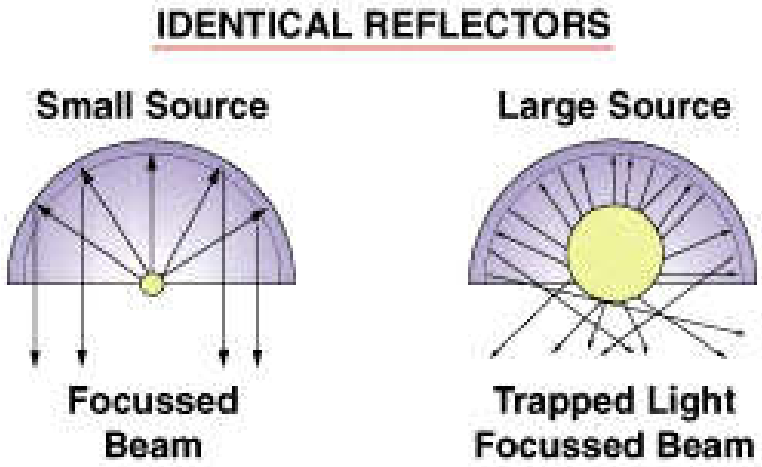


(Source: Kitsinelis S., 2015. *Light Sources: Basics of Lighting Technologies and Applications*, 2nd Ed., CRC Press, Boca Raton, FL.)

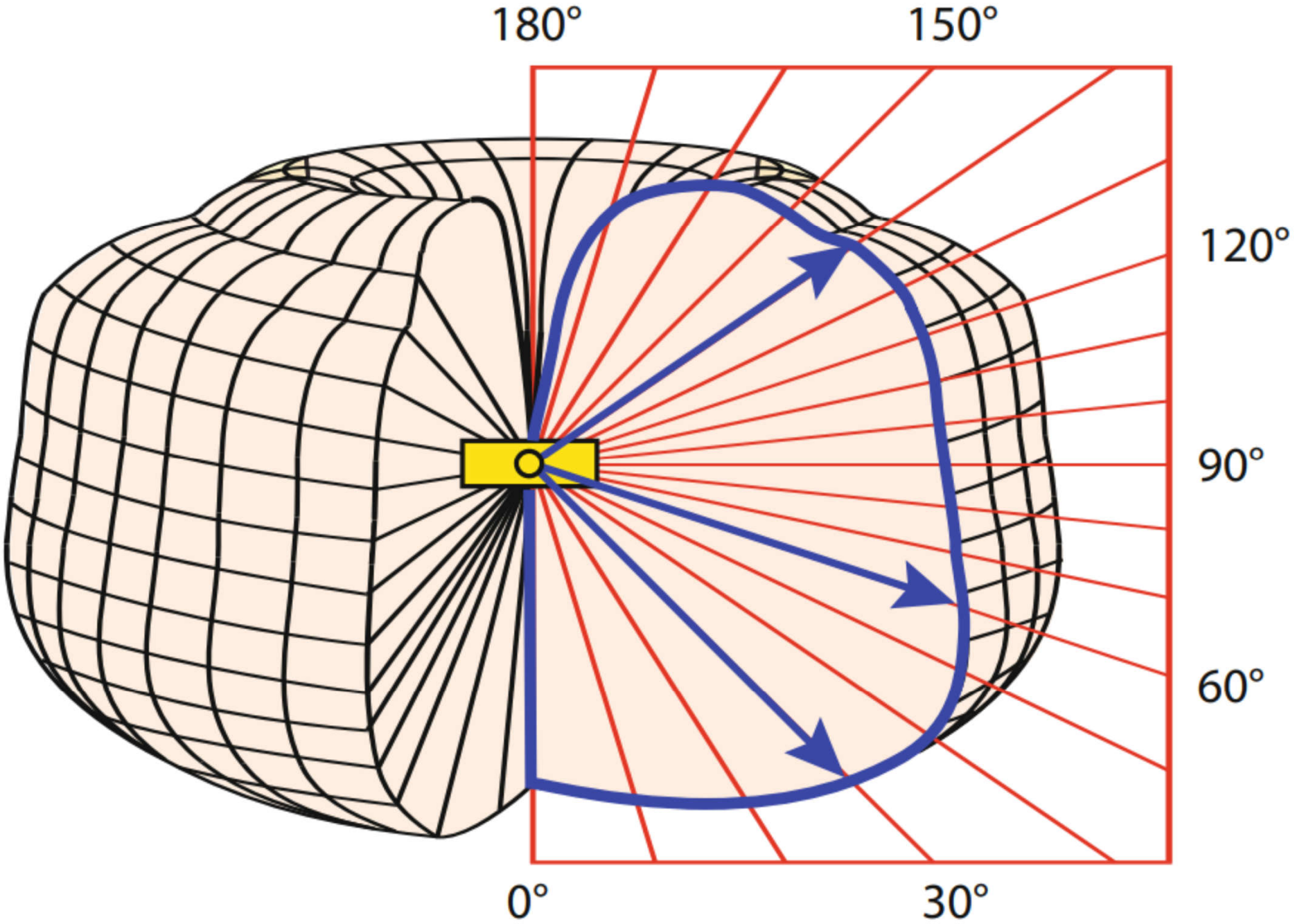
Luminaires



- Luminaire (light fixture)
  - A complete lighting system:
    - A housing and lampholders
    - Lamps (w/ a ballast/transformer)
    - Optical system
      - Reflector, and either a lens, louver or diffuser
      - For controlling brightness
  - It may also include some type of electrical control dimmers, hilo switching, daylight sensors, etc.
  - Control light distribution in various directions

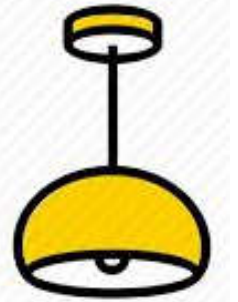


Light distribution of a luminaire
(The lengths of the arrows represent the luminous intensities)



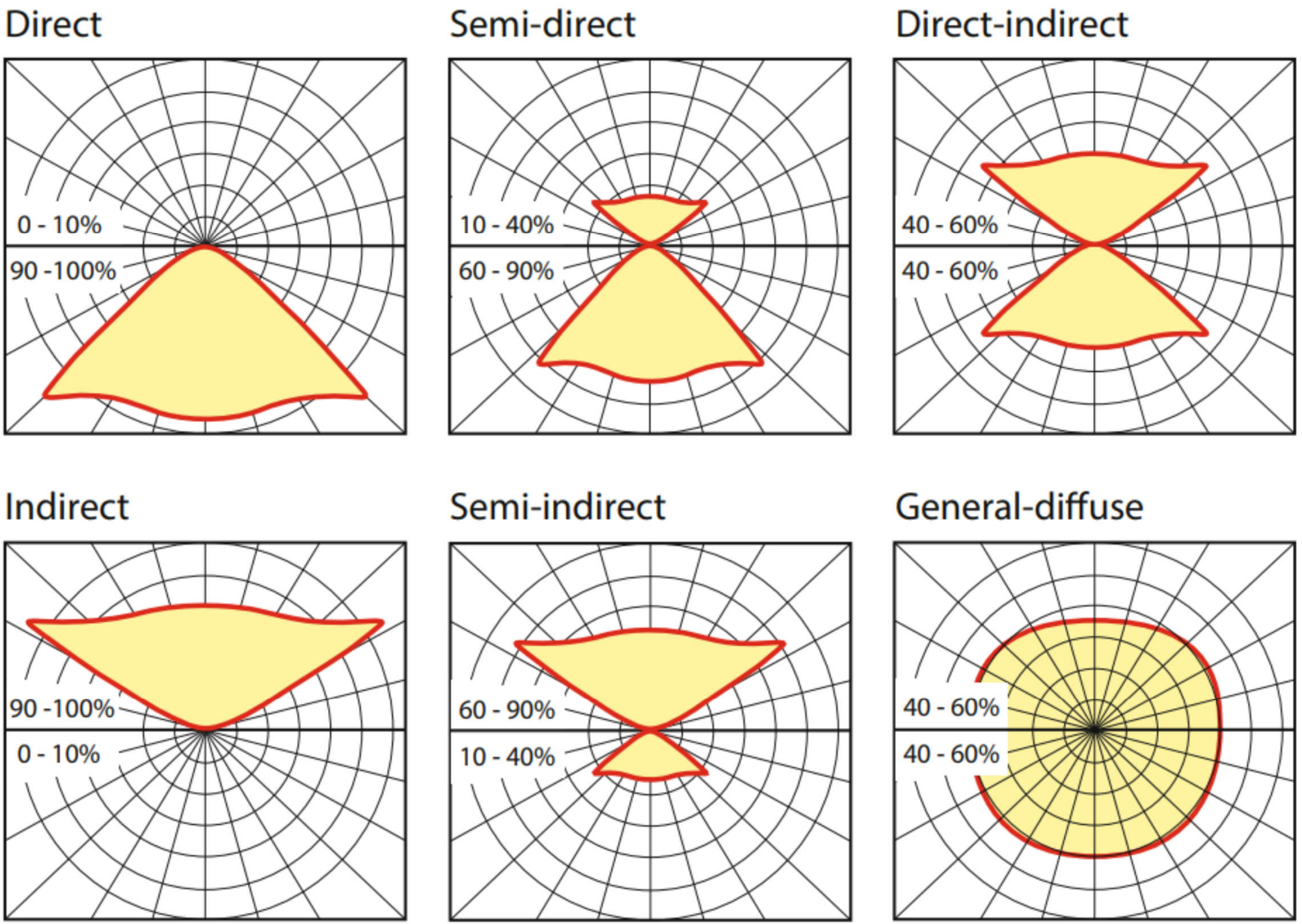
(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

Luminaires



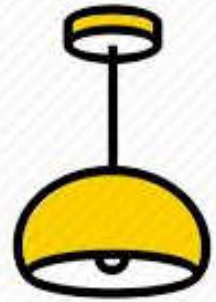
- Six basic classifications of luminaires:
  - Direct luminaire where all the light is directed down
  - Semi-direct luminaire where the majority of the light is directed down
  - General diffuse luminaire where light is distributed in all directions
  - Direct-indirect luminaire where light is distributed equally up and down
  - Semi-indirect luminaire where the majority of light is directed up
  - Indirect luminaire where all the light is directed up

Luminaire classification system for indoor lighting luminaires

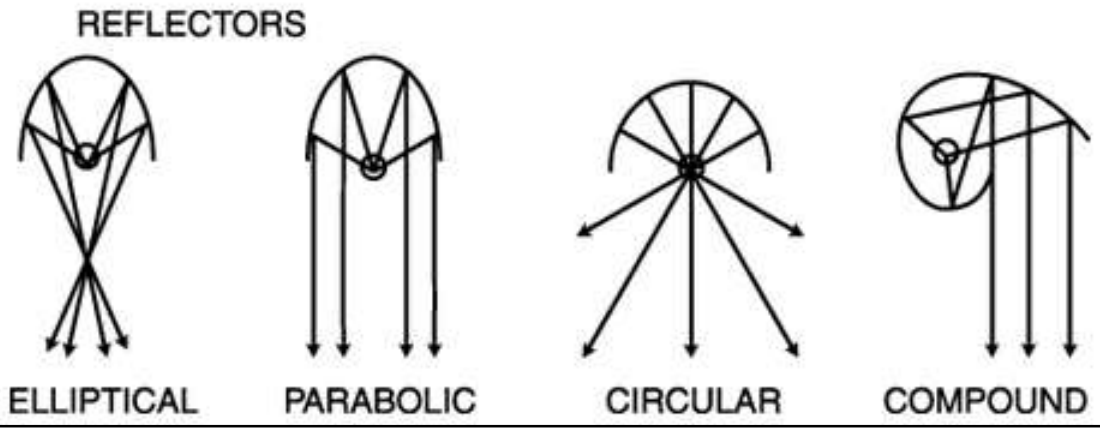


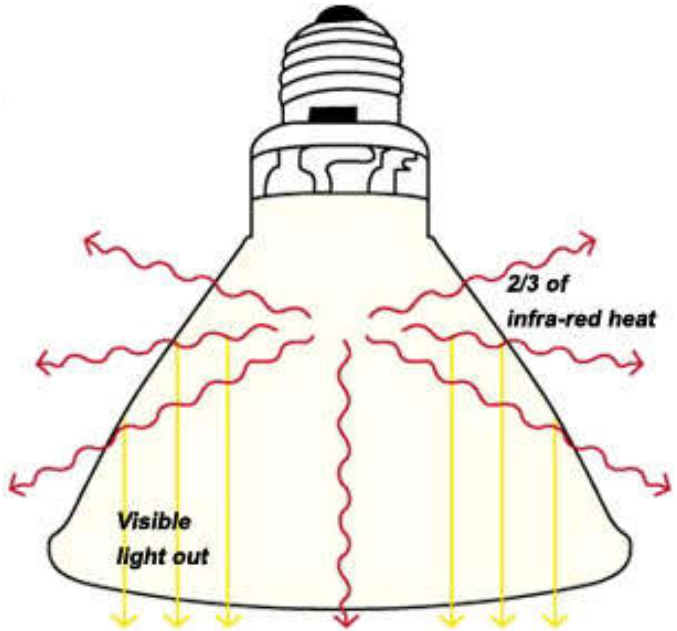
(Source: van Bommel W., 2019. *Interior Lighting: Fundamentals, Technology and Application*, Springer International Publishing, Cham.)

Luminaires



- Optical systems (for controlling light)
  - Reflection
    - Specular, diffuse, spread, selective
  - Transmission
    - Direct, diffuse, spread, selective
  - Refraction





Methods of controlling light

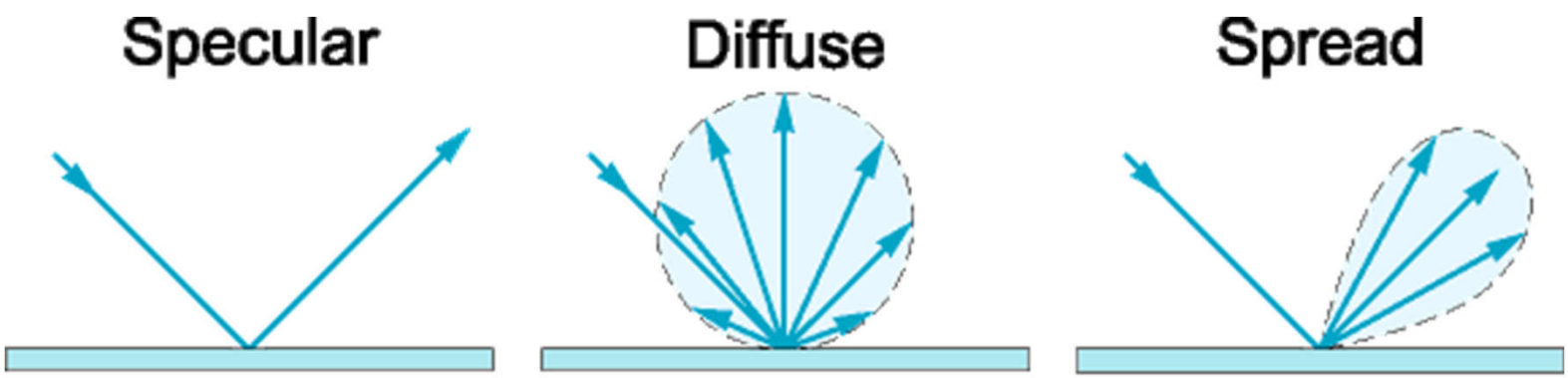


Fig. 3.2 Specular, diffuse, and spread reflection from a surface.

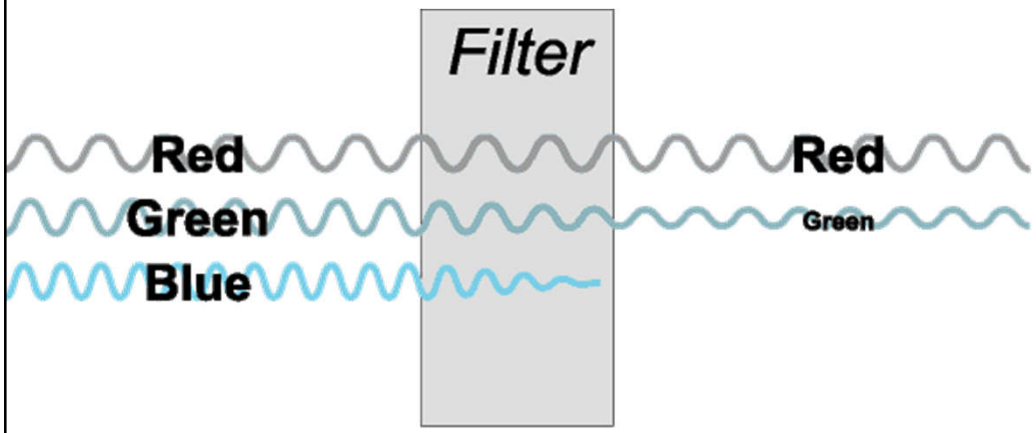


Fig. 3.3 Transmission through an optical filter.

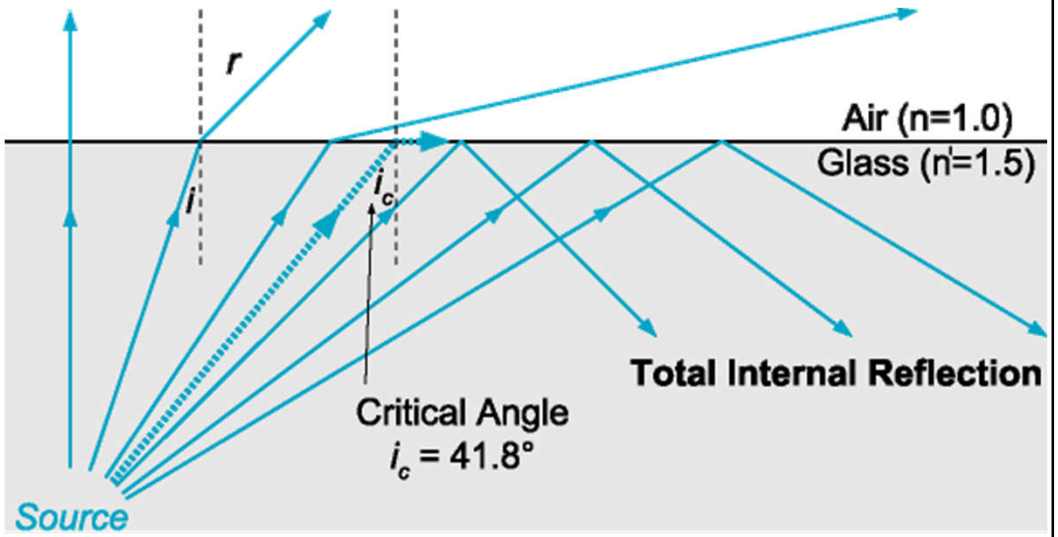
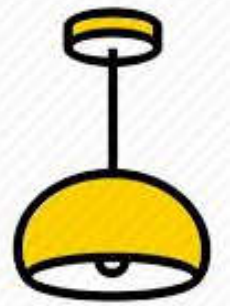
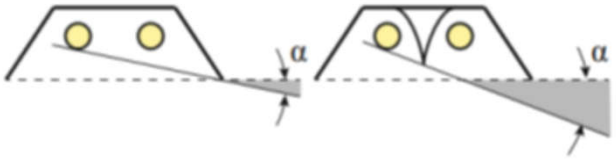


Fig. 3.5 Refraction and total internal reflection.

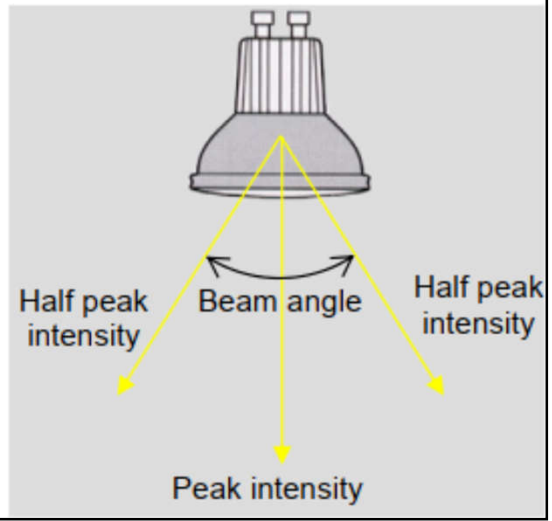
(Source: IESNA Handbook 9th ed.)

Luminaires

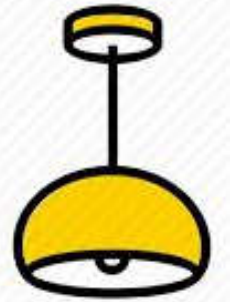




- Shielding angle
  - Shielding lamps from direct view into critical directions with the aid of the housing of the luminaire or with mirrors or baffles
  - The higher the lamp luminance, the larger the shielding angle needs to be
- Beam angle
  - Angle where the light intensity has fallen to 50% of the peak value

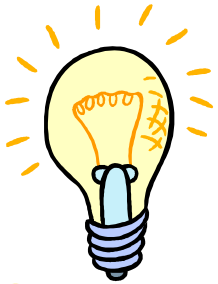


Luminaires



- Luminaire Efficacy Rating (LER)
  - LER = (Photometric Efficiency x Total Lamp Lumens x Ballast factor) / Luminaire Input Watts
- How to classify fluorescent luminaires & systems
  - Mounting: recessed, surface (ceiling or wall) & suspended
  - Distribution: direct, indirect, direct/indirect
  - Type of fluorescent lamp: T12, T8, T5
  - Nominal dimensions: 1 x 4, 2 x 4, etc
  - Application: commercial, industrial, residential, special purpose

Further Reading



- The Electric Light (Edison Tech Center) http://www.edisontechcenter.org/Lighting.html
  - Incandescent Lamps http://www.edisontechcenter.org/incandescent.html
  - The Fluorescent Lamp http://www.edisontechcenter.org/Fluorescent.html
  - Mercury Vapor Lamps http://www.edisontechcenter.org/MercuryVaporLamps.html
  - Metal Halide Lamps http://www.edisontechcenter.org/metalhalide.html
  - Sodium Lamp http://www.edisontechcenter.org/SodiumLamps.html
  - LEDs and OLEDs http://www.edisontechcenter.org/LED.html
- Lamp types, lamp data and control gear http://ibse.hk/IBTM5680/Lamps.pdf