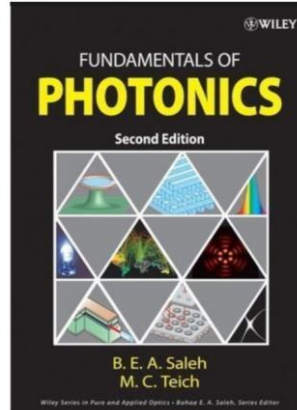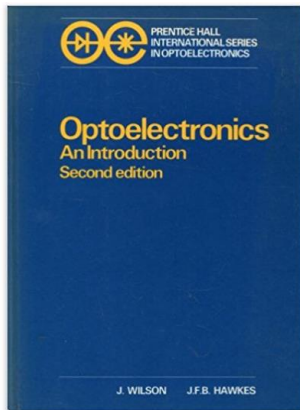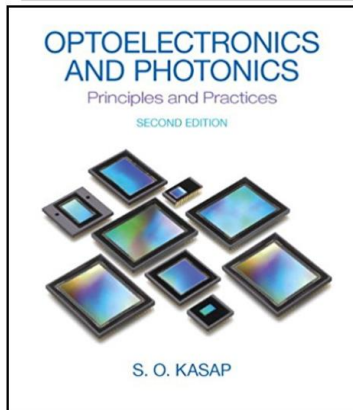# Optoelectronics-I
Chapter-3

Assoc. Prof. Dr. Isa NAVRUZ

Lecture Notes - 2018

Recommended books

Department of Electrical and Electronics
Enginnering, Ankara University
Golbasi, ANKARA

Wave Nature of Light

Objectives

When you finish this lesson you will be able to:

- ✓ Describe a *wave front.*
- ✓ Describe the relationship between *light rays* and *wave fronts*.
- ✓ Define *phase angle* and its relationship to a *wave front*.
- ✓ Calculate *water wave displacement* on a sinusoid-like waveform as a *function of time and position.*
- ✓ State the *principle of superposition* and show how it is used to combine two overlapping waves
- ✓ Light Sources, Non-Laser and Laser Light Sources
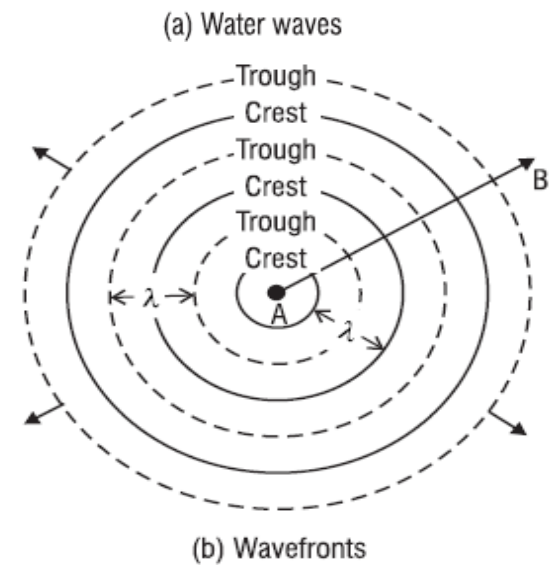
Wave Nature of Light

Wavefront

Wave optics treats light as a series of propagating electric and magnetic field oscillations. While we cannot see these extremely rapid oscillations, their wave behaviour is similar to that of water waves.

To illustrate the movement of water waves is useful to explain the wavefront.

(a) Water waves

✓ The solid circles in Fig (b) depict the outward-moving wave crests; the dashed circles represent wave troughs.


(b) Wavefronts

✓ A **wavefront is** a surface over which an optical wave has a constant phase.
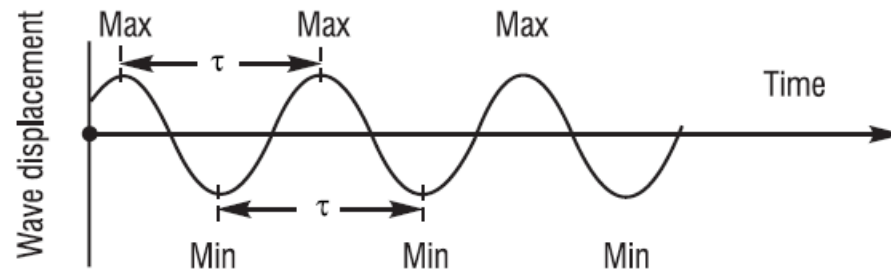
Wave Nature of Light

Wavefront

✓ If we were able to look along the surface of the pond, we would see a *sinusoid-like* profile of the traveling wave.

✓ We can see a sinusoid-like profile of the traveling wave by taking a snapshot of the water displacement at a certain instant of time along a direction.
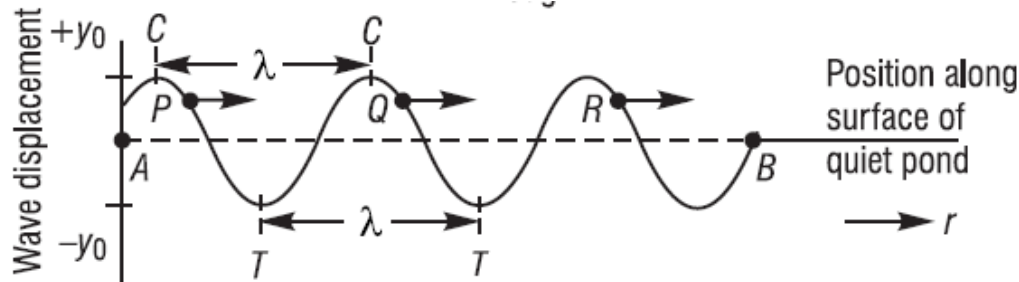
Distance is denoted by the variable r

(a) Wave profile along the pond at a *certain instant of time*

wave displacement as a function of time—*at a fixed position*

(b) Wave displacement *at a fixed* position on the pond as a function of time

Wave Nature of Light

Sinusoidally varying

✓ In both the fixed time and fixed position, the wave motion can be defined as a sinusoidal equation.

$$y(r, t) = y_0 \sin\left[\frac{2\pi}{\lambda}(r - vt)\right]$$

where: $y(r, t)$ is the wave displacement at position r and time t

y_0 is the wave amplitude

λ is the wavelength

r is the position along the traveling wave

v is the wave speed, equal to $\lambda \times f$, and

t is the time

Wave Nature of Light

Sinusoidally varying

If we "freeze" time at some value t_0. $\quad y(r, t_0) = y_0 \sin\left[\dfrac{2\pi}{\lambda}(r - \text{constant})\right]$

On the other hand, if we select a fixed position r_0

$$y(r_0, t) = y_0 \sin\left[\dfrac{2\pi}{\lambda}(\text{constant} - vt)\right]$$

The factor in brackets in the Equation $\left[\dfrac{2\pi}{\lambda}(r - vt)\right]$

defines the *phase angle* ϕ of the wave at position r and time t.

The phase angle is the *same for any point on a given wave front*

Wave Nature of Light

Sinusoidally varying

For example, for the wavefronts whose phase angles are $\left[\frac{\pi}{2}\right], \left[\frac{\pi}{2}+2\pi\right], \left[\frac{\pi}{2}+4\pi\right] \cdots$
(for these angle, $\sin\phi$ equals +1) , *the wavefronts are crests*

Similarly, *the wavefronts are troughs* for $\left[3\frac{\pi}{2}\right], \left[\frac{3\pi}{2}+2\pi\right], \left[\frac{3\pi}{2}+4\pi\right]$, etc

Exercise
Consider circular water waves as shown in the figure. The cork bobs up and down and back again—a complete cycle—once per second, and generates waves that measure 10 cm from crest to crest. Some time after the wave motion has been established, we begin to time the motion with a stopwatch. At a certain time t = 10 s on the watch, we notice that the wave profile has the shape shown below.
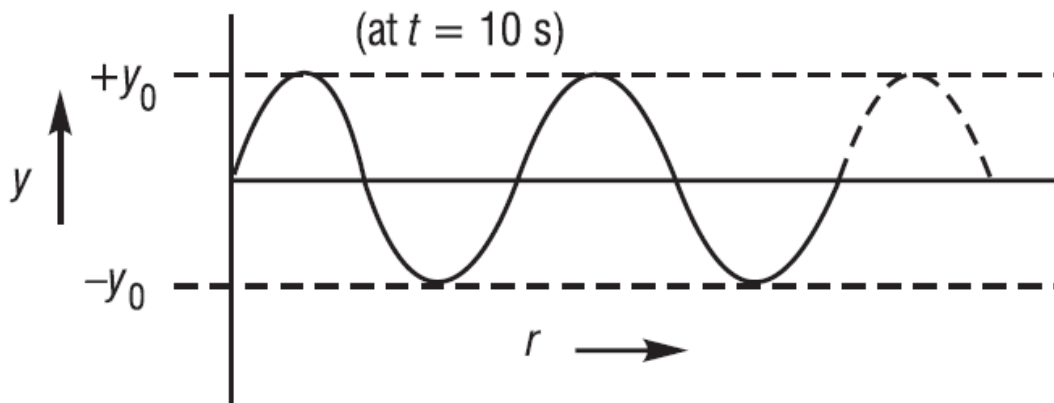
Wave Nature of Light

Exercise

(a) What is the wave frequency f for this water wave?

(b) What is its wavelength λ?

(c) What is its wave speed v?

(d) What is the phase angle ϕ for a wave front at position $r = 102.5$ cm at time $t = 10$ s?

(e) What is the wave displacement y on the wave front at $r = 102.5$ cm?

(f) What is the phase angle ϕ for a wave front at $r = 107.5$ cm at $t = 10$ s?

(g) What is the wave displacement y on the wave front at $r = 107.5$ cm?

(h) If we focus on the wave motion at the position $r = 105$ cm and let time vary, what kind of motion do we observe?
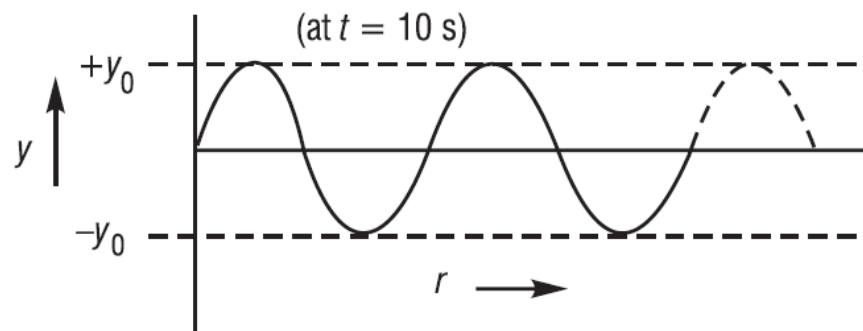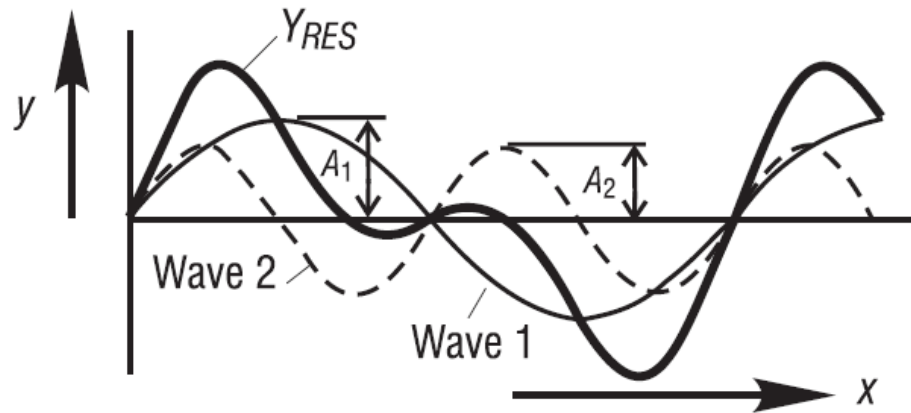
Wave Nature of Light

Interaction of Light Waves

When two or more waves move simultaneously through a region of space, each wave proceeds independently as if the other were not present.

This principle holds for water waves, mechanical waves and for sound waves in gases, liquids and solids.

Wave 1 alone causes a "displacement" $Y1$ and Wave 2 alone a displacement $Y2$. The principle of superposition states that the resultant displacement YRES;
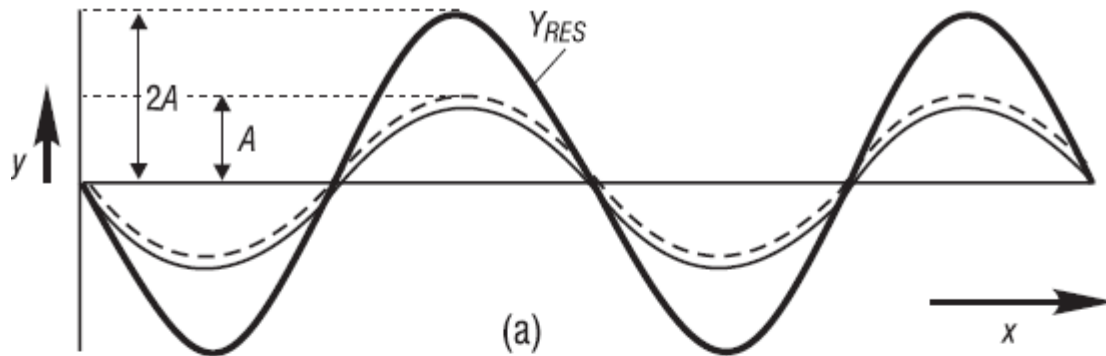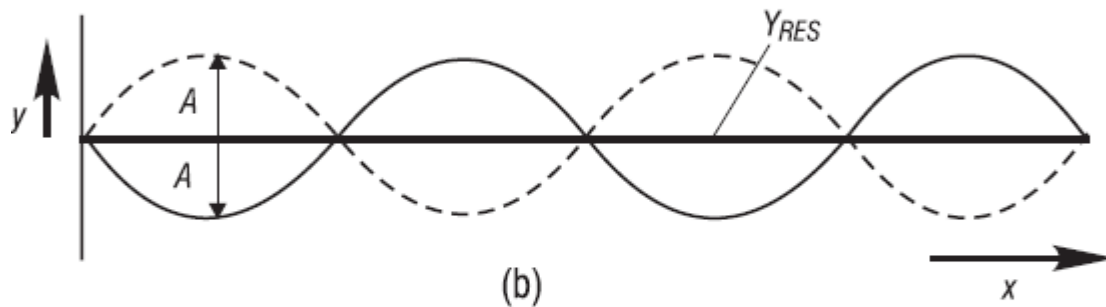
$$Y_{RES} = Y_1 + Y_2$$

Superposition of two waves moving along the same direction
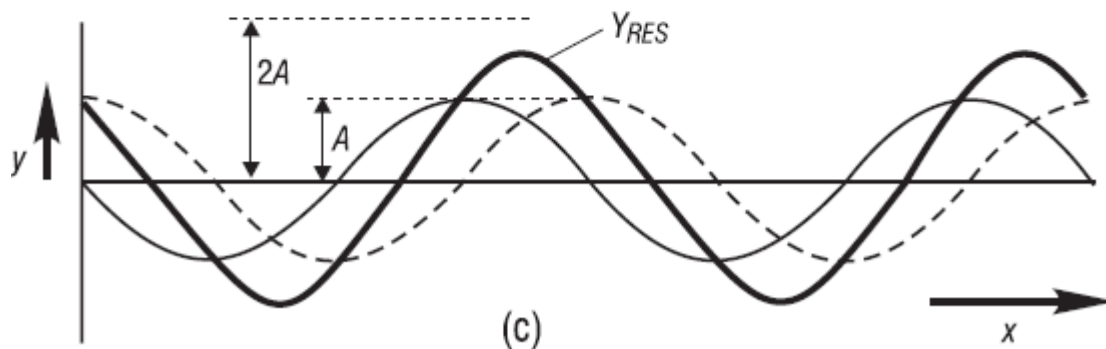
Wave Nature of Light

Interaction of Light Waves

exactly in phase
constructive interference

exactly out of phase
destructive interference

*neither completely in phase
nor completely out of phase*

Figure 4-5 *Interference of two identical sinusoidal waves*

Wave Nature of Light

Light Sources

Light occurs in different wavelengths, just as waves on water. The color of light depends on its wavelength. Violet light has the shortest wavelength of all visible colors, and red light has the longest.

- ✓ *White light* is a combination of all visible colors or wavelengths.

- ✓ *Laser light*, unlike ordinary light, is unique in that it usually consists of only a single color of light. The wavelengths of this single color occur within a very narrow range because they are not practically perfectly uniform in length.

- ✓ **Monochromaticity** is the laser light's property of containing only one color.
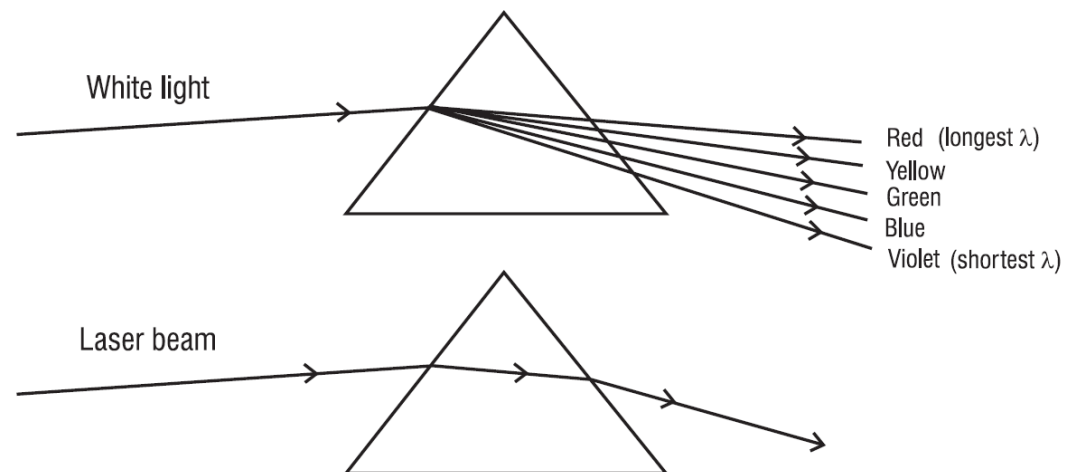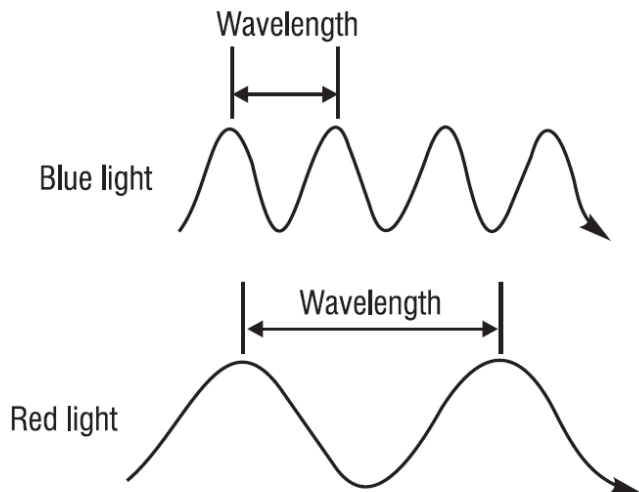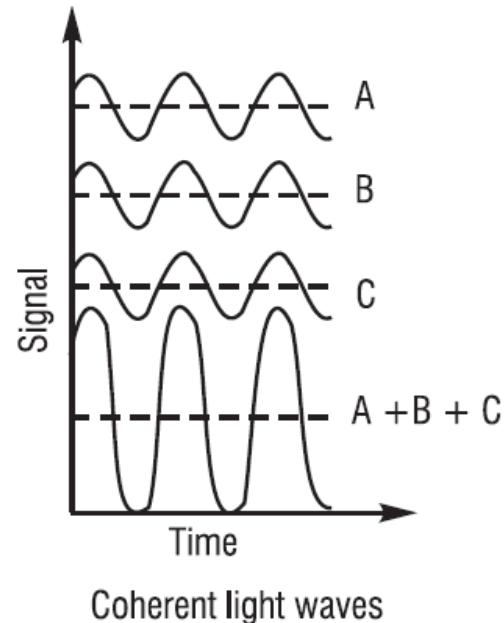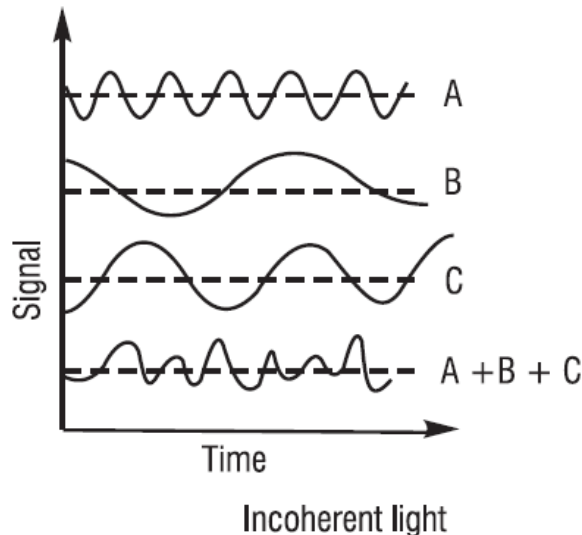
Wave Nature of Light

Light Sources

Incoherent light waves produced by ordinary sources. They combine in a random fashion and don't produce a wave larger than any of the single various waves.

By contrast, Coherent light is produced "in the same phase". The result wave is a wave much stronger than that of any single wave. (**constructive interference)**

Incoherent light

Coherent light waves

Wave Nature of Light

Light Sources

light emitted by a conventional bulb

light emitted by a laser

Ordinary light is
- ✓ highly divergence
- ✓ Polychromatic
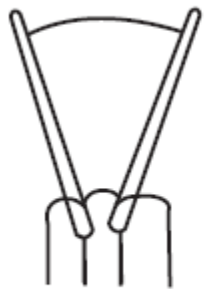- ✓ Incoherent
- ✓ Mostly unpolarized

Laser light is
- ✓ very directional
- ✓ Monochromatic
- ✓ Coherent
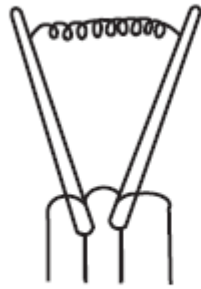- ✓ Polarized

Wave Nature of Light

Incandescent Sources

A tungsten filament is used for incandescent lamps because of its low vapor pressure, high melting point (3655 K). Most modern incandescent lamps are filled with gas to increase the lifetime of the filament.

The tungsten-halogen-type lamp has become increasingly common. The important feature of the tungsten-halogen lamps is that the particles of tungsten collected by the filament are prevented from depositing on the glass. Thus, the lamps do not form a black coating on the inner surface.
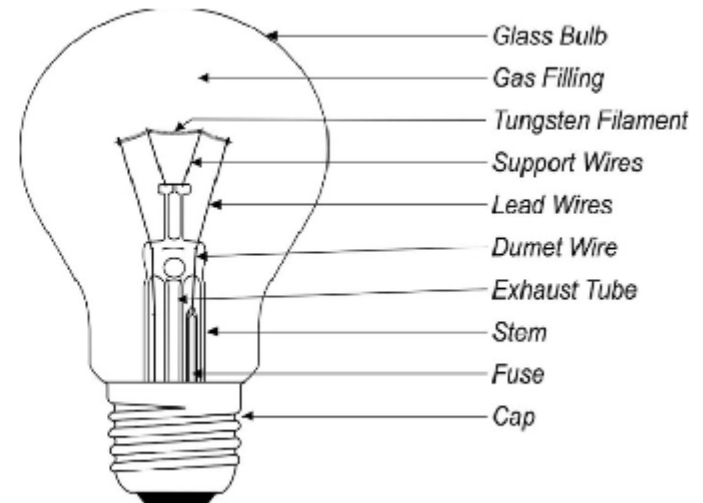
straight *Coiled* *Coiled coil*

An Incandescent Lamp

Glass Bulb
Gas Filling
Tungsten Filament
Support Wires
Lead Wires
Dumet Wire
Exhaust Tube
Stem
Fuse
Cap

Wave Nature of Light

Fluorescent Light Sources

Fluorescent light sources are low-pressure discharge lamps with a fluorescent phosphor. Most fluorescent lights consist of mercury discharge lamps that emit 90% of their energy at 253.7-nm wavelength. These ultraviolet photons can excite a number of phosphors, producing a range of wavelengths from infrared to ultraviolet.

Fluorescent lamps can have either cold or hot cathode electrodes. Cold electrodes are used when a rapid start is necessary. Hot cathode electrodes give greater luminous efficiency and because of this most lamps today use hot cathode electrodes. The luminous efficiency of a fluorescent lamp increases with its length. For example, an 80-inch lamp is 40% more efficient than a 15-inch lamp.

The output of a fluorescent lamp is also a function of the type of ballast used.
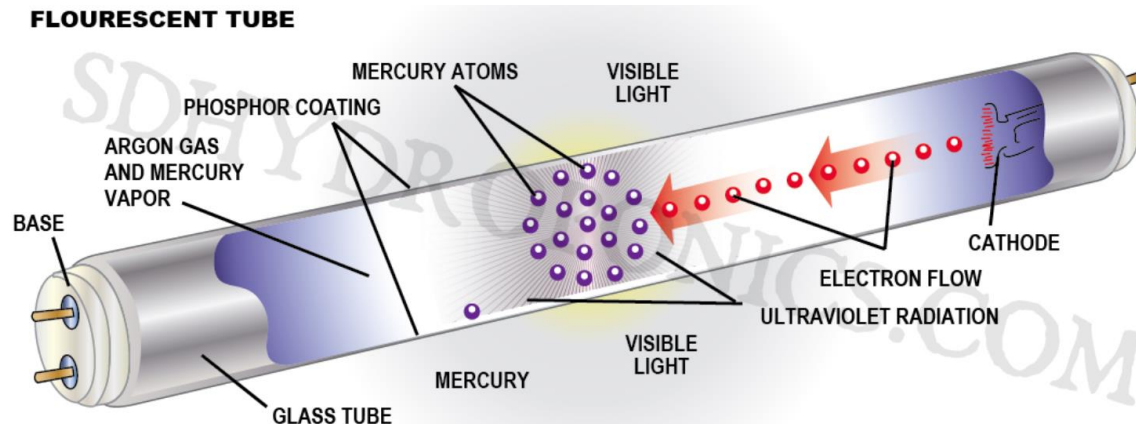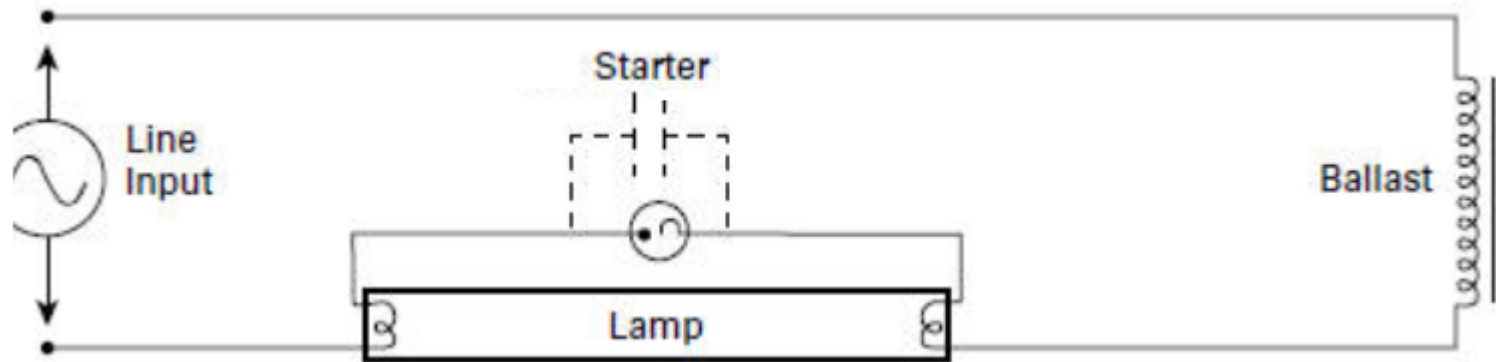

The image is cited from website of https://readymag.com/thegiftedbold son/physics/5/

Wave Nature of Light

Fluorescent Light Sources

The ballast is used to restrict the current flow from an electrical connection to a fluorescent bulb. This restriction is needed because without a regular, fluorescent bulbs will grow in current consumption as they warm.


The starter is simply a timed switch. When you turn on a fluorescent tube, the starter is a **closed switch**. The filaments at the ends of the tube are heated by electricity, and they create a cloud of electrons inside the tube. The fluorescent starter is a **time-delay switch** that opens after a second or two. When it opens, the voltage across the tube allows a stream of electrons to flow across the tube and ionize the mercury vapor. Without the starter, a steady stream of electrons is never created between the two filaments, and the lamp flickers.

Currently, *electronic starters* widely are used to "soft start" the lamp by preheating the cathodes.

Wave Nature of Light

High-Intensity Discharge Lamps (HID)

High-intensity discharge (HID) lamps can be made of mercury, sodium, or metal halides. The gas pressures inside the lamps are usually 2–4 atmospheres.
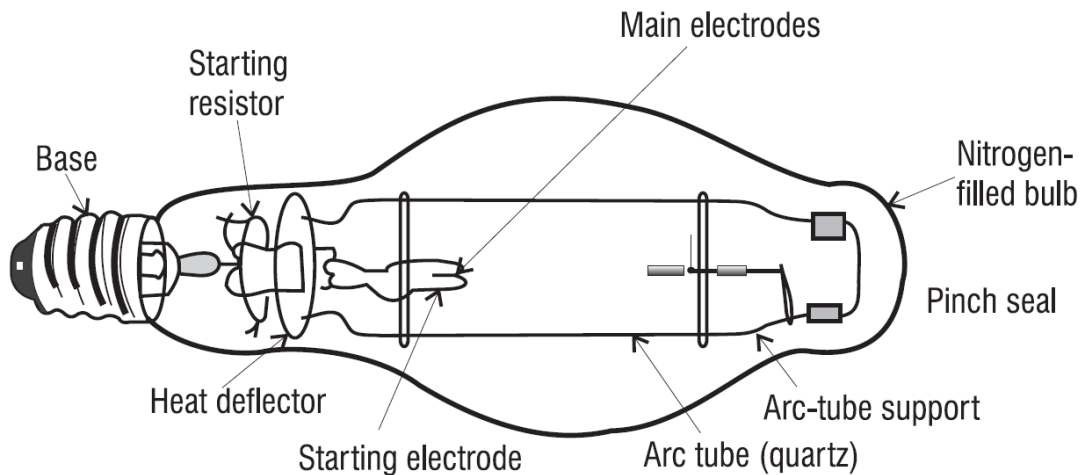
HID lamps—specifically those containing mercury—have two envelopes: the inner quartz discharge tube and an outer glass jacket. The outer jacket absorbs the UV radiation generated by the internal operation of the bulb. In places like gymnasiums, high-bay industrial areas, and public buildings, these lamps are often not enclosed in protective fixtures. The outer jacket can be broken in some instances by flying projectiles without damaging the inner discharge tube. If the lamp does not extinguish, substantial levels of UV radiation will be emitted to the outside.

Wave Nature of Light

Other Light Sources

Flashlamp and *arc lamps* are high-intensity discharge devices commonly used in photography and laser technology and usually contain gases such as xenon and krypton. The flash or arc is initiated by a high voltage across the discharge tube, which in turn ionizes the gas and produces a high-intensity light with output peaks in both the visible and infrared regions of the electromagnetic spectrum.
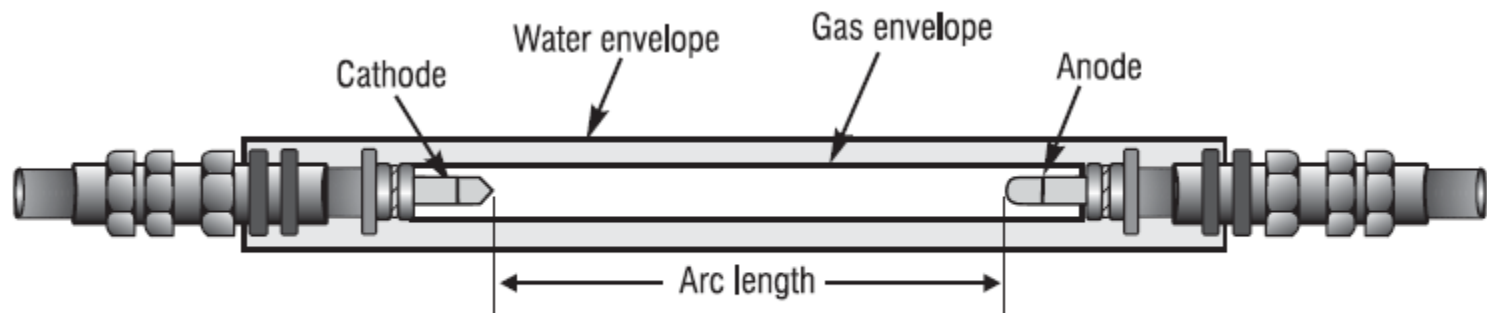

Diagram of a gas arc lamp with water jacket for cooling

Light-emitting diodes (**Leds**) are semiconductor devices that are directly modulated by varying input current. **Lasers** ared istinguished from other light sources by their coherence. A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.

The subject of Leds and Lasers will be examined in detail in next sections.

Wave Nature of Light

Standing Waves

The simplest example of two waves with the same frequency adding with varying phase is given by two cosine waves travelling in opposite directions adding to give an interference pattern of standing waves.

Two waves with equal amplitudes travelling in the directions +z and -z add as

$$\psi_1 = A \cos(kz - \omega t)$$
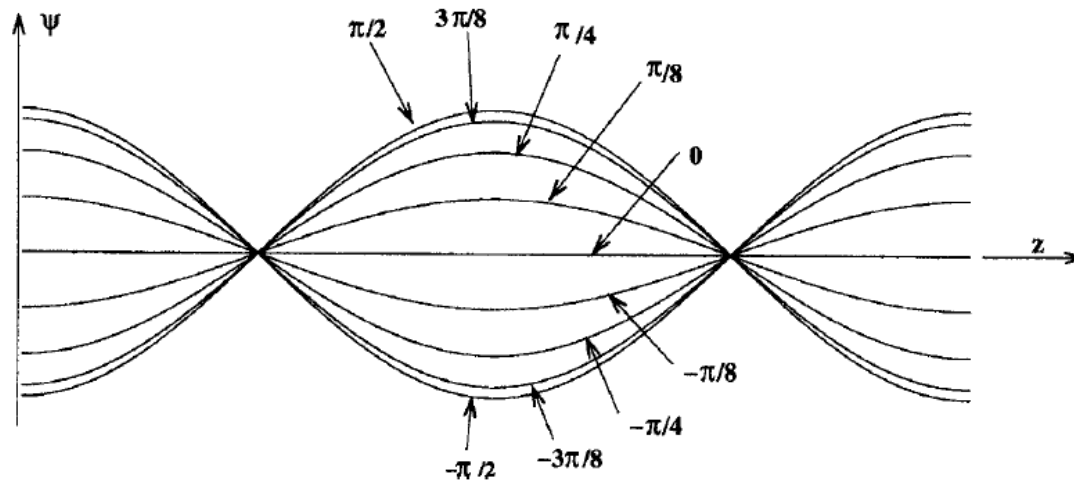$$\psi_2 = A \cos(-kz - \omega t)$$

$$\psi = \psi_1 + \psi_2$$

We can write the wave equations in complex form

$$\tilde{\psi} = A \exp[-i(\omega t \pm kz)]$$

$$\tilde{\psi} = A \exp(-i\omega t)[\exp(-ikz) + \exp(ikz)]$$
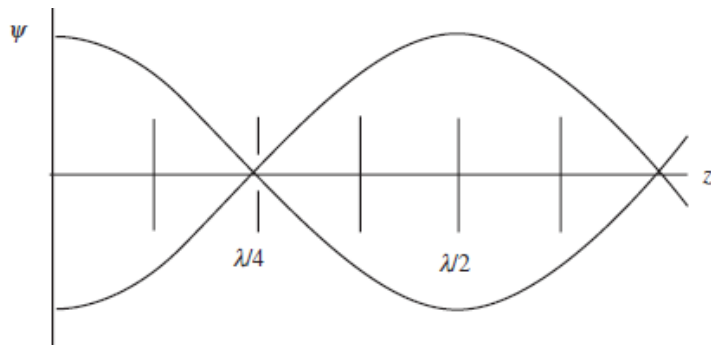$$= 2A \cos kz \exp(-i\omega t)$$

This is a wave with the same phase everywhere at a given time, but with an amplitude varying with position z. The result wave has amplitude 2A cos (kx) and phase ωt.
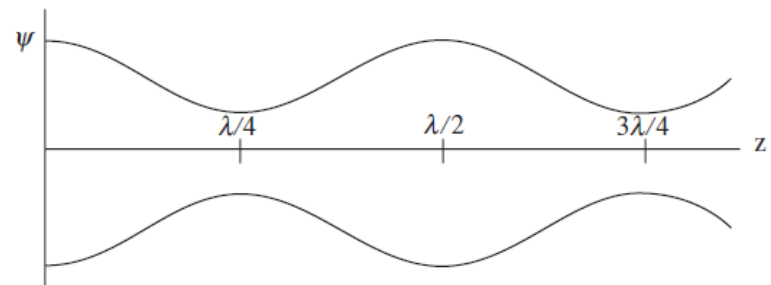
Wave Nature of Light

Standing Waves

The oscillation in a standing wave pattern with intervals of one-sixteenth of the period

The envelope of the standing wave pattern formed by two sinusoidal waves of equal amplitudes, in phase at z = 0 and travelling in opposite directions.

The standing wave pattern for waves of unequal amplitude does not have zero amplitude at the nodes.