PH 201

OPTICS & LASERS

Lecture_Polarization_1

Polarization

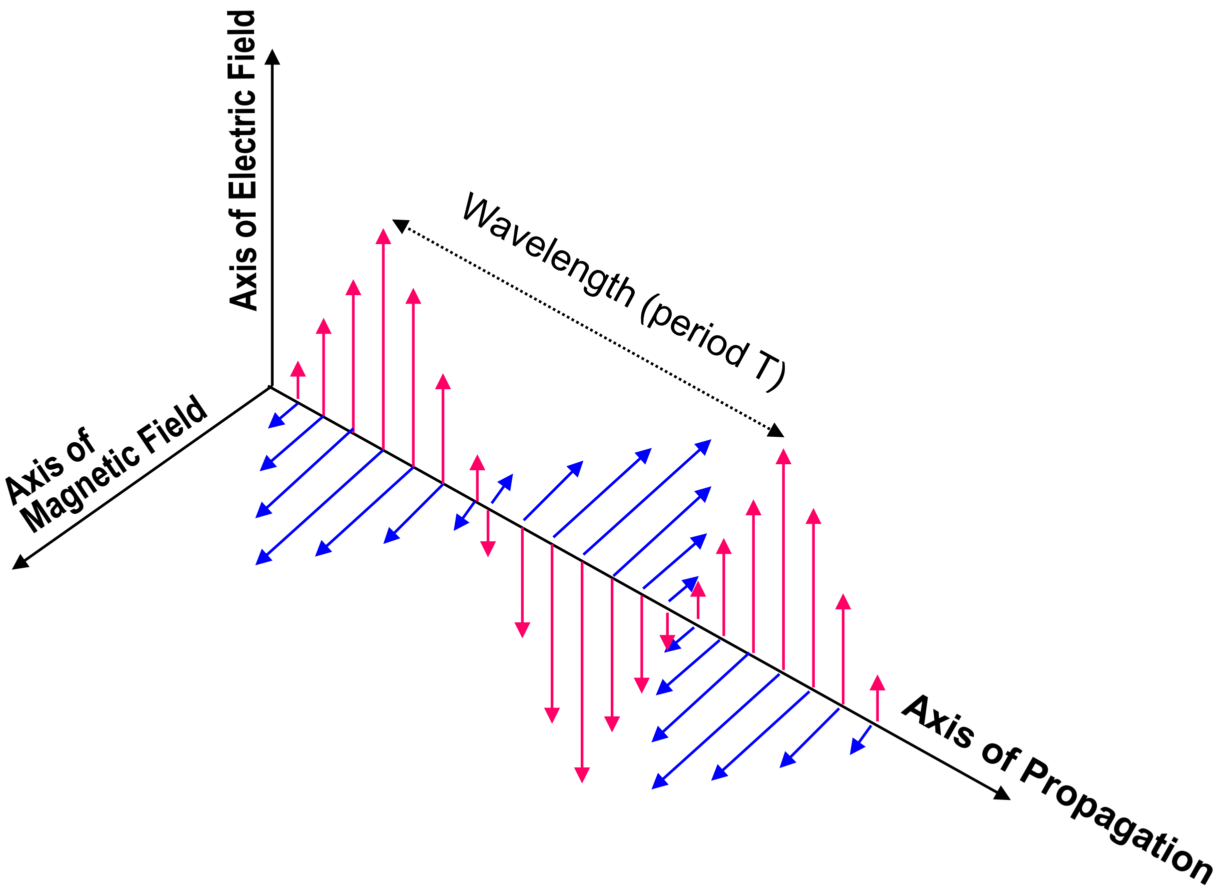
- It is a property applying to transverse waves that specifies the **geometrical orientation of oscillations**.

- In a transverse wave, direction of the oscillation is transverse to the direction of motion of the wave, so the oscillations can have different directions perpendicular to the wave direction.

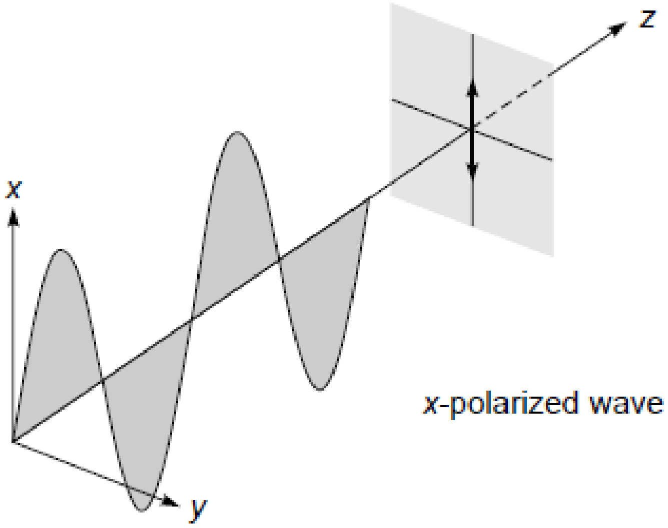
- **Ex.** In a musical instrument like a guitar string. Depending on how the string is plucked, vibrations can be in a vertical direction, horizontal direction, or at any angle perpendicular to string.

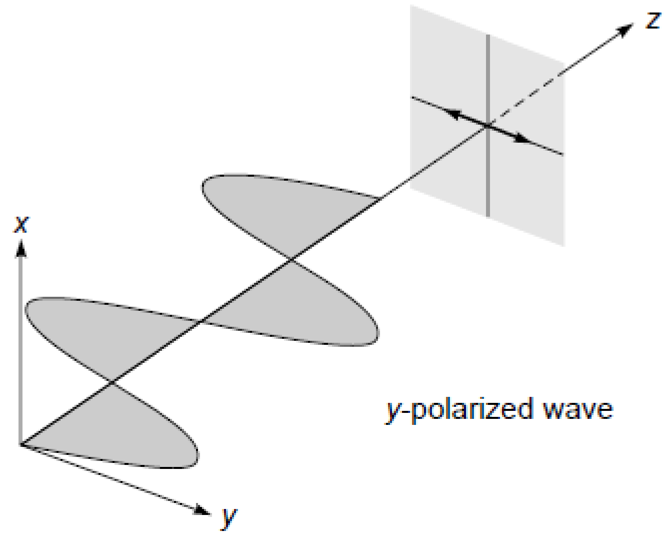
Electromagnetic Waves

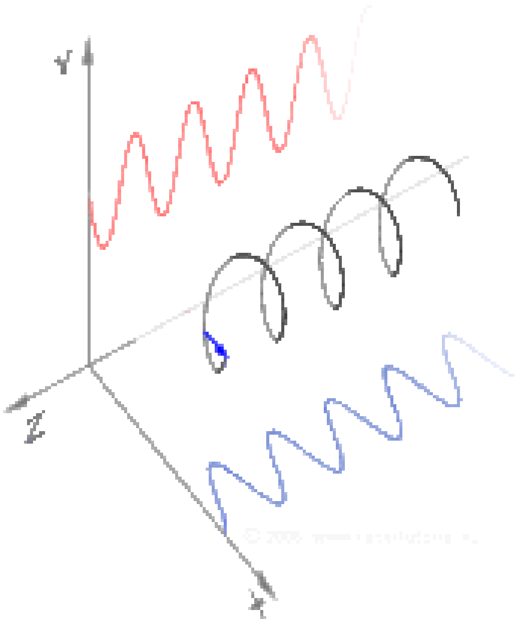
Light, is an em wave & is produced whenever a charged particle is accelerated. In 3-D appearance of an em wave it would be two perpendicular waves, one of electric field ***E*** & one of magnetic field ***H***, in phase rippling along in a straight line.



Polarization







Important Milestones

1669: **Erasmus Bartholinus** discovered double refraction in calcite

1678: **Christiaan Huygens** gave theory of double refraction in calcite

1809: **Malus** showed polarization of light by reflection

1811: **David Brewster** stated Brewster's law

1828: **William Nicol** invented the prism which produced polarized light

1929: **Edwin Land** patented Polaroid, which is a synthetic plastic sheet used to polarize light

Linearly Polarized Light

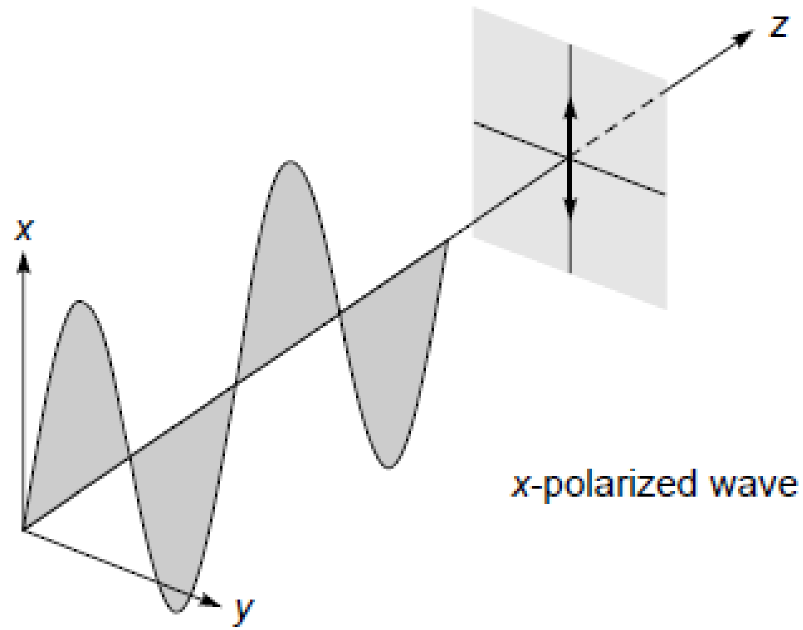
- If we move one end of a string up & down, then a transverse wave is generated.

- Each point of string executes a sinusoidal oscillation in a straight line (along x-axis), & wave is, known as a ***linearly polarized wave***. It is also known as a plane polarized wave because string is always confined to *xz* plane.

- At any instant, displacement will be a cosine curve.
- Displacement for such a wave can be written as

$$x(z,t) = a\cos(kz - \omega t + \phi_1)$$

$$y(z,t) = 0$$



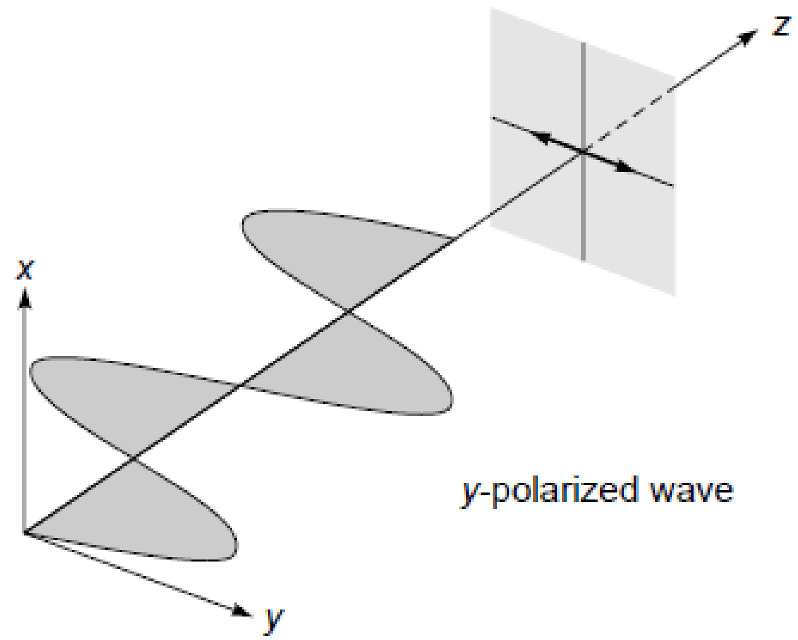
An *x*-polarized wave on a string with displacement confined to *xz* plane.

a: amplitude of wave

Φ_1: phase constant to be determined from initial conditions; *y* coordinate of displacement is always zero.

- Further, an arbitrary point $z = z_0$ will execute simple harmonic motion of amplitude *a*.
- String can also be made to vibrate in *yz* plane for which displacement is given by

$$y(z,t) = a\cos(kz - \omega t + \phi_2)$$
$$x(z,t) = 0$$



A *y*-polarized wave on a string with displacement confined to *yz* plane.

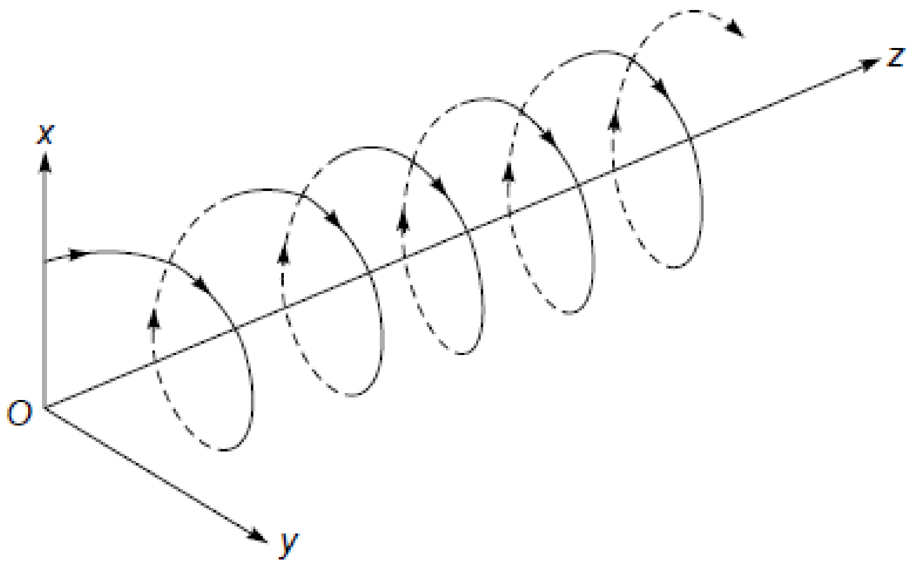
- In general, string can be made to vibrate in any plane containing *z*-axis.

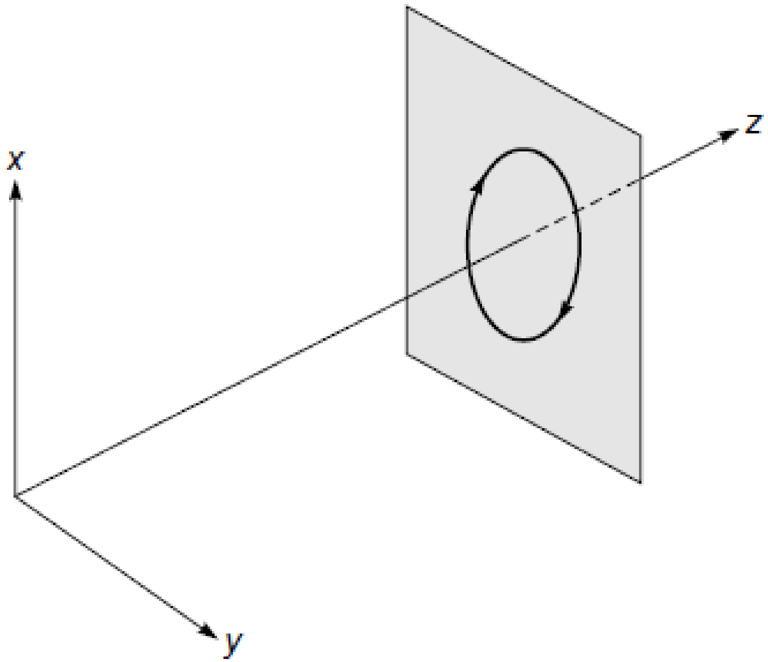
- If one rotates the end of string on circumference of a circle, then each point of the string will move in a circular pat; such a wave is known as a **circularly polarized wave**.
- Corresponding displacement is given by

$$x(z,t) = a\cos(kz - \omega t + \phi)$$

$$y(z,t) = a\sin(kz - \omega t + \phi)$$

$$\Rightarrow \quad x^2 + y^2 = a^2$$





Displacement corresponding to a circularly polarized wave – all points on the string are at same distance from *z*-axis.

Each point on the string rotates on the circumference of the circle.

- Consider a long narrow slit in the path of string.

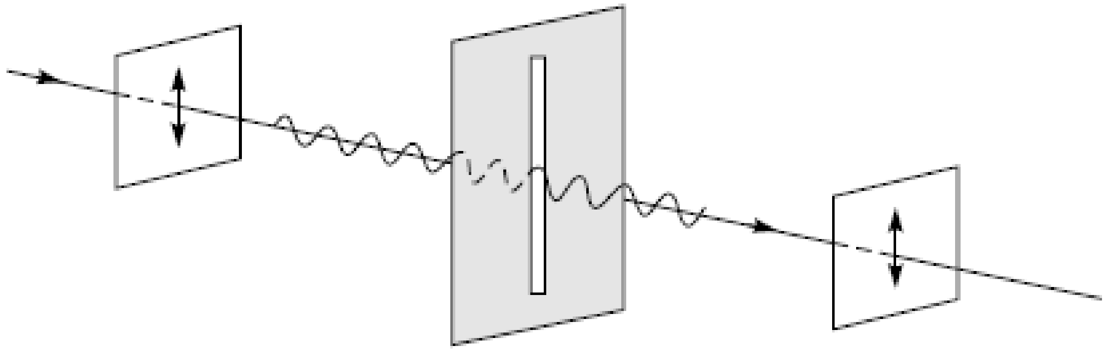
- If **length of slit is along direction of displacement**, then entire amplitude will be transmitted.

- If **slit is at right angles to direction of displacement**, then almost nothing will be transmitted to other side of slit.

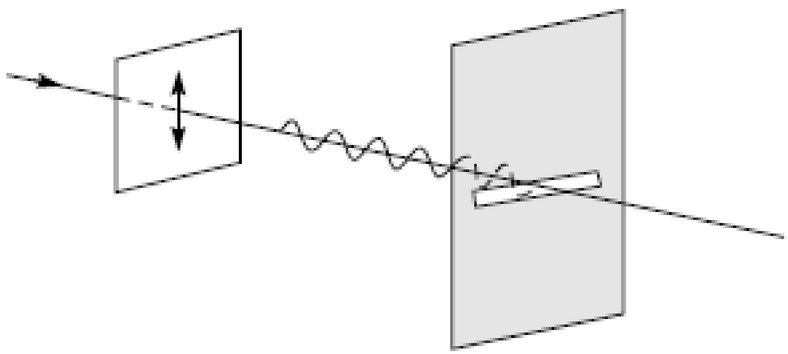
- This is so because the slit allows only component of displacement, which is along the length of slit, to pass through.

- However, if a **longitudinal wave** were propagating through string, then amplitude of transmitted wave would have been same for all orientations of slit.

- Thus, change in amplitude of transmitted wave with the orientation of the slit is **due to the transverse character of wave**.



(a)



(b)

If a linearly polarized transverse wave (propagating on a string) is incident on a long narrow slit, then slit will allow only component of displacement, which is along length of slit, to pass through.

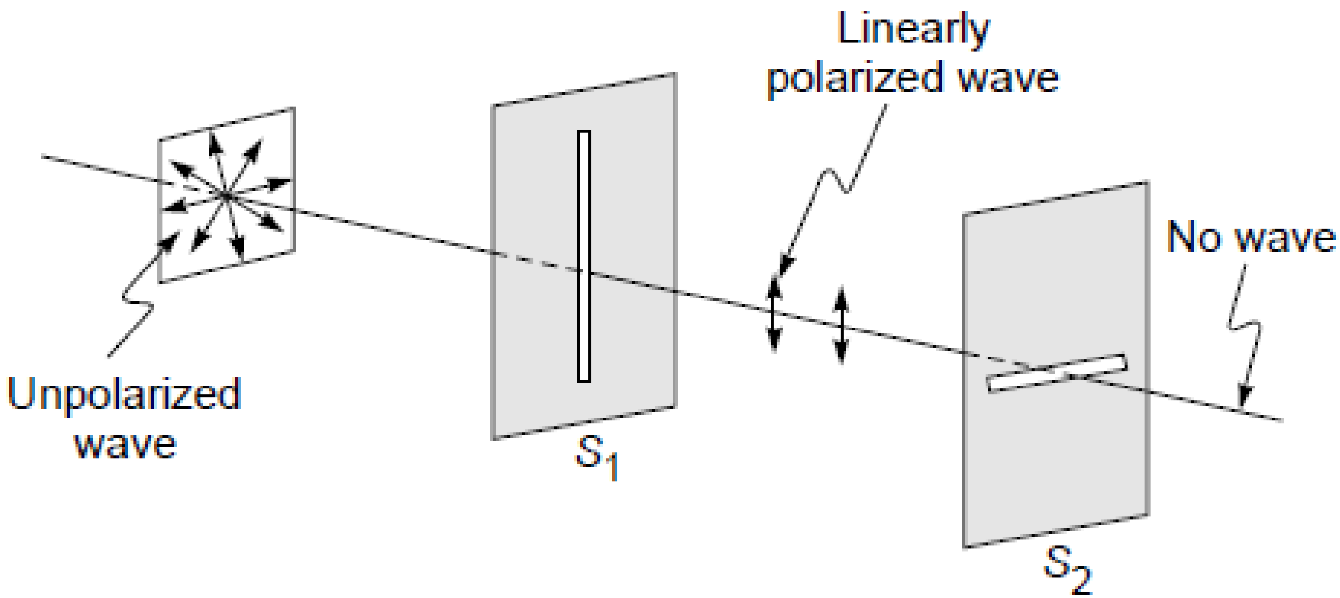
- Consider transverse wave generated at one end of a string.

- If plane of vibration is changed in a random manner in very short intervals (short compared to detection time) of time, then such a wave is known as an **unpolarized wave**.

- If an unpolarized wave falls on a slit S_1, then displacement associated with transmitted wave is along length of slit & a rotation of slit does not affect amplitude of transmitted wave, although plane of polarization of transmitted wave depends on orientation of slit.

- Thus, transmitted wave is linearly polarized, & slit S_1 is said to act as a **polarizer**.

- If this polarized beam falls on another slit S_2, then by rotating slit S_2 we obtain a variation of transmitted amplitude; 2^{nd} slit is said to act as an **analyzer**.



If an unpolarized wave propagating on a string is incident on a long narrow slit S_1, then transmitted beam is linearly polarized & its amplitude does not depend on orientation of S_1. If this polarized wave is allowed to pass through another slit S_2, then intensity of emerging wave depends on relative orientation of S_2 with respect to S_1.

- Transverse character of light waves was known in early years of 19th century; however, nature of displacement associated with a light wave was known only after Maxwell put forward his famous *em* theory.

- Associated with a plane *em* wave are an electric field ***E*** & a magnetic field ***B***, which are at right angles to each other.

- For a linearly polarized wave propagating in *z*-direction, electric & magnetic fields can be written as

$$E_x = E_0 \cos(kz - \omega t) \qquad E_y = 0 \qquad E_z = 0$$

$$B_x = 0 \qquad B_y = B_0 \cos(kz - \omega t) \qquad B_z = 0$$

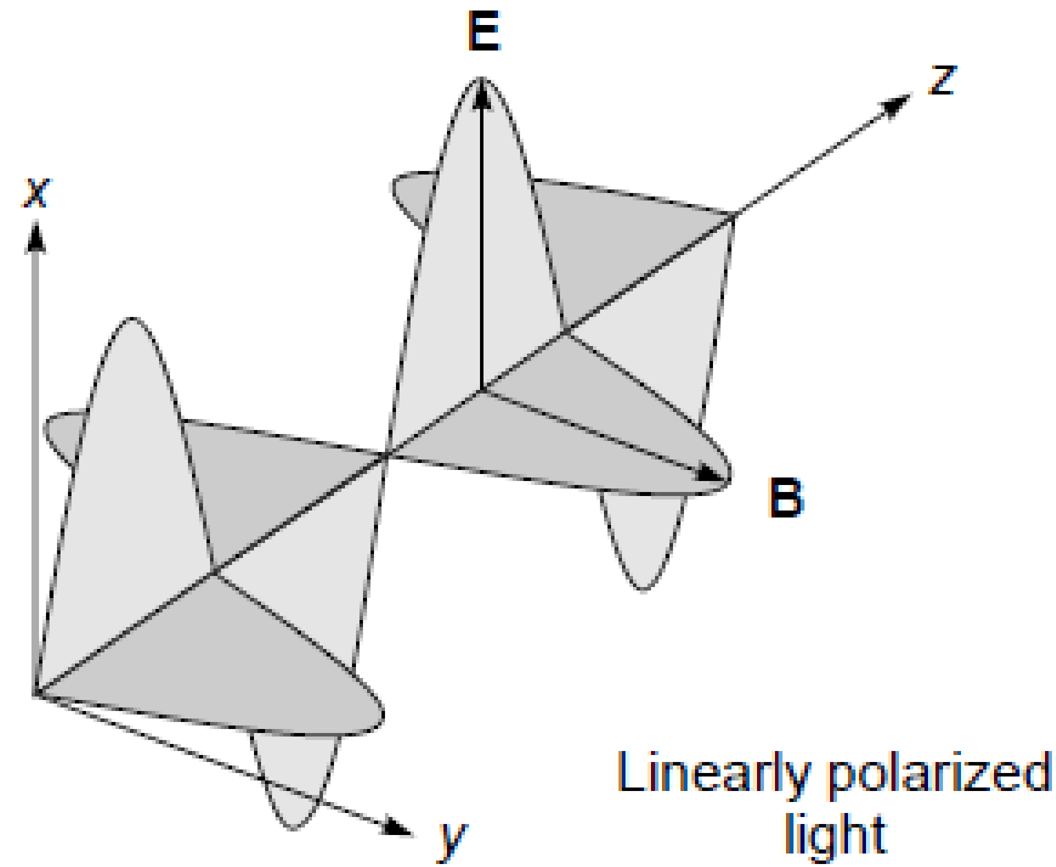
$$k = \frac{\omega}{v} = \omega\sqrt{\varepsilon\mu}, \qquad v = \frac{1}{\sqrt{\varepsilon\mu}}$$

ε: dielectric permittivity of medium

μ: magnetic permeability of medium

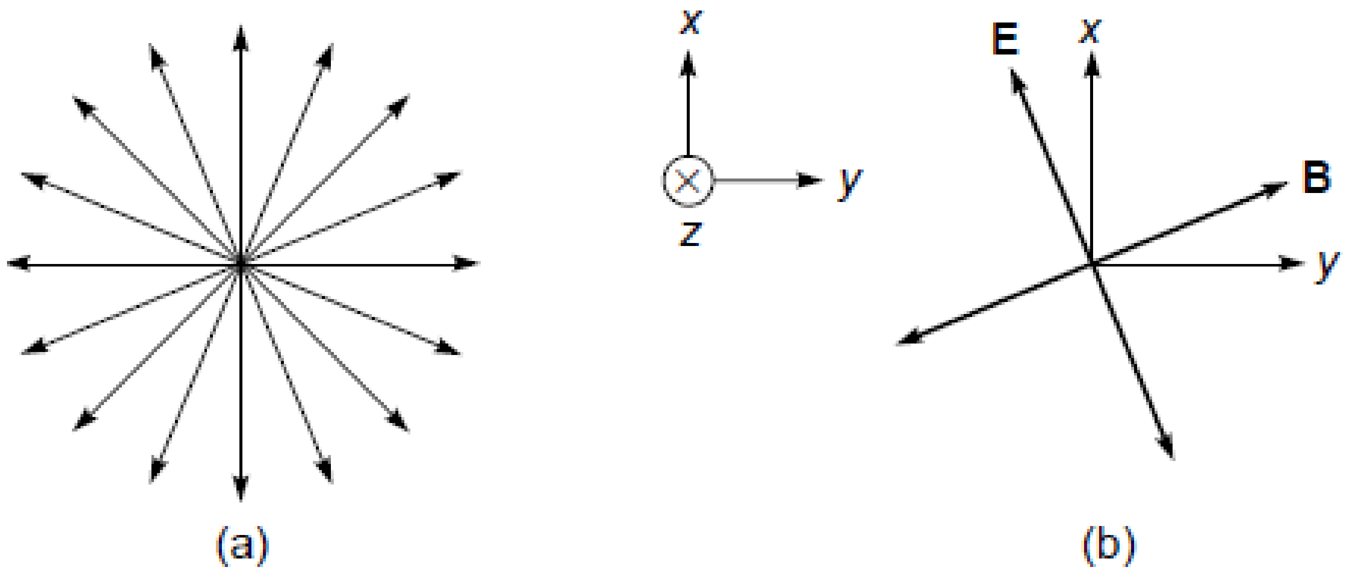
EM theory

$$B_0 = \frac{1}{v} E_0$$



An x-polarized electromagnetic wave propagating in *z* direction.
Direction of propagation is along the vector E × B.

- In general, an ordinary light beam is unpolarized; i.e., the electric vector (in a plane transverse to the direction of propagation) keeps changing its direction in a random manner.
- A Polaroid is a plastic like material used for producing polarized light. Consider an ordinary light beam falling on a Polaroid P_1.
- When an unpolarized beam is incident on a Polaroid, emergent light is linearly polarized with its electric vector oscillating in a particular direction.
- Direction of electric vector of emergent beam depends on orientation of Polaroid.
- Component of $\boldsymbol{E}$ along a particular direction gets absorbed by Polaroid, & component at right angles to it passes through.
- Direction of electric vector of emergent wave is usually called **pass axis** of Polaroid.



(a) For an unpolarized wave propagating in +*z* direction, electric vector (which lies in *xy* plane) continues to change its direction in a random manner. (b) For a linearly polarized wave, electric (or magnetic) vector oscillates along a particular direction.

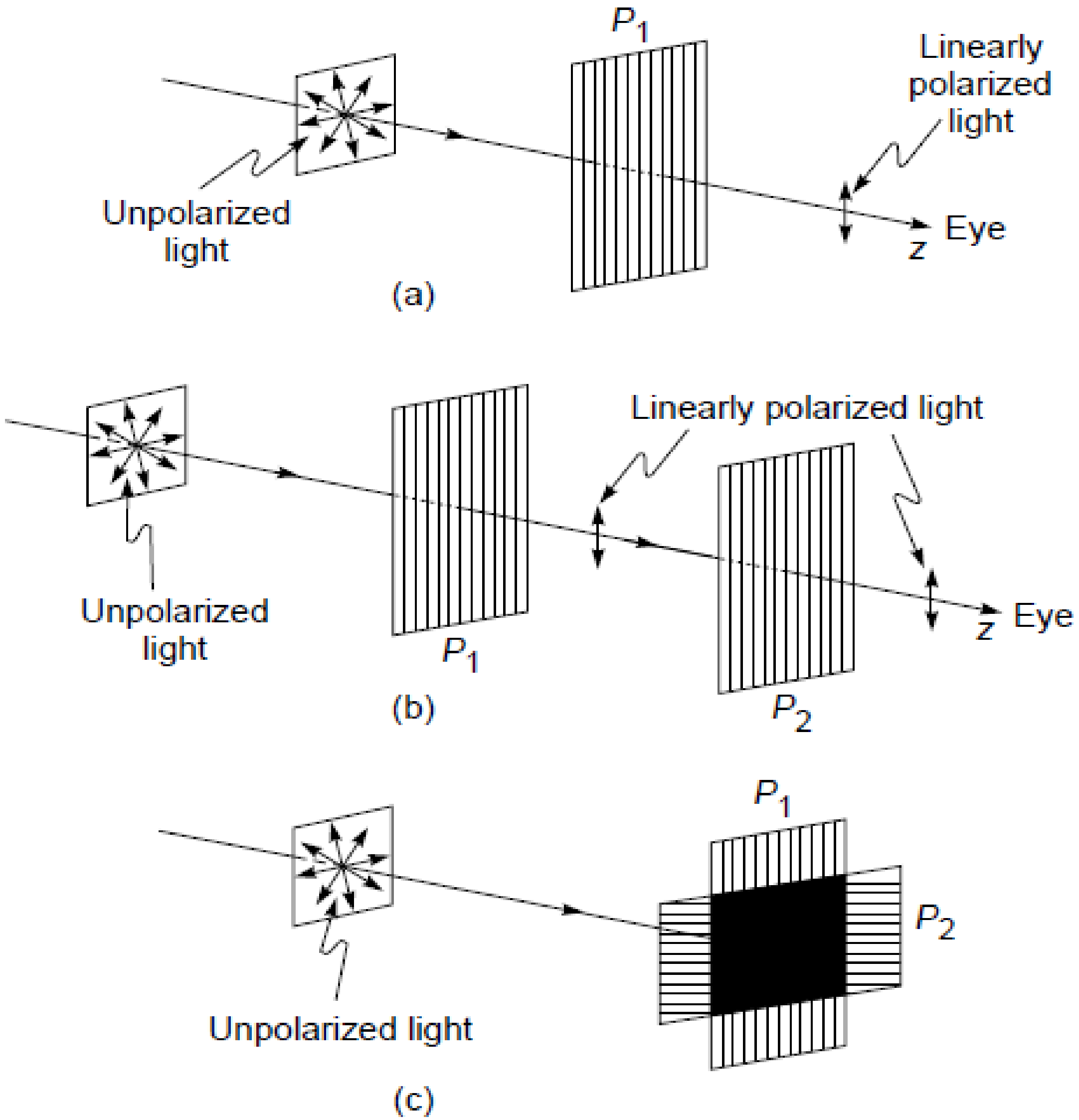
- If position of eye is as shown in Fig. (a), then one will observe no variation of intensity if Polaroid is rotated about z axis.

- If we place another Polaroid P_2, then by rotating Polaroid P_2 (about z axis) we will observe variation of intensity, when two Polaroids are parallel, maximum light will pass through second Polaroid & when two Polaroids are perpendicular to each other, no light will pass through second Polaroid.

- A similar phenomenon will also be observed if instead of rotating Polaroid P_2 we rotate P_1.

- This phenomenon proves transverse character of light; i.e., displacement associated with a light wave is at right angles to direction of propagation of wave.

- Polaroid P_1 acts as a polarizer, & transmitted beam is linearly polarized. Second Polaroid acts as an analyzer.



If an ordinary light beam is allowed to fall on a Polaroid, then emerging beam will be linearly polarized; & if we place another Polaroid P_2, then intensity of transmitted light will depend on relative orientation of P_2 with respect to P_1.