General Physics I (PHYS 101)

Lecture 19

Polarization

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Outline

The phenomenon by which unpolarized light becomes polarized is called *polarization*. The unpolarized light has vibrations along all possible plane perpendicular to the direction of propagation of light whereas the light having vibrations only along a single plane is called *polarized light*.

According to electromagnetic theory, light wave consists of mutually perpendicular electric field $\vec{E}$ and magnetic field $\vec{H}$. So in polarized light $\vec{E}$ or $\vec{H}$ are confined to vibrate along a straight line perpendicular to the direction of propagation of light wave. Experiments on polarization showed that light has transverse wave motion in which vibrations of particles are perpendicular to the direction of propagation of wave. When unpolarized light passes through polarizing filters, it becomes polarized. Such polarizing filters are called Polaroids and are used in sunglasses and camera lenses.

The plane containing the direction of vibration and direction of propagation of light is called *plane of vibration*. The plane perpendicular to the plane of vibration and containing the direction of propagation of light is called *plane of polarization*.

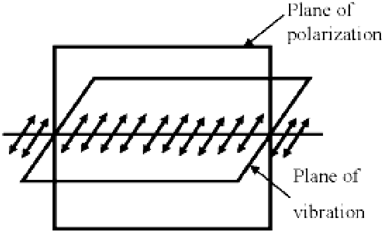

Figure 1: Plane of polarization and vibration

Polarization by reflection

When ordinary light is incident on the surface of any transparent material, the reflected beam is partially plane polarized. The vibrations of reflected beam are parallel to the reflecting surface.

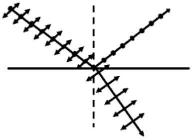

Figure 2: Polarization by reflection

The reflected beam becomes completely plane polarized for a particular angle of incidence called the polarizing angle denoted by i_p. The vibration of incident unpolarized light may be resolved in to two directions; parallel and perpendicular to the reflecting surface. The reflected light is only due to the components parallel to the reflecting surface and transmitted light is due to components perpendicular to it.

Double refraction

When a ray of ordinary unpolarized light is passed through some crystals like Calcite, it splits up into two refracted rays. This phenomenon is called double refraction. One of the refracted rays follows the ordinary laws of refraction and hence called the ordinary ray (O-ray) whereas the other refracted ray does not follow it and is called the extraordinary ray (E-ray). Therefore, if an object is viewed through such crystal, two images of the object are observed. One image corresponds to O-ray and is called ordinary image, the other corresponds to E-ray and is called extraordinary image. If we rotate the crystal, the image corresponding to E-ray rotates while the other does not move.

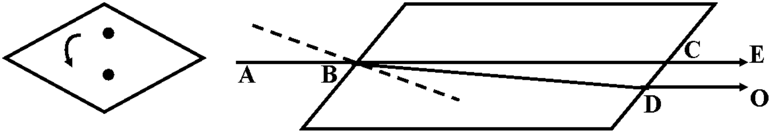

Figure 3: Double refraction

Let a ray AB be incident on a calcite crystal at an angle of incidence i. The ray AB is split up inside the crystal into two refracted rays along BC and BD such that angles of refractions are r_2 and r_1 respectively. The rays emerge from the crystal along CE and DO which are parallel. The refractive index of ordinary ray, $\mu_o = \frac{\sin i}{\sin r_1}$ and that of extraordinary ray, $\mu_e = \frac{\sin i}{\sin r_2}$. It is observed that refractive index of ordinary ray is constant while refractive index of extraordinary ray varies with the angle of incidence i.

In calcite crystal, $r_1 < r_2$ therefore, $\mu_o > \mu_e$. Hence the velocity of ordinary ray is less than that of velocity of extraordinary ray $(v_o < v_e)$. Such crystals are called negative crystals for examples tourmaline and ruby.

There are other crystals for which $\mu_e > \mu_o$ i.e. $v_o > v_e$. Such crystals are called positive crystals for example quartz and iron oxide.

Brewster's law

When ordinary beam of light is reflected from the surface of transparent medium, the reflected ray is completely plane polarized at some particular angle of incidence. This angle of incidence is called polarizing angle or Brewster's angle denoted by i_p (or i_B).

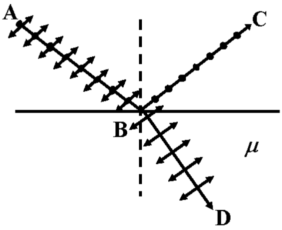

Figure 4: Brewster's law

If μ is the refractive index of the medium, it is found that $\mu = \tan i_p$ i.e. tangent of angle of polarization for a given medium is numerically equal to refractive index of that medium also at the polarizing angle the reflected and the refracted rays are perpendicular to each other. This is called Brewster's law.

Let a beam of unpolarized light AB be incident at an angle equal to polarizing angle i_p on the surface of transparent medium. The beam AB is reflected along BC and refracted along BD. Let r be the angle of refraction. Then, we have

$$\mu = \frac{\sin i_p}{\sin r} \tag{1}$$

Also from Brewster's law

$$\mu = \tan i_p = \frac{\sin i_p}{\cos i_p} \tag{2}$$

Brewster's law (contd.)

From (1) and (2), we find

$$\cos i_p = \sin r = \cos\left(\frac{\pi}{2} - r\right) \Rightarrow i_p = \frac{\pi}{2} - r$$
$$\therefore i_p + r = \frac{\pi}{2}$$

From figure, $< CBD = \pi - (i_p + r) = \pi - \frac{\pi}{2}$

$$\therefore < CBD = \frac{\pi}{2}$$

Thus, angle between refracted ray and reflected ray is $\frac{\pi}{2}$ i.e. they are perpendicular to each other.