4.6 LINEAR POLARIZERS AND MALUS'S LAW

Natural light such as the light from the Sun is unpolarized. It is generally a random mixture of various waves of different polarizations and frequencies. Any device that produces polarized light is called a **polarizer**. A **linear polarizer** is a device that lets through a linearly polarized and blocks any wave that oscillates at 90-degrees to the axis. In other words, a linear polarizer produces a linearly polarized light. If an incident light is neither polarized along the preferred axis nor along right-angle to it, then only the vector component of electric field along the preferred axis passes through the polarizer. This leads to a reduced intensity in the transmitted light when compared to the incident light.

How much is the intensity changed? To find that, let us setup an experiment that produces a linearly polarized light with a known direction of polarization, which is then passed through an identical polarizer whose preferred axis makes an angle θ with respect to the polarization direction of the polarized light (Fig. 4.8). The first polarizer is called a polarizer and the second an **analyzer**.

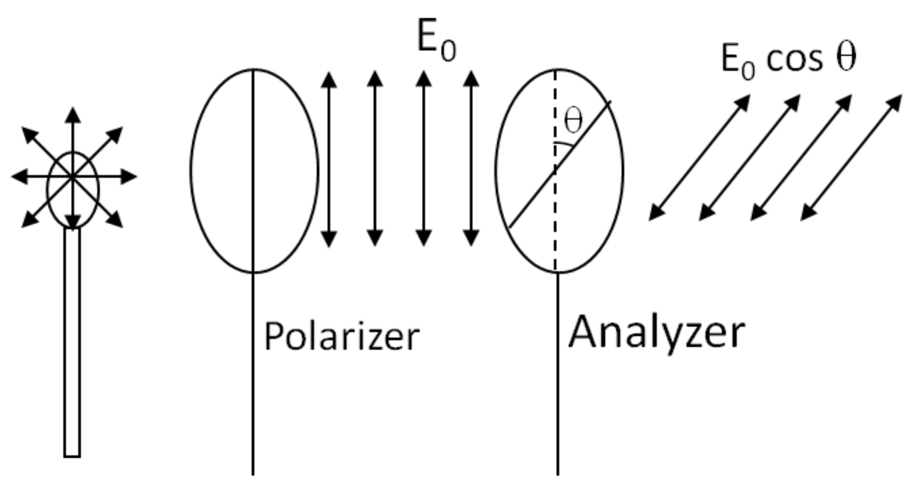

Figure 4.8: The polarizer and analyzer in a study of polarization of light.

If the amplitude of the electric field before the analyzer is E_0, then after the analyzer only the component along the axis of the polarizer, viz. $E_0 \cos\theta$, will be transmitted. We know that the intensity of an electromagnetic wave is proportional to the square of the amplitude of the electric field.

$$I \propto (\text{Amplitude of Electric Field})^2 . \tag{4.33}$$

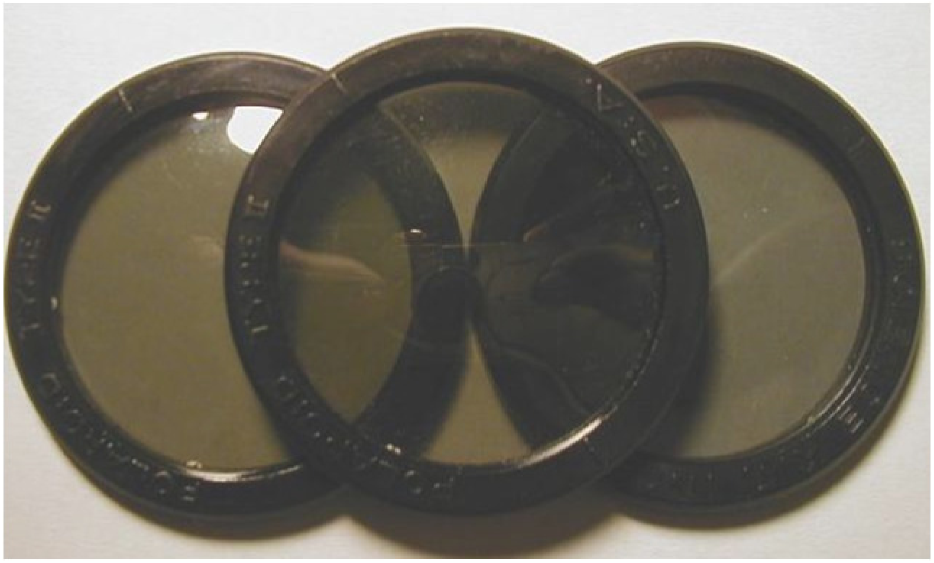

Figure 4.9: Polaroid at the top has its axis parallel to the one the left but perpendicular to the one at the right. Light is completely blocked by the arrangement to the right. (Photo by MS)

Therefore the intensity of light will drop as when polarized light passes through the analyzer according to the following formula.

$$\frac{I_{\text{after analyzar}}}{I_{\text{before analyzar}}} = \cos^2\theta. \tag{4.34}$$

This experimental observation is called the **Malus's law**. When a light wave is sent through through two plane polarizers whose axes are 90-degrees to each other then no light emerges at the other end. Two polarizers with axes at right angle to each other as shown in Fig. 4.9 are also called crossed **Polaroids**.

A physical **wire grid polarizer** can also produce polarized light. The electric field component parallel to the wire is absorbed by electrons in the wire, while the electric field perpendicular to the wires is transmitted (Fig. 4.10). This is the principle behind the common plastic Polaroid called the H-sheet.

In H-sheet Polaroid, clear polyvinyl alcohol is stretched along its chains, and then dipped into iodine solution which imbeds into the plastic and arranges along the long hydrocarbon chains, essentially making molecular size wires of iodine. These Polaroids transmit electromagnetic waves whose polarization is ninety degrees to the direction of "iodine wires".

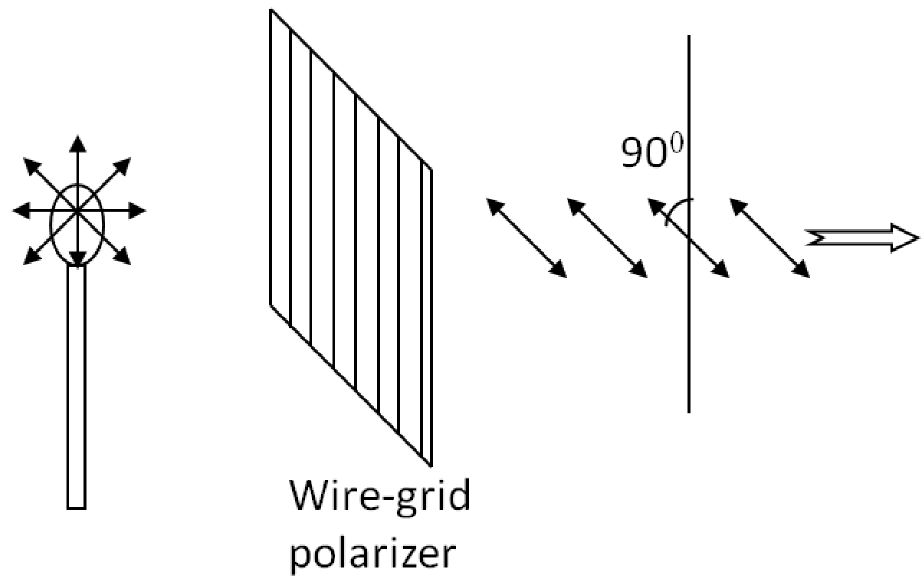

Figure 4.10: A wire-grid polarizer polarizes light at right-angle to the wires.

We have also seen that **reflecting light off of a plane surface at the Brewster's angle** produces a linearly polarized light; the reflected light in this case has its electric field perpendicular to the plane of incidence. Passing an unpolarized light through special crystals, called birefringent crystals, also produces polarized light as discussed below.

By using an appropriate arrangement of linear polarizers, you can obtain polarized light that is polarized in any desired direction in the plane perpendicular to the direction of the wave. However, each polarizer reduces the intensity of light by blocking off the perpendicular components. There are optical elements, called **retarders** and **compensators** that change the polarization by changing the phase of a wave rather than absorbing perpendicular components. Suppose a plane polarized light traveling along x-axis has a particular ratio of y- and z-components of electric field. The ratio remains fixed for the wave as it travels through space. A retarder will retard the phase of one of the components. Thus when the wave emerges from the retarder, the electric field would be pointed in another direction in space, still in the yz-plane. The full-wave plate, half-wave-plate and quarter-wave plates cause relative retardations of the phase by 2π radians, π radians and $\pi/2$ radians respectively. Also commonly available are compensators which can be used to produce retardation to a desired degree.