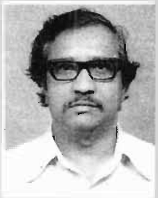
In this section of Resonance, *we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.*

Polarization of Light — An Experimental Approach



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This article briefly explains the theory of polarization with an emphasis on experimental aspects pertaining to colour separation and viewing optical stresses. These experiments can be conducted very easily using simple materials available in the local market. A high school student or any interested person can perform these experiments. Although the experiments are based on the basic theory explained in standard text books on physics, these books do not suggest the kind of experiments described here.

Introduction

Waves can be classified as longitudinal and transverse. A sound wave in a fluid is an example of a longitudinal wave, while light is an example of a transverse wave. Another example of a transverse wave is a jerk given at one end to a taut string which is fixed at the other end. Certain phenomena such as reflection, interference and diffraction can be observed with any type of wave. However, there is one phenomenon which is based on the transverse nature of waves and that is polarization. Obviously, this can be observed only in case of light, not sound in air.

Explanation

Let us assume we are in a room with a window having vertical bars only. A long string is tied at one end to a tree outside and the other end is in the room. The string is kept taut by pulling it by hand.

In the first stage, we give a vertical jerk to the string.. The oscillation will be in a vertical direction and will travel along the length of the string. This is transverse vibration and is perpendicular to the direction of propagation of the oscillation. Clearly, this oscillatory motion will pass through the window bars since they are also vertical and will not obstruct the motion. If a horizontal jerk is given to the string, the oscillation will not pass through the window as the vertical bars will oppose it.

In the second stage, we consider that there is one more window beyond the first window with its bars horizontal. Now, if we repeat our experiment, the oscillations will pass only through the first window but not through the second window.

Here we have considered the waves or disturbance created in the string, which is of transverse nature. Light waves are also transverse waves. The difference between our example and the light waves is that the string motion was only up and down while for the light it is present in all possible directions perpendicular to the direction of propagation of light. There are special 'windows' which will allow only a particular direction of vibration to pass through it. Such a 'window' is called a 'Polarizer' or a 'Polaroid'. *Figure 1* shows the mechanism of polarization.

Polarization studies have shown that the grains of cosmic dust present in our galaxy have been oriented in the weak galactic magnetic field so that their long dimension is parallel to this field. Polarization studies have also shown that Saturn's rings consist of ice crystals. The size and shape of virus particles can be determined by the polarization of ultraviolet light scattered from them. Useful information about the structure of atoms and nuclei is gained from polarization studies of their emitted radiation in all parts of the electromagnetic spectrum.

Polarization in Nature

In nature, there are two simple ways to get polarized light. One is scattering of light by air. The sunlight is scattered by air and we get sky light as polarized light. Another example is the phenomenon of reflection of light from nonmetallic surfaces.

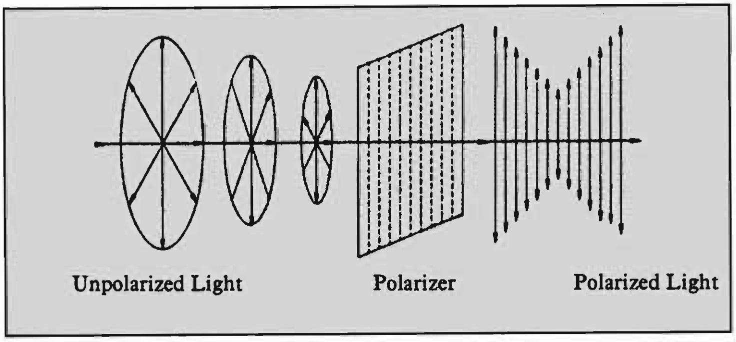


Figure 1 Mechanism of polarization.

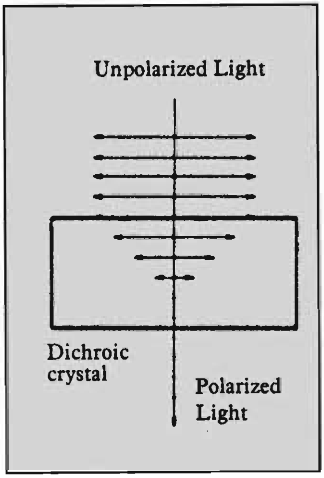
When light is reflected from the water surface or any shining surface, it is polarized too.

Polarizers

The early polarizers were made up of various types of anisotropic crystals wherein the velocity of light is not the same in all directions. Such crystals are said to be doubly *refracting* or *bi-refringent.*

Various polarizers were developed by scientists using composite prisms of such crystals, the best being the Nicol prism. Nicol prism was developed in 1828 and was in use for almost 100 years. Other polarizers are also known by the names of their developers viz. Rochon, Wollaston, Glen, Foucault etc. However, these polaroids are difficult to construct, costly and not convenient to handle.

Figure 2 Dichroism.



Some crystals have the property of dichroism wherein (*Figure2*) one component of vibration of light waves is absorbed to a larger extent than the other. Therefore, if such a crystal is cut to the proper thickness, one component of vibration of light waves is practically eliminated and the other component perpendicular to it is transmitted, e.g. Tourmaline.

Polaroid sheets using needle-like dichroic crystals or polymeric molecules which have been adjusted in a particular direction by stretching while the medium is being solidified were made by

Edwin Land in 1928. By this method, it is now possible to prepare sheets as large as 2 ft. wide and 200 feet long. These can be cut into suitable sizes for the sake of convenience.

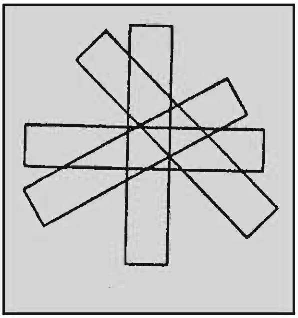


Figure 3 A suggested layout of cello-tapes over a glass sheet.

Experiments with Polaroid Sheets

For simplicity, let us assume that polaroids in sheet form are available and describe the various experiments. Later, it will be shown that the experiments can be conducted and very interesting phenomena can be seen using materials easily available in the market.

Experiment No. 1

In the first experiment, take a plain, flat glass piece of size about 5cm x 7cm. Even a broken glass piece will do. Stick some pieces (4-5) of cello-tape about 3-4 cm long over the glass piece crossing and overlapping each other in a random manner (*Figure 3*). Now hold one piece of polaroid near your eye, beyond that the glass piece and beyond that another polaroid sheet and look towards a bright source of natural light *i.e* white light. We can then see beautiful colours. If the optical axis of one polaroid sheet is parallel to the optical axis of the other we see a particular set of colours. If we turn any one of the polaroids at right angles to the original plane, then we see another set of colours. The colours in these two cases are complementary colours. If we put a gelatine paper folded in random manner, then we can also see colours. If we tilt the glass piece, we can see some other colours as the effective thickness of the cello-tape increases.

The reason for getting these colours is that the thickness of the cello-tape or of the gelatine paper acts as half wave plate for a particular colour only, say red. Then only red component of white light will emerge from the half-wave plate[1] as linearly polarized light. All other wave lengths (i.e. colours) will emerge as circularly or elliptically polarized light. When the other polarizer sheet is in a position to transmit the red linearly

[1] A half wave plate introduces 180° of phase difference between the x-and y-components of the vibration. Thus, after transmission, the direction of vibration is reflected in the x (or equivalently y) axis.

"The purest and most thoughtful minds are those which love colour the most" -John Ruskin, The Stones of Venice

Figure 4 Sress pattern in acrylic piece.

polarized light completely, it will transmit red light and attenuate all the other colours to varying extents.

Experiment No. 2

In the second experiment, take a piece of acrylic of size 3cm x 3cm and 3mm or 6mm thick. Such a piece can be purchased from market or a set-square can be cut to a suitable size. Now, clamp this piece in a C-clamp of G-clamp and view it with the arrangement of polaroids described above. We can see the stress pattern developed in the acrylic sheet. In a photo-elastic study lab this is used to view and analyse the stress patterns in say a gear wheel, by making acrylic models. The stress pattern can be 'frozen' by heating the piece in an oven slowly and cooling it slowly. Then if required, a cross section can be taken by cutting the piece with a saw and studied like a CAT-scan of the brain. In our experiment we had kept the piece of acrylic, duly clamped, in the sunlight at about 11 a.m. and removed at about 4 p.m. to freeze the stresses. The stress pattern is seen because of the property of the acrylic which becomes birefringent due to stress (*Figure 4*).

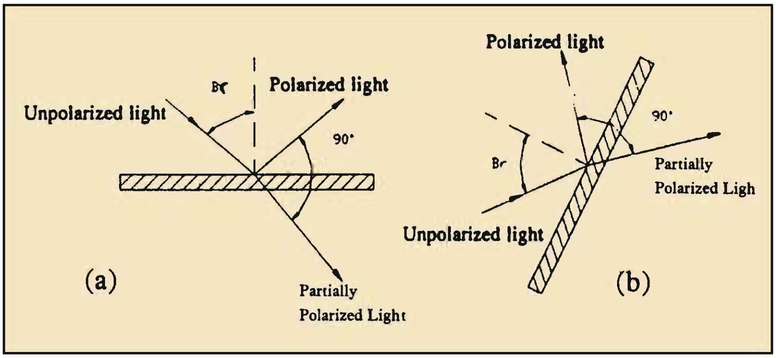
Experiments with Simple Material using Basis Theory

In both the above experiments, we have used two polaroids; one is known as the polarizer and the other is known as the analyser depending upon their action. These sheets are special purpose sheets and are not generally available in local markets.

We now try to conduct these experiments without using any special material. For this, consider the theory given below:

Laws of Polarization

Consider a particular case when light is incident on the surface of a glass sheet. There is a particular angle of incidence when the reflected light and the transmitted light are perpendicular to each other. In such a case the angle obtained is the *polarization*

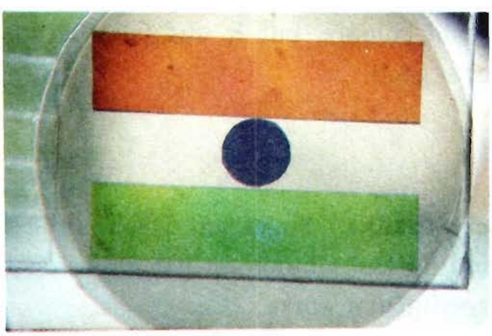


Figures 5a and b Polarizing angle or Brewster angle.

angle. The reflected light is polarized at right angles to the plane of the incident light and the normal and the transmitted light is polarized in the plane of the incident light and the normal. The dominantly transmitted light is strong but partially polarized and the reflected light is weak but strongly polarized. This phenomenon was first observed by Malus in 1809 and empirically deduced by Brewster in 1812. The polarizing angle is dependent on the refractive index of the glass.

For ordinary glass whose refractive index is about 1.5 to 1.6, the polarizing angle or the Brewster angle is about 56° to 58°. The various angles are shown in the *Figures 5a* and *5b*. Both of these figures are identical but *Figure 5b* is turned anticlockwise for about 60°.

Considering the above theory and also the fact that scattered light (i.e. sky light) is polarized as also the light reflected from



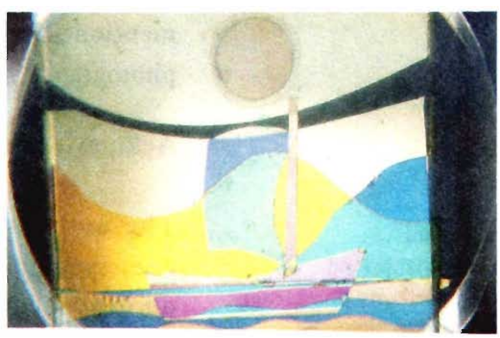


Figure 6 (left) Flag using polarization principle. Figure 7 (right) A sail boat using polarization principal.

nonmetals, we can make an arrangement to see the above phenomena without using polaroid sheets.

Consider both the experiments again. Now instead of using the polarizer sheet, sky light or light reflected from the flooring tiles or glass sheets can be used as a source of polarized light. Thus we can conduct the experiment with only one polaroid. To conduct the experiment without the other polaroid which we call as analyser, consider the arrangement of glass sheets shown in the *Figure 5b*. If we hold the glass sheet near our eye making an angle of about 60° about the vertical, we get polarized light, so this serves as the second polaroid or analyser. The colours we see are not so bright as with the actual polaroids but we can very clearly see the effect of polarization.

It may be mentioned that the topic of polarization is not covered in the school syllabus. It is included in the college syllabus but there is not much emphasis on experimental aspects. It now seems possible that polarization can be included in the school syllabus with simple experiments.

Some photographs (*Figures 6 and 7*) are included which show the national flag of India and a small sail boat. The pictures are prepared by pasting clear transparent cello-tapes of various thicknesses on a glass sheet. Trials were required to get the colours of our national flag. The photographs are taken by using polaroids to get good colours in the photograph. However, if we actually view the pictures on sheet with the simple arrangements mentioned, we see good colours, but it was felt that their photographs may not be good.

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