STUDYING THE POLARIZATION OF LIGHT

1. The aim of the laboratory

To observe the phenomenon of light polarisation, thus supporting the transverse character of light waves. To consider the approach given to the matter by Malus's law, and to examine practical applications of polarised light.

2. Theoretical approach

In figure 1, a transverse mechanical waves are sent along a rope that passes through a slot. Under these circumstances, waves can be sent along the rope only if the waves are generated parallel to the direction of the slot. Each slot permits only those waves with the proper orientation to pass through. The waves are said to be polarized in a particular plane, or plane polarized. Vertically polarized waves cannot pass through a horizontal polarizer (Fig.1 right).

Before the electromagnetic theory was developed, light was assumed to be a longitudinal wave disturbance. Electromagnetic theory predicts that light is a transverse wave. The interference and diffraction experiments cannot provide evidence of the transverse nature of light waves. Only the polarization theory and experiments can support the theoretical electromagnetic prediction that light waves are transverse.

Fresnel observed that a beam of light falling on a calcite crystal ($CaCO_3$) was separated into two beams that were incapable of producing interference fringes (Fig. 2). Young suggested that this could be explained by assuming that light consisted of transverse waves that were separated into component waves having oscillating planes at right angles to each other. He called this a plane polarization effect, and the phenomenon is called double refraction. The ordinary wave (o-wave) travels in the crystal with the same speed v_o in all directions, the crystal having a single index of refraction n_o. The extraordinary wave (e-wave) travels in the crystal with a speed that is greater than v_o. The index of refraction for the extraordinary wave $n_e = c/v_e$ is smaller than n_0. Besides calcite, there are other refracting crystals: ice (H_2O); quartz (SiO_2); wurzite (ZnS); dolomite

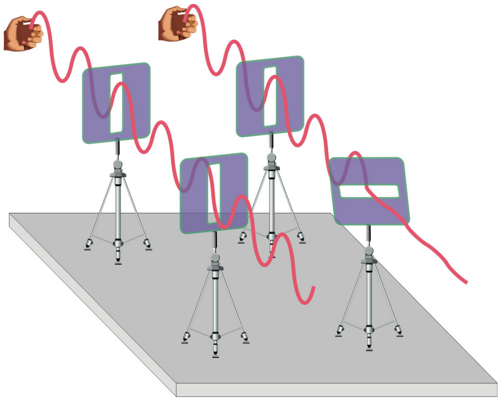

Fig. 1 Polarized mechanical waves.

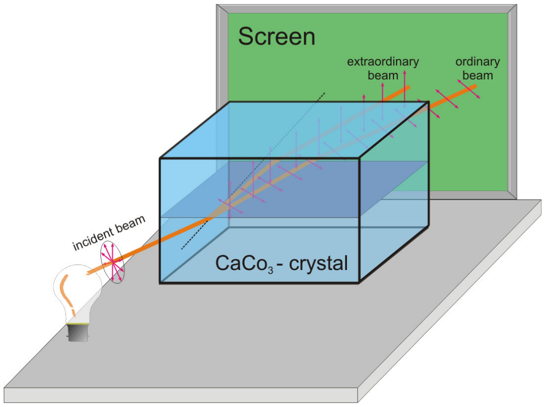

Fig. 2 Double refraction of light across a calcite crystal.

$(CaO.MgO_2\ CO_2)$; siderite $(Fe.CO_2)$.

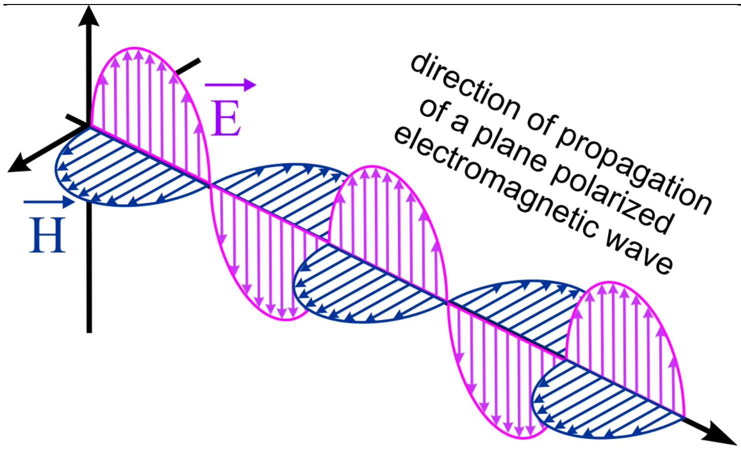

Figure.3.

Fig. 3 shows an electromagnetic, plane-polarized wave. The vibrations of the E vector are parallel to each other for all points in the wave. At any such a point, E and the direction of propagation form a plane called plane of vibration. In a plane polarized wave, all such planes are parallel. The light propagated in a given direction consists of independent wavetrains whose planes of vibration are randomly oriented about the direction of propagation. Such light, though still transverse, is unpolarized.

Certain crystalline substances transmit light in one plane of polarization and absorb light in other polarization planes. *Tourmaline* is such a material. This property of crystals in which one polarized component of incident light is absorbed and the other is transmitted is called *dichroism* (See Fig.4.). Dichroic crystals of *quinine iodosulphate* transmit plane polarized light very efficiently but the crystals are too small for practical use. There is a method of embedding these crystals in cellulose films so that the dichroic properties of the crystal are retained. This polarizing film is known commercially as *Polaroid*.

Ordinary light, incident obliquely on the surface of a glass plate is partly reflected and partly refracted. Both the transmitted and the reflected beams are partly polarized (Fig. 5.). The component of the incident light lying in the plane parallel to the surface of the glass is largely reflected. The component in the plane perpendicular to the surface is largely refracted. A particular angle af incidence at which polarization of the reflected light is complete, known as the *polarization angle*, can be found experimentally.

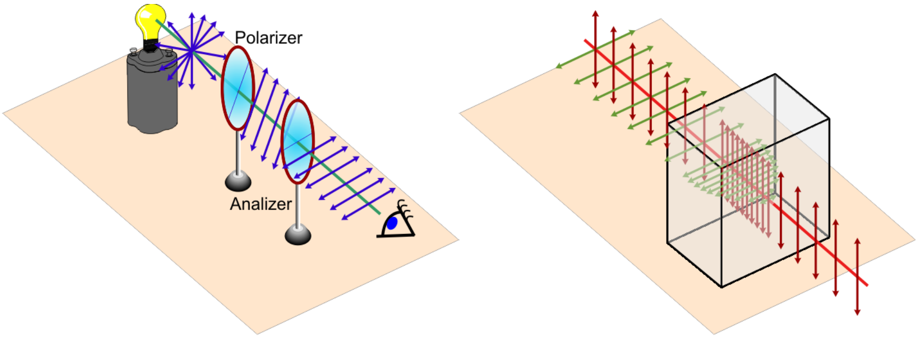

Figure 4

● σ = component of the electric field in an electromagnetic wave, that vibrates perpendicular to the plane of figure

↕ π = component of the electric field in an electromagnetic wave, that vibrates parallel to the plane of figure

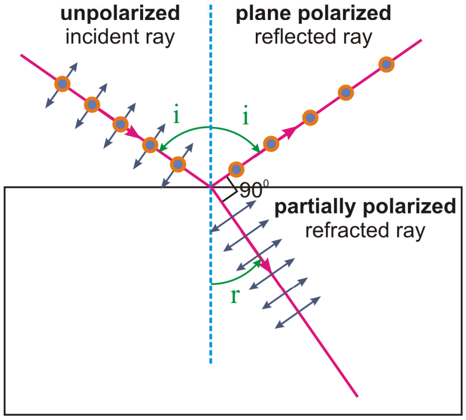

Figure 5.

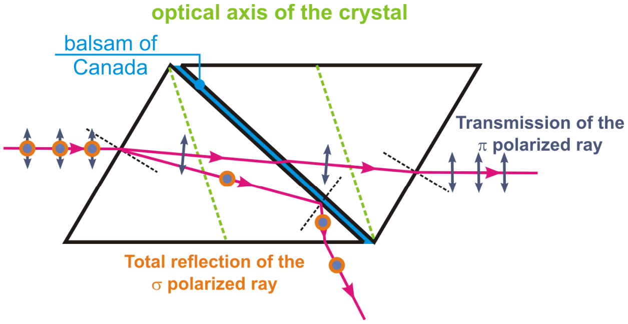

Figure 6.

Calcite crystals (Iceland spar) are sometimes polished, cut through and cemented back together in such a way that one of the polarized beams is totally reflected at the cemented face. Such a crystal, known as a *Nicol* prism, can be used to produce a beam of completely polarized light (Fig. 6).

While rotating the Nicol about the incident ray, the plane of vibration is also rotated. If a bunch of natural light rays passes through a polarizer, prior to pass through an analyzer, the intensity of the emerged ray is given by the law of Malus:

$$I = I_0 \cdot \cos^2(\theta), \tag{1}$$

where θ is the angle between the planes of vibration of light before and after the analyser, I_0 - the intensity of light entering the analyser.

3. Applications

The polarized light is often used in science and technique. In science we can mention the use at: i) the determination of nucleus spin on the polarimetric way; ii) the study of Stark, Zeeman and Faraday effects; iii) the study of molecular structure by optical rotational polarization; iv) in astrophysics is used at the study of polarized light to characterize various remote systems like the nebula. In techniques, the polarized light is used at: i) the analysis by photoelasticity method of mechanic tensions induced by external forces in various pieces; ii) measurements of angular rotation and linear or angular displacements (telemetry). In metrology is used at: i) light flux modulations; ii) optical filters with various properties and diverse applications, etc.

4. Experimental Procedure

The scheme of the device used is presented in fig. 7. Light from the source S reaches the polarizer N. The Nicol can be rotated about a vertical axis and the resulted light can be analyzed by the analyzer A (a plane mirror mounted at 45^{o}).

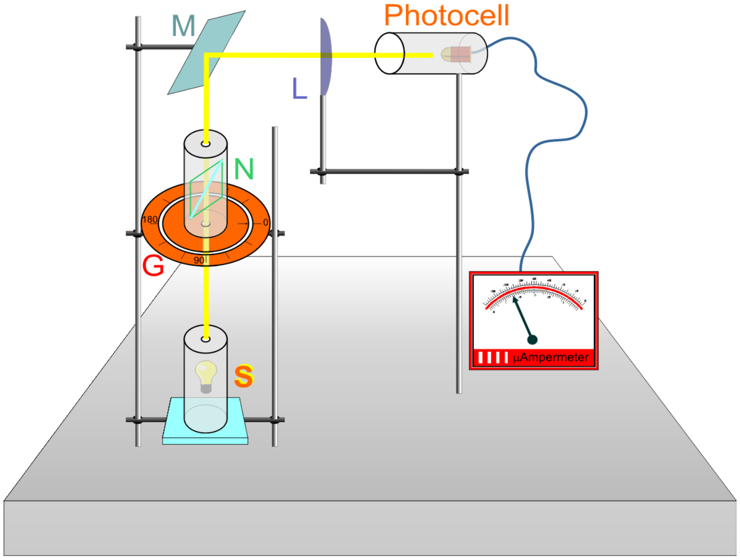

Figure 7.

The intensity of the reflected light is measured by means of a photosensitive cell which generates electrical currents proportional to the intensity of the luminous flux incident on the cathode. The photosensitive device is placed in the focus of a lens L. The Nicol tube has to be rotated about a vertical axis, 30^{o} by 30^{o} up to 360^{o}. This will change the angle between the axis of polarization of the Nicol and that of the analyzer. As a result, the amount of light falling on the photosensitive element will change, and thus a current of variable intensity will be measured in the circuit of the photosentive element. At 0^{o} between the two axes of polarisation, the whole amount of light is transmitted after the analyzer, as their polarization axes are parallel. When the angle becomes 90^{o}, one says that they are crossed polarizers, there should be no light transmitted after the second polarizer (extinction). In fact, as the beam emerging from the Nicol prism not totally polarised, there will be a component that can still be transmitted (reflected) by the analyzer, and a small current can be measured. Record the current corresponding for every value of the angle of rotation, in the Data Table.

Data table

θ (^{0})	0	30	60	90	120	150	180	210	240	270	300	330	360
I_{exp} (µA)													
I_{calc} (µA)													

where, $I_{calc} = I_{exp}^{max} \cdot \cos^2\theta$

Plot the graph of $I_{exp} = f(\theta)$ and of $I_{calc} = f(\theta)$, in polar coordinates, on the same millimetric paper graph.