(For Counsellor's use only)

Grade . . . . Name . . . .

Evaluated by . . . . Enrolment Number . . . . .

EXPERIMENT 11

PRODUCTION, DETECTION AND REFLECTION OF POLARISED LIGHT

11.1 INTRODUCTION

Experience in optics, especially in interference experiments, reveals that light is a wave phenomenon.

Question: Have you done **any** experiments in your school which are explained **by** interference of light? Write down what you **remember.**

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Question: Do you remember any natural observations which are explained by interference of light? Write down what you remember. (Hint: Oil **films** on a wet pavement?)

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The theory of electromagnetic waves (You may have studied this if you have completed your Electric and Magnetic Phenomena course.) requires that the quantity which changes in an **electromagnetic wave must be only in the** plane **of the** wave front and hence must have a vector character. This means it must be transverse, or perpendicular to the direction of propagation of the wave. Light, of course is one example of an electromagnetic wave!

It is this transverse character of light which gives rise to experimental effects called **polarisation.**

This experiment will help you to **find** out yourself if this is the case. You will find out **if** experiments come to the same conclusion as the theory about **how** light behaves – as a polarised wave or otherwise, Some of the experiments will be done in the lab, and some of those will measure quantities numerically. In addition to those "quantitative" experiments, you can do quite a few non-measuring experiments just in the world around you. In fact there are many polarisation effects in **nature** which can be seen without apparatus or with really **simple** apparatus. You can **look at** the sky or at light reflected **from various** surfaces to find **these effects.**

How many can you think of now?

Probably not a lot, but ask yourself this question again after the experiment is over!

OBJECTIVES

After performing this experiment you should be able to:

- Verify by knowing some examples, that the electromagnetic wave theory predicts polarisation effects **correctly.**
- **Produce,** by **several** methods, both linearly **polarised** and partially polarised light.
- **Demonstrate** the methods of detecting the **polarisations** mentioned in the previous sentence.
- Find the **rules** by which polarised light is reflected from glass, as a function of the angle of incidence.
- Correlate this experimental rule with the predictions of electromagnetic theory.

11.2 APPARATUS

2 - **polariser/analyser** eyepieces with angle **scales.**
1 - student spectrometer.
1 - prism for the spectrometer.
2 - calcite plates.
1 - 60-watt filament frosted bulb and holder.
1 - coloured filter.

11.3 STUDY MATERIAL

11.3.1 A model of perpendicular, or transverse waves.

Let us think of a light wave as going in a particular direction in a straight line, say **left-to-right.**

The oscillating quantities are perpendicular to this direction, so we can think of them as lying on this page, as shown by the short arrows shown in Fig.11.1.

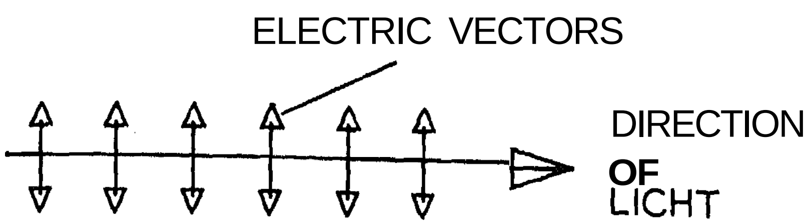

FIGURE 11.1

But we can as easily think of the arrows as being also perpendicular to the page, in which case the heads of the arrows would just be visible as dots, as shown in Fig.11.2.

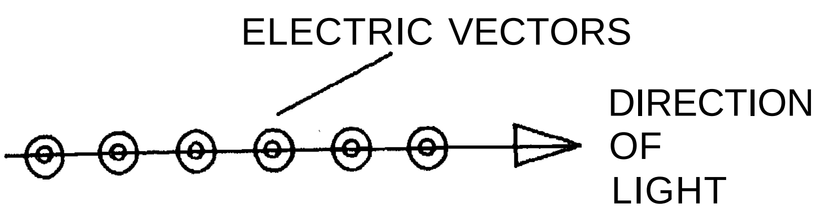

FIGURE 11.2

Or we could also think of them as being a combination of oscillations both lying in the page, perpendicular to the page, or in fact in any direction at all. But remember that the arrows are perpendicular to the direction of the light! The Figure 11.3 shows these possibilities, looking from the direction in which the light is going, that is, as though the light is approaching your eye.

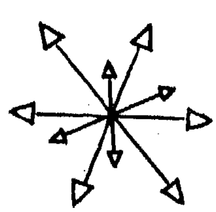

FIGURE 11.3

Further, these arrows need not be in phase. This means that at a time when one direction is at a maximum, the other need not be also at a maximum. What a lot of possibilities there are!

11.3.2 A SPECIAL CASE

In this experiment we will think only of light in which the oscillating quantities lie in one plane only. This is a plane which also contains the direction of the wave. You could think of this as the example in Figure 11.1 above, or the example in Figure 11.2 above. Such a light wave is called a **"LINEARLY POLARISED WAVE"**. (Some books may refer to this as plane-polarized wave). In electromagnetic wave theory you learn that the quantities which oscillate are the electric and the magnetic field vectors, Light which does not have this special property, but in which the oscillating quantities lie in randomly-placed planes containing the direction of the wave, is called **"UNPOLARISED LIGHT"**.

11.3.3 Some Ways to Produce Linearly Polarised Light

The simplest way is to have a special material that simply fillers out all of the light except the part for which the electric vectors lie in one plane (the "PLANE OF POLARISATION"). This might sound like magic - but in fact there are a number of materials which do that! Some are the minerals calcite and tourmaline. A special plastic material also acts in this way and is known as "Polaroid". These materials work by letting through only the parts of the oscillation which lie in the particular plane which the materials transmit. The rest of the light is absorbed in the material.

QUESTION: Why does the Polaroid sheet in your eyepiece look grey? Write your answer here.

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A second way of making linearly polarised light involves reflecting unpolarised light from the surface of a dielectric such as glass or polished wood. This is an easy way to make polarised light, but as with many other things, you have to know how to view it!

11.3.4 How to Observe Polarised Light

Unfortunately our eyes are not sensitive in any significant way to the polarisation of light. That means that we need some help to overcome the problemof detecting polarisation. The answer to this problem is really simple. You observe polarised light by the same means you produced it! The easiest way is to view light through a Polaroid sheet.

Question: What is the polarising property of such a sheet?

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If indeed the sheet lets through light of one plane of oscillation, then the following table could be true.

Light incident the Polaroid	Light coming through on the Polaroid
Oscillation of electric field is parallel to the direction which the Polaroid transmits	All of the light comes through.
Same, but the oscillation is perpendicular to the Polaroid direction.	None of the light comes through.

QUESTION: Make a suitable sketch illustrating the above conditions.

QUESTION: **What** happens for in-between cases? Write your present idea, if you have one.

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We can guess that the **component** of linearly polarised light parallel to the transmitting direction will be **transmitted**, while the component perpendicular will be not transmitted. Remember "components"? You used them in mechanical problems to "resolve" velocities in various directions. In just the same way you resolved velocity vectors, you can resolve the electric vectors of a light wave. **The usual resolution is along the** Polaroid **transmitting direction,** and the perpendicular direction. And the **same** rule is used: the component of a **linearly-polarised** wave transmitted through a Polaroid is proportional to the COSINE of the angle θ between the oscillation plane and the Polaroid transmitting plane!

Amplitude transmitted = Incident Amplitude * $\cos(\theta)$

So - that's how you find the plane of oscillation of a linearly polarised wave. You **turn a** Polaroid until **none of** the wave is transmitted. Then the wave has **an oscillation plane** just perpendicular (90^0) to the Polaroid transmitting plane.

11.3.5\ How *to* Find the Polaroid Transmitting.Plane

You may have noticed a **problem** in the previous section. How are you to find out the transmitting direction of the Polaroid ?

The answer to this is to observe a wave **whose polarisation** you know from some fundamental physics reasoning. We usually use light reflected from a dielectric surface at a fairly glancing angle, say about 60 degrees. **The rule** which theory gives us is that at such an angle, **most** if not all of the light is **polarised** with **the oscillations** parallel to the dielectric surface.

You will try this out in the **experiment.** It is a lot easier to do than it is to explain!

11.3.6 Polariser and Annlyser

From the above, you will understand that sometimes a Polaroid acts to **produce polarised** light. Then we call it a "polariser".

Sometimes the same Polaroid acts to find out the presence of polarised light. Then we call it an "analyser".

We can say the following, in terms of these two new words,

When a **polariser and** analyser are parallel, then maximum light is transmitted through the pair.

When a polariser and analyser are crossed (perpendicular)' then no light is transmitted.

When the angle **between** the polariser direction and the analyser direction is theta, the transmitted light has an amplitude proportional to **$\cos(\theta)$.** This is known **as "the** law **of Malus".**

Question: To transmit half **the** light amplitude incident, what angle should there be between **polariser** and analyser?

CALCULATION:

ANSWER: ....

Please note that our eye (and almost every other detecterof light) responds not to the amplitude of the light, but to the light, which is the amplitude.

Thus the law of Malus is :

Transmitted intensity = (incident intensity) * $\cos^2(\theta)$

Question: To transmit half the light intensity incident, what angle should there be between polariser and analyser?

CALCULATION:

ANSWER: ....

11.3.7 Another way to Make Polarised Light

Some crystals and othermaterials have a property known as optical activity. They don't treat light of two perpendicular polarisations in different ways. Calcite (calcium carbonate) is one of those materials. (It is found very commonly in many countries, including India.) Calcite is often found in crystalline form, when it is clear and colourless. Such crystals often have flat and clear developed crystal faces or plane surfaces.

If you place such a crystal on a paper you will find that two images of the writing on the paper will appear. You'll do this in the experiment. What distinguishes the two images? Try it later and see, but we can reveal now that the difference has to do with polarisation!

11.3.8 Yet Another Example of Polarised Light

Polarised light this way, but you can of light which is scattered from molecules. Try looking at the blue sky through a Polaroid analyser. (We'll try this later in the experiment, or you can take your analyser and have an advance look!).

You'll see several interesting and important effects which are due to polarisation of the blue-sky light. Be patient, and we'll see these later.

HINT: The effects are most prominent if you look at right angles to the direction of the direct sunlight, in early morning or late afternoon.

11.3.9 Dielectric Reflection in Detail

You have read several times above about the polarising effect of reflection from a dielectric surface.

Question: How 'do you characterise a "dielectric"? Remember your electricity studies to answer this question!

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Now we will look at the quantitative rules that govern this kind of reflection. We won't deal with derivations, but we can use the of electromagnetic theory. In the experiment you will try to find how closely nature agrees with the theory!

First a little setting-up of the scene.

A wave-front incident on a plane surface defines. This is determined by the incident ray. (direction-vector of the wave-front) and the component of this vector onto the surface. We'll take the special case where the wave-front is linearly polarised.

This polarisation has two components (there is that concept again -and not for the last time!). One is perpendicular to the plane of incidence ("senkrecht in German) and quantities relating to this component get the subscript S The other component is parallel to the plane, and quantities relating to this get the subscript p.

Traditionally, quantities relating to the incident, reflected and refracted wavefront are denoted as follows:

E : Refers to incident quantities.
R : Refers to reflected quantities.
E': Refers to refracted quantities.

The rules for reflection from dielectrics provide us a way to calculate the R and E'values for an E-wave incident under quite a complete range of conditions. The reflection rules are as follows.

$$R_s/E_s = (-)\sin(i - r)/\sin(i + r)$$

$$R_p/E_p = \tan(i - r)/\tan(i + r)$$

$$E'_s/E_s = 2*\sin(r)*\cos(i)/\sin(i + r)$$

$$E'_p/E_p = 2*\sin i*\cos i/(\sin(i + r)*\cos(i - r))$$

where i = angle of incidence
r = angle of refraction

QUESTION: If you know the angle of incidence how will you will find the angle of refraction?

A special case is one in which the plane of incident polarisation is at 45 degrees to the plane of incidence. This means the E_s component is the same as the E_p component.

Then

$$(R_p/E_p) I (R_s/E_s) = R_p/R_s = \tan(\theta)$$

So,

$$R_p/R_s = \tan\theta = \cos(i + r)/\cos(i - r),$$

(where modulus values are taken)

where theta is the angle of the plane of the reflected polarisation compared to the plane of the P-polarisation. In the experiment you will try to create this special situation. You will see how the result compares with the relation above. Thus you will see that the polarisation rules are really followed in practice.

REFERENCES:

Jenkins & White Fundamentals of Optics
Mc Graw-Hill (any edition)

Longhurst, R.S. Geometrical and Physical Optics
Longmans (any edition)

Ghatak, A.J. An Indtroducation to Modern Optics
Tata Mc Graw Hill (1971) Chapter 3.

11.4 PRECAUTIONS

A. Generally, with any optics experiment, you must keep all the surfaces clean! You can use a clean soft cloth, and plain water.

Before you start the experiment, look at each surface:

Polaroid analyser/polarisers
Prisms
Telescope lens
Collimator lens

Often you will see finger marks made by earlier users.

Make the cleancloth damp, and gently rub each surface until the marks are less. Just the way you cleaneye-glasses.

Keep the surfaces clean!

B. Please follow the adjustment steps for section 11.5.4. very carefully, If results seem unexpected, go back to the Step 1, and repeat the whole series.

C. Optics experiments can be a lot of fun, but see, not always for what "the book" says you should see!

You will learn a lot.

11.5 THE EXPERIMENTS

11.5.1 Polaroid

Take one tube with a Polaroid mounted on it and just look through it at a light (say a tube light). Note the brightness with.& without the Polaroid. Rotate the Polaroid and note variations of the light seen through the Polaroid.

Source: Tube Light

With Polaroid - ______________________

Without Polaroid ______________________

Rotating Polaroid ______________________

Fill in the table with your observations most **bright, less bright, more** bright, changing **brightness,** etc.

Put the two Polaroids in **series** (one after another) and again look at the tuba light. Rotate the second Polaroid (the analyser). Record your observations.

Source : Tube **Light**

Second Polaroid rotated : ______________________________

Try to notice any special directions (most bright, **least** bright).

Set the analyser for most brightness. Remove the analyser (look just through the **polariser).** Describe the relative brightness.

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Write your explanation of this.

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Set the analyser for least brightness. Remove the analyser. Describe the relative brightness.

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Write your explanation of this.

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11.5.2 Polarisation by Reflection

Look at the tube-light, or any other light reflected on a desk-top or from a glass window. See the actual light, in the reflecting surface.

Look now at this reflected light through **an analyser** (Polaroid) and describe the brightness as you rotate the analyser.

ROTARY POSITION OF ANALYSER POLAROID	**BRIGHTNESS**
Perpendicular to surface	______________________
Parallel to surface	______________________
Intermediate Position	______________________

11.5.3 Polarisation by Scattering

Look at the blue sky through a Polaroid. Do this in the morning or evening. Keep the sun on your right side or left side, observe the sky in front of you and above you. Rotate the analyser and describe your observations of brightness, for several positions of the Polaroid rotation.

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11.5.4 The Rule of Reflection Polarisation

You will find the rule by which polarised light is reflected from a dielectric surface, at least for the special case of 11.3.9.

Set up a prism on a spectrograph, As shown, in Figure 11.4

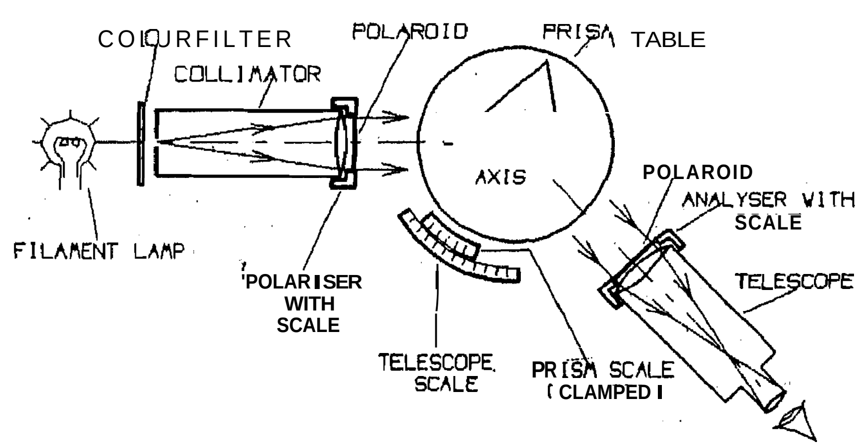

FIGURE 11.4

The following adjustments must be made:

1. Make sure the eyepiece is focussed clearly on the cross-wire. Push or pull the eyepiece to adjust this. Focus the telescope at a very distant object.
(Do not change these adjustments, ever!)

2. Look through the telescope at the collimator and adjust the collimator (slit-width and then collimator focus) until you see a slit image which is somewhat wide, with edges in sharp focus. Then don't change this adjustment.

Adjust the prism table until one polished prism face is **perpendicular to the** telescope. (This means using **the** leveling **screws,** while looking at the slit reflected in **the face** of the' prism).

4. Remove prism, look through telescope at the slit, line up the vertical cross-wire with the edge of the slit, then **fix the** prism-table with table **scale** to read 180 degrees and **clamp It** Don't unclamp later on!

Put the Polaroid analyser on the telescope lens, put the **prism on** the table with table axis **in** the prism face, set **the** telescope at about 115 degrees.

6. Rotate the prism **table** (But not its scale. Loosen the little screw on the table rod to do **this)** until you see the slit reflected in the prism. (This is near the angle of most **polarisation)**

Rotate the analyser Polaroid until brightness is **minimum.** Hold the Polaroid and set it scale to "zero", or note the reading. Enter in the Table as **"Zero Analyser** Reading". This is the "perpendicular" **polarisation** direction.

8. Take off the prism. Look straight at the slit again. (180 degrees scale). Rotate analyser to 45 degrees. Put polariser on the collimator lens. Rotate **polariser** to minimum brightness. Now incident **light** must be at **45°** degrees, which is the required case!

9. Replace prism. Set telescope to about 50 degrees (angle of **incidence-abut** 25 degrees). Rotate the prism table (as in 6. above) to reflect the slit into the telescope.

10. Rotate the **analyser for minimum** brightness. Note the analyser scale reading in the next Table. **Repat** the adjustment for minimum brightness two more times, and enter the **readings.**

11. Repeat from **Step 9.,** for angles of incidence between 25 degrees and **80 degrees** in steps of 5 degrees, noting the analyser angle each time.

TABLE 1

reading:...............

ANGLE OF INCIDENCE	ANALYSER READING			OF 1,2,3	AVG. ANALYSER ANGLE**	AVG. R_p/R_s	Tan(€!)
	TRIAL 1	TRIAL2	TRIAL3				
25							
30							
35							
40							
45							
50							
55							
60							
65							
70							
75							
80							

** AVERAGE ANALYSER ANGLE = AVERAGE **ANALYSER** READING ZERO READING (STEP 7.)

Estimate the percent error of the average.

11.5.5 CALCULATIONS

For each of **the angles** of incidences above, **calculate R_p/R_s. Add one column** to the Table above, for this.

Now calculate the TAN (average **analyser** angle) and add a column to the table also. Compare these last two columns. You can make graphs of each vs incident angle, or from the ratio of the two columns, or other means of **comparision.** Use the graph area below, if **you want. Use another graph sheet and attach it, if you need more space.**

Comment on **your comparisions.** Comment on whether yoy feel your theoretical calculations **agreed** with the experiment.

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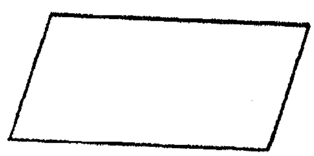
11.5.6 ANOTHER EXPERIMENT USING A CALCITE CRYSTAL

Take the **crystal,** lay it on your paper and trace the edges. By extending these edge lines, measure **the** two angles which characterise the crystal shape.

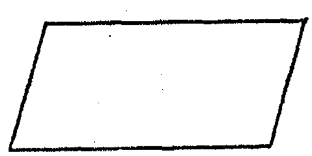
Obtuse angle = ____________________

Acute angle = ____________________

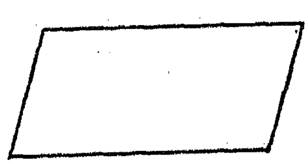
Place the crystal over a very black dot, on a white paper. Mark the dots you **see, on** the sketch below.



Using a Polaroid analyser, **mark** on the **diagram** below the direction of polarisation of each dot.



Rotate the crystal about an axis perpendicular to the table. Mark on the diagram here how the dots move, as the crystal has rotated.



Place another crystal just over the first, in the same orientation. What **happens** to the dots as the pair of crystals are rotated together? Mark their apparent motion on the diagrams below. Rotate the second one by 180 **degrees** so **the crystals are in opposite orientation** with each other. What do you see ?

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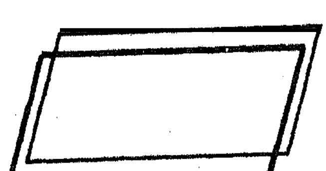

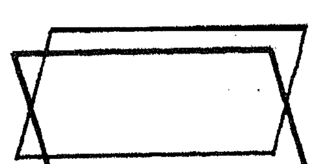

Test and record the **polarisation** in all cases. Using your Polaroid as analyser. Write your explanation of these observations.

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11.6 CONCLUSIONS

Here you can find **out if you** have **met the** Objectives listed **in Section** 11.1. **Answer the** questions below in a brief **manner**

a. Do any of the experiments reveal an agreement with the results of the theory of polarised light? Which experiments?

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b. **Write down** one method at least for producing linearly polarised light, and **one** for partially polarised light.

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c. Describe one rule you have found for the way polarised light is reflected from glass, at **various** angles. Refer to any useful results above in section 11.5.

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d. In your opinion, how well does **this rule** agree with **the** stated results of electromagnetic theory?

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