Grange Physics A.S. - Polarisation of waves

How does polarisation work?

Many kinds of polariser filter out waves, leaving only those with a polarisation along the direction allowed by the polariser. Any kind of transverse waves can be plane polarised.

You will need

* three polarising slots (hardboard, see below)
* a 3 or 4 m length of rubber pressure tubing that can be threaded through the slots
* a G clamp, retort stand, boss and clamp to secure one end of the rubber tubing
* three polarisers, optical, 50mm  50mm, to place on an overhead projector
* plastic moulded transparent ruler with notch

Seeing polarisation

You can see polarisation in:

* waves on a rope
* light waves
* 3cm microwaves

Waves on a rope

You need three hardboard sheets about 0.5 m  0.5 m, with a centrally cut slot about 300 mm long and 15 mm wide, marked with arrows showing the permitted direction of vibration.

Visibly polarised waves on a rope can be passed or blocked by a mechanical 'polarising filter', consisting just of a board with a slot cut in it.

If the slot lies along the direction of vibration, the wave gets through. If the slot lies across the direction of vibration, the wave is stopped (or reflected). If the slot lies at some in-between angle, some of the wave gets through, but not all.

If the slot is at an angle  to the direction of vibration of the incoming wave then only a component *A* cos ** of the original wave amplitude A is transmitted. The component A sin  perpendicular to the slot is blocked. The emerging wave is polarised parallel to the slot: the direction of polarisation has effectively been rotated, and the amplitude of the wave has been reduced.

When the permitted direction of vibration or polarisation of the filter is parallel to the direction of the polarisation of the wave, it is transmitted by the filter.





Polarising light

Light from a hot filament lamp is unpolarised (or rather, is emitted in randomly changing directions of polarisation). A polarising filter made of polaroid polarises the light. The filter passes components vibrating parallel to a special direction, and removes components vibrating perpendicular to this direction, so roughly halving the intensity of the light. A second filter with its special direction at right angles to that of the first will cut out almost all the light.

If you look through a polarising filter at light reflected from glass surfaces, you will often find that it is at least partly polarised. Just rotate the filter to see if there is a reduction in brightness. Try the same with the blue sky on a sunny day.

A third polariser put between two 'crossed' filters can let some light through. The middle filter rotates the direction of polarisation of light from the first filter so that some of it now gets through the second one. This is put to use in visualising stress patterns in materials.



A piece of acetate with a notch cut in it and bent to stress the material at the notch will show stress patterns if placed between crossed polarising filters.



Polarised 3 cm microwaves (for reference)

You can easily show that these microwaves are polarised when they are emitted. This can be done just by putting a receiver in front of the transmitter, and then rotating either around the direction between them. When they are 'crossed' (at right angles) the signal reception drops to zero.

A polarising filter can be made of a grille of metal wires. Held with its wires parallel to the direction of polarisation (the direction of oscillation of the electric field) it does not pass any signal. Held with the grille at right angles to the direction of polarisation, the microwaves get through.

Safety

It is important to check that the power supplies are electrically safe. Those transmitters using a Klystron oscillator require about 300 V at a hazardous current. Ensure that all high voltage connectors are a safety pattern.





This seems to be contradictory behaviour compared to the ‘mechanical filter’. When the grill is parallel to the direction of polarisation, the free electrons in the metal are accelerated by the electric field in the em wave, thus absorbing energy from the wave. The energy is re-radiated in all directions (the metal acts like an aerial), so the wave travelling in the onward direction as if it had passed through the grill is very weak.

Plane polarised waves meeting a grill with wire at right angles to the direction of vibration do not have much energy absorbed by the free electrons in the metal. They can only be moved for a short distance, so most of the energy in the wave passes onwards.

You have now:

1. Seen polarisation in several different cases.

2. Understood that transverse waves show polarisation.

3. Practised thinking three-dimensionally about examples of polarisation.

4. Seen that polarising filters select a preferred direction of polarisation.

5. Seen that the direction of polarisation can be rotated by a polarising filter.

6. Noted the use of polarisation in observing stress patterns.

Social and human context

The technological importance of the polarisation of electromagnetic waves in their transmission and reception, and in aerial design.

Polaroid glasses reduce glare and enable the user to see through reflections from water or glass. Photoelasticity and the optical stress analysis of model structures can be more economical than building prototypes.

The blue light, scattered by gas molecules and density fluctuations in the air, is partly polarised, and is used by some insects including bees to aid their navigation.

External reference

This activity is taken from Advancing Physics chapter 3, 120P

Polarisation by scattering

Scattered light is polarised

Light like that from the blue sky is scattered. It is also polarised, and the direction of polarisation contains information about the direction of the Sun, used by birds and insects for navigation.

You will need

* parallel beam projector (with small circular aperture)
* power supply, 0–12 V dc and ac, 6 A
* plastic tank, rectangular
* polariser, optical
* skimmed milk (a few drops)

Getting scattered light

Light is scattered by very small particles suspended in water. If it is scattered at right angles to its original direction, the scattered light cannot oscillate along its direction of travel, so it must be polarised.



1. Fill a transparent tank with water. Add a drop or two of milk and stir. The aim is to make the water cloudy enough for a beam of light shone through it to be **just** visible, no more, from the side.

2. Shine a narrow beam of light through the tank.

3. Look through a polarising filter at the beam as seen looking horizontally at the side of the tank. The diagram shows that this light must be **vertically polarised**. Turn the polariser until the beam becomes invisible. The direction of polarisation in which the polariser passes polarised light must now be parallel to the beam in the tank. Mark this direction on the polariser.

4. Now look down on the beam from above. This scattered light must also be polarised at right angles to the beam, as shown in the diagram. Test this by holding the polariser with its transmission direction along the tank: the beam should become invisible again.

You have seen

1. Light being polarised by scattering.

2. How to deduce the polarisation direction of a polariser.

If the day is sunny and the sky blue, take the chance to check that the blue sky at right angles to the direction of the sun is polarised, and note that the direction agrees with that deduced from the direction of the Sun.

Social and human context

Some insects and birds use the polarisation of light from the sky for navigation.

External reference

This activity is taken from Advancing Physics chapter 3, 130E

Polarisation in practice

Answer these questions about uses of polarisation.

**Radio and television**

Most portable radios have a vertically extendable stick aerial of a metre or so in length to receive signals. TV aerials can have many short horizontal rods attached to them.

1. What limit does the length of the stick place on the frequency band received by the radio aerial?

2. Explain why the orientations of the two aerials might be so different.

3. Outline how the radio wave produces a varying potential difference across the aerial.

It is midday. The Sun is in the south, and is 56 above the horizon.

4. Which direction should you face to observe the maximum polarisation of light scattered from the sky?

5. The sky on the horizon is observed through a Polaroid filter which is then rotated. What angle with the horizontal will the filter make when maximum transmission occurs?

6. Ants emerging from a nest in shadow have been observed to turn their heads skywards and to rotate them about their body axis. Can you make sense of this behaviour, given that ants' eyes have a natural polarising filter?

7. If you turned to face the northern horizon, with the Sun at your back, would you expect to find any evidence of polarisation in the scattered light? Explain, possibly using a diagram.

Magnetic compasses are rather useless in polar regions. However, if the Sun is below the horizon but there is scattered light from the sky a solar compass can be used which analyses the polarisation of the scattered light.

8. Why are magnetic compasses useless near the Earth's poles?

9. How might a solar compass operate, and why would you need a clock as well to determine direction?

The next group of questions attempt to get you to think about photoelastic stress analysis and what might be occurring in a stressed plastic specimen showing the effect between crossed polarising filters.

10. What must the plastic be doing to the light to enable passage through crossed Polaroid filters?

11. What evidence is there that different colours have their direction of polarisation rotated by different amounts?

12. What determines this amount of rotation?

13. A ruler shows coloured bands before any stress is applied. Why is this?

14. What does a line of equal colour (an isochrome) indicate?

15. Sugar solution has the ability to rotate the direction of polarisation of light depending on the concentration of the solution. Suggest how this could be used in a sugar factory to test the strength of a sugar solution.

16. If a liquid crystal display on a watch, calculator or laptop computer is viewed through a polarising filter, the display can be extinguished for certain orientations of the filter. What does this tell you about the construction of such devices?

Hints

1. Use f = c/ λ

2. Think about the possible polarisation direction of the electric field.

3. Consider a free electron in the metal of the aerial.

4. What direction is south at the North Pole?

5. In which direction in relation to the Sun will the light from the sky show maximum polarisation?