Notes for teachers

on module 5:

Polarisation

Polarisation is a fundamental property of light and understanding how it works has helped researchers to harness and control this effect for various applications. It has a wide variety of applications in pharmaceuticals, television and computer displays, and even fishing goggles are based on this property. This effect is not just interesting, it is extremely useful.

Summary: In this module, students learn how to rotate the polarisation of linearly polarised light and how polarisers work. They also learn how to build their own polarimeter and measure the rotation of polarisation due to a sugar solution.

The module contains one chapter:

- Twisting light: Using polarisers to rotate the polarisation of light and building a polarimeter

Designed for: upper secondary level (age ca. 16 to 18)

Duration: The module requires one lesson of ca. 40 min.

What students should already know:

- light behaves as waves

What students will learn:

- Basic concept of polarised light
- How polarisers work
- Rotating the polarisation of light
- How to building a polarimeter
- Applications of polarisation in LCD displays

This module includes:

- 1 worksheet
- 1 fact sheet

Chapter 1 | Twisting Light

Suggested lesson outline

In this chapter, students will investigate polarisation of light and how to use different materials to rotate the polarisation. They will also build their own ”sugar polarimeter” and test the effect of different concentrations of sugar solution on the polarisation of light. Using these methods they will learn how the fundamental property of polarisation can be used in different applications and breakthroughs such as Liquid Crystal Displays (LCDs).

Timing in minutes	**Activity**	**Material**
homework	Reading of laser safety instructions	Laser Safety Rules
0-5	Introduction: Reading of first part of worksheet	WS11.1
5 – 15	Working through Questions 1-5 of worksheet	WS11.1
15 – 30	Reading through Parts 6-7 and building a polarimeter	2 Polarisers 1 Laser module *Not provided:* 1 clear mug/glass Clothes clips to hold polarisers in place Screen Water Sugar (1-2 teaspoons or equivalent)
30 – 40	Working through LCD Displays explanation on Fact Sheet	FS11.1, Lenses

Description of suggested lesson

Polarisers and how they work

After the students have read through the first part of the worksheet, they might need guidance regarding the vector decomposition of waves. Please explain to them how this works either by illustrating it with a string or by drawing it on the board. The main idea is to have the students use reasoning to arrive at conclusions for Parts 1 to 5.

To this end, you could play a ”game” in class where instead of providing a direct answer you answer each question they ask you with another question. This challenges the students to be very specific with their questions and also to think about various ways to answer the questions you put to them. This is very important for their perspective on discovery and will deepen their understanding of scientific conclusions.

When the students have completed Parts 1-2 on the worksheet, move around the groups to see and discuss their observations. Once all the groups have looked through the polarisers at various objects around them, ask them to work through Parts 3-4. In these experiments, students should first see that they can cut off light when the polarisers are held at ninety degrees (crossed) to each other (they ”see” black) and when they put a third polariser between the crossed polarisers they suddenly can see something again!

Once the students have seen this effect, ask them to work through Part 6 and to see if they can spot something similar happening when other transparent materials are held between the crossed polarisers. Students should be led to understand that the third polariser and the plastics are in fact *rotating* the polarisation of the light after the first polariser such that the second polariser can transmit it.

Ask the students to work through Part 6 on the worksheet and test out the effects with their mobile phone screens. You can tell them to summarise their ideas and come up with a hypothesis of how they think LCD's work by thinking about why the light coming out of their mobile phone screens is polarised and in what direction. You can also tell them that their hypothesis will be tested when they learn later on in the fact sheet about the workings of an LCD.

Then, they can read through Part 7. Tell your students that they will now test how some "materials" rotate the polarisation of light and by how much. They will do this by building a "sugar polarimeter". A polarimeter is a device used to measure the angle of rotation caused by passing polarized light through an optically active substance.

If your students have not worked with these lasers before, it is important that students have read, understood and signed the laser safety worksheets. It is however, crucial to repeat these instructions before they use the lasers as the safe handling of lasers is another essential skill they can learn during this module.

Ask the students to read through Part 8 of the worksheet and build their own setup. The one shown in the picture is one example of how to set up the polariser. However, they might be able to find a better method! One of the polarisers should be stably mounted so that they will not fall over during the experiment. Students can rotate the second polariser to find the angle at which the beam is completely extinguished.

Note that warm tap water will be sufficient to dissolve the sugar. If this is not available, the students can use room-temperature tap water, but the sugar may take longer to dissolve. Tell the students not to add large quantities of water at first because a fairly concentrated solution will be needed to see the rotation of polarisation.

Students could also first test with just water (no sugar dissolved) and see if this has any effect on the polarisation. However, do not suggest this if they do not at first come up with this question on their own.

Once they have completed Part 8, ask them to read through Part 9 and build a hypothesis. You can work your way around the groups to see their hypotheses and guide them by asking where they think the rotation is coming from (sugar only, water only, the mixture)

Fact Sheet

The fact sheet contains information on Liquid Crystal Displays and how the effect of polarisation is used in them. More information for discussion with your students is contained in the "Background Information" provided. Ask your students to think back to the experiment with their mobile phone (or laptop) screens in Part 7 of the worksheet. They were able to recognise that the light that passed out was polarised in a certain direction. Most of them will probably have some awareness of Liquid Crystal Displays (LCD Screens) even before they do the experiment and may even have an LCD device at home. Ask them to compare their hypotheses about how twisting light helps in making LCD's possible with the explanation provided in the fact sheet.

Background Information

Liquid Crystals

Liquid Crystals are a state of matter that have properties between those of solids and liquids. For instance at a macroscopic scale, a liquid crystal might flow, but on a microscopic level its molecules may be crystal like.
Liquid Crystals were discovered in 1888 by an Austrian botanical physiologist, Friedrich Reinitzer, while he was working on physio-chemical properties of cholesterol (now known was cholestrolic liquid crystals) with the help from a physicist, Otto Lehmann. Reinitzer discovered three important properties of cholestrolic liquid crystals – that it had two melting points, it reflected circularly polarised light and it could rotate the polarisation direction of light. The research was continued by Lehmann, who realized that he had encountered a new phenomenon and was in a position to investigate it. He studied several molecules and by the end of August 1889 he had published his results in the Zeitschrift für Physikalische Chemie. Lehmann's work was continued and significantly expanded by the German chemist, Daniel Vorländer, who, from the beginning of 20th century until

his retirement in 1935, had synthesized most of the liquid crystals known. However, liquid crystals were not popular among scientists and the material remained a pure scientific curiosity for about 80 years. The next step to commercialization of liquid crystal displays was the synthesis of further chemically stable substances (cyanobiphenyls) with low melting temperatures by George Gray.

Liquid Crystal Display Technology

Each pixel of an LCD typically consists of layers of molecules aligned between two transparent electrodes and two polarising filters with transmission planes being perpendicular to the other. If there was no liquid crystal between the polarisers, light passing through the first would be completely blocked by the second. The surface of the electrodes is treated so as to align the liquid crystal molecules in a particular direction.

In some cases, this treatment is done by rubbing a thin polymer layer in one direction using a cloth. So the liquid crystals on the layer next to the surface become aligned in the direction of rubbing. These electrodes are made of a transparent conductor called Indium Titanium Oxide (ITO). If an electric field is not applied, the alignment of the liquid crystals is defined by the alignment on the surfaces of the electrodes. In a typical ”twisted nematic device” (more information provided below), the surface alignment of the molecules on the two electrodes are perpendicular to each other so the molecules arrange themselves in a helical or twisted way. This reduces the degree of rotation of the polarisation of any incident light so a display appears grey when switched off. When a voltage is applied, the liquid crystal molecules in the centre of the layer are completely untwisted and therefore incident light can pass straight through, this light will be blocked by the second polariser and therefore the pixel will appear black. Thus the degree of grey can be controlled by controlling the voltage applied across each pixel. However, several pixels are needed for a standard display and it is not possible to control the voltage across each pixel individually. Thus, the display is ”multiplexed”. In this way, the pixels are grouped in columns and controlled by its own voltage source. On the other side, the electrodes are grouped in rows and get their own voltage sink. The groups are designed so that each pixel has its own unique combination of source and sink. Electronics and software are then used to turn on the sinks and drive the sources for each pixel.

Passive and Active Matrix Addressed LCD’s

Some displays such as in older laptop screens, personal organisers or electronic weighing scales or the original Nintendo GameBoy have a passive matrix structure using super-twisted nematic (or STN) or double-layer STN technology. In passive matrix addressed displays, each row or column of pixels is connected to a single electrical circuit. The pixels are addressed one at a time by row and column. This system is called ”passive” because the pixel must retain its state between refreshes without an active electrical charge. As the system gets bigger and bigger and the number of pixels grow, passive matrices are not very feasible. Slow response times and poor contrasts are a problem with such displays.

Today, most screens use active matrix addressed display technology. Here, a matrix of thin-film transistors (TFT’s) is added to the polarizing and colour filters. Each pixel has its own dedicated transistor, allowing each column line to access one pixel. When a row line is activated, all of the column lines are connected to a row of pixels and the correct voltage is driven onto all of the column lines. The row line is then deactivated and the next row line is activated. All of the row lines are activated in sequence during a refresh operation. Active-matrix addressed displays look "brighter" and "sharper" than passive-matrix addressed displays of the same size. They generally have quicker response times producing much better images.

Twisted Nematic Effect

In the nematic phase, the rod shaped organic molecules of a liquid crystal have no positional order and are free to flow just like a liquid. They have long range order in that they self align to have their long axes parallel. They can be easily aligned by applying electrical or magnetic fields.

The twisted nematic effect is based on the precisely controlled realignment of these molecules when an electric field is applied. This is achieved with little power consumption and at low operating voltages. In the OFF state, i.e. when no electric field is applied between the electrodes, a twisted configuration of liquid crystal molecules is formed between two glass plates. In the ON state, i.e. when a field is applied between the two electrodes, the crystal re-aligns itself with the external field (right diagram). This "breaks" the careful twist and fails to re-align the polarized light passing through.

Organic Light Emitting Diode Displays vs. LCD's

A rapidly growing technology today is organic LED's. An **organic light emitting diode** (**OLED**) is a light-emitting diode (LED) in which the emissive electroluminescent layer is a film of organic compounds that emit light when an electrical current is applied to them. This layer of organic semiconductor material is located between two electrodes. Generally, at least one of these electrodes is transparent. The basic difference between OLED's and LCD's is that the former operates by creating light while the latter is based on blocking light. OLED displays can be thinner and lighter than LCD displays and also achieve higher contrast. However the organic compounds used in OLED's make their life span much shorter than LCD's.

Students might ask

How do polarising sunglasses work?

When light encounters the boundary between two media of different refractive indices a fraction of light gets reflected. This fraction depends on the polarisation and angle of incidence. When light is incident at the Brewster's angle (given by), the light with the *p* polarisation will not be reflected. When non-polarised light, such as sunlight, is incident on a reflecting surface at Brewster's angle, the reflected light is perfectly polarised (s-polarised) perpendicular to the incident plane. For a glass medium ($n_2 \approx 1.5$) in air ($n_1 \approx 1$), Brewster's angle for visible light is approximately 56°, while for an air-water interface ($n_2 \approx 1.33$), it is approximately 53°.

Polarised sunglasses are designed to protect the eye from this "glare" or reflected sunlight from surfaces like water or metal. This reflection is usually horizontally polarised and the lenses are vertically polarised to cut off this light.

Polarising filters in photography?

The **polarizing filter** used with most modern cameras is a circular polarizer. The first stage of the polarizer is a linear filter which filters out light that is linearly polarized in a specific direction. The second stage, for technical reasons related to the auto sensors within the camera, then circularly polarizes the light before it enters the camera. The polarizing filter has two applications in both colour photography and black-and-white photography: it reduces reflections from some surfaces and it can darken the sky. The electrons in the air molecules scatter sunlight (Rayleigh scattering) and the blue part (shorter wavelengths) of the spectrum gets scattered more than the red part (longer wavelengths) so that the sky looks blue. The polarising filter in a camera can filter out the polarised component of light from the sky for a colour photograph so that the contrast of the blue sky against the white clouds is enhanced.