Question 20 **(20 marks)**

Polarisation of light

Figure 1: Pair of polarised sunglasses

When you buy a pair of polarised sunglasses, the main purpose they serve is to reduce the intensity of light hitting your eyes. How they achieve this is described below.

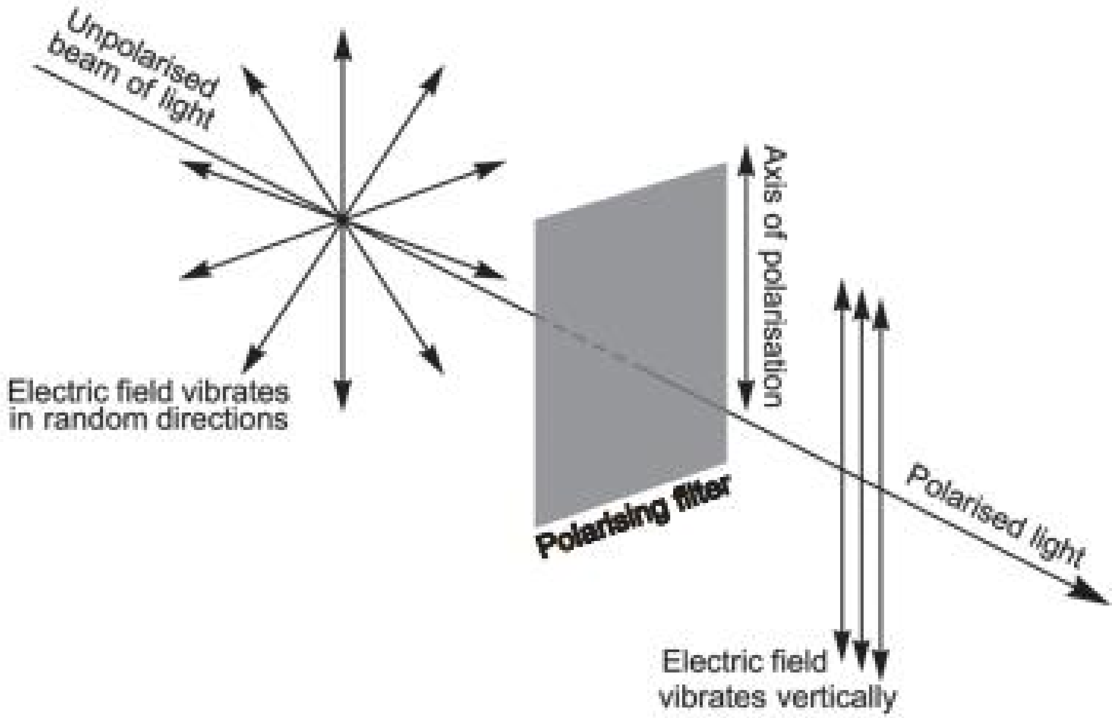


Figure 2: Randomly polarised light passing through a polarising filter

Light waves are a combination of oscillating magnetic and electric fields. As the magnetic field changes, it induces a changing electric field, which in turn induces a magnetic field and so on. A beam of light consists of transverse waves oscillating in all directions around the line of propagation. A polarised filter can be thought of as a series of slits that only allows those waves to pass through with their electric fields oscillating in the same direction as the axis in the filter.

But the filters do not have actual slits in them. The material consists of long chain polymers. Electrons in these chains are free to move along the chains but not between them. A light wave's electric field does work on these electrons and causes them to absorb the wave's energy. Therefore, light waves which are polarised parallel to the chains get absorbed and those travelling perpendicular pass through undisturbed. Those travelling at an angle to the chains are partially absorbed. The axis of the filter is perpendicular to the chains.

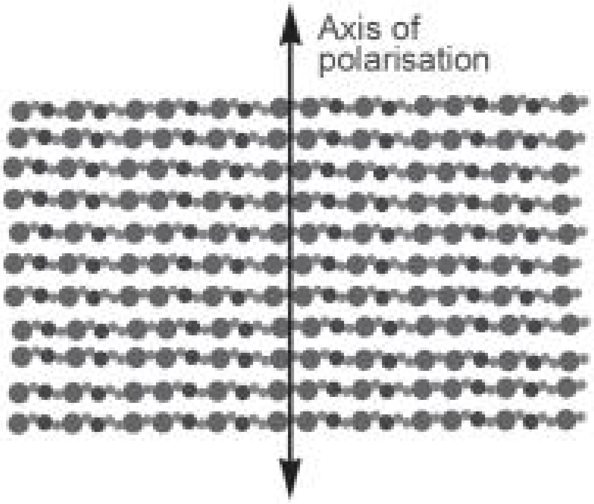


Figure 3: Axis of polarisation is perpendicular to the aligned long chain polymer molecules

Figure 4 illustrates this point. Only the component of the electric field parallel to the axis of a polarising filter is allowed to pass. In the diagram, angle θ represents the angle between the direction of polarisation of incident light and the axis of a polarising filter. After passing through the filter, the amplitude of the electric field has been reduced by a factor of $\cos\theta$.

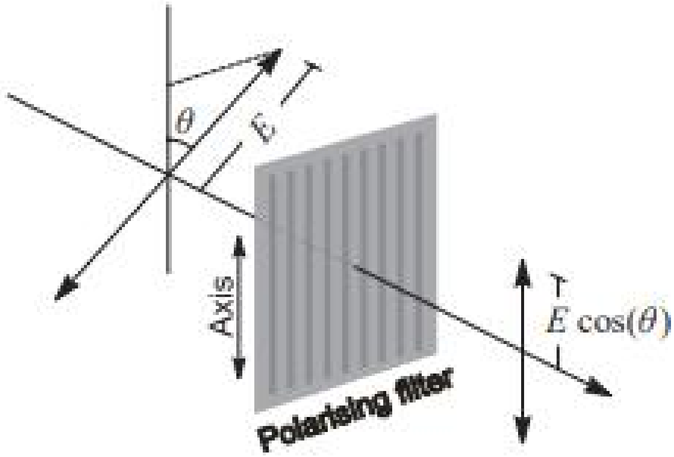


Figure 4: Polarising filter with angle θ shown

Since intensity of a wave is proportional to its amplitude squared, the intensity I of the transmitted wave is related to the initial intensity I_0 of the incident light by the following relationship, known as Malus' Law:

$$I = I_0 \cos^2\theta.$$

A single polarising filter reduces the wave's intensity by exactly 50.0%. Intensity is measured in watts per square metre (W m^{-2}).

(a) With reference to Figure 3 on page 35, discuss how unpolarised light can become polarised. (4 marks)

(b) Define the axis of a polarising filter and describe its function. (2 marks)

(c) According to Malus' Law, at what angle to the direction of polarisation of the incident light should the axis of a polarising filter be oriented in order to

(i) allow the light to pass without reduction in intensity? (1 mark)

Answer: ____________ °

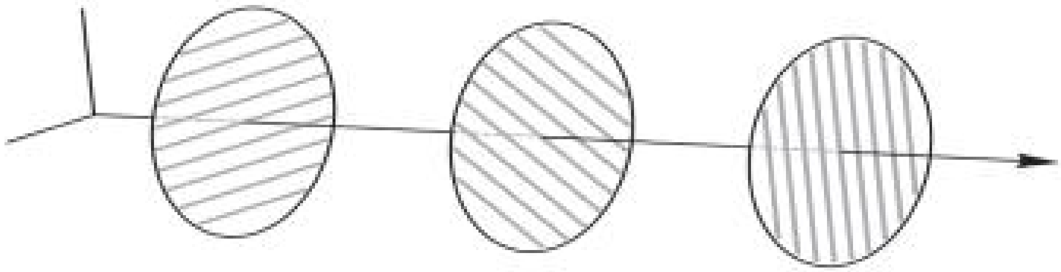
(ii) completely block the passage of the light? (1 mark)

Answer: ____________ °

(d) Use Malus' Law to calculate the angle between the direction of polarisation of the incident light and the axis of a polarising filter if the incoming light has its intensity reduced by 75.0%. (4 marks)

Answer: ____________________ °

(e)



A group of students placed two polarising filters at right angles and saw no light being transmitted. They placed a third filter between the first two at 45.0° to each one and noticed light was transmitted.

(i) Explain how inserting the third filter allowed light to hit the screen when no light was hitting it before. (3 marks)

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(ii) What percentage of the original light's intensity is hitting the screen with the third filter in place? (2 marks)

Answer: ____________________ %

(f) A photon's energy is given by $E = hf$. When light passes through a polarising filter, the total energy transmitted is reduced but the frequency of each photon remains the same. Using the particle model of light, account for the reduction in transmitted energy. (3 marks)