# Questions

## Module 7: The Nature of Light

### 7.2 Wave Model

Multiple-choice questions: 1 mark each

**1.** Which of the following models of light best predicts the behaviour of light travelling through a polarising film?

(A) Young's particle model of light.

(B) Particle model of light.

(C) Wave model of light.

(D) Newton's corpuscular model of light.

**2.** Newton stated that the light from all luminous objects consisted of corpuscles radiating out in straight lines. How did Newton explain the reflection of this light?

(A) When reflected, the particles travel in a curved path due to gravity

(B) When reflected, the particles travel in a curved path as they are unaffected by gravity.

(C) When reflected, the particles travel in a straight line as they are unaffected by gravity.

(D) When reflected, the particles travel in a straight line due to gravity.

**3.** Which of these correctly states Huygens' Principle?

(A) Light particles travel in straight lines as wavelets until they hit a surface.

(B) The propagation of a wave explains the diffraction of light.

(C) All points on a wavefront are interconnected, so that propagation of the wave can occur.

(D) Each point on a wavefront may be considered as a source of secondary wavelets.

4. Which of the following phenomena supports that light travels as a transverse wave and not as a longitudinal wave?

(A) Polarisation

(B) Interference

(C) Diffraction

(D) Reflection and refraction

5. Which of these statements best describes the diffraction of light?

(A) This occurs when two or more light waves of the same frequency combine to reinforce or cancel each other.

(B) The spreading out of a wave after it has passed a barrier or has passed through a small opening.

(C) The change in direction of a ray light when it passes from one medium into another medium with a different density.

(D) This occurs when a ray of light bounces off a smooth surface at the same angle as it hits the surface.

6. Why is a laser light able to be used in experiments to demonstrate the wave nature of light?

(A) Laser light is an incoherent source of light that can travel through slits.

(B) Laser light is coherent, monochromatic source of light.

(C) Laser light contains many frequencies of light that are in phase with each other.

(D) Laser light consists of wavelets that are in phase with each other.

7. How did Huygens' theory about light differ from that proposed by Newton?

(A) Huygens explained light as having many wavefronts, while Newton explained light as a series of wavelets.

(B) Huygens theory could not be proved experimentally, whereas Newton's theory had better evidence to support it.

(C) Huygens theory could not explain diffraction and interference of light, whereas Newton's theory did.

(D) Huygens proposed that light was a type of wave, while Newton explained light in terms of particles or 'corpuscles.

8. Young's double-slit experiment provided evidence to support the wave model of light.

What did Young observe on the screen when he shone monochromatic coherent light on two closely separated narrow slits?

(A) An interference pattern consisting of a series of alternating light and dark bands.

(B) A diffraction pattern consisting of a series of alternating light and dark bands.

(C) An interference pattern consisting of two bright lines.

(D) A diffraction pattern consisting of two bright lines.

9. What happens during polarisation?

(A) After light waves pass through a polariser, their vibrations are stopped in all directions.

(B) After light waves pass through a polariser, they are vibrating in one direction.

(C) After light waves pass through a polariser, interference occurs producing dark and light bands.

(D) After light waves pass through a polariser, their direction of vibration is restricted to a vertical plane.

10. What does polarisation show about light?

(A) It can travel through space.

(B) It travels at the speed of light.

(C) It is a transverse wave.

(D) It is a longitudinal wave.

11. When a ray of light passes through a polarising filter, its intensity is decreased by 75%.

What is angle between the filter and the plane of polarisation of the light?

(A) 15°

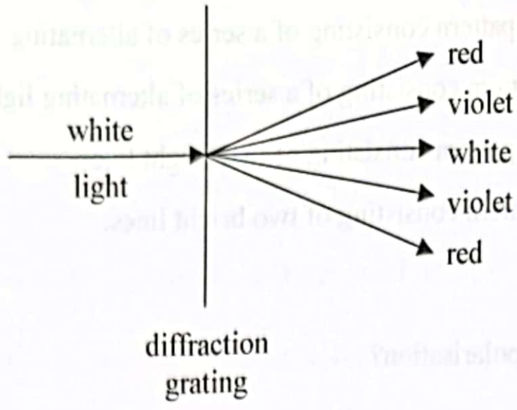
(B) 30°

(C) 45°

(D) 75°

## Short-answer questions

**12.** The diagram below illustrates the behaviour of white light incident on a diffraction grating.




Explain why red light is deviated more than violet by the diffraction grating.

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*1993 HSC Q Elective 2 (c) (ii) ... 2 marks*

**13.** The immense stature of Newton led to the acceptance of his 'corpuscular' model for light and the rejection of a wave model for many years. Eventually the wave model was accepted.

Describe how each of the following scientists explained the behaviour of light according to the wave model:

(a) Huygens: ..........................................................................................

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(b) Young: ..........................................................................................

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*Adapted 1987 HSC Q Elective 1L (a) ... 2 + 2 = 4 marks*

14. Describe an experiment to justify the belief that light is a transverse wave.

Clearly state why the described behavior of light supports a transverse wave model for light.

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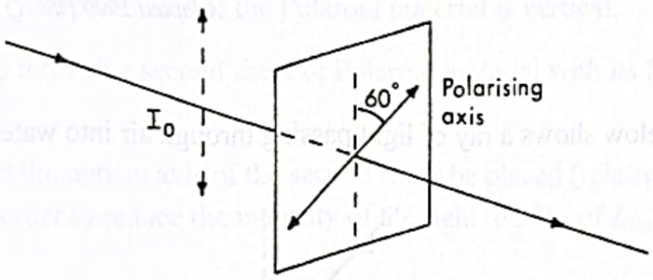
*Adapted 1991 HSC Q Elective 1L (b) ... 2 marks*

15. Vertically polarised light of intensity $I_0$ is incident on a clear polarising sheet whose axis of polarisation forms an angle of 60° to the vertical, as shown below.




*[Note: The intensity of light entering a filter ($I_0$) is now referred to as $I_{max}$ by the NSW Physics Syllabus.]*

(a) Determine the intensity of the light that passes through the sheet, expressed as a percentage of the original light. Justify your answer.

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(b) The polarised light is now replaced with unpolarised light of the same intensity.

What is the resulting intensity of the light that passes through the polarising sheet?

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*Adapted 1987 HSC Q Elective 2 (c) ... 2 + 1 = 3 marks*

16. Etienne Malus made a number of important observations about the polarisation of light and how the intensity of light changes. Use Malus' law to answer these questions.

*[Note: The SI unit for light intensity is the candela (cd), based on a candle of standard brightness.]*

(a) Light rays from a lamp with an intensity of 100 cd are passed through a polariser. What intensity will these light rays have after passing through the polariser? Explain why.

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(b) The light rays are then passed through a second polariser at 30° to the plane of polarisation of light, held parallel to the first polariser and on the same side as the lamp. What will be the intensity of the light rays now? Show any calculations.

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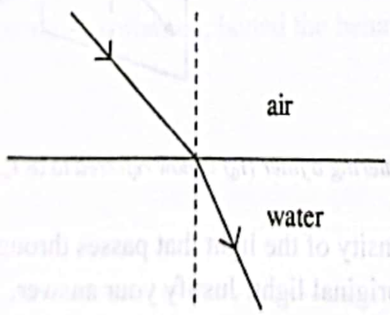
*Adapted 1990 HSC Q Elective 2 (d) ... 2 + 2 = 4 marks*

17. The diagram below shows a ray of light passing through air into water.




(a) What name is given to this bending of light by change of medium? ..............................

(b) How did Newton explain this phenomenon?

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*1991 HSC Q Elective 1L (a) ... 1 + 2 = 3 marks*

18. A student reported on a polarisation experiment. The following is a section of notes from their report:

> 'I held up a piece of Polaroid film and looked up through it at the blue sky. As I rotated the film through 360°, the light intensity varied.'

Describe the variation in light intensity that the student would have seen. Explain why.

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*1995 HSC Q33(f) ... 3 marks*

19. Light with intensity $I_{max}$ passes through a sheet of Polaroid material that reduces the light intensity to 0.5 $I_{max}$. The optical axis of the Polaroid material is vertical.

The light then passes through a second sheet of Polaroid material with its face parallel to that of the first sheet.

At what angle should the optical axis of the second sheet be placed (relative to the optical axis of the first sheet) in order to reduce the intensity of the light to 30% of $I_{max}$?

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*Adapted 1996 HSC Q33(e)(i) ... 2 marks*

*[Note: The intensity of light entering a filter ($I_0$) has been changed here to $I_{max}$ as this is the term now used in the NSW Physics Syllabus.]*

**20.** When unpolarised light is passed through a Polaroid filter, polarised light of intensity $I_{max}$ is produced. After another Polaroid filter is placed in front of this light, the light intensity decreases to $\frac{1}{8} I_{max}$.

Calculate the angle between the axes of the two Polaroid filters.

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... *2 marks*

**21.** Data from Young's double-slit experiment can be analysed using the formula: $d \sin\theta = m\,\lambda$

Calculate the wavelength (in nm) of a laser light that is directed through a pair of thin slits that have a 45 μm separation. The bright fringes formed on a screen 2.5 m from the double slit are 3.2 cm apart.

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... *2 marks*

## 7.2 Wave Model

### Multiple choice: 1 mark each

**1.** C **2.** C **3.** D **4.** A **5.** B **6.** B **7.** D **8.** A

**9.** B **10.** C **11.** B

### Explanations:

**1.** **C** Transverse waves, as described in the wave model of light, can pass through a polarising film when their plane of vibration aligns with the axis of the polariser. This explains the polarising behaviour of light. So (C) is the answer. Young demonstrated the interference of light and that light travelled in waves. He did not propose a particle model of light. Hence (A) is incorrect. Particle or corpuscular models do not explain the polarising behaviour, as particles only travel in a straight line. So (B) and (D) are incorrect.

**2.** **C** When reflected, light particles travel in a straight line as they are unaffected by gravity ... as in (C).

**3.** **D** Huygens' Principle states that every point on a wavefront is a source of wavelets that spread out and travel in the forward direction, with the same speed as the source wave. The new wavefront will be tangential to all of the wavelets. So (D) is the only correct answer.

**4.** **A** Polarisation is explained by transverse waves having vibrations aligned with the polarising plane of the polariser. Longitudinal waves with vibrations along the direction of propagation would not display polarisation. Hence (A) is the answer. The other properties given in (B), (C) and (D) would be displayed by both transverse and longitudinal waves, so (B), (C) and (D) are all incorrect.

**5.** **B** Diffraction is the spreading of waves past a barrier or through a narrow gap, as in (B). Interference is described in (A), refraction in (C) and reflection in (D). So (A), (C) and (D) are all incorrect.

**6.** **B** It is only when light is coherent that the wave nature of light can be demonstrated, as when Young used 'monochromatic coherent' light in his double-slit experiment. Laser light is a source of 'monochromatic coherent' light as all the waves in a laser light are of the one frequency (i.e. monochromatic) and are in phase (i.e. coherent). So (B) is the only correct answer.

7. **D** Huygens described the behaviour of light in terms of waves and proposed that every point on a wavefront acts as a source of secondary wavelets that travel in the direction of the wave. Whereas Newton described light in terms of particles (or corpuscles). So (D) is the answer and (A) is incorrect. Neither theory had good experimental evidence to support it. Newton's prestige as a scientist was the reason his theory prevailed over Huygens. So (B) is incorrect. Huygens' theory did explain diffraction and interference, so (C) is incorrect.

8. **A** Light passing through two narrow slits is coherent and so is able to produce an interference pattern, as in (A) and (C). This pattern consists of alternating bright and dark bands, not two bright lines. So (A) is correct and not (C). The pattern is not a diffraction pattern. So (B) and (D) are incorrect.

9. **B** When light waves reach a polariser, only light waves with vibrations aligned with the plane of the polariser are transmitted, while those aligned at right angles to the direction of the plane of the polariser are absorbed. So the light waves are not stopped, but are only vibrating in one direction. So (B) is the answer and (A) is incorrect. Interference does not occur, so (C) is incorrect. The direction of vibration is not necessarily a vertical plane, but can be in any direction that depends on the orientation of the polariser's plane of vibration. So (D) is incorrect.

10. **C** Polarisation is a property of transverse waves, as in (C). It is not a property of longitudinal waves, so (D) is incorrect. It is not related to the need for a medium, nor to the speed of the wave. So (A) and (B) are incorrect.

11. **B** $I = I_{max}\cos^2\theta$

$\frac{I}{I_{max}} = \cos^2\theta = 75\% = 0.75$

So, $\cos\theta = 0.8660$

$\therefore\ \theta = 30°$ … as in (B)

*[Note: For Malus' Law, the NSW Physics Syllabus uses the equation: $I = I_{max}\cos^2\theta$*
*Other sources generally use: $I = I_0\cos^2\theta$*
*So, the intensity of light entering a polarising filter, $I_0 = I_{max}$ ]*

## Short-answer questions

**12.** Red light has a longer wavelength than violet light. This leads to larger diffracting angles than violet and so the interference pattern is spread out over a larger distance than for violet light.

**13.** (a) Huygens said that every point on a wavefront may be considered to act as a source of circular secondary wavelets that travel in the direction of the wave. He proposed that waves slow down when they encounter an optically denser medium.

(b) In his double-slit experiment, Young showed the wave characteristics of light when he passed light through the slits and obtained a series of light and dark bands on a screen due to their interference with each other.

**14.** *Experiment*: Unpolarised light was passed through a polariser with a vertical axis. This polarised light was then passed to a second polarising filter (an analyser). As the analyser was rotated through 90°, the light intensity was observed.

*Reason*: Transverse light waves have a plane of oscillation. The polariser only allows light waves with vertical axes of oscillation to pass through, while waves in the horizontal plane cannot pass through. When the analyser's plane of polarisation is horizontal, no polarised light can pass through it. The light intensity will increase as the analyser is rotated 90°. Once its plane of polarisation is aligned with the first polariser, all the polarised light can pass through it.

[Note: This supports light being a transverse wave rather than longitudinal, as longitudinal waves cannot be polarised and will pass through both horizontal and vertical planes.]

**15.** (a) $I = I_{max}\cos^2\theta = I_{max}\cos^2 60 = \frac{1}{4} I_{max}$ [as $\cos^2 60 = (\frac{1}{2})^2 = \frac{1}{4} = 0.25$]

$\therefore \dfrac{I}{I_{max}} = 25\%$ … as the polariser blocks out the light waves that are not aligned with its axis of polarisation, and so it reduces the intensity to 25% of its original intensity.

(b) The resulting intensity, $I = \frac{1}{2} I_{max}$ [OR 50% $I_{max}$ ]

[Note: Unpolarised light has its vibrations randomly oriented in all directions. However, when unpolarised light is transmitted through a Polaroid filter, it can be thought of as being made up of two equal polarised beams of light that are vibrating at right angles to one another. One of these two beams is transmitted through the Polaroid filter and is aligned to its axis, while the other is absorbed. So, the transmitted intensity is 50% of the incident intensity. The mathematical proof of this involves advanced calculus that beyond the Physics syllabus.]

**16.** (a) 50 cd – as the polariser blocks out light waves that are not aligned with its axis of polarisation, hence reducing the intensity by 50%.

(b) $I = I_{max}\cos^2\theta = I_{max}\cos^2 30$

$= 50 \times \cos^2 30$

$= 37.5$ cd

17. (a) Refraction.

(b) Newton's theory was that the small particles, or 'corpuscles' of light experienced an attractive force as they passed from air into water, a denser medium. This force increased the normal component of their velocity, but not the tangential component. So the direction of the particles was bent towards the normal. Hence they travelled faster in the denser medium.

18. As the film was rotated through 360°, the student would have observed the intensity decreasing and increasing between two points of maximum intensity and two points of minimum intensity that are 90° apart. This occurs because when the polariser is rotated, the intensity is greater when the polariser's axis of polarisation is aligned to the polarisation direction of the blue sky light.

[Note: Blue sky light is partially polarised vertically due to the scattering of sunlight – as the blue end of the spectrum is scattered more than the red end.]

19. $I_{\text{Polaroid 1}} = 0.5\, I_{max}$ and $I_{\text{Polaroid 2}} = 0.3\, I_{max}$

Using $I = I_{max}\cos^2\theta$

$0.3\, I_{max} = 0.5\, I_{max}\cos^2\theta$

So, $\cos^2\theta = \frac{0.3}{0.5}$

$\therefore$ the angle between the two sheets $(\theta)$ must be 39.2°.

20. Using $I = I_{max}\cos^2\theta$

$\frac{1}{8} I_{max} = I_{max}\cos^2\theta$

So $\cos^2\theta = \frac{1}{8}$

$\therefore$ angle between the two Polaroid filters, $\theta = 69.3°$

21. $\tan\theta = \frac{0.032}{2.5}$ So $\theta = \tan^{-1}(\frac{0.032}{2.5}) = 0.73°$

Path difference, $m = 1\lambda$ *[Note: As the path difference (m) between the rays resulting in the first fringe from the centre is $1\lambda$]*

Using $d \sin\theta = m\lambda$

$$\lambda = \frac{d \sin\theta}{m} = \frac{45 \times 10^{-6} \times \sin 0.73}{1} = 5.76 \times 10^{-8}\ \text{m}$$

$\therefore$ wavelength of laser light = 576 nm *[Note: 1 nm = $1 \times 10^{-9}$ m]*