**Waves**

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| **Topic area** | **Text book pre-reading** | **Syllabus ref** | **Max possible score in exam questions** | **Your score in exam questions** |
| Key terms, equations and units |  |  | 10 |  |
| Wave terminology | p179-182 | 4.4.1 | 9 |  |
| Wave properties and oscilloscopes | p183-184 | 4.4.1 | 9 |  |
| Electromagnetic waves | p187-188 | 4.4.2 | 7 |  |
| Reflection, refraction, Snell’s Law and total internal reflection | p192-199 | 4.4.2 | 15 |  |
| Polarisation | p189-191 | 4.4.1 & 2 | 10 |  |
| Superposition and interference | p200-202 | 4.4.3 | 9 |  |
| Diffraction of waves and two source interference | p204-208 | 4.4.3 | 9 |  |
| Youngs Double Slit experiment  | p209-210 | 4.4.3 | 7 |  |
| Stationary vs. progressive waves | P216-218 | 4.4.4 | 15 |  |
| Measuring the speed of sound | P219 | 4.4.4 | 10 |  |
| Total | 110 |  |

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| **By the end of this topic you should be able to…** | **Check**  |
| Describe the difference between a longitudinal and transverse wave and describe how these are represented graphically |  |
| Define the terms displacement, amplitude, wavelength, period, frequency and wave speed. |  |
| Describe how you could use an oscilloscope to determine the frequency of a wave |  |
| Calculate frequency from time period and wave speed from frequency and wavelength |  |
| Define what is meant by intensity of a wave and how this links to amplitude |  |
| State what is meant by the electromagnetic spectrum and state properties which are common to all of these forms of radiation and the order of magnitude of individual forms of radiation within the spectrum. |  |
| Define the law of reflection and sketch ray diagrams to show this.  |  |
| Describe how light is refracted, sketch ray diagrams to show this and describe how you would show this experimentally |  |
| Describe what is meant by the refractive index and how this links to the angle of incidence. Calculate this from materials knowing the speed of light in a vacuum and the speed of light in the material |  |
| Explain how total internal reflection occurs and how this can be shown experimentally, link this to the "critical angle". |  |
| Describe how waves can become polarised and explain how this can be shown experimentally for microwaves and light |  |
| State the principle of superposition of waves, including how this can be demonstrated graphically, and explain how this effect can be demonstrated using sound, light and microwaves.  |  |
| State the difference between constructive and destructive interference in terms of path difference and phase difference |  |
| Describe Young's double-slit experiment as evidence for interference of light waves, and describe how this can be used to find the wavelength of light |  |
| Explain the similarities and differences between a progressive wave and a stationary wave  |  |
| State features of stationary waves including nodes and antinodes and why these form in relation to wavelength. |  |
| Draw stationary wave patterns formed on a stretched spring and air columns in closed and open tubes |  |
| Describe how the speed of sound in air can be found experimentally using stationary waves |  |
| Describe the relationship between musical harmonics, fundamental frequencies and stationary waves |  |

**Glossary of key terms- Match the term to the definition (5)**

Longitudinal, Transverse, Amplitude, Frequency, Wavelength, Period, Displacement, Refractive index,

Snell’s Law, Critical angle, Total internal reflection, Polarised, Superposition, Interference, Diffraction, Path difference, Phase difference, Coherent, Progressive wave, Stationary wave, Fundamental frequency, Node, Antinode, Intensity

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|  | Waves with a constant phase difference |
|  | A wave where there is a net transfer of energy |
|  | The frequency at which the first harmonic occurs |
|  | The point on a stationary wave with no displacement |
|  | A wave where oscillations are parallel to the direction of energy transfer |
|  | Number of waves passing a point per unit time |
|  | The distance between two equivalent points on a wave (e.g. peak to peak or trough to trough) |
|  | A wave where oscillations are perpendicular to the direction of energy transfer |
|  | The time taken for one wavelength to pass a point |
|  | The point of a stationary wave with maximum displacement |
|  | The refractive index of a primary material multiplied by the sin of the angle of incidence is equal to the refractive index of the secondary material multiplied by the sin of the angle of refraction |
|  | The maximum displacement of a wave |
|  | The distance from the equilibrium position |
|  | The angle beyond which total internal reflection will occur |
|  | The ratio of the speed of light in a vacuum to the speed of light in a medium |
|  | Where all light is reflected internally rather than refracting through the boundary between materials as the angle of incidence exceeds the critical angle |
|  | The resultant wave from superposition of two or more waves |
|  | The spreading out of a wave as it passes through a gap |
|  | A wave where light rays travel in only one plane |
|  | Overlapping of two or more waves |
|  | Power per unit area |
|  | Difference in phase angle between two waves |
|  | Difference in path length between two waves |

**Equations given in exam- Complete the table with the definition of each variable symbol (5)**

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| **Variable symbol** | **Variable** | **Unit symbol** |
| **v** |  |  |
| **f** |  |  |
| **λ** |  |  |
| **T** |  |  |
| **P** |  |  |
| **A** |  |  |
| **n** |  |  |
| **c** |  |  |





**Introduction to waves and wave terminology**

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| 1. | 1. Define the terms wavelength, frequency and period used to describe wave motion.wavelength, λ .......................................................................................................................................

 frequency, f .......................................................................................................................................... period, T .............................................................................................................................................**[3]**1. Starting from the definition of speed v, derive the wave equation which relates λ, f and v. Explain your reasoning clearly.

  **[3]** |

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| 2. | A guitar manufacturer wants to investigate the quality of sound produced from a new uniform polymer string. Fig. 18.1 shows the string which is kept in tension between a clamp and a pulley. The frequency of the mechanical oscillator close to one end is varied so that a stationary wave is set up on the string.The frequency of the oscillator is 60 Hz.Use Fig. 18.1 to calculate the speed of the transverse waves on the string.speed = .......................................... m s−1  [3]  |

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**Wave properties and using oscilloscopes**

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| 3(a). | A loudspeaker emits a sound wave. A microphone is connected to an oscilloscope. The trace produced on the screen of the oscilloscope due to the sound wave is shown in Fig. 1.**Fig. 1**The vertical y-sensitivity of the oscilloscope is set to 10 mV div−1 and the horizontal time-base is set to 0.50 ms div−1.* 1. Determine the amplitude of the signal displayed on the oscilloscope.

amplitude = ........................................................... mV **[1]**1. The frequency f of the sound wave is the same as the frequency of the signal shown in Fig. 1. Determine f.

f = ........................................................... Hz **[2]**1. The speed of sound in air is 330 m s−1. Calculate the wavelength λ of the sound wave.λ = ........................................................... m **[1]**

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|   (b). | The output from the loudspeaker is adjusted so that the **intensity** of the sound wave at the microphone is a quarter of its original value. The controls on the oscilloscope are not altered.Describe and explain how the signal displayed on the oscilloscope will be different from Fig. 1.   **[2]**  |

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| 4. | A sound wave is an example of a longitudinal wave.1. State what is meant by the term **longitudinal** wave.

**[1]**1. A microphone is connected to an oscilloscope. Sound of frequency 500 Hz is incident on the microphone.The oscilloscope time-base is set to 0.5 ms cm−1 and the y-gain set to 1.0 mV cm−1.The signal displayed on the oscilloscope screen has an amplitude of 2.0 mV.The oscilloscope grid is shown below.

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| Sketch the oscilloscope trace on the grid above. | **[2]** |

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**Properties of electromagnetic waves**

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| 5. | State **two** properties which distinguish electromagnetic waves from other transverse waves.  **[2]**  |

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| 6. |  Radio waves and X–rays are both electromagnetic waves.State one difference between radio waves and X–rays. **[1]**  |

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| 7. | Microwaves and X-rays are examples of electromagnetic waves.1. The following are possible wavelengths of electromagnetic waves.0.2 km     2 m     2 cm     0.2 mm     2 µm     200 nm     200 pmSelect from the list above a typical wavelength of a microwave and an X-ray.

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| microwave |  |

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| X-ray |  |
| **[2]** |

1. One property of electromagnetic waves is that they are transverse waves.State **two** other properties.

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| 1. |  |
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| 2. |  |
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| **[2]** |

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  **Reflection, refraction, Snell’s Law and total internal reflection**

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| 8(a). | The table shows the refractive index n of air and glass for blue light. It also shows the speed v and the wavelength λ of blue light in air.

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|  | **Air** | **glass** |
| refractive index n | 1.00 | 1.53 |
| speed of light v / m s−1 | 3.00 × 108 |  |
| wavelength λ/m | 4.69 × 10−7 |  |

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1. Show that the frequency f of blue light in air is 6.40 × 1014 Hz.

**[1]**1. Complete the table by determining the missing values for v and λ for glass. Write your answers to 3 significant figures.

**[2]** |

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|   (b). | A semi-circular block of glass is placed in air.**Fig. 2.1** shows the path of blue light through the air and the semi-circular glass block.

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| **Fig. 2.1** (not to scale) |  |

1. The angle i is 30°.1. Determine angle p.

p = ............................................................ ° **[1]**2. Determine angle q, using the information from the table in **(a)**.q = ............................................................ ° **[2]**1. The angle i is increased from 30° to 60°.Describe and explain how angles p and q will change. In your answer, include the term **critical angle**.

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|   (c). | **Fig. 2.2** shows a semi-circular glass block with the blue light replaced by red light.

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| **Fig. 2.2** (not to scale) |  |

The dashed lines show the original paths of the blue light.

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| Draw on **Fig. 2.2** the path of the red light in the glass block and out of the glass block. | **[2]** |

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| 9. |  A student is given a semi-circular glass block.Describe with the aid of a ray diagram how an experiment can be conducted to accurately determine the critical angle for light within the glass block and hence the refractive index of the glass.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ **[3]**  |

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**Polarisation**

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| 10. | 1. Describe what is meant by a plane polarised wave.

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Explain why the lamp cannot be seen by the eye.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**[2]**1. A third polarising filter is placed between the first two with its transmission axis at 45° to each of the others as shown in Fig. 6.2.

Explain whether or not any light reaches the eye through the three filters.In your answer you should state clearly the condition for light to be transmitted by a polarising filter.   \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**[3]** |

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| 11. | A narrow beam of unpolarised light is incident at the boundary between air and glass.Fig. 18 shows the incident ray, the reflected ray and the refracted ray at the air-glass boundary.**Fig. 18 (not to scale)**The refractive index of air is 1.00 and the refractive index of the glass is 1.50.The angle of incidence of the light is 56.3°.Describe how you can demonstrate in the laboratory that reflected light is plane polarised.\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**[2]**  |

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| 12. | Which of the following waves can be polarised and has a typical wavelength of about a few centimetres?

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| **A** | microwaves |
| **B** | ultraviolet |
| **C** | sound |
| **D** | visible light |

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| Your answer |  | **[1]** |

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**Superposition and interference**

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| **1(a).** | State what is meant by coherent waves.  **[1]**  |

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| **(b).** | Two transverse waves **P** and **Q** can pass through a point **X**. **Fig. 25.1** shows the displacement-time graphs of a particle at point **X** for each wave independently.State, with a reason, the motion of the particle at point **X** when both waves are present.  **[2]**  |

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 **Diffraction of waves and two source interference**

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| **2.** | At an open air concert two loudspeakers are placed 5.0 m apart at the front of a stage and are sounding a note of frequency 1200 Hz. A row of seats is 30 m from the stage and parallel to it.Describe and explain, as precisely as possible, what different people along this row will hear. You must include calculations in your answer. The speed of sound in air is 330 m s−1.    **[4]**  |

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| **3.** | Fig. 5.1 shows two microwave transmitters **A** and **B** 0.20 m apart. The transmitters emit microwaves of frequency 10 GHz, of equal amplitude and in phase. A microwave detector is placed at **O** a distance of 4.0 m from **AB**.* 1. Explain why the amplitude of the detected signal changes when the detector is moved in the direction **OP**.

   **[2]*** 1. Calculate the distance between adjacent **maximum** and **minimum** signals.

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| distance = ........................................................... m **[2]** |

1. Explain why the amplitude of the detected signal changes when the detector is moved in the direction **OQ**.

  **[2]**1. Explain why the amplitude of the detected signal decreases to a minimum before increasing again as transmitter **A** is moved a small distance in the direction **AR** with the detector fixed at **O**. Calculate the distance **A** is moved to cause this minimum signal at **O**.

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| distance = ........................................................... m **[2]** |

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 **Youngs double slit experiment**

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| **4.** | This question is about the brightest wavelength (590 nm) of light from a sodium lamp.\*A student is to measure this wavelength by the double-slit method. The lamp, a single slit, a double slit and a clear glass screen are to be set up perpendicular to a common centre line as shown in Fig. 4.A pattern of bright and dark fringes should then be observable through the screen. The screen has millimetre rulings along it. The slit separation a is about 0.5 mm and can be measured using a travelling microscope, having a vernier scale to 0.05 mm. The student is also given two 1 metre rulers and a magnifying glass.The measurements required to calculate the wavelength in the experiment are a, D and y on Fig. 4.* Explain how the student measures D and y using the apparatus provided.
* State the uncertainty expected in each measurement and how each could be minimised.
* Estimate the uncertainty in the measured value of the wavelength.

                **[6]**  |

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| **5(a).** |  State the principle of superposition of waves.  **[1]**  |

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| **(b).** | Fig. 16.1 shows an arrangement to demonstrate the interference of monochromatic light.**Fig. 16.1**Coherent blue light from a laser is incident at a double-slit. The separation between the slits is 0.25 mm. A series of dark and bright lines (fringes) appear on the screen. The screen is 4.25 m from the slits.Fig. 16.2 shows the dark and bright fringes observed on the screen.**Fig. 16.2**The pattern shown in Fig. 16.2 is **drawn to scale**.1. Use Fig. 16.2 to determine accurately the wavelength of the blue light from the laser.

wavelength = ......................................... m **[3]**1. The blue light is now replaced by a similar beam of red light.State and explain the effect, if any, on the fringes observed on the screen.

   **[2]**  |

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 **Stationary versus progressive waves**

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| **6.** | Fig. 4.2 shows a section of string held under tension between a clamp and a pulley, 80 cm apart. A mechanical oscillator is attached to the string close to the clamped end. The frequency of the mechanical oscillator is varied until the stationary wave shown is set up between the clamp and the pulley. The same four points as in Fig. 4.1 are marked on the string.1. Describe how a stationary wave is different from a progressive wave.

    **[2]**1. Explain how the stationary wave is formed on this string.

     **[3]**1. Describe, using the terms amplitude, frequency and phase difference, how the motions of the points **P**, **Q** and **S**
	1. are similar,

  * 1. are different.

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|  **[3]** |

1. In Fig. 4.2 the frequency of oscillation is 30 Hz. State, with a reason, the lowest frequency of oscillation of the string at which the motions of all of the points **P**, **Q**, **R** and **S** are
	1. in phase,

  * 1. all at rest.

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| --- |
| **[4]** |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  **Speed of sound**

|  |  |
| --- | --- |
|  |  |
| **7.** | The speed of sound in air can be determined by forming stationary waves in the laboratory. Fig. 24.1 shows an arrangement used by a student to determine the speed of sound v.

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| --- |
| **Fig. 24.1** |

A loudspeaker is placed in front of a smooth vertical wall in the laboratory. The loudspeaker is connected to a signal generator.**Stationary waves** of frequency f are formed in the space between the wall and the loudspeaker.A microphone is used to determine the mean separation L between adjacent nodes.Fig. 24.2 shows the data plotted by the student.

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| --- |
| **Fig. 24.2** |

* 1. Draw a straight line of best fit and determine the gradient of this line.

|  |
| --- |
| gradient = ................................................ Hzm **[2]** |

* 1. Explain why the gradient of the line is , where v is the speed of sound.

**[2]*** 1. Use your answer in part **(i)** and the information given in **(ii)** to determine v.

|  |
| --- |
| v = ................................................ m s–1**[1]** |

1. The smaller values of L are much more difficult to determine with the microphone in this experiment and this produces large percentage uncertainty in the values of .Suggest how this percentage uncertainty may be reduced in this experiment.

**[2]** |

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|  |

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| --- | --- |
|  |  |
| **8.** | A student is investigating stationary waves in a hollow tube. The tube is open at one end and closed at the other end. The student connects a signal generator to a loudspeaker which is placed just above the tube as shown in Fig. 6.**Fig. 6**The length of the tube is 65.0 cm.As the frequency of the signal generator is slowly increased from 0 Hz the student observes sound that varies in loudness. The loudest sound occurs at frequencies 130 Hz, 390 Hz and 650 Hz.The experiment is then repeated with a hollow tube of the **same** length but open at both ends. The loudest sound now occurs at frequencies 260 Hz, 520 Hz and 780 Hz.Using your knowledge and understanding of stationary waves explain these observations. Include in your answer how you could determine an experimental value for the speed of sound in air.                 **[6]**  |

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