

OCR A-LEVEL PHYSICS A • H556

PHYSICS



EXAM QUESTION PACK

4.4 WAVES

SCORE

/235

PERCENTAGE

%

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- 1 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.

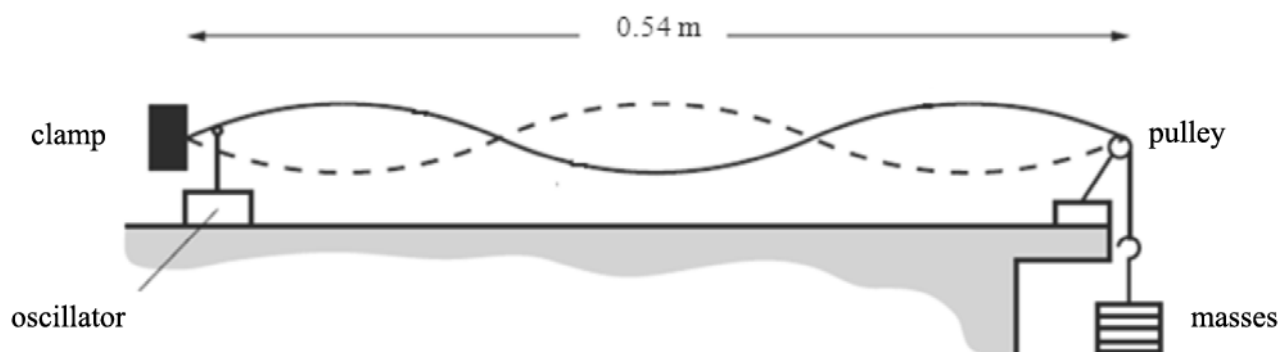


Fig. 18.1

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]

- 2(a) A patient has an X-ray scan taken in hospital. The high-energy X-ray photons interact with the atoms inside the body of the patient.

Explain what is meant by a *photon* and state **one** of its main properties.

----- [2]

- (b) An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

- (i) Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16} \text{ s}^{-1}$.

[1]

- (ii) The anode is made from metal of specific heat capacity $140 \text{ J kg}^{-1} \text{ K}^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = _____ $^{\circ}\text{C s}^{-1}$ [3]

- (iii) A single electron is responsible for producing an X-ray photon. Calculate the shortest wavelength of the X-rays produced from the X-ray tube.

wavelength = _____ m [2]

- 3(a) 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.

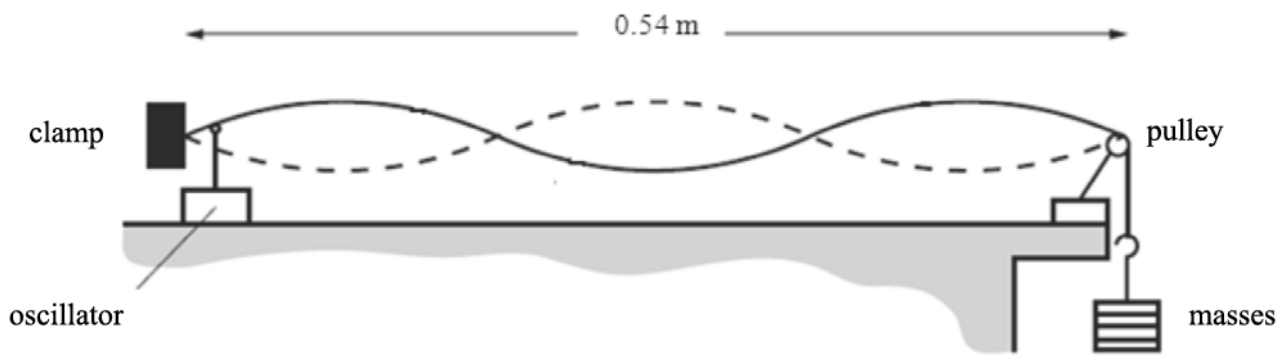


Fig. 18.1

Explain how the stationary wave is formed on this stretched string.

[2]

- (b) The speed v of the transverse waves on the string is directly proportional to $\sqrt{T}$, where T is the tension in the string.

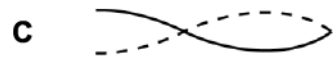
The tension T in the string is increased by 14 %. The frequency f of the oscillator is adjusted to get the same stationary wave pattern as Fig. 18.1.

Calculate the percentage increase in the frequency f .

increase = ----- % [2]

4 A student blows across the open end of an empty bottle.

Which diagram shows a possible stationary wave pattern for this bottle?



Your answer

[1]

$i / ^\circ + 0.5^\circ$	10	20	30	40	50	60	70	80
$r / ^\circ \pm 0.5^\circ$	6	13	20	25	31	35	39	41



Discuss how you could use the data from the table to graphically determine a value for the refractive index of glass.

[6]

(b) Fig.17 shows a ray of light at the boundary between glass and water.

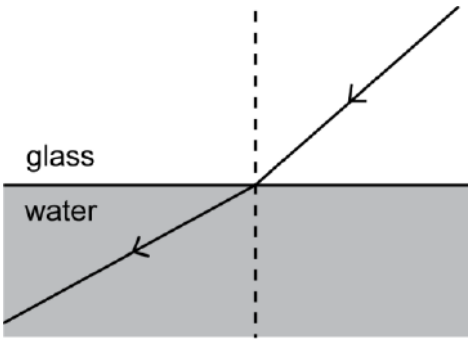


Fig. 17 (not to scale)

Use Fig. 17 to describe and explain how the wavelength of the light changes as light travels from glass to water.

[3]

6(a) State the meaning of *coherence*.

[1]

(b) Fig. 18 shows a loudspeaker placed in front of two narrow slits in a metal plate.

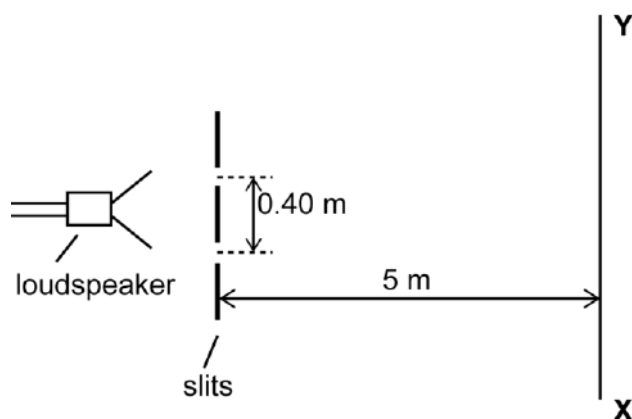


Fig. 18

The loudspeaker emits sound waves of frequency 2.8 kHz. The separation between the centres of the narrow slits is 0.40 m.

A microphone, moved along the line XY at a distance of 5.0 m from the slits, detects regions of low and high intensity sound.

The separation between adjacent regions of low and high intensity sound is 0.75 m.

- (i) Explain how you can use an oscilloscope set to a time-base of 0.1 ms div^{-1} to check that the frequency of sound is 2.8 kHz.

[3]

- (ii) Explain how the arrangement shown in Fig. 18 produces an interference pattern along the line XY.

----- [4]

(iii) Calculate the wavelength of sound.

wavelength = ----- m [3]

(iv) Calculate the speed of sound.

speed = ----- m s⁻¹ [1]

(v) State and explain the effect, if any, on the position and the intensity of the maxima when the amplitude of the transmitted waves is halved.

----- [3]

- 7(a) Some students are asked to use the laboratory 28 mm microwave transmitter **T** and receiver **R** apparatus to design a demonstration to illustrate the principle of a radar speed measuring device.

In Fig. 3.1, a movable hardboard sheet **H**, which is a partial reflector of microwaves, is placed in front of the metal sheet **M**, which is fixed.

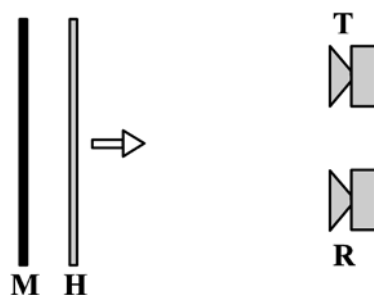


Fig. 3.1

The students expect the detected signal to change between maximum and minimum intensity when sheet H moves a distance of 7 mm towards the receiver.

When the detected signal is passed through an audio amplifier to a loudspeaker a sound should be heard. They claim that when the sheet moves at 2.8 m s^{-1} the frequency heard should be 200 Hz. You are to evaluate whether their experiment is feasible and whether their conclusions are correct.

- (i) Explain why the detected signal strength should vary and discuss what factors will determine whether the difference between maxima and minima can be detected.

[6]

- (ii) Justify the students' predictions of 7 mm between maxima and minima and a sound at 200 Hz for a speed of

2.8 m s^{-1} .

[3]

- (b) A police speed detector gun works by a different principle. Two short pulses of electromagnetic radiation, a time t_0 apart, are 'fired' at the front of the vehicle which is moving directly towards the gun. The reflected pulses are received at a time t apart. A digital readout on the top of the gun displays the speed of the vehicle.

In the space below, by considering how far the vehicle moves in time t_0 , show that the speed of the vehicle is given by the expression

$$v = \frac{c(t_0 - t)}{2t_0}$$

where c is the speed of light.

[3]

- 8 An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

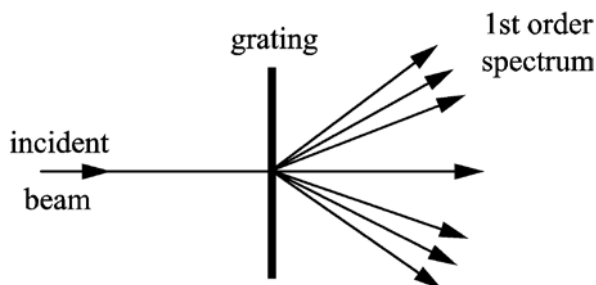


Fig. 6.1

These three emission lines all arise from transitions to the same final energy level. The part of the energy level diagram of hydrogen relevant to these transitions is shown in Fig. 6.2.

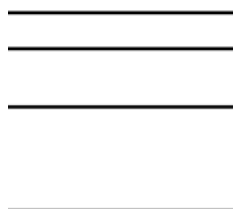


Fig. 6.2

- (i) Draw lines between the energy levels to indicate the transitions which cause the three emission lines and label them with their wavelengths.

[1]

- (ii) There are other possible transitions between the energy levels shown in Fig. 6.2. The least energetic of these produces photons of 4.8×10^{-20} J.

Calculate the wavelength of these photons.

State in which region of the electromagnetic spectrum this wavelength is found.

wavelength _____ m

region: _____

[3]

- 9(a) Fig. 5.1 shows a horizontal copper wire placed between the opposite poles of a permanent magnet. The wire is held in tension T by the clamps at each end. The length of the wire in the magnetic field of flux density 0.032 tesla is 6.0 cm.

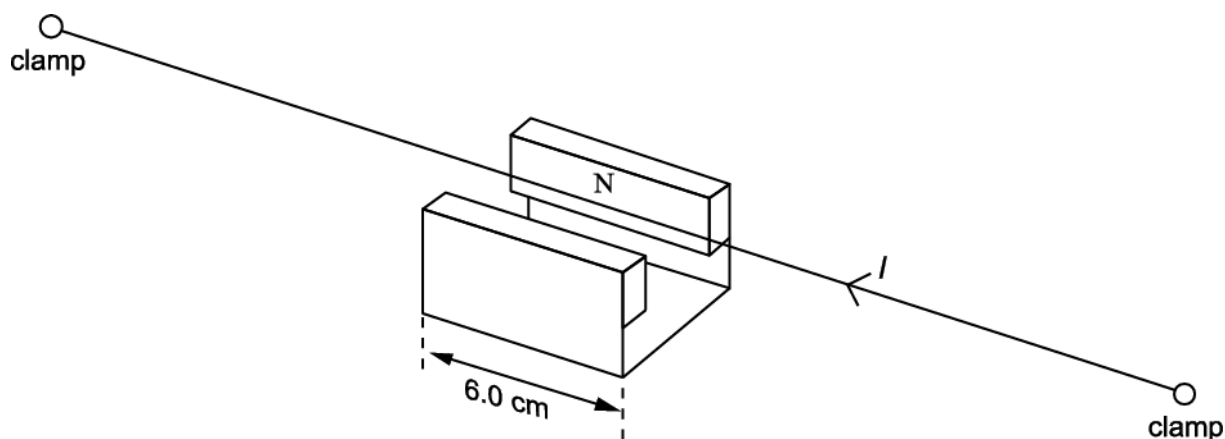


Fig. 5.1

The direct current is changed to an alternating current of constant amplitude and variable frequency, causing the wire to oscillate. The frequency of the current is increased until the fundamental natural frequency of the wire is found as shown in Fig. 5.2. This is 70 Hz.

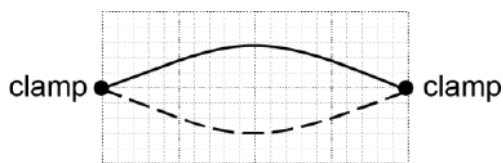


Fig. 5.2

- (i) In the situation shown in Fig. 5.2 the amplitude of the oscillation of the centre point of the wire is 4.0 mm. Calculate the maximum acceleration of the wire at this point.

maximum acceleration = _____ m s^{-2} [2]

- (ii) The frequency is increased until another stationary wave pattern occurs. The amplitude of this stationary wave is much smaller.

1 Sketch this pattern on Fig. 5.3 and state the frequency

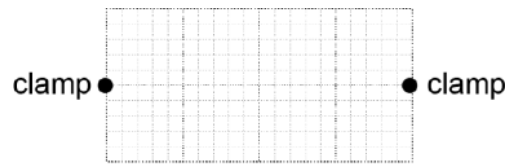


Fig. 5.3

frequency = _____ Hz [1]

- 2 Explain why the amplitude is so small. Suggest how the experiment can be modified to increase the amplitude.

----- [3]

(b)

The speed v of a transverse wave along the wire is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension and μ is the mass per unit length of the wire.

- (i) Assume that both the length and mass per unit length remain constant when the tension in the wire is halved. Calculate the frequency of the new fundamental mode of vibration of the wire.

frequency = _____ Hz [1]

- (ii) In practice the mass per unit length changes because the wire contracts when the tension is reduced. For the situation in which the tension is halved the strain reduction is found to be 0.4%.

- 1 Calculate the percentage change in μ . State both the size and sign of the change.

percentage change in μ = _____ % [1]

- 2 Write down the percentage error this causes in your answer to (i). State, giving your reasoning, whether the actual frequency would be higher or lower than your value.

----- [2]

10(a) In Fig. 18.1 the solid line represents the displacement s against distance x graph for a **progressive** transverse wave on a stretched string at time $t = 0$. The dotted line shows the graph for the same wave at a later time $t = 2.5$ ms.

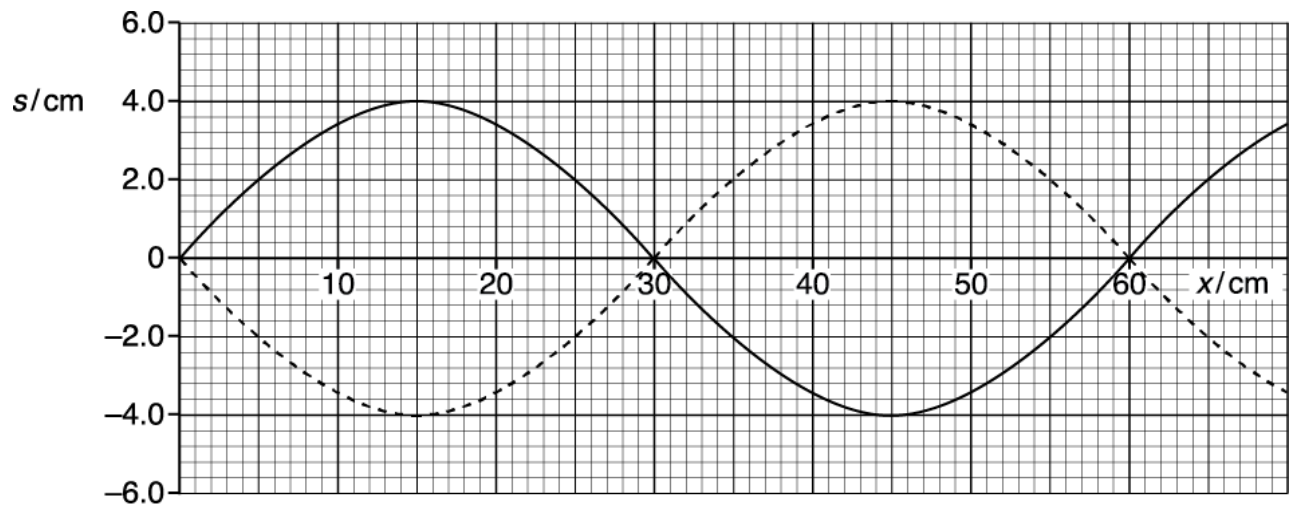


Fig. 18.1

Determine the frequency f of this wave.

$f =$ _____ Hz [3]

(b) *Fig. 18.2 shows an arrangement used to investigate **stationary** sound waves in a tube closed at one end.

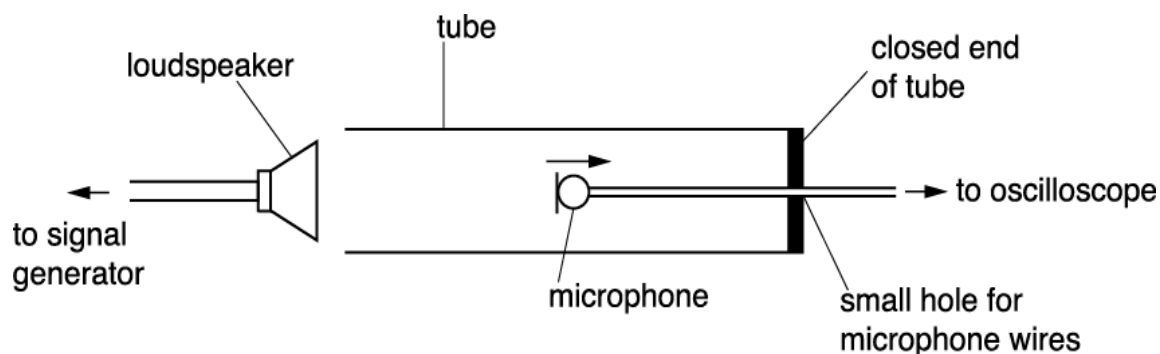


Fig. 18.2

A loudspeaker is placed at the open end of the tube. The loudspeaker emits sound of constant frequency. A small microphone is placed inside the tube. The microphone is connected to an oscilloscope. The microphone is slowly moved from the open end of the tube towards its closed end. The signal detected by the microphone shows regions of maximum and minimum intensity of sound. The distance between adjacent positions of maximum signal is 0.26 m.

Fig. 18.3 shows the signal displayed on the oscilloscope when the output signal from the microphone is maximum. The time-base on the oscilloscope is set at 0.50 ms div^{-1} .

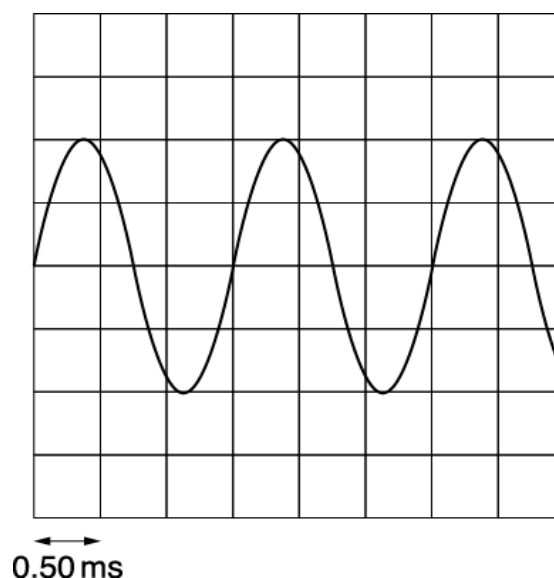


Fig. 18.3

[6]

[6]

11 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.

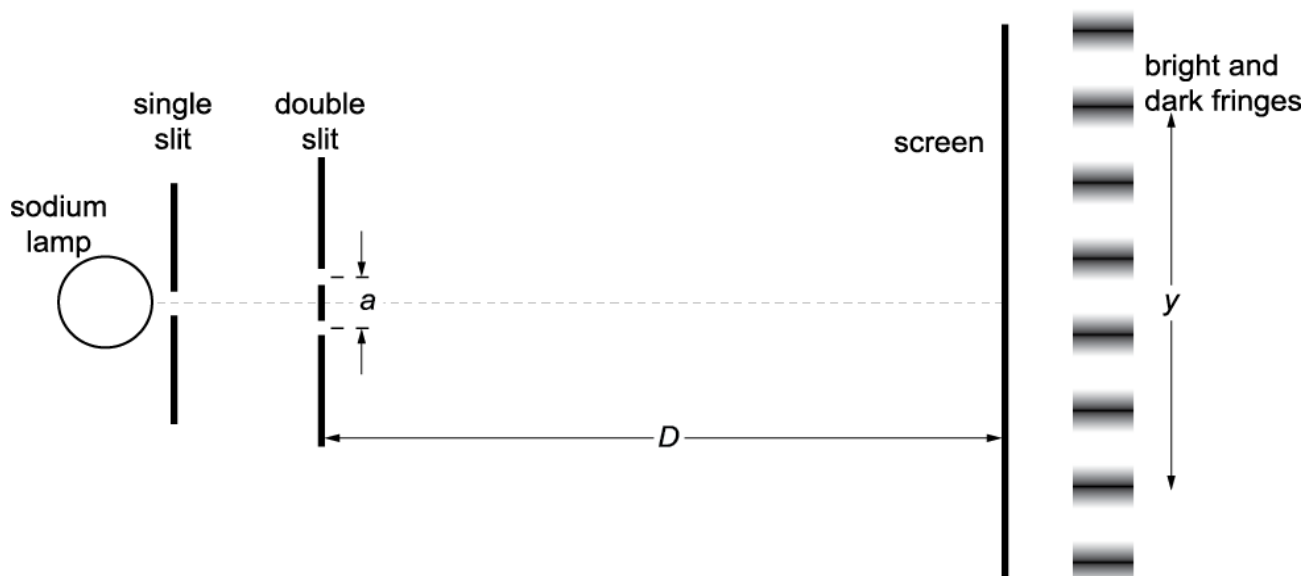


Fig. 4 (not to scale)

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]

12 A grain of a radioactive powder which emits gamma rays accidentally falls onto the workbench.

A sensitive gamma-ray detector is used to look for this grain. The grain can be assumed to be a point source which emits radiation **uniformly in all directions**.

The background count-rate before the accident was negligible.

The detector registers a count-rate of 20 s^{-1} when it is 1.0 m from the grain.

(i) Explain why the count-rate rises to 320 s^{-1} when the detector is moved to 0.25 m from the grain.

----- [2]

(ii) A thin lead sheet is now placed on the bench over the grain. This causes the count-rate to halve to 160 s^{-1} . The detector is moved from its position at 0.25 m towards the grain until the count-rate returns to 320 s^{-1} .

1 State the value of the count-rate if the sheet is now removed.

count-rate = _____ s^{-1} [1]

2 Calculate the distance of the detector from the grain.

distance = _____ m [2]

13(a) Lasers are often used to form precision-welded joints in titanium. To form one such joint it is first necessary to increase the temperature of the titanium to its melting point. Fig. 5.1 shows the joint and the volume of titanium to be heated.

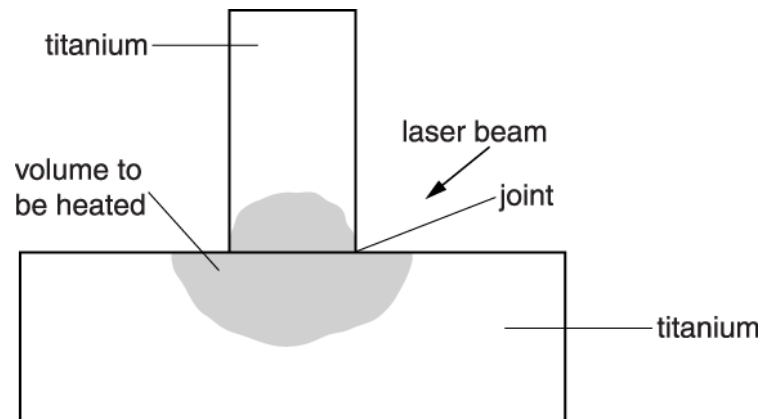


Fig. 5.1

The photon beam from the laser is focused onto the shaded volume of the joint and is converted into thermal energy in the titanium.

The wavelength of the photons is 1.1×10^{-6} m.

Show that the energy of a photon in the beam is 1.8×10^{-19} J.

[1]

- (b) Photons are emitted from the laser at a constant rate of $6.3 \times 10^{19} \text{ s}^{-1}$.

Estimate the time taken to raise the temperature of the shaded volume of titanium shown in Fig. 5.1 to melting point. Use the data below for your calculations.

initial temperature = $20 \text{ }^{\circ}\text{C}$

melting point of titanium = $1700 \text{ }^{\circ}\text{C}$

density of titanium = $4.5 \times 10^3 \text{ kg m}^{-3}$

specific heat capacity of titanium = $520 \text{ J kg}^{-1} \text{ K}^{-1}$

shaded volume of titanium being heated = $8.1 \times 10^{-12} \text{ m}^3$.

time = _____ s [3]

- (c) In practice it takes a longer time to reach the melting point.
State and explain **two** factors that will increase the time taken.

----- [2]

- (d) To complete the weld more photons must be focused onto the joint. During this final stage the temperature remains constant. Explain why this is to be expected.

----- [1]

- 14 A progressive wave of amplitude a has intensity I . This wave combines with another wave of amplitude $0.6a$ at a point in space. The phase difference between the waves is 180° .

What is the resultant intensity of the combined waves in terms of I ?

- A $0.16 I$
- B $0.4 I$
- C $1.6 I$
- D $2.6 I$

Your answer

[1]

- 15 Stationary waves are produced in a tube closed at one end and open at the other end. The fundamental frequency is 120 Hz.

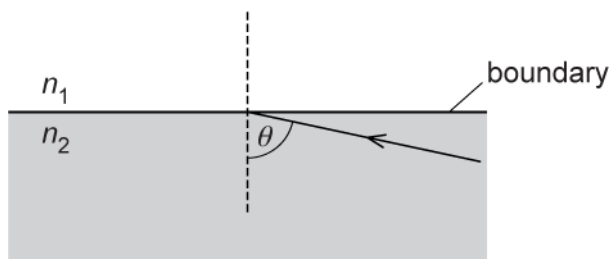
What is a possible frequency of a harmonic for this tube?

- A 60 Hz
- B 240 Hz
- C 360 Hz
- D 480 Hz

Your answer

[1]

- 16 A ray of monochromatic light is incident at the boundary between two transparent materials of refractive index n_1 and n_2 . The critical angle θ is equal to 80° .



What is the ratio $\frac{n_1}{n_2}$?

- A 0.17
- B 0.98
- C 1.02
- D 5.76

Your answer

[1]

17(a)

State the *principle of superposition* of waves.

[1]

(b) Fig. 16.1 shows an arrangement to demonstrate the interference of monochromatic light.

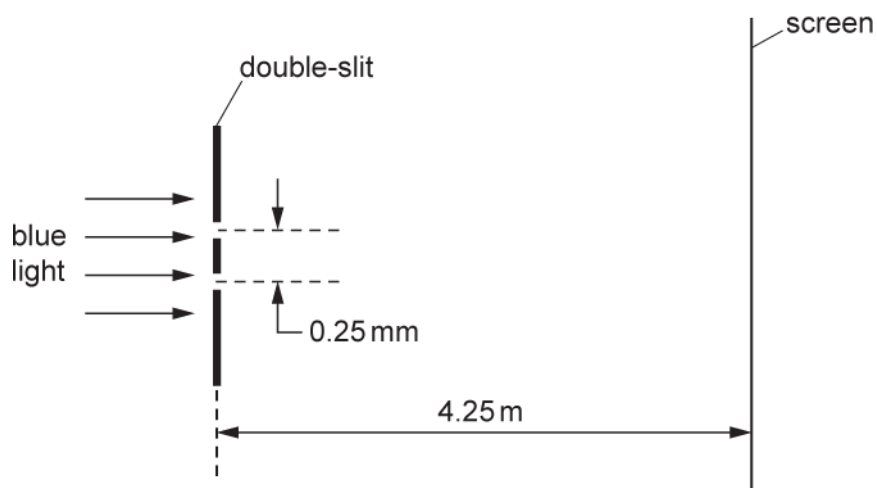


Fig. 16.1

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.

(i) Use Fig. 16.2 to determine accurately the wavelength of the blue light from the laser.

wavelength = _____ m [3]

(ii) 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]

18(a)

Electromagnetic radiation is incident on a negatively charged zinc plate. Electrons are emitted from the surface of the plate when a weak intensity ultraviolet source is used. Electrons are not emitted at all when an intense visible light from a lamp is used.

Explain these observations.

[4]

- (b) The **maximum** wavelength of the electromagnetic radiation incident on the surface of a metal which causes electrons to be emitted is 2.9×10^{-7} m.

Calculate the maximum kinetic energy of electrons emitted from the surface of the metal when each incident photon has energy of 5.1 eV.

maximum kinetic energy = ... J [3]

- (c) Electromagnetic radiation of constant wavelength is incident on a metal plate. Photoelectrons are emitted from the metal plate. Fig. 19.1 shows an arrangement used to determine the maximum kinetic energy of electrons emitted from a metal plate.

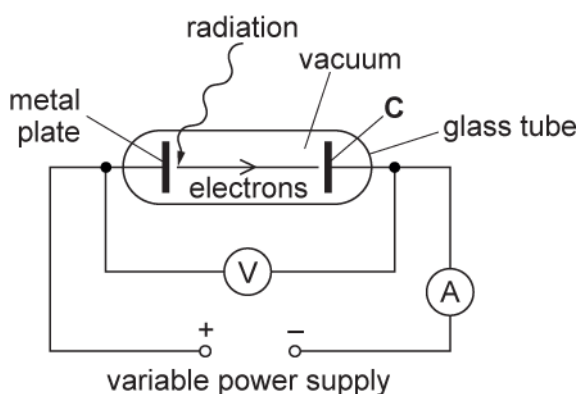


Fig. 19.1

The metal plate and the electrode C are both in a vacuum. The electrode C is connected to the negative terminal of the variable power supply.

Fig. 19.2 shows the variation of current I in the circuit as the potential difference V between the metal plate and C is increased from 0 V to 3.0 V.

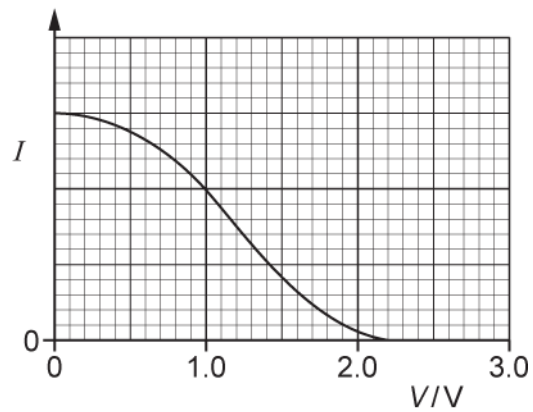


Fig. 19.2

Explain why the current decreases as V increases and describe how you can determine the maximum kinetic energy of the emitted electrons.

[3]

19(a)

A loudspeaker mounted on a bench is emitting sound of frequency 1.7 kHz to a microphone. Fig. 5.1 shows an illustration of the bulk movement of the air at one instant of time.



Fig. 5.1

The maximum displacement of the air particles from their mean positions is 2.0×10^{-6} m.

The speed of sound in air at 17 °C is 340 m s^{-1} .

(i) On Fig. 5.2, sketch the sinusoidal variation of the displacement of the air with distance between C and R.

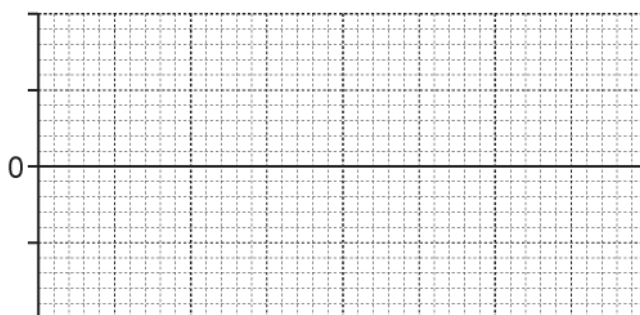


Fig. 5.2

- 1 Label the axes and include sensible scales.
- 2 On Fig. 5.2, mark one point where air particles are moving at maximum speed. Label it X.
- 3 On Fig. 5.2, mark one point where air particles are moving at maximum speed but travelling in the opposite direction to the air particles in 2. Label it Y.

[4]

(ii) Calculate

1 the maximum speed $v_{\max}$ of the oscillating particles in the sound wave

$$v_{\max} = \text{-----} \text{ m s}^{-1} [2]$$

2 the root mean square speed c of the air molecules in the room.

The molar mass of air is $2.9 \times 10^{-2} \text{ kg mol}^{-1}$.

$$c = \text{-----} \text{ m s}^{-1} [2]$$

(b)



Students are given the equipment in Fig. 5.1 together with a metre rule. They are also given a second loudspeaker connected to the same signal generator at 1.7 kHz. They are asked to design an experiment where they would need to take just **one** measurement and be able to determine the value of the speed of sound.

They set up the experiment in two different ways as shown in Fig. 5.3(a) and (b).

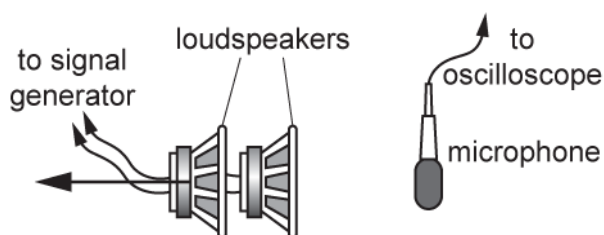
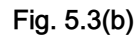


Fig. 5.3(a)



In method **(b)** the microphone is moved to the left or to the right with the loudspeakers fixed a certain distance apart as shown in Fig. 5.3(b).

[6]

This image shows a blank sheet of white paper with ten horizontal dashed lines, typical of primary-ruled notebook paper. The lines are evenly spaced and extend across the width of the page. There is no handwriting or other markings on the paper.

20 Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.

A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

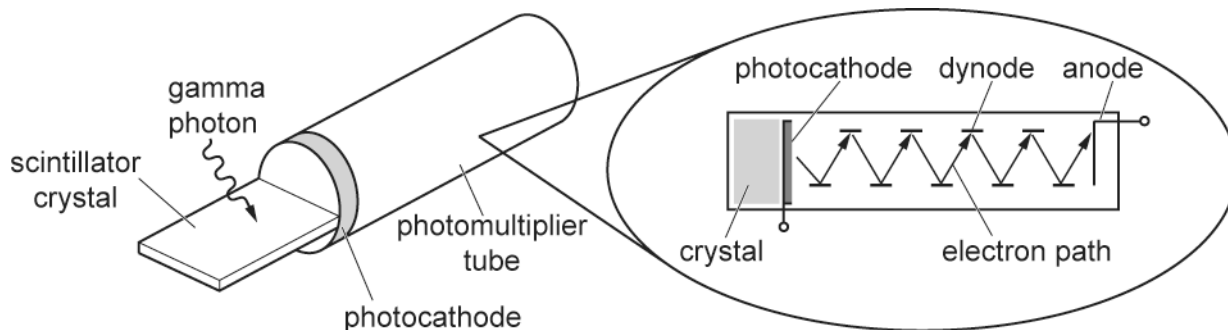


Fig. 6.1

Fig. 6.2 shows a section through the scintillator crystal in air.

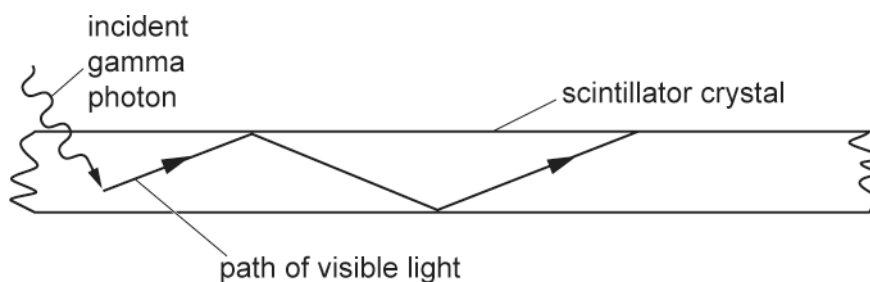


Fig. 6.2

- (i) The refractive index of the scintillator crystal for visible light is 1.69. The refractive index of air is 1.00. Calculate the critical angle C for this crystal.

$C = \text{-----}^\circ$ [2]

(ii) Explain why the visible light inside the scintillator crystal follows the path shown in Fig. 6.2.

[2]

21 An electron has a de Broglie wavelength equal to the wavelength of X-rays.

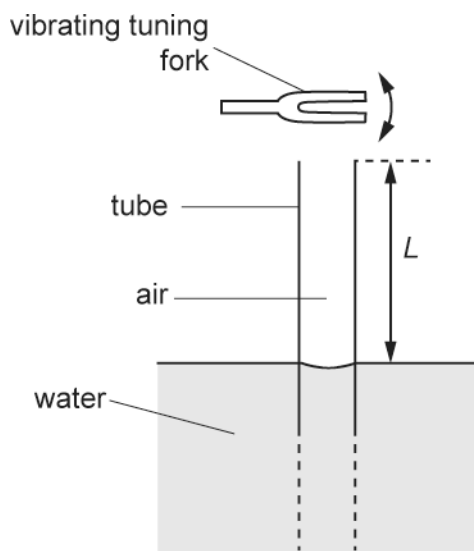
What is the **best** estimate of the momentum of this electron?

- A $10^{-30} \text{ kg m s}^{-1}$
- B $10^{-27} \text{ kg m s}^{-1}$
- C $10^{-23} \text{ kg m s}^{-1}$
- D $10^{-18} \text{ kg m s}^{-1}$

Your answer

[1]

- 22 A vibrating tuning fork is held above the open end of a long vertical tube. The other end of the tube, which is also open, is immersed in a tank of water. The length L of the air column within the tube is changed by raising or lowering the tube.



The wavelength of sound from the vibrating tuning fork is 150.0 cm.

What length L of air column will **not** produce a stationary wave within the tube?

- A 37.5 cm
- B 75.0 cm
- C 112.5 cm
- D 187.5 cm

Your answer

[1]

- 23 A small loudspeaker emits sound uniformly in all directions.
The amplitude of the sound is $12\ \mu\text{m}$ at a distance of 1.5 m from the loudspeaker.

What is the amplitude of the sound at a distance of 4.5 m from the loudspeaker?

- A $1.3\ \mu\text{m}$
- B $4.0\ \mu\text{m}$
- C $6.9\ \mu\text{m}$
- D $12\ \mu\text{m}$

Your answer

[1]

24(a)

Fig. 19.1 shows the image from an experiment using a ripple tank.

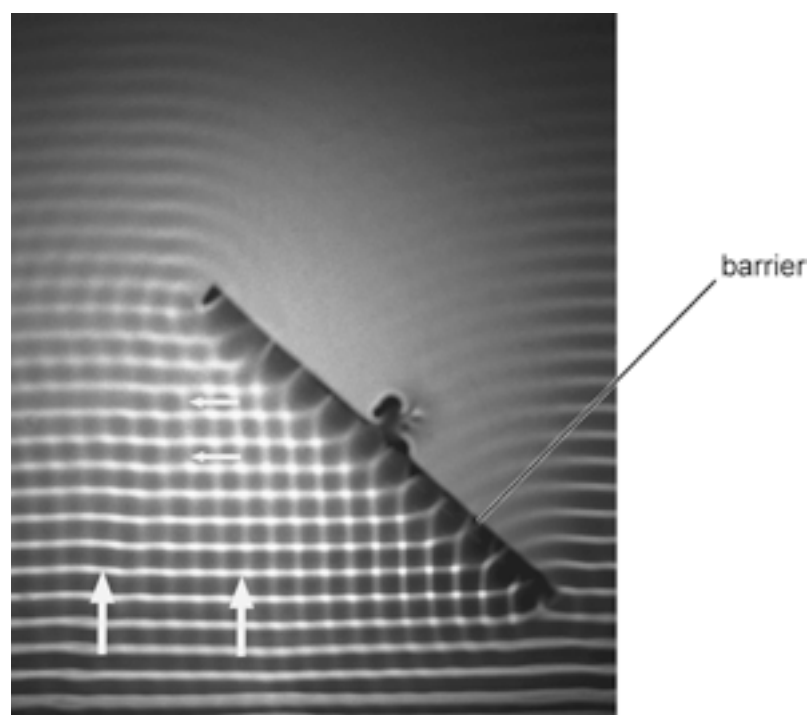


Fig. 19.1

A straight ruler repeatedly hits the surface of water. Waves on the surface of the water travel in the direction shown by the two large upward white arrows. The waves are incident at a solid barrier.

Closely examine the image shown in Fig. 19.1.

State **two** wave phenomena (properties) that can be observed in this image. You may annotate Fig. 19.1 to support your answer.

[2]

- along the line from P to Q which is parallel to the line joining the two transmitters, as shown in Fig. 19.2.

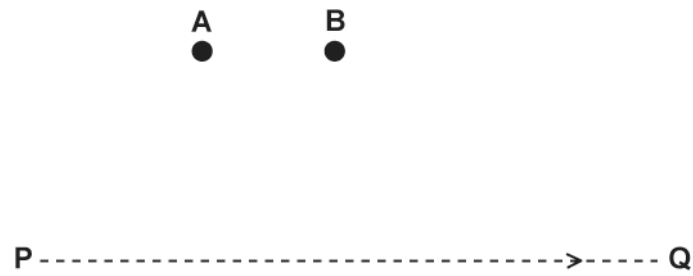


Fig. 19.2

Explain why the output signal from the receiver fluctuates between minimum and maximum values as the receiver moves from P to Q.

[3]

25(a) 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.

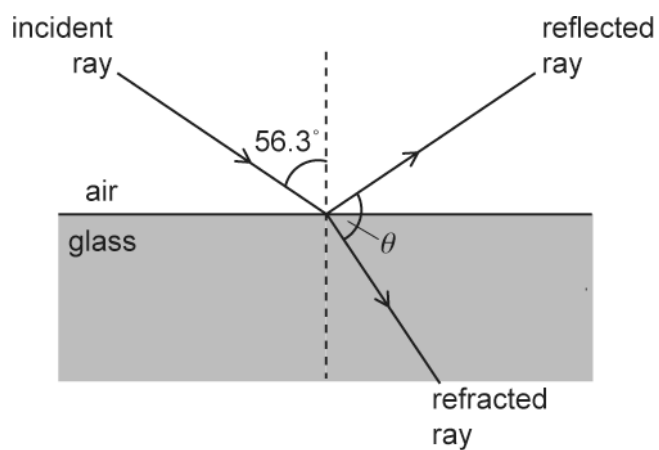


Fig. 18 (not to scale)

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° .

Show that the angle θ between the refracted ray in the glass and the reflected ray in the air is 90.0° .

[3]

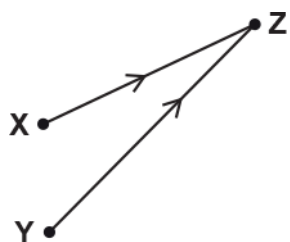
(b) Describe how you can demonstrate in the laboratory that the reflected light is plane polarised.

[2]

(c) Calculate the time t taken for the refracted light to travel a depth of 6.0 cm of glass.

$$t = \text{-----} \text{ s [2]}$$

- 26 Coherent radio waves from transmitters **X** and **Y** are emitted in phase. The waves interfere **constructively** at point **Z**.



The distance **XZ** is 16.0 m and the distance **YZ** is 20.0 m.
The radio waves have wavelength λ .

Which value of λ is not possible?

- A 1.0 m
- B 2.0 m
- C 3.0 m
- D 4.0 m

Your answer

[1]

27 Which of the following statements is/are correct about electromagnetic waves?

- 1 They can be plane polarised.
- 2 They can be refracted and diffracted.
- 3 They have the same speed in a vacuum and in glass.

- A Only 1
- B Only 3
- C Only 1 and 2
- D 1, 2 and 3

Your answer

[1]

28(a) This question is about waves.

The **period** of a progressive wave can be determined from Fig. 16.1. Add a correct label to the horizontal axis so that the period can be found.

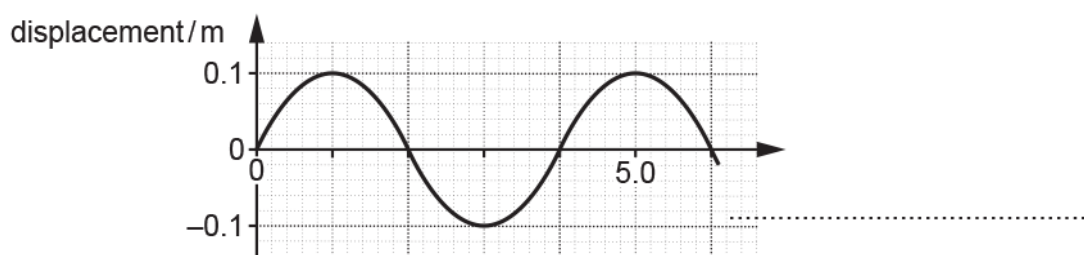


Fig. 16.1

[1]

- (b) A progressive wave has wavelength λ , frequency f and period T .

Show that the speed v of the wave is given by the equation $v = f\lambda$.

[2]

- (c) A scientist is investigating the interference of light using very thin transparent material. A sample of the transparent material is placed in a vacuum. Fig. 16.2 shows the path of two identical rays of light L and M from a laser.

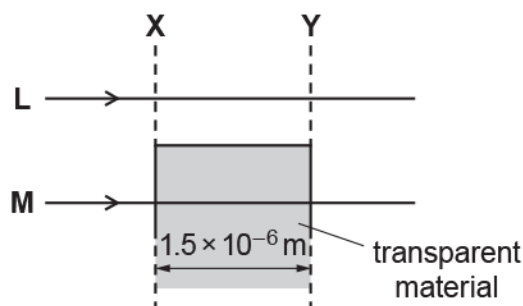


Fig. 16.2

The refractive index of the material is 1.20. The thickness of the material is 1.5×10^{-6} m. The wavelength of the light in vacuum is 6.0×10^{-7} m.

- (i) Show that the difference in time t for the two rays to travel between the dashed lines X and Y is 1.0×10^{-15} s.

$t = \dots\dots\dots$ s [3]

(ii) Calculate the period T of the light wave.

$t = \dots\dots\dots$ s [2]

(iii) The rays of light are in phase at the dashed line X.

Use your two answers above to state the phase difference ϕ in degrees between the light rays at Y.

$\phi = \dots\dots\dots^\circ$ [1]

- (d) *The speed v of surface water waves in shallow water of depth d is given by the equation $v = \sqrt{gd}$, where g is the acceleration of free fall.

The speed v is about 1 ms^{-1} for a depth of about 10 cm.

You are provided with a rectangular plastic tray, supply of water and other equipment available in the laboratory.

Describe how an experiment can be conducted in the laboratory to test the validity of the equation above and how the data can be analysed to determine a value for g .

[6]

29(a) Fig. 17.1 shows the variation with distance of the displacement of a **stationary** wave at time $t = 0$.

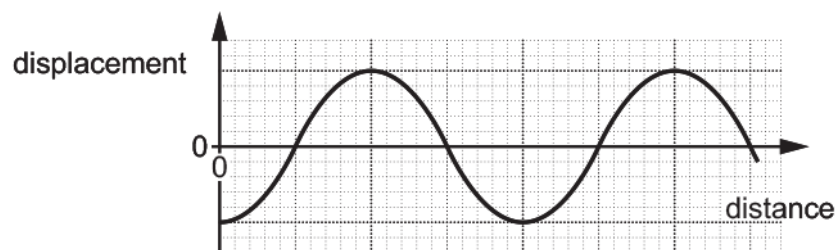


Fig. 17.1

The period of the wave is T .

- (i) On Fig. 17.1, sketch a graph to show the variation of the displacement at time $t = \frac{T}{2}$.

[1]

- (ii) On Fig. 17.1, show the positions of **all** the nodes. Label each node **N**.

[1]

- (b) Stationary sound waves are formed in a tube closed at one end.
Fig. 17.2 shows three stationary wave patterns formed in the air column of the tube.

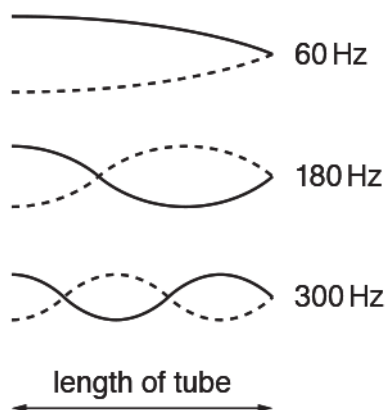


Fig. 17.2

The frequency f of the oscillations for each stationary wave is shown in Fig. 17.2.

Use Fig. 17.2 to explain how the frequency f of the sound wave depends on the wavelength λ .

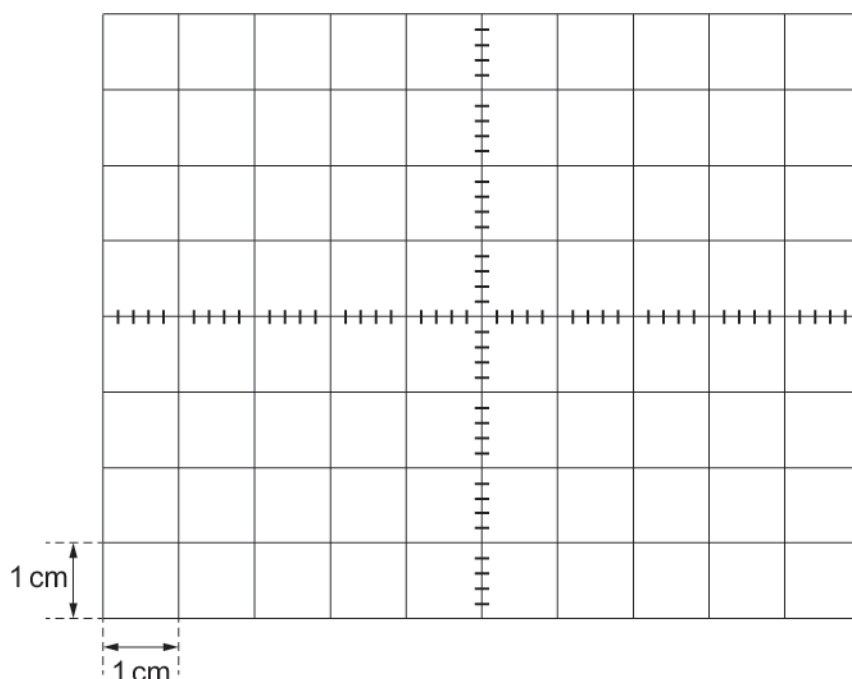
[3]

30(a) A sound wave is an example of a longitudinal wave.

- (i) State what is meant by the term **longitudinal wave**.

[1]

- (ii) 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.



Sketch the oscilloscope trace on the grid above.

[2]

(b) Microwaves and X-rays are examples of electromagnetic waves.

(i) The following are possible wavelengths of electromagnetic waves.

0.2 km 2 m 2 cm 0.2 mm 2 μ m 200 nm 200 pm

Select from the list above a typical wavelength of a microwave and an X-ray.

microwave _____

X-ray _____

[2]

(ii) One property of electromagnetic waves is that they are transverse waves.

State **two** other properties.

1. _____

2. _____

[2]

31(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.

	air	glass
refractive index n	1.00	1.53
speed of light $v / \text{m s}^{-1}$	3.00×10^8	
wavelength λ/m	4.69×10^{-7}	

(i) Show that the frequency f of blue light in air is $6.40 \times 10^{14} \text{ Hz}$.

[1]

(ii) Complete the table by determining the missing values for v and λ for glass. Write your answers to 3 significant figures.

[2]

(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.

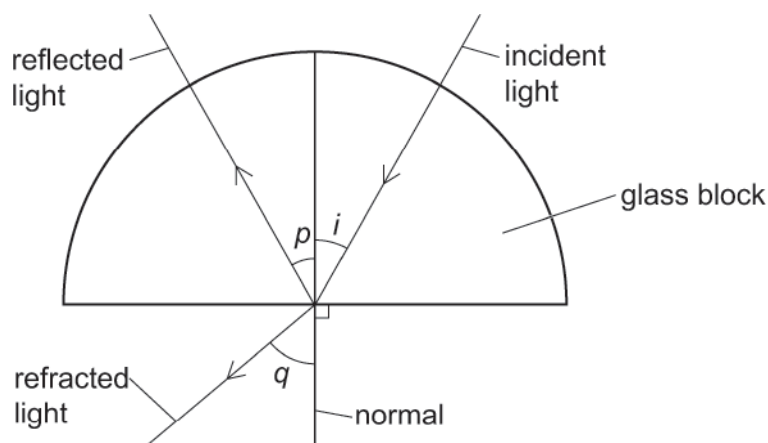


Fig. 2.1 (not to scale)

(i) The angle i is 30° .

1. Determine angle p .

$p = \dots\dots\dots^\circ$ [1]

2. Determine angle q , using the information from the table in (a).

$q = \dots\dots\dots^\circ$ [2]

(ii) 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**.

[4]

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

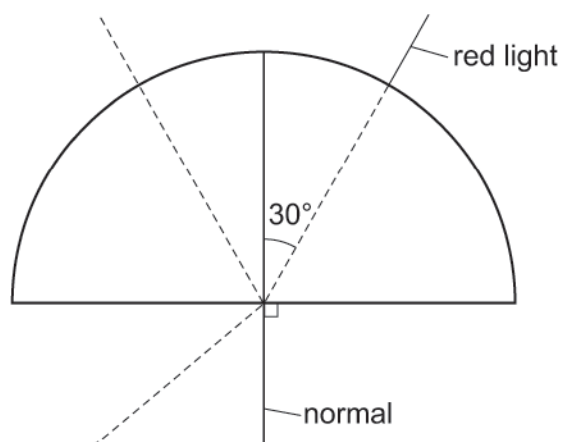


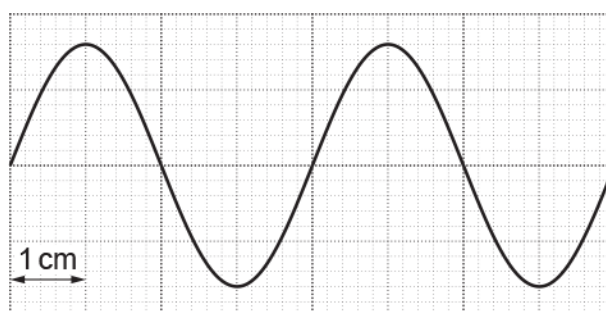
Fig. 2.2 (not to scale)

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

Draw on Fig. 2.2 the path of the red light in the glass block and out of the glass block.

[2]

- 32 The diagram below shows the oscilloscope trace for an electrical signal.



The time-base setting of the oscilloscope is $2 \mu\text{s cm}^{-1}$.

What is the frequency of the signal?

- A 125 Hz
- B 250 Hz
- C 125 kHz
- D 250 kHz

Your answer

[1]

33 This question is about a progressive wave and a stationary wave.

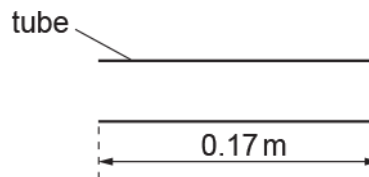
Which statement is correct?

- A A progressive wave has at least one node.
- B All progressive waves are longitudinal.
- C All particles oscillating between two adjacent nodes in a stationary wave are in phase.
- D The superposition of two waves travelling in the same direction produces a stationary wave.

Your answer

[1]

34 A stationary sound wave, in its fundamental mode of vibration, is formed in a tube open at both ends.



The length of the tube is 0.17 m. The speed of sound in air is 340 m s^{-1} .

Which row for this stationary wave is correct?

	Number of nodes	Frequency of stationary wave / Hz
A	1	500
B	1	1000
C	2	1000
D	2	2000

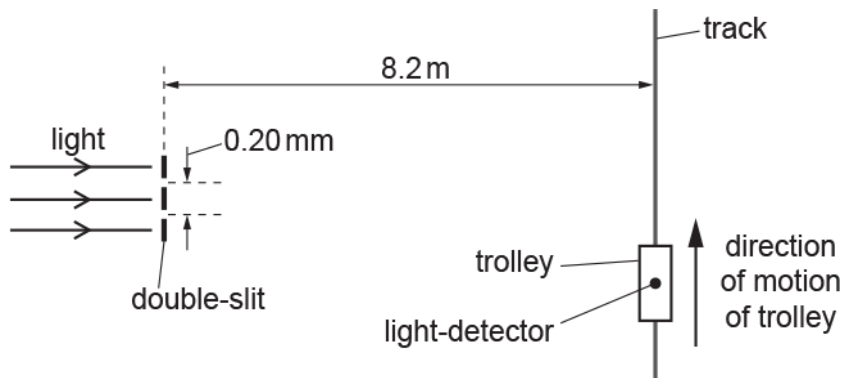
Your answer

[1]

35(a) State the principle of superposition.

[1]

(b) The diagram below shows monochromatic light from a laser incident normally at a double-slit.



The diagram is **not** drawn to scale.

A small light-detector is mounted onto a trolley on a frictionless track. The trolley travels along the track at a constant speed.

The separation between the slits is 0.20 mm. The perpendicular distance between the slits and the track is 8.2 m.

A series of bright and dark fringes are detected at the moving light-detector.

(i) Explain, in terms of phase difference, the origin of the fringes.

[2]

(ii) The speed of the trolley is 0.18 m s^{-1} and the frequency of the light is $4.75 \times 10^{14} \text{ Hz}$.

Calculate the time interval t between successive bright fringes.
Write your answer to 2 significant figures.

$t = \dots\dots\dots$ s [3]

36(a) The International Space Station (ISS) orbits the Earth at a height of $4.1 \times 10^5 \text{ m}$ **above** the Earth's surface.

The radius of the Earth is $6.37 \times 10^6 \text{ m}$. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1} .

Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

[1]

(b)

(i) Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

$g = \dots\dots\dots \text{ N kg}^{-1}$

[3]

(ii) The speed of the ISS in its orbit is 7.7 km s^{-1} . Show that the period of the ISS in its orbit is about 90 minutes.

[2]

(c) Use the information in (b)(ii) and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = $2.9 \times 10^{-2} \text{ kg mol}^{-1}$
- temperature of air inside the ISS = $20 \text{ }^{\circ}\text{C}$

[3]

- (d) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to (b)(ii) to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2 .
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W [4]

37(a) This question is about investigations involving an electromagnetic wave.

A vertical transmitter aerial emits a **vertically polarised** electromagnetic wave which travels towards a vertical receiver aerial. The wavelength of the wave is 0.60 m.

Fig. 5.1 shows a short section of the oscillating electric field of the electromagnetic wave.

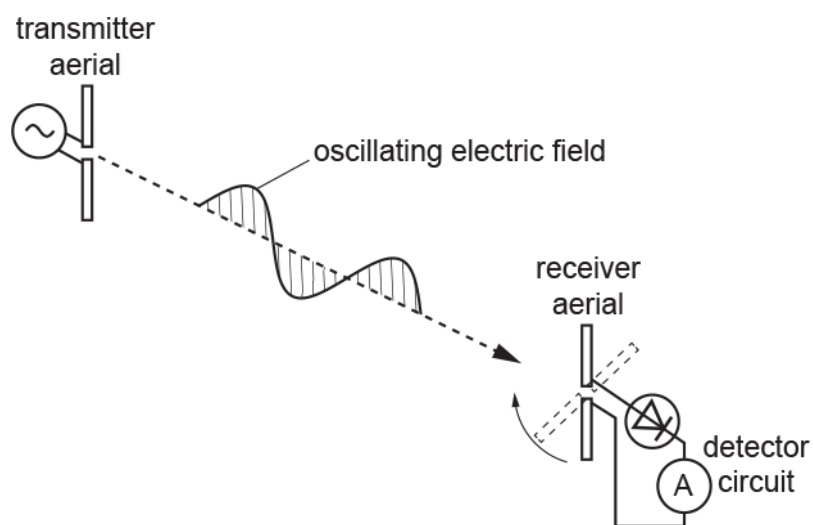


Fig. 5.1

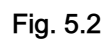
Calculate the frequency f of the transmitted wave.

$f = \dots\dots\dots$ Hz [2]

(b) * A student carries out two investigations with these electromagnetic waves.

In **investigation 1**, the student rotates the receiver aerial about the horizontal axis joining the two aerials, as shown in Fig. 5.1.

In **investigation 2**, the student places a metal sheet behind the receiver aerial. The student moves the sheet backwards and forwards along the horizontal axis joining the two aerials, as shown in Fig. 5.2.



- Explain why the ammeter sometimes gives a maximum reading and sometimes a zero (or near zero) reading.
- State the orientations of the receiver aerial in **investigation 1**, and the positions of the metal sheet in **investigation 2**, where these maximum and zero readings would occur.

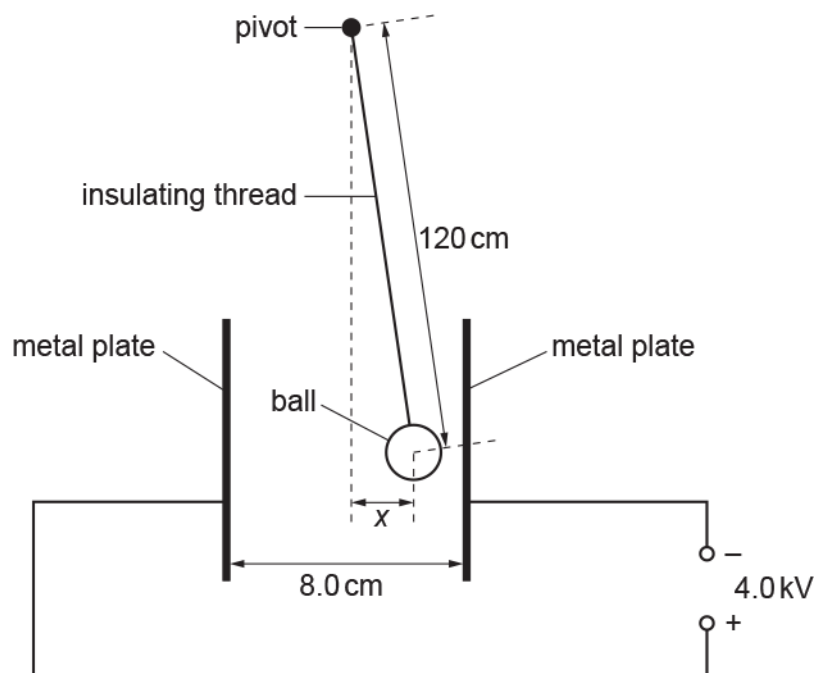
[illegible]

Blank lined paper for writing.

38(a) A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm . The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm .

The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm . The plates are connected to a 4.0 kV power supply.

The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement x from the vertical, as shown below. The diagram is **not** drawn to scale.



- (i) Show that the electric force acting on the charged ball is $4.5 \times 10^{-4}\text{ N}$.

[2]

- (ii) Draw, on the diagram above, arrows which represent the **three** forces acting on the ball. Label each arrow with the name of the force it represents.

[2]

(iii) By taking moments about the pivot, or otherwise, show that $x = 1.8$ cm.

[2]

- (b) The ball is still positively charged.

The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.

Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.

[4]

(c) When the ball oscillates between the plates, the current in the external circuit is 3.2×10^{-8} A.

A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.

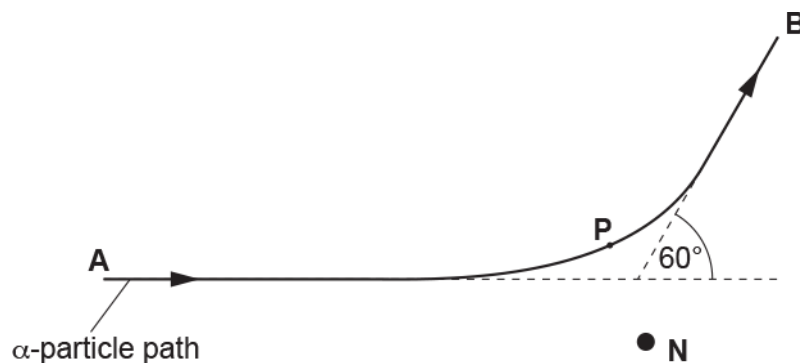
Calculate the frequency f of the oscillations of the ball.

$f =$ Hz [2]

- 39 A beam of α -particles is incident on a thin gold foil. Most α -particles pass straight through the foil. A few are deflected by gold nuclei.

The diagram shows the path of one α -particle which passes close to a gold nucleus **N** in the foil. The α -particle is deflected through an angle of 60° as it travels from **A** to **B**.

P marks its position of closest approach to the gold nucleus.



The initial kinetic energy of each α -particle is 5.0 MeV.

Show that the magnitude of the initial momentum of each α -particle is about $10^{-19} \text{ kg m s}^{-1}$.
Take the mass of the α -particle to be $6.6 \times 10^{-27} \text{ kg}$.

[3]

40 A sound wave is incident at the ear.

The amplitude of the sound wave is 7.8 nm. The intensity of the sound at the earhole is $4.8 \times 10^{-7} \text{ W m}^{-2}$.

- (i) Determine the power of the sound incident at the earhole by estimating the diameter of the earhole in mm.

diameter of earhole $\approx$ mm

power = ... W [2]

- (ii) A different sound wave is now incident at the ear.

The intensity of this wave is $9.6 \times 10^{-7} \text{ W m}^{-2}$.

Calculate the amplitude A in nm of this sound wave.

$A =$ nm [2]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			$\lambda / 2 = 0.54 / 3 = 0.18 \text{ m}$	C1	
			$\lambda = 0.18 \times 2 = 0.36 \text{ (m)}$	C1	
			$v = 60 \times 0.36$; speed = $21.6 \text{ m s}^{-1} \approx 22 \text{ (m s}^{-1})$	A1	
			Total	3	
2	a		Quantum / packet of (electromagnetic) energy	B1	Allow: Particle of energy
			Any one from: Can travel in a vacuum / has speed of $3 \times 10^8 \text{ m s}^{-1}$ in a vacuum / has no charge / has no (rest) mass / causes ion-isation / has momentum	B1	Allow: Travels at the speed of light / c in a vacuum Examiner's Comments The majority of the candidates gave a decent definition of the photon and gave one of its main properties. The most common properties listed were ' <i>photon has no mass</i> ' and ' <i>photon can travel in a vacuum</i> '.
	b	i	number per second = $4.8 \times 10^{-3} / 1.6 \times 10^{-19}$	M1	Note: This must be seen to gain a mark Examiner's Comments Most candidates scored a mark for dividing 4.8×10^{-3} by 1.6×10^{-19} . A small number used a slightly longer route to show that the number of electrons incident at the anode was $3.0 \times 10^{16} \text{ s}^{-1}$. They calculated the total power dissipated using the potential difference and current and then divided the power by the energy gained by each electron ($2.4 \times 10^{-14} \text{ J}$).
		i	number per second = $3.0 \times 10^{16} \text{ s}^{-1}$		
		ii	(incident power =) $150 \times 10^3 \times 4.8 \times 10^{-3}$ or (incident power =) $3.0 \times 10^{16} \times 150 \times 10^3 \times 1.6 \times 10^{-19}$	C1	Note an incident power of 720 (W) scores this C1 mark
		ii	$(P = mc[\Delta\theta/\Delta t])$ $0.99 \times 720 = 0.0086 \times 140 \times [\Delta\theta/\Delta t]$	C1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	rate of temperature increase = $590\text{ }(^{\circ}\text{C s}^{-1})$	A1	Note: Answer to 3 sf is $592\text{ }(^{\circ}\text{C s}^{-1})$ Allow: 2 marks for $598\text{ }(^{\circ}\text{C s}^{-1})$ or $600\text{ }(^{\circ}\text{C s}^{-1})$; 99% omitted Allow: 2 marks for $1.97 \times 10^{-14}\text{ }(^{\circ}\text{C s}^{-1})$; 3.0×10^{16} omitted Examiner's Comments The answers were generally easy to follow. The modal range for this question was two to three marks. The best candidates gave brief and flawless answers. Some candidates lost a mark for - premature rounding of numbers within the calculation; - failing to convert the mass into kg; - subtracting 273 K from the correct answer.
		iii	(photon energy = maximum KE of electron)	C1	Allow: $E = 720/3.0 \times 10^{16}$
		iii	$E = 150 \times 10^3 \times 1.6 \times 10^{-19}$ or $E = 2.4 \times 10^{-14}\text{ (J)}$		
		iii	$2.4 \times 10^{-14} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{\lambda}$ (Allow any subject)		
		iii	wavelength = $8.3 \times 10^{-12}\text{ (m)}$	A1	Allow: 1 mark $8.3 \times 10^{-10}\text{ (m)}$; $E = 2.4 \times 10^{-16}\text{ (J)}$ used Examiner's Comments The more able candidates performed well in this question. The energy of a single photon was equal to the maximum kinetic energy of a single electron. The omission rate was noticeably high for candidates in the lower quartile. The most common errors made were using mc^2, $1.6 \times 10^{-19}\text{ J}$ and 720 J as the energy of the photon. A small number of candidates tried to use the de Broglie equation to determine the shortest wavelength of the X-rays.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a		Waves are reflected at the pulley end.	B1	
			This produces nodes and antinodes on the string.	B1	
	b		$v \propto f$ and since $v \propto \sqrt{T}$, therefore $f \propto \sqrt{T}$	C1	
			frequency will increase by a factor of $\sqrt{1.14} = 1.068$, therefore increase = 6.8%	A1	
			Total	4	
4			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5	a		Level 3 (5–6 marks) Clearly labelled diagram. Procedure is correct including appropriate measurements Analysis is correct and includes A5. (6 marks) Any point omitted or incorrect (5 marks). <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Good diagram. Most measurements made Some analysis. (4 marks) Any point omitted or incorrect (3 marks). <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Basic diagram with incomplete labels. Some measurements. Limited analysis. (Maximum 2 marks) <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 x 6	Diagram 1. Labelled diagram of glass block & ray box 2. Incident and refracted rays shown 3. Normal shown and correct i and r Procedure 1. Block placed on paper 2. Incident and refracted rays marked 3. Angles measured using a protractor Analysis 1. $\sin i$ and $\sin r$ calculated 2. $\sin i$ against $\sin r$ graph plotted 3. Straight line of best fit drawn 4. gradient = refractive index (n) 5. Error bars drawn to find the gradient
	b		The ray is refracted away from the normal, therefore the refractive index of water is less than the refractive index of glass or speed of light in water is greater than the speed of light in glass. The frequency remains constant. $v = f\lambda$ and therefore the wavelength of light increases as it travels from glass to water.	B1 B1 B1	
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6	a		Waves / sources with constant phase difference.	B1	
	b	i	Place a microphone close to loudspeaker and connect it to the oscilloscope.	B1	Allow 'connect oscilloscope to the signal generator (which is connected to the loudspeaker)'
		i	Measure the number of divisions between neighbouring peaks of the signal. (AW)	B1	
		i	The separation between the neighbouring peaks should be 3.6 divisions.	B1	
		ii	The sound is diffracted at each slit.	B1	
		ii	The diffracted waves interfere in the space beyond the slits.	B1	
		ii	There is loud sound / maxima / constructive interference when phase difference is zero or when path difference $n\lambda$.	B1	
		ii	There is quiet sound / minima / destructive interference when phase difference is 180° or when path difference is $(n + \frac{1}{2})\lambda$.	B1	
		iii	$x = 2 \times 0.75 (= 1.5 \text{ m})$	C1	
		iii	$\lambda = \frac{0.40 \times 1.5}{5.0}$	C1	
		iii	$\lambda = 0.12 \text{ (m)}$	C1	
		iv	$v = 2800 \times 0.12$ $v = 340 \text{ (m s}^{-1}\text{)}$	B1	Possible ecf from (iii)
		v	Position does not depend on intensity, hence no change.	B1	
		v	Intensity decreases	M1	
		v	by a factor of 4.	A1	
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
7	a	i	reflected signals from M (amplitude a) and H (amplitude A) are added at the receiver	B1	accept interfere.
		i	path difference between moving reflected signal and fixed reflected signal varies between 0 and λ	B1	or phase difference between the two received signals varies between 0 and 2π
		i	sum of the displacements at the receiver varies between $A + a$ and $A - a$	B1	
		i	any 3 from - signal from M is attenuated because travels further; - absorbed passing twice through H or some reflected at the back of H - signal from H will increase as H moves towards the detector - if A is much greater than a then variation will be difficult to detect.	B1	allow absorbed or similar word for attenuated.
		i			allow full credit for discussion in terms of $(A^2 - a^2)/(A^2 + a^2)$.
		ii	detected signal varies between max and min for $\lambda/4 (= 7.0 \text{ mm})$ as path difference is $\lambda/2$	B1	
		ii	every $\lambda/2$ (14 mm) moved, the signal goes through one cycle	B1	
		ii	so for 200 Hz must go through 100λ in 1 s = $2.8 \text{ (m s}^{-1}\text{)}$.	B1	
	b		in time t_0 car moves vt_0	B1	
			path lengths travelled by the two pulses differ by $c(t_0 - t)$	M1	justified e.g. best solved by imagining first pulse takes time T_0 and second time T and then $T_0 - T = t_0$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			but this is twice the distance the car has moved as it is a reflected signal so $2vt_0 = c(t_0 - t)$.	A1 A0	– t and / or drawing a space diagram.
			Total	12	
8		i	3 downward arrows correctly labelled.	B1	longest being 4.33×10^{-7} (m)
		ii	$\Delta E = hc/\lambda$	C1	
		ii	$\lambda = 6.63 \times 10^{-34} \times 3 \times 10^8 / 4.8 \times 10^{-20} = 4.1(4) \times 10^{-6}$ (m)	A1	
		ii	region: infra red	B1	allow ecf if wavelength calculation incorrect.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9	a	i	$a = (-) 4\pi^2 f^2 x = 4 \times 9.87 \times 4900 \times 0.004$	C1	allow 774 (m s ⁻²)
		i	$a = 770 \text{ (m s}^{-2}\text{)}$	A1	
		ii	1 sketch showing one wavelength and 140 (Hz)	B1	both sketch and value required for 1 mark
		ii	2 driving force is around nodal point / AW;	B1	max 3 of the 4 marking points
		ii	points either side of nodal point try to move in opposite directions when force in one direction / AW;	B1	
		ii	move magnet to antinodal point; ¼ of distance between clamps	B1	
	b	i	$f \propto \sqrt{T}$ so $f = 70/\sqrt{2} = 49$ or 50 Hz	B1	
		ii	1 μ increases / goes up by 0.4%	B1	allow +0.4% NOT 0.4%
		ii	2 0.2%,	B1	or half of answer to (ii)1
		ii	f is lower because μ is bigger and μ is on the bottom of the formula	B1	or greater inertia present with same restoring force / other physical argument
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
10	a		wavelength = 60 (cm) $v = 0.30/2.5 \times 10^{-3} = 120 \text{ (m s}^{-1}\text{)}$ $f = 120/0.60 = 200 \text{ (Hz)}$	C1 C1 A1	Ignore POT Possible ECF from incorrect value of speed v
	b		*Level 3 (5–6 marks) Clear explanation and analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some explanation and some analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited explanation or limited analysis <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: Explanation • Sound reflected at closed end • Superposition / interference produces stationary wave within tube • Maximum identified as anti-nodes • Minima identified as nodes Analysis • $\lambda/2 = 0.26 \text{ (m)}$ or $\lambda = 0.52 \text{ (m)}$ • period = 1.5 (ms) • frequency = $1/0.0015$ or frequency = 660 (Hz) • $v = 0.52 \times 660 = 340 \text{ m s}^{-1}$ (Note: $v = 350 \text{ m s}^{-1}$ if there is no rounding.)
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11			Level 3 (5–6 marks) Clear methods of measurement, statement of uncertainties and how to minimise them <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Adequate methods of measurement, statement of uncertainties and how to minimise them <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited methods of measurement, statement of uncertainties or how to minimise them <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Indicative scientific points may include: M measurement D measured with metre rulers y measured using mm graticule on glass screen observed with hand lens U uncertainty D maximum ± 2 mm in 1.5 to 2.0 m 0.1% y ± 0.5 mm in the position of the centre of each maximum, giving an uncertainty of ± 1 mm $x = 600 \times 10^{-9} \times 2/5 \times 10^{-4} = 2.4$ mm so we have $y = 5x$ with $\pm 1/(2.4 \times 5)$ so of order of 8 to 10% in value of x. a vernier to ± 0.05 mm in 0.5 mm gives uncertainty of order of 10% total uncertainty of about 20% or ± 100 nm to 120 nm A minimising uncertainties D maximise distance available on bench y measuring across the maximum number of x possible a suggesting that a more sensitive method is needed, e.g. using slide projector to display enlarged image of slits on screen compared to millimetre scale projected on screen or similar
			Total	6	
12		i	$I = I_0/r^2$ or $I = kr^{-2}$	B1	allow inverse square law statement
		i	(k = 20) so $I = 20/(0.25)^2 = 20 \times 16 = 320$	B1	
		ii	640	B1	
		iii	$640 = 20/r^2$	C1	ecf(ii)1
		iii	so $r = \sqrt{(20/640)} = 0.18$ (m)	A1	accept 0.177 (m)
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a		$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{1.1 \times 10^{-6}}$	B1	Values must be substituted
			$E = 1.8 \times 10^{-19} \text{ (J)}$	A0	Answer to 3sf is $1.81 \times 10^{-19} \text{ (J)}$ Examiner's Comments This question was specifically included to give a hint as to the method to be used in (b). The question was written in a 'show' format to enable candidates to answer (b) even if they could not recall this area of synoptic work. However this did mean that all working, including substitution, had to be shown and this did result in a small number losing the mark.
	b		$m = \rho V = 8.1 \times 10^{-12} \times 4.5 \times 10^3 = (3.645 \times 10^8)$	C1	Allow: ecf from (a) and mass of titanium Examiner's Comments Again this question had three distinct strands to the physics. The vast majority of candidates were capable of determining the correct mass and thermal energy required to raise the temperature of the titanium. A small number of errors were seen in these two strands however: mainly in transposition of the density formula and converting temperature changes incorrectly to kelvin scale. The final stage to determine the time was less confidently handled with transposition errors and some strange manipulation of the equations which usually resulted in the reciprocal of the correct answer. Perhaps the very small time involved in this form of welding surprised a few candidates.
			Thermal energy gained = $(mc \Delta\theta) = 3.645 \times 10^{-8} \times 520 \times [1700 - 20] (= 0.0318)$ $1.81 \times 10^{-19} \times 6.3 \times 10^{19} \times t = 0.0318$	C1	
			$t = 2.8 \times 10^{-3} \text{ (s)}$	A1	
	c		Thermal energy is conducted / transferred to the rest of titanium / metal	B1	Not: heat lost to surroundings

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Photons are reflected / scattered from / not absorbed the titanium surface	B1	Examiner's Comments The answers given for this question were disappointing. All too often the only factor quoted was the vague '<i>heat lost to the surroundings</i>'. A significant number of candidates scored one mark by identifying the loss of thermal energy to the non-shaded volume of titanium. Only a tiny minority realised that some photons would be reflected from the metal surface. Other suggestions such as '<i>photons are absorbed in the air</i>', '<i>photons would miss the target</i>', '<i>not all photons have the same energy</i>', '<i>the laser needs to heat up as well</i>' were not given any credit. Marks for this discriminating question were mostly awarded only to the more able candidates.
	d		(Photon) energy is converted into potential energy (rather than kinetic energy) OR Energy is used to change solid to liquid / phase (rather than increase kinetic energy) OR Energy provides (specific) latent heat of fusion (rather than increase kinetic energy)	B1	Allow: energy is used to overcome the forces between atoms / breakdown the crystal structure of titanium (rather than increase kinetic energy) Examiner's Comments This question discriminated across the entire spectrum of ability, largely as a result of candidates writing about the lack of a temperature change rather than focusing on what actually happened to the energy supplied at this stage. Many answers were merely statements lacking in the vital explanation. It was, however, encouraging to see that the physics involved in this unfamiliar situation was broadly understood by the candidates.
			Total	7	
14			A	1	
			Total	1	
15			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		(When two or more waves meet at a point in space) the resultant (displacement) is equal to the (vector) sum of the individual <u>displacements</u> of waves (meeting at a point)	B1	Allow total / Σ / net for resultant Not amplitude for displacement Examiner's Comment Most candidates made a poor start to Section B by incorrectly stating the principle of superposition. Instead of '<i>the resultant displacement being the sum of the individual displacements of the waves</i>', candidates wrote about the addition of amplitudes. Some simply wrote about constructive (or destructive) interference and stationary waves.
	b	i	Clear evidence of at least two fringe separations used to determine x and x in the range 7.0 to 9.0 mm $\lambda = \frac{0.25 \times 10^{-3} \times 8 \times 10^{-3}}{4.25} \text{ (Allow any subject)}$ $A = 4.7 \times 10^{-7} \text{ (m)}$	B1 C1 A1	Expect 8 (mm) Allow ecf for incorrect value of x Examiner's Comment One mark for this question was reserved for accurately determining the separation x between adjacent fringes using at least two fringe separations. About a quarter of the candidates did this and secured maximum marks for calculating the wavelength of blue light. A wide range of 7 mm to 9 mm was allowed for x. Most candidates used the correct equation and had no problems with powers of ten. Almost all the answers were written in standard form.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Red light has longer wavelength / λ and separation between fringes increases (AW) Separation between fringes justified in terms of $x \propto \lambda$ or $x = \lambda D / a$, D and a are constants	M1 A1	Allow other acceptable labels for D and a Examiner's Comment This was generally well answered with most candidates giving correct explanation of why the fringe pattern was more spread out. Many candidates wrote concise answers such as 'the <i>fringe separation increases because red light has longer wavelength and fringe separation x wavelength</i>'. The two most common errors were: • Red light has shorter wavelength than blue light. • The pattern had something to do with the refraction of light through the double-slit.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18	a		Photon(s) mentioned One-to-one interaction between photons and electrons Energy of photon is independent of intensity / intensity is to do with rate (of photons / photoelectric emission) / photon energy depends on frequency / energy of photon depends on wavelength / photon energy $\propto$ frequency / photon energy $\propto 1/\lambda$ energy of uv photon(s) > work function (of zinc) / frequency of uv > threshold frequency	B1 B1 B1 B1	Allow 'photon absorbed by an electron' Allow: collide etc. for interaction Allow $E = hf$ or $E = hc/\lambda$ Allow energy of light photon(s) < work function (of zinc) / frequency of light > threshold frequency Allow $\geq$ instead of > here Not $f > f_0$ Examiner's Comment Many candidates wrote enthusiastically about photoelectric effect and understood the significance of work function energy (or threshold frequency) and the one-to-one interaction between photon and an electron. Some candidates did not mention 'photons' and this limited the marks they could acquire. The role of intensity was less understood. Many candidates thought it was linked to 'the <i>number of photons</i>' or 'the <i>amount of electrons emitted</i>'. The important term rate of the missing ingredient. Top-end candidates gave eloquent answers, typified by the response: '<i>intensity of visible light only affects the rate of photons incident on the plate but not the energy of each photon</i>'. Two common misconceptions were: • Photons were emitted from the negative plate. • Confusing threshold frequency and work function energy.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		$\phi = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{2.9 \times 10^{-7}} \text{ or } 6.86 \times 10^{-19} \text{ (J)}$ $E = 5.1 \times 1.60 \times 10^{-19} \text{ or } 8.16 \times 10^{-19} \text{ (J)}$ $\text{max kinetic energy} = (8.16 - 6.86) \times 10^{-19}$ $\text{max kinetic energy} = 1.3 \times 10^{-19} \text{ (J)}$	C1 C1 A 1	Note: Using 5.1 and not 8.16×10^{-19} cannot score this mark or the next mark Allow 2 marks for 0.81 eV Examiner's Comment This was a notable success for most of the candidates. Examiners were pleased to see a range of techniques being used to get the correct answer of 1.3×10^{-19} J. Many answers showed excellent structure, effortless conversion of energy from electronvolt to joule and excellent use of the calculator when dealing with powers of ten. Most candidates scored three marks. A small number of candidates left the final answer as 0.81 eV; the only thing missing was the conversion to J.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		Any <u>three</u> from: The electrons are repelled by C / electrons travel against the electric field (AW) The electrons are emitted with a 'range' of speed / velocity / kinetic energy (AW) As V increases the slow(er) electrons do not reach C and hence I decreases maximum KE in the range 2.1 eV to 2.2 eV or $3.36 \times 10^{-19} \text{ J}$ to $3.52 \times 10^{-19} \text{ J}$	B1×3	Note 'range' can be implied by 'highest' or 'lowest' Allow 'find p.d. when current is (just) zero, and then $KE = e \times V$ Examiner's Comment The electrons emitted from the metal plate have a range of kinetic energy. The emitted electrons are repelled by the negative electrode C. Fewer electrons reach C as the p.d. is increased. When the p.d. is about 2.2 V, and the current zero, the most energetic electron are stopped from reaching C. This makes the maximum kinetic energy of the electrons equal to 2.2 eV or $3.4 \times 10^{-19} \text{ J}$. The question baffled most candidates. Some top-end candidates commented on '<i>the electrons repelled by C</i>' and the maximum kinetic energy of the emitted electrons being 2.2 eV. Such answers were rare. Too many candidates made guesses with answers such as '<i>the current drops because resistance increases</i>' and '<i>temperature increases and hence the current decreases</i>'.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a	i	sin or cos wave with 1.5 wavelengths (between C and R) y-axis showing scale, i.e. (amplitude) 2.0×10^{-6} (m) correct scale on x-axis showing $\lambda = 0.2$ (m) X and Y labelled at adjacent intercepts on x-axis	B1 B1 B1 B1	unit must be present, e.g 10^{-6} m NOT if axis labelled time Examiner's Comments Most candidates correctly labelled the scale on the displacement axis of the sinusoidal graph that they drew. The points where the air particles were moving the fastest were also well known. Fewer labelled <i>distance</i> on the x-axis, many incorrectly writing <i>time</i>. Only the better candidates marked the correct scale on this axis and very few indicated that there were 1.5 wavelengths between the points C and R.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	1 $v = A\omega$ or $2\pi fA$ $v = (2 \times 10^{-6} \times 2 \times 3.14 \times 1.7 \times 10^3 =)$ $2.1 \times 10^{-2} \text{ (m s}^{-1}\text{.)}$ 2 $\frac{1}{2}Mv^2 = \frac{3}{2}RT$ and $T = 290$ $v = \sqrt{(3 \times 8.31 \times 290 / 0.029)}$ $v = 5(.0) \times 10^2 \text{ (m s}^{-1}\text{.)}$	C1 A1 C1 A1	or $\frac{1}{2}mv^2 = \frac{3}{2}kT$ so $v^2 = 3 \text{ (k / m)} 290$ N.B. remember to record a mark out of 4 here Examiner's Comments Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled <i>path</i> and <i>phase</i> difference or referred to <i>nodes</i> and <i>antinodes</i> detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used <i>maxima</i> and <i>minima</i> in place of <i>antinodes</i> and <i>nodes</i> although most recognised this to be a <i>standing</i> wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	b	Level 3 (5 – 6 marks) Clear description and explanation for both experiments and some discussion of uncertainty <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.</i> Level 2 (3 – 4 marks) Some description and explanation for both experiments or clear description and explanation for one experiment and some discussion of uncertainty <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Limited description and explanation for one experiment <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 × 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2⁺ for 3 marks, etc. Indicative scientific points may include: Description and explanation Experiment (a) • Coherent signals / (sound) waves • Interference / superposition • Maximum signal / minimum signal • Idea of how wavelength is determined (e.g. distance between adjacent max positions = λ) • $v = f \times \lambda$ Experiment (b) • Stationary / standing wave produced • Superposition of waves travelling in opposite directions • Nodes / antinodes • Idea of how wavelength is determined (e.g. distance between adjacent nodes = $\lambda/2$) • $v = f \times \lambda$ Uncertainty • Measure multiples of λ • to reduce % uncertainty (by factor n) • move from minimum signal to minimum signal • so can increase sensitivity of scope to get better fix on each minimum position / increase loudness from speaker • Lower frequency from signal generator • so increases A with (%) uncertainty reduced • Do experiment outside • to reduce background reflections from room (so that sharper minima should be observed)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Examiner's Comments Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled <i>path</i> and <i>phase</i> difference or referred to <i>nodes</i> and <i>antinodes</i> detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used <i>maxima</i> and <i>minima</i> in place of <i>antinodes</i> and <i>nodes</i> although most recognised this to be a <i>standing</i> wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20		i	$\sin C = 1/n = 1/1.69 (= 0.592)$	C1	
			$C = 36^\circ$	A1	
		ii	<u>Total internal reflection</u> occurs because the <u>angle of incidence</u> (at the surface) is greater than the <u>critical angle</u>/ <u>36°</u>	B1 B1	allow because <u>i</u> > <u>C</u> Examiner's Comments Almost all of the candidates managed to calculate the critical angle correctly. The explanation in part (ii) was not so successful. The majority gained the mark for total internal reflection but most omitted the crucial words of <i>incidence</i> to qualify which angle must be greater than the critical angle. The example here (exemplar 10) shows the perfect succinct answer. Exemplar 10 the crystal has a higher refractive index than air and the angle of incidence is greater than the critical angle, so the light undergoes total internal reflection.
			Total	4	
21			C	1	
			Total	1	
22			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23			B	1	Examiner's Comments The emission of sound '<i>uniformly in all direction</i>' was the clue that the intensity of the wave followed an inverse square law relationship with distance from the source. The intensity is also directly proportional to amplitude². This meant that amplitude of the wave is inversely proportional to the distance from the source. The correct answer (key) for this question is B. The most popular distractor was C, where 12 μm was divided by $\sqrt{3}$. Exemplar 1 A 1.3 μm B 4.0 μm C 6.9 μm D 12 μm Handwritten notes: $A = 12 \times 10^{-6} \text{ m}$, $I \propto A^2$, $I \propto \left(\frac{1}{r}\right)^2$, $A \propto \left(\frac{1}{r}\right)$ Your answer   This exemplar illustrates the sensible strategy from a top-end candidate. The key ideas are jotted down and analysis completed: $I \propto 1/r^2$ and $I \propto A^2$, therefore $A \propto 1/r$. The distance r increases by a factor of 3, therefore the amplitude will decrease by a factor of 3. This makes the answer 4.0 μm. The final sum being done either in the head or calculator – this is of little significance. What is important here is that all the important ideas have been extracted competently from the question. A commendable technique.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
24	a		Any two from: • Reflection • Diffraction • Interference / superposition	B1 × 2	Allow correct annotation of Fig. 19.1 for each effect Examiner's Comments Most candidates scored two marks for identifying any two from diffraction, superposition (or interference) and reflection. A few answers were spoilt by mentioning either <i>refraction</i> or <i>total internal reflection</i>.
	b		Interference / superposition (of microwaves along PQ) Maximum (signal) / constructive (interference) when waves are in phase Minimum (signal) / destructive (interference) when waves are in anti-phase	B1 B1 B1	Allow constructive when <u>phase</u> difference is $n \times 360^\circ$ (n is an integer) / 0° / 360° Allow destructive <u>phase</u> difference is $[2n + 1] \times 180^\circ$ (n is an integer) / 180° Not 'out of phase' Special case - allow 1 mark from the last two B1 marks, for signal linked to <u>path</u> difference and wavelength Examiner's Comments Many candidates made a start by defining coherence, this was not necessary. Most candidates realised that the maximum and minimum signals were linked to superposition, or interference, of the waves from A and B. The majority of the candidates equated coherence with 'in phase' and gave explanations in terms of path difference instead of phase difference. Constructive interference could not be linked to an integer number of wavelengths

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					but it could be linked to the waves being in phase. Similarly, for destructive interference, the apt explanation was that the waves are in anti-phase at points of minimum signal. Specific values of phase differences were allowed. For anti-phase, 'completely out of phase' was allowed.  Some of the common misconceptions were: • The maximum and minima signals were related to antinodes and nodes • The variation in the signal was due to Doppler effect
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
25	a		$1.00 \times \sin 56.3 = 1.50 \times \sin r$ (Any subject) $r = 33.7^\circ$ Correct working / reasoning leading to 90.0° (e.g. $\theta = 180 - (56.3 + 33.7)$, therefore $\theta = 90.0^\circ$)	M1 A1 A1	Allow with or without the 1.00 Allow 34° <u>Examiner's Comments</u> Generally, candidates answered this question well with most making a good start with the equation $n \sin \theta = \text{constant}$. Most candidates correctly calculated the angle of refraction to be 33.7°; only a small proportion lost marks because of rounding errors. The final mark was reserved for steps clearly showing that the angle θ marked on the figure was equal to 90.0°. A pleasing number of candidates annotated the figure with angles and labels in order to ensure this last mark was picked up. A very small number of candidates attempted to either use $\sin C = 1/n$ or omitted $n \sin \theta = \text{constant}$ altogether.
	b		Use a polaroid / polarising filter Rotation will change intensity	B1 B1	Allow brightness / light <u>Examiner's Comments</u> Most candidates scored well deserved 2 marks here for opting to use a polarising filter and rotating it to see variation in the intensity of the transmitted light. A small number of candidates chose the wrong equipment – the most common of these were diffraction grating, a single slit and microwave receiver.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		distance = $6.0 / \cos 33.7$ or 7.2 (cm) OR $v = 3.00 \times 10^8 / 1.50$ or 2.00×10^8 (m s ⁻¹) $t = 7.2 \times 10^{-2} / 2.00 \times 10^8$ $t = 3.6 \times 10^{-10}$ (s)	C1 A1	Allow 34° Allow 2×10^8
			Total	7	
26			c	1	<u>Examiner's Comments</u> This question was assessing knowledge and understanding of path difference and constructive interference. The path difference is 4.0 m. With the waves in phase at X and Y, this means that the distance of 4.0 m must be equal to a multiple of wavelengths. This condition is satisfied by all but C. You cannot get 4.0 m by multiplying 3.0 m by an integer. The majority of the candidates effortlessly picked up 1 mark here.
			Total	1	
27			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a		time	B1	Allow t but not T Ignore any correct unit given with the correct label Not a wrong unit with the correct label, e.g. t / m (CON) Not just a unit of time, e.g. second <u>Examiner's Comments</u> Almost all candidates did well here by correctly labelling the horizontal axis. Most answers also included the unit, e.g. time / s. A very small number of candidates had <i>distance</i>, <i>time period</i>, <i>frequency</i> and <i>velocity</i> for the label.
	b		($v = \text{distance/time}$) $v = \frac{\lambda}{T}$ $f = \frac{1}{T}$ and $v = f\lambda$ or There are f wavelengths per unit time $v = \text{distance travelled per unit time}$ and $v = f \times \lambda$	M1 A1 M1 A1	Allow '(distance travelled is) λ in one period / T Not t for T Allow '...in 1 s' instead of 'per unit time' Allow λ / 'waves'; not cycles / oscillations instead of wavelengths <u>Examiner's Comments</u> For maximum marks, it was important for candidates to clearly show all the steps leading to the wave equation. Supportive text always helps with the clarity of answers. The vast majority of the candidates produced flawless answers in terms of λ, f and T. A significant number of candidates used t or d, which made their working ambiguous. Some tried their luck with 4.0 s from Fig. 16.1, which led to no marks. The exemplar 3 below shows a model response supported by equations and text and exemplar 4 shows that even top end candidates make mistakes.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 3 A progressive wave has wavelength λ, frequency f and period T. Show that the speed v of the wave is given by the equation $v = f\lambda$. distance travelled in one period = λ time = T $\therefore$ speed of wave = $\frac{\text{distance}}{\text{time}} = \frac{\lambda}{T}$ $T = \frac{1}{f}$ so $f = \frac{1}{T}$ speed, $v = f\lambda$. [2] This is a model response for a show-type question. The text provides continuity and supports the derivation of the wave equation. A perfect solution. Exemplar 4 (b) A progressive wave has wavelength λ, frequency f and period T. Show that the speed v of the wave is given by the equation $v = f\lambda$. $f = \frac{1}{T}$ $v = \frac{\lambda}{T}$ $\lambda = vT$ $f = \frac{1}{T}$ $\lambda = vT$ $\therefore v = f\lambda$ $f = \frac{1}{T}$ $\lambda = vT$ $\therefore v = f\lambda$ (m s^{-1}) [2] This was a high scoring candidate overall who misunderstood the question here. The focus is on S.I. units of the various quantities and not on a derivation of $v = f\lambda$ from first principles.
	c	i	(speed in material =) $\frac{3.0 \times 10^8}{1.20}$ or 2.5×10^8 (ms^{-1}) $(t_V =) \frac{1.5 \times 10^{-6}}{3.0 \times 10^8}$ or 5.0×10^{-15} (s) $(t_M =) \frac{1.5 \times 10^{-6} \times 1.20}{3.0 \times 10^8}$ or 6.0×10^{-15} (s) $t = [6.0 - 5.0] \times 10^{-15} = 1.0 \times 10^{-15}$ (s)	C1 C1 C1 A0	Allow other correct methods Note omitting or incorrect use of 1.2 is XP Allow 1 SF answer 5×10^{-15} Allow 1 SF answer 6×10^{-15} Note this also scores the first C1 mark Note omitting or incorrect use of 1.2 is XP <u>Examiner's Comments</u> Generally, candidates answered this question extremely well and most scoring full marks In (c)(i), the solutions ranged from being well-structured to an assortment of

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					equations and substitutions filling the entire answer space. Equations for refractive index and speed were easily used to show the answer to be 1.0×10^{-15} s. In (c)(ii), candidates either calculated the frequency of 5.0×10^{14} Hz and then used $T = f^{-1}$ or calculated T directly using $T = \frac{6.0 \times 10^{-7}}{3.0 \times 10^8} = 2.0 \times 10^{-15} \text{ s.}$ (c)(iii) provided some discrimination with middle and top candidates getting the correct answer of 180°. As always, error carried forward (ECF) rules apply in calculations. This helped those candidates who got an incorrect answer of 2.4×10^{-15} s in (c)(ii) to score a mark for 150°.  Misconception There were some missed opportunities, with some candidates making the following mistakes. - In (c)(i) calculating the difference in the time for the two rays by halving the period of 2.0×10^{-15} s. - In (c)(ii) using the wavelength in vacuum of 6.0×10^{-7} m but the incorrect speed of $2.5 \times 10^8 \text{ ms}^{-1}$ to calculate the period. This gave an answer of 2.4×10^{-15} s; examiners allowed 1 mark for this method. - In (c)(iii), a small number of candidates, mainly at the low-end, confused the symbol ϕ for phase difference to be work function. This produced some bizarre answers.
		ii	$(f=) \frac{3.0 \times 10^8}{6.0 \times 10^{-7}}$ or 5.0×10^{14} (Hz) or $(T=) \frac{6.0 \times 10^{-7}}{3.0 \times 10^8}$ $T = 2.0 \times 10^{-15}$ (s)	C1 A1	Allow 1 SF of 2×10^{-15} Allow 1 mark for 2.4×10^{-15} (s); $2.5 \times 10^8 \text{ ms}^{-1}$ used

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$\phi = 180^\circ$	B1	Possible ECF from (i) and (ii) Note answer must be $\phi = (c)(i) \times 360^\circ / (c)(ii)$ Not an answer in rad, e.g. π rad
	d		Level 3 (5–6 marks) Clear description and clear analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Clear description or Clear analysis or Some description and some analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or Limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Use level of response annotations in RM Assessor Indicative scientific points may include: Description • Method for creating wave / pulse, e.g. lifting and releasing tray, dropping a ball into the water, ripple-tank arrangement, etc. (Details not expected) • speed = distance ÷ time or $v = x \div t$ or $v = f\lambda$ • Measure distance travelled using a ruler • Use a stopwatch / timer/ video technique / strobe to measure time / frequency • Measure the depth of water using a ruler etc • Record / measure / determine v for different d • Repeat to find average v Analysis • Plotting a graph, e.g. v against $\sqrt{d}$ or v^2 against d or $\lg v$ against $\lg d$ etc. • Correct determination of g from straight-line graph or • Table with v and $\sqrt{d}$ or v^2 and d • Correct calculation of average value of g from the table <u>Examiner's Comments</u> This level of response (LoR) question was designed to assess practical skills of planning, implementation, analysis and evaluation from module 1 of the specification, together with the mathematical skills of graphs from Section M3. The context of the question was waves

Mark Scheme

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					and the relationship between wave speed v and depth d of the water. A holistic approach to marking is used, with marks given according answers matching the descriptors for the various levels. There is no one perfect answer for this question, examiners were expecting an eclectic approach. The key things examiners were looking for were: - A plausible technique for creating the waves on the surface of the water. - Method for determining the speed of the waves. - Instruments used for measurements. - Techniques used to produce reliable results. - The graph plotted, and how the acceleration of free fall g is determined from the data. On occasions, the methods used for determining the speed of the waves and creating the waves were a bit creative, but perhaps plausible in the hands of very competent physicists. For examples, light-gates were often used to determine the speed of the waves. The intricacies of this method were often omitted, but given lots of time, the technique could be made to work. There were some interesting suggestions about using a motion-sensor above a floating ball to determine the frequency of the waves. Examiners were not looking for perfection. Most candidates either dropped objects into the water or struck the side of the tray to create the waves. The speed was often determined by dividing the distance travelled by the wave by the time it took to travel a known distance. Candidates either plotted v^2 against d or v against $\sqrt{d}$ to determine g. Across the ability range, the analysis sections of the

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			answers were generally better than the descriptions. The exemplar 5 shows a response that scored Level 3 (L3) and exemplar 6 shows a response that missed out on a top score because of lack of detail in the description. Exemplar 5 * Fill the plastic tray with a supply of water, up to ~~depth of 30cm~~ a shallow depth. * Measure the depth of water using a ruler with a mm scale. This can be placed in the plastic tray. Record the depth reading. * Using a ripple machine (a rod connected to a vibration generator) surface water waves can be produced by the repeated motion of the rod on the water. * ~~Connect the vibration generator to~~ Adjust the frequency of the vibration generator until water waves are present on the surface of the water. These may be hard to spot at first. * Using a ruler, measure the distance between the rod and the end of the tray, then, using a stop watch ^{measure} ~~record~~ the time taken for the wave ^{from} to reach the end of the tray. Now, alter the distance ^{regular intervals}. * Calculate the speed using distance / time. * Calculate v^2 by squaring this answer. * Plot a graph of v^2 against d (depth of water). This should produce a straight line through the origin. * Gradient of this line = g. $\rightarrow v = \sqrt{gd}$ $v^2 = g \cdot d$ $y = \frac{g}{m}x$ This exemplar shows that examiners are not expecting perfection with the practical skills or the analysis. The description here is clear, as is the analysis. This response met all the requirements of a Level 3 score.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 6 Using the plastic tray, changing the depth of the water while not adjusting frequency of the driver or wave producer was keeping a constant frequency. As the depth of the water changes, the wave speed will change. Measure wave speed by measuring time for wave to travel full length of tray or a set distance. Using v^2 against d change in depth to have a varied range of wave speed. Using v^2 against d will result in the gradient of graph being equal to value of g. The relationship will be confirming by a constant gradient through origin since g is a constant value. A mechanical driver would be expected to keep wave frequency constant, meaning the speed of water waves will only change because of depth of water. Additional answer space if required. Using $f = v$ and $10 \times 10^{-2} = d$ value of 10 N kg^{-1} can be calculated. Measure a range of values for depth with related speed of waves to plot data and graph. This exemplar shows a Level 2 response. You will notice that the description is not as robust as that shown in exemplar 5. The analysis in both is similar. There are small margins between the levels.
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a	i	'Inverted' graph	B1	Ignore amplitude Examiner's Comments The majority of the candidates drew the correct variation of the displacement after a time of half a period. In (a)(ii), it was good to see the nodes clearly marked with the letters N. The most common mistake was to draw a curve with a different period with nodes at all the points where the displacement was zero.
		ii	Nodes shown correctly	B1	Expect at least 2 nodes labelled N No mark if the labels N are omitted Note the nodes must be on the original graph and not that sketched in (a)(i)
	b		Correct relationship between length of tube and λ for at least two stationary waves speed / v is constant or $f\lambda = \text{constant}$ or $f \propto 1/\lambda$ Calculation comparing at least two stationary waves to show $f\lambda = \text{constant}$ or $f \propto 1/\lambda$	B1 B1 B1	Allow L for length of tube Example $L = \lambda/4$ at 60 Hz, $L = 3\lambda/4$ at 180 Hz $L = 5\lambda/4$ at 300 Hz Allow $\lambda/4$ linked to 60 (Hz) etc on diagram or in text Not just f increases λ decreases Note - calculation can also score the previous B1 mark E.g f increases by a factor of 5 (from 60 Hz to 300 Hz) and λ decreases by the same factor (of 5) Examiner's Comments The majority of the candidates scored 1 mark for either mentioning that the wavelength was <i>inversely proportional to the frequency</i> or identifying the correct relationship between the length of the tube and the wavelength. Generally, the explanations lacked cohesion and showed poor comprehension of stationary waves formed within a fixed column of air. The common errors are highlighted below.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					 Misconception There were some missed opportunities, with some candidates making the following mistakes. • wavelength = $\lambda/4$, $3\lambda/4$ and $5\lambda/4$, instead of length of tube = $\lambda/4$, $3\lambda/4$ and $5\lambda/4$. • Correctly identifying the relationship between L and λ, but then confusing L and λ, and stating that the $f \propto \lambda$. • Using an equal sign instead of the proportionality symbol, e.g. <i>frequency is inversely proportional wavelength, hence $f = 1/\lambda$.</i>
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30	a	i	<u>Vibrations</u> or <u>oscillations</u> parallel to direction of travel of the wave / direction of energy transfer	B1	
		ii	Amplitude of 2 cm (in each direction) Sinusoidal shape (by eye) with period of 4 cm – at least two waves	B1 B1	Check peak, equilibrium and trough positions <u>Examiner's Comments</u> In this question (a)(ii), candidates were required to sketch the trace. While perfect drawings are not expected, since the grid is given, candidates should try to use it effectively. The amplitude should be two squares above and two squares below for the peaks and troughs respectively. Similarly, for the period (4cm) using the grid, candidates should be able to make sure that the drawing is consistent at the peak, trough and zero lines.
	b	i	Microwave: 2 cm X-ray 200 pm	B1 B1	
		ii	Any two from: May be reflected / refracted / diffracted / interference May be polarised Travel in a vacuum (at a constant speed / $3 \times 10^8 \text{ m s}^{-1}$) Oscillation of electric and magnetic fields.	$B1 \times 2$	Allow speed of light
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
31	a	i	$(f = v/\lambda) = 3.00 \times 10^8 \div 4.69 \times 10^{-7} (= 6.40 \times 10^{14} \text{ Hz})$	B1	$6.397 \times 10^{14} \text{ Hz}$
		ii	$1.96 \times 10^8 \text{ (ms}^{-1}\text{)}$ $3.07 \times 10^{-7} \text{ (m)}$	B1 B1	Allow $3.06 \times 10^{-7} \text{ (m)}$ (uses (i)) Not ECF for incorrect speed
	b	i	1. $p = 30^\circ$ 2. $\sin q = 0.5 \times 1.53$ or 0.765 $q = 50^\circ$	B1 C1 A1	Allow 49.9° Note 19° does not score
		ii	p always equals i or p increases with i / when $i = 60^\circ$, $p = 60^\circ$ Any three from: as i increases, q increases (until i equals the critical angle) when $i = \text{critical angle}$, $q = 90^\circ$ critical angle = 41° when i is greater than critical angle, <u>total</u> <u>internal reflection</u> occurs when $i = 60^\circ$, there is no angle q or no refracted ray	B1 B1 $\times 3$	 Not $q = 0$
	c		Straight line to centre of block and reflects along original ray P Straight line to centre of block and refracts with angle q less than 49.9° but greater than 30°	B1 B1	
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32			C	1	
			Total	1	
33			C	1	
			Total	1	
34			A	1	
			Total	1	
35	a		(When two or more waves meet at a point) the resultant displacement is (equal to) the sum of the (individual) displacements (of the waves)	B1	Allow sum / total / net for resultant Ignore vector sum
	b	i	phase difference = $n \times 360(^{\circ})$ for bright (fringes) / constructive (interference) phase difference = $(n + \frac{1}{2}) \times 360(^{\circ})$ for dark (fringes) / destructive (interference)	B1 B1	Allow zero or $n \times 2\pi(\text{rad})$ or even number of π (rad) or even number of $180(^{\circ})$ Allow $180(^{\circ})$ or $(n + \frac{1}{2}) \times 2\pi(\text{rad})$ or odd number of π (rad) or odd number of $180(^{\circ})$ Special case: 1 mark for 'completely in phase for bright fringes / constructive (interference) and in anti-phase / completely out of phase for dark fringes / destructive (interference)'
		ii	$\lambda = \frac{3.0 \times 10^8}{4.75 \times 10^{14}}$ or $\lambda = 6.316 \times 10^{-7} \text{ (m)}$ $x = \frac{6.316 \times 10^{-7} \times 8.2}{0.20 \times 10^{-3}}$ or $x = 0.0259 \text{ (m)}$ $t = 0.14 \text{ (s)}$	C1 C1 A1	Note the answer must be given to 2 SF for this mark Special case: allow 1 mark for $8.6 \times 10^{-11} \text{ s}$ on the answer line; incorrect physics using $0.18 = 4.75 \times 10^{14} \lambda$
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
36	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	Allow astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) <u>Examiner's Comments</u>  Misconception Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	$M = 5.97 \times 10^{24}(\text{kg})$ or ISS orbital radius $R = 6.78 \times 10^6(\text{m})$ or $g \propto 1/r^2$ $(gr^2 = \text{constant so}) g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ $g = 8.66 (\text{N kg}^{-1})$	C1 C1 A1	or $g (= GM/R^2) = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ Allow rounding of final answer to 2 SF i.e. 8.7 (N kg ⁻¹) <u>Examiner's Comments</u> The simplest method here was to use the fact that g is inversely proportional to r^2 , so $gr^2 = \text{constant}$. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g . Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating $(6.37 \times 10^6 + 4.1 \times 10^5)$ incorrectly.
		ii	$2\pi r/T = v$ or $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3 \text{ s } (= 92 \text{ min})$	M1 A1	ECF incorrect value of R from b(i)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_A mc^2$) = $\frac{3}{2}RT$ = $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500 \text{ (m s}^{-1}\text{)}$ (= $7.7 \times 10^3 / 15$)	C1 C1 A1 A0	or $\frac{1}{2}mc^2 = \frac{3}{2}kT$ or $c^2 = 3kT/m$ or $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ not $(7.7 \times 10^3 / 15) = 510 \text{ (m s}^{-1}\text{)}$ <u>Examiner's Comments</u> The success in this question depended on understanding the meaning of the term m in the formula $\frac{1}{2}mc^2 = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took m to be the mass of one mole (the molar mass, M) whereas m is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}Mc^2 = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= IA) = $1.4 \times 10^3 \times 2500 = 3.5 \times 10^6 \text{ W}$ power absorbed = $0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5 \text{ W}$ cells in Sun for $(92 - 35 =) 57$ minutes average power = $57/92 \times 2.45 \times 10^5 = 1.5 \times 10^5 \text{ (W)}$	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation $(90 - 35 =) 55$ minutes using $T = 90$ minutes ECF value of T from b(ii) $55/90 \times 2.45 \times 10^5 = 1.5 \times 10^5 \text{ (W)}$ using $T = 90$ minutes <u>Examiner's Comments</u> Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
37	a		$c = f\lambda$ or $f = 3.0 \times 10^8 / 0.60$	C1	Allow $v = f\lambda$
			$f = 5.0 \times 10^8$ (Hz)	A1	Allow 5×10^8

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	b	Level 3 (5 – 6 marks) Response shows clear distinction between investigations; clear and correct reasoning is given for the situations which give maximum / minimum readings in <u>both</u> cases, including correct numerical values <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Response refers to both investigations; some reasoning is given for the situations which give maximum / minimum readings in <u>both</u> investigations, including some numerical values <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Limited reasons are given for the situations which give maximum / minimum readings in <u>either</u> investigation <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	B1 x 6	Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2⁺ for 3 marks, etc. Indicative scientific points may include: explanation 1 • receiver aerial vertical – electrons are driven (maximum distance) up and down along the length of the aerial because the oscillations (of the electric field) are vertical, causing maximum (a.c.) current • receiver aerial horizontal – electrons are driven (minimum distance) across the aerial because the oscillations (of the electric field) are only in the vertical plane (no oscillation along the aerial to cause current), so zero / minimum current • rotation of receiver aerial by $\pm 90^\circ$ (or 90° and 270°) from vertical leads to zero current explanation 2 • reflected wave superposes with incident wave at receiver aerial • coherent waves as from same source • constructive interference / waves in phase gives max current • reflected wave has travelled $n\lambda$ further, $n = 0, 1$, etc • so max current when plate is at $\lambda/2$, $2\lambda/2$, etc from receiver aerial, i.e. 30, 60 cm • destructive interference / waves 180° (π rad) out of phase gives zero current • reflected wave has travelled $(2n + 1)\lambda/2$ further, $n = 0, 1$, etc • so zero current when plate is at $\lambda/4$, $3\lambda/4$, etc from receiver aerial, i.e. 15, 45 cm • reflected signal will be weaker the further it has to travel so no longer complete cancellation (ammeter reads close to zero)

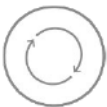
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Note: Give full credit to candidates who take the 180° (π rad) phase change on reflection into account, which gives max current at 15, 45 cm etc and zero current at 30, 60 cm etc. <u>Examiner's Comments</u> This was the second of the two LoR questions in this paper. It required knowledge of polarisation, superposition and interference. There is no one perfect model response but generally, for Level 3, candidates were required to give clear reasoning for the situations which gave both maximum and minimum readings in both investigations. Such candidates included correct numerical values in their responses (although 'half a wavelength' was acceptable in place of 30cm). Level 2 responses were sometimes incomplete (e.g. giving the maximum position but not the minimum position) or confused (e.g. the maximum and minimum positions were given but were the wrong way around). Level 1 responses came from candidates who misunderstood the physics of one of the situations, or who confused phase difference and path difference, or whose descriptions were generally too vague to gain much credit. It may be helpful to point out that investigation 2 was not about the formation of a stationary wave; rather, it was about two overlapping coherent waves forming regions of constructive and destructive interference. A common misconception was that the maximum and minima signals were related to antinodes and nodes.  Misconception A minimum or zero reading does not occur when two waves are merely out of phase. They must be <i>completely</i> out of phase. The best way to describe this is to say that they are <i>in antiphase</i>.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
38	a	i	$F = QE = QV / d$ or $E = 5(.0) \times 10^4 \text{ (Vm}^{-1}\text{)}$ $F = 9.0 \times 10^{-9} \times 4000 / 8.0 \times 10^{-2} (= 4.5 \times 10^{-4} \text{ N})$	C1 A1	$F = 5.0 \times 10^4 \times 9.0 \times 10^{-9}$ Examiner's Comments Many lower ability candidates did not appreciate the uniform nature of the electric field between the plates and attempted to use Coulomb's Law.
		ii	weight; arrow vertically downwards tension; arrow upwards in direction of string electric (force); arrow horizontally to the <u>right</u> (not along dotted line)	B1 x 2	All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn Ignore position of arrows Allow W or 0.030(N) (not gravity or g) Allow T Allow F or E or $4.5 \times 10^{-4} \text{ (N)}$ or electrostatic Ignore repulsion or attraction Not electric field / electric field strength / electromagnetic Examiner's Comments Most candidates scored a mark for showing the weight and tension forces accurately. Only a small proportion labelled the electric force arrow correctly and drew it as clearly perpendicular to the plates.  AfL Do not use the word 'gravity' in place of 'weight'

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$W x = F l$ $0.03 x$ $= 4.5 \times 10^{-4} \times 120$ or $= 4.5 \times 10^{-4} \times 1.2$ $x = 1.8 \text{ cm}$ or $x = 0.018 \text{ m}$	M1 M1 A0	Allow any valid alternative approach e.g. M1 deflection angle $\theta = 1^\circ$ M1 $x = 120 \sin \theta$ 1 mark for each side of the equation <u>Examiner's Comments</u> Although most candidates knew the principle of moments, many were unable to apply it correctly in this situation. More practice at this sort of question is recommended.
	b		Electric force/field (strength) increases Ball deflected further from vertical / moves to the right / touches negative plate Ball acquires the charge of the (negative) plate when it touches (Oscillates because) constantly repelled from (oppositely) charged plate	B1 B1 B1 B1	Must be clear which force is increasing Must have the idea of a repeating cycle <u>Examiner's Comments</u> The purpose of this question was to challenge the candidates to use their knowledge of electric fields in a novel practical situation. The word 'oscillate' confused many candidates, who tried to explain why the ball would perform simple harmonic motion.
	c		$I = Qf$ or $Q = It$ $f = 3.2 \times 10^{-8} / 9.0 \times 10^{-9} = 3.6 \text{ (Hz)}$	C1 A1	
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
39			(k.e. =) $E = 5.0 \times 10^6 \times 1.6 \times 10^{-19}$ $v = \sqrt{(2E/m)}$ or $= \sqrt{(2 \times 8.0 \times 10^{-13} / 6.6 \times 10^{-27})} = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ $p (= mv) = 6.6 \times 10^{-27} \times 1.6 \times 10^7$ giving $p = 1.1 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$	C1 C1 A1	$E = 8(.0) \times 10^{-13} \text{ J}$ or ($E = p^2/2m$ so) $p = \sqrt{(2mE)}$ Note: A value of $v = 1.6 \times 10^7 \text{ (ms}^{-1}\text{)}$ automatically scores both C1 marks even if the calculation for E is not shown or $p (= \sqrt{(2mE)}) = \sqrt{(2 \times 6.6 \times 10^{-27} \times 8.0 \times 10^{-13})}$ giving $p = 1.0 \times 10^{-19} \text{ (kg m s}^{-1}\text{)}$ Full substitution of values must be shown and answer (if calculated) must be correct <u>Examiner's Comments</u> This question provided an excellent opportunity for candidates to produce immaculate responses: identify the physics involved, select and write down the correct formula, do the necessary conversion (MeV to J), rearrange the formula, substitute correctly and then write the final response in standard form to a correct number of significant figures. Some of the common errors were: • forgetting to convert 5.0 MeV into J • not showing a full substitution of values (which is necessary for a 'show that' question) • not calculating the response to more than 1 s.f. (which is necessary for a 'show that' question).
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
40		i	sensible diameter, e.g. 7 (mm) (power = $4.8 \times 10^{-7} \times \pi \times (0.0035)^2$) power = 1.8×10^{-11} (W)	C1 A1	Allow 2 – 16 (mm) Not πd^2 ; this is XP Note check for AE (condone rounding error here) Possible ECF for diameter outside the range 2 – 16 (mm) Allow 1 SF answer here
		ii	($I \propto A^2$; intensity doubles) $A = \sqrt{2} \times 7.8$ (or equivalent) $A = 11$ (nm)	C1 A1	Allow the C1 mark for $4.8 (\times 10^{-7}) = k \times [7.8 \times (10^{-9})]^2$
			Total	4	