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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Waves (4.4)

A Level Physics A (H556) · Module 4: Electrons, waves and photons

96 questions · 534 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions run from the lowest mark tariff to the highest, so similar questions sit together.
Click any row below to jump straight to that question.
On every question page, click ANSWER in the top-right corner to jump to its mark scheme.
Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

96 questions · 534 marks · lowest tariff first

MULTIPLE-CHOICE QUESTIONS

48 questions in this booklet

7 The intensity against wavelength graph of an object at 750 °C peaks at a wavelength of λ. The temperature of the object is raised to 960 °C.

What is the wavelength now at the new peak intensity in terms of λ?

A 0.78λ

B 0.83λ

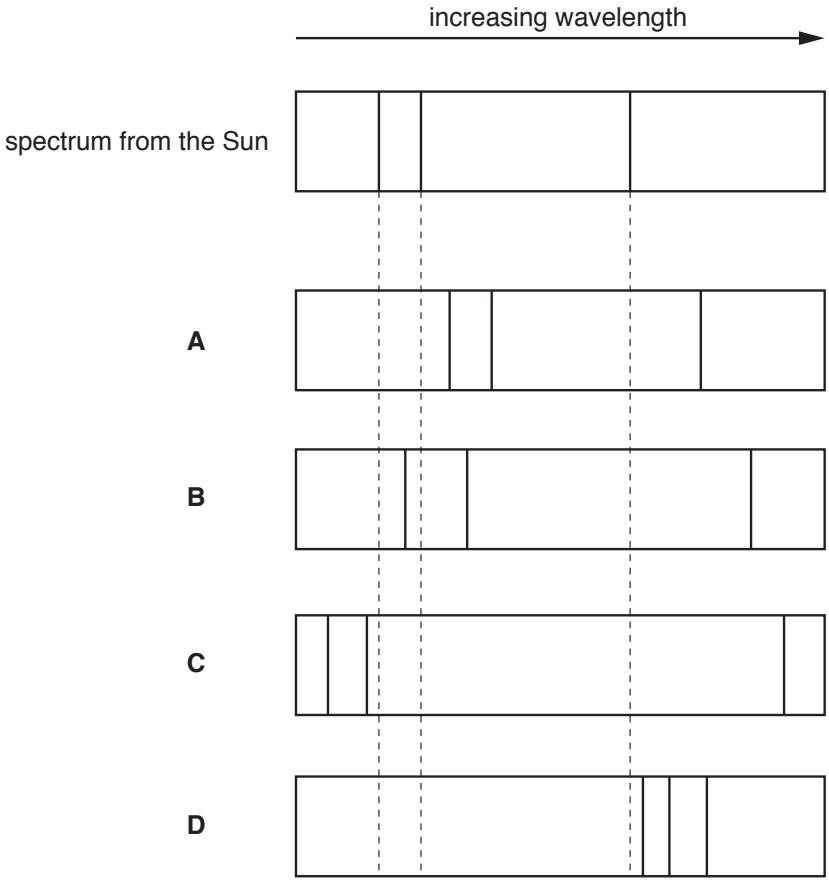
C 1.2λ

D 1.3λ

Your answer ☐ **[1]**

10 Part of the line spectrum for light from the Sun is shown below.

Which spectrum best shows light from a similar star to the Sun?



Your answer ☐ **[1]**

5 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 $0.16I$

B $0.4I$

C $1.6I$

D $2.6I$

Your answer ☐ **[1]**

6 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]**

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14 There are four important attenuation mechanisms by which X-ray photons may interact when they pass through matter.

In which mechanism is the X-ray photon scattered with a longer wavelength?

A simple scattering

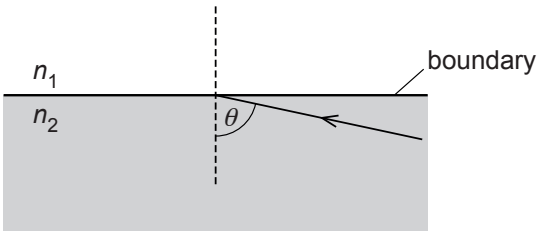
B Compton effect

C pair production

D photoelectric effect

Your answer ☐ **[1]**

15 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]**

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SECTION B

Answer **all** the questions.

3 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 $10^{-30}\,kg\,m\,s^{-1}$

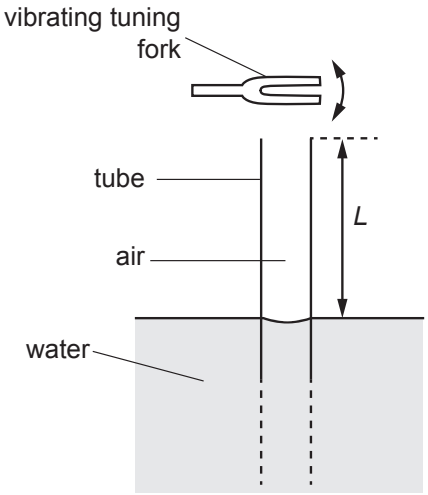
B $10^{-27}\,kg\,m\,s^{-1}$

C $10^{-23}\,kg\,m\,s^{-1}$

D $10^{-18}\,kg\,m\,s^{-1}$

Your answer ☐ **[1]**

4 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]**

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7 A small loudspeaker emits sound uniformly in all directions.
The amplitude of the sound is 12 μm 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 μm

B 4.0 μm

C 6.9 μm

D 12 μm

Your answer ☐ **[1]**

3 A solid cylindrical glass rod has length 20.0 ± 0.1 cm and diameter 5.00 ± 0.01 mm.

What is the percentage uncertainty in the calculated volume of this rod?

A 0.1%

B 0.2%

C 0.7%

D 0.9%

Your answer ☐ **[1]**

4 A simple harmonic oscillator has maximum speed 24 m s^{-1} and amplitude 5.6 cm.

What is its angular frequency?

A 0.23 rad s^{-1}

B 21 rad s^{-1}

C 68 rad s^{-1}

D 430 rad s^{-1}

Your answer ☐ **[1]**

15 An astronomer analyses the light from a distant galaxy.
One of the spectral lines in the spectrum observed from the galaxy has wavelength 610 nm.
The same spectral line has a wavelength of 590 nm when measured in the laboratory.

What is the speed of this galaxy?

A $9.8 \times 10^{6}\,m\,s^{-1}$

B $1.0 \times 10^{7}\,m\,s^{-1}$

C $2.9 \times 10^{8}\,m\,s^{-1}$

D $3.0 \times 10^{8}\,m\,s^{-1}$

Your answer ☐ **[1]**

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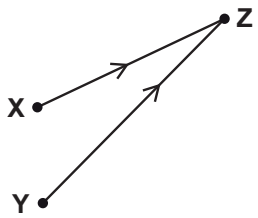
Question 16 begins on page 10

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SECTION B

Answer **all** the questions.

4 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]**

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Turn over

7 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

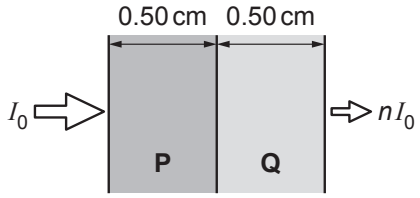
C Only 1 and 2

D 1, 2 and 3

Your answer ☐ **[1]**

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12 The intensity of a beam of X-rays incident on material **P** is I_0.
The beam passes through 0.50 cm of material **P** and 0.50 cm of material **Q**.



The absorption (attenuation) coefficients of **P** and **Q** are 0.60 cm^{-1} and 0.20 cm^{-1} respectively.
The intensity of the beam after passing through both **P** and **Q** is nI_0.

What is the value of n?

A 0.67

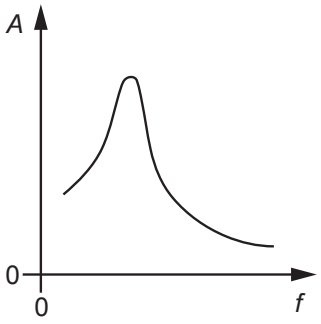
B 0.74

C 0.82

D 0.90

Your answer ☐ **[1]**

4 An oscillator is forced to oscillate at different frequencies.
The graph of amplitude *A* against driving frequency *f* for this oscillator is shown.



The damping on the oscillator is now **decreased**.

Which of the following statements is/are correct?

1 The amplitude of the oscillations at any frequency decreases.
2 The maximum amplitude occurs at a lower frequency.
3 The peak on the graph becomes thinner.

A Only 1

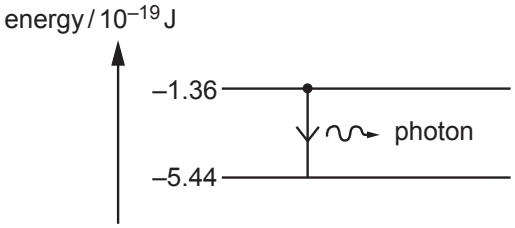
B Only 2

C Only 3

D 1, 2 and 3

Your answer ☐ **[1]**

6 The diagram below shows two energy levels for the electron in the hydrogen atom.



The electron makes the transition shown by the arrow.

What is the wavelength of the photon emitted?

A 293 nm

B 366 nm

C 488 nm

D 1460 nm

Your answer ☐ **[1]**

9 Laser light of wavelength of 640 nm is incident normally at a diffraction grating.
The separation between adjacent lines (slits) is 3.3×10^{-6} m.

What is the **total** number of bright spots that can be observed in the diffraction pattern?

A 5

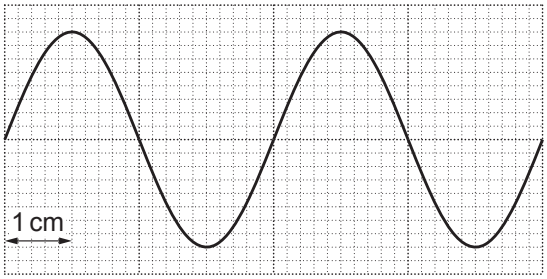
B 6

C 10

D 11

Your answer ☐ **[1]**

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



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

What is the frequency of the signal?

A 125 Hz

B 250 Hz

C 125 kHz

D 250 kHz

Your answer ☐ **[1]**

6 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.

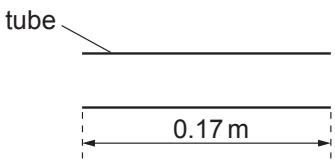
C All particles oscillating between two adjacent nodes in a stationary wave are in phase.

D The superposition of two waves travelling in the same direction produces a stationary wave.

Your answer ☐ **[1]**

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11 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]**

15 What can be deduced from the diffraction of electrons by a thin film of graphite?

A Electrons are leptons.

B Electrons are negatively charged.

C Electrons interact with atoms on a one-to-one basis.

D Electrons travel as waves.

Your answer ☐ **[1]**

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SECTION B

Answer **all** the questions.

5 A spectral line corresponds to a wavelength λ_1 in the laboratory.
The same spectral line observed in the spectrum of a receding galaxy corresponds to a wavelength λ_2.
The distance of the galaxy from the Earth is d. The speed of light in a vacuum is c.

What is the correct expression for the Hubble constant H_0?

A $H_0 \approx \frac{c(\lambda_2 - \lambda_1)}{d\lambda_1}$

B $H_0 \approx \frac{c\lambda_1}{d(\lambda_2 - \lambda_1)}$

C $H_0 \approx \frac{c\lambda_2}{d\lambda_1}$

D $H_0 \approx \frac{c\lambda_1}{d\lambda_2}$

Your answer ☐ **[1]**

6 For a simple harmonic oscillator, the maximum speed is v_{max} when the amplitude is A. The frequency of the oscillations is f.

Which expression is correct for this oscillator?

A $v_{max} = fA$

B $v_{max} = 2\pi fA$

C $v_{max} = f^2A$

D $v_{max} = 4\pi^2f^2A$

Your answer ☐ **[1]**

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2 Monochromatic light from a laser is incident normally on a diffraction grating.
A series of bright dots are formed on a distant screen.

Which **two** terms can be used to explain these bright dots?

A diffraction, interference

B reflection, interference

C refraction, diffraction

D refraction, reflection

Your answer ☐ **[1]**

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8 A double-slit is used in an interference experiment to independently investigate the light from two sources **K** and **L**. The light from the sources have different wavelengths.
The table below shows some data.

Light source	Wavelength of light	Separation between adjacent bright fringes	Distance between screen and double-slit
K	λ	1.2 mm	D
L	0.80λ		$0.50D$

What is the separation between adjacent bright fringes for source **L**?

A 0.48 mm

B 1.2 mm

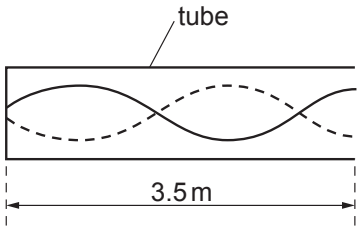
C 1.9 mm

D 3.0 mm

Your answer ☐ **[1]**

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9 A stationary sound wave formed in a tube is shown below.



The tube is closed at one end. The length of the tube is 3.5 m.
The speed of sound is 340 m s^{-1}.

What is the frequency of the sound wave?

A 97 Hz

B 120 Hz

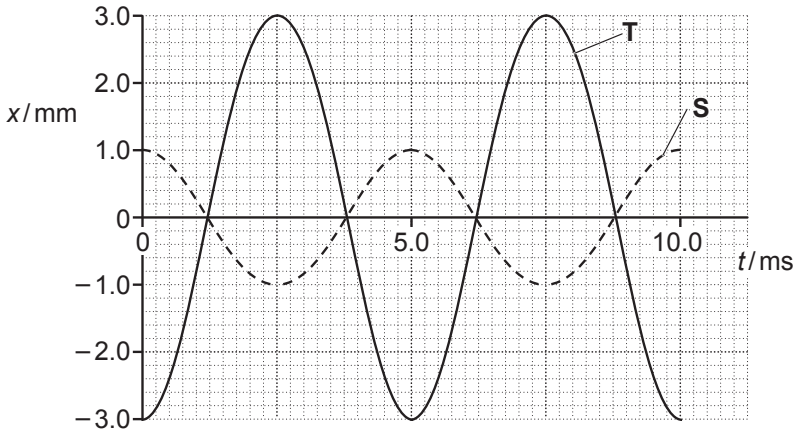
C 240 Hz

D 486 Hz

Your answer ☐ **[1]**

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11 The diagram below shows the graphs of displacement x against time t for two waves **S** and **T**.



The waves meet at a point in space.
The superposition of these two waves produces a resultant wave.

What is the frequency f and the amplitude A of the resultant wave?

A $f = 100\,\text{Hz}$, $A = 2.0\,\text{mm}$

B $f = 100\,\text{Hz}$, $A = 4.0\,\text{mm}$

C $f = 200\,\text{Hz}$, $A = 2.0\,\text{mm}$

D $f = 200\,\text{Hz}$, $A = 4.0\,\text{mm}$

Your answer ☐ **[1]**

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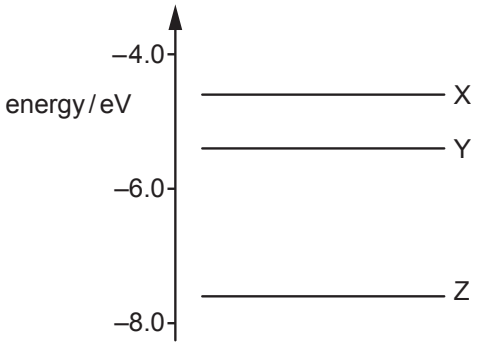
1 A student has constructed the table below of possible scalar and vector quantities.

	Scalar	Vector
A	acceleration	momentum
B	displacement	amplitude
C	frequency	wavelength
D	mass	centripetal force

Which row is correct?

Your answer ☐ **[1]**

12 The diagram shows three energy levels X, Y and Z of an electron within a gas atom.



Which transition is correct when the electron absorbs a photon with the shortest wavelength?

A Z ⟶ X

B X ⟶ Z

C Y ⟶ X

D X ⟶ Y

Your answer ☐ **[1]**

13 Light from a hydrogen source is incident normally at a diffraction grating. The first order maximum of the H-alpha spectral line of wavelength 486 nm is observed at angle of 30.0°.

Light from a distant receding star is observed using the same diffraction grating. The light is incident normally at the grating as before. The speed of this star is 0.16*c*, where *c* is the speed of light in a vacuum.

What is the observed angle of the first order maximum of the H-alpha spectral line from the light of this receding star?

A 24.8°

B 30.0°

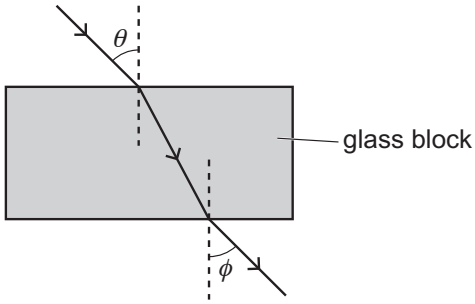
C 34.8°

D 35.5°

Your answer ☐ **[1]**

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9 A student is investigating the refraction of light by a rectangular glass block. The glass block is surrounded by air.
The diagram below shows the path of the light as it enters the block, when it is refracted within the block and when it exits the block.



Which statement is correct?

A The angles θ and ϕ are the same because the glass block is surrounded by air.

B The product of $\sin\theta$ and the refractive index of glass is a constant.

C The refractive index of glass is less than the refractive index of air.

D The speed of light is the same in both air and glass.

Your answer ☐ **[1]**

10 A proton of mass 1.67×10^{-27} kg is travelling at a speed of 2.0×10^{5} m s^{-1}.

The table below shows the mass and speed of four particles **A**, **B**, **C** and **D**.

Particle	Mass / kg	Speed / 10^5 m s^{-1}
A	9.11×10^{-30}	5.0
B	8.80×10^{-28}	3.0
C	2.49×10^{-28}	2.0
D	3.34×10^{-27}	1.0

Which particle has the same de Broglie wavelength as the proton?

Your answer ☐ **[1]**

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11 A beam of sound of intensity I_0 is reflected off the surface of water.
The amplitude of the reflected sound is $\frac{1}{4}$ the amplitude of the incident sound.

What is the intensity of the reflected sound in terms of I_0?

A $\frac{I_0}{16}$

B $\frac{I_0}{8}$

C $\frac{I_0}{4}$

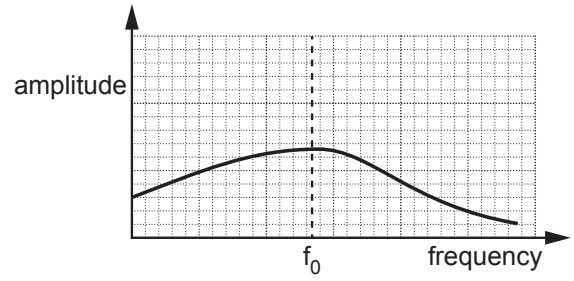
D I_0

Your answer ☐ **[1]**

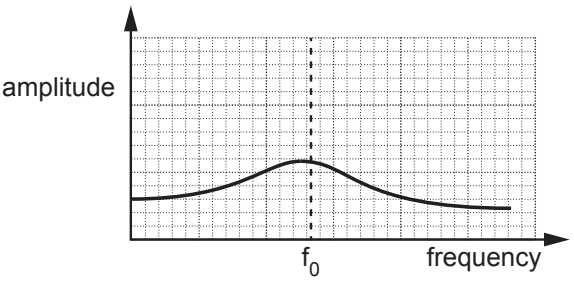
12 Four different oscillator systems are forced to oscillate at various frequencies. The graphs show the amplitude of oscillation for each frequency. f_0 is the undamped resonant frequency for each oscillator. The vertical axes on the graphs are all to the same scale.

Which of the oscillators, **A** to **D**, is the most heavily damped?

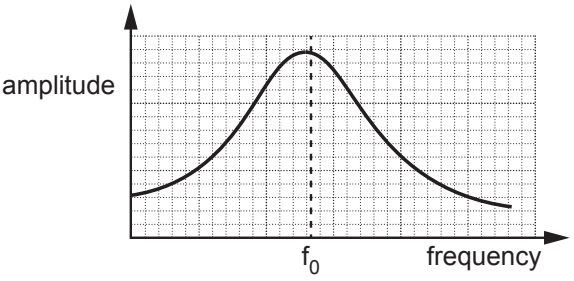
A



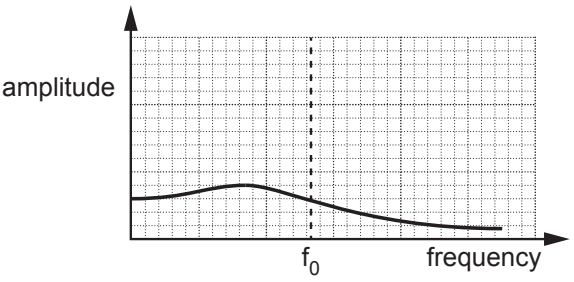
B



C



D



Your answer ☐ **[1]**

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Turn over

10 A column of air in a tube of length *L*, closed at one end, is forced to vibrate at its fundamental frequency. A standing wave is set up inside the tube.

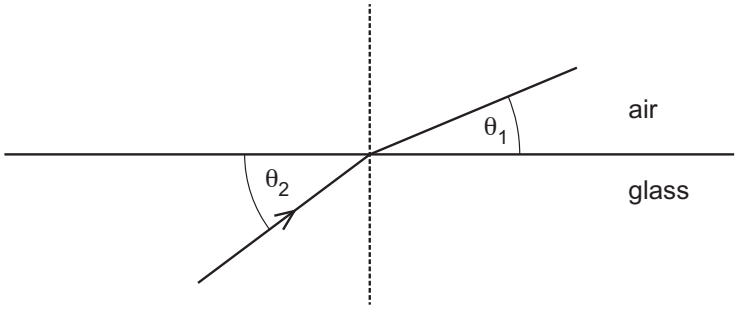
Which row in the table is correct for this standing wave?

	Number of nodes inside the tube	Wavelength / m
A	1	L
B	1	2L
C	1	4L
D	2	2L

Your answer ☐ **[1]**

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11 A ray of light is travelling through glass with refractive index n = 1.51. The diagram (not to scale) shows light incident on a glass / air interface.



Which of these statements is/are true?

1 wavelength of light in glass < wavelength of light in air

2 $n_{glass} = 2n_{air}$

3 $\theta_2 > 48°$

A 1 only

B 1 and 2

C 3 only

D 1 and 3

Your answer ☐ **[1]**

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10 The natural frequency of an oscillator vibrating in air is 20 Hz.

Which statement is correct about this oscillator?

A The natural period of the vibrating oscillator is 5.0 ms.

B The oscillator can be forced to vibrate at maximum amplitude at a frequency of about 20 Hz.

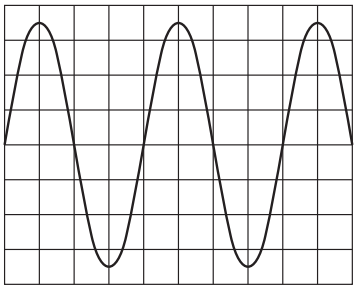
C The oscillator can be made to resonate at a frequency of about 40 Hz.

D The period of the freely vibrating oscillator gets smaller as its amplitude decreases.

Your answer ☐ **[1]**

6 The image shows a display of an oscilloscope which is measuring an alternating voltage. The time base is set at 0.1 s / division. The voltage scale (y-sensitivity) is set at 0.5 V / division.

Which row of the table shows the correct amplitude and correct frequency?

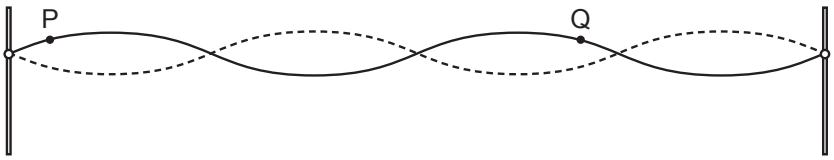


	amplitude / V	frequency / Hz
A	1.75	0.4
B	1.75	2.5
C	3.50	0.4
D	3.50	2.5

Your answer ☐ **[1]**

9 The diagram shows a string stretched between two posts.

The string is plucked and a stationary wave is set up.



What is the phase difference between P and Q?

A 0 rad

B $\frac{\pi}{4}$ rad

C $\frac{\pi}{2}$ rad

D π rad

Your answer ☐ **[1]**

11 Monochromatic light of wavelength 600 nm is passed through a diffraction grating.

Maxima are formed on a screen 3.0 m from the grating. The distance between the two first order maxima, on either side of the zero maximum, is 1.42 m.

What is the spacing, in m, between lines on the diffraction grating?

A 1.3×10^{-6}

B 1.4×10^{-6}

C 2.5×10^{-6}

D 2.6×10^{-6}

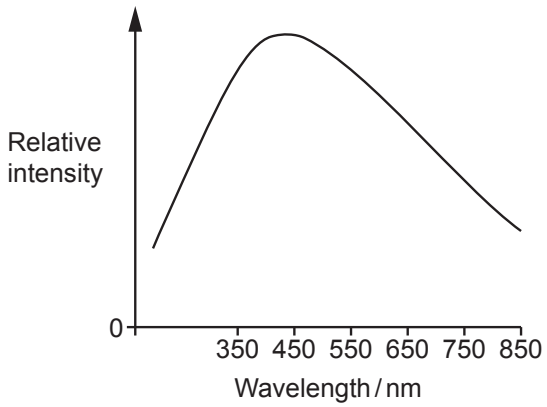
Your answer ☐

[1]

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13 The surface temperature of the Sun is 5800 K and the peak wavelength is 500 nm.

What is the surface temperature, in K, of the star represented by the graph below?



A 3400

B 5200

C 6400

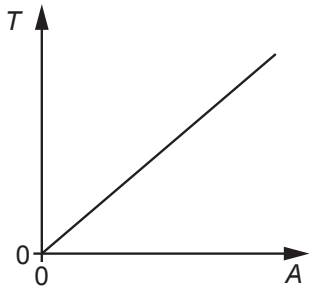
D 9900

Your answer ☐

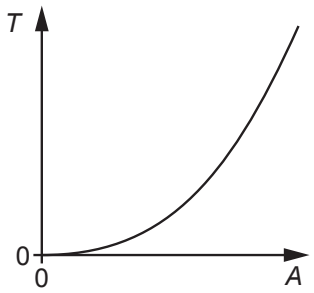
[1]

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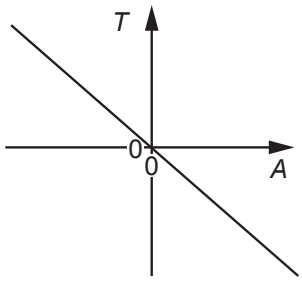
14 A body moves with simple harmonic motion. Which graph shows the correct relationship between its period, T, and its amplitude, A?



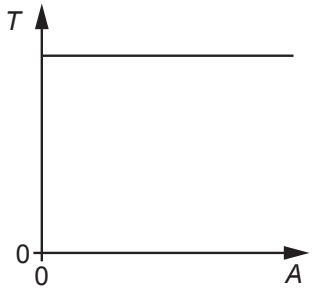
A



B



C



D

Your answer ☐

[1]

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15 Which of these statements about the Universe is implied by the Cosmological principle?

A Dark energy is found in every galaxy

B Kepler's laws can be applied to any solar system

C Matter and anti-matter were formed in the very early Universe

D Microwave background radiation corresponds to a temperature of 2.7 K

Your answer ☐

[1]

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Turn over

Section B

8 A student uses a tube closed at one end to determine the speed of sound. A stationary wave is formed within the tube.

Which of the following quantities can be used to determine the speed of sound in air?

A length of air column in tube, number of antinodes

B length of air column in tube, resonant frequency

C number of nodes, number of antinodes

D number of nodes, resonant frequency

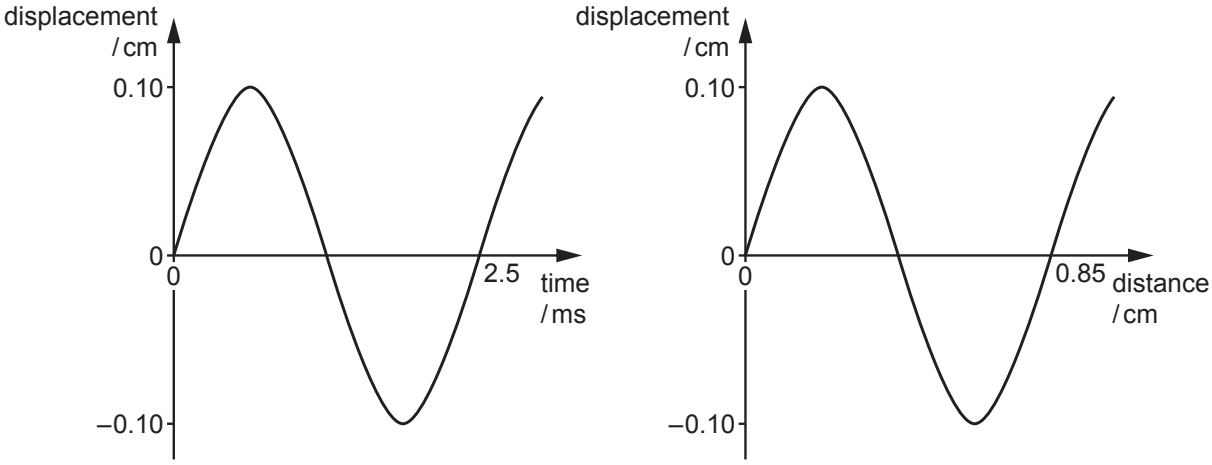
Your answer ☐

[1]

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Turn over

10 The diagrams show representations of a progressive wave.



Which row of the table correctly identifies its properties?

	Amplitude / cm	Frequency / Hz
A	0.10	400
B	0.85	2500
C	0.85	400
D	0.10	2500

Your answer ☐

[1]

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11 A proton with kinetic energy 1.6×10^{-17} J is travelling at right angles to a magnetic field. The magnetic flux density is 0.050 T.

What is the magnitude of the force on the proton?

A 8.0×10^{-19} N

B 1.1×10^{-15} N

C 2.8×10^{-6} N

D 6900 N

Your answer ☐

[1]

12 The intensity of the Sun's radiation at the surface of the Earth is 1400 W m^{-2}.

The distance between the centre of the Sun and the surface of the Earth is 1.5 × 10^{8} km.

How much mass is converted into radiant energy in the Sun in one second?

A 3.5 × 10^{8} kg

B 1.1 × 10^{9} kg

C 4.4 × 10^{9} kg

D 1.3 × 10^{18} kg

Your answer ☐

[1]

4-MARK QUESTIONS

2 questions in this booklet

19 Fig. 19 is an incomplete Hertzsprung-Russell (HR) diagram of stars in our galaxy.

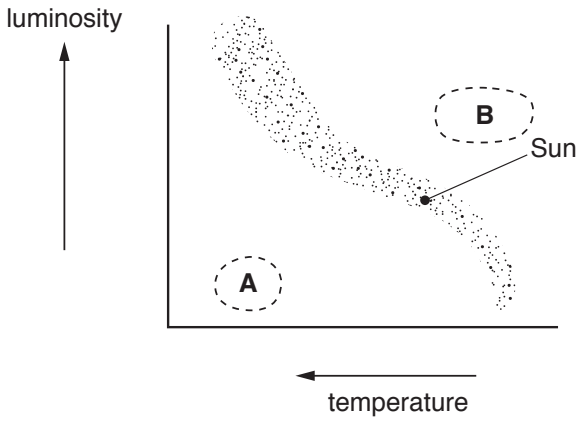


Fig. 19

The position of the Sun on the HR diagram is shown in Fig. 19.

(a) State the type of stars found in regions **A** and **B**.

A ..... **B** ..... **[1]**

(b) The Sun is a main sequence star. Its surface temperature is 5800 K. The wavelength of the emitted light at maximum intensity is 550 nm.

Beta Pictoris is also a main sequence star. The wavelength of the emitted light at maximum intensity from this star is 370 nm.

(i) Calculate the surface temperature of Beta Pictoris.

temperature = ... K **[2]**

(ii) On Fig. 19, mark the likely position of Beta Pictoris with a letter **P**. **[1]**

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18 **Fig. 18** represents a tube open at both ends.

Air inside the tube is forced to oscillate by a speaker and produces a standing wave.

The length of the tube is 30.0 cm.

The wave speed inside the tube is 340 ms^{-1}.

(a) On **Fig. 18** sketch the standing wave for the fundamental mode of vibration.

Fig. 18

[1]

(b) Calculate the frequency f_0 of the speaker that is producing the standing wave inside the tube.

f_0 = ... Hz **[1]**

(c) The frequency of the speaker is increased.

Calculate the next frequency f_1 that will produce a standing wave in this tube.

f_1 = ... Hz **[2]**

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5-MARK QUESTIONS

2 questions in this booklet

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

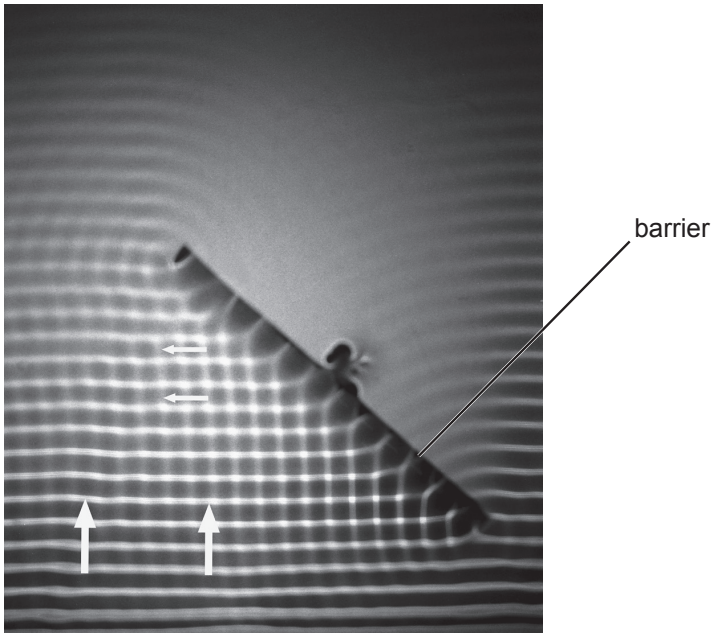


Fig. 19.1

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]**

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(b) Two transmitters, **A** and **B**, emit coherent microwaves in all directions. A receiver is moved at constant speed along the line from **P** to **Q** which is parallel to the line joining the two transmitters, as shown in Fig. 19.2.

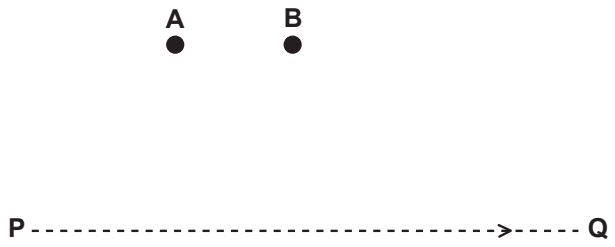


Fig. 19.2

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

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..... **[3]**

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

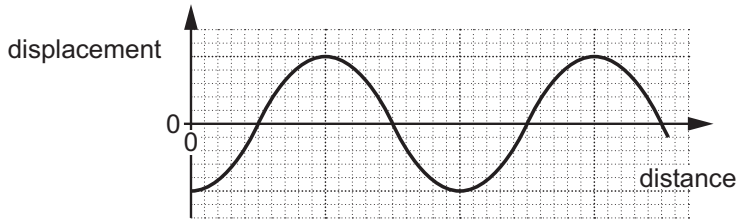


Fig. 17.1

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.

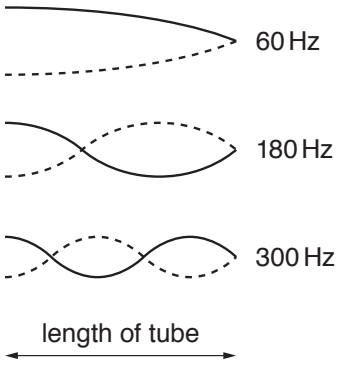


Fig. 17.2

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.

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..... **[3]**

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6-MARK QUESTIONS

4 questions in this booklet

16 **(a)** State the *principle of superposition* of waves.

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..... **[1]**

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

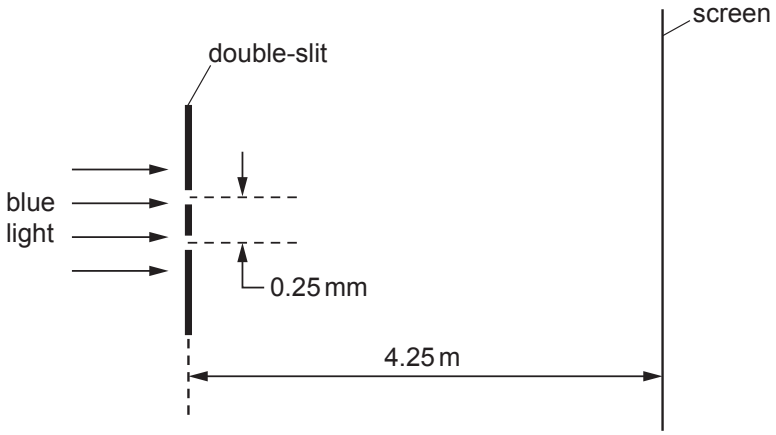


Fig. 16.1

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**.

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(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]**

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24 A group of students are conducting an experiment to determine the wavelength of monochromatic light from a laser.
Fig. 24.1 shows the laser beam incident normally at a diffraction grating.

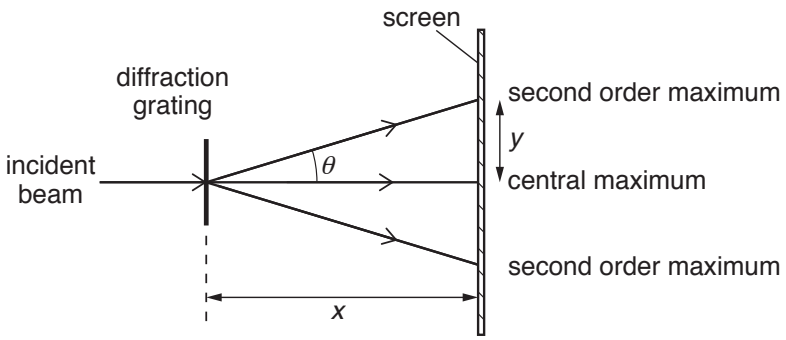


Fig. 24.1

The students use a diffraction grating with 600 lines mm^{-1}. They vary the distance x between the grating and the screen from 1.000 m to 2.000 m. They measure the distance y from the **central** maximum to the **second order** maximum.

(a) The students decide to plot a graph of y against $\sqrt{x^2 + y^2}$.

Show that the gradient of the graph is equal to sin θ, where θ is the angle between the central maximum and the **second** order maximum.

[1]

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(b) Fig. 24.2 shows the graph plotted by the students.

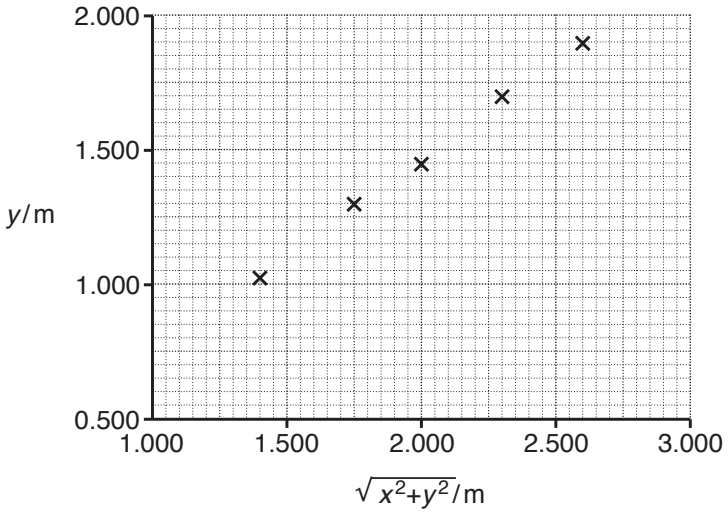


Fig. 24.2

(i) Use Fig. 24.2 to determine an accurate value of the wavelength λ of the light from the laser.

λ = ... m **[3]**

(ii) Suggest why there are no error bars shown in Fig. 24.2.

.....

..... **[1]**

(iii) Suggest how the precision of this experiment may be affected by using a protractor to measure the angle θ.

.....

..... **[1]**

22* A star has a mass similar to that of the Sun.

Describe how the position of this star on a Hertzsprung-Russell (H-R) diagram changes as it evolves.

Fig. 22.1 is a blank H-R diagram.

You may add information to **Fig. 22.1** as part of your response.

Fig. 22.2 shows the relative intensities of different wavelengths of light in the spectrum of a star.

Explain how information from **Fig. 22.2** could be used to suggest the stage of evolution of the star. Describe the limitations of the analysis.

[6]

Fig. 22.1

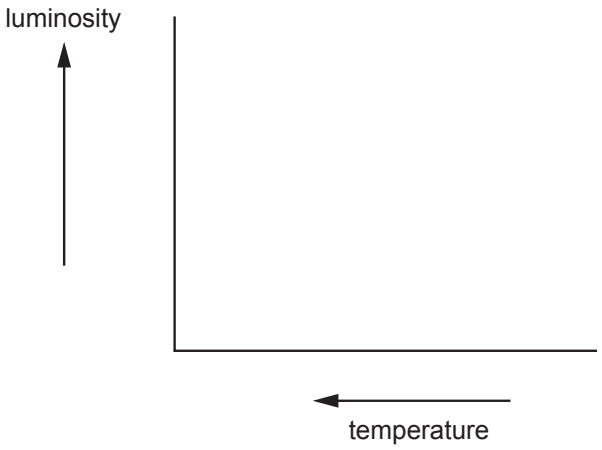
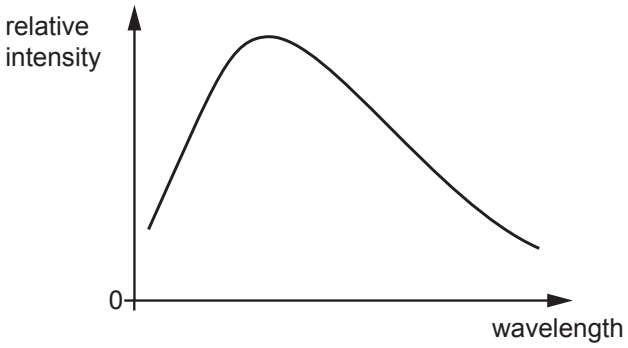


Fig. 22.2



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Additional space if required

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19* Describe how to determine the wavelength λ of a monochromatic laser pointer using a diffraction grating.

As part of your answer, explain how to

- analyse the measurements collected using a graphical method.
- improve the accuracy of the measurements taken.

You are given the number of lines per mm for the diffraction grating.

[6]

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Additional space if required

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7-MARK QUESTIONS

2 questions in this booklet

18 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.

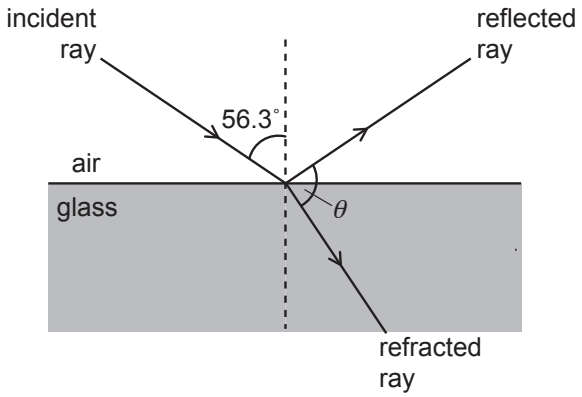


Fig. 18 (not to scale)

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°.

(a) 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.

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..... **[2]**

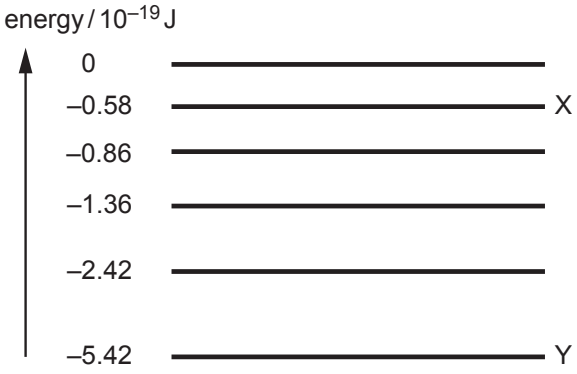
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(c) Calculate the time *t* taken for the refracted light to travel a **depth** of 6.0 cm of glass.

t = ... s **[2]**

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23 The diagram shows some of the energy levels of the electron in a hydrogen atom.



(a) An electron moves from energy level X to energy level Y.

Show that the wavelength of the photon produced is about 410 nm.

[2]

(b) The light from the stars in a distant galaxy is analysed on the Earth using a diffraction grating.

Dark lines are observed in the spectrum.

An astronomer concludes that the dark line at a wavelength 432 nm corresponds to the electron transition between X and Y.

(i) Explain the origin of the dark lines.

.....

.....

.....

..... **[2]**

(ii) Calculate the recession velocity v of the galaxy.

v = ... $m\,s^{-1}$ **[2]**

(iii) State the name of the theory that is supported by evidence from the measurement of the recession velocities of galaxies in the universe.

..... **[1]**

8-MARK QUESTIONS

4 questions in this booklet

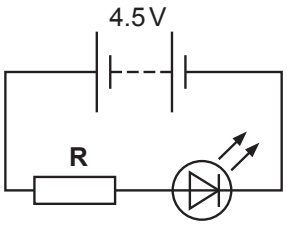
17 A light-emitting diode (LED) emits red light when it is positively biased and has a potential difference (p.d.) greater than about 1.8 V.

(a) The energy of a photon of red light is about 1.8 eV.

Calculate the wavelength λ of this red light.

λ = ... m **[3]**

(b) The LED is connected into a circuit, as shown below.



The battery has electromotive force (e.m.f.) 4.5 V and negligible internal resistance.
The resistor **R** has resistance 150 Ω.
Assume the p.d. across the LED is 1.8 V.

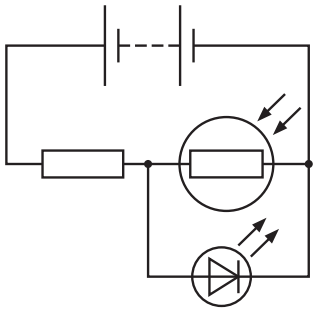
Calculate the ratio $\frac{\text{power dissipated by LED}}{\text{power dissipated by resistor}}$.

ratio = ... **[2]**

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Turn over

(c) The diagram below shows a circuit designed by a student.



The LED is very close to, and facing the light dependent resistor (LDR).
The circuit is taken into a dark room.

(i) The student thought that the LED would switch on.
Instead, the LED was found to repeatedly switch on and off.

Explain this behaviour of the LED in this potential divider circuit.

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..... **[2]**

(ii) Suggest a possible refinement so that the LED switches on permanently when taken into the dark room.

.....

..... **[1]**

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Turn over

21 **(a)** A high-energy X-ray photon interacts with an electron of an atom through the **Compton effect**.

Describe this effect.

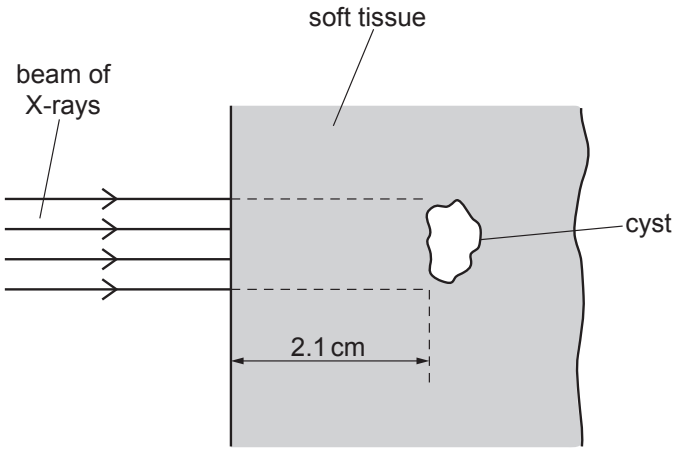
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..... **[2]**

(b) The diagram below shows a beam of X-rays incident normally on some soft tissue.



The attenuation (absorption) constant of the soft tissue is $0.85\,cm^{-1}$.
The intensity of the beam is $4.6 \times 10^{3}\,W\,m^{-2}$.
There is a small cyst 2.1 cm from the surface of the soft tissue. The cross-sectional area of the cyst normal to the beam is $3.4 \times 10^{-4}\,m^{2}$.

The beam is switched on for 30 s.

Calculate the X-ray energy incident on the cyst in a period of 30 s.

energy = ... J **[4]**

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(c) The attenuation coefficients of the cyst and the soft tissues in **(b)** were similar. This prevented imaging the cyst using a two-dimensional X-ray image.

Name a different X-ray technique that could be used to image the cyst. Explain the advantage of this technique.

.....

.....

..... **[2]**

17 A light-emitting diode (LED) can be used to determine the Planck constant h. When the LED just starts to emit light, the equation below is valid

$$eV = \frac{hc}{\lambda}$$

where V is the potential difference (p.d.) across the LED, λ is the wavelength of the light emitted, c is the speed of light in vacuum and e is the elementary charge.

(a) In the equation above, $\frac{hc}{\lambda}$ is the energy of a photon emitted from the LED.

Determine the S.I. base units for h.

base units = ... **[2]**

(b)* Describe how an experiment can be carried out in the laboratory to determine h from a graph. Your description must include how V and λ are accurately determined. Assume that the values of e and c are known. **[6]**

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Additional answer space if required

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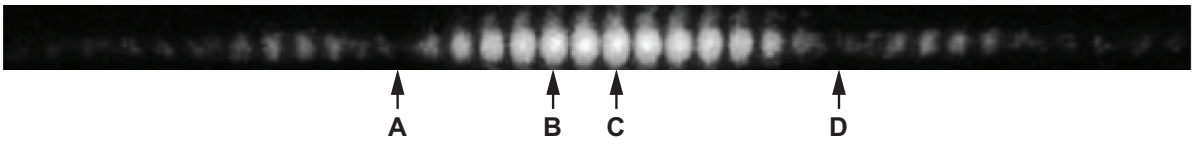
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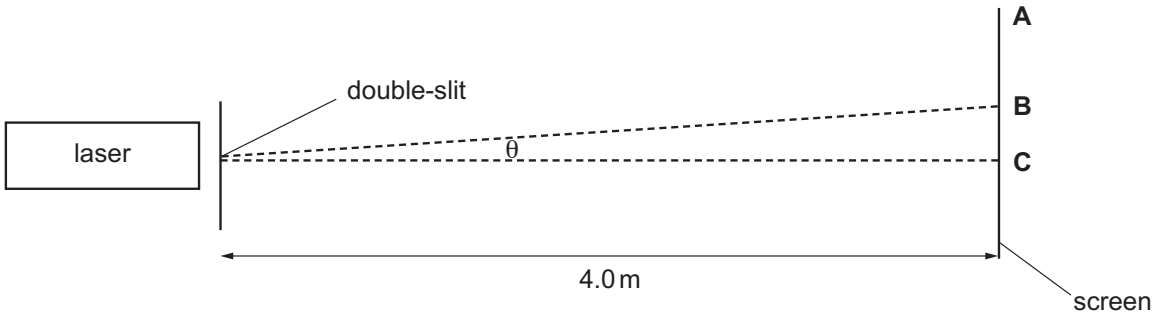
16 **Fig. 16.1** shows the pattern obtained in a Young double-slit experiment. The pattern is **not** to scale. Three regions of the pattern are labelled **A**, **B** and **D**. The central maximum is labelled **C**.

Fig. 16.1



Red light of wavelength 640 nm was used in the experiment. The distance between the centres of the two slits was 1.00×10^{-5} m. The distance from the double-slit to the screen was 4.0 m.

Fig. 16.2



(a) Name the physical processes that cause the features labelled **A**, **D** and **B**, **C** in **Fig. 16.1**.

A and **D** .....

B and **C** ..... **[2]**

(b) The Young double-slit experiment uses **coherent** waves. State what **coherent** means.

.....

..... **[1]**

(c) Explain how the part of the pattern labelled **B** is formed.

.....

.....

..... **[2]**

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(d) Calculate the angle θ from the central maximum **C** to the maximum labelled **B** as shown in **Fig. 16.2**.

θ = ... ° **[3]**

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9-MARK QUESTIONS

6 questions in this booklet

23 **(a)** According to the Cosmological principle, the Universe is isotropic, homogeneous and the laws of physics are universal.

State what is meant by the term *homogeneous*.

.....

..... **[1]**

(b) Astronomers often use absorption spectral lines to determine the relative velocity of distant galaxies. The wavelength of a specific absorption spectral line observed in the laboratory is 280 nm.

The galaxy RXJ1242-11 is 200 Mpc away from the Earth and it has a massive black hole at its centre.

(i) Calculate in nm the wavelength λ of the same spectral line from RXJ1242-11 when **observed** from the Earth. Assume the Hubble constant is 68 km s^{-1} Mpc^{-1}.

λ = ... nm **[3]**

(ii) State one of the characteristics of a black hole.

.....

..... **[1]**

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(c) The Universe evolved from the Big Bang.

Describe the evolution of the Universe up to the formation of the first nuclei.

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..... **[4]**

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5 Hydrogen atoms excited in a discharge tube only emit four different discrete wavelengths of visible photons.

***(a)** In a semi-darkened room, a single slit is placed in front of the discharge tube. A student holds a diffraction grating which has 300 lines per millimetre.
The student looks through the grating at a 15 cm plastic ruler placed 0.50 m away, as shown in Fig. 5.1.
The paths of the different colours of light from the slit to the student's eye are shown in Fig. 5.2.

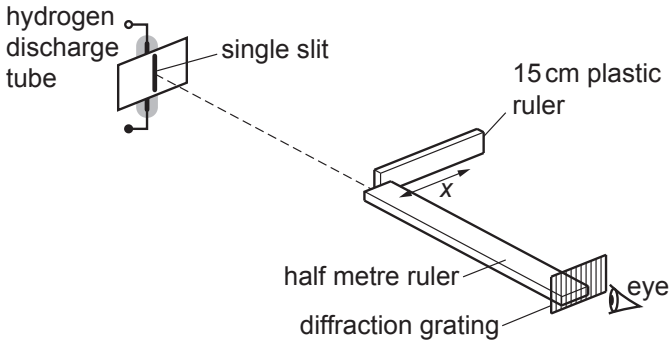


Fig. 5.1 (not to scale)

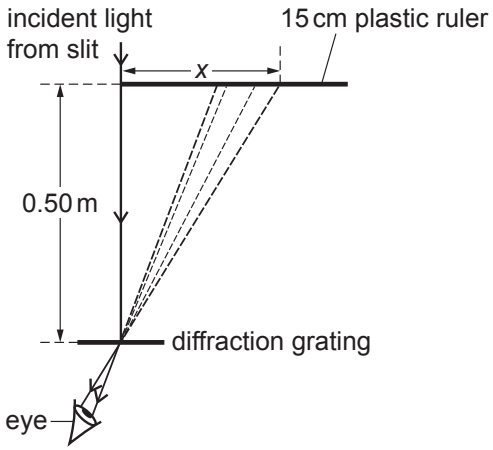


Fig. 5.2 (not to scale)

Four **first** order images of the slit, one at each photon wavelength, are observed as vertical lines against the background of the plastic ruler, as shown in Fig. 5.3.

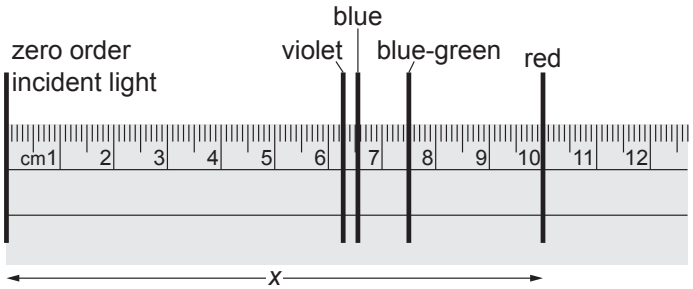


Fig. 5.3

The student decides to determine the wavelength of the photons which form the **red** line observed at x = 10 cm on the ruler.

- Describe how the information that has been given can be used to determine the wavelength of the red photons.
- Estimate the percentage uncertainty in the measured value of the wavelength. **[6]**

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Additional answer space if required.

Question 5 continues on page 18

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(b) (i) Show that the energy of a photon of wavelength 486 nm is 4.09×10^{-19} J.

[1]

(ii) Fig. 5.4 shows some of the energy levels of an electron in a hydrogen atom.

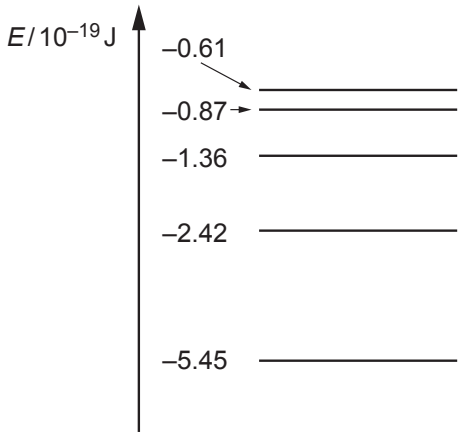


Fig. 5.4 (not to scale)

Draw an arrow on Fig. 5.4 to show an electron transition which would cause the **emission** of a photon of wavelength 486 nm. **[2]**

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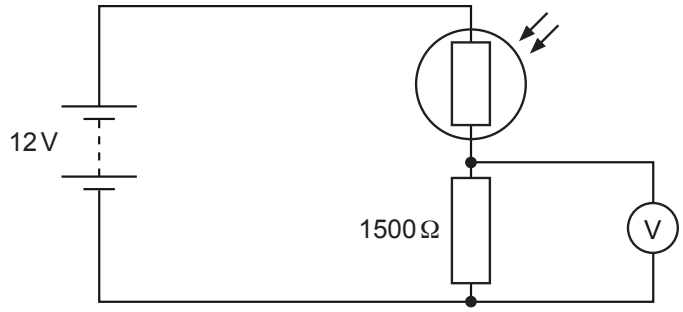
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Question 6 begins on page 20

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2 This question is about a light-dependent resistor (LDR).

(a) A student connects a potential divider circuit as shown below. It contains an LDR.



The fixed resistor has resistance 1500 Ω.
The battery has electromotive force (e.m.f.) 12 V and negligible internal resistance.
The voltmeter has extremely high resistance.

(i) When the LDR is covered, its resistance is 3000 Ω.

Calculate the voltmeter reading.

voltmeter reading = ... V **[2]**

(ii) When fully illuminated, the resistance of the LDR is 100 Ω.
Show that the voltmeter reading **changes** by more than 7 V.

[1]

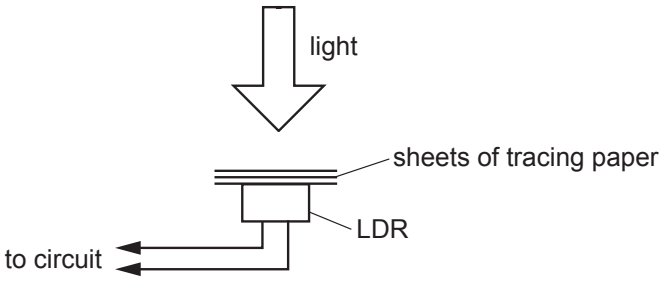
Question 2 is continued on page 6

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***(b)** The current in an LDR depends on the intensity of light incident on it.

A student decides to alter the intensity of light incident on an LDR by using sheets of tracing paper and a light source.

The diagram below shows **part** of an arrangement suggested by the student.



It is suggested that the current I in the LDR is given by the expression

$I = ke^{-nx}$

where x is the **total** thickness of the sheets of tracing paper, and k and n are constants.

Describe how the student could carry out an experiment to verify the validity of this expression and determine k and n. Include in your answer

- a circuit diagram
- a possible table for the results, including the headings
- the graph plotted to determine k and n
- any precautions taken to improve the quality of the results. **[6]**

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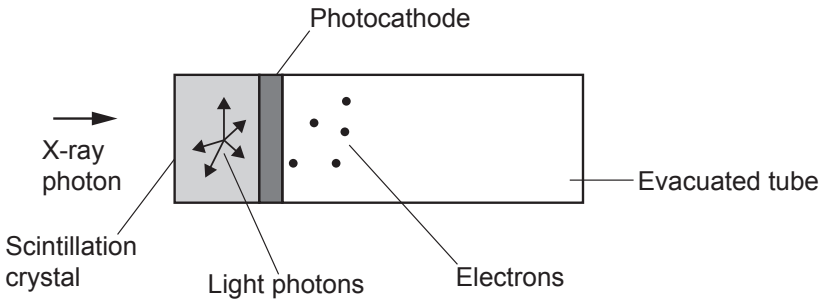
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Additional answer space if required

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19 The diagram shows part of an X-ray telescope which uses a crystal scintillation device to detect low energy X-rays from the stars.

X-rays hit the crystal and cause it to emit visible light photons. These travel to the photocathode in an evacuated tube. The photocathode uses the light photons to produce electrons.



Each X-ray photon detected by the telescope has an energy of 32 keV.

The light photons have a wavelength of 510 nm.

The efficiency of the crystal is 15%.

(a) Show that each X-ray photon produces about 2000 light photons.

[3]

(b) The photocathode has a work function of 2.3 eV.

(i) Explain what is meant by the *work function*.

.....

..... **[1]**

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(ii) Calculate the maximum kinetic energy of the electrons leaving the photocathode.

maximum kinetic energy = ...J **[2]**

(iii) 12 X-ray photons are detected every minute.

Use your answer to **(a)** to calculate the current I leaving the photocathode. Assume that all the photons of light produce photoelectrons.

I = ... A **[2]**

(iv) State one other assumption you have made to enable you to calculate the current I in **(b)(iii)**.

.....

..... **[1]**

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1 A flute is a musical instrument made from a long tube that is open at both ends.

A stationary sound wave in the tube produces a musical note.

The lowest frequency note that a standard flute produces in air is 262 Hz.

The speed of sound in air at a temperature of 20 °C is 340 m s^{-1}.

(a) Show that a standard flute has an approximate length of 0.65 m.

[3]

(b) In an ideal gas, the speed v of sound is given by

$$v = \left(\frac{\gamma RT}{M}\right)^{1/2}$$

where

γ is a dimensionless constant that depends on the gas

R is the molar gas constant

T is the absolute temperature

M is the molar mass of the gas.

The table below shows values of γ and M for both air and helium.

Gas	γ	M / g mol^{-1}
Air	1.40	29.0
Helium	1.67	4.00

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(i) The kinetic model of an ideal gas assumes that there are a large number of particles in rapid, random motion.

State **two** further assumptions for the kinetic model of an ideal gas.

1 .....

.....

2 .....

..... **[2]**

(ii) A standard flute is placed inside a sealed chamber.

The chamber is filled with helium at a temperature of –10 °C.

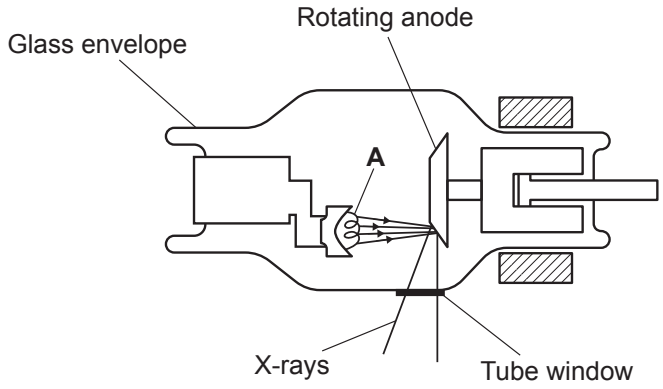
Calculate the lowest frequency that the flute could produce inside the chamber.

frequency = ... Hz **[4]**

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18 X-rays are used for diagnostic imaging in a hospital.

The diagram shows the structure of an X-ray tube.



(a) Name the component labelled **A** on the diagram.

..... **[1]**

(b) Suggest why the anode is made to rotate.

..... **[1]**

(c) X-rays are produced at characteristic wavelengths which depend on the material of the anode.

Describe how the electrons from component **A** are responsible for producing X-rays.

.....

.....

..... **[2]**

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Turn over

(d) An electron strikes the anode. The kinetic energy of the electron changes from 150 keV to 60 keV.

Calculate the minimum wavelength, λ, of the X-ray photon emitted by the interaction of the electron with the anode.

λ = ... m **[3]**

(e) A radiologist targets a uniform beam of X-rays at a tumour 4.6 cm below the skin of a patient. The beam is at right angles to the surface of the skin.

The intensity of the X-ray beam at the tumour is 30% of the incident intensity.

Calculate the attenuation coefficient, μ, of the tumour tissue in cm^{-1}.

μ = ...cm^{-1} **[2]**

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10-MARK QUESTIONS

7 questions in this booklet

19 Fig. 19.1 shows an electric circuit.

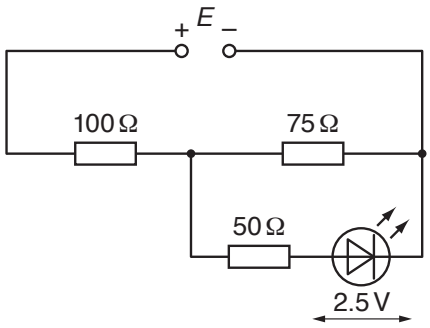


Fig. 19.1

The power supply has electromotive force (e.m.f.) E and negligible internal resistance.

The resistance values of the resistors are shown in Fig. 19.1. The I–V characteristic of the light-emitting diode (LED) is shown in Fig. 19.2.

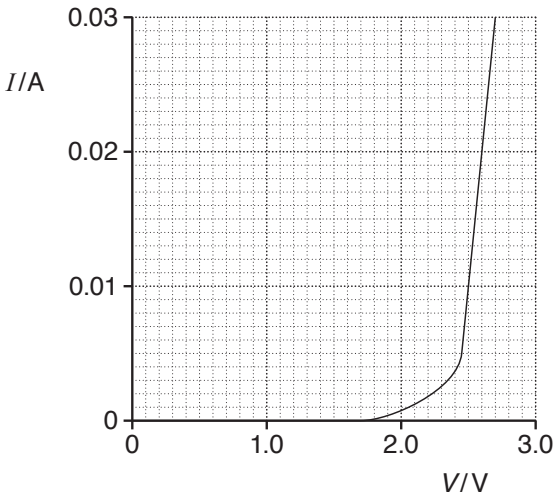


Fig. 19.2

The potential difference (p.d.) across the LED is 2.5 V.

(a) Use Fig. 19.2 to show that the p.d. across the 50 Ω resistor is 0.50 V.

[2]

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(b) Calculate the e.m.f. E of the power supply.

E = ... V **[3]**

(c) The LED emits blue light of wavelength 4.7×10^{-7} m.

(i) Estimate the number of blue light photons emitted from the LED per second.

number of photons per second = ... s^{-1} **[3]**

(ii) The light from the LED is incident on a metal of work function 2.3 eV.

Explain, with the help of a calculation, whether or not photoelectrons will be emitted from the surface of the metal.

.....

.....

..... **[2]**

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20 **(a)** 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 $4.8 \times 10^{-7}\,W\,m^{-2}$.

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

diameter of earhole ≈ ..... mm

power = ... W **[2]**

(ii) A different sound wave is now incident at the ear.
The intensity of this wave is $9.6 \times 10^{-7}\,W\,m^{-2}$.

Calculate the amplitude A in nm of this sound wave.

A = ... nm **[2]**

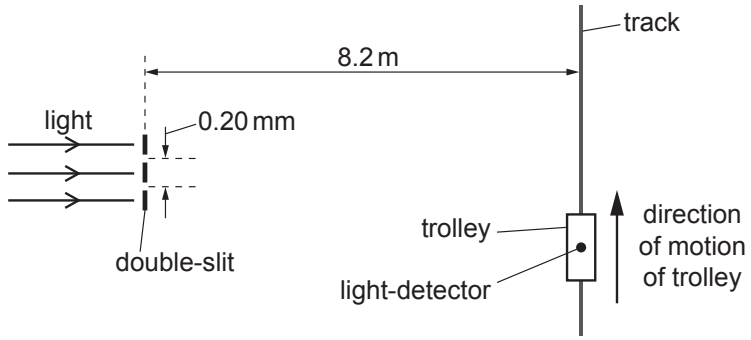
(b) State the **principle of superposition**.

.....

..... **[1]**

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(c) 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 × 10^{14} Hz.

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

t = ... s **[3]**

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16 (a) The normal frequency range of hearing for young people is from 20 Hz to 20 kHz.

(i) The speed of sound in air is 340 m s^{-1}.

Calculate the **shortest** wavelength a young person can hear.

wavelength = ... m **[2]**

(ii) Describe how you can use an oscilloscope, and other additional laboratory equipment, to determine the actual upper limit of the frequency range for a young person.

.....

.....

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..... **[3]**

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(b) State **one** difference and **one** similarity between the **oscillations** of a stationary sound wave and a progressive sound wave.

Difference: .....

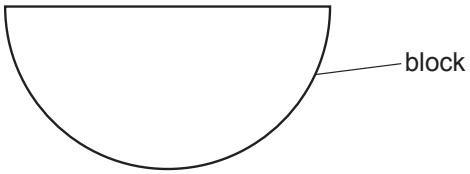
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Similarity: .....

.....

[2]

(c) You are provided with a ray-box, a semi-circular block of plastic and other normal laboratory equipment.
The outline of the block is shown below.



Describe how you could measure the refractive index *n* of the block using the critical angle method. Draw on the diagram and label it to make your answer clear.

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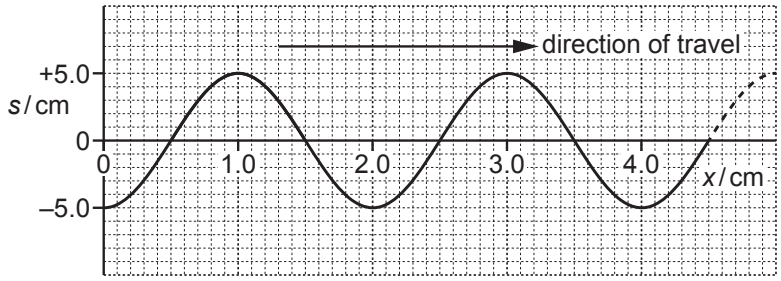
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..... **[3]**

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16 **(a)** A graph of displacement s against distance x for a **progressive** wave at time $t = 0$ is shown below.



Determine:

(i) the phase difference ϕ in radians between the points on the wave at $x = 1.5\,\text{cm}$ and $x = 2.5\,\text{cm}$

$\phi =$ ..... rad **[1]**

(ii) the displacement s at time $t = \frac{3}{4}T$ at $x = 1.5\,\text{cm}$, where T is the period of the oscillations of the wave.

$s =$ ..... cm **[1]**

(b) A beam of coherent light of wavelength λ is incident normally at two parallel slits (double-slit). A series of bright and dark fringes are formed on a distant screen placed parallel to the line joining the slits.
The location of some of these fringes is shown in **Fig. 16.1**.

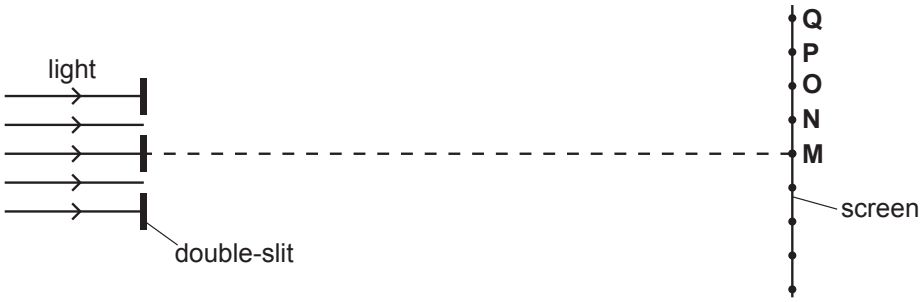


Fig. 16.1 (not to scale)

The bright fringes are seen at points **M**, **O** and **Q**. The dark fringes are seen at points **N** and **P**.

State the phase difference ϕ in degrees, and the path difference d in terms of wavelength λ, for the waves from the two slits meeting at point **P**.

$\phi =$ ..... ° **[1]**

$d =$ ..... λ **[1]**

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(c) A student is doing an experiment to determine the speed of sound in air by producing stationary waves inside a horizontal glass tube.

Fine powder is sprinkled inside the tube. A loudspeaker is placed close to the open end of the tube. The other end of the tube is closed. The loudspeaker is connected to a signal generator producing a frequency of 2.72 kHz.
The powder inside the tube forms piles at certain locations inside the tube, see **Fig. 16.2**.

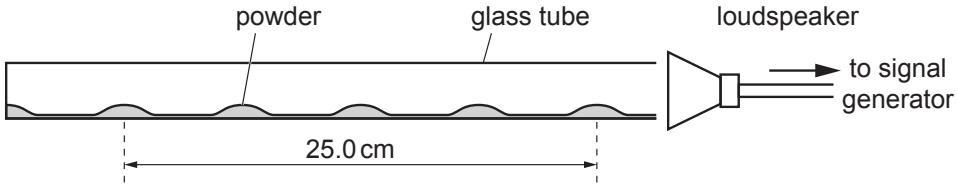


Fig. 16.2 (not to scale)

(i) Suggest why the powder piles up at the nodes within the tube.

.....

..... **[1]**

(ii) Use **Fig. 16.2** to determine the speed of sound *v*.

v = ... m s^{-1} **[3]**

(iii) Determine the fundamental (minimum) frequency f_0 of the stationary wave that can be formed within this tube.

f_0 = ... Hz **[2]**

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Turn over

22 Radiographers commonly use molecules containing fluorine F-18 as tracers in positron emission tomography (PET) scanning.

Fluorine has a proton number of 9.

F-18 decays to oxygen (O) by β^+ decay.

(a) Write the equation for the decay of a nucleus of F-18 using nuclear notation.

[2]

(b) The β^+ particle (positron) produced travels only a short distance in the patient before it meets an electron and is annihilated.

Calculate the wavelength λ of gamma photons produced.

λ = ... m **[3]**

(c) X-rays and gamma-rays are produced by different physical processes.

Briefly describe both processes.

.....

.....

..... **[2]**

(d) F-18 has a half-life of 109.7 minutes.

Explain the advantage that this has for the patient but the disadvantage that this has for the radiographers.

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..... **[3]**

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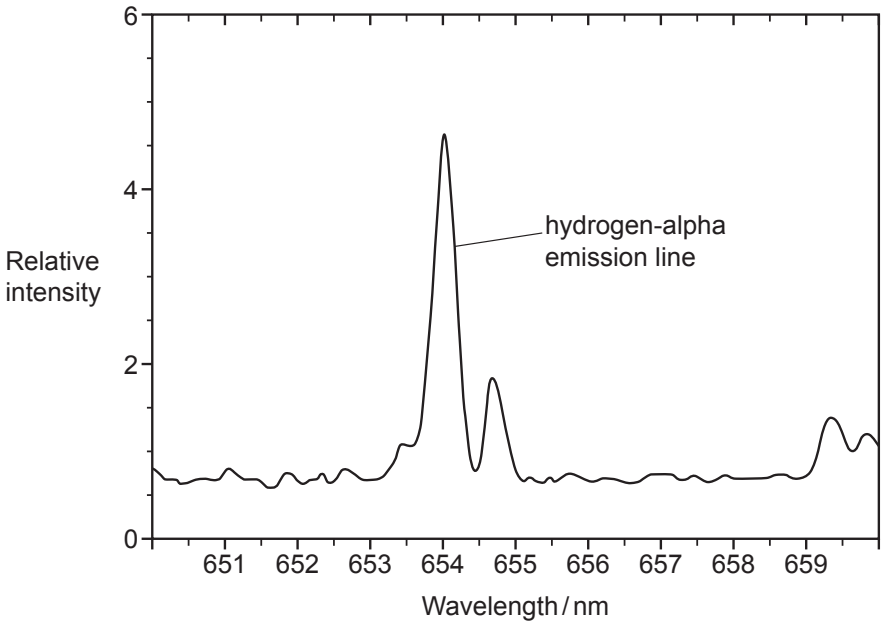
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Turn over

23 The diagram below shows the part of the spectrum of light from the galaxy M87 with a strong hydrogen-alpha emission line.

The spectrum of a sample of hydrogen gas analysed in a laboratory on Earth showed this emission line to be at 656.3 nm.



(a) Calculate the magnitude of the recession velocity of M87.

velocity = ... $km\,s^{-1}$ **[3]**

(b) Estimate the distance in light years to M87 using Hubble's law.

Hubbles constant $H_o = 2.5 \times 10^{-19}\,s^{-1}$

distance = ... ly **[2]**

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(c) Estimate the percentage uncertainty in the distance calculated in part **(b)** using the width of the emission line in the diagram.

percentage uncertainty = +/– ..... % **[2]**

(d) Other methods have shown M87 is actually 50 million light years from Earth.

Suggest why M87 might contradict Hubble's law.

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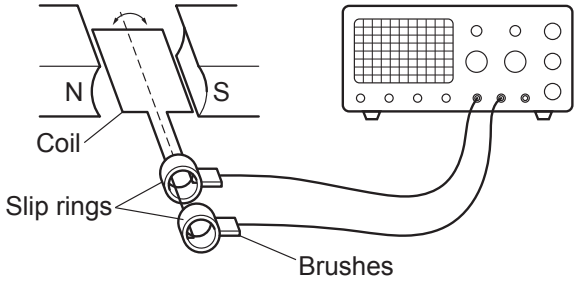
..... **[2]**

(e) Suggest **one** reason why the Big Bang theory is still the accepted model of the origin of the Universe.

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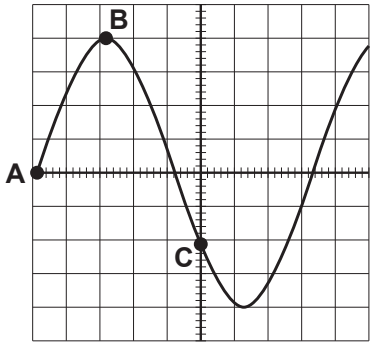
..... **[1]**

21 The diagram shows a simple a.c. generator connected to an oscilloscope (CRO).

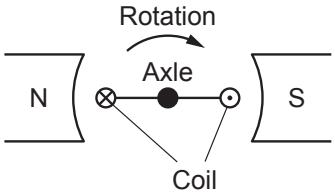


Students turn the coil at a steady rate and an a.c. signal is displayed on the oscilloscope screen, as shown in **Fig. 21.1**.

Fig. 21.1



(a) Which position on the signal, **A**, **B** or **C**, corresponds to the generator position shown below?



view from end of coil

Tick **one** box.

A	
B	
C	

[1]

(b) Draw on **Fig. 21.1** to show how the signal would change if the coil is rotated at a steady, faster rate. **[2]**

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(c) The coil is rotated 45° clockwise from the position shown in **(a)** in a time of 0.13 s.
The magnetic field between the poles of the magnet is uniform and is 25 mT.
The coil has 120 turns.
The coil is 8.0×10^{-2} m long and 4.0×10^{-2} m wide.

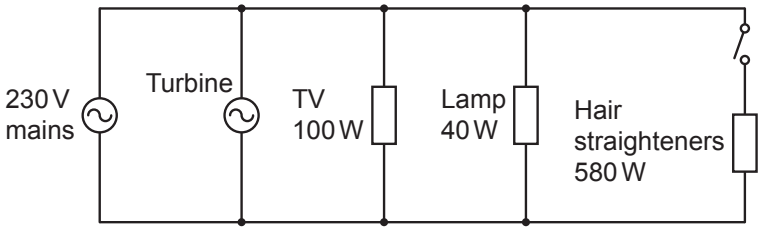
(i) Calculate the change in flux linkage.

Change in flux linkage = ... Wb **[2]**

(ii) Calculate the average induced electromotive force (e.m.f.) ε across the contacts of the coil.

ε = ... V **[2]**

(d) A larger generator is used in a wind turbine to supply electricity to a house. The house is also connected to the 230 V mains supply.



The TV and lamp are switched on.

When the turbine is providing a steady 400 W, the hair straighteners are switched on.

Calculate the current, I, drawn from the mains supply.

I = ... A **[2]**

(e) State the unit used to measure the electrical energy supplied to homes in the UK.

..... **[1]**

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Turn over

11-MARK QUESTIONS

7 questions in this booklet

25 (a) The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_{9}F$) is made from the isotope of oxygen-18 ($^{18}_{8}O$).

$$^{18}_{8}O + {}^{1}_{1}p \rightarrow {}^{18}_{9}F + {}^{1}_{0}n + \gamma$$

The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of 0.25×10^{-11} J. The binding energy of the $^{18}_{8}O$ nucleus is 2.24×10^{-11} J and the binding energy of the $^{18}_{9}F$ nucleus is 2.20×10^{-11} J. The proton and the neutron have zero binding energy.

(i) Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

.....

.....

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..... **[2]**

(ii) Estimate the minimum wavelength λ of the gamma ray photon (γ).

λ = ... m **[3]**

(iii) Fluorine-18 is a positron emitter.
Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

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..... **[2]**

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(b) Describe how the components of a computerised axial tomography (CAT) scanner can produce high-quality images of the internal structures of a patient.

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..... **[4]**

5 **(a)** A magnet rotates inside a shaped soft iron core. A coil is wrapped around the iron core as shown in Fig. 5.1. The coil is connected to an oscilloscope.

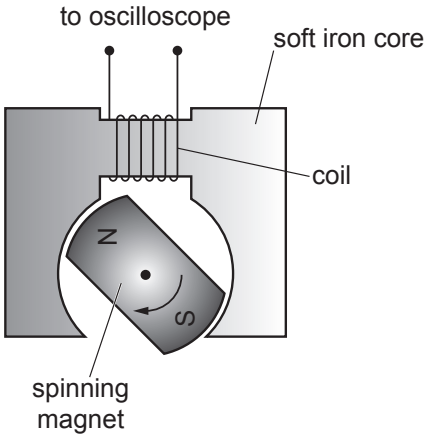


Fig. 5.1

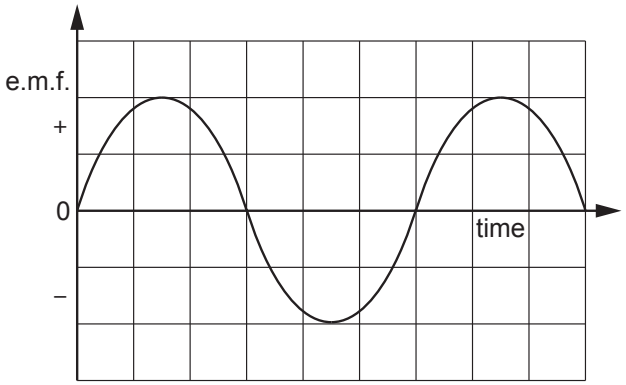


Fig. 5.2

The spinning magnet induces an e.m.f. in the coil. A graph of the e.m.f. displayed on the oscilloscope screen is shown in Fig. 5.2.

(i) Explain the shape of the graph in terms of the magnetic flux linking the coil.

.....

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..... **[2]**

(ii) On Fig. 5.3 sketch a graph of the magnetic flux linkage of the coil against time. The variation of the induced e.m.f. across the coil is shown as a dotted line. **[1]**

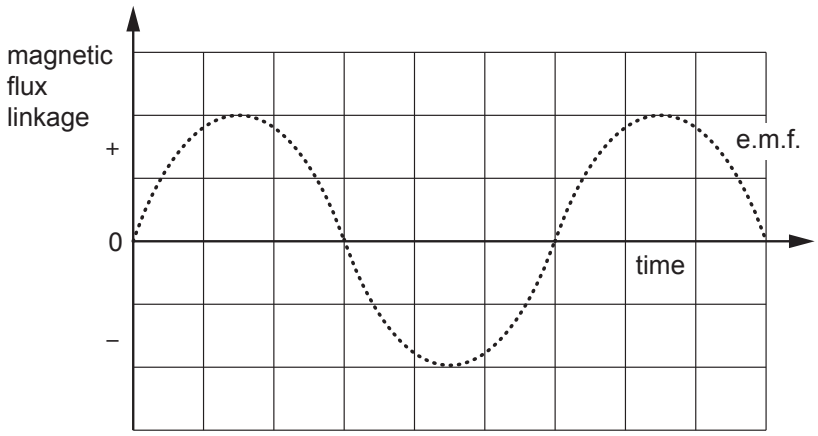


Fig. 5.3

Question 5 is continued on page 14.

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(iii) The coil shown in Fig. 5.1 has 150 turns. The maximum induced e.m.f. V_0 across the coil is 1.2 V when the magnet is rotating at 24 revolutions per second.

Calculate the maximum **magnetic flux** through the coil using the equation

$$V_0 = 2\pi \times \text{(frequency)} \times \text{(maximum magnetic flux linkage)}$$

Give a unit with your answer.

maximum flux = ... unit ..... **[2]**

(b)* A student is given a transformer with coils **X** and **Y**, as shown in Fig. 5.4.

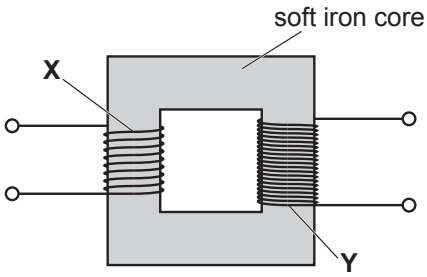


Fig. 5.4

The student is intending to investigate how the maximum induced e.m.f. V_0 in coil **Y** depends on the frequency *f* of the alternating current in coil **X**.

The changing magnetic flux density in coil **X** induces an e.m.f. in coil **Y**. Faraday's law indicates that the maximum induced e.m.f. V_0 should be directly proportional to *f*.

Describe how you would investigate the suggested relationship between V_0 and *f* in the laboratory using these coils. In your description include all of the equipment used and how you would analyse the data collected.

Use the space below to draw a suitable diagram.

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.... [6]

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Turn over

6 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.

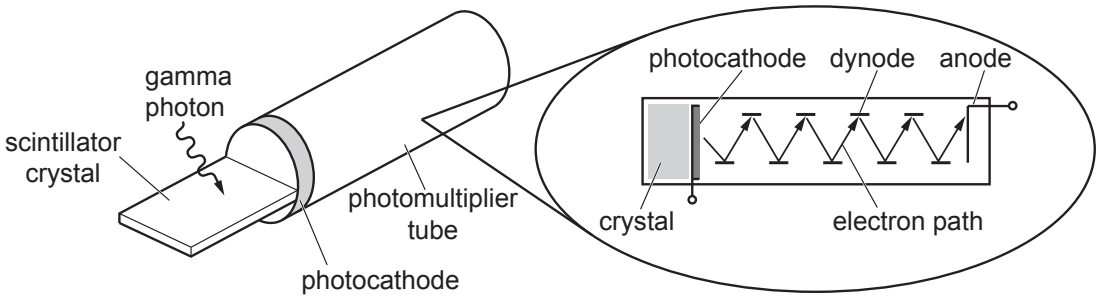


Fig. 6.1

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

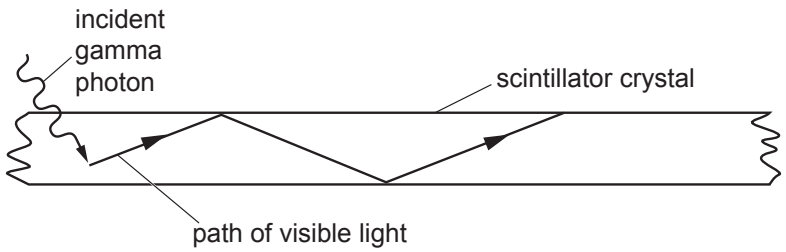


Fig. 6.2

(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 = ... ° **[2]**

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

.....

.....

.....

..... **[2]**

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(b) A high energy gamma photon passing through the scintillator crystal converts some of its energy into visible light photons of mean wavelength 450 nm.

Show that the energy of a single photon of wavelength 450 nm is less than 3 eV.

[3]

(c) The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.

(i) Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

(ii) 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is 4^9.

The pulse of electrons at the anode lasts for a time of 2.5×10^{-9} s.

Calculate the average current due to this pulse.

average current = ... A **[3]**

19 (a) The Planck constant h is an important fundamental constant in quantum physics.

Determine the S.I. base units for h.

base units = ... **[2]**

(b) A researcher is investigating the de Broglie wavelength of charged particles.

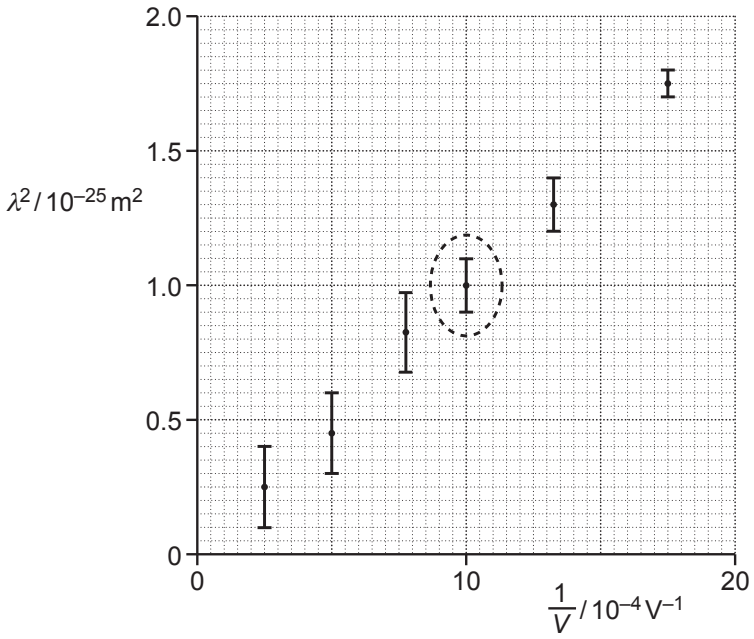
The charged particles are accelerated through a potential difference V. The de Broglie wavelength λ of these particles is then determined by the researcher.

Each particle has mass m and charge q.

(i) Show that the de Broglie wavelength λ is given by the expression $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$.

[2]

(ii) The researcher plots data points on a λ^2 against $\frac{1}{V}$ grid, as shown below.



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1 Calculate the percentage uncertainty in λ for the data point circled on the grid.

percentage uncertainty = ... % **[2]**

2 Draw a straight line of best fit through the data points. **[1]**

3 The charge q on the particle is $2e$, where e is the elementary charge.

Use your best fit straight line to show that the mass m of the particle is about 10^{-26} kg.

[4]

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4 Astronomers can detect microwave background radiation coming from space in every direction.

The temperature of this microwave radiation is 2.7 K and its **total** intensity is about 3×10^{-6} W m^{-2}.

(a) Describe the origin of the microwave background radiation.

.....

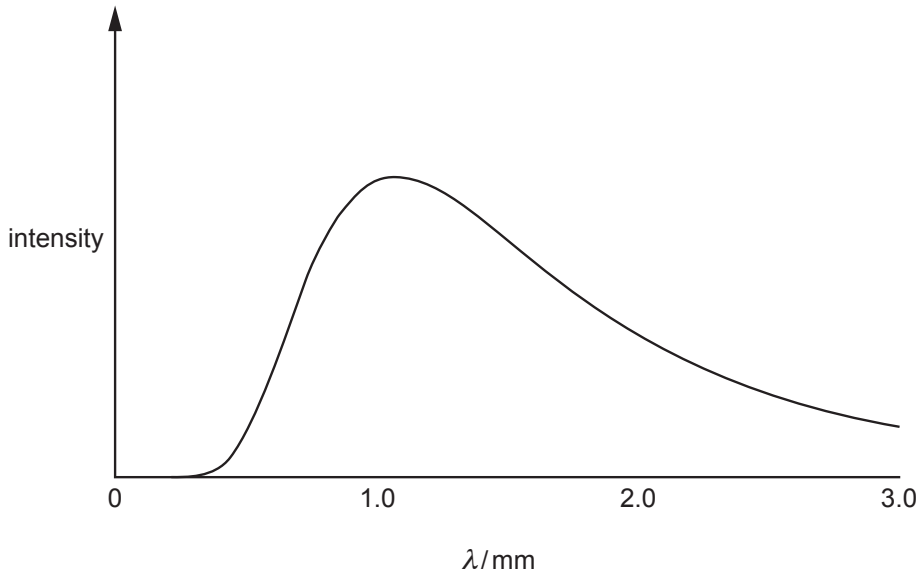
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..... **[2]**

(b) The figure below shows how the intensity of the microwave background radiation varies with its wavelength λ.

The **peak** intensity is at a wavelength of 1.1 mm.



This spectrum of microwave background radiation changes with temperature according to Wien's displacement law.

(i) Suggest and explain how the spectrum might have looked in the distant past. You may draw on the figure to support your answer.

.....

.....

.....

..... **[2]**

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(ii) Calculate the energy of a photon which has a wavelength of 1.1 mm.

energy = ... J **[2]**

(iii) Estimate the number of photons of microwave background radiation incident per second on the back of your hand.

Assume that all emitted photons have the energy calculated in **(ii)**, and that the back of your hand has a surface area of 150 cm^2.

number of photons per second = ... s^{-1} **[2]**

(iv) A scientist suggests that the microwave background radiation could be used as an energy source.

The scientist proposes using large tanks of water to absorb the microwave radiation.

Estimate the maximum rise in temperature that could be produced per second for a large cylindrical tank of depth 5.0 m. Assume that all microwave radiation incident on the top of the tank is absorbed.

density of water = 1000 $kg\,m^{-3}$
specific heat capacity of water = 4200 $J\,kg^{-1}\,K^{-1}$

maximum rise in temperature per second = ... $°C\,s^{-1}$ **[3]**

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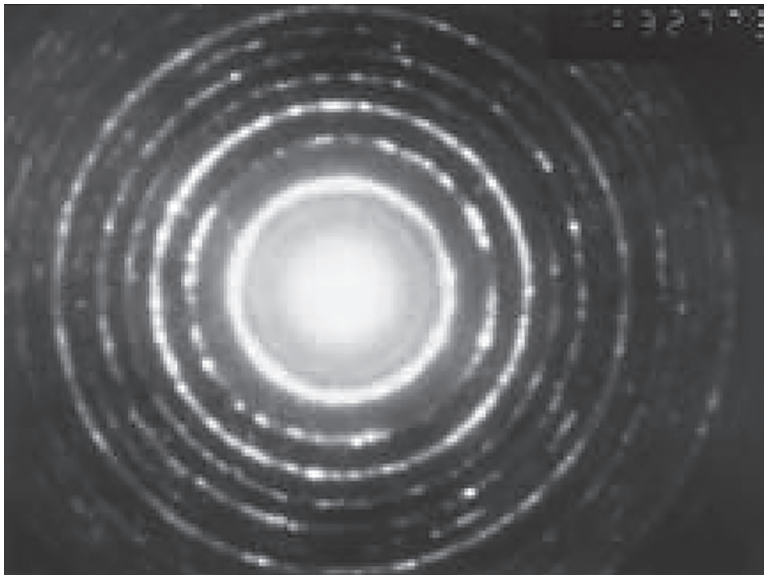
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19 The picture shows an electron diffraction pattern produced by graphite in a cathode-ray tube.



(a) Describe the experiment that produces this pattern. Draw a labelled diagram of the apparatus to help you.

.....

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..... **[4]**

(b) Explain why light and dark circles as shown in the picture are produced, stating what this evidence provides about electron behaviour.

.....

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..... **[3]**

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(c) A potential difference (p.d.) 5 kV is used to accelerate the electrons.

(i) Calculate the work done W on the electrons.

W = ... J **[1]**

(ii) Calculate the de Broglie wavelength λ of the accelerated electrons.

λ = ... m **[2]**

(iii) Suggest a value for the spacing between the graphite atoms.
Justify your answer.

.....

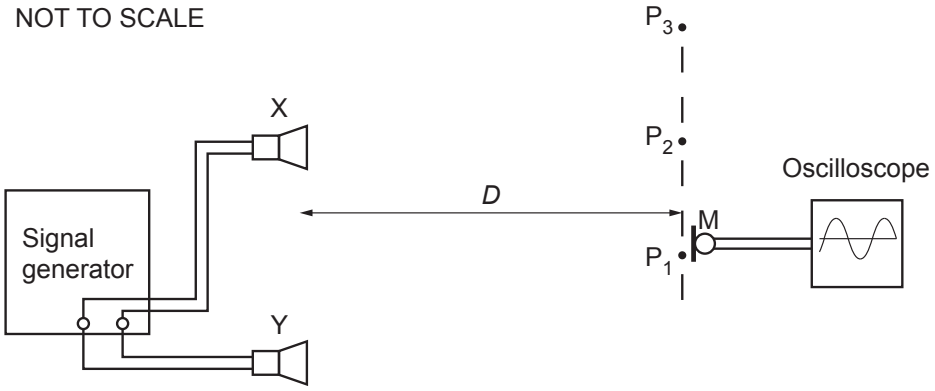
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..... **[1]**

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17 The diagram shows two identical loudspeakers X and Y connected to a signal generator.
The loudspeakers emit sound waves of the same amplitude and frequency which are in phase.

A microphone M is moved along a line from P_1 to P_3 and the signal recorded on an oscilloscope.



As the microphone is moved along the line P_1 to P_3 the oscilloscope shows maximum signal at P_1, zero signal at P_2 and the next maximum signal at P_3.

(a) Explain these observations.

.....

.....

.....

..... **[2]**

(b) The distance between the centres of X and Y is 70.0 cm, the distance *D* (as shown in the diagram) is 4.00 m and the distance from P_1 to P_2 is 1.25 m.

Use the two source interference formula to calculate the frequency of the sound waves.
(Speed of sound = 340 m s^{-1})

frequency = ... Hz **[3]**

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(c) Loudspeaker Y is now replaced with a loudspeaker that produces sound waves of twice the original amplitude.

Describe how the signal observed on the oscilloscope varies as the microphone is moved along the line P_1 to P_3.

.....

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..... **[2]**

(d)

(i) Explain what is meant by the term *intensity*.

.....

..... **[1]**

(ii) Calculate the factor by which the intensity of the sound waves at P_1 in **(c)** is larger than the intensity of the original sound waves at P_1.

factor = ... **[3]**

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12-MARK QUESTIONS

2 questions in this booklet

5 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.

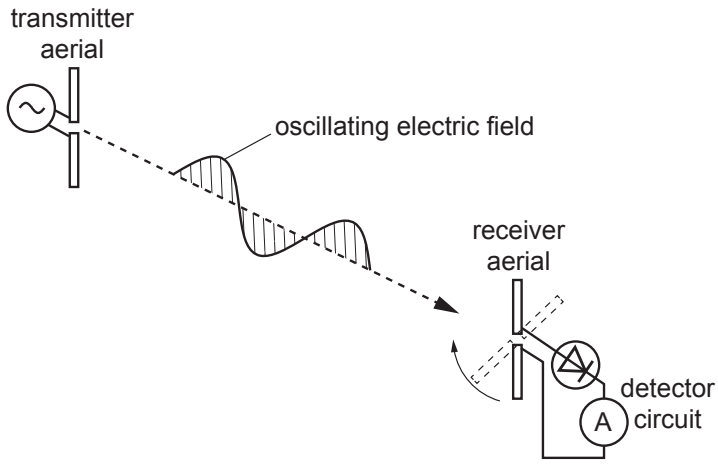


Fig. 5.1

(a) Calculate the frequency f of the transmitted wave.

f = ... Hz **[2]**

(b) The electromagnetic wave is caused by electrons oscillating in the transmitter aerial. Each electron oscillates with simple harmonic motion.

Calculate the maximum acceleration a_{max} of an electron which oscillates with an amplitude of 4.0×10^{-6} m.

a_{max} = ... $m\,s^{-2}$ **[3]**

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(c) Suggest why the diode in **Fig. 5.1** is necessary for an ammeter to detect a signal at the receiver aerial.

.....

.....

..... **[1]**

***(d)** 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**.

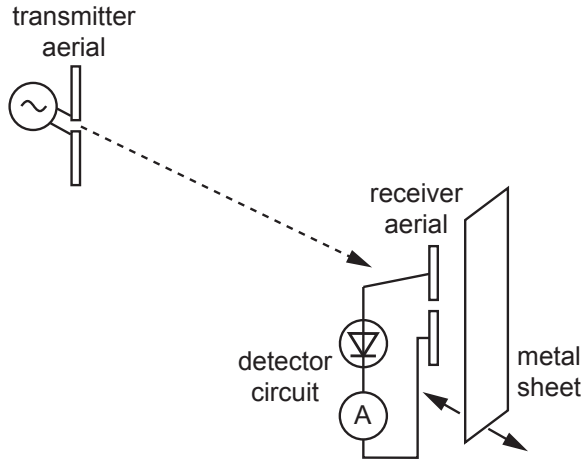


Fig. 5.2

For each of these two investigations:

- 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.

[6]

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Turn over

Additional answer space if required.

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20 Superposition is a characteristic property of waves.

(a) Draw a diagram in the space below to show how superposition between two waves can cause destructive interference.

[2]

(b) In an experiment to determine the wavelength λ of red light, a laser is placed in front of a double slit. The red light from the laser is incident normally at the double slits. Equally spaced light and dark fringes are visible on a distant screen.

The distance between the double slits is d and the distance between the slits and the screen is D.

A diagram of the apparatus is shown below.

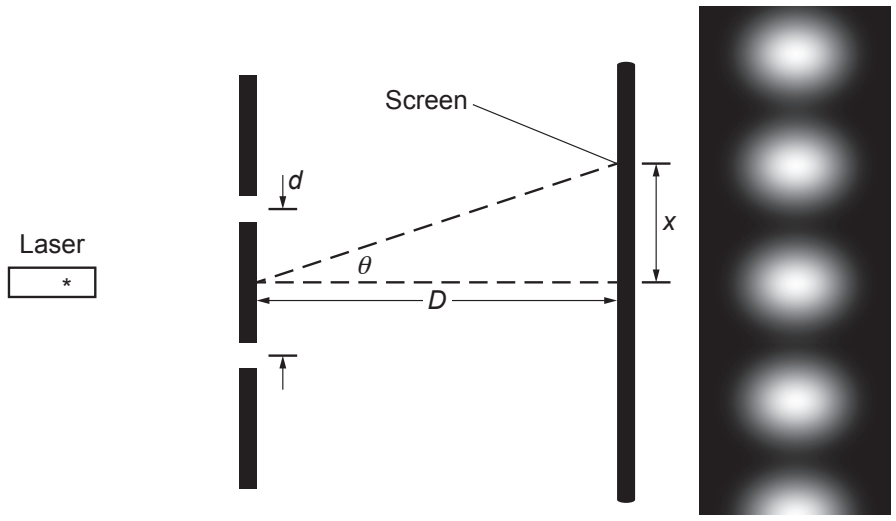


diagram not to scale

(i) Show that the fringe spacing, x, is approximately

$$x \approx \frac{D\lambda}{d}$$

State clearly any approximations you make.

Approximations ..... **[3]**

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(ii) Explain how the fringe pattern changes if

1 the laser emitting red light is replaced with a green laser

.....

.....

..... **[2]**

2 the laser emitting red light is replaced with a white light **filament** lamp.

.....

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..... **[2]**

(c) Visible light can be plane polarised.

Explain why sound waves cannot be plane polarised.

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..... **[3]**

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13-MARK QUESTIONS

1 question in this booklet

5 A student is investigating stationary waves in the air column inside a tube, using the apparatus shown in **Fig. 5.1**.

The loudspeaker emits sound of frequency f and wavelength λ. The tube is initially fully immersed in the water. The student then slowly raises the tube until the oscilloscope trace shows its first maximum. A stationary wave of fundamental frequency f is produced in the air column. When this occurs, the student measures the length l of the tube above the water level.

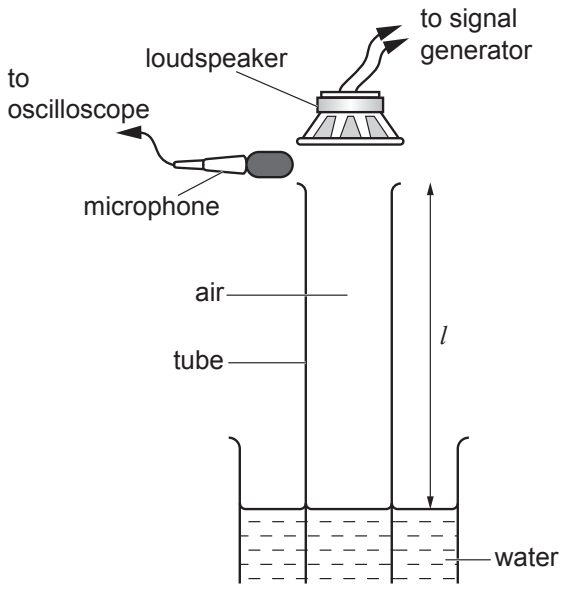


Fig. 5.1

(a) Explain how a stationary wave of fundamental frequency is produced and state the relationship between l and λ.

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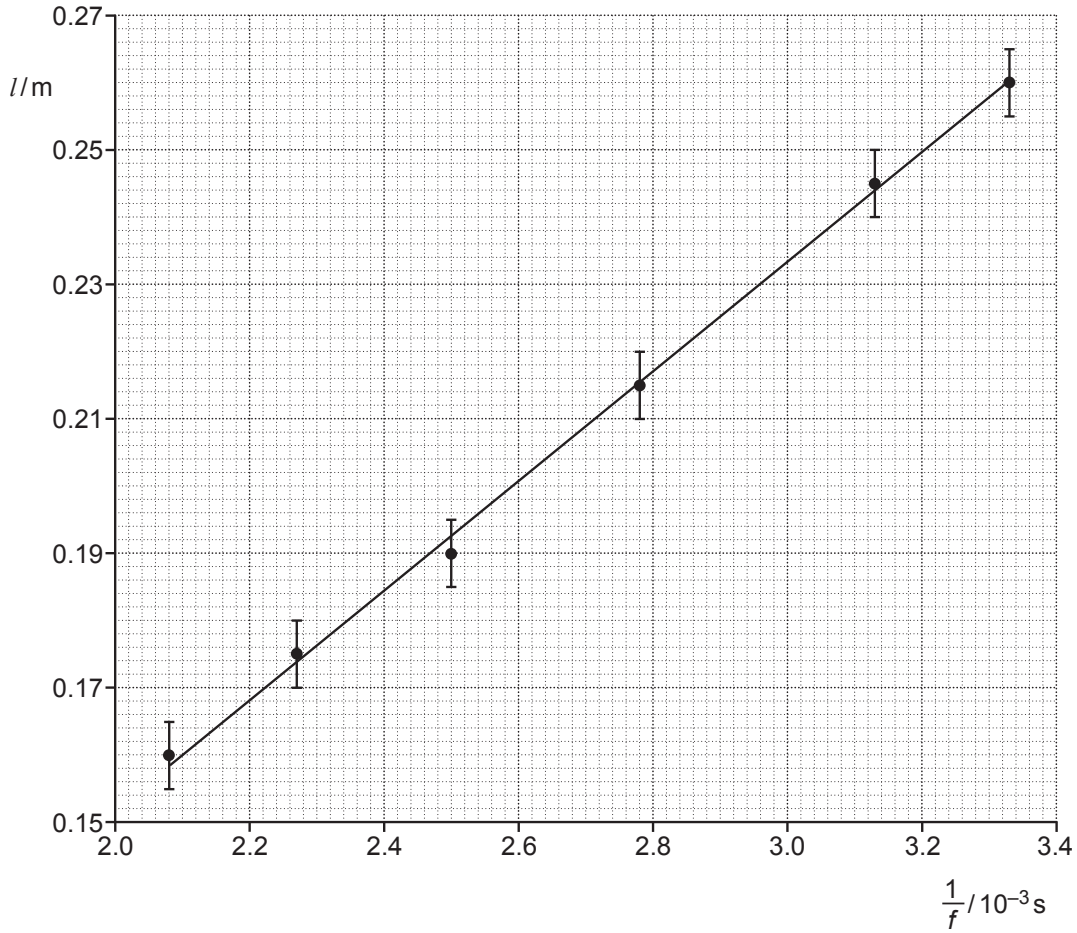
..... **[4]**

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(b) Theory suggests that f and l are related by the equation $4(l + k) = \frac{v}{f}$, where v is the speed of sound in air and k is a constant.

The student measures corresponding values of l and f and plots a graph of l against $\frac{1}{f}$.

The data points, error bars and the line of best fit drawn by the student are shown in the graph below.



(i) Show that the line of best fit has gradient = $\frac{v}{4}$ and y-intercept = $-k$.

[2]

(ii) Calculate v from the gradient of the line of best fit.

v = ... $m\,s^{-1}$ **[3]**

Question 5 is continued on page 16

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(c) The experiment is repeated using the same tube and an unlabelled tuning fork, as shown in **Fig. 5.2**. The distance *l* is measured as 22 cm.

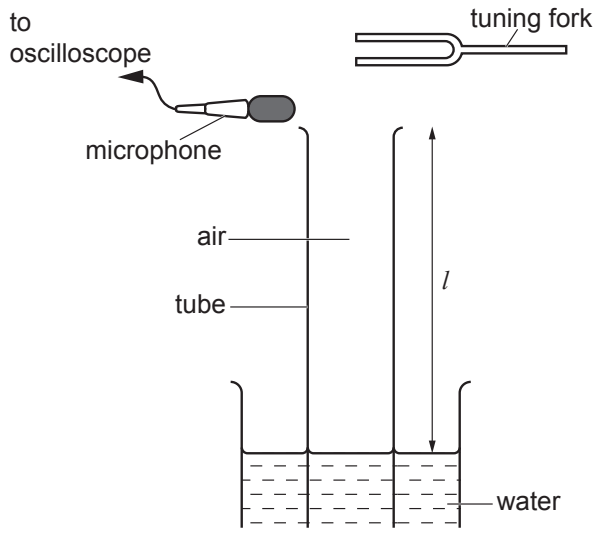


Fig. 5.2

The frequency of the vibrating tuning fork is *F*.

(i) Use the line of best fit on the graph to estimate *F*.

F = ... Hz **[2]**

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(ii) The percentage uncertainty in the value of F can be written as $100\frac{\Delta F}{F}$ where ΔF is the absolute uncertainty in F.

Use the rules for combining uncertainties to write an expression for the percentage uncertainty in the value of F in terms of v and its absolute uncertainty Δv, l and its absolute uncertainty Δl, and k and its absolute uncertainty Δk.

[2]

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14-MARK QUESTIONS

7 questions in this booklet

21 **(a)** Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms. The energy levels are labelled **A**, **B**, **C** and **D**.

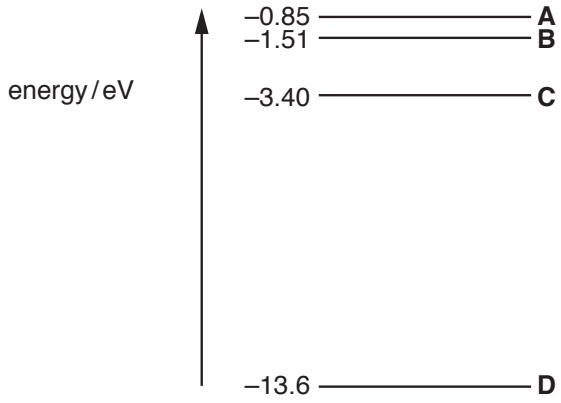


Fig. 21.1 (not to scale)

(i) Explain why the energy levels are negative.

.....

..... **[1]**

(ii) An electron makes a transition (jump) from level **C** to level **A**.

1 Calculate the energy gained by this electron.

energy = ... eV **[1]**

2 Calculate the wavelength in nm of the photon absorbed by this electron.

wavelength = ... nm **[3]**

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(b) Light from a distant galaxy is passed through a diffraction grating. Fig. 21.2 shows the part of the spectrum of light that shows a strong hydrogen-alpha emission line.

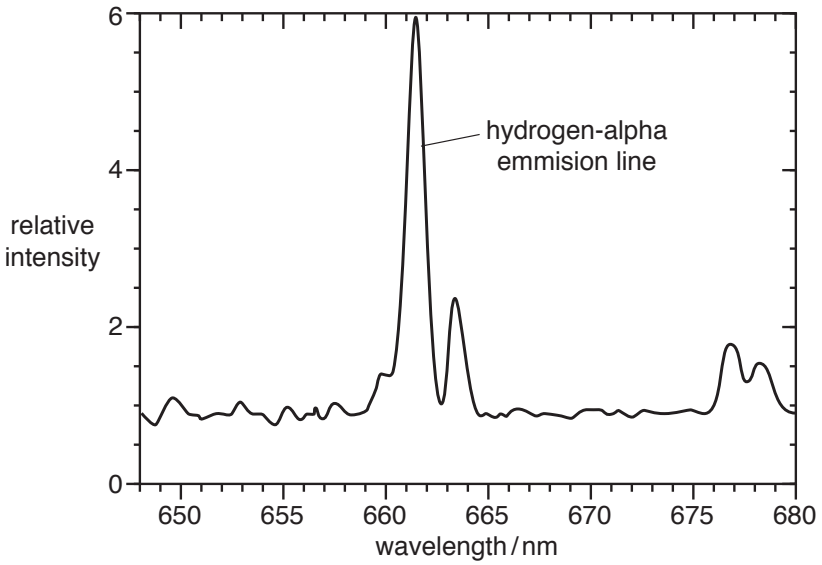


Fig. 21.2

(i) State how an emission line is produced.

.....

..... **[1]**

(ii) State an adjustment that could be made to the experimental arrangement that would space the emission lines more widely.

.....

..... **[1]**

(iii) In the laboratory, the wavelength of the hydrogen-alpha emission line is 656.3 nm. Use Fig. 21.2 to determine the recession velocity of the galaxy.

recession velocity = ... $m\,s^{-1}$ **[3]**

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Turn over

(iv) Suggest why hydrogen spectral lines play an important role in determining red shift of galaxies.

.....

..... **[1]**

(c) Light from a similar star is viewed in a galaxy **further** away. The star is part of a pair of stars which orbit a common centre of mass.
Describe and explain how the equivalent spectrum might appear.

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..... **[3]**

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5 **(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**.

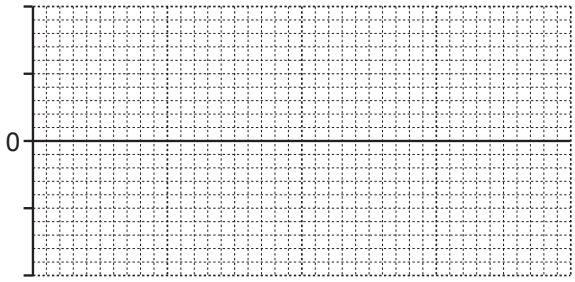


Fig. 5.2

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} = ... m s^{-1} **[2]**

2 the root mean square speed $c_{r.m.s.}$ of the air molecules in the room.
The molar mass of air is 2.9×10^{-2} kg mol^{-1}.

$c_{r.m.s.}$ = ... m s^{-1} **[2]**

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(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).

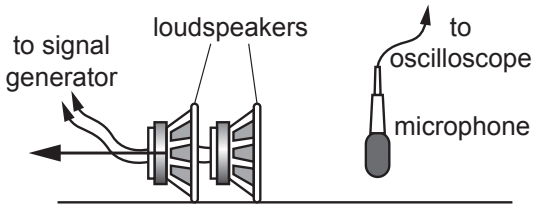


Fig. 5.3(a)

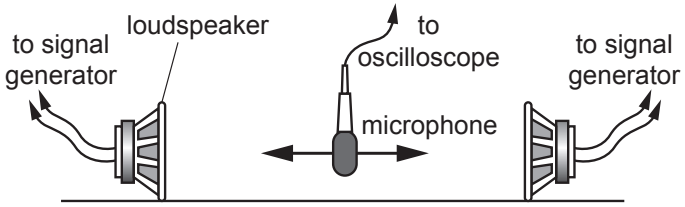


Fig. 5.3(b)

In method **(a)** the microphone is fixed and one loudspeaker is moved to the left as shown in 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).

Describe and explain how both methods can be used to accurately determine the speed of sound. In your description, discuss how the uncertainty in the value for the speed of sound can be minimised in one of the methods, without using any other apparatus. **[6]**

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Question 6 begins on page 18.

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20 (a) An approximate value of the Planck constant h can be determined in the laboratory using light-emitting diodes (LEDs). An LED suddenly starts to conduct and emit monochromatic light when the potential difference across an LED exceeds a minimum value V_0.
The potential difference V_0 and the wavelength λ of the emitted light are related by the equation

$$V_0 = \left(\frac{hc}{e}\right) \times \frac{1}{\lambda}$$

where e is the elementary charge and c is the speed of light in a vacuum.

Fig. 20.1 shows some data points plotted by a student on a V_0 against $\frac{1}{\lambda}$ graph for five different LEDs.

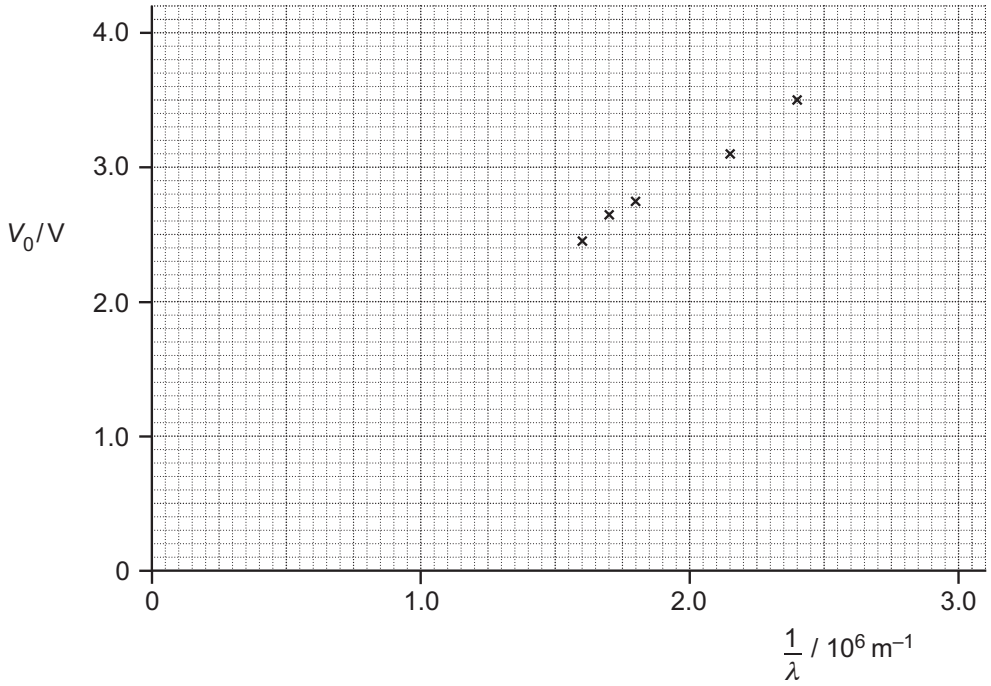


Fig. 20.1

The potential difference across each LED was measured using a digital voltmeter with divisions ±0.01 V. The values for the wavelengths are accurate and were provided by the manufacturer of the LEDs.

The value of V_0 was determined by directly observing the state of the LED in the **brightly** lit laboratory.

(i) Draw the straight line of best fit on Fig 20.1 and determine the gradient of the line.

gradient = ... V m **[2]**

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(ii) Use your answer in **(i)** and the equation on page 20 to determine a value for *h* to 2 significant figures. Show your working.

h = ... J s **[3]**

(iii) Calculate the percentage difference between your value in **(ii)** and the accepted value of the Planck constant.

difference = ... % **[1]**

(iv) Identify the two types of errors shown by the data in Fig. 20.1 and suggest how you could have refined the experiment to reduce or eliminate these errors.

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..... **[4]**

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(b) Fig. 20.2 shows a gold-leaf electroscope with a clean zinc plate.

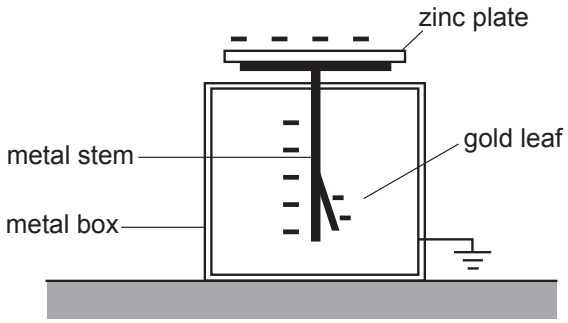


Fig. 20.2

The zinc plate, metal stem and the gold-leaf are given a negative charge by briefly connecting the zinc plate to the negative electrode of a high-voltage supply.

The gold leaf is fully diverged.

The position of the leaf is not affected by intense white light from a table lamp incident on the zinc plate. The gold leaf collapses very quickly when low-intensity ultraviolet radiation from a mercury lamp is incident on the zinc plate.

Explain these observations in terms of photons.

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..... **[4]**

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Question 21 is on page 24

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18 A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

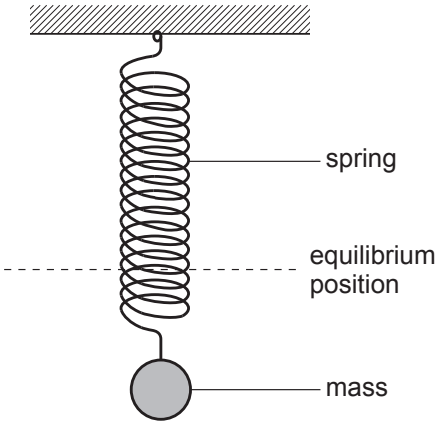


Fig. 18.1

At time $t = 6.5\,\text{s}$ the magnitude of the acceleration a of the mass is $3.6\,\text{m s}^{-2}$ and its displacement x is $4.6 \times 10^{-2}\,\text{m}$.

(a) (i) Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz.

[3]

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(ii) Calculate the amplitude *A* of the oscillations.

A = ... m **[2]**

(b) The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

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..... **[4]**

Question 18 continues on page 16

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(c) Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

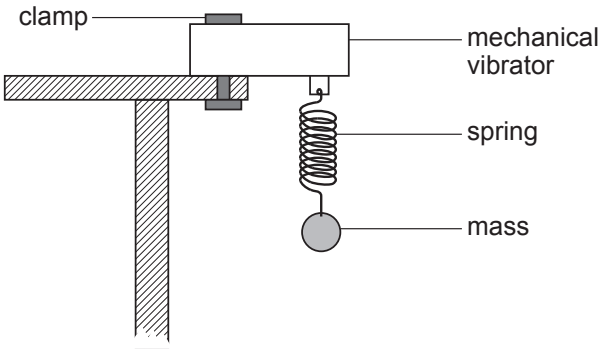


Fig. 18.2

The mass oscillates in air.

(i) The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

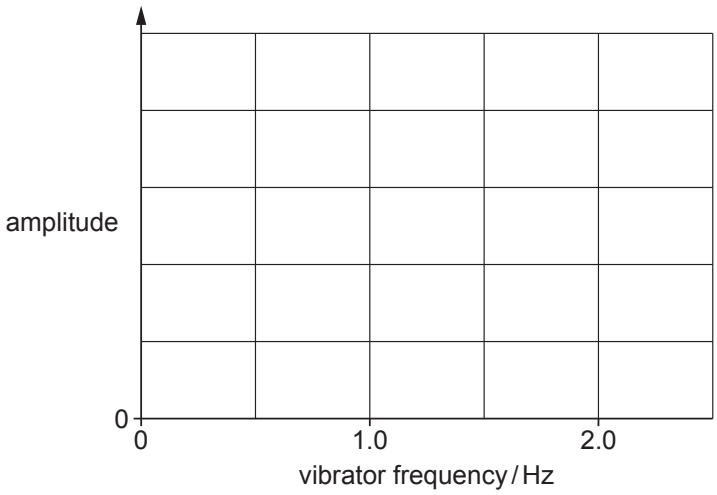


Fig. 18.3

[2]

(ii) A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**. **[1]**

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(iii) Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

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..... **[2]**

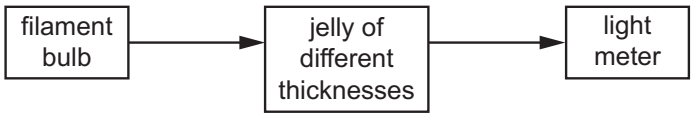
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23 As light passes through a substance its intensity decreases exponentially with distance.

$I_x = I_0 e^{-\mu x}$

I_x is the intensity of light at a given thickness of jelly
I_0 is the intensity of light immediately before it enters the jelly
μ is the constant of proportionality
x is the thickness of the jelly that the light has passed through.

Some students are studying the absorption of visible light by red jelly. They set up the experiment below.



- The power to the bulb is kept constant.
- The distance between the bulb and the light meter is kept constant.
- Blocks of jelly of different thickness are used.
- They measure the intensity of light using a light meter.

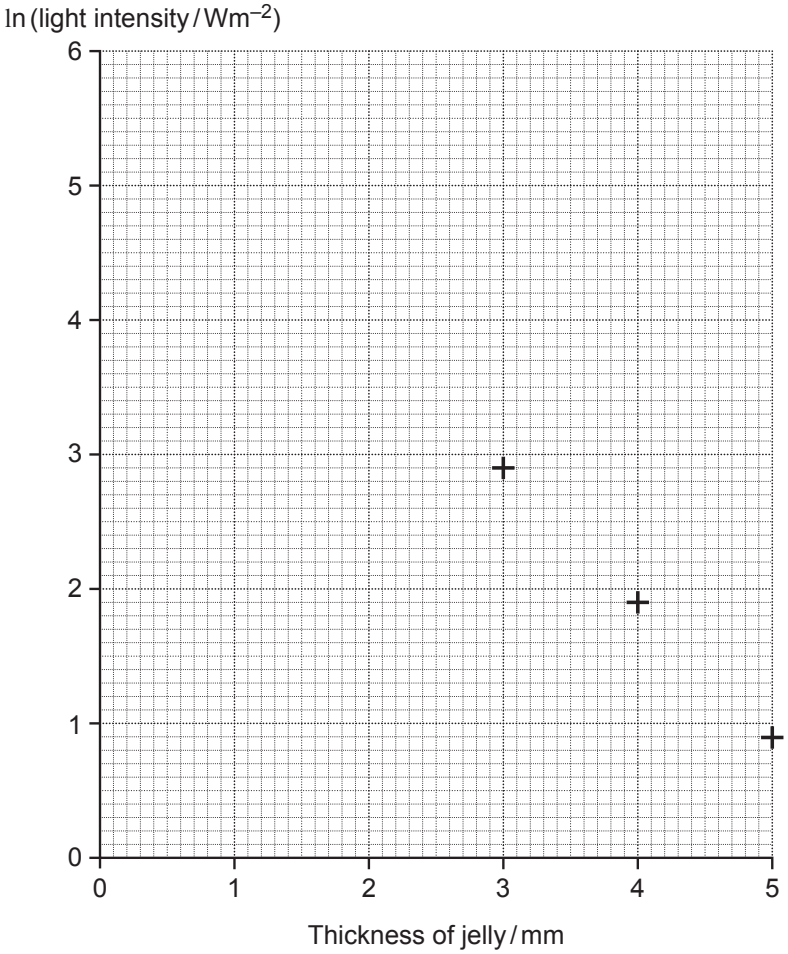
(a) The table below shows their results and the natural log of the light intensity.

Thickness of jelly / mm	Light intensity / Wm^{-2}	ln (light intensity / Wm^{-2})
1	122	
2	46.5	
3	17.8	2.88
4	6.82	1.92
5	2.62	0.960

(i) Complete the last column of the results table for the 1 mm and 2 mm thicknesses of jelly. **[1]**

(ii) Plot the results from the table on the graph. Three points have already been plotted. **[1]**

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(iii) Draw a best-fit straight line through your data points. **[1]**

(b) **(i)** Show how the equation for exponential absorption of light can give a straight line graph with a negative gradient.

[2]

(ii) Use your graph to determine the intensity of the light I_0 before it enters the jelly.

I_0 = ... Wm^{-2} **[2]**

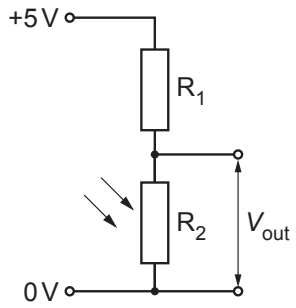
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(iii) Use your graph to determine the constant of proportionality μ in units of mm^{-1}.

μ = ... mm^{-1} **[2]**

(c) The students decide to make their own light meter using this circuit.



The value of R_1 is 5 kΩ. The value of R_2 was 100 Ω when 1 mm jelly was used and 8 kΩ when 5 mm jelly was used.

(i) Calculate the output voltage range obtained in this experiment.

range = ... V **[2]**

(ii) Describe **two** ways the output voltage range could be increased.

1 .....

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2 .....

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[2]

(iii) Explain how the circuit responds to a change in light intensity.

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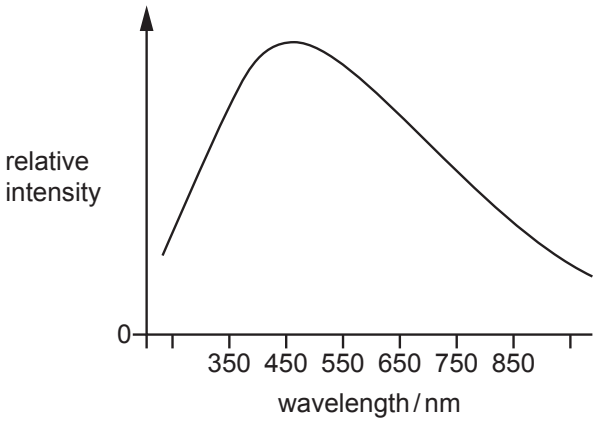
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21 This question is about analysing the electromagnetic radiation from the star Nu Persei in the Milky Way galaxy.

Fig. 21.1 shows the relative intensities of different wavelengths of electromagnetic radiation from Nu Persei.

Fig. 21.1



The surface temperature of the Sun is 5800 K and its wavelength at which maximum intensity is emitted is 500 nm.

The luminosity of Nu Persei is 2.3×10^{29} W.

(a)

(i) Use **Fig. 21.1** to show that the surface temperature of Nu Persei is about 6300 K.

[2]

(ii) Estimate the radius of Nu Persei.

radius = ... m **[3]**

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(b) Electromagnetic radiation is collected from Nu Persei by a sensor with an efficiency of 11% and cross-sectional area $1.0 \times 10^{-4}\,m^2$.

The radiant power collected by the sensor is $7.0 \times 10^{-15}\,W$.

(i) Show that the radiant power per unit area arriving at the sensor is about $6 \times 10^{-10}\,W\,m^{-2}$.

[2]

(ii) By the time the electromagnetic radiation from Nu Persei reaches Earth, the radiation from Nu Persei is evenly distributed over a spherical area with radius equal to the distance between Nu Persei and Earth.

Calculate the distance of Nu Persei from Earth in light years.

distance = ... light years **[4]**

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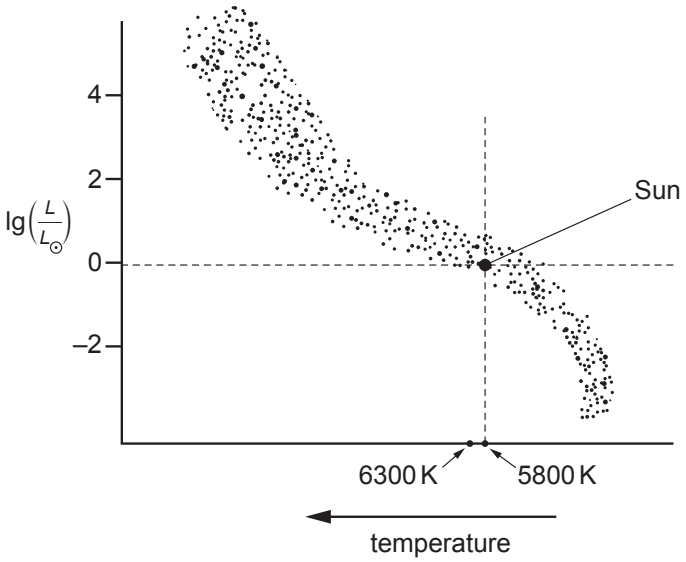
(c) The luminosity of Nu Persei was estimated using the temperature of Nu Persei and the Hertzsprung-Russell (HR) diagram in **Fig. 21.2**. L is the luminosity of a star and $L_{\odot}$ is the luminosity of the Sun.

The temperature data from earlier in this question is repeated in the table below.

Star	Surface temperature / K
Sun	5800
Nu Persei	6300

Comment on the uncertainty in your value, calculated in **b(ii)**, of the distance of Nu Persei from Earth. You may write on the diagram as part of your answer.

Fig. 21.2



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..... **[3]**

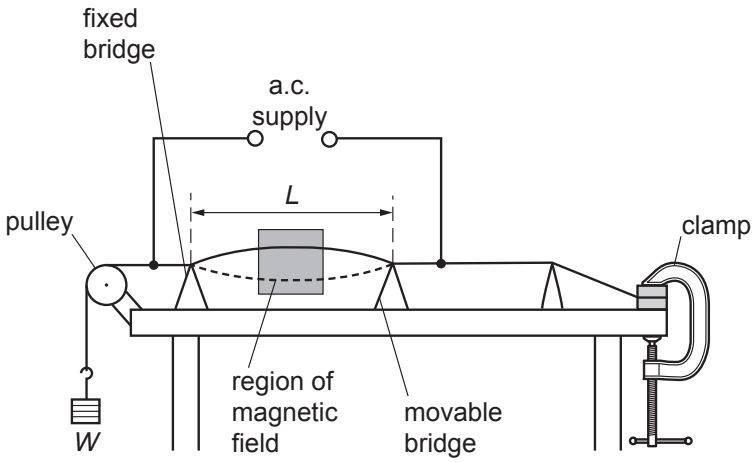
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2 A student carries out an experiment to measure the frequency, *f*, of the mains electricity supply, using the apparatus shown in the diagram.



The wire passes between the poles of a magnet. It is held in tension by the weight *W* of the mass hanger. The fixed bridge and the movable bridge are separated by distance *L*.

Mains frequency current is passed through the wire. The student adjusts the movable bridge until the wire vibrates at its fundamental frequency. The weight *W* and the length *L* are recorded. This is repeated for several different weights.

(a) Explain how a stationary wave is formed on the wire.

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..... **[2]**

(b) It can be shown that the fundamental frequency f_0 of a wire of length *L* under tension *W* is given by the equation

$$f_0 = \frac{1}{2L}\sqrt{\frac{W}{\mu}}$$

where μ is the mass per unit length of the wire, and has a value of $8.0 \times 10^{-4}\,\text{kg m}^{-1} \pm 2\%$.

(i) Suggest why the magnetic flux density, *B*, of the magnet does not appear in this equation.

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..... **[1]**

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(ii) Suggest a method to determine the mass per unit length, μ, of the wire.

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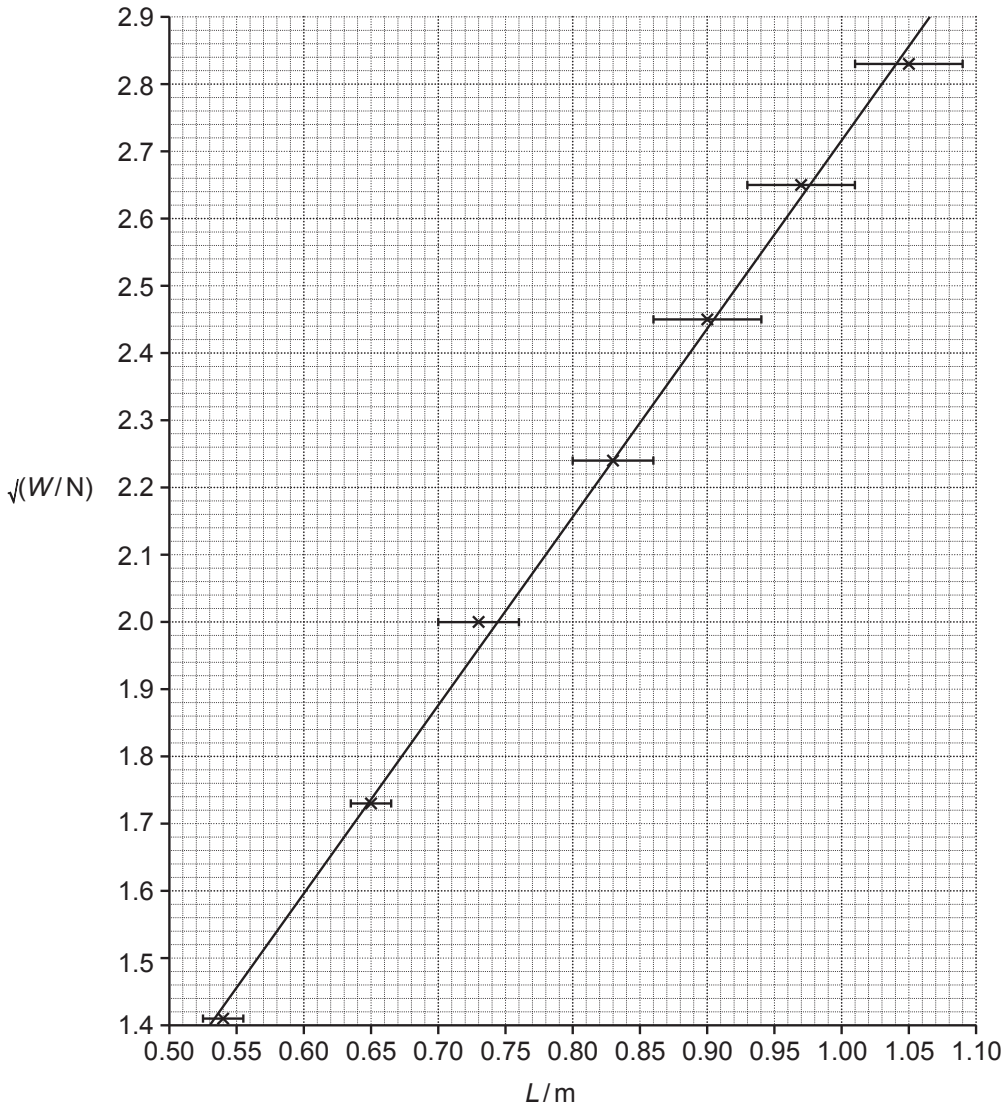
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(c) The graph shows the results of the experiment.



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The student draws a best fit line on the graph. The gradient of the best fit line is 2.81 $N^{1/2} m^{-1}$.

(i) Draw a worst acceptable line on the graph. **[1]**

(ii) Use your worst acceptable line to calculate the percentage uncertainty in the gradient of the best fit line.

gradient = 2.81 ± ..... $N^{1/2} m^{-1}$ % **[3]**

(iii) Calculate a value for the mains frequency, *f*, including a percentage uncertainty.

f = ... Hz ± .....% **[3]**

(iv) Evaluate the accuracy of your value for *f*, given that the true value is 50.0 Hz.

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..... **[2]**

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15-MARK QUESTIONS

3 questions in this booklet

19 This question is about a simple pendulum made from a length of string attached to a mass (bob). For oscillations of small amplitude, the acceleration a of the pendulum bob is related to its displacement x by the expression

$$a = -\left(\frac{g}{L}\right)x$$

where g is the acceleration of free fall and L is the length of the pendulum.
The pendulum bob oscillates with simple harmonic motion.

(a) (i) Show that the period T of the oscillations is given by the expression

$$T^2 = \frac{4\pi^2}{g}L.$$

[3]

(ii) A student notices that the amplitude of each oscillation decreases over time.
Explain this observation and state what effect this may have on T.

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..... **[2]**

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(b)* Describe with the aid of a labelled diagram how an experiment can be conducted and how the data can be analysed to test the validity of the equation $T^2 = \frac{4\pi^2}{g}L$ for oscillations of small amplitude.

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..... **[6]**

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(c) Another student conducts a similar experiment in the laboratory to investigate the small amplitude oscillations of a pendulum of a mechanical clock. Each 'tick' of the clock corresponds to **half** a period.

(i) Show that the length of the pendulum required for a tick of 1.0 s is about 1 m.

[2]

(ii) If the pendulum clock were to be used on the Moon, explain whether this clock would run on time compared with an identical clock on the Earth.

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..... **[2]**

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16 This question is about waves.

(a) 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. **[1]**

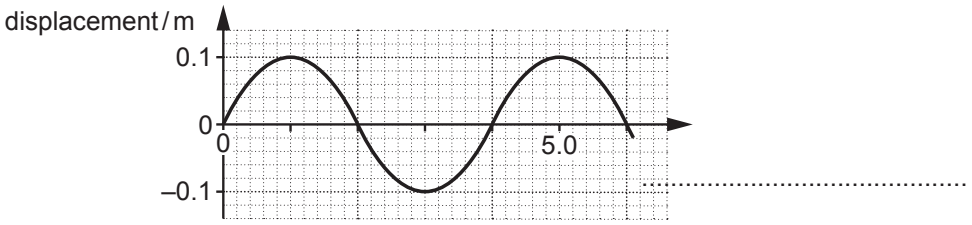


Fig. 16.1

(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.

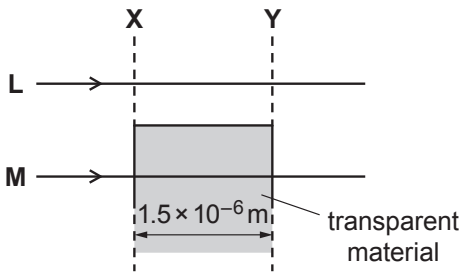


Fig. 16.2

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.

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(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 = ... s **[3]**

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

T = ... 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**.

ϕ = ... ° **[1]**

Question 16 continues on page 12

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(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 $1\,m\,s^{-1}$ 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]**

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23 Algol is a triple-star system, with stars Aa1, Aa2 and Aa3 orbiting each other.
This triple-star is 90 light-years from the Earth.

(a) Here is some data on the star Aa1.

- radius = $(1.90 \pm 0.14) \times 10^{9}$ m
- mass = $(6.31 \pm 0.42) \times 10^{30}$ kg.

Calculate the gravitational field strength g at the surface of Aa1 to **3** significant figures.
Include the absolute uncertainty in your answer. Assume that the other stars of the system exert negligible gravitational force on Aa1.

g = ... ± ..... $N\,kg^{-1}$ **[4]**

(b) The table shows some data about the three stars of Algol.

Star	Luminosity of star / $L_{\odot}$	Surface temperature of star / K
Aa1	182	13 000
Aa2	6.92	4500
Aa3	10.0	7500

The luminosity of each star is in terms of the solar luminosity $L_{\odot}$.

(i) Define the **luminosity** of a star.

.....

..... **[1]**

(ii) Use Stefan's law to determine the ratio $\frac{\text{radius of star Aa2}}{\text{radius of star Aa3}}$.

ratio = ... **[2]**

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(iii) Use Wien's displacement law to explain which star would have the **longest** wavelength at the peak intensity of the emitted electromagnetic radiation.

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..... **[2]**

(iv) Suggest how an astronomer using just an optical telescope can deduce that the three stars of Algol have different surface temperatures.

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..... **[1]**

(v) The light from each star passing through a diffraction grating shows an absorption line spectrum.

Explain how a specific absorption line is produced in this type of spectrum in terms of **photons** and **electrons**.

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..... **[3]**

(c) The Aa1 star could evolve into a black hole.

State **two** ways in which the black hole would differ from the Aa1 star.

1. .....

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2. .....

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[2]

17-MARK QUESTIONS

1 question in this booklet

5 A student experiments with microwaves emitted from a transmitter. The frequency f of the microwaves from the transmitter can be adjusted.

(a) The microwaves are produced by an alternating current in the transmitter.

In one experiment, f is 11 GHz. In a wire in the transmitter, the magnitude of the **maximum** alternating current is 20 mA. The wire has cross-sectional area $1.4 \times 10^{-8}\,m^2$ and is made of a metal with free electron number density $8.0 \times 10^{28}\,m^{-3}$.

(i) Show that the maximum drift velocity of each free electron in the wire is about $0.1\,mm\,s^{-1}$.

[3]

(ii) The student models the average motion of the free electrons in the wire as simple harmonic motion.

Use your answer to **(i)** to calculate the amplitude A of this motion.

A = ... m **[3]**

(iii) Without further calculation, explain how the maximum acceleration of a free electron varies as the frequency f is adjusted, provided that the maximum alternating current remains constant.

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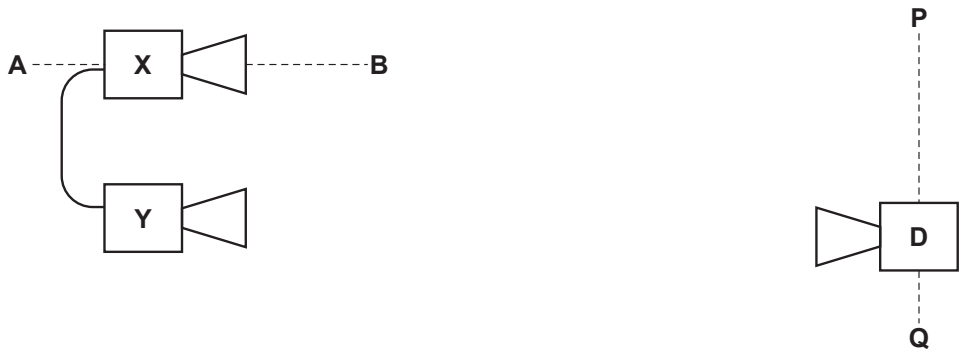
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(b) The student connects two microwave transmitters **X** and **Y**, and places them in front of a microwave detector **D**, as shown in the diagram below.



The transmitters **X** and **Y** produce **coherent** vertically polarised microwaves with the same frequency *f*.

The detector **D** is sensitive to vertically polarised microwaves only.

When the detector **D** is moved along the line **PQ**, a pattern of maximum and minimum intensity is observed. Adjacent maxima are separated by a distance *x*.

(i)* Explain:

- why this pattern of intensity occurs
- the expected relationship between the frequency *f* and the distance *x*
- how to verify this relationship experimentally. **[6]**

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(ii) Transmitter **X** is rotated about the line **AB** and the experiment is repeated at different orientations until it has been rotated by 180°.

Describe and explain the observed patterns of maximum and minimum intensity.

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..... **[3]**

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MARK SCHEMES

official OCR mark schemes

7	B	1	

10	**B**	**1**	

5	**A**	**1**	

6	**C**	**1**	

14	**B**	**1**	

15	B	1	
	Total	15	

SECTION B

Question	Answer	Marks	Guidance

3	**C**	**1**	

4	**B**	**1**	

7	**B**	**1**	

3	D	1	

4	D	1	

15	**B**	**1**	
	Total	**15**	

4	C	1	

7	C	1	

12	A	1	

4	C	1	

6	C	1	

9	D	1	

5	C	1	

6	C	1	

11	B	1	

15	**D**	**1**	
	Total	**15**	

SECTION B

General rule: For substitution into an equation, allow any subject – unless stated otherwise in the guidance

Question	Answer	Marks	Guidance

5	A	1	

6	B	1	

2	A	1	

8	A	1	

9	B	1	

11	C	1	

Question	Answer	Marks	Guidance
1	D	1	

12	**A**	**1**	

13	**D**	**1**	

9	**A**	**1**	

10	**D**	**1**	

11	**A**	**1**	

12	D	1	

10	**C**	**1**	

11	**D**	**1**	

10	**B**	**1**	

6	B	1	

9	**A**	**1**	

11	D	1	

13	C	1	

14	D	1	

15	**B**	**1**	
	Total	**15**	

SECTION B

General rule: For substitution into an equation, allow any subject - unless stated otherwise in the guidance

Question	Answer	Mark	Guidance

8	B	1	

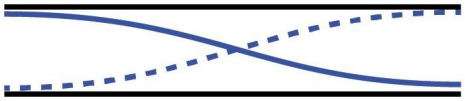
10	A	1	

11	B	1	

12	C	1	

Question			Answer	Marks	Guidance
19	(a)		**A** = white dwarf and **B** = red giant	**B1**	**Allow:** red supergiant for B **Not:** neutron star for A
	(b)	(i)	(λT = constant) $550 \times 5800 = 370 \times T$ T = 8600 (K)	 **C1** **A1**	 **Allow** however expressed Answer is 8620 to 3 sf
		(ii)	**P** on the main sequence and to LEFT of Sun.	**B1**	**Allow:** ECF from **(b)(i)** **Note:** temperature of Sun is 5800 K.
			Total	**4**	

Question	Answer	Marks	Guidance

18	**(a)**			**B1**	Both parts needed – either dotted or solid. Correct curvature needed by eye. Middle node by eye. **IGNORE** lines outside of tube
	(b)		Frequency f_0 = 340 / 0.600 = **567** (Hz)	**A1**	Correct to at least 2 significant figures No ecf from 18(a)
	(c)		Next wavelength for standing wave is λ = 0.300m Frequency = 340 / 0.300 = **1.13 x 10^3** (Hz)	**C1** **A1**	Ecf from (b) if wavelength used is 0.600m Correct to at least 2 significant figures **Special case:** If wavelength drawn in (a) is 0.300m and f_0 in (b) = 1130 Hz, then allow ecf (C1) for next λ = 0.200m and (A1) frequency as 1700 Hz for full credit.

Question			Answer	Marks	Guidance
19	(a)		Any **two** from: • Reflection • Diffraction • Interference / superposition	**B1 × 2**	**Allow** correct annotation of Fig. 19.1 for each effect
	(b)		Interference / superposition (of microwaves along **PQ**)	**B1**	
			Maximum (signal) / constructive (interference) when waves are in phase	**B1**	**Allow** constructive when phase difference is $n \times 360°$ (n is an integer) / 0° / 360°
			Minimum (signal) / destructive (interference) when waves are in anti-phase	**B1**	**Allow** destructive phase difference is $[2n + 1] \times 180°$ (n is an integer) / 180° **Not** 'out of phase' **Special case -** allow 1 mark from the last two B1 marks, for signal linked to path difference and wavelength
			Total	**5**	

17	**(a)**	**(i)**	'Inverted' graph	**B1**	**Ignore** amplitude
		(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	**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
			speed / *v* is constant **or** $f\lambda$ = constant **or** $f \propto 1/\lambda$	**B1**	**Not** just *f* increases λ decreases
			Calculation comparing at least **two** stationary waves to show $f\lambda$ = constant **or** $f \propto 1/\lambda$	**B1**	**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)
			Total	**5**	

Question			Answer	Marks	Guidance
16	(a)		(When two or more waves meet at a point in space) the resultant (displacement) is equal to the (vector) sum of the individual displacements of waves (meeting at a point)	B1	**Allow** total / Σ / net for resultant **Not** amplitude for displacement
	(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	B1	**Expect** 8 (mm)
			$\lambda = \frac{0.25\times10^{-3}\times8\times10^{-3}}{4.25}$ (Allow any subject)	C1	**Allow** ecf for incorrect value of x
			$\lambda = 4.7 \times 10^{-7}$ (m)	A1	
		(ii)	Red light has longer wavelength / λ **and** separation between fringes increases (AW)	M1	
			Separation between fringes justified in terms of $x \propto \lambda$ or $x = \lambda D/a$, D and a are constants	A1	**Allow** other acceptable labels for D and a
			Total	**6**	

Question			Answer	Marks	Guidance
24	(a)		y = sin (θ) $\sqrt{x^2+y^2}$ compared with "y=mx+c"	B1	**Allow:** gradient = $\frac{\Delta y}{\Delta(\sqrt{x^2+y^2})}$ with sin (θ) = O/H **Not:** gradient = $\frac{y}{(\sqrt{x^2+y^2})}$ **unless** "c=0" seen.
	(b)	(i)	(Straight line of best fit showing) gradient = 0.73 ($d\sin\theta = n\lambda$) $\frac{1.0\times10^{-3}}{600}\times 0.73 = 2\times\lambda$ $\lambda = 6.1\times10^{-7}$ (m)	C1 C1 A1	**Allow:** gradient in range 0.70-0.76. **Allow:** evaluation of θ = 44-50 (degrees) in place of gradient **Allow:** any subject **Note**: Gradient in range 0.70-0.76 gives λ in range (5.8 - 6.4) × 10^{-7} m
		(ii)	(Scales/distances are large compared with the absolute uncertainty so) **absolute uncertainty is too small** to be shown (reasonably on this graph's scale) (AW)	B1	**Ignore**: **error** too small
		(iii)	(The values for λ or θ will be) less precise (as independent measurements less likely to agree) (AW)	B1	
			Total	6	

22			**Level 3 (5–6 marks)** Clear description, explanation and limitations with correct annotations on diagram *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of evolution **and** some explanation of analysis or Some description of evolution **and** some limitations *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited explanation or limitations *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	Use level of response annotations in RM Assessor **Indicative scientific points may include:** **Description of evolution** ● Main sequence labelled ● Red giants/supergiants labelled ● White dwarves labelled ● Correct order of evolution ● Dependence on mass/Chandrasekhar's limit ● Evolutionary track shown on diagram **Explanation of analysis** ● Identification of peak wavelength from graph ● Use of Wien's law ● Determination of temperature ● Gives the horizontal co-ordinate **Limitations** ● Does not give luminosity data ● Cannot distinguish between similar temperature stars (e.g. white dwarf, main sequence or a hot super giant) ● Need luminosity data to classify the star ● Difficult to isolate light from stars in other galaxies to analyse ● If looking at stars in other galaxies, have to account for red shift requiring emission data.

19			**Level 3 (5–6 marks)** description and analysis, with an appropriate comment about accuracy *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Description and some graphical analysis and some comment about accuracy *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Incomplete description or analysis, or an appropriate comment about accuracy *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	NB – use of two slit interference formula is incorrect physics. Mark XP and treat description as incomplete **Indicative scientific points may include:** **Description** ● Angles or distances measured from central maximum ● Some method of measuring angle directly, e.g. protractor ● Measuring distances from grating to screen and from central maximum to others ● Description of maxima ● White screen or wall ● Recognition and mitigation of risk of injury to eye **Analysis** ● Graph of d sin theta against n with gradient lambda (or workable alternative) ● Conversion of lines per mm to distance between lines

Question			Answer	Mark	Guidance
					Accuracy ● Use large room to achieve large distances ● Large distance reduces relative uncertainty ● Measure distance between corresponding maxima and halve ● Use of trigonometry to convert measured distances into angles from the centre ● use spots either side of the centre ● change diffraction grating for smaller d so that maxima are more spaced out ● change diffraction grating for larger d so that there are more maxima (and so more points on the graph) ● darken the room
			TOTAL	6	

Question			Answer	Marks	Guidance
18	(a)		1.00 × sin56.3 = 1.50 × sin*r* (Any subject) *r* = 33.7° Correct working / reasoning leading to 90.0° (e.g. θ = 180 – (56.3 + 33.7), therefore θ = 90.0°)	M1 A1 A1	**Allow** with or without the 1.00 **Allow** 34°
	(b)		Use a polaroid / polarising filter Rotation will change intensity	B1 B1	 **Allow** brightness / light
	(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	

23	**a**		Difference in energy level = 4.84 (× 10^{-19}) (J) $\lambda = hc/4.84 \times 10^{-19}$ and 4.11×10^{-7} (m) seen	M1 A1	Accept (-.58 - (-5.42)) for 4.84 Accept E = hf to find f, followed by $\lambda = c/f = 4.11 \times 10^{-7}$ (m) seen Allow 4.104×10^{-7} (m) seen
	b	**i**	Dark lines are **absorption** lines / idea of photon absorption / idea of electrons absorbing energy / idea of electrons making transition to higher energy level (i.e. excitation) Caused by light passing through (cooler) stellar atmosphere or Earth's atmosphere	B1 B1	 Allow (cooler) gases/hydrogen (gas)
		ii	$\Delta\lambda / \lambda = 22/410$ or $21/411$ $v = 0.054c = 1.6(1) \times 10^{7}$ (m s^{-1})	C1 A1	 NB 21/411 gives 1.5×10^{7} (m s^{-1}) Any evidence of use of 432 as denominator of $\Delta\lambda / \lambda$ is XP zero marks
		iii	Big Bang / Expanding universe i.e. Hubble's Law / dark matter or dark energy / AW	B1	 ignore redshift ignore Doppler
			TOTAL	7	

17	**(a)**		(E =) $1.8 \times 1.6 \times 10^{-19}$ **or** 2.88×10^{-19} (J) $1.8 \times 1.6 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{\lambda}$ $\lambda = 6.9 \times 10^{-7}$ (m)	**C1** **C1** **A1**	
	(b)		(V_R =) 2.7 (V) **or** (current =) 0.018 (A) (ratio = $\frac{0.018 \times 1.8}{0.018 \times 2.7}$) ratio = 0.67	**C1** **A1**	**Note** the mark can be scored on circuit diagram **Note** values of powers are: 0.0324 W and 0.0486 W **Allow** 2/3; **Not** 0.66 (rounding error)
	(c)	**(i)**	In darkness LDR has more resistance / p.d. across LDR is large **or** In light LDR has less resistance / p.d. across LDR is small Clear idea that when the LED is on, this will force the p.d. across LED / LDR to decrease, forcing the LED to switch off (ORA) (The cycle of LED switching on and off is repeated)	**B1** **B1**	Note the explanation must be in terms of p.d. / potential divider. **Ignore** current
		(ii)	A sensible suggestion, e.g. Point the LED away from the LDR / increase distance (between LED and LDR) / insert a card between (LED and LDR)	**B1**	
			Total	**8**	

21	**(a)**		Electron removed / ejected (from atom) Photon (scattered with) increased wavelength / lower frequency / lower energy	**B1** **B1**	 Needs a comparative statement
	(b)		(intensity $I = I_0e^{-\mu x}$) = $4.6 \times 10^3 \times e^{-0.85 \times 2.1}$ Either: (power =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4}$ Or (energy per unit area =) $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 30$ energy = $4.6 \times 10^3 \times e^{-0.85 \times 2.1} \times 3.4 \times 10^{-4} \times 30$ energy = 7.9 (J)	**C1** **C1** **C1** **A1**	intensity = 772 (W m^{-2}) power = 0.262 (W) energy per unit area = 23160 J m^{-2} energy at surface = 47 (J) 2 marks
	(c)		CAT (CT) scan Any one from • A CAT scan will give 3D image • A CAT scan gives better contrast	**M1** **A1**	 Insufficient: more detail / clearer image
			Total	**8**	

Question			Answer	Marks	Guidance
17	(a)		eV or J → [kg m^2 s^{-2}] in base units by any method base units = kg m^2 s^{-1}	C1 A1	**Allow** kg (m s^{-1})^2 **Allow** base units in any order
	*(b)		**Level 3 (5–6 marks)** Clear description of method **and** analysis of data *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description of method **and** analysis of data **or** Clear description **or** Clear analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1× 6	**Indicative scientific points may include:** **Description** • Circuit with LED connected to a variable supply (and series /current limiting resistor) / or use of variable resistor • p.d. across LED increased until LED emits light • Voltmeter (across LED) used to measure V • Use a range of LEDs • λ determined using diffraction grating / spectrometer / double-slit / use $n\lambda = d\sin\theta$ / $\lambda = ax/D$ **OR** λ determined from manufacturer's data / known wavelength • Darkroom used / tube placed over LED used to establish switching of LED / switch-on identified from finite ammeter reading **Analysis of data** • Plot of V against λ^{-1} / eV against λ^{-1} / eV against c/λ • Line of best-fit drawn through the points • Straight line (through origin) • Correct gradient for described graph hc/e or hc or h • Correct arrangement for determination of h h = (gradient × e) / c or h = gradient / c (allow numerical values for e *and/or* c)
			Total	**8**	

16	**(a)**		Interference given in A and D and/or B and C A and D diffraction **OR** A and D = destructive interference / destructive superposition **AND** B and C = constructive interference / constructive superposition	**B1** **B1**	**IGNORE** superposition alone
	(b)		The waves have a constant/same/fixed phase relationship	**B1**	Constant/same/fixed phase difference **IGNORE** in phase, frequency, wavelength, diffraction and other correct physics **REJECT** incorrect references to amplitude and other wave properties
	(c)		Waves arrive in phase / path difference of whole number of wavelengths Phase difference = 4π or 720^0 / with a path difference of 2λ	**C1** **A1**	Phase difference = 0 or path difference = $n\lambda$

Question			Answer	Mark	Guidance
	(d)		$\lambda = a\,x / D = 640\text{x}10^{-9} = 1.00\text{x}10^{-5}$ x x / 4 (= 0.256 (m))	**C1**	Correct substitution 0.256m assumes correct substitution
			B to C = 2x = 0.512 (m)	**C1**	Recognition that B-C is two fringe separation, and evaluation
			$\theta = \tan^{-1}(0.512 / 4) =$ **7.3** (°)	**A1**	Correct to at least 2 significant figures **ALLOW** $\theta = \sin^{-1}(0.512 / 4) =$ 7.4 (°) Note: RAD mode in calculators (0.127) MAX 2 marks Note: No doubling of x with correct working leading 3.7° MAX 2 marks
			Alternative method: Use of n $\lambda = d \sin\theta$		
			substitution of λ and d with any integer value of n	**(C1)**	e.g. n x = $1.00\text{x}10^{-5}$ x sin θ where n is an integer
			recognition that n = 2	**(C1)**	
			$\theta = \sin^{-1}(2 \times 640 \times 10^{-9} / 1.00\text{x}10^{-5}) =$ **7.4** (°)	**(A1)**	Correct to at least 2 significant figures Note: only allow use of incorrect value of n = 1, leading to 3.7° MAX 2 marks Note: RAD mode in calculators (0.128) MAX 2 marks

Question			Answer	Marks	Guidance
23	(a)		Uniform distribution of matter (everywhere in the Universe)	B1	**Allow:** density of Universe (approximately) constant throughout **Not:** references/idea of isotropic/"looks the same in all directions"
	(b)	(i)	$v = 68 \times 200 = 13600$ (km s^{-1}) or 13.6 x 10^6 m s^{-1} $(\Delta\lambda = \frac{v}{c} \times \lambda)$ (change in λ =) $13600 \times 10^3 \times 280/3.00 \times 10^8$ or 13 (nm) or 13 x 10^{-9} (m) (λ = 280 + 13) λ = 290 (nm)	C1 C1 A1	**Allow:** Any correct velocity if unit matches. **Allow:** ECF for incorrect v **Answer to 3 sf is 293 (nm)** **Allow:** ECF for incorrect $\Delta\lambda$
		(ii)	Any suitable <u>one</u> from: • Very/infinitely dense • Idea that escape velocity ≥ c or 'light cannot escape it'	B1	**Allow:** singularity **Allow:** physical radius ≤ event horizon radius **Allow:** Distorts space(time) **significantly** / bends light **significantly** **Allow:** Emits Hawking radiation
	(c)		Any three from: 1. At the Big Bang the Universe is a singularity / very dense / very hot 2. Expansion / inflation / high energy (gamma) photons but no matter 3. Quarks and leptons form / Quark-Gluon Plasma phase 4. Quarks combine to form neutrons / protons / hadrons 5. **Hadrons / neutrons <u>and</u> protons / nucleons combine** to make nuclei All candidate's points in the correct sequence	M1x3 A1	**Allow for point 1:** fundamental forces unified **Ignore:** Any phase after nuclei phase e.g. recombination era /formation of atoms/formation of CMBR
			Total	9	

5	(a)		**Level 3 (5 - 6 marks)** Clear procedure or correct determination of wavelength, plus reasonable estimation of uncertainty in λ or (sin) θ *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3 – 4 marks)** Description of procedure or correct determination of λ, but no estimation of uncertainty **or** Clear estimation of uncertainty in wavelength but limited description of procedure and/or determination of λ or (sin) θ **or** Some description of procedure, an attempt to determine the wavelength, and an attempt to estimate uncertainty in some of the measurements (e.g. in x) *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** A limited selection from the scientific points worthy of credit. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	**B1 x 6**	**Use level of response annotations in RM Assessor, e.g. L2 for 4 marks, L2^ for 3 marks, etc.** L1 maximum for any answers which use formula $\lambda = ax/D$ **Indicative scientific points may include:** **Procedure** • use formula $n\lambda = d\sin\theta$ • n = 1 since first order spectrum • find d using number of lines/mm = 300 mm^{-1} • find θ using distance of grating from plastic ruler = 0.50 m and x = 0.10 m (**not** protractor) **Determination of wavelength** • calculate d (= $10^{-3}/300$) = 3.3 x 10^{-6} m • use x = 0.10 m and distance to grating = 0.50 m to calculate tan θ (= 0.2) • θ = 11.3° • sin θ = 0.196 • alternatively, calculate hypotenuse of triangle (using Pythagoras's theorem) = 0.51 m, giving sinθ (= $0.10/2600^{½}$) = 0.196 • **allow** use of small angle rule (sin$\theta \approx$ tan$\theta \approx \theta$ = 0.2) • calculate λ (= 0.196 × $10^{-3}/300$) = 650 nm **Estimation of uncertainty** • negligible uncertainty in d (and n) • uncertainty in sin θ is found using uncertainty in distance measurements • uncertainty in each distance measurement is ± 1.0 mm **or** ± 0.5 mm **or** ± 2.0 mm • maximum % uncertainty in tan θ / θ / sin θ = 3% • so % uncertainty in λ = % uncertainty in sin θ = 3%

Question			Answer	Marks	Guidance
5	(b)	(i)	$E = (hc/\lambda) = 6.63 \times 10^{-34} \times 3(.00) \times 10^{8} / 486 \times 10^{-9}$ $E = 4.09 \times 10^{-19}$ (J)	M1 A0	This is a 'show that' question so the mark is for giving the full substitution of values leading to an answer correct to 3 SF
		(ii)	(vertical) arrow pointing downwards from -1.36 to -5.45	B1 B1	
			Total	9	

Question	Answer	Marks	Guidance

Question			Answer	Marks	Guidance
2	(a)	(i)	R = 3000 + 1500 V = 12 × 1500/4500 = 4(.0) (V)	C1 A1	R = 4500 (Ω) ***or*** $I = V/R$ = 12 /4500 = 2.67 mA V_{1500} = 2.67 mA x 1.5 kΩ = 4.0 (V)
		(ii)	V (= 12 × 1500/1600) = 11.25 (V) ΔV = 11.25 – 4.0 = 7.25 (V)	C1 A0	
	(b)		**see next page**		

Question			Answer	Marks	Guidance
	(b)	*	**Level 3 (5–6 marks)** Clear description of a valid experiment which would lead to accurate results, sensible suggestions for table, graph and accuracy *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Reasonable description of experiment and sensible suggestion for table **or** graph **or** accuracy, or attempt at all three *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Attempt at experiment and attempt at table **or** graph **or** accuracy *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.	**B1 x 6**	**Indicative scientific points may include:** **Experiment** • Diagram(s) to show electrical circuit and/or set-up of apparatus • Use ammeter in series to measure current I through LED • Use micrometer to measure thickness of (one sheet of) tracing paper • or use calliper with m sheets of thickness t; measure t and use $x = mt$ • Measure I for various x • Calculate ln I **Results table** • Need columns for total thickness x (or number of sheets m *and* $x = mt$), current I, ln (I) • Units if included should be appropriate and presented in an appropriate format e.g. ln(I/mA) **Graph** • plot ln I against x • expect straight line graph with negative gradient and non-zero intercept • gradient = - n *and* y–intercept c = ln k • $k = e^c$ (alternatively, k is the current when no sheets of paper are used) **Accuracy** • work in darkened room/constant low light conditions • keep distance between light-source and LDR constant • use same power light source and same LDR throughout • position yourself so as not to cast shadow on LDR • clamp equipment to bench to ensure distances do not change
			Total	**9**	

Question	Answer	Marks	Guidance

19	**(a)**		Calculation in eV: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19}$ (J) $E_{\text{light photon}} = 3.9 \times 10^{-19} / 1.6 \times 10^{-19}$ $= 2.44$ (eV) Number of photons = ($E_{\text{X-ray photon}}/E_{\text{light photon}}$) x efficiency = (32 000 / 2.44) x 0.15 = 1969	**C1** **C1** **C1** **A0**	Calculation in J: $E_{\text{light photon}} = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 510 \times 10^{-9}$ $= 3.90 \times 10^{-19}$ (J) $E_{\text{X-ray photon}} = 32 \times 10^{3} \times 1.6 \times 10^{-19}$ $= 5.12 \times 10^{-15}$ (J) Number of photons = ($E_{\text{X-ray photon}}/E_{\text{light photon}}$) x efficiency = ($5.12 \times 10^{-15} / 3.90 \times 10^{-19}$) x 0.15 = 1969 Answer to at least 3sf **Allow** use of 2.4eV for energy of light photon to give 2000 in either method
	(b)	**(i)**	(The work function is) the minimum energy required to release an electron (from the surface of a metal)	**B1**	**Allow** minimum work done for minimum energy **Do not allow** idea of energy needed to release multiple electrons **Do not allow** release of electron from atom **Do not allow** idea of ionisation energy
		(ii)	$\phi = 2.3 \times 1.6 \times 10^{-19}$ (= 3.68×10^{-19} J) $KE_{\text{max}} = (3.90 - 3.68) \times 10^{-19} = 2.2 \times 10^{-20}$ (J)	**C1** **A1**	Or $\phi = 2.44 - 2.3$ (= 0.14 eV) $KE_{\text{max}} = 0.14 \times 1.6 \times 10^{-19} = 2.2 \times 10^{-20}$ (J) Answer to at least 2sf **Allow** use of 2.4 eV to give 1.6×10^{-20} (J) ecf light photon energy from (a)

Question			Answer	Mark	Guidance
		(iii)	$I\left(=\frac{Q}{t}\right) = \frac{12\times1969\times1.6\times10^{-19}}{60}$ = 6.3 x 10^{-17} (A)	C1 A1	**Allow** full credit for use of 2000 Answer to at least 2sf (6.30) **Allow** use of *N*= 2000 to give I = 6.4 x 10^{-17} (A) **Allow** ecf on *N* from (a)
		(iv)	One from: One to one interaction between (light) photon and electron That there are no secondary electrons That the current is continuous / X-rays arrive at a constant rate within the minute (or 1 every 5s) All the electrons leave the photocathode	B1	

1	(a)		$\lambda = \frac{v}{f}$ $(= \frac{340}{262})$ $\lambda = 2L$ $(L =) \frac{1.30}{2} = 0.65$ (m)	B1 B1 B1	Formula may be implied by substitution **Allow** *c* for *v* Relationship may be inferred from a correct diagram of fundamental drawn in a tube open at both ends, or from a statement such as 'half a wavelength fits inside the tube' Some working leading to correct answer must be shown; don't accept a bald answer **Allow** *L* = 0.649 (0.64885) as evidence of working Do not allow working backwards from the answer
	(b)	(i)	Any **two** from • particles occupy negligible volume (compared to volume of container/gas) • collisions are (perfectly) elastic • time of collisions is negligible (compared to the time between collisions) • negligible <u>forces</u> exist between particles (except during collisions)	B1 × 2	Mark as for Short Answer Questions (requiring only a list by way of a response) and contradictory responses see page 3. **Allow** zero / no / none for negligible throughout **Ignore** particles occupy negligible space **Ignore** particles are very small **Allow** <u>kinetic</u> energy is conserved (during collisions) **Allow** the particles move at constant velocity (in between collisions) **Ignore** type of force if specified

Question			Answer	Mark	Guidance
1	(b)	(ii)	$M = 4.00 \times 10^{-3}$ (kg mol^{-1})	C1	This C1 mark is for converting M into kg mol^{-1} **Allow ECF** for an incorrect POT in M
			$T = 263$ (K)	C1	T = -10 (K) is **XP** onwards (first C1 mark can still be scored) but **allow ECF** for incorrect conversion of T.
			$v^2 = \frac{1.67 \times 8.31 \times 263}{4.00 \times 10^{-3}}$ $v = 955$ (m s^{-1})	C1	This C1 mark is for correct substitution into the given formula; v^2 does not need to be calculated for the mark but seeing $v = 955$ implies the mark **Allow** M given to 1sf **Allow** 8.3 or R for 8.31 If a value for γ or M is taken from the wrong row of the table, this is a TE (M must be in kg/mol). If both wrong values are used, count this as a single TE.
			$f = (\frac{v}{\lambda} =) \frac{955}{1.30} = 730$ (Hz)	A1	**ECF** candidate's value of λ or L ($\lambda = 2L$) from 1a **Allow** $f = 740$ (Hz) For reference, POT error in M gives $v = 30.2$ (ms^{-1}) and $f = 23$ (Hz)
			Alternative method using ratios		

Question			Answer	Mark	Guidance
			$\frac{f_1}{f_2} = \left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2}$ or $\frac{v_1}{v_2} = \left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2}$	C1	
			T = 263 (K)	C1	T = -10 (K) is **XP** onwards (first C1 mark can still be scored) but **allow ECF** for incorrect conversion of T
			$\left(\frac{\gamma_1 T_1 M_2}{\gamma_2 T_2 M_1}\right)^{1/2} = \left(\frac{1.67 \times 263 \times 29}{1.4 \times 293 \times 4}\right)^{1/2}$ = 2.786	C1	This C1 mark is for substitution and the ratio 2.786 does not need to be calculated for the mark The values for M may be given in kg/mol or left in g/mol as long as there is consistency **Allow** M = 4 to 1sf
			f (= 2.786 x 262) = 730 (Hz)	A1	**Allow** f = 740 (Hz) If using $\frac{v_1}{v_2}$ then v = 2.786 x 340 = 947 giving f (= v / λ = 947 / 1.3) = 730 (Hz) but **ECF** candidate's own value of λ or L ($\lambda = 2L$) from 1a
			Total	**9**	

Question	Answer	Mark	Guidance

18	**(a)**	Heater / cathode / filament	B1	**ALLOW** filament lamp **IGNORE** Thermionic
18	**(b)**	Cooling / preventing melting (of anode)	B1	**NOT** just 'so the same spot isn't hit all the time'
18	**(c)**	Electrons (in anode) are removed from (inner) energy level (by collision) (Outer) electron (in anode) falls to lower energy level (emitting characteristic X-ray photon)	B1 B1	Alternative answer: Electrons decelerate on collision with anode (X-rays / photons are produced) because of change in <u>kinetic</u> energy (of electrons)
18	**(d)**	Photon energy, $(E) = 90 \times 10^3 \times 1.6 \times 10^{-19}$ $(= 1.44 \times 10^{-14}$ J) $\lambda = hc/E = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.44 \times 10^{-14}}$ $= 1.4 \times 10^{-11}$ (m)	C1 C1 A1	**ALLOW** calculation of conversion of 150 keV (2.4×10^{-14}) or 60 keV (9.6×10^{-15}) for this mark only No conversion to J or conversion using wrong physics (e.g. division by 1.6×10^{-19}) to J is XP Use of $\lambda = h/p$ and $E = mc^2$ is XP Correct to at least 2 significant figures

Question		Answer	Mark	Guidance
18	(e)	($I = I_0 e^{-\mu x}$ to give) $0.3 = e^{-(\mu \times 4.6)}$	C1	**ALLOW** $3.3 = e^{(\mu \times 4.6)}$ Expect to see both 0.3 and 4.6 correctly substituted into equation
		μ (= - ln (0.3) / 4.6) = 0.26 (cm^{-1})	A1	Correct to at least 2 significant figures (0.262 cm^{-1}) Negative final answer (- 0.26) loses second mark

19	**(a)**		current = 0.01 (A) p.d. = 0.01 × 50 (= 0.50 V)	**M1** **A1**	
	(b)		(V_{75} =) **0.5 + 2.5** (V) **or** (R_{LED}) = **250** (Ω) **or** (R_p =) **60** (Ω) (I_{100} =) **0.05** (A) (E = 3.0 + 0.05 × 100) E = 8.0 (V)	**C1** **C1** **A1**	**Allow** other correct methods **Note** there is no ECF from **(a)** **Allow** 1 SF for the p.d. of 3 (V) There is no ECF here from wrong physics (XP) from the parallel network **Allow** 1 SF answer of 8
	(c)	**(i)**	(P =) 0.01 × 2.5 **or** 0.01^2 × 250 **or** $2.5^2/250$ **or** 0.025 (W) (E_{photon} =) $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{4.7\times10^{-7}}$ **or** 4.23 × 10^{-19} (J) (number per second = $\frac{0.025}{4.23\times10^{-19}}$) number per second = 5.9 × 10^{16} (s^{-1})	**C1** **C1** **A1**	**Allow** 4.0 × 10^{-19} (J); which is 2.5 eV **Note** using 4.0 × 10^{-19} (J) gives 6.25 × 10^{16} (s^{-1})
		(ii)	(E_{photon} =) 2.64 (eV) **or** (ϕ =) 3.68 × 10^{-19} (J) **or** (f_0 =) 5.55 × 10^{14} (Hz) **or** (λ_0 =) 5.40 × 10^{-7} (m) Photoelectrons are emitted and 2.6(4) > 2.3 **or** 4.23 × 10^{-19} > 3.68 × 10^{-19} **or** 6.38 × 10^{14} (Hz) > 5.55 × 10^{14} (Hz) **or** 4.7 × 10^{-7} (m) < 5.40 × 10^{-7} (m)	**M1** **A1**	Possible ECF from **(i)** **Allow** 2.6 (eV) **or** 3.7 × 10^{-19} (J) **Allow** 2.5 (eV) as the energy of the photon **Note** the conclusion must be consistent with **(i)** **Allow** $hf > \phi$ **Note** this can be implied by calculating the KE of the emitted electron
			Total	**10**	

20	**(a)**	**(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 $4.8 \ (\times 10^{-7}) = k \times [7.8 \times (10^{-9})]^2$
	(b)		(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
	(c)	**(i)**	phase difference = $n \times 360(°)$ for bright (fringes) / constructive (interference) phase difference = $(n + ½) \times 360(°)$ for dark (fringes) / destructive (interference)	**B1** **B1**	**Allow** zero **or** $n \times 2\pi$(rad) **or** even number of π (rad) **or** even number of 180(°) **Allow** 180(°) **or** $(n + ½) \times 2\pi$(rad) **or** odd number of π (rad) **or** odd number of 180(°) **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** $\lambda = 6.316 \times 10^{-7}$ (m) $x = \frac{6.316 \times 10^{-7} \times 8.2}{0.20 \times 10^{-3}}$ **or** x = 0.0259 (m) t = 0.14 (s)	**C1** **C1** **A1**	 **Note** the answer must be given to 2 SF for this mark **Special case:** allow 1 mark for 8.6×10^{-11} s on the answer line; incorrect physics using $0.18 = 4.75 \times 10^{14} \lambda$
			Total	**10**	

16	**(a)**	**(i)**	($v = f\lambda$) $340 = 20 \times 10^3 \times \lambda$ wavelength = 1.7×10^{-2} (m)	**C1** **A1**	**Allow** 1 mark for 17 (m); 20 Hz used
		(ii)	Loudspeaker and signal generator Frequency increased until limit of hearing frequency determined using $f = 1/T$	**B1** **B1** **B1**	**Allow** this mark for a labelled diagram **Do not allow** t for time period
	(b)		Difference: (stationary waves) has nodes / antinodes Similarity: Oscillations are longitudinal	**B1** **B1**	Differences and/or similarities can be described in terms of net energy transfer, phase or amplitude variations
	(c)		Diagram showing angle within the block measured relative to the normal Increase the (incident) angle until the ray of light runs along the boundary / suffers total internal reflection (ORA) **or** angle measured using a protractor n determined using $n = 1/\sin C$	**B1** **B1** **B1**	Allow i / θ / C as the angle to be measured. Must be clear which angle is being measured. Expect the normal as a line perpendicular to straight edge of block, and emergent ray. No labels expected for the rays or the normal. Formula in this arrangement
			Total	**10**	

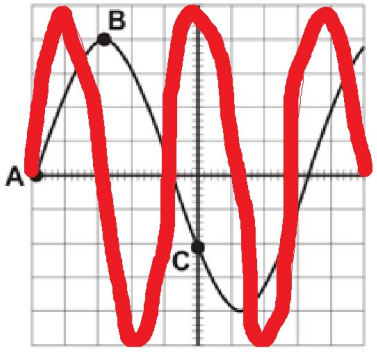
16	**(a)**	**(i)**	π (rad)	**B1**	**Allow** 3.14 or 3.1 (rad) **Do not allow** answer in degrees
		(ii)	- 5.0 (cm)	**B1**	**Allow** 1 SF. **Must** see negative sign.
	(b)		540 (°) 1.5 (λ)	**B1** **B1**	**Allow** 180° **Do not allow** answer in radians **Allow** 3/2
	(c)	**(i)**	Zero amplitude / displacement / oscillations / movement (at the nodes)	**B1**	**Allow** minimum or least for zero throughout **Ignore** references to pressure e.g. min/max pressure **Allow** correct answers in terms of pressure gradients **Penalise** incorrect answers in terms of antinodes **Ignore** correct answers in terms of antinodes
		(ii)	2λ = 25 (cm) / λ = 12.5 (cm) $v = 2720 \times 0.125$ v = 340 (m s^{-1})	**C1** **C1** **A1**	 **Maximum** one POT error in this question **Special case: one mark only** for bare 340 (m s^{-1}) with no working **Allow** 2 marks for 170 m s^{-1} if calculated from λ = 6.25 (cm)
		(iii)	$11f_0 = 2.72$ ($\times 10^3$) **or** $11/4 \times 12.5 = \lambda_o/4$ **or** λ_o = 1.375 (m) f_0 = (340 / 1.375) = 247 (Hz)	**C1** **A1**	**Allow** length of tube = 0.344 (m) **Allow** 250 (Hz) **Allow** ecf on v from (c)(ii).
			Total	**10**	

22	**(a)**		$^{18}_{9}F \rightarrow {}^{18}_{8}O + {}^{0}_{1}\beta^{+}$ (+ν)	**C1** **A1**	Correct fluorine isotope Correct equation **ALLOW** numbers written to right of symbol **ALLOW** e / e^+ / $\overline{e}$ / β for positron symbol with correct numbers **IGNORE** gamma in products **ALLOW** $^{0}_{0}\upsilon$ for neutrino **ALLOW** ν_e for neutrino
	(b)		$E = mc^2 = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2$ $= 8.2 \times 10^{-14}$ (J) $E = hc / \lambda = 8.2 \times 10^{-14} = 6.63 \times 10^{-34} \times 3 \times 10^8 / \lambda$ $\lambda = 3.00 \times 10^8 \div 1.2367 \times 10^{20} =$ **2.4×10^{-12}** (m)	**C1** **C1** **A1**	Working leading to evaluation of E **ALLOW** factor of 2 leading to 1.6×10^{-13} (J) **NOT** use of $\lambda = h/mv$ where v is 3×10^8 alone **XP** **ALLOW** use of $\lambda = hc/mc^2$ or $\lambda = h/mc$ **ALLOW** Use of electron mass = 0.511 MeV giving 8.2×10^{-14} (J) Correct to at least 2 significant figures Answer of 4.9×10^{-12} or 1.2×10^{-12} allow 2/3 due to incorrect accounting for factor of 2
	(c)		X-rays formed when <u>electrons</u> (in an atom) de-excite	**B1**	**ALLOW** X-rays may be produced by acceleration / deceleration of (fast moving) electrons / X-rays are produced when (fast moving) electrons are incident on a metal target / X-rays may be produced when electrons lose kinetic energy

Question			Answer	Mark	Guidance
			Gamma rays come from the decay of <u>nuclei</u> (in unstable isotopes)	**B1**	**ALLOW** gamma rays come from (the decay of) radioactive <u>nuclei</u> / gamma rays come from the <u>nucleus</u> of unstable atoms / gamma rays come from the de-excitation of <u>nuclei</u> / gamma rays come from <u>annihilation</u> of particle-antiparticle (pairs) / **IGNORE** gamma from fission
	(d)		The half-life is short	**B1**	**ALLOW** activity is high **IGNORE** it decays quickly
			Advantage: Exposure of the patient to <u>ionising</u> radiation is kept as low as possible.	**B1**	
			Disadvantage: (Radiographers have a) short time to scan/diagnose the patient	**B1**	**ALLOW** F18 has to be manufactured on site before use / high activity means exposure is high during handling **IGNORE** short time to treat the patient

23	**(a)**		$\Delta\lambda =$ 656.3 - 654 (nm) or 2.3 (nm) $v = c \times \Delta\lambda / \lambda = 3 \times 10^8 \times 2.3 / 656.3$ $=1050$ km s^{-1}	C1 C1 A1	Allow between 2.25 and 2.35 Check denominator is 656.3 and not 654 (XP) Ignore minus sign Accept 1100 (km s^{-1})
	(b)		$d=v/H_0 = 1050000 \div 2.5 \times 10^{-18} = (4.2 \times 10^{23}$ m) 4.2×10^{23} m $\div 9.5 \times 10^{15} = 4.4 \times 10^7$ light years	C1 A1	ECF from (a) Using 1100 km s^{-1} gives 4.6×10^7 ly
	(c)		Absolute uncertainty in $\Delta\lambda$ in range of 0.4-1.2 nm % Uncertainty = (candidate's abs uncertainty ÷ 2.3) × 100= 21%	C1 A1	Allow value that if rounded to 1sf would be in the range Accept 1sf answer Allow in range 17 – 52 %

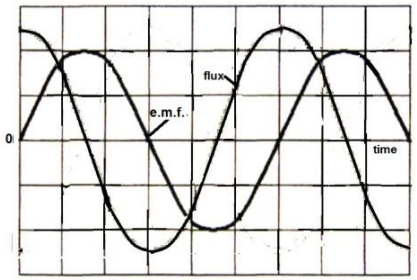
Question			Answer	Mark	Guidance
	(d)		Any two from: Hubble's law assumes/predicts all galaxies moving away / AW (from evidence in question) M87 is blue shifted/moving towards the Milky Way / AW Idea that M87 may 'gravitationally associated' with Milky Way/Local cluster/Virgo supercluster Suitable comment comparing absolute uncertainty with difference in velocities or percentage uncertainty with percentage difference	B1 B1 B1 B1	i.e. correct statement of Hubble's law Accept has a negative recession velocity Allow any reasonable alternative E.g. percentage uncertainty from change in wavelength s larger than the percentage difference in the quoted distance and the calculated distance
	e		One from • Cosmic microwave background evidence • Very few galaxies are blue shifted	B1	Allow decipherable truncations or acronyms e.g. CMBR, MBR Allow other reasonable ideas that supports model (e.g. nucleosynthesis ratios, He:H ratio enhancement (extra helium), universe may not be uniform and/or isotropic, no other model is consistent with the evidence, universe is still expanding)
			TOTAL	10	

21	**(a)**	B	A1	
21	**(b)**	Amplitude drawn is larger Time period drawn is smaller	B1 B1	At least one complete cycle needs to be drawn for any credit Consider all cycles drawn. All peaks must be greater than amplitude of given wave and consistent within ½ square of each other For T, only mark **first** complete cycle – do not insist on symmetry but such that the end of the first cycle is less than or equal to 8 squares e.g. 

	Question	Answer	Mark	Guidance
21	(c) (i)	$\Phi = BA\cos\theta = 25 \times 10^{-3} \times (8.0 \times 10^{-2} \times 4.0 \times 10^{-2})$ x cos 45 (= 5.66×10^{-5} Wb) Change in flux linkage = $N\Phi$ = $120 \times 5.66 \times 10^{-5}$ = 6.8×10^{-3} (Wb)	C1 A1	**ALLOW** sinθ for cosθ Only apply POT error in coil dimensions once Calculation of area of circle using one of the given coil dimensions is XP Correct to at least 2 significant figures (6.79×10^{-3}) **IGNORE** sign
21	(c) (ii)	Induced emf ($E = -\Delta\Phi / \Delta t$) = (-) 0.0068 / 0.13 $\mathcal{E}$ = (-) 0.052 (V)	C1 A1	**ALLOW** ECF for flux linkage above but answer to (c)(i) x 120 ÷ 0.13 scores zero marks for this question Correct to at least 2 significant figures **IGNORE** sign
21	(d)	Total power requirement = 580+40+100 = 720 W Power required from mains = 720 - 400 = 320 (W) Mains current drawn = (P / V) = 320 / 230 = 1.4 (A)	 C1 A1	**ALLOW** other methods e.g. total current required = (40 + 100 + 580) / 230 = 3.13 (A) Current supplied by mains = current required -current from turbine = 3.13 – (400/230) = 1.4 (A) Correct to at least 2 significant figures

	Question	Answer	Mark	Guidance
21	(e)	kWh or kilowatt-hour	B1	**IGNORE** case of letters

Question			Answer	Marks	Guidance
25	(a)	(i)	Proton is repelled (by nucleus) (High-speed) proton can get close to (oxygen) nucleus	B1 B1	 **Allow** 'proton can experience the strong (nuclear) force' **Not** 'collide / hit nucleus'
		(ii)	E = [0.25 - (2.24 - 2.20)] × 10^{-11} (J) **or** 0.21 × 10^{-11} (J) $\lambda = \frac{6.63 \times 10^{-34} \times 3.00 \times 10^{8}}{0.21 \times 10^{-11}}$ (Any subject) λ = 9.5 × 10^{-14} (m)	C1 C1 A1	 **Allow** 2 marks for 6.9 × 10^{-14}; E = 0.29 × 10^{-11} used **Allow** 1 mark for a value correctly calculated based on any other incorrect value for E (e.g. 8(.0) × 10^{-14} for E = 0.25 × 10^{-11} and 5(.0) × 10^{-13} for E = 0.04 × 10^{-11})
		(iii)	Used in PET (scans) Any **one** from: Used to diagnose function of organ / brain / body Detection of cancer / tumour Non-invasive / no surgery / no infection 3D (image)	M1 A1	
	(b)		X-ray (tube) moves around the patient A thin (fan-shaped X-ray) beam is used (Images / scans of) cross-sections through the patient are taken Any **one** from: • A three-dimensional image is produced • (Soft) tissues can be identified	B1 B1 B1 B1	**Allow** 'X-rays passed through different angles.' **Allow** 'slice(s)' **Allow** 'good contrast image'
			Total	11	

Question			Answer	Marks	Guidance
5	(a)	(i)	the flux in the coil changes/ increases/ decreases/ varies (caused by the spinning/rotating magnet) causing a sinusoidal/alternating e.m.f./AW	B1 B1	**or** e.m.f. is proportional to /equals rate of change of flux linkage/linking the coil **or qualification, e.g.** magnet vertical gives minimum flux through core or maximum rate of change of flux or vice versa with magnet horizontal **or** maximum flux is when emf is zero **or** minimum flux is when emf is maximum **or** vice versa
		(ii)		B1	**allow** ± cos wave of correct period, constant amplitude at least one cycle **N.B.** quality: curve must look like a reasonable sine wave as one is present on the page to copy
		(iii)	$\varphi = BA = V/2\pi fN = 1.2/(2 \times \pi \times 24 \times 150)$ $\varphi = 5.3 \times 10^{-5}$ Wb / T m^2	 B1 B1	 **allow no other** unit combinations; NOT T m^{-2}
	(b)		**see page 9**	B1 x 6	
			Total	**11**	

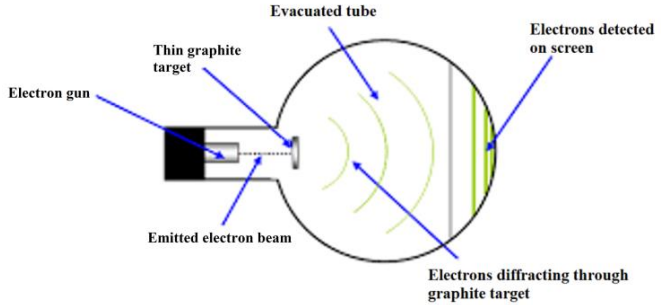
Question	Answer	Marks	Guidance
5	**Level 3 (5–6 marks)** Clear description, some measurements and full analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some description, some measurements and some analysis. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description and/or limited measurements and/or limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.	B1 x 6	**Indicative scientific points may include:** **Description** **a.** Signal generator/a.c. supply connected to coil X **b.** Coil Y connected to voltmeter / oscilloscope (can be on diagram) **c.** Use oscilloscope to determine period / frequency or read off signal generator **d.** Adjust signal generator / use of rheostat to keep current constant in coil X **Measurements** **1.** Vary *f* and measure *V* **2.** Keep current in coil X constant **3.** Detail on how to measure e.m.f. e.g. 'height x *y*-gain' **4.** Detail on how to measure period on oscilloscope screen using time base and hence *f* **Analysis** **1.** Determine f from period measurement, f = 1/T **2.** Plot a graph of *V* against *f* **3.** Relationship valid if straight line through the origin

Question			Answer	Marks	Guidance
6	(a)	(i)	sin C = 1/n = 1/1.69 (= 0.592) C = 36°	C1 A1	
		(ii)	Total internal reflection occurs because the angle of incidence (at the surface) is greater than the critical angle/ 36°	B1 B1	**allow** because $i > C$
	(b)		E = (hc/λ =) 6.63 × 10^{-34} × 3.0 x 10^{8}/450 × 10^{-9} E = 4.42 × 10^{-19} (J) energy = 2.76 (eV)	C1 C1 A1	**N.B.** the answer here must be 2 SF or more
	(c)	(i)	2.76 – 2.3 = 0.46 eV (so only 0.5% of energy/AW)	B1	**allow** 2.8 – 2.3 = 0.5 eV and 3.0 – 2.3 = 0.7 eV possible **ecf** from **(b)**
		(ii)	n = 2000 × 4^{9} (= 5.24 × 10^{8}) Q = ne = 8.4 × 10^{-11} (C) I = 8.4 × 10^{-11} / 2.5 × 10^{-9} average current = 0.034 (A)	C1 C1 A1	**allow ecf** for wrong n **allow** 34 m(A); answer is 1.7 x 10^{-5} A if 2000 omitted (2/3)
			Total	**11**	

19	**(a)**		$h \rightarrow$ J s / $h \rightarrow$ N m s / J $\rightarrow$ kg m^2 s^{-2} base unit = kg m^2 s^{-1}	**C1** **A1**	
	(b)	**(i)**	$Vq = ½\ mv^2$ **and** $\lambda = \frac{h}{mv}$ Clear algebra leading to $\lambda^2 = \frac{h^2}{2mq} \times \frac{1}{V}$	**M1** **A1**	**Allow** *p* for *mv* **Allow** *e* for *q* in **(b)(i)** – this is to be treated as a 'slip'
		(ii)1	(% uncertainty in λ^2 =) 10% (% uncertainty in λ =) 5%	**C1** **A1**	 **Note** 10 (%) on answer line will score the C1 mark
		(ii)2	Straight line of best fit passes through all error bars	**B1**	
		(ii)3	gradient = 1.0 ($\times$ 10^{-22}) $\frac{h^2}{2mq} =$ gradient $\frac{(6.63\times10^{-34})^2}{2\times m\times 3.2\times 10^{-19}}$ = gradient m = 6.9 $\times$ 10^{-27} (kg) (hence about 10^{-26} kg)	**C1** **C1** **C1** **A1**	**Ignore** POT for this mark; **Allow** $\pm$ 0.20 ($\times$ 10^{-22}) Possible ECF for incorrect value of gradient **Note check for AE** (condone rounding error here) **and** answer must be about 10^{-26} (kg) for any incorrect gradient value for this A1 mark **Special case**: 1.37 $\times$ 10^{-26} kg scores 3 marks for q = 1.6 $\times$ 10^{-19} C because answer is about 10^{-26} kg
			Total	**11**	

Question			Answer	Marks	Guidance
4	(a)		Any two points from • (During / shortly after) the Big Bang **or** (Universe was initially) very hot **or** (Universe was initially) gamma photons • Universe expanded **or** Universe cooled (to 2.7K) • wavelength of (gamma) photons subsequently increased	**B1 x 2**	**Allow** radiation for photons throughout **Allow** cosmos / space for Universe but **not** matter / everything **Allow** frequency/energy of photons subsequently decreased **Allow** wavelength of photons/radiation has redshifted **Allow** wavelength of photons has stretched
	(b)	(i)	$\lambda_{max} \propto 1/T$ (T has decreased over time so in the past) the <u>peak</u> was at a shorter wavelength / further to the left on the graph	**B1** **B1**	**Not** $\lambda_{max} = 1/T$ May be inferred from candidate's diagram **Ignore** overall shape of spectrum
		(ii)	$E \left(= \frac{h\,c}{\lambda}\right) = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.1 \times 10^{-3}}$ $E = 1.8 \times 10^{-22}$(J)	**C1** **A1**	Full substitution needed if judging explicitly

Question			Answer	Marks	Guidance
4	(b)	(iii)	**EITHER** $\frac{3\ x\ 10^{-6}}{1.8\ x\ 10^{-22}}$ **or** 1.66×10^{16} (photons $m^{-2}\ s^{-1}$) **OR** $3 \times 10^{-6} \times (150 \times 10^{-4})$ **or** 4.5×10^{-8} (W)	**C1**	
			number of photons per second $\left(= \frac{3 \times 10^{-6} \times 150 \times 10^{-4}}{1.8 \times 10^{-22}}\right)$ $= 2.5 \times 10^{14}$ (s^{-1})	**A1**	**Allow** 2×10^{14} (s^{-1}) or 3×10^{14} (s^{-1}) Expect to see $1.66 \times 10^{16} \times 150 \times 10^{-4}$ **or** $\frac{4.5 \times 10^{-8}}{1.8 \times 10^{-22}}$
		(iv)	$E = Pt = IAt$ and $V = Ah$ where A is CSA of cylindrical tank and h is height of tank $\Delta\theta = \frac{E}{mc} = \frac{I \cancel{A} t}{\rho \cancel{A} h\ c} = \frac{It}{\rho hc}$ and so $\frac{\Delta\theta}{t} = \frac{I}{\rho hc}$		
			$E = mc\Delta\theta$ **and** $m = \rho V$	**C1**	**Allow** nonstandard letters as long as meaning is clear **Allow** 1000 (kg m^{-3}) for ρ **Allow** $\pi r^2 h$ **or** $5\pi r^2$ for V
			max temp rise s^{-1} $\left(= \frac{\Delta\theta}{t}\right) = \frac{3 \times 10^{-6}}{1000 \times 5 \times 4200}$	**C1**	
			max temp rise $s^{-1} = 1 \times 10^{-13}$ (°C s^{-1})	**A1**	**Allow** answer to more than 1s.f. (1.43×10^{-13} (°C s^{-1}))
			Total	**11**	

19	**(a)**		Any four from: In an evacuated tube (Electrons released by) thermionic emission / (low voltage supply causes) emission of electrons from cathode/filament/electron gun Electrons accelerated towards anode / electrons accelerated through (high) pd / electric field Diffracted through a graphite (target) / graphite is thin Electrons detected on a (phosphor) screen / electrons produce visible light on impact with screen	**4xB1**	**ALLOW** marking points as labels on the diagram or as the answer lines. 
	(b)		(Provides evidence of) wave nature of electrons Light circles caused by constructive interference / waves arriving in phase Dark circles caused by destructive interference / waves arriving in antiphase	**B1** **B1** **B1**	 **ALLOW** out of phase by 180 / π **NOT** just out of phase
	(c)	**(i)**	Work done = 1.60×10^{-19} x 5×10^{3} = **8.0×10^{-16}** (J)	**A1**	**ALLOW** correct answer to 1 significant figure

Question			Answer	Mark	Guidance
		(ii)	$W = ½ mv^2 = 8 \times 10^{-16} = ½ \times 9.11 \times 10^{-31} \times v^2$ $= 4.2 \times 10^7$ ms^{-1} $\lambda = h/mv = 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 4.2 \times 10^7$ = **1.7 x10^{-11}** (m) OR Momentum of electrons = $\sqrt{2 \times m_e \times W}$ $= \sqrt{2 \times 9.11 \times 10^{-31} \times 8 \times 10^{-16}}$ = (3.82 x10^{-23} kgms^{-1}) 6.63 x 10^{-34} / 3.82 x10^{-23} = **1.74 x10^{-11}** (m)	**C1** **A1** **(C1)** **(A1)**	Substitution leading to velocity Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure Ecf from (c)(i) **ALLOW** correct answer to 1 significant figure
		(iii)	(For diffraction to occur) the gap needs to be approximately the same size as the wavelength so spacing should be 1.74 x 10^{-11} m	**B1**	Reason and value required. **ALLOW** suggested value spacing as (c)(ii) same power of ten

17	(a)		At P_1 (and / or P_3), waves (arrive) in phase and undergo constructive interference At P_2, waves (arrive) in antiphase and undergo destructive interference	B1 B1	**Allow** maxima / loud areas for at P_1 and P_3 **Allow** phase difference of 0 or $2n\pi$ (rad) or 360° **Allow** explanation in terms of path difference (path difference = $n\lambda$ and undergo constructive interference) **Allow** superposition for interference **Allow** minimum / quiet areas for P_2 **Not just** "out of phase" **Allow** completely out of phase / out of phase by $(2n+1)\pi$ (rad) or 180° **Allow** explanation in terms of path difference (path difference = $(n+1/2)\ \lambda$ and undergo destructive interference) **Allow** superposition for interference **Do not allow** deconstructive for destructive
	(b)		$\lambda = (\frac{ax}{D} =) \frac{0.70 \times 2.5}{4}$ = 0.4375 (m) $f = \frac{v}{\lambda} = \frac{340}{0.4375} = 780$ (Hz)	C1 C1 A1	**Allow** λ = 0.44 (m), then f = 770 (Hz) Correct to at least 2sf **Special case**: use of *x* as 1.25 leading to *f* = 1554 (Hz) for 1 mark
	(c)		Amplitude / maximum (of the signal) larger than previous amplitude seen at P_1 (and at P_3)	B1	**Ignore** numerical value of how much the amplitude is larger **Allow** reference to P_3 alone **Allow** height or signal for amplitude throughout

Question			Answer	Mark	Guidance
			Non-zero amplitude seen <u>at P_2</u>	**B1**	**Ignore** "louder"
	(d)	**(i)**	power per unit area (perpendicular to the direction of energy transfer)	**B1**	**Allow** energy per unit time for power **Allow** equation in words, or in symbols with all symbols defined **Do not allow** power per area or power over area
		(ii)	intensity is proportional to (amplitude)^2 amplitude in (a) = 2 and amplitude in (c) = 3 (ratio of amplitudes = 3/2) so factor = 9/4 (or 2.25)	**C1** **C1** **A1**	**Allow** *A* (or *a*) for amplitude and *I* (or i) for intensity in both C marks **Allow** any valid ratio e.g. 9:4

Question	Answer	Mark	Guidance

Question			Answer	Marks	Guidance
5	(a)		$c = f\lambda$ **or** $f = 3.0 \times 10^8 / 0.60$ $f = 5.0 \times 10^8$ (Hz)	**C1** **A1**	**Allow** $v = f\lambda$ **Allow** 5×10^8
	(b)		$a_{max} = -\omega^2 A$ or $a_{max} = -(2\pi f)^2 A$ $\omega = 2 \times \pi \times 5.0 \times 10^8 = 3.1(4) \times 10^9$ (rad s^{-1}) or $10^9\pi$ a_{max} $(= \pi^2 \times 10^{18} \times 4.0 \times 10^{-6}) = 3.9 \times 10^{13}$ (m s^{-2})	**C1** **C1** **A1**	**Allow** without the minus sign **ECF** from **(a)** **Not** $4.0 \times 10^{12}\pi^2$
	(c)		the current (induced in the aerial) is alternating (5×10^8 times per second) (so the meter would register zero) / AW **or** the diode (half-)rectifies the current / changes the current (from a.c.) to d.c. / AW	**B1**	**Allow** 'a diode only lets current pass through in one direction' AW
	(d)		**see next page**	**B1 x 6**	
			Total	**12**	

Question			Answer	Marks	Guidance
5	(d)	*	**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 *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **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 *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited reasons are given for the situations which give maximum/minimum readings in <u>either</u> investigation *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	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 ± 90° (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 nλ further, n = 0,1, etc • so max current when plate is at λ/2, 2λ/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)λ/2 further, n = 0,1, etc • so zero current when plate is at λ/4, 3λ/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) **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.

H556/03 Mark Scheme November 2020

Question	Answer	Marks	Guidance

20	**(a)**	Two waveforms in antiphase Clearly indicated resultant shown as no disturbance e.g. 	B1 B1	**ALLOW** diagram of waves superimposed **ALLOW** waveforms of different amplitudes **ALLOW** smaller amplitude resultant wave if two initial waves have different amplitudes For both marks: • Description allowed to support the diagram in both marks • Each initial waveform must have at least one complete cycle
20	**(b) (i)**	(First bright fringe when) d sinθ = λ OR Path difference is λ Use of tan θ = x/D leading to x/D = λ/d	B1 B1	**ALLOW** use of tanθ and sinθ interchangeably throughout **ALLOW** d sinθ = n λ where n = 1

Question		Answer	Mark	Guidance
		giving x ≈ Dλ/d sinθ ≈ θ OR θ ≈ tanθ OR sinθ ≈ tanθ	 B1	 Approximation should be given on answer line or clearly identified as such, with use of ≈
20	**(b) (ii) (1)**	The wavelength decreases So, the spacing / x decreases	M1 A1	**ALLOW** reverse argument **ALLOW** use of λ for wavelength **IGNORE** frequency comments **IGNORE** fringes get smaller
20	**(b) (ii) (2)**	Fringes disappear Because the light from the source is not <u>coherent</u>	B1 B1	**ALLOW** there is no interference pattern seen
20	**(c)**	Polarisation is when oscillations are (only) in one direction which is perpendicular to direction of propagation / energy transfer / travel Sound waves are longitudinal In longitudinal/sound waves, the oscillation is parallel to the direction of propagation / energy transfer / travel	B1 B1 B1	**ALLOW** vibrates for oscillates

Question			Answer	Marks	Guidance
5	(a)		the (sound) wave reflects at the water (surface) reflected wave interferes/superposes with the incident wave to produce a (resultant) wave with a node at the water surface and an antinode at the top of the tube $l = \lambda/4$	B1 B1 B1 B1	 **Allow** the (two) waves interfere/superpose **Do not allow** interact/combine
	(b)	(i)	$l = (v/4)(1/f) - k$ Correct comparison with $y = mx + c$	M1 A1	Correct manipulation of equation **must** be shown
		(ii)	large triangle used to determine gradient gradient calculated correctly v = 320 (m s^{-1})	B1 B1 B1	$\Delta x > 0.6 \times 10^{-3}$s Expect between 80 and 82 (m s^{-1}) **Allow** 320 ± 20; **allow ECF** from an incorrect gradient
	(c)	(i)	Value of $1/F$ determined correctly from graph F = 350 (Hz)	C1 A1	**Allow values between** 2.83 x 10^{-3}s and 2.84 x 10^{-3}s **Allow** only alternative methods which use values from line of best fit
		(ii)	$(100\ (\Delta F/F) =)\ 100\ \Delta v/v$ $+ \frac{100\ (\Delta l + \Delta k)}{(l + k)}$	B1 B1	
			Total	**13**	

Question	Answer	Marks	Guidance

Question			Answer	Marks	Guidance
21	(a)	(i)	electron bound to nucleus / represents energy electron must gain to leave the atom / total energy of electron in atom is less than that of a free electron	B1	**Allow** ionisation level defined as zero as AW for 'represents electron must gain energy to leave atom / move up energy level' **Allow** potentials for attractive forces are negative.
		(ii)1	energy = 2.55 (eV)	B1	Ignore sign
		(ii)2	energy = $2.55 \times 1.60 \times 10^{-19}$ (J) $\lambda = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.55\times1.60\times10^{-19}}$ (Allow any subject) wavelength = 4.9×10^{-7} (m) wavelength = 490 (nm)	C1 C1 A1	Possible ECF from **(ii)1** **Note:** wavelength = 488 (nm) to 3 sf
	(b)	(i)	Electron(s) makes a transition to a lower (energy) level / loses energy **and** emitting a photon(s) / EM radiation	B1	
		(ii)	Reduce grating separation / increase distance between grating and screen	B1	**Allow** 'use finer grating' or 'use grating with more lines mm^{-1}' **Not** 'smaller slit size'
		(iii)	wavelength (of peak) = 661.5 nm $v = 3.0 \times 10^{8} \times (661.5 - 656.3) /$ **656.3** recession velocity = 2.4×10^{6} (m s^{-1})	C1 C1 A1	**Allow:** between 661 and 662 nm **Note:** check divided by 656.3 nm Range of acceptable answers. 2.1(5)-2.6(1) x 10^{6}
		(iv)	(Relative) abundance of hydrogen (AW)	B1	**Allow** 'Hydrogen commonly found in stars' (AW)
	(c)		Less intense Galaxy is moving faster **and** therefore greater / longer wavelength (AW) Periodic shift in wavelength (if plane of orbit is in line of sight) (ORA)	B1 B1 B1	 **Allow** 'greater red shift' / 'greater Doppler shift' / 'to the right' for longer wavelength **Allow** argument referring to splitting of line because of relative velocities of two component stars. **Not** idea of blue shift.
			Total	14	

Question			Answer		Guidance
5		(i)	sin **or** cos wave with 1.5 wavelengths (between **C** and **R**) y-axis showing scale ,i.e. (amplitude) 2.(0) x 10^{-6} (m) correct scale on x-axis showing λ = 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
		(ii)1	v = Aω **or** 2πfA v = (2 x 10^{-6} x 2 x 3.14 x 1.7 x 10^{3} =) 2.1 x 10^{-2} (m s^{-1}.)	**C1** **A1**	
		(ii)2	½Mv^2 = 3/2 RT and T = 290 v = √(3 x 8.31 x 290/0.029) v = 5(.0) x 10^{2} (m s^{-1}.)	**C1** **A1**	**or** ½mv^2 = 3/2 kT so v^2 = 3 (k/m) 290 **N.B. remember to record a mark out of 4 here**
	(b)		**see page 14**	**B1 x 6**	
			Total	**14**	

Question			Answer	Marks	Guidance
5	(b)		**Level 3 (5 - 6 marks)** Clear description and explanation for **both** experiments **and** some discussion of uncertainty *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.* **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 *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited description and explanation for **one** experiment *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	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:** **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 λ with (%) uncertainty reduced • Do experiment outside • to reduce background reflections from room (so that sharper minima should be observed)

Question			Answer	Marks	Guidance
20	(a)	(i)	A straight line with non-zero V_0 intercept	B1	**Ignore** spread of data points on either side of the line **Allow** Intercept > 0 and < 1.0 V
			gradient = 1.3×10^{-6}	B1	**Allow** $(1.10 \text{ to } 1.60) \times 10^{-6}$; no need to check calculation
		(ii)	gradient = $\frac{hc}{e}$ (Any subject)	C1	
			$h = \frac{1.3 \times 10^{-6} \times 1.60 \times 10^{-19}}{3.00 \times 10^{8}}$ (Any subject)	C1	Possible ECF from **(i)**
			$h = 6.9 \times 10^{-34}$ (J s)	A1	**Note** the answer must be given **2 SF** only
		(iii)	difference = $\frac{6.9 \times 10^{-34} - 6.6(3) \times 10^{-34}}{6.6(3) \times 10^{-34}} \times 100$ %		Possible ECF from **(ii)** **Ignore** sign **Not** division by value from **(ii)**
			difference = 4.1 %	B1	**Allow** 1 SF answer
		(iv)	Random (error) / data points are spread about line	B1	
			Systematic (error) / line does not pass through origin	B1	
			Take (many) repeat readings (of V_0) **and** average	B1	
			Conduct the experiment in a darkroom / use (black) tube over the LED to view when it is lit / use a (digital) voltmeter with no zero error	B1	**Allow** other sensible suggestion **Not** faulty voltmeter

10

Question			Answer	Marks	Guidance
	(b)				**Allow** *f* for frequency, λ for wavelength and ϕ for work function throughout **Allow** 'overcome' / 'met' / 'reached' when describing > or < **Allow** photon**s**
			Any **one** from: Energy of visible light photon < work function (of zinc) (frequency of) visible (light/photon) < threshold frequency	**B1**	**Not** f_0 for threshold frequency **Allow** equivalent statement with wavelength
			Any **one** from: Energy of UV photon > work function (of zinc) (frequency of) UV (radiation/photon) > threshold frequency	**B1**	**Allow** = instead of > or < throughout for UV **Allow** equivalent statement with wavelength
			Any **two** from: • Collapse of leaf linked to removal of electrons • One-to-one interaction of photon and (surface) electron • Photon energy is independent of intensity / Intensity linked to rate of photons (incident on the zinc plate)	**B1 × 2**	**Ignore** stem / plate / leaf / electroscope becoming positive
			Total	**14**	

18	(a)	(i)	$a = -\omega^2 x$ seen Suitable linking $a = -\omega^2 x$ and either $\omega = 2\pi f$ or $\omega = 2\pi/T$ with substitution f = 1.41 (Hz)	B1 M1 A1	e.g. $4\pi^2 f^2 = 78.3$ or f = sqrt($3.6/4\pi^2$ x 4.6 x 10^{-2}) or f=8.85/2π or T=0.71… **Allow** f = 1.408… (Hz)
		(ii)	$A = \frac{x}{\cos \omega t}$ or $A = \frac{4.6\times10^{-2}}{\cos(2\times\pi\times1.4\times6.5)}$ (Any subject) A = 0.057 (m)	M1 A1	**Not:** sine for cosine. **Note** A = 0.090(4)(m) if 1.41 used **Note** A = 0.0796 (m) if 1.408 used **Allow** 1 mark for cosine used with calculator in degrees

Question			Answer	Marks	Guidance
	(b)		EPE decreases (from bottom to top)	B1	**Not** EPE becomes 0 (or negative)
			GPE increases (from bottom to top)	B1	**Allow** for the first two marking points: description that refers to total potential energy starts at maximum, is minimum at equilibrium point and max again at top, provided total potential energy is stated to be the sum of EPE and GPE
			KE starts at zero, finishes at zero and max at equilibrium point.	B1	
			Air gains thermal energy / Total energy (of mass and spring) decreases over time	B1	**Allow** as alternative for first three marks: EPE to KE and GPE in bottom half EPE and KE to GPE in top half EPE at start to GPE at top
	(c)	(i)	(Smooth) curve showing amplitude increases and then decreases	B1	**Not:** more than 1 peak **Allow:** asymptote instead of peak
			maximum at 1.4 Hz by eye	B1	
		(ii)	Curve similar shape yet lower at all non-zero f points with peak shifted slightly to left (of 1.4 Hz)	B1	**Allow:** curve without shifted peak i.e. peak at 1.4 Hz ECF their K curve
		(iii)	Bridge close to resonance if frequency of driver is close to natural frequency of bridge	B1	**Allow:** footfall/people walking/wind for driver **Allow:** resonance (occurs) when frequency of driving force is at natural frequency of bridge
			(Close to resonance) giving larger amplitude which causes damage or other named consequence	B1	**Allow**: Maximum for larger
			Total	**14**	

23	**(a)**	**(i)**	4.804 3.839	**A1**	**ALLOW** 2dp for either or both values 4.80 and 3.84
		(ii)	Both points plotted correctly	**A1**	**ALLOW** plotting of their 23(a)(i) values as long as the values lie within the grid range Plotting to within ½ small square
		(iii)	Appropriate line of best fit	**B1**	Straight line with negative gradient Allow best fit line from their plotted points Expect even distribution of points across the whole line for their plotted points
	(b)	**(i)**	$\ln I_x = \ln I_0 - \mu x$ $\ln I_x = -\mu x + \ln I_0$ compare with $y = mx + c$	**C1** **A1**	**ALLOW** log equation in any format **ALLOW** an indication that y = mx + c has been used, with the ln equation in the correct order. Negative sign for required μ.
		(ii)	Correct determination of their y intercept Correct $e^{intercept}$ of their y intercept value	**C1** **A1**	Their intercept recorded to nearest ½ small grid square **ALLOW** values to more than 1 dp Answer to 2 sf
		(iii)	Evidence of use of graph to determine gradient	**B1**	Change in x value greater than half of their line AND points correctly read from the line (not the tabulated values unless they lie on the line).

Question			Answer	Mark	Guidance
			Correct answer for their gradient, and given as positive for μ	B1	½ square tolerance on readings of points Ignore sign on gradient. Correct to at least 2 significant figures **NOT** if graph shows positive gradient
	(c)	**(i)**	(100 / 5100) x 5 (= 0.098) (V) OR (8000 / 13000) x 5 (= 3.077) (V) **0.098 to 3.077** OR **2.98** (V)	**C1** **A1**	**ALLOW** rounding of either or both of these values to 2sf **ALLOW** final answer of range of 0.1 to 3 OR 3 (1sf answer) if more than 1sf seen previously
		(ii)	Any two from: Increase the input voltage Decrease (the resistance of) R_1 / (fixed) resistor Extend range of thickness of jelly used	**2 x B1**	**ALLOW** emf for input voltage but not just potential difference **IGNORE** current **NOT** decrease the resistance alone **NOT** just make jelly thinner/thicker. Must be clear that values below 1mm or above 5mm are to be used.
		(iii)	As the light intensity increases the resistance of the LDR/ R_2 decreases the PD measured (across R_2) decreases OR	**B1**	**ALLOW** reverse argument Must be clear that the resistance is that of the LDR **ALLOW** output voltage/voltmeter reading for PD across R_2

Question			Answer	Mark	Guidance
			As the light intensity increases the total resistance of the circuit decreases the current increases		

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21	**a**	**i**	Estimate of λ_{max} between 440 and 470 nm (T =) 5800 x 500/460 = 6300 K i.e. candidate's value	M1 A1	Allow 2.9 million for 5800 x 500 Allow assumption of 6300 K, calculation of lambda (M1) and then confirmation on graph (A1) for 2 marks
		ii	$L = 4\pi r^2 \sigma T^4$ Correct substitution of values i.e. $2.3 \times 10^{29} = 4\pi r^2 \sigma 6300^4$ radius = $1.4(3) \times 10^{10}$ (m)	C1 C1 A1	
	b	**i**	$P = 7.0 \times 10^{-15} \div 0.11$ $I = 6.36 \times 10^{-14} / 1.0 \times 10^{-4} = 6.4 \times 10^{-10}$ (Wm^{-2})	M1 A1	
		ii	$L/4\pi r^2 = 6.4 \times 10^{-10}$ $r = (L \div (6.4 \times 10^{-10} \times 4\pi))^{0.5}$ $= 5.4 \times 10^{18}$ (m) ($\div 9.5 \times 10^{15}$ =) 560 light years	C1 C1 C1 A1	Allow use of 6×10^{-10} Allow alternative method: Finding intensity at star surface C1 Using ratio of intensities = square of ratio of (star radius / distance to earth) C1 Use of 6×10^{-10} for I gives 580 ly

Question			Answer	Mark	Guidance
	c		Any three from: There is a range/ ‘band’ in the luminosity values at 6300 K range of luminosity is between $L_\odot$ and about 10 $L_\odot$ The uncertainty in the distance calculated = ½ the uncertainty in the luminosity AW Reference to Nu Persei not necessarily being on the main sequence	 B1 B1 B1 B1	Check diagram for rewardable content
			TOTAL	14	

2	(a)		(oscillating) force acting on (current carrying) wire in magnetic field (produces) waves travelling in opposite directions (along the wire) which interfere /superpose	B1 B1	**Ignore** $F = BIl\sin\theta$ unless quantities defined **Ignore** wire moves/oscillates **Allow** forms nodes / anti-nodes for interfere **Allow** produces a (progressive) wave which reflects (from a fixed bridge) and interferes **Allow** bridge needs to be placed at integer number of half wavelengths (for a standing wave to form)
2	(b)	(i)	B/flux density (only) affects size of force / amplitude (of stationary wave)	B1	**Ignore** flux density does not affect frequency / wavelength / speed / period **accept** maximum displacement for amplitude
2	(b)	(ii)	measure length of wire (with ruler) **and** measure mass of wire using balance mass per unit length is mass divided by length	B1 B1	**Allow** any other valid method that includes measurement **Allow** any other valid analysis eg finding gradient of a suitable graph
2	(c)	(i)	worst acceptable line drawn through all error bars	B1	Must pass through +/- half a small square of: RH extreme of bottom bar and LH extreme of top bar for steepest line **or** LH extreme of bottom bar and RH extreme of penultimate bar for shallowest line

2	(c)	(ii)	(calculated) gradient of line of worst fit (calculated)absolute uncertainty in gradient (calculated) percentage uncertainty	M1 C1 A1	**Accept** gradient within the ranges 2.40 to 2.70 for shallow line or 3.00 to 3.30 for steep line. **Accept** 0.15 – 0.45 **Accept** 5.0% to 16.0%
2	(c)	(iii)	$f = \frac{\text{gradient}}{2\sqrt{\mu}}$ $\left(f = \frac{2.81}{2\sqrt{8.0\times10^{-4}}} =\right)$ 49.7 (Hz) (% uncertainty =) (c)(ii) + 1 correctly evaluated	C1 A1 B1	**Allow** any subject and any substituted gradient for this C1 mark only **Accept** 50 (Hz) (2 sig figs) on answer line if 49.7 or 49.67 seen in working Note f = 49.674 eg (11 + 1 =) 12 (%)
2	(c)	(iv)	% difference $\left(= \frac{50.0 - 49.7}{\mathbf{50.0}} \times 100\%\right) = 0.6$ % correct comparison of values for % uncertainty and % difference and appropriate comment	M1 A1	**ECF** their f from (c)(iii) for 49.7 but **not** f = 50(.0) Note if 49.67 is used % diff is 0.66 % **Accept** calculated upper (and lower) bound of f i.e. 49.7 x (1 + % uncertainty from (c)(iii)/100) eg 49.7 x 1.12 = 56 Hz **Accept** calculated upper bound > 50 Hz therefore accurate / falls within the range of stated bounds eg 56 Hz > 50 Hz so accurate
			Total	14	

Question			Answer	Marks	Guidance
19	(a)	(i)	$\omega^2 = g/L$ $\omega = \frac{2\pi}{T}$ Correct substitution $\frac{4\pi^2}{T^2} = \frac{g}{L}$ and rearranging to give correct expression	M1 M1 A1	**Note:** Both M1 marks are required to score this A1 mark
		(ii)	Transfer of **energy** to air / retort stand (because of air resistance / friction) No effect on *T* (as *T* is independent of amplitude in SHM for small amplitude oscillations of pendulum)	B1 B1	**Allow** 'loss of energy from pendulum (due to friction)' **Allow** 'work done' for 'energy' **Allow** 'isochronous'

Question	Answer	Marks	Guidance
(b)*	**Level 3 (5–6 marks)** Clear description including steps to obtain high quality data **and** analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **and** some analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **and** analysis **Or** limited description *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.* **0 marks** No response or no response worthy of credit.	**B1 × 6**	**Indicative scientific points may include:** **Experiment** **Description** • Pendulum string clamped / fixed (can be shown on diagram) • Use a stopwatch to determine time period *T* • Time multiple oscillations to determine *T* • Use a ruler to measure *L* • Vary length *L* and determine *T* **Quality of Data** • Method used to ensure small oscillations • Small angles i.e. <10 degrees • Idea of fiducial mark • Start/stop timing at the centre of the oscillation • Measure from the fixed point to the centre of the bob **Analysis** • Correct plotting of graph, e.g. T^2 against *L* or *T* against $\sqrt{L}$ or lg*T* against lg*L* • Analysis of data table showing T^2/L = constant

Question			Answer	Marks	Guidance
					• Expect a straight line through the origin • Correct gradient of the line e.g. $4\pi^2/g$ Use only L1, L2 and L3 in RM Assessor.
	(c)	(i)	Correct substitution of T = 2(.0 s) into $T^2 = \frac{4\pi^2}{g}L$ length = 0.99 (m)	C1 A1	**Note**: 1 (m) here cannot score this A1 mark
		(ii)	Lower g / gravitational field strength / acceleration (of free fall) on Moon. T is longer (on Moon) **and** justified by $T^2 = \frac{4\pi^2}{g}L$ or $T^2 \propto 1/g$ or $\frac{4\pi^2}{g}$ is larger	B1 B1	**Accept** 'g is a sixth of g on Earth' AW **Not** gravity (is less)
			Total	15	

16	**(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
	(b)		(*v* = distance/time) $v = \frac{\lambda}{T}$ $f = \frac{1}{T}$ and $v = f\lambda$ **or** There are *f* wavelengths per unit time *v* = 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
	(c)	**(i)**	(speed in material =) $\frac{3.0 \times 10^8}{1.20}$ **or** 2.5×10^8 (m s^{-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
		(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); 2.5×10^8 m s^{-1} used

Question			Answer	Marks	Guidance
		(iii)	ϕ = 180 °	B1	Possible ECF from **(i)** and **(ii)** **Note** answer must be ϕ = **(c)(i)** × 360°/**(c)(ii)** **Not** an answer in rad, e.g. π rad
		(d)*	**Level 3 (5–6 marks)** Clear description **and** clear analysis *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear description **or** Clear analysis **or** Some description **and** some analysis *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited description **or** Limited analysis *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **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
			Total	**15**	

23	**(a)**		$g = \frac{G \times 6.31 \times 10^{30}}{(1.90 \times 10^{9})^2}$ g = 117 (N kg^{-1}) $2 \times \frac{0.14}{1.90} + \frac{0.42}{6.31}$ **or** 0.21 **or** 21% (absolute uncertainty =) 25 (N kg^{-1})	**C1** **C1** **C1** **A1**	**Reject** 0.42/(0.14^2) = 21.4 **Note:** final answer of g = 117 ± 25 (N kg^{-1}) with no working scores all 4 marks. **Allow** correct identification of %(r) and %(m) for 1 mark max if no other marks scored. **Allow** alternate method using max/min values of m and r that give the correct absolute uncertainty (28)
	(b)	**(i)**	The (total radiant) power (of a star) /AW	**B1**	
		(ii)	($L = 4\pi r^2 \sigma T^4$) ratio = $\sqrt{(\frac{6.92 \times 7500^4}{10.0 \times 4500^4})}$ ratio = 2.3(1)	 **C1** **A1**	 **Allow** 1 mark for 5.3; square root omitted **Allow** 1 mark for 1:2.3 or 0.43
		(iii)	$\lambda_{(max)} \propto \frac{1}{T}$ Lower temperature star will have the longest wavelength, so it is Aa2	**B1** **B1**	**Allow** word equation **Note** Must mention wavelength <u>and</u> temperature
		(iv)	From their (different) colours	**B1**	

		(v)	Any <u>three</u> from: • Continuous spectrum • Light / radiation / photons passes through cooler gas/star's atmosphere • Photon(s) absorbed by electron(s) • Electron(s) excited / jump / make transition to higher energy level(s) • Electron only promoted if energy of photon matches energy gap between two given levels • Photons remitted in different directions • (so) idea of contrast with non-absorbed wavelengths	**B1 × 3**	
	(c)		Any <u>two</u> from: • Black hole has smaller mass / radius / size • Black hole has higher density/gravitational field strength/ stronger gravitational field • black hole absorbs light / does not emit visible light • Has an escape velocity => c • No fusion in a black hole (ORA)	**B1** **B1**	**Allow** black hole emits Hawking radiation
			Total	**15**	

Question			Answer	Marks	Guidance
5	(a)	(i)			**Allow** v for v_{max} throughout
			$I_{max} = nAv_{max}e$	**B1**	**Allow** I for I_{max} **Allow** q or Q for e / a for A / V for v but **not** N for n
			$v_{max} = \frac{20 \times 10^{-3}}{8 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.4 \times 10^{-8}}$	**M1**	Substitution must be shown in full
			$v_{max} = 1.1 \times 10^{-4}$ (m s^{-1})	**A1**	Answer must be given initially to 2 or more sf (but may later be rounded to 1sf)
		(ii)	$\omega = 2\pi f$	**C1**	May be inferred from working $\omega = 2\pi \times 11 \times 10^{9} = 6.9 \times 10^{10}$ (rad s^{-1})
			$A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{2\pi \times 11 \times 10^{9}}$ **or** $A\ (= v_{max}/\omega) = \frac{1.1 \times 10^{-4}}{6.9 \times 10^{10}}$	**C1**	**Allow** use of $v_{max} = 1 \times 10^{-4}$ (m s^{-1}) **Allow** v_{max} from **(a)(i)** given to more than 2sf but **not ECF** from any value which does not round to 1×10^{-4} (m s^{-1})
			$A = 1.6 \times 10^{-15}$ (m)	**A1**	**Allow** use of $v_{max} = 1 \times 10^{-4}$ (m s^{-1})^1 giving $A = 1.4 \times 10^{-15}$ (m) to 2sf or 1.45×10^{-15} (m) to 3sf Special case: **Allow** $A = 1 \times 10^{-15}$(m) to 1 sf if $v_{max} = 1 \times 10^{-4}$ (m s^{-1}) is used
		(iii)	($a_{max} = \omega^2 A$ and $v_{max} = \omega A$)		
			$a_{max} = 2\pi f\, v_{max}$	**M1**	**Allow** $a_{max} = \omega\, v_{max}$ **Allow** a for a_{max} and v for v_{max}
			Since v_{max} is constant, $a_{max} \propto f$	**A1**	

Question			Answer	Marks	Guidance
5	(b)*	(i)	**Level 3 (5–6 marks)** Clear explanation **and** clear description *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Clear explanation **or** clear description (but not both) **or** Some explanation **and** some description *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation **or** Limited description *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **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:** **Explanation of pattern** • Interference / superposition occurs • Path difference a whole number of wavelengths • means waves are (exactly) in phase (or $\Delta\varphi = 0$) • giving (maximum) constructive interference • which leads to maximum intensity • Path difference an odd number of half wavelengths (or $\Delta\varphi = \pi$ radians) • means waves are in antiphase • giving (maximum) destructive interference • which leads to minimum intensity **Description of relationship between *f* and *x*** • $\lambda = ax/D$ **and** $c = f\lambda \rightarrow x = cD/af$ • so $x \propto 1/f$ (provided a and *D* remain constant) • Use ruler along QP to measure *x (or 10*x/10, say) • Connect oscilloscope to transmitter or detector to measure *f* • Vary *f (*keeping a and *D* constant) and measure corresponding *x* • Calculate *fx* which should remain constant • Or plot graph of 1/*x* against *f* (or x against 1/f) • Should give straight line <u>through the origin</u>

Question			Answer	Marks	Guidance
5	(b)	(ii)	At 90° rotation, (interference) pattern disappears	B1	**Allow** constant intensity along PQ **Not** zero intensity along PQ **Allow** from 0 to 90° the intensities of the maxima decrease (and the minimum intensities increase)
			At 180° rotation, intensities are the same as at 0° but the maximum/minimum positions are switched / reversed	B1	**Allow** from 90 ° to 180 ° the intensities of the maxima increase (and the minimum intensities decrease) but the maximum/minimum positions are switched / reversed from between 0 and 90°
			Waves with polarisations at 90° to each other do not interfere / only waves with same polarisation interfere / only waves with a component in the same plane interfere	B1	**Allow** waves must oscillate in same plane to interfere **Ignore** at 90° rotation, only waves from Y are detected at D because D can only detect vertical polarised waves
			Total	**17**	