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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Waves and the Particle Nature of Light (5)

A Level Physics Topic 5

198 questions · 1094 marks · Mark schemes included

AS & A Level content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or 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

198 questions · 1094 marks · 9 sub-topics

SUB-TOPIC 5.1

WAVE PROPERTIES, PHASE, INTENSITY AND PULSE-ECHO

Sub-topic 5.1 · 40 questions · 149 marks · lowest tariff first

1 Which statement about sound is correct?

- ☒ **A** Sound can travel through a solid.
- ☒ **B** Sound can travel through a vacuum.
- ☒ **C** Sound waves can travel as polarised waves.
- ☒ **D** Sound waves travel in a direction perpendicular to the direction of the oscillations.

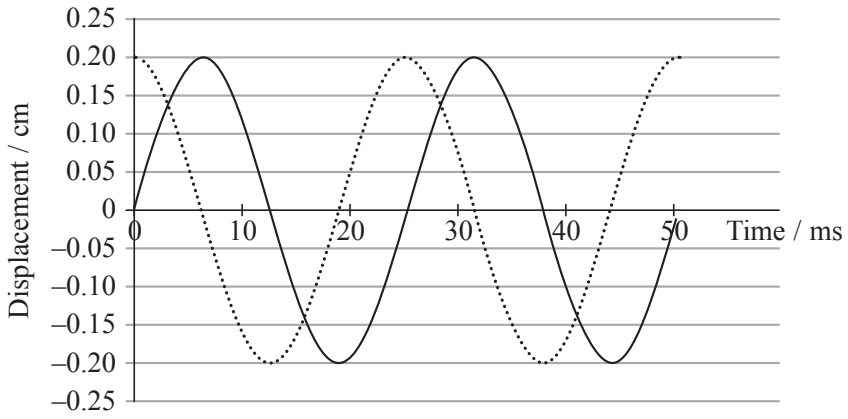
(Total for Question 1 = 1 mark)

2 Which of the following is a correct unit for intensity of light?

- ☒ **A** $\mathrm{J\,m^{-2}}$
- ☒ **B** $\mathrm{W\,s^{-2}}$
- ☒ **C** $\mathrm{W\,m^{-2}}$
- ☒ **D** $\mathrm{J\,s^{-2}}$

(Total for Question 2 = 1 mark)

6 The graph shows the variation of displacement with time for two waves.



What is the phase difference between these two waves?

☒ **A** 6 ms

☒ **B** 0.20 cm

☒ **C** π radians

☒ **D** 90 degrees

(Total for Question 6 = 1 mark)

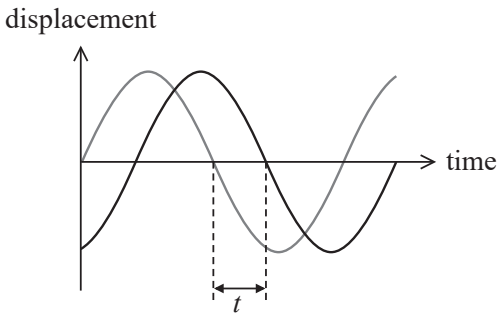
8 Sound waves are produced by a vibrating guitar string.

Which row in the table correctly describes the waves produced?

	Guitar string	Sound
☒ **A**	transverse	transverse
☒ **B**	longitudinal	longitudinal
☒ **C**	longitudinal	transverse
☒ **D**	transverse	longitudinal

(Total for Question 8 = 1 mark)

4 Displacement-time graphs are shown for two waves, each of frequency f and period T.



The phase difference in radians between the two waves is given by

☒ **A** $\frac{2\pi t}{T}$

☒ **B** $\frac{\pi t}{T}$

☒ **C** $\frac{2\pi t}{f}$

☒ **D** $\frac{\pi t}{f}$

(Total for Question 4 = 1 mark)

6 The rate at which energy is transferred to a solar cell of radius r is P.

In the same conditions, the rate at which energy is transferred to a solar cell of radius $2r$ is given by

☒ **A** $\frac{P}{4}$

☒ **B** $\frac{P}{2}$

☒ **C** $2P$

☒ **D** $4P$

(Total for Question 6 = 1 mark)

8 Prenatal ultrasound scans are performed to produce an image of a fetus.



The ultrasound wave is transmitted in pulses so that

☒ **A** exposure of the patient to ultrasound radiation is reduced.

☒ **B** smaller distances can be measured.

☒ **C** the reflected pulse can be detected before the next pulse is transmitted.

☒ **D** there is less diffraction.

(Total for Question 8 = 1 mark)

2 Fishermen use ultrasound pulses to detect shoals of fish under the surface of the water. Some fish are at a depth of 90 m below the surface.

Which of the following is the expression for the time t, in seconds, between the transmitted and the received pulse?

speed of sound in water = $1500\,\text{m}\,\text{s}^{-1}$

☒ **A** $t = \dfrac{90}{1500}$

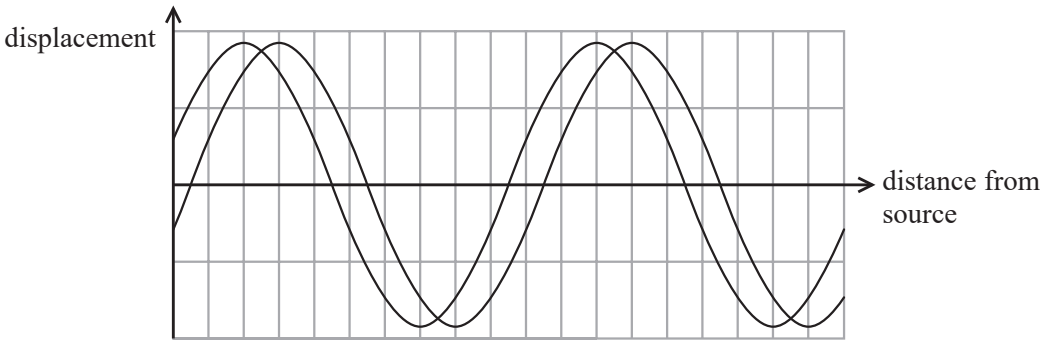
☒ **B** $t = \dfrac{1500}{90}$

☒ **C** $t = \dfrac{90 \times 2}{1500}$

☒ **D** $t = \dfrac{1500}{90 \times 2}$

(Total for Question 2 = 1 mark)

6 The graphs show the position of two identical waves at a time t.



Which of the following is the phase difference between these two waves?

☒ **A** π

☒ **B** $\frac{\pi}{2}$

☒ **C** $\frac{\pi}{5}$

☒ **D** $\frac{\pi}{10}$

(Total for Question 6 = 1 mark)

2 Radar is used to detect the position of an aircraft. Microwave pulses are emitted from the radar transducer. The pulses reflect from the aircraft and are received back at the same transducer. The time in seconds between emission and reception of the pulse is t.

The distance of the aircraft in metres from the transducer is given by

☒ **A** $2 \times 3.0 \times 10^8 \times t$

☒ **B** $2 \times 340 \times t$

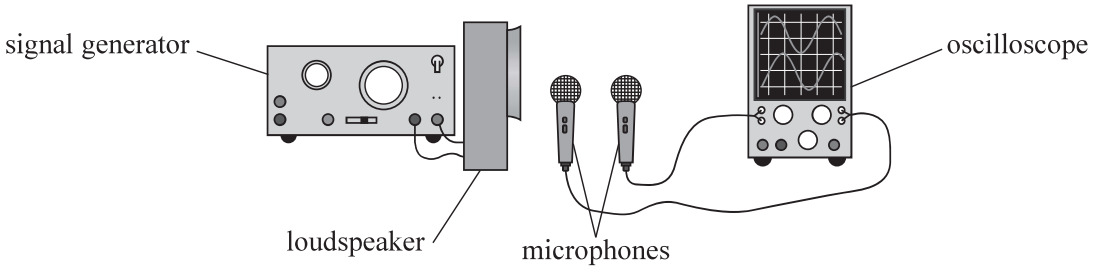
☒ **C** $\frac{3.0 \times 10^8 \times t}{2}$

☒ **D** $\frac{340 \times t}{2}$

(Total for Question 2 = 1 mark)

Questions 6 and 7 refer to the following information.

In an experiment to determine the speed of sound in air, a 2-beam oscilloscope is used to display the signals from two microphones. The microphones are placed in front of a loudspeaker that is connected to a signal generator.



The loudspeaker emits a sound of frequency f.

6 The microphones are placed at different distances from the loudspeaker. The time taken for the sound to travel from the first microphone to the second is t.

Which of the following expressions gives the phase difference between the two signals?

☒ **A** πtf

☒ **B** $2\pi tf$

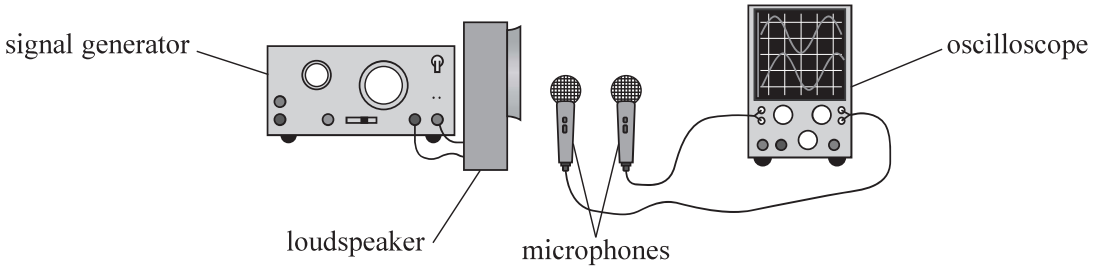
☒ **C** $\frac{\pi f}{t}$

☒ **D** $\frac{2\pi f}{t}$

(Total for Question 6 = 1 mark)

Questions 6 and 7 refer to the following information.

In an experiment to determine the speed of sound in air, a 2-beam oscilloscope is used to display the signals from two microphones. The microphones are placed in front of a loudspeaker that is connected to a signal generator.



The loudspeaker emits a sound of frequency f.

7 The microphones are placed at equal distances from the loudspeaker. The signals are in phase. One of the microphones is moved further away from the loudspeaker. Initially the signals become out of phase. After moving the microphone a distance d the signals are back in phase.

Which of the following expressions gives the speed of sound?

☒ **A** $2fd$

☒ **B** fd

☒ **C** $\frac{2d}{f}$

☒ **D** $\frac{d}{f}$

(Total for Question 7 = 1 mark)

3 A light source radiates a power P onto a surface, covering a circular area of radius r.

Which of the following is the correct expression for the intensity I of the radiation at the surface?

☒ **A** $I = \frac{P}{\pi r^2}$

☒ **B** $I = P\pi r^2$

☒ **C** $I = \frac{P}{2\pi r}$

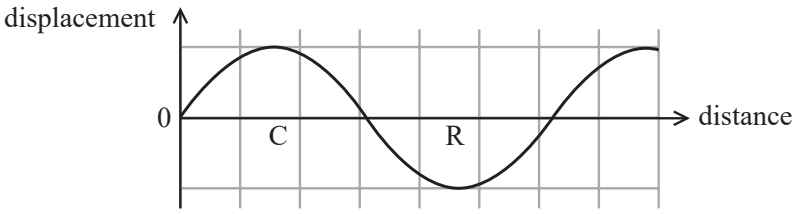
☒ **D** $I = 2P\pi r$

(Total for Question 3 = 1 mark)

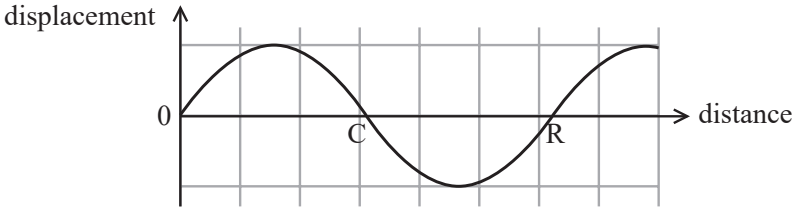
6 A longitudinal wave is represented on a displacement-distance graph. A positive displacement on the graph indicates a displacement to the right.

Which graph shows the correct labelling of possible positions of a compression, C, and a rarefaction, R?

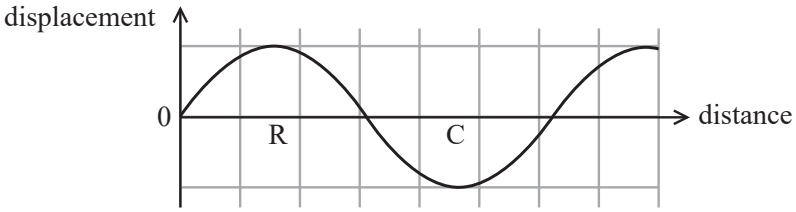
A



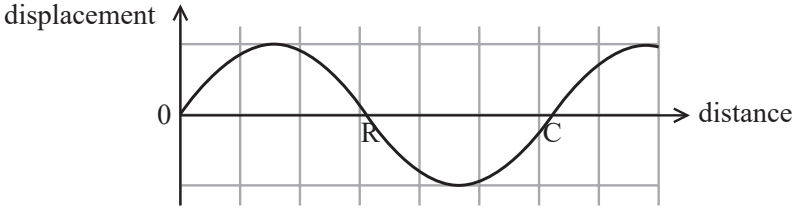
B



C



D



☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 6 = 1 mark)

1 Ultrasound can be used to investigate the structure of organs of the human body using the pulse-echo technique.
The level of detail obtained depends on the wavelength and the length of the pulses.

Which line of the table shows a change to wavelength and a change to pulse length that would each improve the level of detail?

		Wavelength	Pulse length
☒	**A**	decrease	decrease
☒	**B**	increase	decrease
☒	**C**	decrease	increase
☒	**D**	increase	increase

(Total for Question 1 = 1 mark)

6 The diagram shows a source of sound waves and an observer.

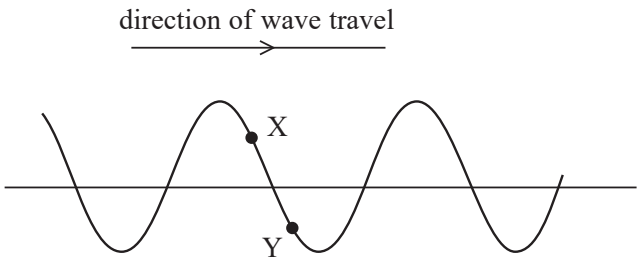


Which row of the table shows a situation which would result in a decrease in the frequency of sound observed?

		Source	Observer
☒	**A**	moves to the right at 20 m s^{-1}	moves to the left at 20 m s^{-1}
☒	**B**	moves to the right at 20 m s^{-1}	moves to the right at 20 m s^{-1}
☒	**C**	moves to the right at 20 m s^{-1}	stationary
☒	**D**	stationary	moves to the right at 20 m s^{-1}

(Total for Question 6 = 1 mark)

7 The diagram shows the position of two particles, X and Y, on a transverse wave. The wave is travelling from left to right.



Which of the following describes the directions in which the particles at X and Y are moving at the instant shown?

		Particle X	Particle Y
☒	**A**	down	down
☒	**B**	down	up
☒	**C**	up	down
☒	**D**	up	up

(Total for Question 7 = 1 mark)

8 A beam of light from a torch with power P is shone onto a surface. The light is spread over a circular area with a radius r.

Which of the following gives the intensity of the light on the surface?

☒ **A** $P \times 4\pi r^2$

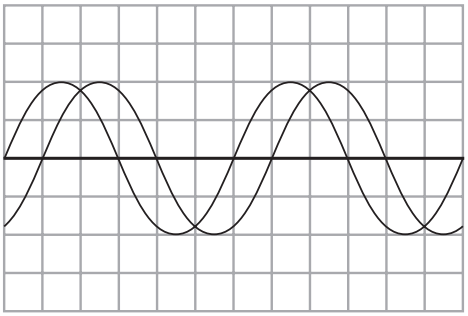
☒ **B** $\frac{P}{4\pi r^2}$

☒ **C** $P \times \pi r^2$

☒ **D** $\frac{P}{\pi r^2}$

(Total for Question 8 = 1 mark)

6 A two-beam oscilloscope is used to display signals from two microphones as shown.

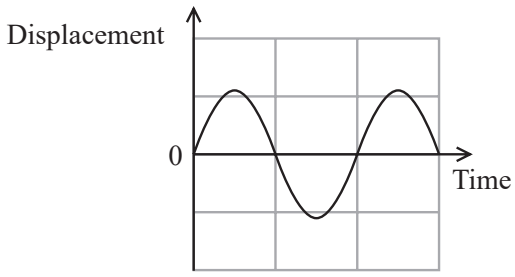


Which of the following could be the phase difference in radians between the traces?

- ☒ **A** $\frac{\pi}{6}$
- ☒ **B** $\frac{\pi}{4}$
- ☒ **C** $\frac{\pi}{3}$
- ☒ **D** $\frac{\pi}{2}$

(Total for Question 6 = 1 mark)

8 A displacement-time graph is shown for a particle in a transverse wave.

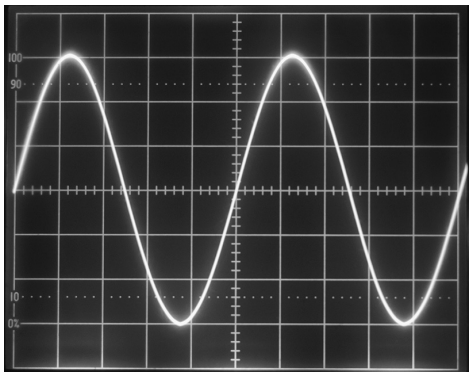


Which property of the wave can **not** be determined directly from the displacement-time graph?

- ☒ **A** amplitude
- ☒ **B** frequency
- ☒ **C** time period
- ☒ **D** wavelength

(Total for Question 8 = 1 mark)

3 A 2-beam oscilloscope is used to determine the speed of sound in air. The oscilloscope screen shown displays the signal used to produce the sound wave.



(Source: © Dorling Kindersley/UIG/SCIENCE PHOTO LIBRARY)

The time-base is set to 50 μs / division.

Which of the following gives the frequency, in Hz, of the signal?

☒ **A** $5 \times 50 \times 10^{-6}$

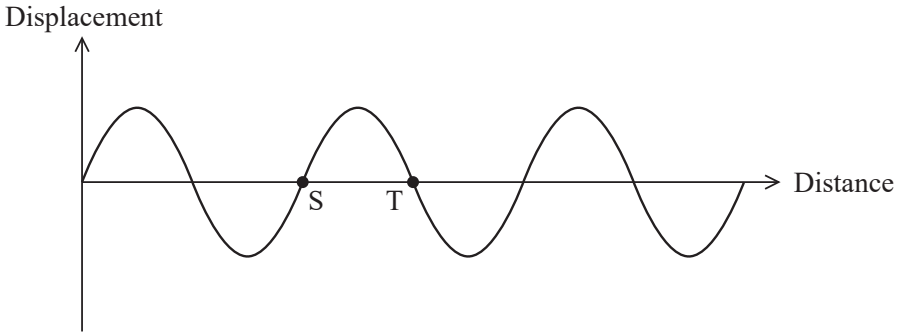
☒ **B** $2.5 \times 50 \times 10^{-6}$

☒ **C** $\dfrac{1}{5 \times 50 \times 10^{-6}}$

☒ **D** $\dfrac{1}{2.5 \times 50 \times 10^{-6}}$

(Total for Question 3 = 1 mark)

1 The graph shows how the displacement of particles in a progressive wave varies with distance along the wave, at a particular instant.



Which of the following is the phase difference between the particles at S and T?

☒ **A** $\frac{\pi}{4}$

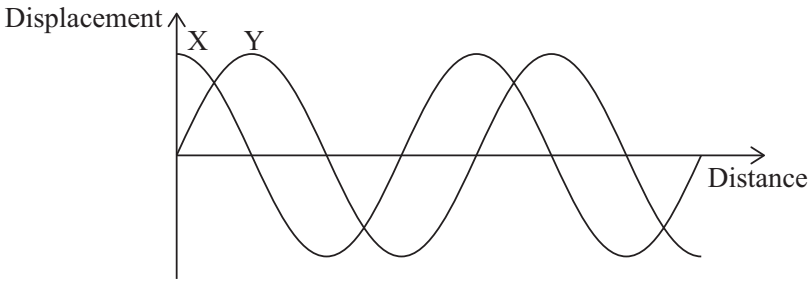
☒ **B** $\frac{\pi}{2}$

☒ **C** π

☒ **D** 2π

(Total for Question 1 = 1 mark)

10 The diagram shows how displacement varies with distance for two waves, X and Y, at a particular instant. The waves are travelling to the right.



Which of the following statements describes the phase relationship between the two waves?

- ☒ **A** X leads Y by 90°
- ☒ **B** X leads Y by 180°
- ☒ **C** Y leads X by 90°
- ☒ **D** Y leads X by 180°

(Total for Question 10 = 1 mark)

1 Which of the following are S.I. units for intensity?

- ☒ **A** Jm^{-2}
- ☒ **B** Js^{-1}
- ☒ **C** Wm^{-2}
- ☒ **D** Ws^{-1}

(Total for Question 1 = 1 mark)

5 Two points on a wave are a distance $\frac{3}{4}\lambda$ apart.

Which of the following is the phase difference between the two points?

☒ **A** $\frac{\pi}{4}$

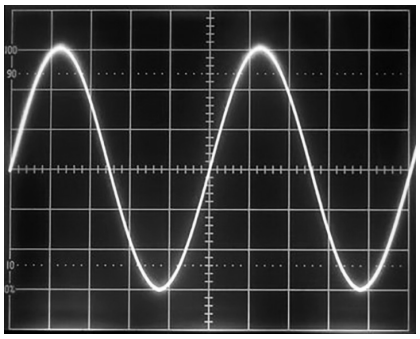
☒ **B** $\frac{3\pi}{4}$

☒ **C** $\frac{\pi}{2}$

☒ **D** $\frac{3\pi}{2}$

(Total for Question 5 = 1 mark)

9 In an investigation to determine the speed of sound in air, a student sets up an oscilloscope to display the waveform of a sound wave as shown.



The timebase is set to 25 μs / division.

(a) Determine the frequency of the sound wave.

(2)

Frequency = ...

(b) The student sets the timebase on the oscilloscope to a lower value per division.

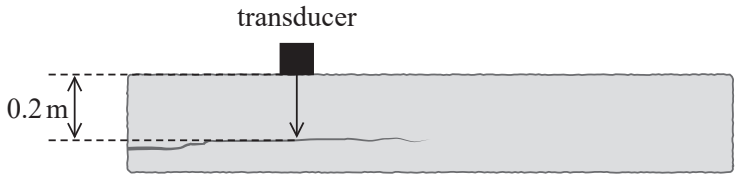
Describe any changes to the appearance of the waveform on the screen.

(1)

(Total for Question 9 = 3 marks)

10 Concrete is a material used in buildings due to its high compressive strength.

(a) A concrete post can be checked for internal cracks using a pulse-echo technique.
A transducer that transmits and receives ultrasound pulses is positioned against the side of the post as shown.



A pulse hits a crack and is reflected and is then detected by the transducer.

Deduce whether a crack at a depth of 0.2 m can be detected.

time between pulses = 160 μs
speed of sound in concrete = 3200 m s^{-1}

(3)

(b) Another concrete post is reinforced with steel rods, to increase its tensile strength.
A steel rod is under a tensile load of 130 N and extends by 4.0×10^{-4} m.
The steel has not reached its elastic limit.

Calculate the elastic strain energy in the steel rod.

(2)

Elastic strain energy = ...

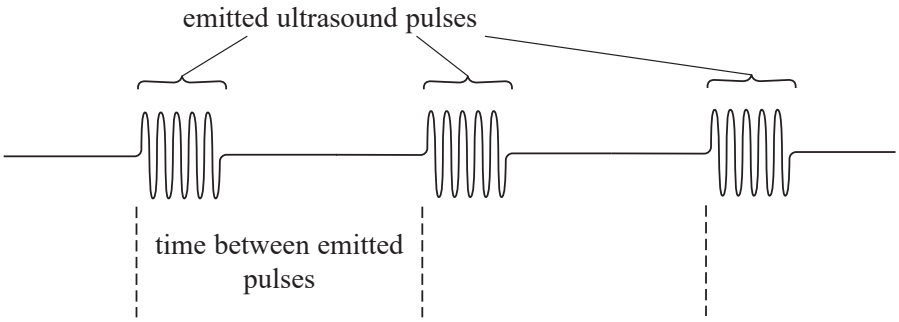
(Total for Question 10 = 5 marks)

***10** In 1969, astronauts placed an array of mirrors on the surface of the Moon. Scientists can use these to monitor the distance from Earth to the Moon. Light from a laser is used with a pulse-echo technique.

Describe how the distance of the Moon from Earth can be determined using a pulse-echo technique.

(Total for Question 10 = 6 marks)

9 Bats use a pulse-echo technique to hunt for moths. The bat emits a series of ultrasound pulses as shown on the oscilloscope trace below.



(a) A stationary bat emits an ultrasound pulse that is reflected from a moth. The bat detects the reflected pulse 36 ms later.

Calculate the distance between the bat and the moth.

speed of sound = 340 m s^{-1}

(3)

Distance = ...

(b) The bat flies towards the moth.

Explain why the bat must change the time between the emitted pulses as the distance between the bat and the moth decreases.

(3)

(Total for Question 9 = 6 marks)

10 Scientists can use a pulse-echo technique with ultrasound to detect plastic in the oceans. A transducer that emits and detects ultrasound pulses is positioned just below the surface of the water.

(a) An ultrasound pulse was transmitted. The pulse was reflected from a piece of plastic under the surface and the pulse was detected 4.1 ms later.

Calculate the distance between the plastic and the transducer.

speed of sound in salt water = 1500 m s^{-1}

(3)

Distance = ...

(b) Give a reason why the ultrasound is emitted in short pulses.

(1)

(c) Explain why small pieces of plastic are more likely to be detected by using ultrasound with a high frequency.

(2)

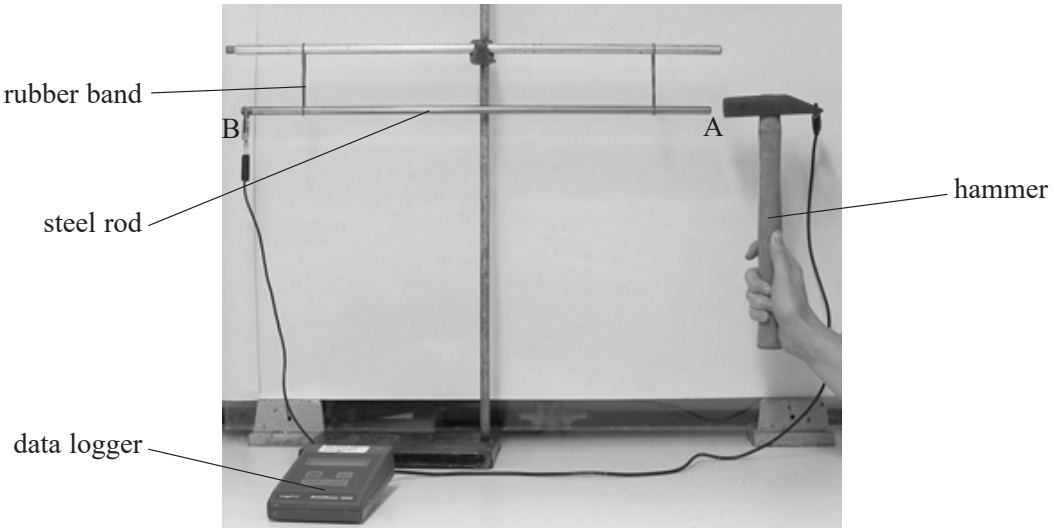
(Total for Question 10 = 6 marks)

***10** A transducer on a ship produces soundwaves. These soundwaves are used with a pulse-echo technique to determine the depth of the sea.

Explain how the depth of the sea is determined using a pulse-echo technique.

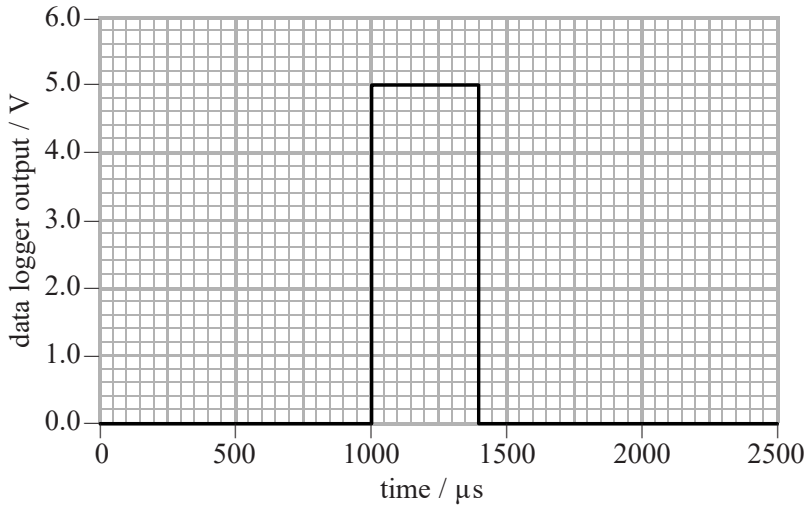
(Total for Question 10 = 6 marks)

7 A teacher is demonstrating how to measure the speed of sound in a steel rod. The equipment comprises a hanging steel rod and a hammer connected to a data logger as shown.



The rod is tapped at A with the hammer. A compression pulse travels to B and is reflected back. When the reflection reaches A the hammer loses contact with the rod. Whilst the hammer is in contact with the rod the output from a 5 V supply is recorded by the data logger.

The graph shows the output from the data logger for one hammer tap.



(a) Explain why a data logger is appropriate for this demonstration.

(2)

(b) (i) Use the graph to show that the speed of the pulse in the rod is about 6000 m s^{-1}.

length of steel rod = 1.18 m

(3)

(ii) The speed of sound v in the rod depends on the Young modulus E and the density ρ of the material of the rod as given by the equation

$$v = \sqrt{\frac{E}{\rho}}$$

Calculate the Young modulus of steel.

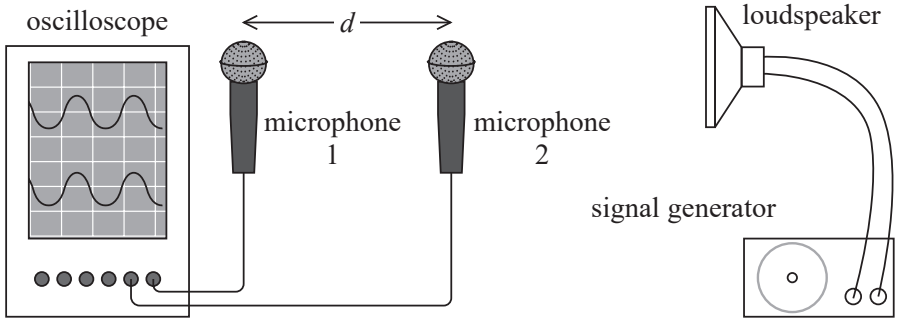
ρ_{steel} = 7850 kg m^{-3}

(2)

Young modulus of steel = ...

(Total for Question 7 = 7 marks)

6 In an experiment to determine the speed of sound in air a student connected two microphones to an oscilloscope, as shown.



The microphones detect sound from the loudspeaker, converting it to an electrical signal. The signal is displayed on the oscilloscope screen.

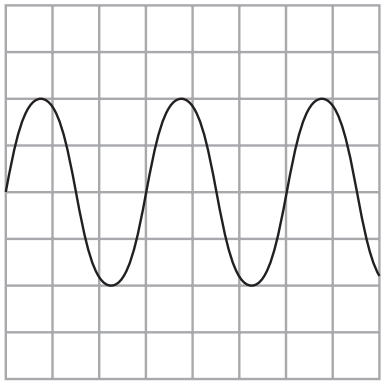
Both microphones were initially positioned the same distance from the loudspeaker. The two signals were in phase on the oscilloscope screen. The student slowly moved microphone 2 towards the loudspeaker, until the two signals on the oscilloscope were in phase again. He then measured the distance d between the microphones to determine the wavelength λ of the sound waves.

$d = 20.5\,\text{cm}$

(a) Comment on the student's experimental technique to determine λ.

(2)

(b) The oscilloscope trace for the signal from microphone 1 is shown below.



The time base of the oscilloscope was set to $0.20\,\text{ms}\,\text{div}^{-1}$.

Determine a value for the speed of sound in air.

(5)

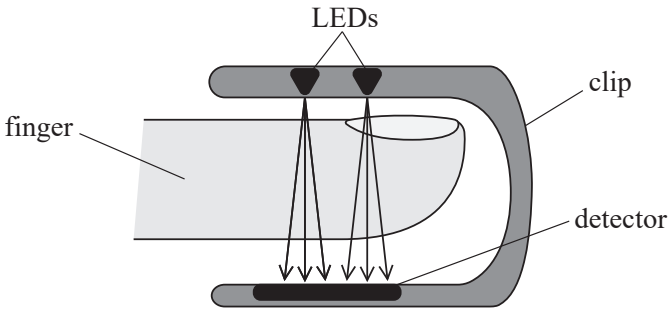
Speed of sound = ...

(Total for Question 6 = 7 marks)

5 An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.





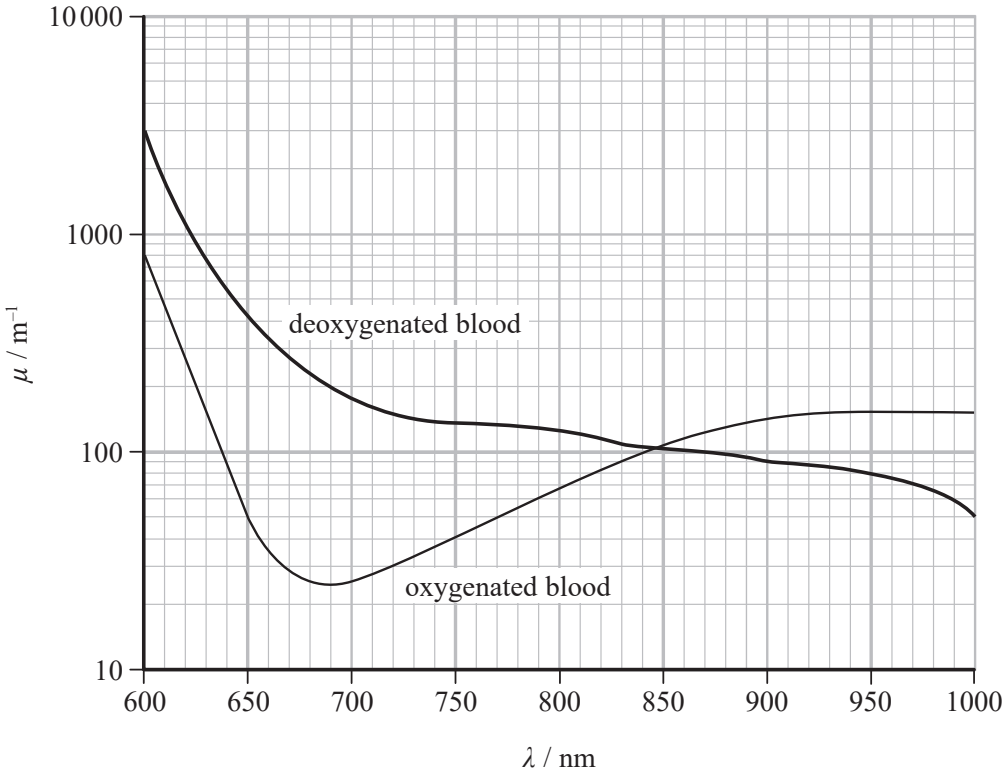
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

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

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



(a) I_0 for the infrared LED is $1.8\,W\,m^{-2}$.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

(3)

$I =$ .....

(b) The oximeter determines I/I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I/I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

(3)

It is suggested that ambient light could affect the readings produced by the oximeter.

Halogen lamps have a filament temperature of 3200 K.

(c) Deduce whether the light from such a lamp would have a significant effect on the oximeter readings.

(3)

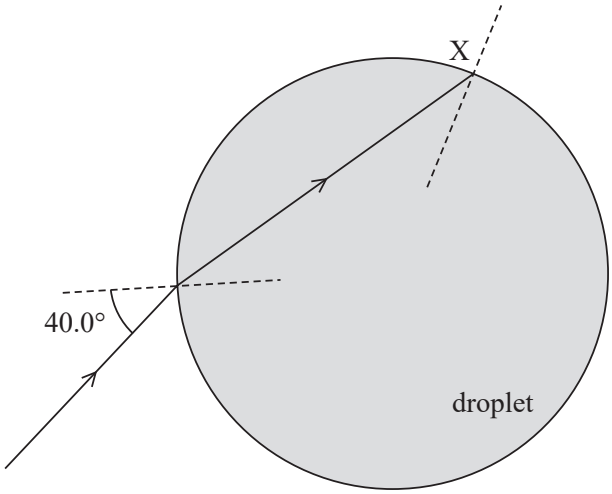
(Total for Question 5 = 9 marks)

14 Lighthouses are located along coastlines to aid navigation. A lighthouse emits an intense beam of light. In clear weather the beam is visible for long distances, but in foggy weather the visibility of the beam is limited.

(a) The beam is refracted by water droplets in the air.

A light ray in the beam is incident on a spherical water droplet with an angle of incidence of 40.0°. The ray passes through the droplet and meets the water-air boundary at X as shown.

Diagram **NOT** to scale



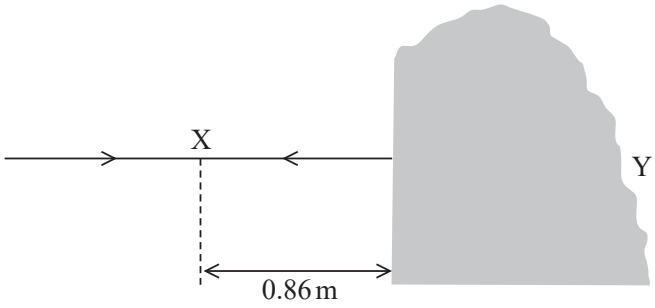
Deduce whether the ray leaves the water droplet at point X.

speed of light in water = $2.25 \times 10^8\,\text{m s}^{-1}$

(4)

(b) A lighthouse is also fitted with a foghorn to emit a loud sound in foggy weather.

A sound wave is incident normally on a large rock and is reflected. The reflected wave meets the incoming wave, creating a standing wave. The closest node to the rock is at point X, 0.86 m from the rock as shown.



(i) Calculate the speed of the sound wave.

frequency of sound wave = 200 Hz

(3)

Speed of sound wave = ...

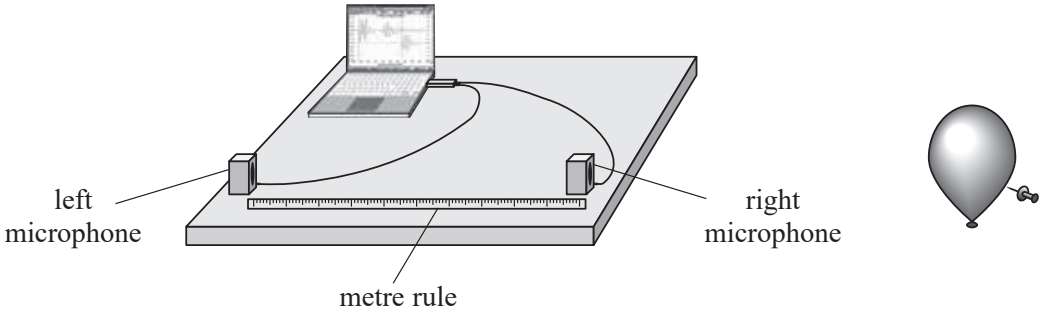
(ii) The rock is about 2 m wide and 2 m high.

Explain why sound would be heard at point Y behind the rock.

(2)

(Total for Question 14 = 9 marks)

15 A student carried out an experiment to determine the speed of sound in air. A short pulse of sound was produced by bursting a balloon near two microphones. The microphones were placed 1.00 m apart and connected to a computer.



The computer was used to determine the time interval between the sound wave being received at the right microphone and being received at the left microphone.

The separation of the microphones was decreased several times and the corresponding time intervals recorded. The student obtained the following results.

Microphone separation / m	Time interval / ms
1.00	3.2
0.90	2.8
0.80	2.4
0.70	2.1
0.60	1.9
0.50	1.5

(a) Criticise these results.

(1)

.....

.....

(b) (i) Plot a graph of microphone separation against time interval.

(4)

(ii) Determine a value for the speed of sound in air.

(2)

.....

.....

.....

Speed of sound in air = ...

(c) The actual speed of sound in air is 330 m s^{-1}.

Comment on the value for the speed of sound in air at this temperature obtained from the student's results, referring to any possible sources of error.

(3)

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(Total for Question 15 = 10 marks)

17 A photographer uses a light meter to measure the intensity of light entering a camera. A simple light meter consists of a light dependent resistor (LDR) connected in a circuit.

(a) The resistance of an LDR depends on the intensity of light incident on the LDR.

Explain how the change in resistance may be modelled in terms of conduction electrons.

(4)

(b) The light meter records an intensity of $1100\,W\,m^{-2}$. The LDR in the light meter has a surface area of $4.0 \times 10^{-5}\,m^2$.

Calculate the energy that is transferred to the LDR every 60 seconds.

(2)

Energy = ...

(c) The light incident on the camera lens is unpolarised. The photographer places a polarising filter in front of the camera lens.

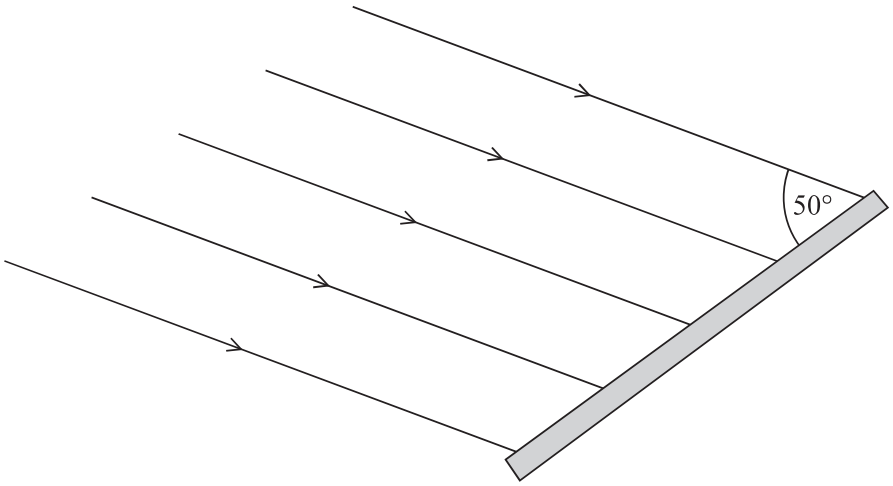
Explain how the polarising filter affects the intensity of light incident on the camera lens.

(4)

(Total for Question 17 = 10 marks)

16 A solar panel uses electromagnetic radiation from the Sun to generate electricity. In one installation a sensor in the solar panel measures the intensity of radiation arriving from different directions. A motor rotates the solar panel so that it always faces the brightest part of the sky.

(a) The intensity of the radiation incident at the surface of the Earth is 1100 W m^{-2}. A solar panel has an area of 2.4 m^2. Radiation is incident on the solar panel at an angle of 50° as shown. The efficiency of the solar panel is 20%.

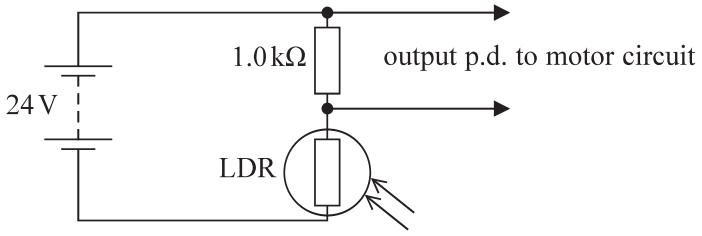


Calculate the electrical power generated by the solar panel.

(3)

Electrical power generated = ...

(b) The circuit diagram shows how a light dependent resistor (LDR) can be used to produce an output potential difference (p.d.) that is dependent on the intensity of light. This output p.d. is connected to a motor circuit that operates the movement of the solar panel.



Initially the motor is switched off. The light intensity increases and the resistance of the LDR decreases to 750 Ω.

The motor switches on when the output p.d. is above 13 V.

Deduce whether this change in light intensity causes the motor to switch on.

(3)

(c) When light is incident on an LDR, electrons move to a higher energy level where they become conduction electrons. This causes the resistance of the LDR to decrease.

A student suggests that this is an example of the photoelectric effect. The student is not correct.

Compare and contrast the photoelectric effect with the effect of radiation incident on an LDR.

(6)

(Total for Question 16 = 12 marks)

17 Weather stations monitor the position of storm clouds.

(a) A microwave pulse is emitted from a transducer at a weather station. The pulse reflects from a storm cloud and is detected at the same transducer 340 µs later.

Calculate the distance between the storm cloud and the weather station.

(3)

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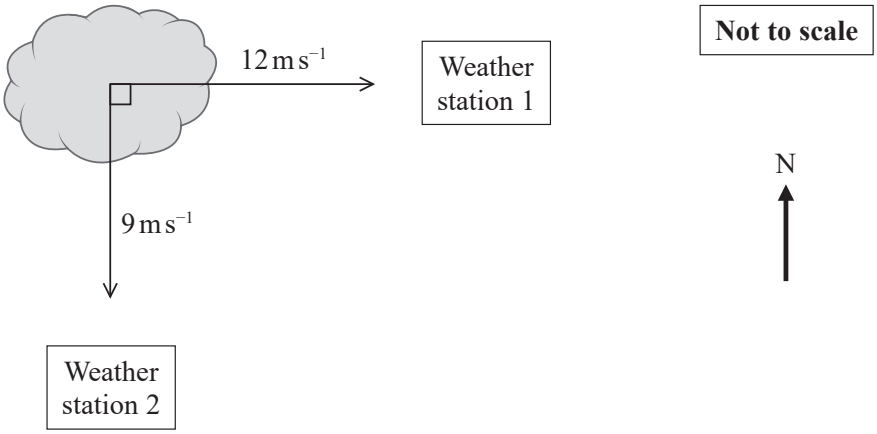
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Distance = ...

(b) The movement of a storm cloud is monitored by two weather stations. The components of the velocity of the storm cloud towards each weather station are shown in the diagram.



Determine the velocity of the storm cloud.

(4)

Magnitude of velocity = ...

Direction of velocity = ...

(c) (i) A raindrop is falling vertically through the air.

The free-body force diagram shows the forces acting on the raindrop.

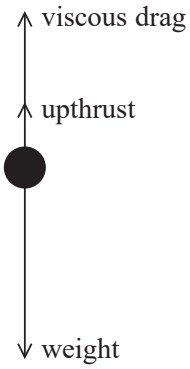


Diagram **NOT** drawn to scale

The raindrop is travelling at terminal velocity. The raindrop is spherical with a radius of 0.10 mm and a weight of 4.1×10^{-8} N.

Calculate the magnitude of the terminal velocity.

viscosity of air = 1.3×10^{-5} Pa s
density of air = 1.2 kg m^{-3}

(4)

Magnitude of terminal velocity = ...

(ii) The value of terminal velocity calculated using the data in (c)(i) is greater than the actual terminal velocity of the raindrop.

Explain why the calculation in (c)(i) may not be valid.

(2)

.....

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.....

(Total for Question 17 = 13 marks)

14 Two students are carrying out an investigation to determine a value for the speed of sound in air.

They stand 80 m from a building. One student hits two pieces of wood together to make a loud sound and a short time later an echo is heard. The other student uses a stopwatch to measure the time interval t between the two pieces of wood being hit and the echo being heard. The procedure is repeated. The students also measure the air temperature.

(a) Explain how a sound wave travels through air.

(2)

.....

.....

.....

.....

(b) The students repeat the investigation on a different day. The results are shown in the table.

	temperature / °C	**t_1 / s**	**t_2 / s**	**t_3 / s**	**mean t / s**
Day 1	12	0.51	0.43	–	0.47
Day 2	18	0.44	0.69	0.48	0.46

(i) Deduce why the students thought it necessary to make a third measurement on day 2.

(1)

.....

.....

(ii) Calculate the percentage uncertainty in the mean value of time on day 1.

(2)

.....

.....

.....

.....

Percentage uncertainty = ...

(iii) Calculate the difference in the value for the speed of sound between day 1 and day 2 obtained from these results.

(2)

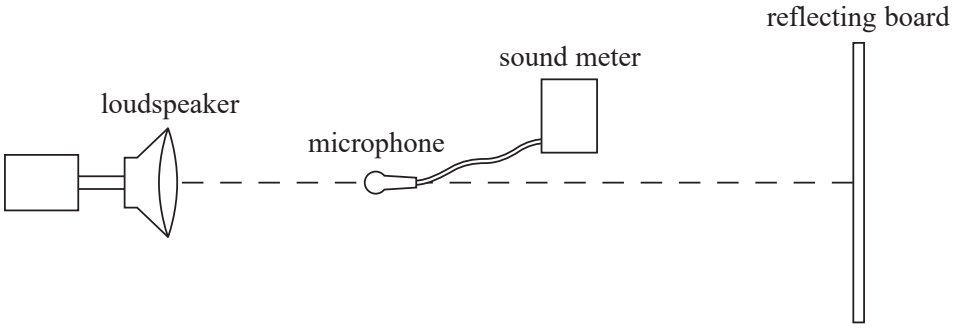
Difference in speed = ...

(iv) The students state that the difference in the speed of sound between day 1 and day 2 is due to the change in air temperature.

Explain whether the results obtained are sufficient for this statement to be made.

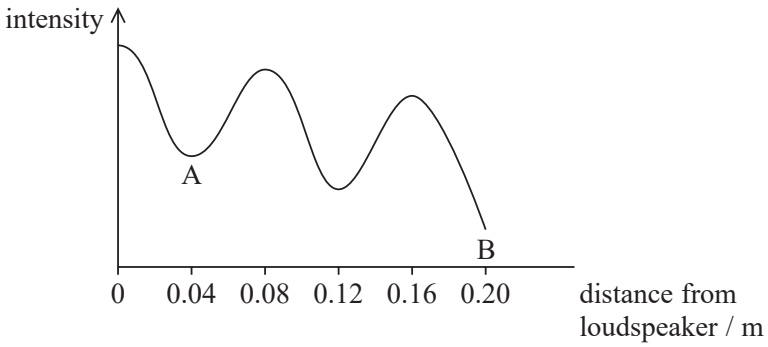
(2)

(c) An alternative method to determine a value for the speed of sound is shown in the diagram.



A loudspeaker is placed at a distance from a vertical reflecting board. Sound waves reflect off the board and set up a standing wave between the loudspeaker and the board. A microphone connected to a sound meter is moved in a straight line from the loudspeaker to the board. As the microphone is moved, the sound meter records the varying intensity of the standing wave.

The sketch graph shows how the intensity varies with distance from the loudspeaker.



(i) Explain why the intensity at point B is less than the intensity at point A.

(3)

(ii) Use the graph to determine a value for the speed of sound.

frequency of sound wave = 2.0 kHz

(3)

Speed of sound = ...

(Total for Question 14 = 15 marks)

SUB-TOPIC 5.2

SUPERPOSITION AND STATIONARY WAVES

Sub-topic 5.2 · 22 questions · 160 marks · lowest tariff first

2 The velocity of a wave on a string is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the string and μ is a constant.

Which of the following pairs of variables, if plotted, would produce a straight line graph?

	x-axis	*y*-axis
☒ **A**	T	$\sqrt{v}$
☒ **B**	v	T
☒ **C**	$\frac{1}{v}$	T
☒ **D**	$\sqrt{T}$	v

(Total for Question 2 = 1 mark)

3 Which of the following is a correct statement about a stationary wave?

☒ **A** All points on the wave oscillate in phase.

☒ **B** A node is formed at a point of constructive interference.

☒ **C** Stationary waves can only be formed from transverse waves.

☒ **D** Two points $\frac{\lambda}{2}$ apart oscillate with the same amplitude.

(Total for Question 3 = 1 mark)

Questions 7 and 8 refer to an experiment to investigate stationary waves on a string.

A string of length l, fixed at both ends, is placed under tension T and plucked. The fundamental frequency f of the vibrating string is measured and the speed v of the wave on the string is calculated.

7 Which of the following gives the speed of the wave?

☒ **A** $v = 4fl$

☒ **B** $v = 2fl$

☒ **C** $v = fl$

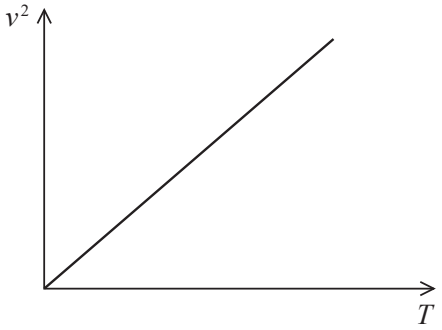
☒ **D** $v = \frac{fl}{2}$

(Total for Question 7 = 1 mark)

Questions 7 and 8 refer to an experiment to investigate stationary waves on a string.

A string of length l, fixed at both ends, is placed under tension T and plucked. The fundamental frequency f of the vibrating string is measured and the speed v of the wave on the string is calculated.

8 Corresponding values of v^2 against T are plotted. A straight line graph is obtained, as shown.



Which of the following expressions for the mass per unit length μ of the string is correct?

☒ **A** μ = gradient

☒ **B** $\mu = \sqrt{\text{gradient}}$

☒ **C** $\mu = \dfrac{1}{\text{gradient}}$

☒ **D** $\mu = \dfrac{1}{\sqrt{\text{gradient}}}$

(Total for Question 8 = 1 mark)

4 A string is held under tension. When it is plucked it vibrates with a frequency f.

Which of the following would result in a lower value for f?

☒ **A** decreasing the cross-sectional area of the string

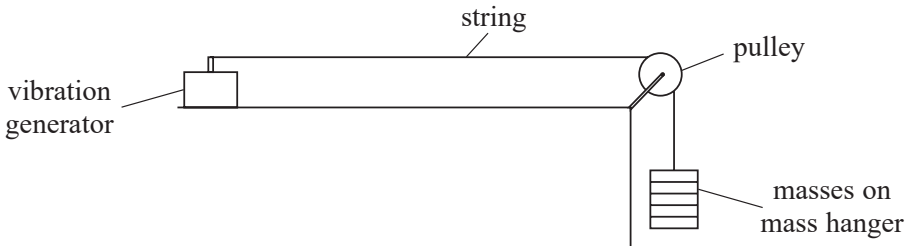
☒ **B** decreasing the density of the material of the string

☒ **C** increasing the length of the string

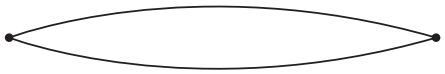
☒ **D** increasing the tension

(Total for Question 4 = 1 mark)

10 The diagram represents an arrangement used to generate standing waves on a string.



A standing wave pattern with two nodes is obtained as shown.



Which of the following single changes could produce a standing wave pattern with three nodes?

- ☒ **A** decreasing the distance between the vibration generator and pulley
- ☒ **B** decreasing the frequency of the vibration generator
- ☒ **C** decreasing the mass on the mass hanger
- ☒ **D** decreasing the mass per unit length of the string

(Total for Question 10 = 1 mark)

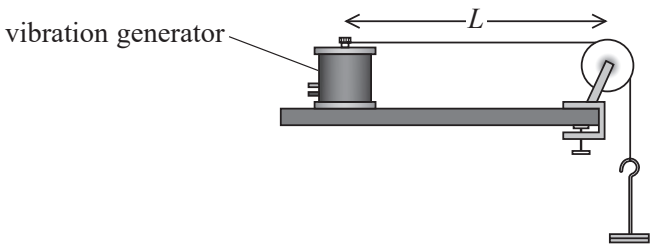
Questions 4 and 5 refer to the following information.

The speed v of a transverse wave on a string is given by

$$v = \sqrt{\frac{T}{\mu}}$$

where μ is the mass per unit length of the string and T is the tension in the string.

5 A fixed length L of string is connected to a vibration generator and held under tension T as shown. The frequency of the vibration generator is varied until, at a frequency f, a standing wave with one antinode is observed. T is increased and the procedure is repeated.



Which of the following describes the variation in f as T increases?

- ☒ **A** decreases linearly
- ☒ **B** decreases non-linearly
- ☒ **C** increases linearly
- ☒ **D** increases non-linearly

(Total for Question 5 = 1 mark)

11 The photograph shows a stringed instrument called a cello being played with a bow.



(Source: © Vadim Ponomarenko/Alamy Stock Photo)

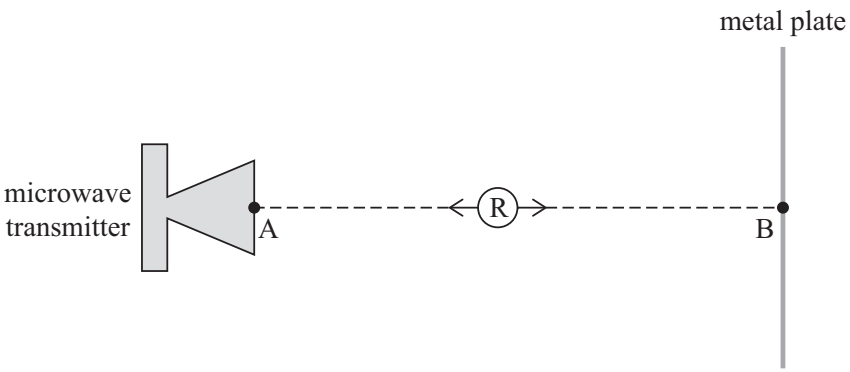
A standing wave forms on a cello string when the bow moves across the string.

Deduce whether a thicker string will produce a note of higher or lower frequency compared with a thinner string.

Assume each string is the same length and at the same tension.

(Total for Question 11 = 4 marks)

2 A transmitter produces microwaves with a frequency of 10.7 GHz. The microwaves are directed towards a metal plate. A microwave receiver R is placed between the transmitter and the metal plate, as shown.



When R is moved along the line AB, the intensity of microwaves received is observed to increase from minimum to maximum a number of times. The distance between successive minima is about 1.5 cm.

Explain these observations. Your answer should include a calculation.

(Total for Question 2 = 5 marks)

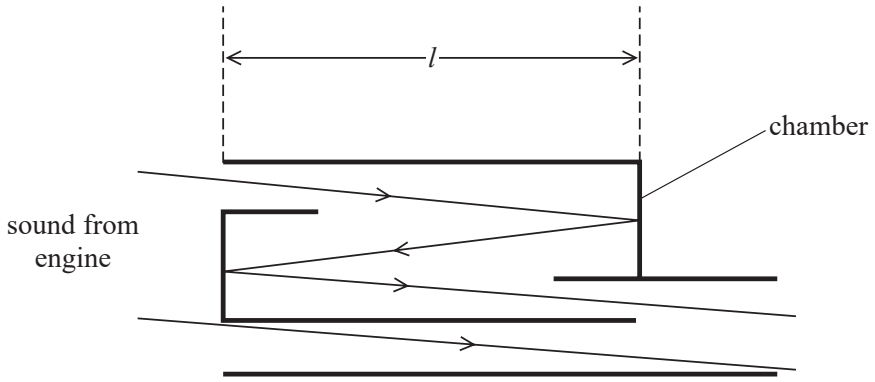
12 Vibrations of a car engine cause a sound wave in air.

(a) Describe how the displacement of air molecules causes pressure variations in the air.

(3)

(b) A silencer is a device fitted to a car to reduce the sound from the engine.
Some sound passes through the silencer chamber and is reflected twice. Some sound passes straight through the chamber without being reflected.

The simplified diagram shows the paths of the sound as it travels through the chamber. Sound leaving the chamber is a combination of sound waves from the two paths. The sound waves are in phase as they enter the chamber.



An engine produces sound with a frequency of about 140 Hz.

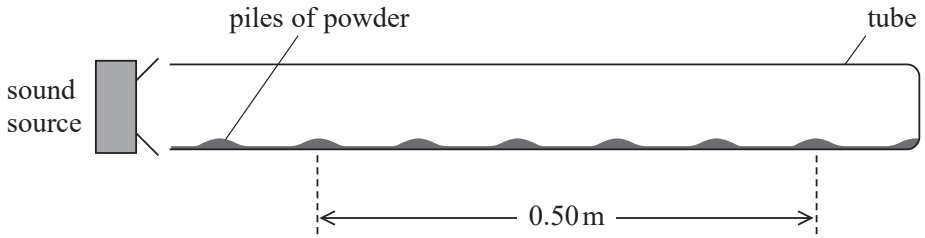
Explain why, to reduce this sound, the length l of the chamber should be about 60 cm.

speed of sound in air = 340 m s^{-1}

(4)

(Total for Question 12 = 7 marks)

14 In an experiment to determine the speed of sound in air, a powder is sprinkled over the base of a horizontal glass tube. One end of the tube is closed. A sound source is placed at the open end of the tube, as shown.



Soundwaves travel along the tube and reflect from the closed end.

(a) Explain why the powder forms into small piles at regular intervals along the length of the tube.

(5)

(b) When the frequency of the source is 1.8 kHz the positions of six piles and the distance they cover is 0.50 m, as shown on the diagram.

Calculate a value for the speed of sound.

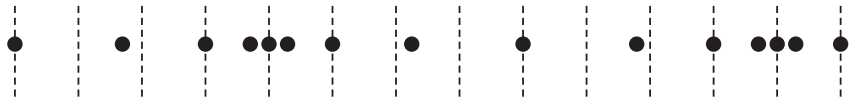
(3)

Speed = ...

(Total for Question 14 = 8 marks)

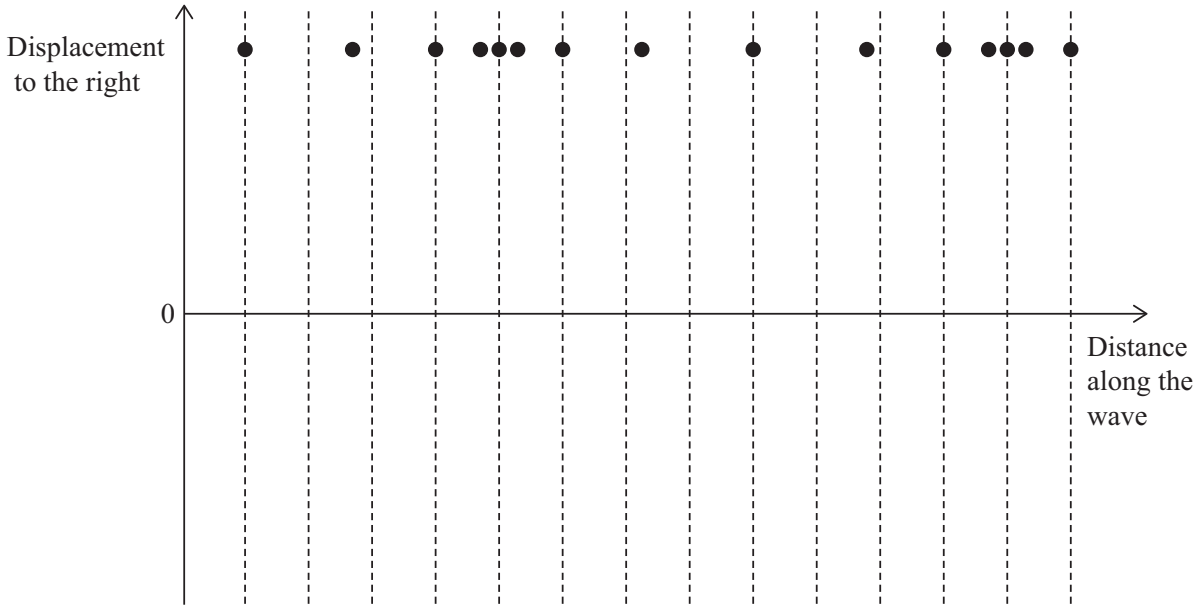
11 A violin is a musical instrument that has four strings under tension. When a string is plucked, a standing wave is produced on the string creating a longitudinal wave in the air.

(a) The diagram shows the position of particles along a longitudinal wave at a particular time. The vertical dotted lines represent the equilibrium positions of the particles.



Sketch, on the axes below, a displacement-distance graph that corresponds to the longitudinal wave. You do not need to add scales to the axes.

(2)



(b) Each of the four strings on a violin produces a different musical note when plucked.

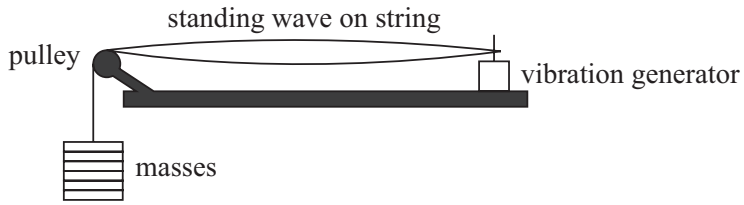
(i) One of the strings has a diameter 7.6×10^{-4} m.

Show that the mass per unit length μ of this string is about $0.0005\,\text{kg}\,\text{m}^{-1}$.

density of material of the strings = $1200\,\text{kg}\,\text{m}^{-3}$
length of string = $0.33\,\text{m}$

(3)

(ii) The effect of the tension of a string on the frequency at which standing waves are formed can be investigated using the apparatus shown.



One of the violin strings was investigated.

The frequency was increased until a standing wave with one antinode was observed.

The table shows the diameter D and the mass per unit length μ for the four strings on a violin.

	D / m	μ / kg m^{-1}
String 1	5.0×10^{-4}	0.00024
String 2	7.6×10^{-4}	0.0005
String 3	1.1×10^{-3}	0.0011
String 4	1.7×10^{-3}	0.0027

Deduce which violin string was being investigated.

frequency = 277 Hz
length of string between the pulley and the generator = 0.33 m
mass hung from string = 3.9 kg

(3)

(Total for Question 11 = 8 marks)

18 The harp is a musical instrument with many strings, as shown.



(Source: © Peter Voronov/Shutterstock)

All the strings are under tension.

The strings on one type of harp are made from nylon of density $1070\,\text{kg}\,\text{m}^{-3}$. One string has a diameter of $1.14\,\text{mm}$.

(a) (i) Show that the mass per unit length μ of the string is about $1.1 \times 10^{-3}\,\text{kg}\,\text{m}^{-1}$.

(2)

(ii) When the middle of the string is plucked, a note of frequency 440 Hz is produced.

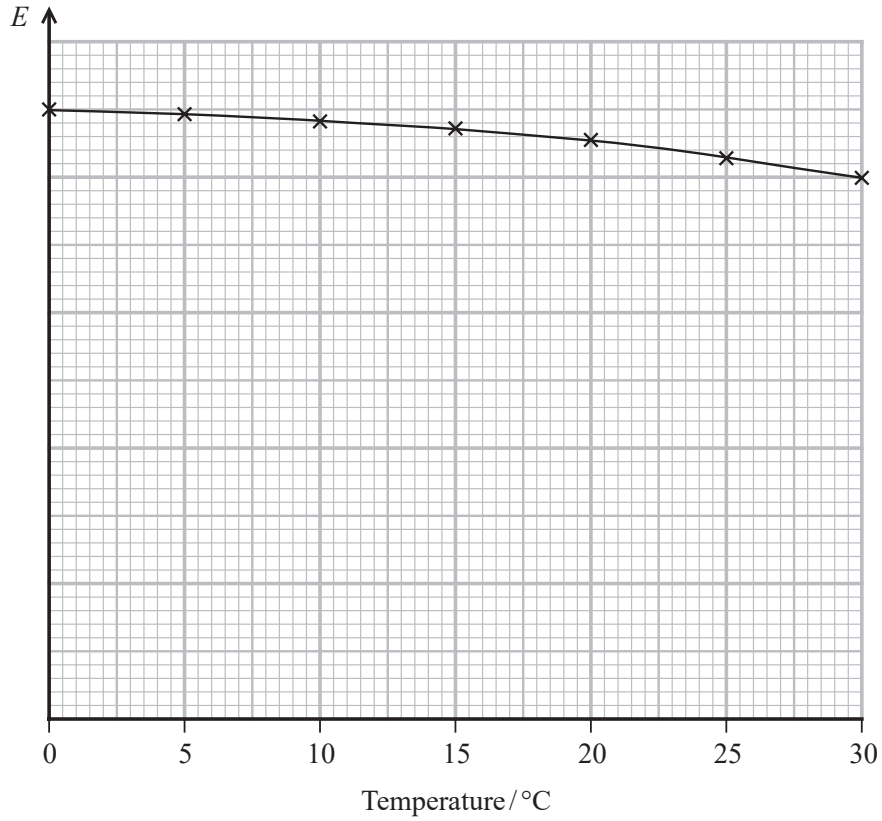
Calculate the tension in the string.

length of string = 41.0 cm

(4)

Tension in string = ...

(b) The graph shows how the Young modulus E of the nylon varies with temperature.



When the harp is played, the temperature of the string increases.

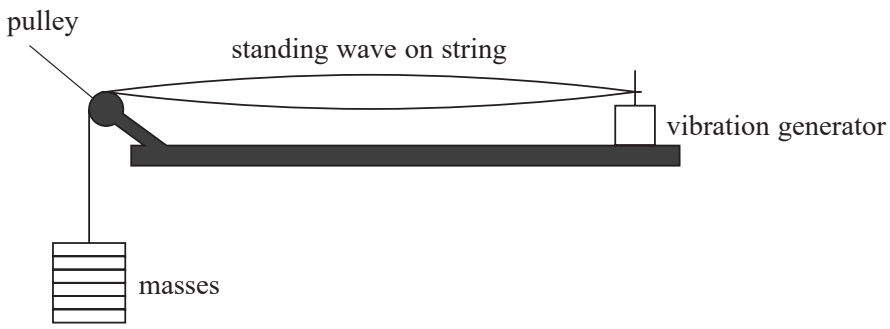
Explain how this temperature change would affect the frequency of the note produced when the string is plucked.

(3)

(Total for Question 18 = 9 marks)

12 A student was studying musical instruments.

(a) The student set up a standing wave on a string using the apparatus shown.



The standing wave had one antinode, as shown above, when the vibration generator had a frequency f.

The student then increased the frequency.

Describe what was observed as f was gradually increased to $2f$.

(2)

(b) A guitar has metal strings under tension. When a string is plucked it vibrates, producing a sound wave in the air.

Describe how the vibrating string produces pressure variations in the air.

(3)

(c) A guitar player changes the length of string that vibrates by pressing on the string as shown.



The guitar player plucks a string to play a note. A standing wave with one antinode is set up on the string.

He can vary the length of string that vibrates from 21 cm to 63 cm.

Deduce whether a note of frequency 196 Hz can be played on the string.

tension in string = 56 N
mass per unit length of the string = 5.0×10^{-3} kg m^{-1}

(4)

(Total for Question 12 = 9 marks)

12 A student carries out an experiment using a guitar string. She investigates the effect of varying the tension in the guitar string on the frequency of sound produced when the string is plucked.

(a) Describe a method of varying and measuring the tension in the string.

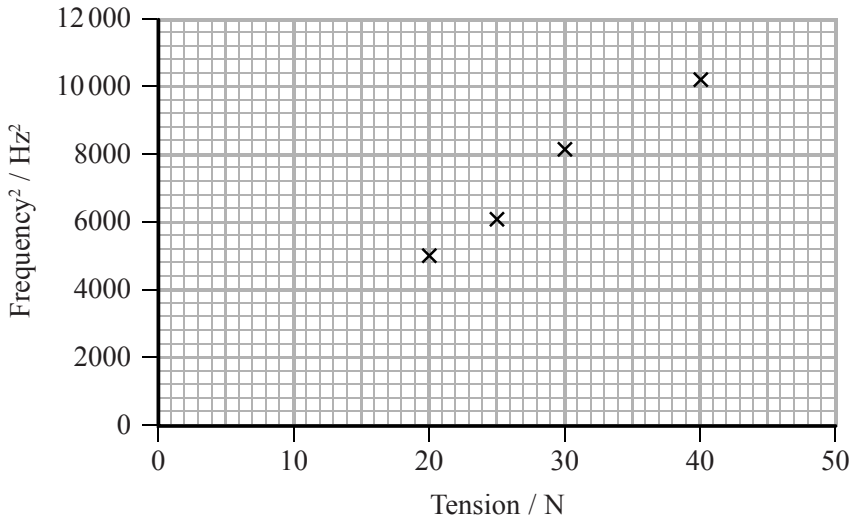
(2)

(b) The student records the following data and plots a graph.

Tension / N	20	25	30	35	40
Frequency / Hz	70	78	90	95	101
Frequency^2 / Hz^2	4900	6084	8100		10201

Complete the table and graph.

(3)



(c) The student reads that guitar strings have a mass per unit length of between 0.4×10^{-3} kg m^{-1} and 7×10^{-3} kg m^{-1}.

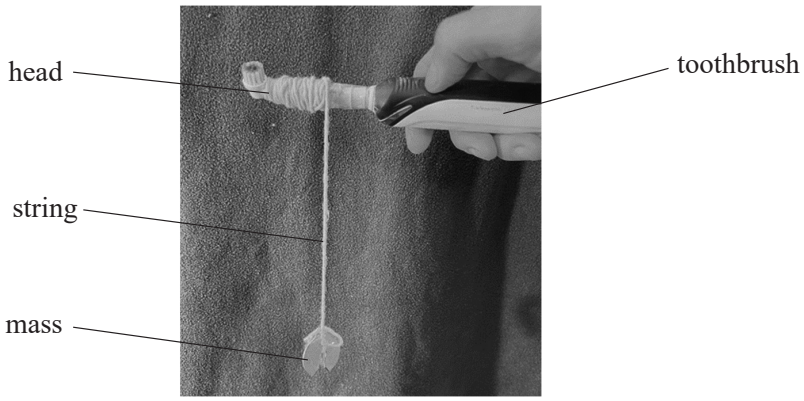
Determine whether the guitar string used in this experiment lies within this range.

length of string vibrating = 0.40 m

(5)

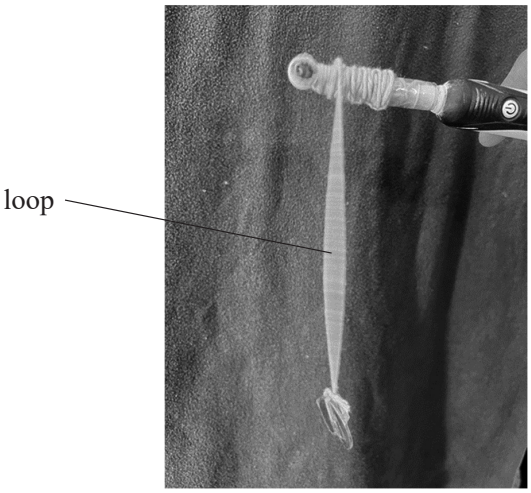
(Total for Question 12 = 10 marks)

15 A student wound a piece of string around the head of an electric toothbrush. The student attached a small mass to the other end of the string, as shown in Photograph 1.



Photograph 1

The toothbrush was switched on and the head started to vibrate. The student rotated the toothbrush slowly to unwind the string. At a particular length, large vibrations were observed on the string. The string formed a loop, as shown in Photograph 2.



Photograph 2

(a) Explain how the vibrations of the toothbrush head caused the loop to form.

(5)

(b) The student continued to unwind the string and the loop disappeared. When the length of the unwound string was twice that shown in Photograph 2 two loops were seen. Three loops were seen when the unwound length was three times that shown in Photograph 2 and so on.

Determine the frequency of vibration of the toothbrush head.

unwound length of string with 4 loops = 0.69 m
mass on string = 0.010 kg
mass per unit length of string = 9.1×10^{-4} kg m^{-1}

(5)

Frequency = ...

(Total for Question 15 = 10 marks)

11 The photograph shows a guitar. The strings of the guitar are at the same tension.



When a string is plucked, a standing wave is set up on the string.

*(a) Explain how a standing wave is set up on a string.

(6)

(b) A thicker string produces a note with a lower fundamental frequency than a thinner string of the same material.

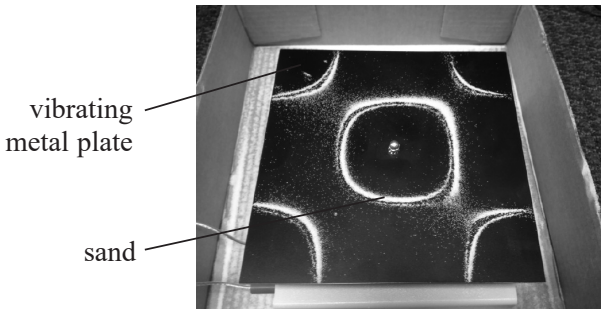
Justify this statement.

(5)

(Total for Question 11 = 11 marks)

6 Rosslyn Chapel is a 15th century chapel in Scotland. Inside the chapel, small sandstone cubes protrude from a number of arches. It has been suggested that carvings on these cubes bear a resemblance to standing wave patterns that can be produced on a vibrating metal plate.

A metal plate is made to vibrate and sand is scattered evenly across its surface. At a certain frequency the sand moves to produce the standing wave pattern shown below.



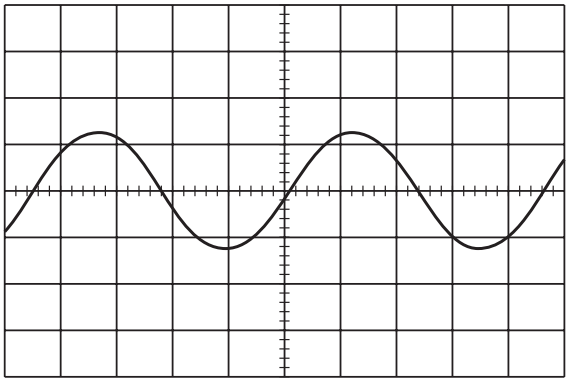
(Source: https://skullsinthestars.com/2013/05/02/physics-demonstrations-chladni-patterns/#jp-carousel-7353)

(a) Explain why the sand moves to different positions when a standing wave is formed on the plate.

(3)

(b) The plate is set into movement by a vibration generator. The wavelength of the waves produced in the plate was estimated to be 0.32 m.

The signal applied to the vibration generator is shown on the oscilloscope trace below. The time base of the oscilloscope was set to 0.50 ms div^{-1}.



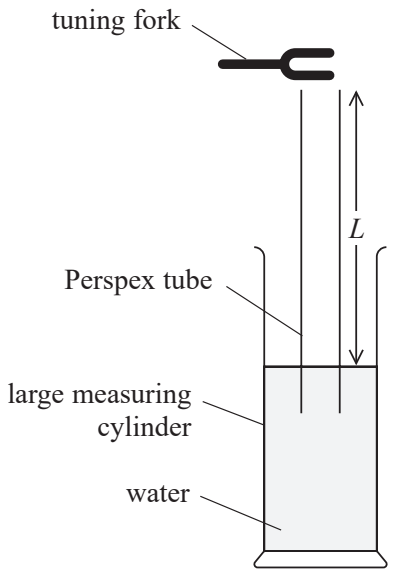
The waves produced in the plate travel at a speed much less than the speed of sound in air.

Evaluate whether the data supports a value for the speed of waves in the plate that is much less than the speed of sound in air.

speed of sound in air = 340 m s^{-1}

(5)

(c) The speed of sound in air can be determined by creating a standing wave in a column of air. The diagram shows a tuning fork just above the open end of a tube.



The tuning fork produces a sound wave of known frequency f. Several tuning forks are available, each with a different frequency.

A student adjusted the length L of the air column. A loud sound was heard when a standing wave was produced. A node was formed at the water surface, and an antinode was formed at the open end of the tube.

The student used values of L and f to determine a value for the speed of sound.

Describe a graphical method that the student could have used to determine a value for the speed of sound.

(3)

(Total for Question 6 = 11 marks)

15 The photograph shows a guitar.

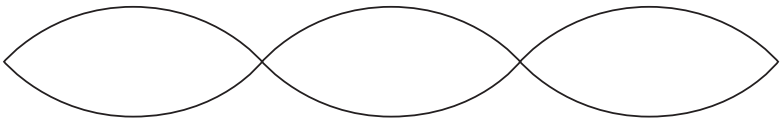


When a guitar string is plucked, a standing wave is created.

(a) Explain how a standing wave is created on the string.

(3)

(b) The diagram shows a standing wave on a guitar string.



The oscillating length of the guitar string is 66 cm.

(i) State the wavelength for this standing wave.

(1)

Wavelength = ...

(ii) Calculate the frequency of vibration for this standing wave.

tension in guitar string = 88.6 N

mass per unit length of guitar string = 4.47×10^{-3} kg m^{-1}

(3)

.....

.....

.....

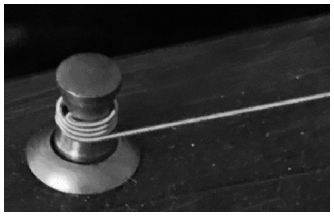
.....

.....

.....

Frequency = ...

(c) One end of the guitar string is wrapped around a cylindrical tuning peg. Turning the peg changes the total length of the string and hence changes the tension in the string. This changes the frequency of vibration of the string.



(i) The length of one string is 68 cm.

Calculate the extension required to produce a tension of 93.4 N in the string.

Young modulus of string material = $1.8 \times 10^{9}\,\text{N m}^{-2}$

cross-sectional area of string = $6.6 \times 10^{-7}\,\text{m}^{2}$

(4)

Extension = ...

(ii) The vibrating length of string is unchanged by turning the tuning peg.

Explain the effect that tightening the string has on the frequency of the sound produced.

(2)

(Total for Question 15 = 13 marks)

14 A seiche is a standing wave that can form on the surface of a lake in strong winds, causing flooding and erosion.

(a) Early in 2020, a single-node seiche was observed on Lake Erie in the USA. A node formed at the centre of the lake. Antinodes formed at the two ends of the lake.

The speed v of a seiche wave is given by

$$v = \sqrt{gh}$$

where h is the mean depth of the water.

Calculate the period of oscillation of the seiche.

length of Lake Erie = 400 km
mean depth of Lake Erie = 19 m

(3)

Period of oscillation = ...

(b) Erosion causes clay particles to be washed into the lake, making the lake cloudy. The lake can remain cloudy to a depth of about 4 m for more than 6 months.

One spherical clay particle has a radius of 2.5×10^{-7} m.

Deduce whether this particle takes more than 6 months to fall 4 m.
You should assume that the water in the lake remains still.

viscosity of water = 1.0×10^{-3} kg m^{-1} s^{-1}
density of water = 1000 kg m^{-3}
density of clay = 2650 kg m^{-3}

(6)

(c) The temperature of the lake decreases with depth.

Explain how this may affect the rate at which a particle falls.

(2)

(d) In an investigation to determine the viscosity of water, a student drops a small sphere into a cylinder of water. The student uses a stopwatch to record the time it takes for the sphere to fall through the water.

Assess whether the stopwatch is suitable for measuring the time in this investigation.

(2)

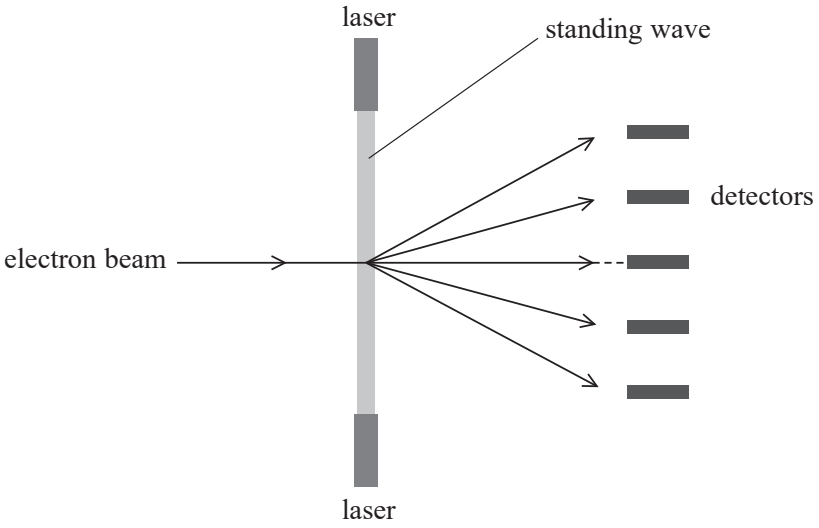
(Total for Question 14 = 13 marks)

15 Read the extract and answer the questions that follow.

In 1933 it was predicted that a standing light wave could act as a diffraction grating that could diffract electrons. The prediction was tested 70 years later due to the development of powerful lasers.

Two identical lasers, emitting coherent light, were pointed towards each other to create the standing wave. A narrow beam of electrons passed through the standing wave. The nodes in the standing wave acted like gaps in a diffraction grating.

The pattern of the diffracted electrons was observed by detectors placed behind the standing wave as shown.



(a) Describe how a standing wave can be created from the light emitted by the two lasers.

(5)

(b) A diffraction pattern is detected 0.24 m from the grating created by the laser light. The distance between the central maximum and the 1st order maxima of the diffraction pattern is 55 μm.

Calculate the wavelength of the electrons in the beam that passes through the standing wave created by the laser light.

wavelength of light from laser = 532 nm

(3)

Wavelength = ...

(c) The wavelength of monochromatic light can be determined using a diffraction grating with about 500 lines per mm.

Explain why the wavelength of electrons can **not** be determined using this diffraction grating.

(2)

*(d) A laser produces light with discrete wavelengths.

The laser contains a gas. A current in the gas causes the atoms in the gas to move to an excited state.

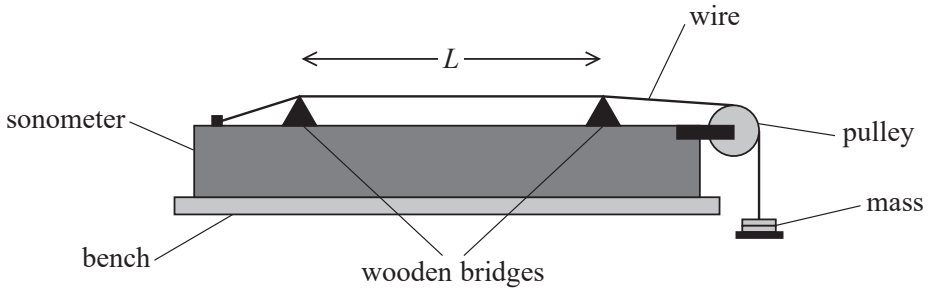
Explain why the excited atoms emit light with discrete wavelengths.

(6)

(Total for Question 15 = 16 marks)

13 A student used a sonometer to investigate the properties of a stretched wire. The sonometer is a long hollow wooden box.

A steel wire is attached to one end of the box and rests on two wooden bridges. The wire is placed under tension T by hanging a mass from the end of the wire, as shown.



The student placed the base of a vibrating tuning fork in contact with the wire, at one of the bridges. This set the wire into oscillation. He adjusted the position of the other bridge until a single-loop standing wave was produced on the wire between the bridges.

(a) Explain how an antinode is produced at the mid-point of the wire between the bridges.

(3)

(b) The student repeated this for a series of tuning forks with different frequencies f. For each fork he measured the distance L between the bridges.

The steel wire, of mass per unit length μ, was placed under tension T by hanging a mass of 2.10 kg from the end of the wire.

(i) State one safety precaution that should be taken when carrying out the investigation.

(1)

.....

(ii) The student plotted a graph of L^2 against $1/f^2$.

Show that the gradient of this graph is equal to $\frac{T}{4\mu}$

(3)

.....

.....

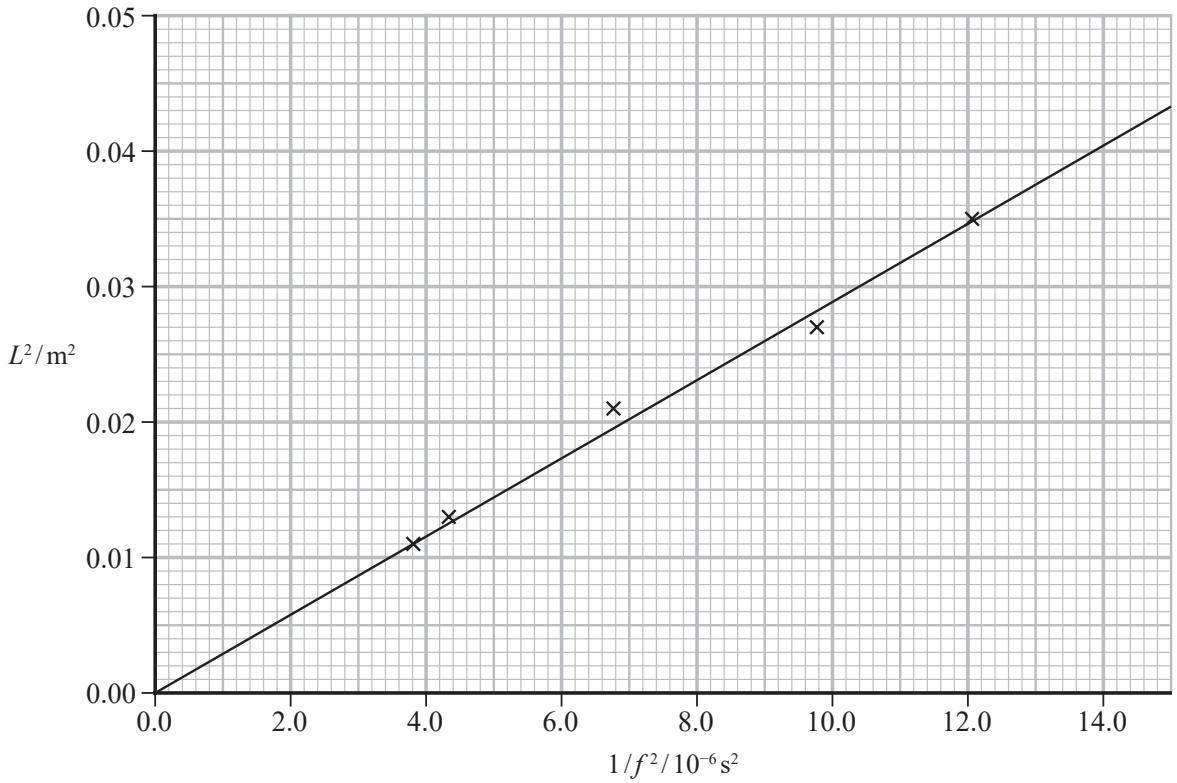
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.....

.....

(iii) The student's graph is shown below.



The value of μ for different standard wire gauge (SWG) steel wire is shown in the table.

SWG	μ / g m^{-1}
22	3.15
24	1.95
26	1.31

Deduce which wire the student used in the investigation.

(4)

(c) The student then found a value of μ for a brass wire, using a different method.

(i) He measured the diameter d of the wire using a micrometer.

Explain one technique the student should use when measuring d.

(2)

(ii) The student obtained the following data.

d / mm			
0.55	0.59	0.57	0.58

The stated value of μ for the brass wire used by the student was $2.14 \times 10^{-3}\,\text{kg m}^{-1}$.

Deduce whether the student's data supports this value for μ.

density of brass = $8700\,\text{kg m}^{-3} \pm 200\,\text{kg m}^{-3}$

(6)

(Total for Question 13 = 19 marks)

SUB-TOPIC 5.3

REFRACTION AND TOTAL INTERNAL REFLECTION

Sub-topic 5.3 · 18 questions · 79 marks · lowest tariff first

4 For total internal reflection to take place, the angle of incidence must be

☒ **A** greater than or equal to the critical angle.

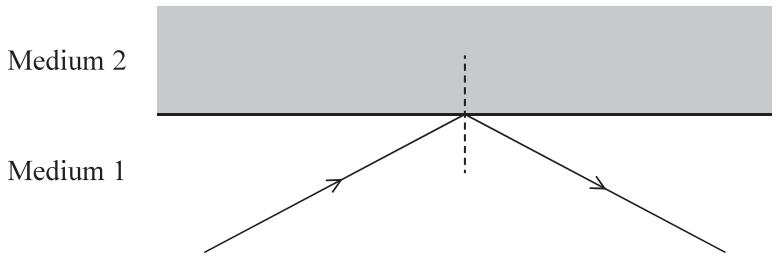
☒ **B** greater than the critical angle.

☒ **C** less than or equal to the critical angle.

☒ **D** less than the critical angle.

(Total for Question 4 = 1 mark)

5 A ray of light travels through medium 1 of refractive index n_1 and is incident at an interface with medium 2 of refractive index n_2. The ray is totally internally reflected at the interface.



speed of the light in medium 1 = v_1

speed of the light in medium 2 = v_2

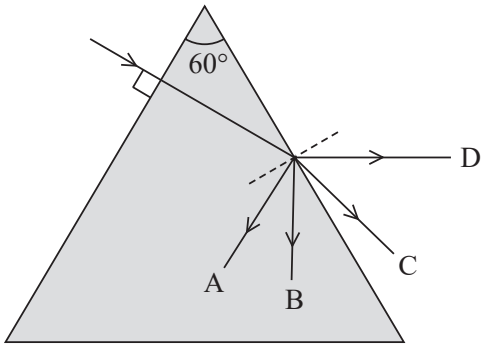
Which row of the table is correct for this situation?

☒ **A**	$v_1 > v_2$	$n_1 > n_2$
☒ **B**	$v_1 < v_2$	$n_1 > n_2$
☒ **C**	$v_1 > v_2$	$n_1 < n_2$
☒ **D**	$v_1 < v_2$	$n_1 < n_2$

(Total for Question 5 = 1 mark)

Questions 2 and 3 refer to the following information.

A ray of light, in air, is incident on the edge of a triangular glass prism as shown.
The critical angle for a light ray meeting a glass to air boundary is 35°.



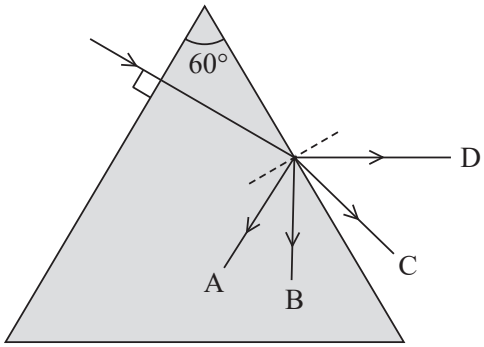
2 Which path, A, B, C or D, will the ray follow?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 2 = 1 mark)

Questions 2 and 3 refer to the following information.

A ray of light, in air, is incident on the edge of a triangular glass prism as shown.
The critical angle for a light ray meeting a glass to air boundary is 35°.



3 Which of the following gives the value of the refractive index of the glass?

☒ **A** $\sin 35$

☒ **B** $\dfrac{1}{\sin 35}$

☒ **C** $\sin^{-1}\left(\dfrac{1}{35}\right)$

☒ **D** $\dfrac{1}{\sin^{-1}\left(\dfrac{1}{35}\right)}$

(Total for Question 3 = 1 mark)

2 Light travelling in glass of refractive index n_g is incident at a boundary with water of refractive index n_w. The critical angle for the boundary is C.

Which of the following expressions is correct for this boundary?

☒ **A** $\sin C = \frac{1}{n_g}$

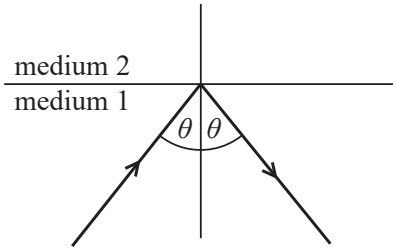
☒ **B** $\sin C = \frac{n_w}{n_g}$

☒ **C** $\sin C = \frac{n_g}{n_w}$

☒ **D** $\sin C = \frac{1}{n_w}$

(Total for Question 2 = 1 mark)

8 Total internal reflection occurs when light is incident on the boundary between medium 1 and medium 2, as shown.



The refractive index of medium 1 is n_1 and the refractive index of medium 2 is n_2.

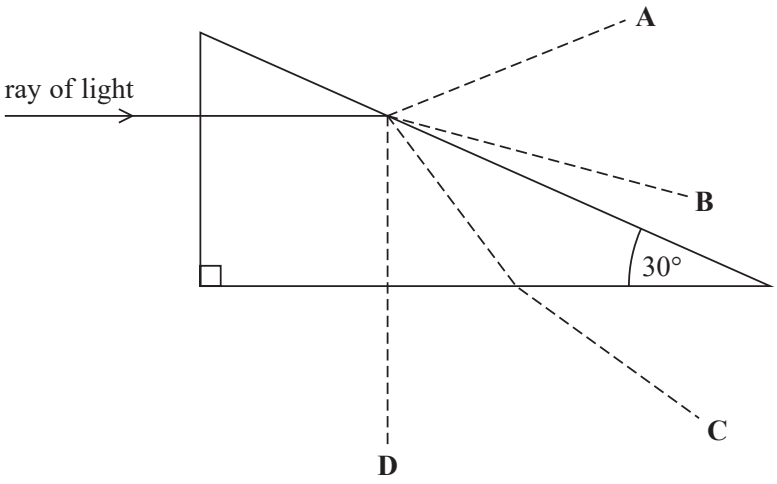
The critical angle for the boundary is C.

Which row of the table is correct?

☒	**A**	$\theta < C$	$n_1 > n_2$
☒	**B**	$\theta < C$	$n_2 > n_1$
☒	**C**	$\theta > C$	$n_1 < n_2$
☒	**D**	$\theta > C$	$n_2 < n_1$

(Total for Question 8 = 1 mark)

8 A ray of light is directed towards a prism as shown.
The prism is made from a material with refractive index 1.5

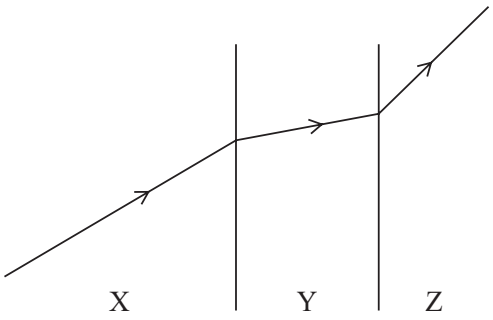


Which of the dashed lines best shows the subsequent path of this ray of light?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 8 = 1 mark)

7 The diagram shows a ray of light passing from medium X to medium Y to medium Z. The speed of light in medium X is v_X, the speed of light in medium Y is v_Y and the speed of light in medium Z is v_Z.



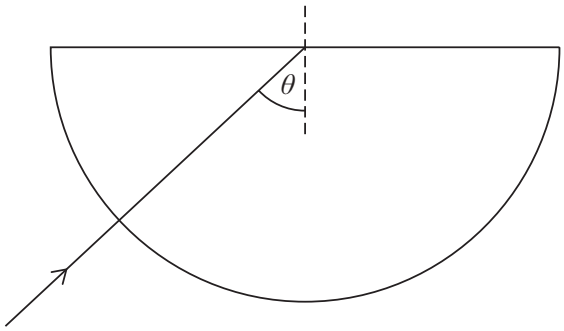
Which of the following shows the speeds in order of increasing magnitude?

- ☒ **A** v_Y v_X v_Z
- ☒ **B** v_Z v_X v_Y
- ☒ **C** v_X v_Y v_Z
- ☒ **D** v_Y v_Z v_X

(Total for Question 7 = 1 mark)

3 Light enters a semicircular glass block, as shown. The ray of light reaches the straight edge of the block at an angle of incidence θ.

The critical angle for glass is c.

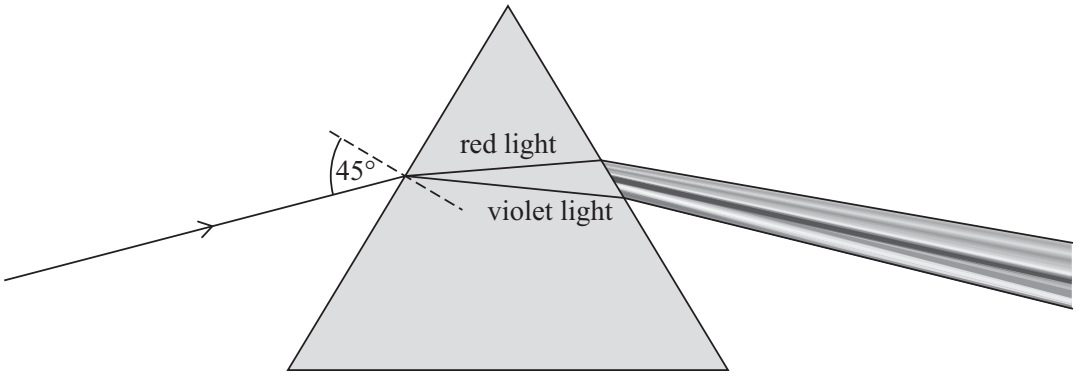


Which of the following statements for light incident at the straight edge of the block is correct?

- ☒ **A** When θ is greater than c, then no light is reflected.
- ☒ **B** When θ is greater than c, then no light is transmitted.
- ☒ **C** When θ is less than c, then no light is reflected.
- ☒ **D** When θ is less than c, then no light is transmitted.

(Total for Question 3 = 1 mark)

12 The image from the cover of a music album is represented below.



White light enters the prism at an angle of incidence of 45°. The light disperses and splits into a spectrum of colours as it enters the prism.

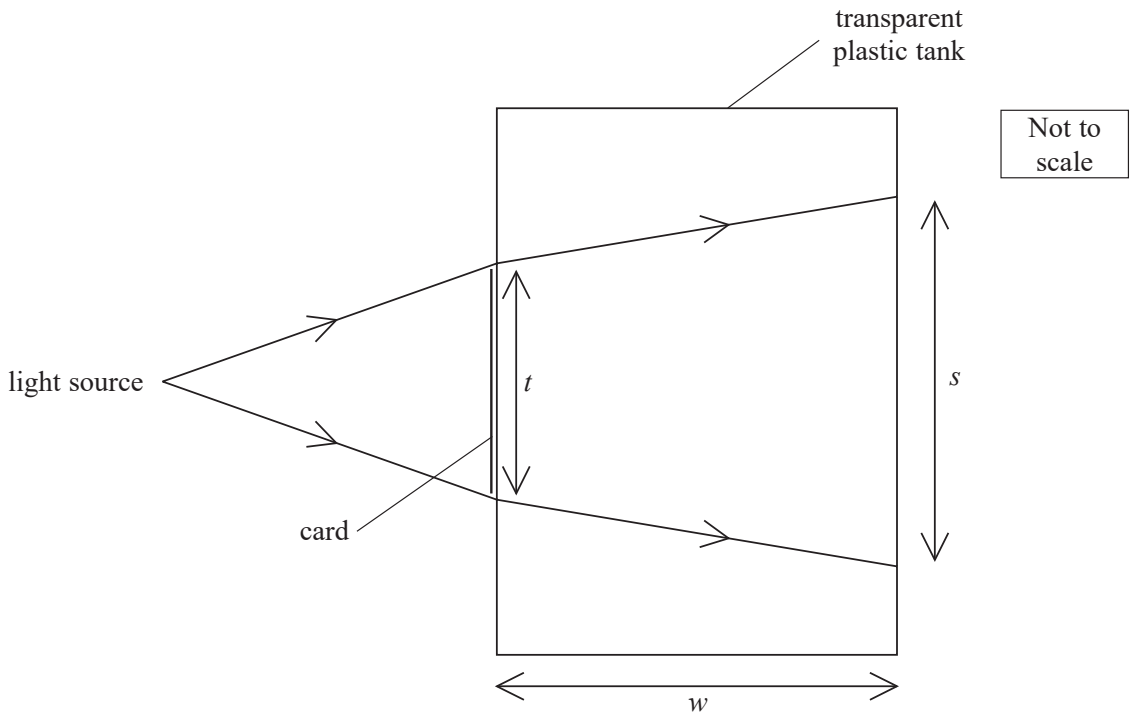
In this image the angle of refraction for violet light at the first boundary is 22°. The angle between the red light and the violet light is 11°.

Evaluate whether the angle between the red light and the violet light is accurate.

$$\frac{\text{speed of violet light in prism}}{\text{speed of red light in prism}} = 0.99$$

(Total for Question 12 = 4 marks)

12 The diagram shows a transparent tank, with thin plastic sides, that can be used to determine the refractive index of a transparent liquid.



A rectangle of opaque card is stuck on the side of the tank containing the liquid. A light source is placed in front of the tank and the width s of the shadow of the card, which is formed on the back of the tank, is measured. The width t of the card and the width w of the tank are also measured.

(a) The angle of incidence of the light as it enters the tank is 7.2°

Show that the refractive index of the liquid is about 1.4

$w = 35.0\,\text{cm}$
$t = 4.0\,\text{cm}$
$s = 10.2\,\text{cm}$

(3)

(b) Determine the speed of light in the liquid.

(2)

.....

.....

.....

.....

Speed of light = ...

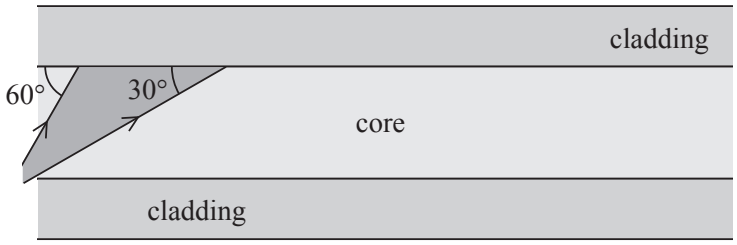
(Total for Question 12 = 5 marks)

9 A simple optical fibre consists of a core surrounded by cladding. The refractive index of the core is 1.56 and the refractive index of the cladding is 1.20.

(a) Show that the critical angle for light between these two media is about 50°.

(3)

(b) The diagram shows a diverging beam of light incident on the boundary between the core and the cladding. One side of the beam strikes the boundary at 60° and the other side at 30° as shown.



Three students each suggest a different outcome for the beam of light at the boundary.

Student A says "all the beam will totally internally reflect".

Student B says "all the beam will refract".

Student C says "some of the beam will totally internally reflect and some will refract".

State which student is correct, adding to the diagram to illustrate your answer.

(3)

(Total for Question 9 = 6 marks)

12 On sunny days a mirage can sometimes be observed when a virtual image of the sky is seen on the surface of a road.



The Sun's rays heat up the surface of the road. The heated road then heats the surrounding air so that the layer of air just above the road is at a higher temperature than the air above it.
Warm air has a lower refractive index than cool air.

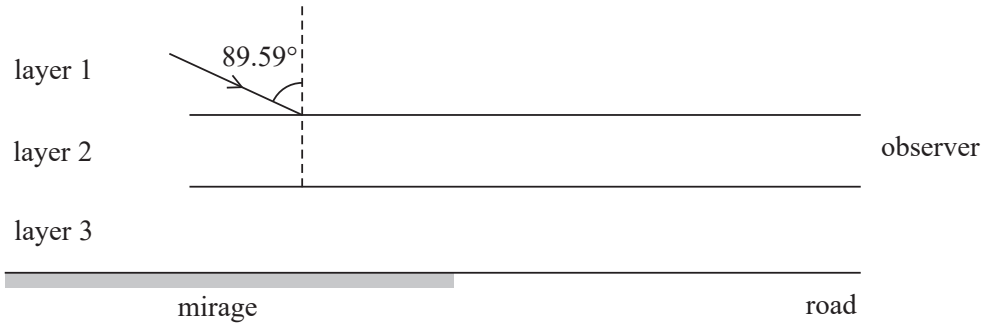
(a) State what is meant by a virtual image.

(1)

.....

.....

(b) The diagram represents a simple model which is sometimes used to explain how a mirage is formed. The three layers, each with a different refractive index, represent air at three different temperatures. Layer 3 represents the air at the highest temperature closest to the road.
A light ray is shown incident at the interface between layer 1 and layer 2.



	refractive index
layer 1	1.00032
layer 2	1.00030
layer 3	1.00028

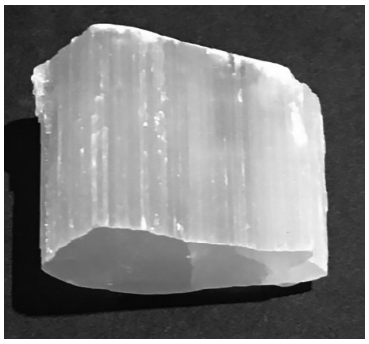
critical angle for light travelling from layer 1 to layer 2 = 89.64°
critical angle for light travelling from layer 2 to layer 3 = 89.64°

Use the information to discuss whether the observer sees a mirage on the road in the position shown.

(6)

(Total for Question 12 = 7 marks)

12 The photograph shows a sample of the mineral selenite. Selenite is made up of many long, narrow crystals.



Selenite has a refractive index of 1.52

(a) Calculate the speed of light in selenite.

(2)

Speed of light in selenite = ...

(b) (i) State what is meant by critical angle.

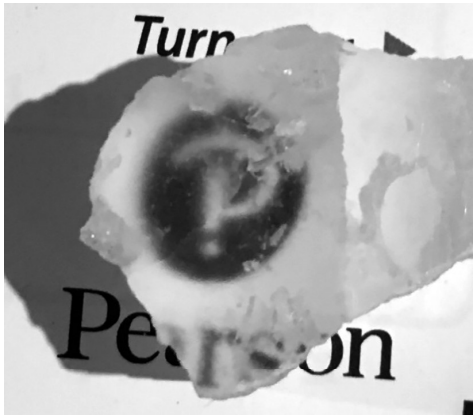
(1)

(ii) Calculate the critical angle for light in selenite.

(2)

Critical angle for light in selenite = ...

(c) Selenite can act as a collection of optical fibres, so that an image of writing beneath the mineral sample appears as if it is at the upper surface as shown.



Explain how light travels through a selenite crystal.

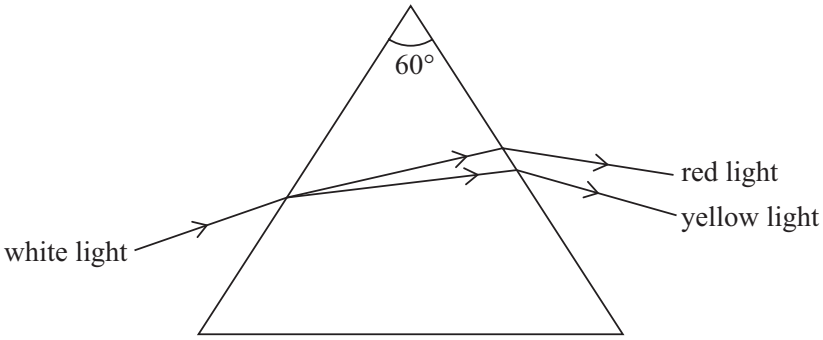
(2)

(Total for Question 12 = 7 marks)

12 A glass prism can be used to disperse white light into a spectrum.

The diagram shows the paths of red and yellow light as they pass through the prism and back into air.

Not to scale



(a) Calculate the critical angle for yellow light travelling from glass to air.

refractive index of yellow light in glass = 1.63

(2)

.....

.....

.....

.....

Critical angle = ...

(b) The white light is incident on the air-glass interface with an angle of incidence = 40°.

Calculate the angle of refraction of the red light as it leaves the prism.

speed of red light in glass = $1.9 \times 10^8\,\text{m s}^{-1}$

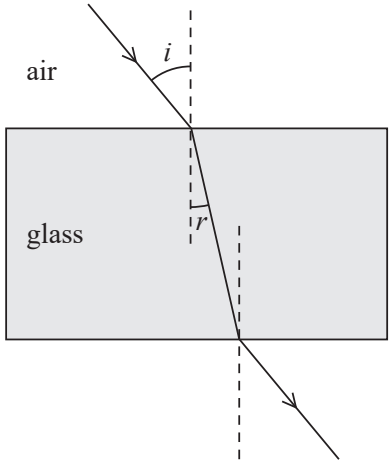
(5)

Angle of refraction = ...

(Total for Question 12 = 7 marks)

11 A student is carrying out an experiment to identify which type of glass a rectangular block is made from.

The student shines a ray of light onto one surface of the rectangular block.



The student marks the path of the ray on paper. He takes corresponding measurements of the angle of incidence i and the angle of refraction r at the air-glass interface.

(a) State two precautions the student should take to improve the accuracy of these measurements.

(2)

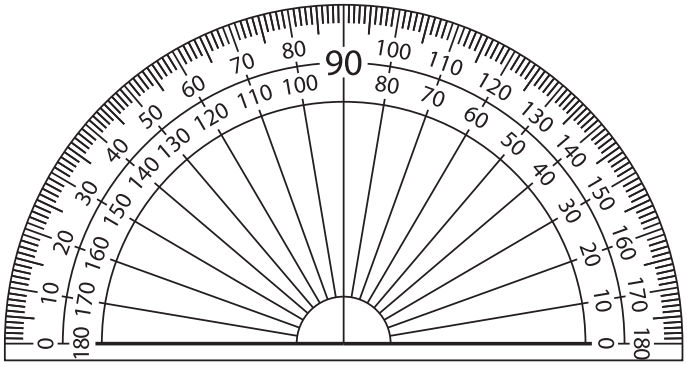
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(b) The student uses the protractor shown.



He records his results in the table.

i / °	r / °
10	5
20	13
30	17
40	24
50	29
62	37

(i) Comment on whether the student has recorded his measurements of i and r to the correct number of significant figures.

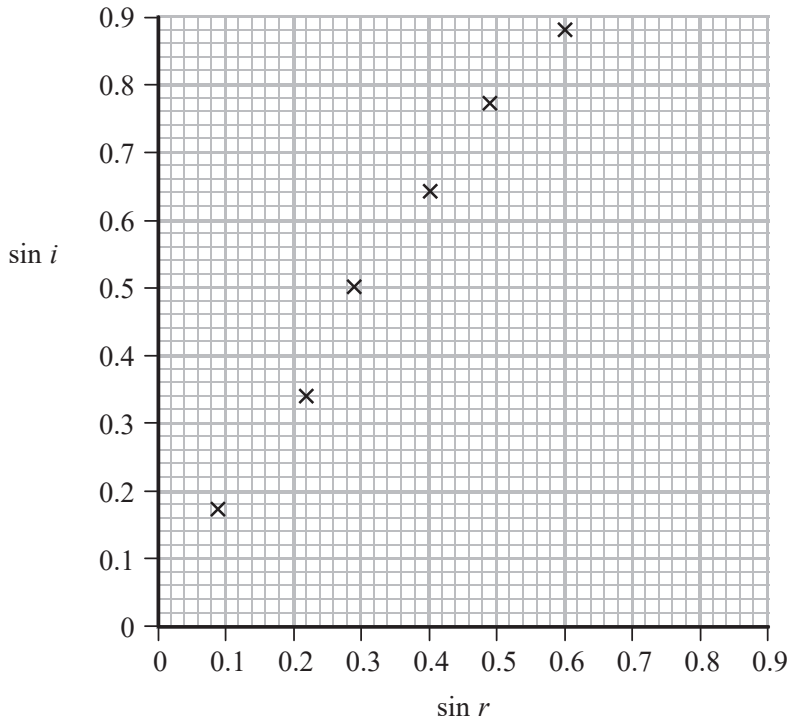
(2)

(ii) Calculate the percentage uncertainty in the value of r when $i = 50°$.

(2)

Percentage uncertainty in r = ...

(c) The student plots his results on a graph of sin i against sin r.



The refractive index for three types of glass is shown.

Type of glass	Refractive index
Silica	1.458
Crown	1.755
Flint	1.925

(i) Draw a line of best fit.

(1)

(ii) Deduce which type of glass the rectangular block is made from.

(3)

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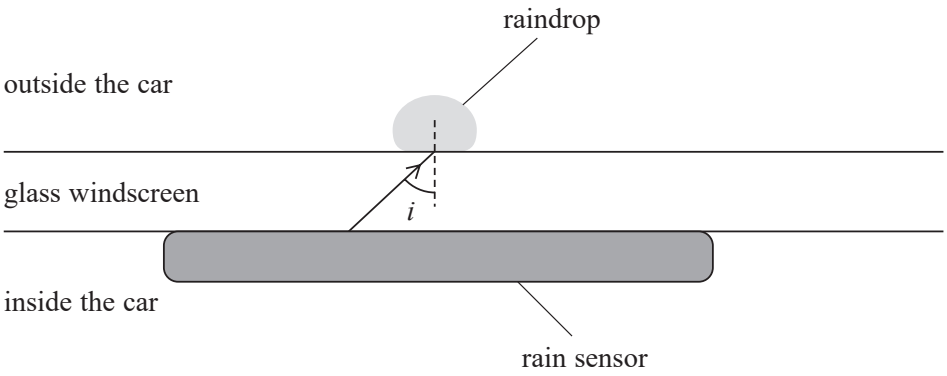
Type of glass .....

(Total for Question 11 = 10 marks)

15 A rain sensor is mounted on the inside of a car windscreen. When the rain sensor detects raindrops on the windscreen, a motor is switched on to operate the windscreen wipers.

(a) The rain sensor consists of a series of infrared emitters and detectors. Infrared rays are emitted from a sensor, travel through the glass windscreen and are incident on the outside surface.

A ray is incident on the boundary between the glass and a raindrop, as shown.



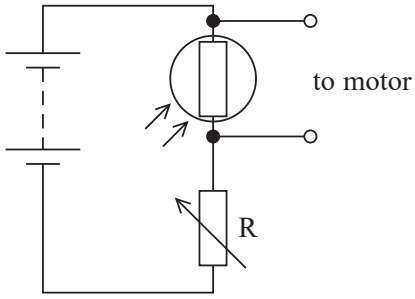
The angle of incidence i is 45°.

Determine what happens to the ray at this boundary.

refractive index of glass = 1.5
refractive index of water = 1.3

(3)

(b) A student modelled a simple infrared detector, using a light dependent resistor (LDR) in series with a variable resistor R. She connected a motor in parallel with the LDR, as shown.



(i) The intensity of the light incident on the LDR increased.

Explain what happened to the speed of the motor. Your answer should include reference to conduction electrons.

(4)

(ii) The power supply consisted of several 1.5 V cells in series.

The student set the resistance of resistor R to 270 Ω and measured the potential difference across the motor as 5.0 V. In this situation the resistance of the LDR was 193 Ω. The motor had a very high resistance.

Deduce the number of cells the student used.

(3)

(Total for Question 15 = 10 marks)

16 Read the extract and answer the questions that follow.

In the 17th century there were two proposed theories to explain the refraction of light. Using a wave model, Huygens stated that light slows down when it passes from air to water. Using a particle model, Newton stated that light speeds up when it passes from air to water. Newton's theory was more readily accepted until the speed of light in water was measured in the 19th century.

In the early 20th century, Einstein used observations from the photoelectric effect to provide evidence for the particle model of light.

Nowadays, both the wave model of light and the particle model of light are accepted, as each can be used to explain different aspects of the behaviour of light.

(a) Give two reasons why Huygens' theory for the refraction of light eventually became accepted.

(2)

(b) A ray of light travelling in air is incident on some water with an angle of incidence of 35°. The angle of refraction is 26°.

Deduce whether this is consistent with Huygens' statement about the speed of light as it passes from air to water. Your answer should include a calculation.

(3)

(c) Diffraction and interference can be explained using the wave model of light.

In an investigation to determine the wavelength of light from a laser, the light passed through a diffraction grating with 300 lines per millimetre.
A diffraction pattern consisting of a series of bright dots was observed on a screen.

The following data were recorded:

distance between grating and screen = 2.00 m
distance from central maximum to 2nd order maximum = 89.0 cm.

Calculate the wavelength of light from the laser.

(3)

.....

.....

.....

.....

.....

Wavelength = ...

(d) In a demonstration of the photoelectric effect, electromagnetic radiation is shone onto a clean metal surface. It can be shown that the metal loses negative charge when the radiation has a frequency above a certain threshold frequency.

Explain how the particle model of light is consistent with this observation.

(3)

(e) In the 1920s, experiments demonstrating diffraction of electrons confirmed de Broglie's work on the wave nature of particles.

In one such experiment an electron had a momentum of 4.8×10^{-24} kg m s^{-1}. Measurements confirmed that the de Broglie wavelength of the electron was 1.40×10^{-10} m.

Deduce that these observations are consistent with the value of h given on the data sheet at the back of this exam paper.

(3)

(Total for Question 16 = 14 marks)

SUB-TOPIC 5.4

LENSES AND OPTICAL INSTRUMENTS

Sub-topic 5.4 · 32 questions · 207 marks · lowest tariff first

9 An object is placed 6.5 cm away from a lens of focal length 3.9 cm. An image is formed 9.8 cm from the lens.

Which of the following is the magnification?

☒ **A** 0.60

☒ **B** 0.66

☒ **C** 1.5

☒ **D** 1.7

(Total for Question 9 = 1 mark)

1 A system of lenses consists of a converging lens and a diverging lens in contact.

The magnitude of the power of the converging lens is 9.4 D and the magnitude of the power of the diverging lens is 4.2 D.

Which of the following is the power of this system of lenses?

- ☒ **A** 13.6 D
- ☒ **B** 5.2 D
- ☒ **C** −5.2 D
- ☒ **D** −13.6 D

(Total for Question 1 = 1 mark)

9 An object is placed 6.5 cm from a lens of focal length 3.9 cm. An image is formed 9.8 cm behind the lens.

Which of the following expressions is equal to the magnification?

☒ **A** $\frac{3.9}{6.5}$

☒ **B** $\frac{6.5}{9.8}$

☒ **C** $\frac{6.5}{3.9}$

☒ **D** $\frac{9.8}{6.5}$

(Total for Question 9 = 1 mark)

8 Which of the following lenses would produce a real image of an object placed 15 cm away from the lens?

- ☒ **A** converging, focal length = 10 cm
- ☒ **B** converging, focal length = 20 cm
- ☒ **C** diverging, focal length = 10 cm
- ☒ **D** diverging, focal length = 20 cm

(Total for Question 8 = 1 mark)

2 An object is placed in front of a lens.

Which row of the table shows a combination that will produce a real image of the object?

		Focal length of lens / cm	Object distance / cm
☒	**A**	−5	10
☒	**B**	−5	2
☒	**C**	5	10
☒	**D**	5	2

(Total for Question 2 = 1 mark)

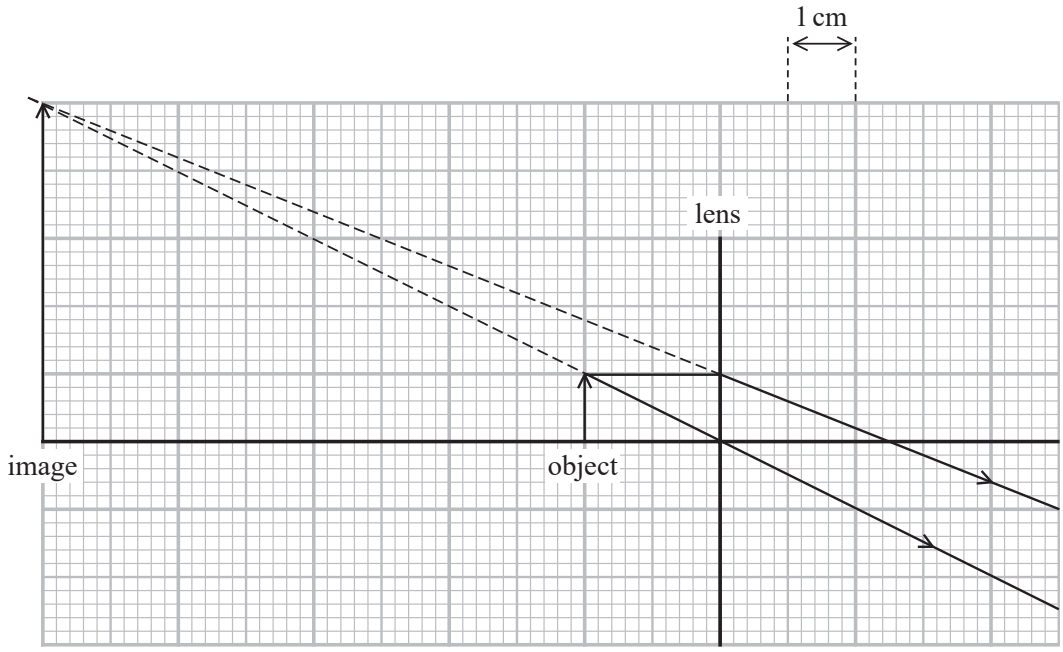
9 The focal length and power of a converging glass lens are determined for the lens in air. The lens is then immersed in water.

Which row in the table shows how the focal length and power of the lens change?

		Focal length	Power of lens
☒	**A**	decreases	decreases
☒	**B**	decreases	increases
☒	**C**	increases	decreases
☒	**D**	increases	increases

(Total for Question 9 = 1 mark)

4 A ray diagram, drawn to scale, is used to locate the size and position of an image formed by a lens as shown.

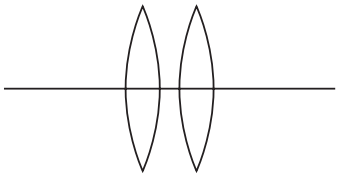


Which row in the table gives the focal length and the type of lens?

		Focal length / cm	Type of lens
☒	**A**	2.5	converging
☒	**B**	2.5	diverging
☒	**C**	10	converging
☒	**D**	10	diverging

(Total for Question 4 = 1 mark)

7 Two thin converging lenses are placed next to each other as shown.



Each lens has a power of 4 D.

Which of the following is the total power of the combined lenses?

☒ **A** 1 D

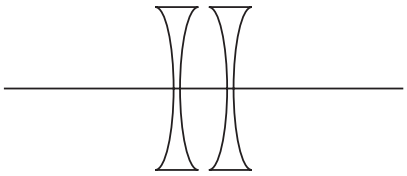
☒ **B** 2 D

☒ **C** 4 D

☒ **D** 8 D

(Total for Question 7 = 1 mark)

2 Two diverging lenses are combined, as shown.



The focal length of each lens is 0.2 m.

Which of the following is the total power of the combination?

- ☒ **A** 5 D
- ☒ **B** –5 D
- ☒ **C** 10 D
- ☒ **D** –10 D

(Total for Question 2 = 1 mark)

4 The image formed by a lens can be described as real or virtual.

Which row of the table describes a real image and a virtual image?

		Real image	Virtual image
☒	**A**	Formed on the same side of the lens as the object	Formed on the same side of the lens as the object
☒	**B**	Can be produced on a screen	Formed on the same side of the lens as the object
☒	**C**	Formed on the same side of the lens as the object	Can be produced on a screen
☒	**D**	Can be produced on a screen	Can be produced on a screen

(Total for Question 4 = 1 mark)

8 A converging lens can be used to produce a real image on a screen.

(a) A converging lens of focal length 15.0 cm is used to project an image of an illuminated object onto a screen. The object is a circle of diameter 4.0 mm and the image must be as large as possible on a screen of size 0.75 m by 1.25 m.

Calculate the distance between the lens and the screen for this image to be displayed.

(3)

Distance between lens and screen = ...

(b) A magazine article includes the statement:

> If the distance from the lens to the screen is doubled, the brightness of the image is halved.

Assess the validity of this statement.

(2)

(Total for Question 8 = 5 marks)

4 A student carried out an experiment to determine the focal length of a converging lens.

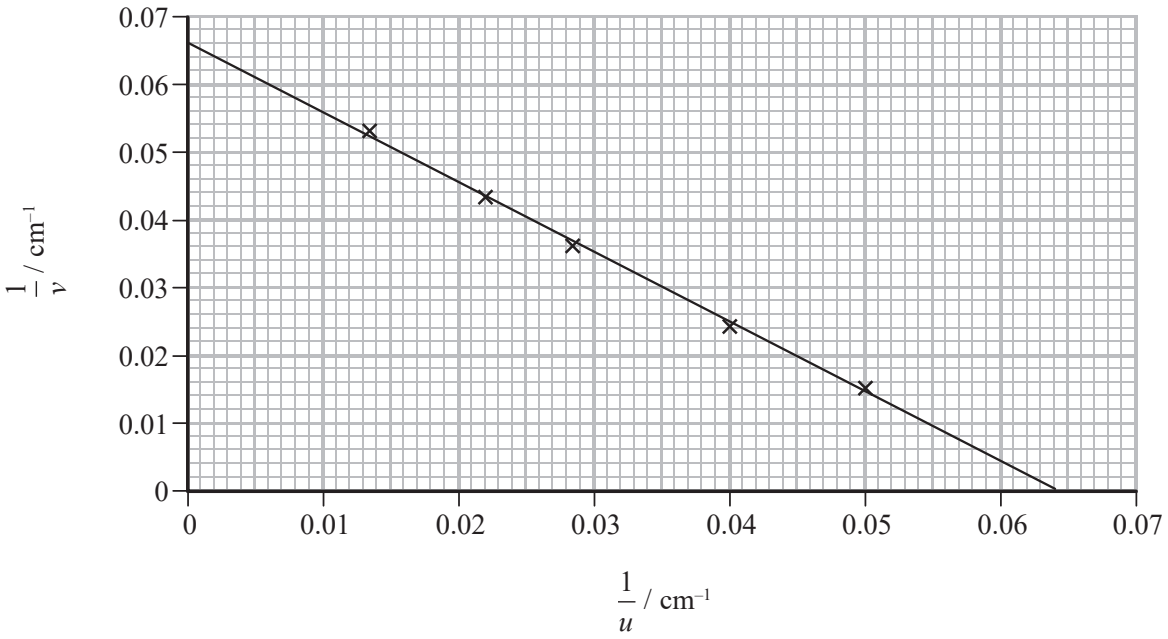
He placed the lens a distance u from an illuminated object. He placed a screen on the other side of the lens and moved the screen until a sharp image of the object was produced. He measured the corresponding image distance v.

The student repeated the procedure for four more values of u.

In his lab report he wrote:

"I made an initial determination of the focal length of the lens and concluded that it was about 15 cm. When I plotted a graph it confirmed my initial determination of the lens focal length."

The student's graph is shown.

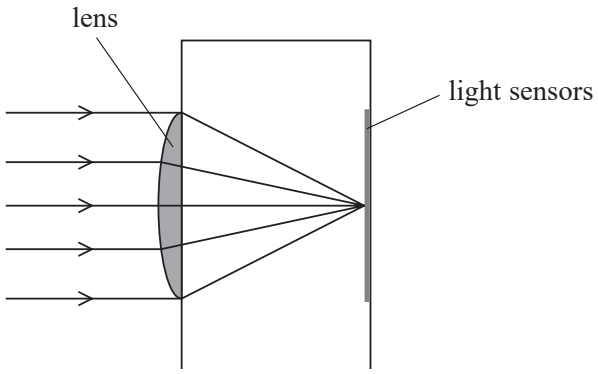


Comment on whether the student's data is consistent with his initial determination of the focal length of the lens.

(5)

(Total for Question 4 = 5 marks)

11 The lens of a mobile phone camera has a focal length of 4.25 mm. Light is focused onto light sensors at the back of the camera, as shown.



(a) The camera is initially focused on an object in the far distance.

Calculate the displacement of the lens that would be required to focus on an object 25.0 cm from the camera.

(4)

Displacement of lens = ...

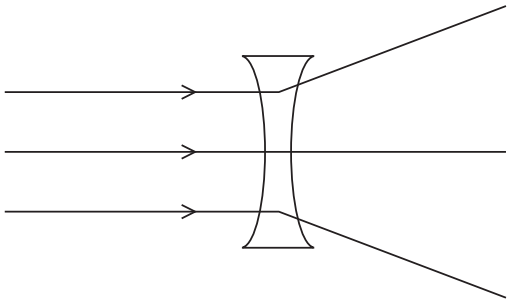
(b) State why the lens and the light sensors in a mobile phone camera can be positioned a fixed distance apart.

(1)

(Total for Question 11 = 5 marks)

11 Converging and diverging lenses may be used in glasses to correct problems with eyesight.

(a) The diagram shows three parallel rays of light incident on a diverging lens and the path of the rays after passing through the lens. The diagram is drawn to actual size.



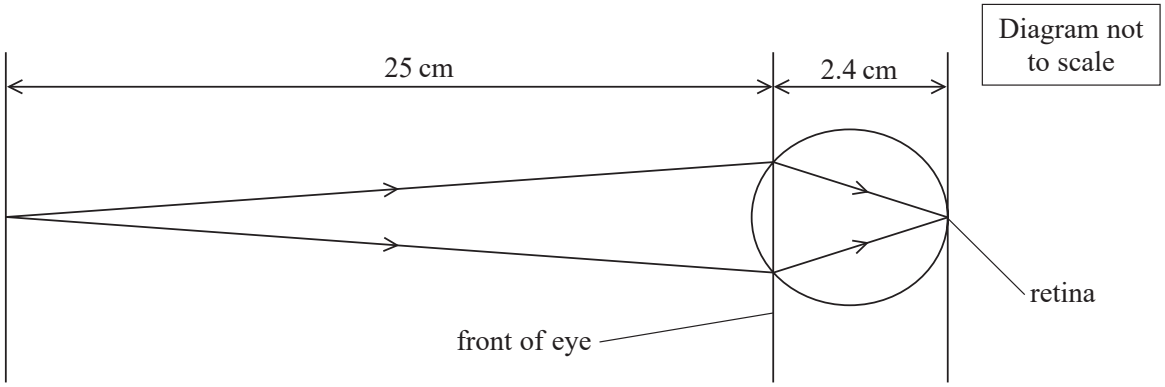
Add to the diagram to determine the focal length of the lens.

(2)

Focal length = ...

(b) The eye acts as a converging lens system.

The diagram shows light rays from an object 25 cm in front of an eye converging to a point on the retina at the back of the eye. The eye has a depth of 2.4 cm.



Calculate the optical power of the eye.

(3)

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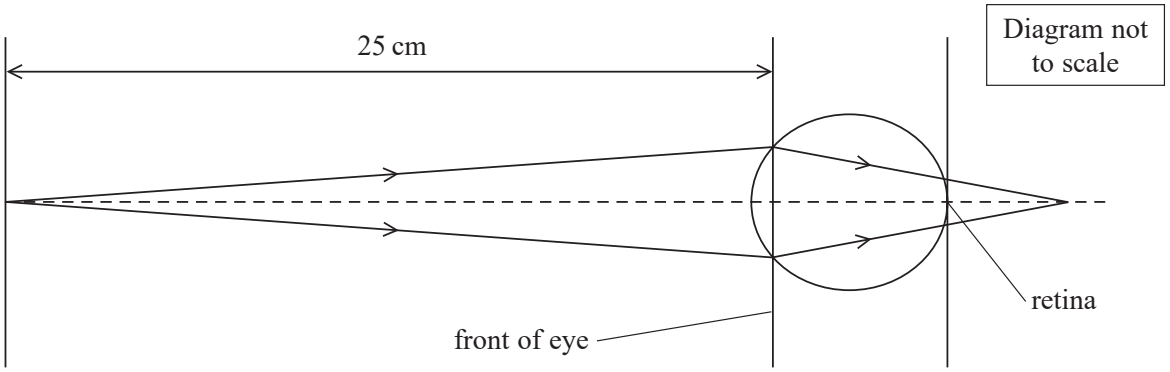
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Power = ...

(c) A person who is long-sighted cannot clearly see objects that are close to the eye.

Rays of light from an object 25 cm in front of the eye would converge to a point behind the retina as shown in the diagram.



This may be corrected by using an additional converging lens.

State how an additional converging lens would enable the light rays from an object 25 cm in front of the eye to converge at a point on the retina.

(1)

.....

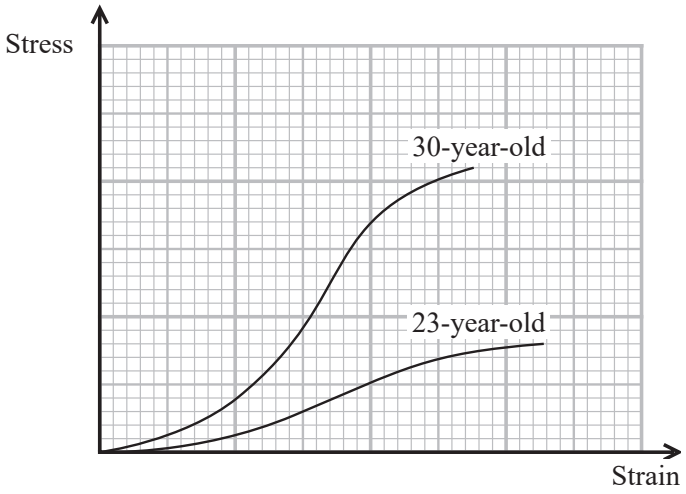
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.....

(Total for Question 11 = 6 marks)

12 The power of the lens in the human eye changes as the lens changes shape. This enables a person to see objects at different distances clearly. To change the shape, muscles in the eye put the lens under stress.

(a) A stress-strain graph for the eye lens for people of different ages is shown.



(i) State one difference between the lens of a 23-year-old and the lens of a 30-year-old.

(1)

.....

.....

(ii) Give a reason for your answer, making reference to the graph.

(1)

.....

.....

(b) A teacher was modelling the human eye. He placed an object 60 cm from a converging lens system. A real image of the object was observed with a magnification of 0.5

The converging lenses that were available to the teacher had powers of 2D, 3D and 4D.

Deduce which lens, or combination of lenses, the teacher used.

(4)

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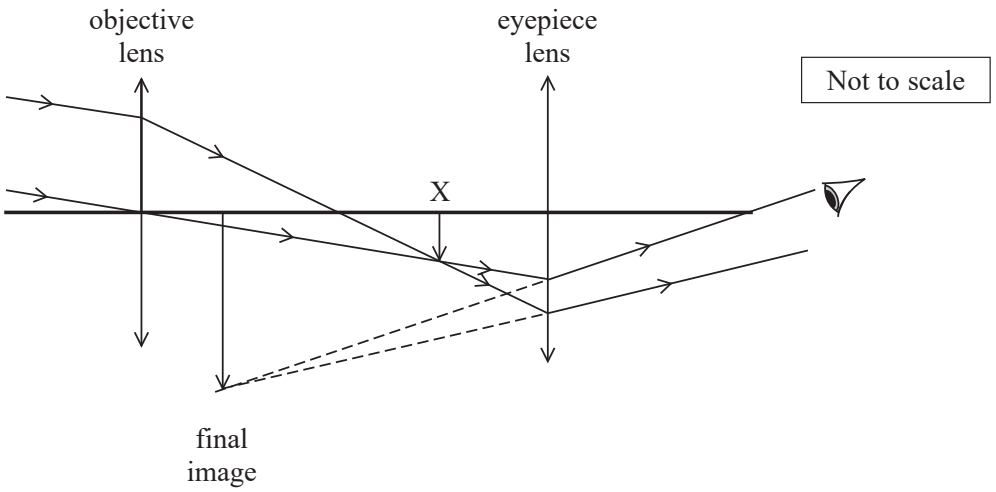
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(Total for Question 12 = 6 marks)

9 A telescope is used to produce a magnified image of a full Moon. The telescope consists of two converging lenses, the objective lens and the eyepiece lens, as shown.



The objective lens produces an inverted image at point X. The image at point X is the object for the eyepiece lens. The eyepiece lens produces a magnified image.

(a) The power of the objective lens is 0.8 D.

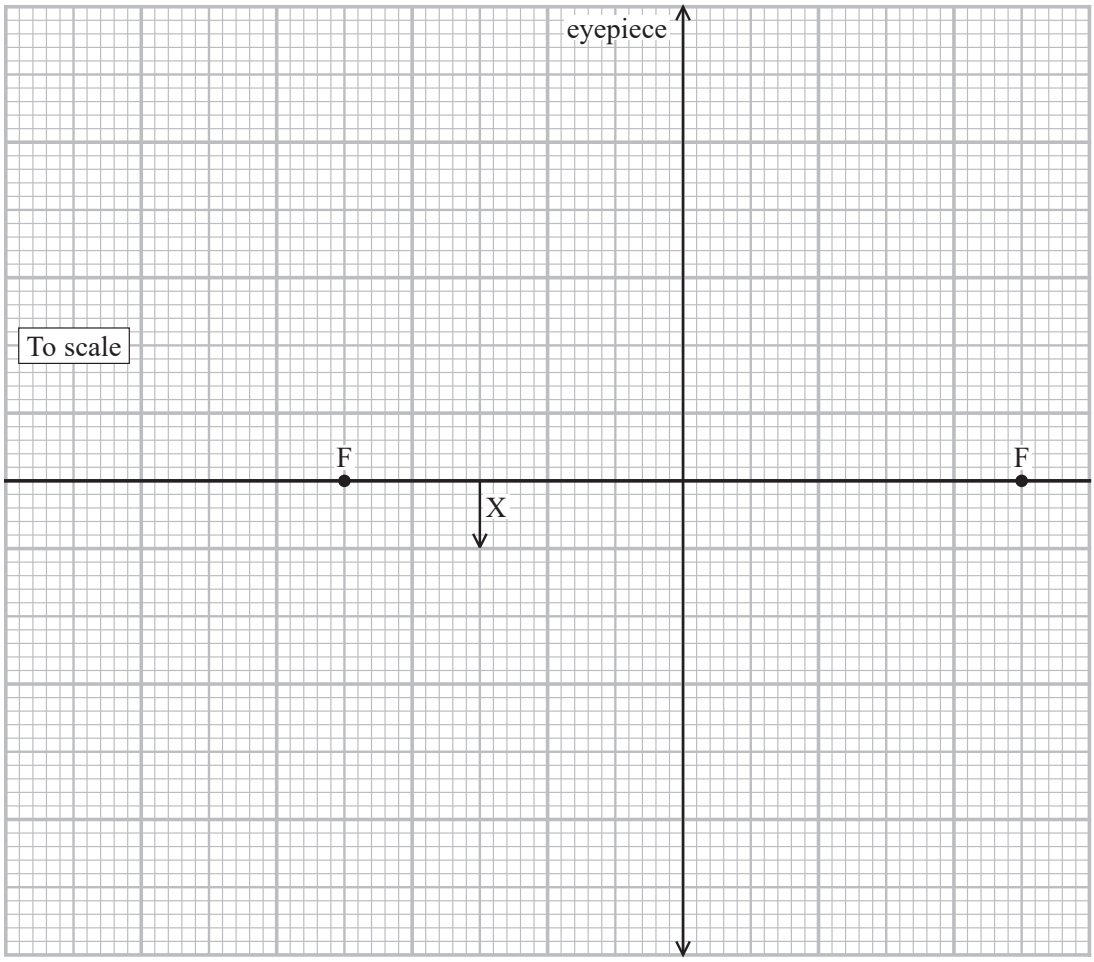
Calculate the distance of the image at X from the objective lens.

(3)

Distance = ...

(b) Complete the ray diagram, to scale, to determine the magnification of the image formed by the eyepiece lens.

(4)



Magnification = ...

(Total for Question 9 = 7 marks)

16 The closest distance from the eye where light from an object can be brought to a focus is known as the near point distance. The near point distance for a human eye is taken to be 25 cm.

A long-sighted eye has a near point distance greater than 25 cm. This may cause problems with focusing on near objects.

A converging lens can be used to correct this problem. The converging lens forms an image of a near object at the actual near point distance of the long-sighted eye.

(a) State the type of image formed by the converging lens when used to correct a long-sighted eye.

(1)

.....

(b) The near point distance for a long-sighted eye is 65 cm.

Calculate the power, in dioptres, of the converging lens required.

(3)

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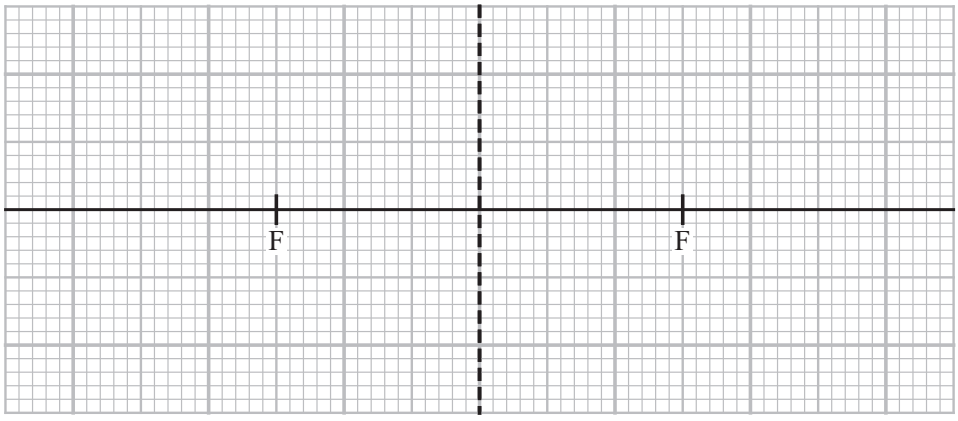
.....

Power of converging lens = ... D

(c) A diverging lens can also be used to correct problems with eyesight.

Draw a ray diagram on the axes below to show the formation of the image of a distant object by a diverging lens. F marks the position of each principal focus of the lens.

(3)

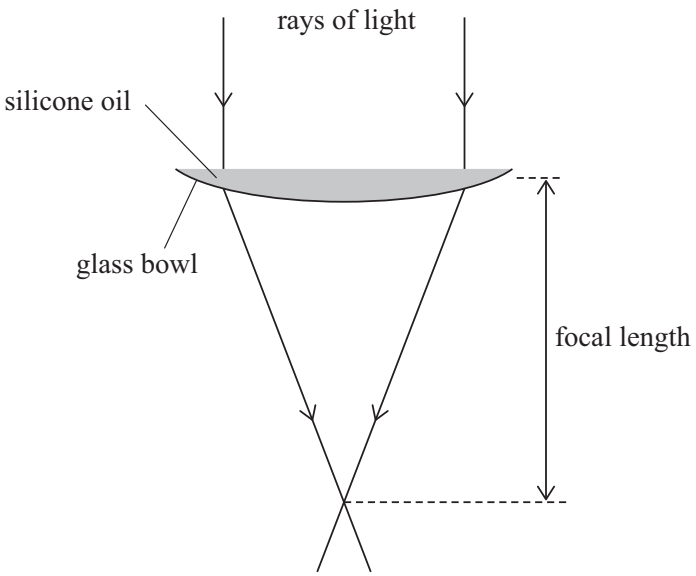


diverging lens

(Total for Question 16 = 7 marks)

15 A student makes a lens by filling a glass bowl with silicone oil. She investigated the refraction of light through this lens.

The student shone light vertically downwards through the lens, as shown.



(a) The student measured the focal length of the lens to be 16.7 cm.

Calculate the power of the lens.

(2)

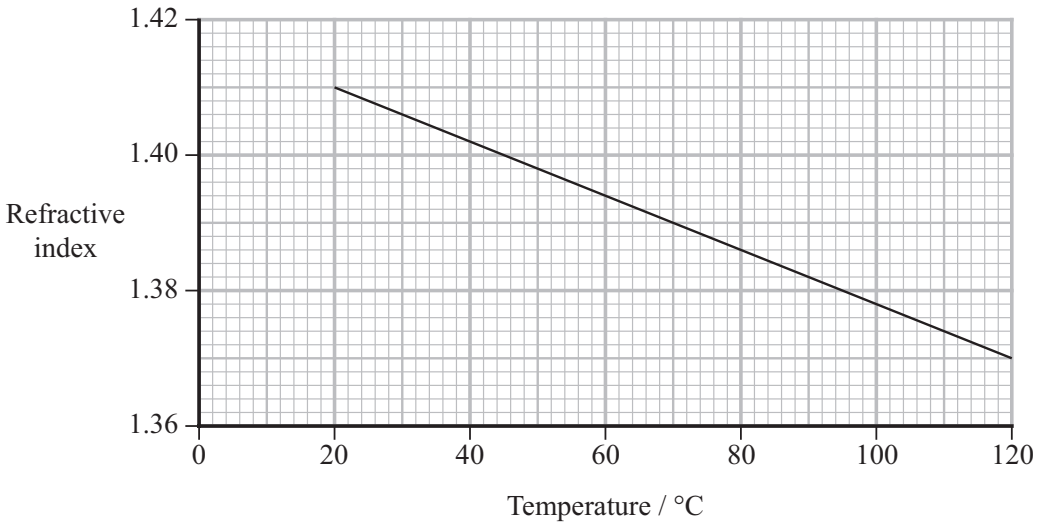
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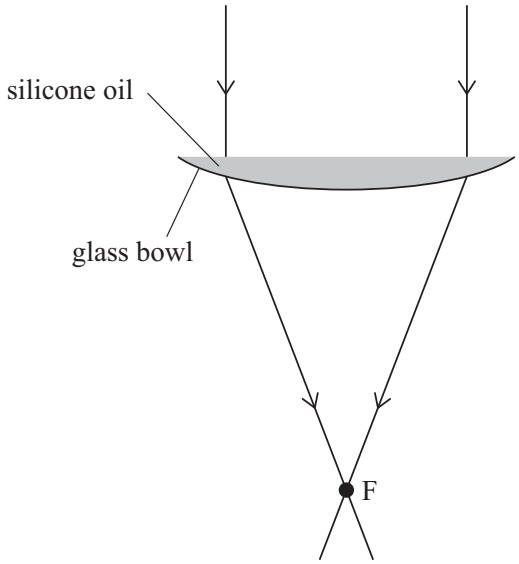
Power = ...

(b) The refractive index of the silicone oil changes with temperature, as shown.



The student connected a light dependent resistor (LDR) to an ohmmeter.

The light was brought to a focus at the focal point F, as shown. The LDR was placed at F.



The student recorded the resistance of the LDR. She then filled the glass bowl with silicone oil at a higher temperature and recorded the resistance of the LDR again.

Deduce the effect on the resistance of the LDR of increasing the temperature of the oil.

(5)

(Total for Question 15 = 7 marks)

10 A student investigated how a converging lens can be used to project a magnified image onto a whiteboard.

In a darkened room, the student placed a smartphone 9.0 cm from the converging lens. The phone's display was projected onto the whiteboard. The converging lens was 75.0 cm from the whiteboard when a clear image was produced.

(a) Calculate the focal length of the lens.

(2)

.....

.....

.....

.....

Focal length = ...

(b) The image projected onto the whiteboard was real.

State what is meant by a real image.

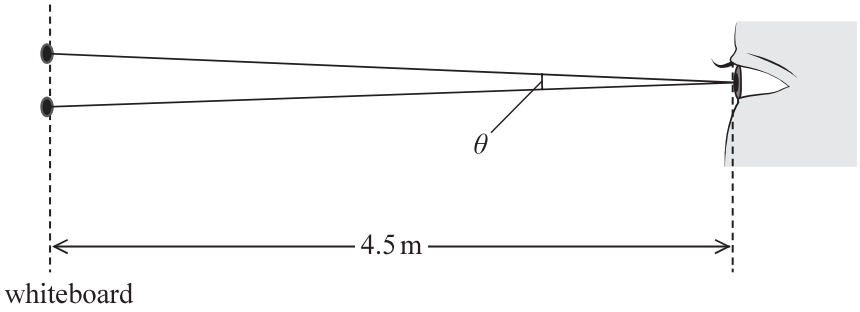
(1)

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(c) The display on the phone contained two dots that were 5.0 mm apart. The student stood 4.5 m from the whiteboard and viewed the image of the dots.

Rays of light from the images of the two dots on the whiteboard were incident at the student's eye with an angle θ between them as shown.



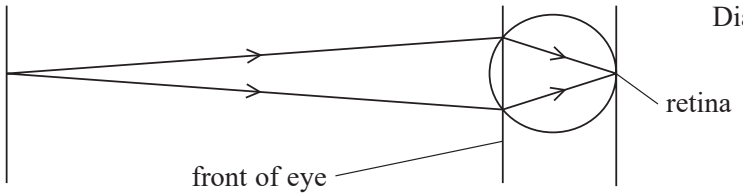
The student could distinguish the two dots if the angle θ was greater than 0.0003 radians.

Deduce whether the student could distinguish the two dots clearly.

(5)

(Total for Question 10 = 8 marks)

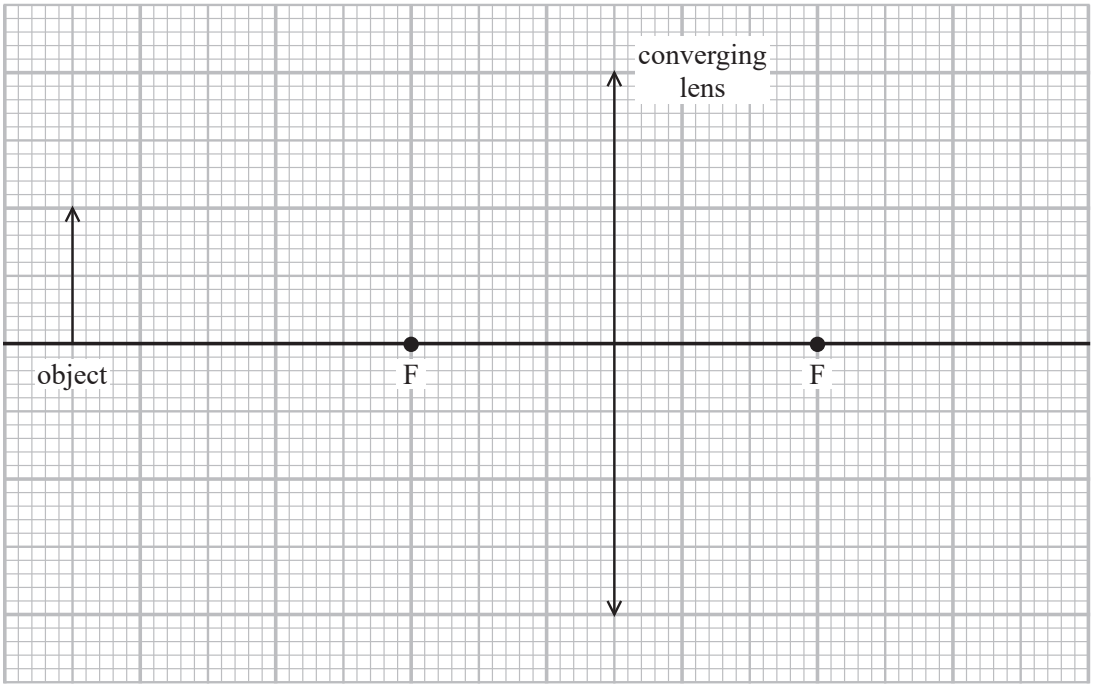
15 The human eye acts as a converging lens system that produces an image on the retina at the back of the eye as shown.



A person with eyesight problems may wear either diverging or converging contact lenses.

(a) The diagram below shows an object in front of a converging lens.

F is the principal focus.



Determine the position and magnification of the image produced by the lens, by completing a ray diagram.

(4)

.....

.....

.....

Magnification = ...

(b) A short-sighted eye cannot focus on distant objects, because the power of the eye is too great.

One student with short sight cannot focus on objects further than 1.5 m without wearing her contact lenses.

To view distant objects, it is determined that the combined power of her eye and her contact lens should be 41.7 D.

Determine the power and type of lens needed to correct her vision. Assume the equations for thin lens apply to both lenses.

distance from eye lens to retina = 2.4 cm

(4)

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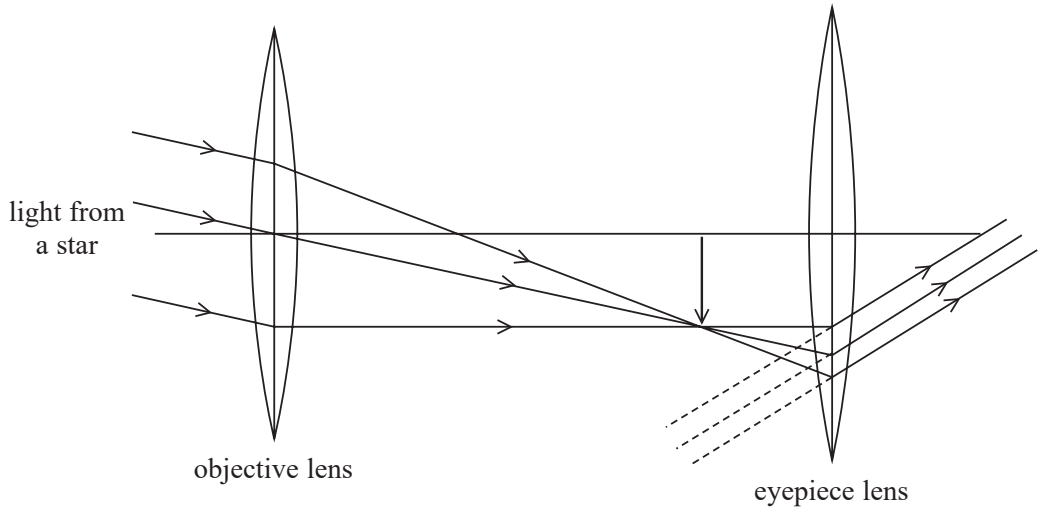
.....

Power = ...

Type of lens .....

(Total for Question 15 = 8 marks)

17 A simple astronomical refracting telescope consists of two converging lenses. Light from a star is brought to a focus by the objective lens and then viewed through an eyepiece lens as shown.



(a) (i) In the arrangement shown, the final image is formed at infinity.

Explain why the separation of the objective and eyepiece lenses is equal to the sum of their focal lengths.

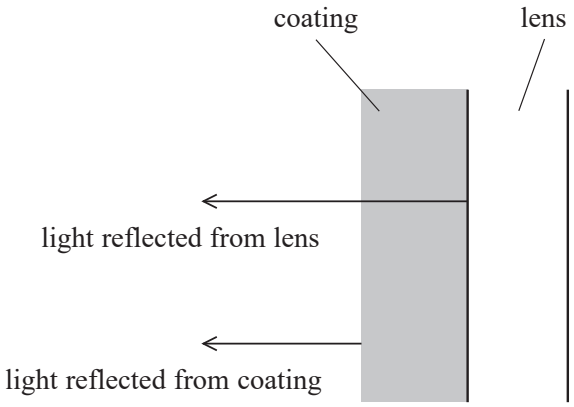
(2)

(ii) State why the final image is inverted.

(1)

(b) Glass lenses used for optical instruments often have an anti-reflective coating. The coating is a thin layer of a transparent substance with refractive index n_c.

Light is reflected from the coating surface and from the lens surface as shown. The reflected light interferes destructively.



When a single-layer coating is used, the coating thickness is chosen to eliminate reflections for green light, which is in the middle of the visible spectrum.

(i) Calculate the minimum thickness d of the coating required for the reflection of green light to be eliminated.

frequency of green light = 6.00×10^{14} Hz
$n_c = 1.38$

(4)

$d =$ .....

(ii) State why white light reflected from coated lenses is seen as purple.

(1)

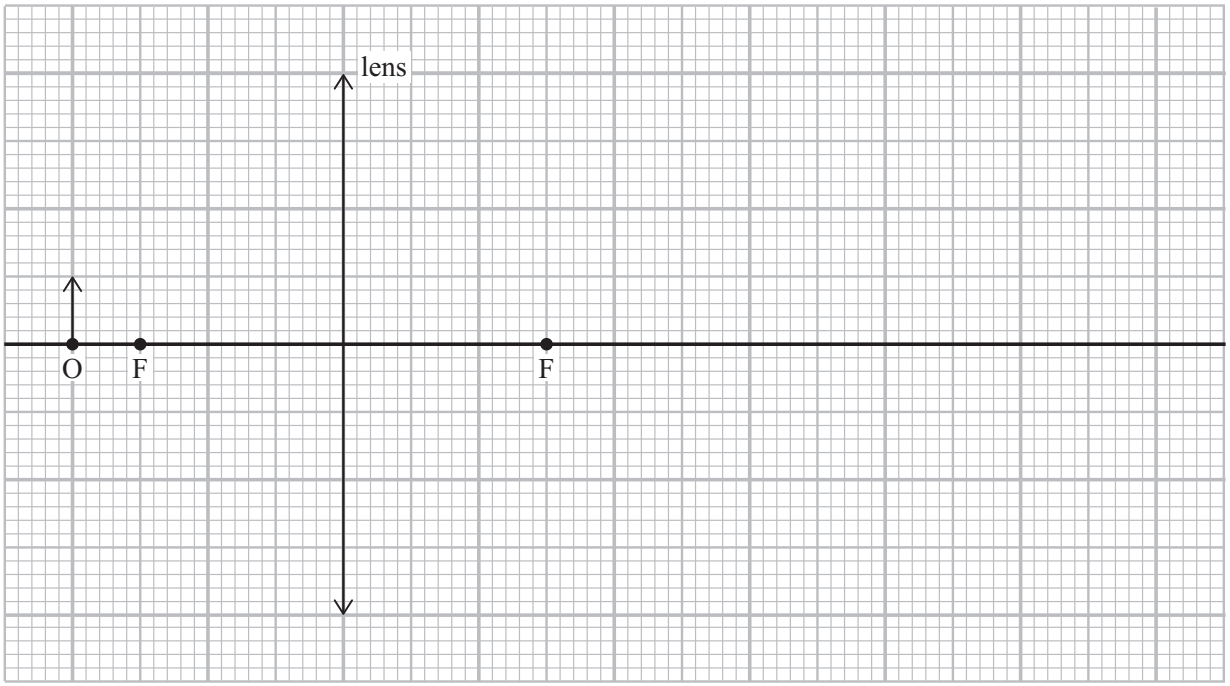
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(Total for Question 17 = 8 marks)

14 A converging lens can be used to produce an image of an object.

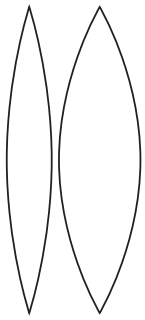
(a) The ray diagram shows an object placed in front of a converging lens.



Complete the ray diagram to locate the image formed by the lens.

(3)

(b) A student used a thin converging lens of power 6.7 D to produce an image on a screen. He adjusted the size of the image by adding a second thin converging lens close to the first lens, as shown.



The following lenses were available.

Lens	X	Y	Z
Power / D	5.3	5.7	6.1

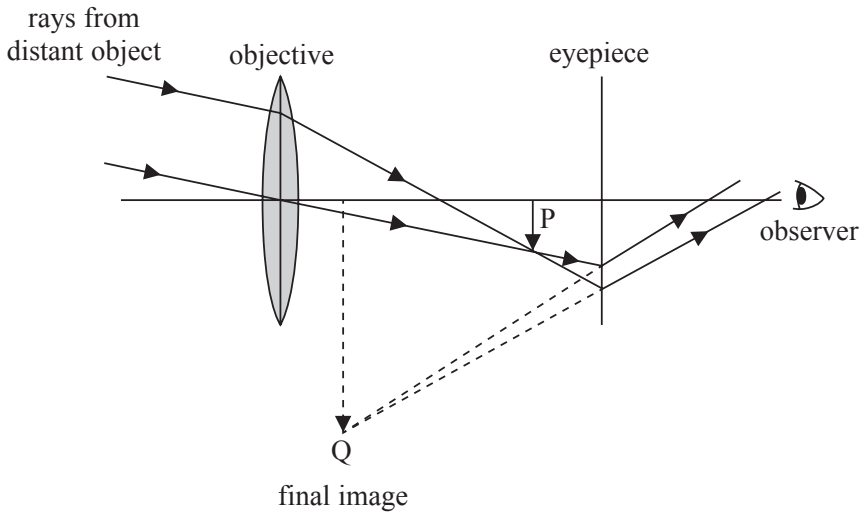
The object was placed 20 cm from the lens combination, and the magnification produced was 0.71

Deduce which lens the student added.

(5)

(Total for Question 14 = 8 marks)

14 A telescope consists of a convex lens (objective) of power 0.820 D and a second lens (eyepiece) as shown.



The objective produces an image at P. This image becomes the object of the eyepiece, which produces a final image at Q.

(a) Show that the focal length of the objective lens is about 1200 mm.

(2)

(b) Telescopes can be used to observe distant objects such as the Moon.

(i) Explain why the image of the Moon produced at P by the objective lens will be at a distance of about 1200 mm from this lens.

(2)

(ii) State the properties of the image at P.

(2)

(c) The eyepiece is at a distance of 100 mm from the image at P. To give a reasonable magnification, the final image at Q should be a virtual image at a distance of 300 mm from the eyepiece.

The following lenses are available:

diverging lens focal length 150 mm,
converging lens focal length 150 mm,
diverging lens focal length 100 mm,
converging lens focal length 100 mm.

Deduce which lens should be used for the eyepiece.

(3)

(Total for Question 14 = 9 marks)

14 A student used two converging thin lenses in combination to form an image of an object.

(a) Show that the power of the combination of lenses was about 20 D.

focal length of lens 1 = 10 cm
focal length of lens 2 = 15 cm

(3)

(b) The object was 4 cm in front of the combination of lenses.

Calculate the image distance.

(2)

Image distance = ...

(c) The object height was 1.4 cm.

Calculate the image height.

(3)

.....

.....

.....

.....

.....

Image height = ...

(d) The object is magnified.

State **two** other properties of the image.

(1)

.....

.....

(Total for Question 14 = 9 marks)

17 The photograph shows a man wearing a virtual reality (VR) headset.

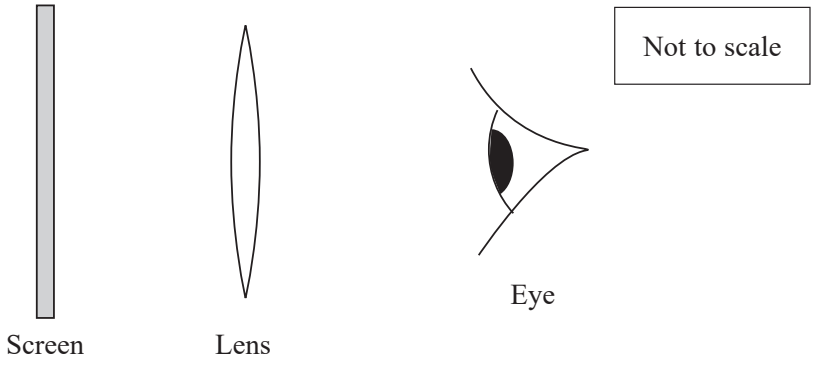


The VR headset gives the illusion of three-dimensional vision.

Inside the VR headset a pair of lenses is used to enable the user to focus on a magnified virtual image of a screen. The lenses can be changed to suit the vision of the user.



(a) In the VR headset the lens is between the eye and the screen, as shown below.

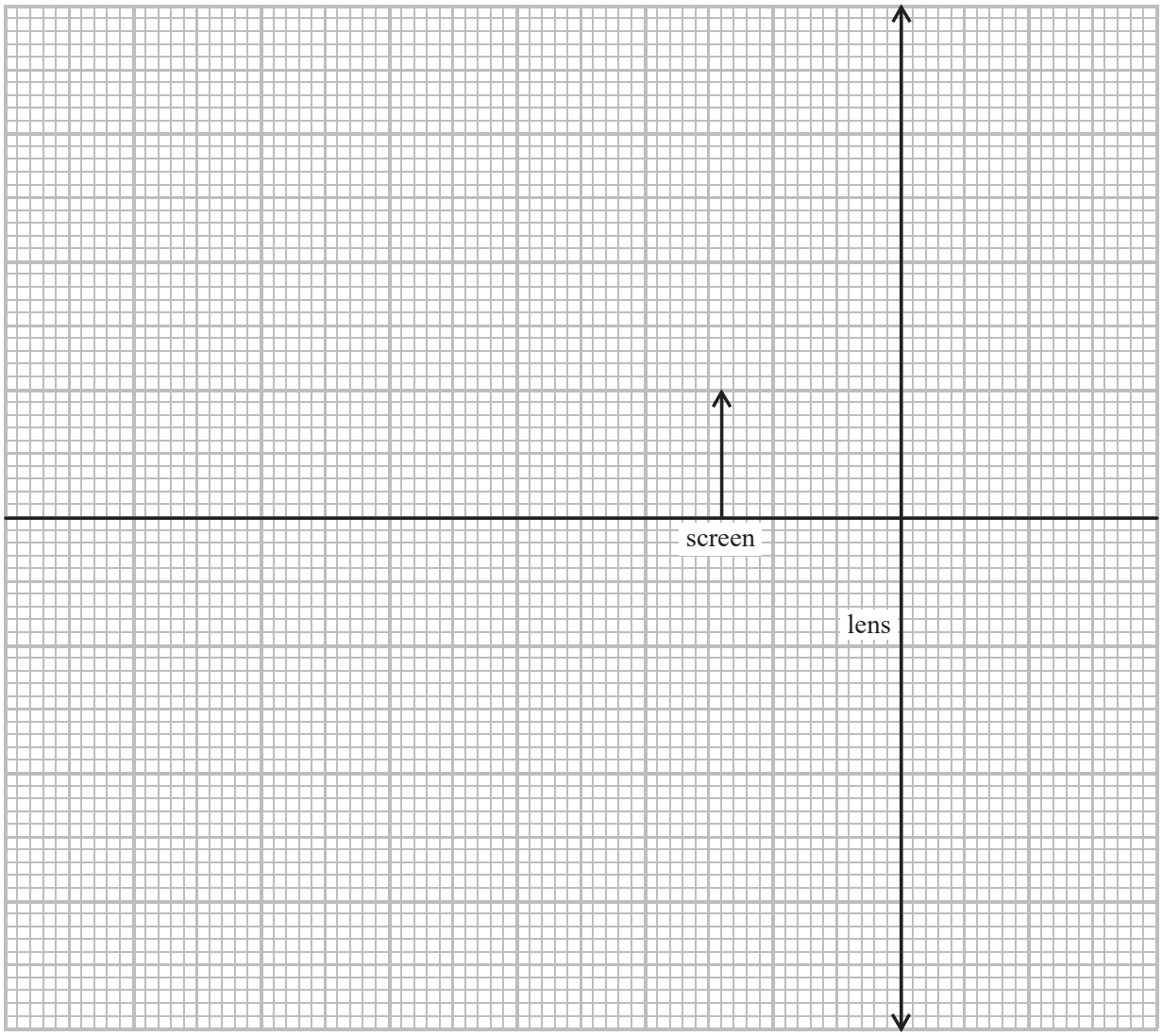


For a particular user of the headset, the image of the screen must be at least 16 cm from the eye and have a magnification of at least 3.0.

Determine whether this would be possible with a lens of focal length 3.8 cm.
Your answer should include a full-scale ray diagram drawn on the grid provided.

(4)

distance from screen to lens = 2.8 cm
distance from lens to eye = 2.2 cm



(b) Plastic Fresnel lenses are used in the VR headset because they are thinner and lighter than traditional glass lenses.

Instead of the continuous curved surface of a converging lens the Fresnel lens has circular ridges, each with an edge at a different angle to the adjacent ridge, as shown in the simplified cross-section in Figure 1. Figure 2 shows a ray of light entering a section of the lens.

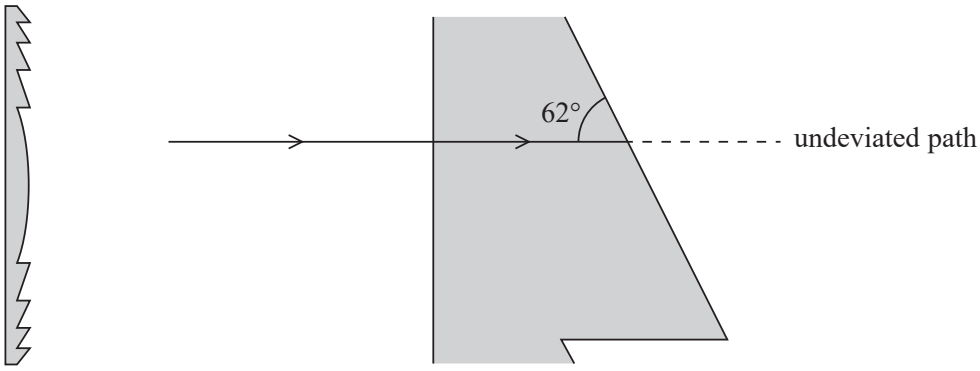


Figure 1 Figure 2

(i) Calculate the angle through which the ray has been deviated as it emerges from the plastic.

(4)

refractive index of plastic = 1.47

Angle = ...

(ii) Explain how the lens focuses a beam of light travelling parallel to the principal axis.

(3)

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(Total for Question 17 = 11 marks)

15 A magnifying glass consists of a converging lens and is used to magnify the details of an object.

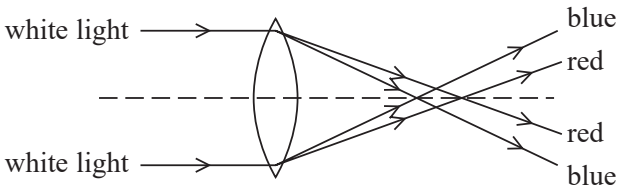
A biologist is studying a flower using a magnifying glass. The anther of the flower has a width of 0.2 mm. The magnifying glass is placed 5.0 cm from the flower and an image of the anther is produced that is 3.5 mm wide.

(a) Calculate the power of the lens in the magnifying glass.

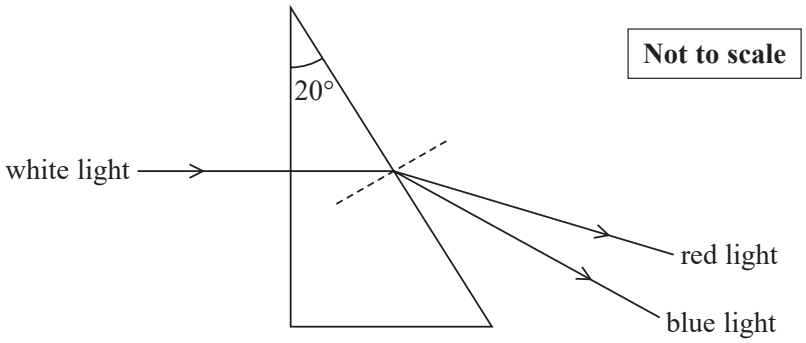
(5)

Power of lens = ...

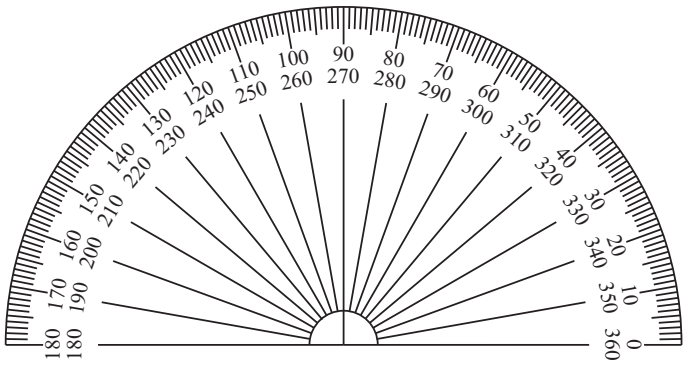
(b) The biologist notices coloured fringes around the edges of the image. This is caused by different coloured light being refracted by different angles as it passes through the lens.



The refractive index of red and blue light as the light passes from glass into air can be investigated using a 20° glass prism.



A ray of white light is incident along the normal and passes straight into the prism. Blue and red light rays are refracted by different angles as they leave the prism. The angles of refraction are measured using a protractor, like the one shown.



(i) Deduce whether the measurements made using the protractor are sufficient to measure the difference in the angles of refraction between blue and red light.

refractive index of red light in glass = 1.509
refractive index of blue light in glass = 1.517

(3)

(ii) The angle of incidence at the glass-air interface can be changed by altering the path of the light as it enters the prism. The angle of incidence of the red light at the glass-air interface is changed to 35°.

Deduce whether the red light will still be refracted at the glass-air boundary.

(3)

(Total for Question 15 = 11 marks)

19 The lens in the eye of an octopus focuses light onto the retina at the back of the eye.

The octopus focuses on objects at different distances from the eye by changing the shape of the eye to move the lens closer or further from the retina.

(a) (i) The power of an octopus lens is 118 D.

Show that the focal length of the lens is about 8.5 mm.

(2)

(ii) Calculate the shortest distance from the eye at which an object may be focused clearly on the retina.

maximum distance from lens to retina = 2.0 cm

(2)

Shortest distance from the eye = ...

(iii) The lens in the eye of an octopus is in contact with seawater. The refractive index of freshwater is less than the refractive index of seawater.

Deduce what would happen to the shortest distance from the eye at which an object may be focused clearly if the octopus was in freshwater.

(3)

(iv) Calculate the speed of light in seawater.

refractive index of seawater = 1.37

(2)

Speed of light in seawater = ...

(b) An octopus can detect the orientation of polarised light.

State what is meant by polarised light.

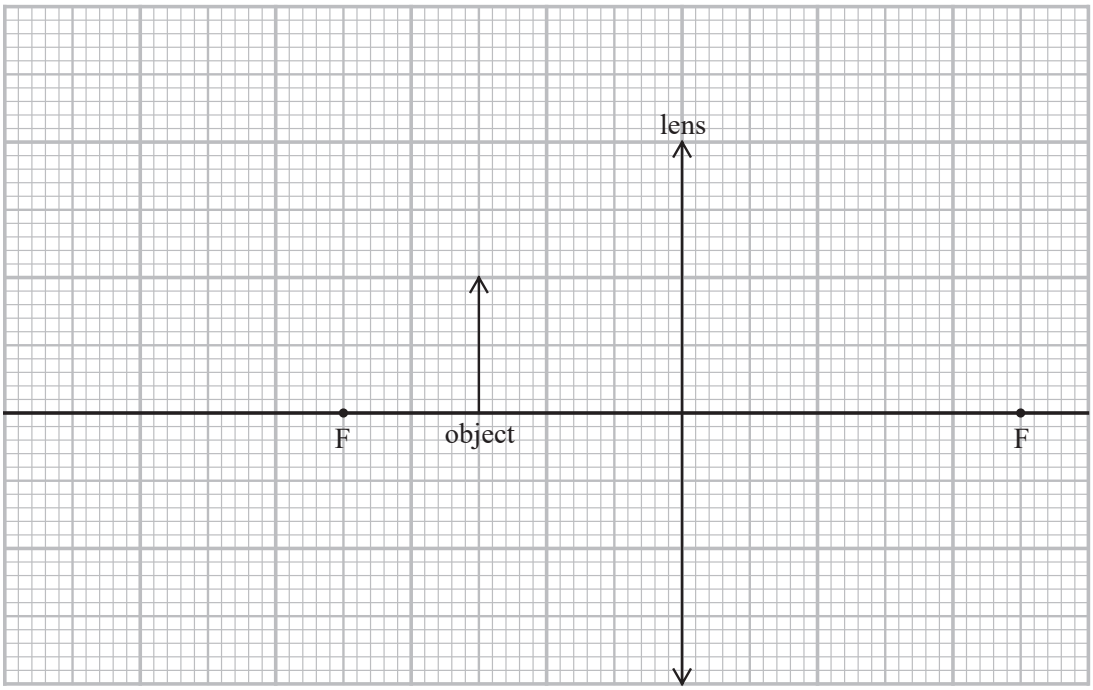
(2)

(Total for Question 19 = 11 marks)

13 A jeweller inspects the quality of a diamond. She uses a converging lens to produce a magnified image of the diamond.

(a) Complete the ray diagram to show how a converging lens produces a magnified image of the object shown.

(2)



(b) With the naked eye, the jeweller can detect a scratch that has a width of 0.1 mm or greater.

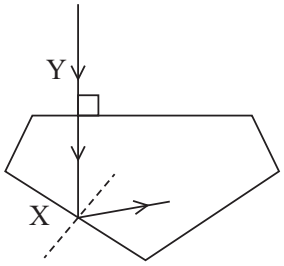
The diamond has a scratch that is 10 µm wide. The jeweller holds the diamond 0.012 m from the converging lens and views the image of the diamond.

Deduce, by calculation, whether the scratch is detectable by the jeweller using the lens.

power of lens = 45 D

(5)

(c) A ray of light enters the diamond along the normal at point Y as shown.



Not to scale

The ray is incident at the diamond-air interface at X with an angle of incidence equal to 40°.

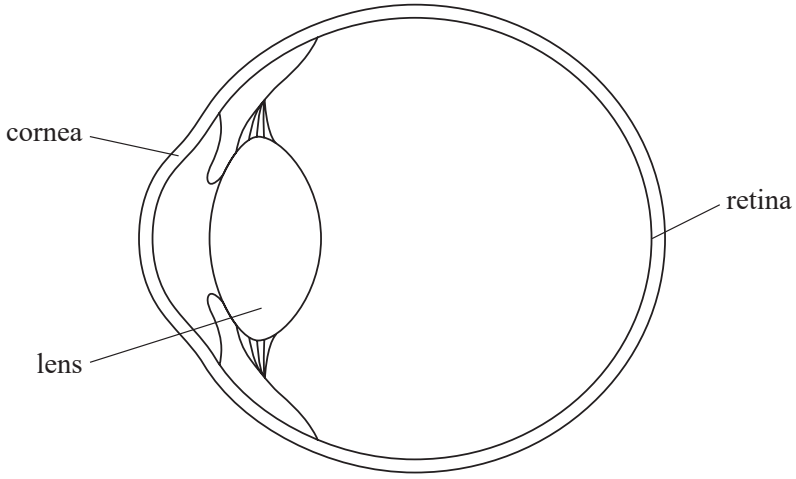
Deduce whether the ray follows the path at X, as shown.

speed of light in diamond = $1.25 \times 10^8\,\text{m}\,\text{s}^{-1}$

(4)

(Total for Question 13 = 11 marks)

18 Light entering a normal eye is refracted by both the cornea and the lens before a focused image is formed on the retina.



(a) It is suggested that the cornea provides 80% of the focusing power of the eye.

Determine whether this is correct.

focal length of cornea = 2.23 cm

focal length of lens for near object = 5.27 cm

(4)

(b) Light from a point object forms a focused image on the retina.

The cornea and lens may be treated as a single lens of focal length 1.6 cm that is 2.4 cm from the retina.

(i) Calculate the distance from the point object to this single lens when a focused image is formed on the retina.

(2)

Distance = ...

(ii) A ray of light strikes the front of the cornea at an angle to the normal in air of 15°.

Calculate the angle of the ray to the normal in the cornea.

speed of light in air = $3.00 \times 10^8\ \text{m s}^{-1}$

speed of light in cornea = $2.18 \times 10^8\ \text{m s}^{-1}$

(3)

Angle to normal in cornea = ...

(c) People swimming under water often wear goggles. The goggles enable them to see objects under water clearly whereas without goggles objects appear blurred.

Explain why wearing goggles has this effect.

speed of light in water = 2.25×10^8 m s^{-1}

(3)

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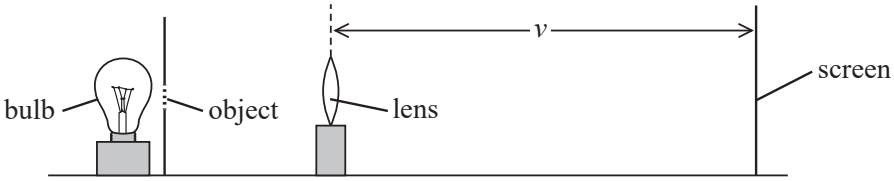
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(Total for Question 18 = 12 marks)

16 A student carried out an experiment to determine the focal length of a converging lens. The student used a bulb to illuminate an object as shown. The converging lens produced an image of the object on a screen. The student adjusted the position of the screen until the image was in focus.

He repeated the procedure for different distances between the object and the lens. The distance v from the lens to the screen was measured for each lens position.



The student measured the height h_o of the object and the height h_i of the corresponding image on the screen for each lens position. The magnification m was calculated.

To determine the focal length f of the lens the student used the equation

$$m = \frac{v}{f} - 1$$

(a) Explain why a graph of m on the y-axis and v on the x-axis should be a straight line.

(2)

(b) The student obtained the following data.

object height, $h_o = 2.04\,\text{cm}$

v / cm	h_i / cm	m
61.5	5.92	2.90
47.0	4.24	2.08
39.6	3.30	1.62
31.2	2.15	
23.8	1.33	0.652

(i) Complete the table and plot a graph of m against v on the grid opposite.

(6)

(ii) Determine a value for f.

(3)

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$f =$ .....

(c) If the distance from object to the lens is less than a certain value, no image is produced on the screen.

Explain why.

(3)

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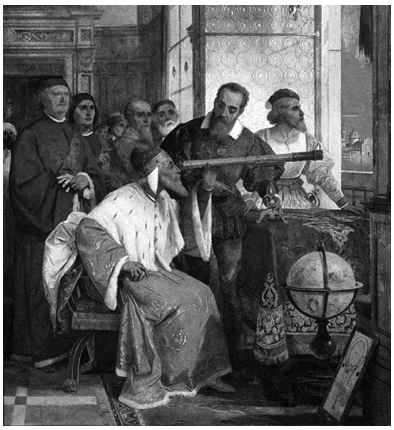
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(Total for Question 16 = 14 marks)

18 Galileo is credited with inventing the first telescope in 1610. The picture shows an early demonstration of the telescope.



(Source: © CPA Media Pte Ltd/Alamy Stock Photo)

A converging lens was positioned at one end of the telescope. A diverging lens was placed at the other end and a person looked through this lens.

(a) The converging lens produced an image at a distance equal to the focal length of the lens.

Explain what can be concluded about the object being viewed.

(2)

(b) The final image produced by the telescope is described as virtual and upright.

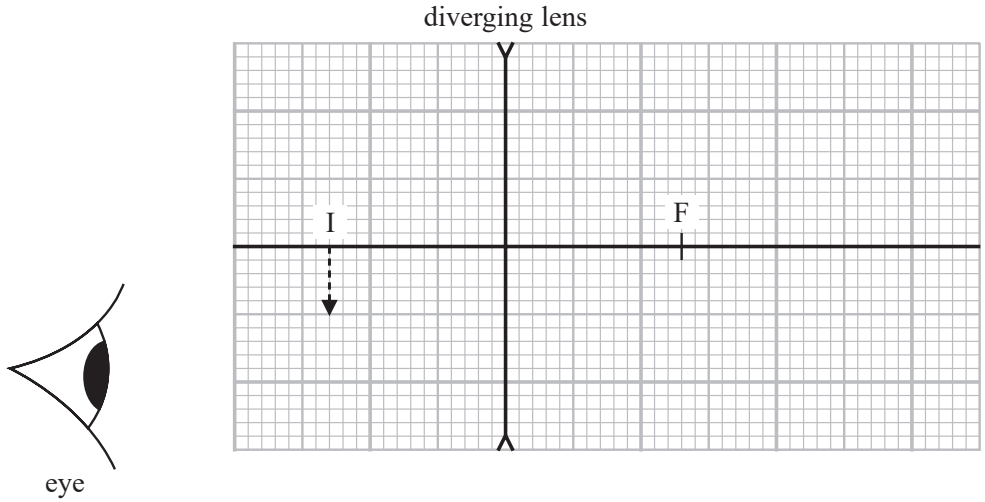
State what is meant by virtual and upright.

(2)

Virtual

Upright

(c) The image, I, produced by the converging lens is at a distance from the diverging lens equal to the focal length of the diverging lens, as shown. This image acts as an object for the diverging lens.



The distance equal to the focal length on the other side of the lens is marked with F.

Draw the ray diagram for the diverging lens.

(3)

(d) Galileo's first telescope had a magnification of 10, and a distance between the centres of the two lenses of 90 cm.

The magnification of the telescope = $\frac{\text{focal length of converging lens}}{\text{focal length of diverging lens}}$

Calculate the focal length of each lens.

(2)

Focal length of converging lens = ...

Focal length of diverging lens = ...

(e) Galileo was the first person to observe Jupiter's larger moons.

Ganymede is Jupiter's largest moon. The distance between the centre of Ganymede and the centre of Jupiter is 1.07×10^6 km. Ganymede takes 171 hours to complete an orbit around Jupiter.

Calculate the mass of Jupiter.

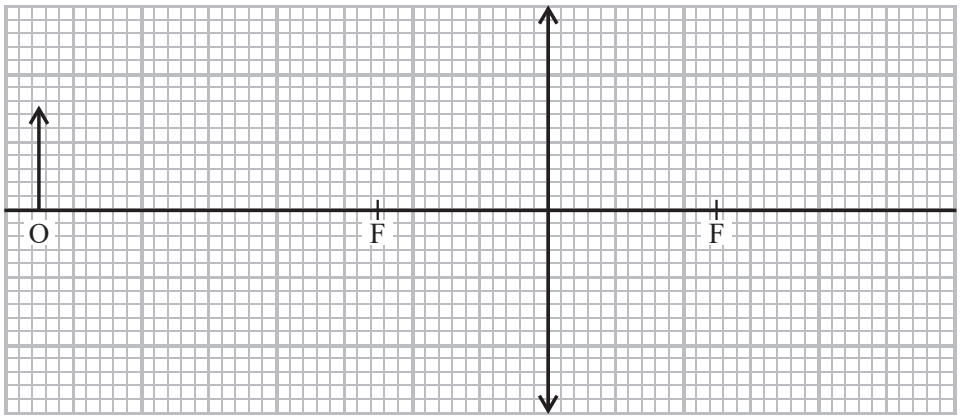
(5)

Mass of Jupiter = ...

(Total for Question 18 = 14 marks)

14 A camera uses a converging lens to produce an image.

(a) The diagram represents an object O and a converging lens.



(i) Complete the ray diagram to determine the position of the image.

(3)

(ii) Determine the magnification of this image.

(2)

.....

.....

.....

Magnification = ...

(iii) State, with justification, whether the image is real or virtual.

(1)

.....

.....

(b) In some cameras, lenses of different focal lengths can be used. A particular camera can use a lens of focal length 50 mm or a lens of focal length 200 mm. Both lenses are made from the same material.

(i) Describe a method to determine an approximate value for the focal length of a converging lens.

(2)

(ii) Explain why the lens with the shorter focal length is thicker at its centre.

(2)

(iii) Both photographs show the same scene photographed from the same position.



Photograph 1



Photograph 2

One photograph was taken using the lens of focal length 50 mm and the other was taken using the lens of focal length 200 mm.

Deduce which lens was used to take photograph 2.

(5)

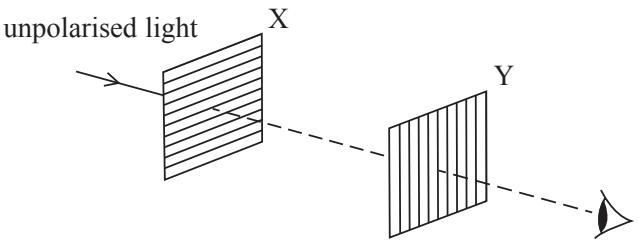
(Total for Question 14 = 15 marks)

SUB-TOPIC 5.5

POLARISATION

Sub-topic 5.5 · 15 questions · 50 marks · lowest tariff first

7 A source of unpolarised light is viewed through two crossed polarising filters X and Y.



Which row in the table correctly describes the light emerging from the two filters?

	Light emerging from filter X	Light emerging from filter Y
☒ **A**	oscillates in every direction	oscillates in one direction
☒ **B**	oscillates in every direction	no light
☒ **C**	oscillates in one direction	oscillates in one direction
☒ **D**	oscillates in one direction	no light

(Total for Question 7 = 1 mark)

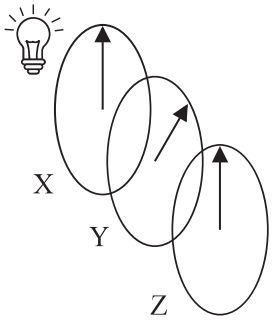
1 Which of the following wave properties is **not** exhibited by sound waves?

- ☒ **A** diffraction
- ☒ **B** interference
- ☒ **C** polarisation
- ☒ **D** refraction

(Total for Question 1 = 1 mark)

5 Three polarising filters X, Y and Z, are placed in front of a source of unpolarised light. The planes of polarisation of the filters are initially parallel.

Filter Y is rotated by 45° as shown.



Filter Z is then rotated clockwise and the intensity of light emerging from Z is measured.

Which angle of rotation of Z will result in the lowest intensity of light?

☒ **A** 90°

☒ **B** 135°

☒ **C** 180°

☒ **D** 225°

(Total for Question 5 = 1 mark)

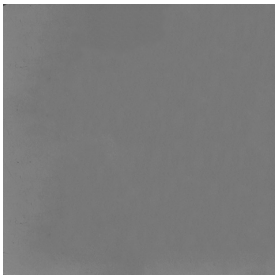
8 Which of the following statements about waves is **not** correct?

- ☒ **A** An unpolarised wave may be polarised on reflection from a surface.
- ☒ **B** Longitudinal waves cannot be plane polarised.
- ☒ **C** The vibrations in an unpolarised wave are in many directions.
- ☒ **D** Transverse waves are always plane polarised.

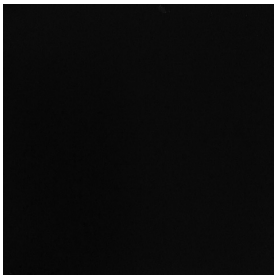
(Total for Question 8 = 1 mark)

2 A source of light is viewed through a polarising filter, as shown in photograph 1.

The filter is rotated through an angle and then viewed, as shown in photograph 2.



Photograph 1



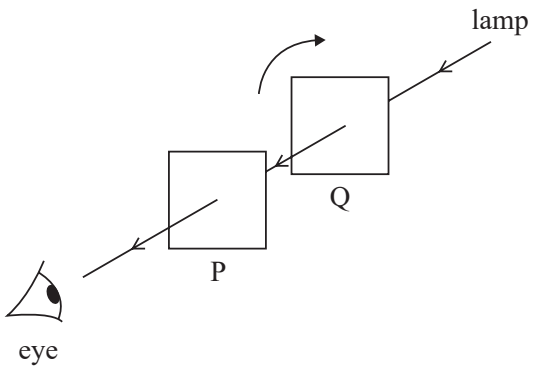
Photograph 2

Which row of the table shows whether the light emitted by the source is polarised or unpolarised, and the angle of rotation of the filter?

	Light emitted by source	Angle of rotation / radians
☒ **A**	polarised	$\frac{\pi}{2}$
☒ **B**	polarised	π
☒ **C**	unpolarised	$\frac{\pi}{2}$
☒ **D**	unpolarised	π

(Total for Question 2 = 1 mark)

5 A lamp is switched on and viewed through two polarising filters P and Q, as shown.



The lamp appears dark when viewed through P and Q.
Q is rotated through 180°.

Which row of the table gives the appearance of the lamp after Q has rotated by 90° from its original position and by 180° from its original position?

	Angle of rotation of 90°	Angle of rotation of 180°
☒ **A**	dark	dark
☒ **B**	dark	bright
☒ **C**	bright	dark
☒ **D**	bright	bright

(Total for Question 5 = 1 mark)

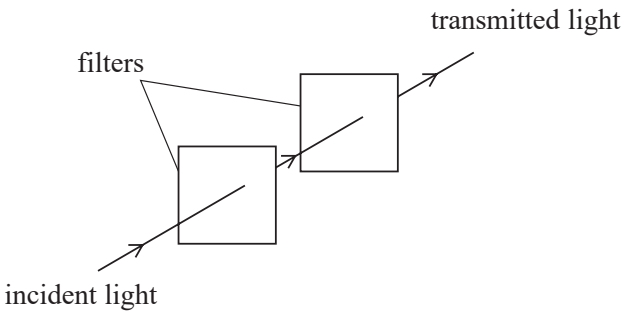
6 A textbook describes waves as having oscillations of different wavelengths in multiple planes. The oscillations are perpendicular to the direction of energy transfer.

Which of the following is being described?

- ☒ **A** stationary waves
- ☒ **B** longitudinal waves
- ☒ **C** polarised transverse waves
- ☒ **D** unpolarised transverse waves

(Total for Question 6 = 1 mark)

8 Unpolarised light passes through two polarising filters, as shown. The planes of polarisation of the two filters are parallel.



One filter is rotated so that the planes of polarisation of the two filters are perpendicular.

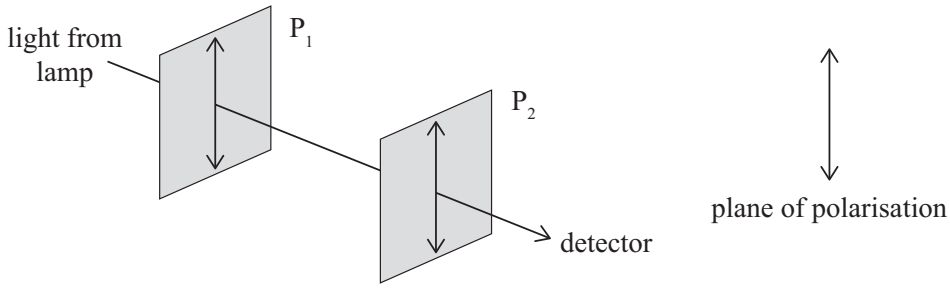
Which of the following describes the change to the intensity of the transmitted light?

- ☒ **A** decreases by half
- ☒ **B** falls to zero
- ☒ **C** increases
- ☒ **D** unchanged

(Total for Question 8 = 1 mark)

9 Light from a lamp passes through two polarising filters, P_1 and P_2, as shown. The light intensity is recorded by a detector.

The filters initially have their planes of polarisation parallel.



Both filters are rotated in the same direction.

Which row of the table gives the changes that result in the minimum intensity of light at the detector?

	Rotation of P_1 / rad	Rotation of P_2 / rad
☒ **A**	$\frac{\pi}{4}$	$\frac{\pi}{2}$
☒ **B**	$\frac{\pi}{4}$	π
☒ **C**	$\frac{\pi}{2}$	π
☒ **D**	$\frac{\pi}{2}$	$\frac{3\pi}{2}$

(Total for Question 9 = 1 mark)

9 The light emitted from a laptop screen is plane polarised.

Explain how the plane of polarisation of the emitted light can be demonstrated using a polarising filter.

(3)

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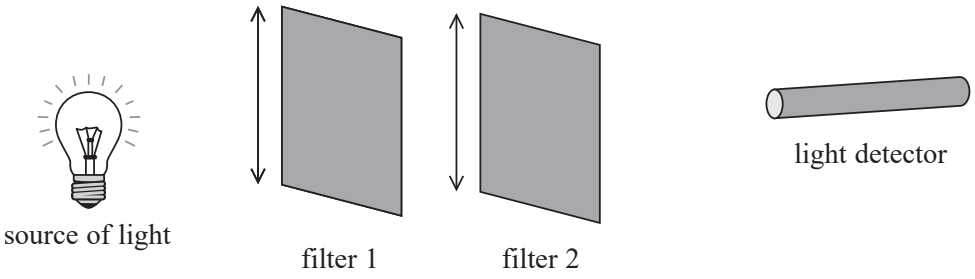
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(Total for Question 9 = 3 marks)

***15** The diagram shows apparatus used to investigate polarising filters.



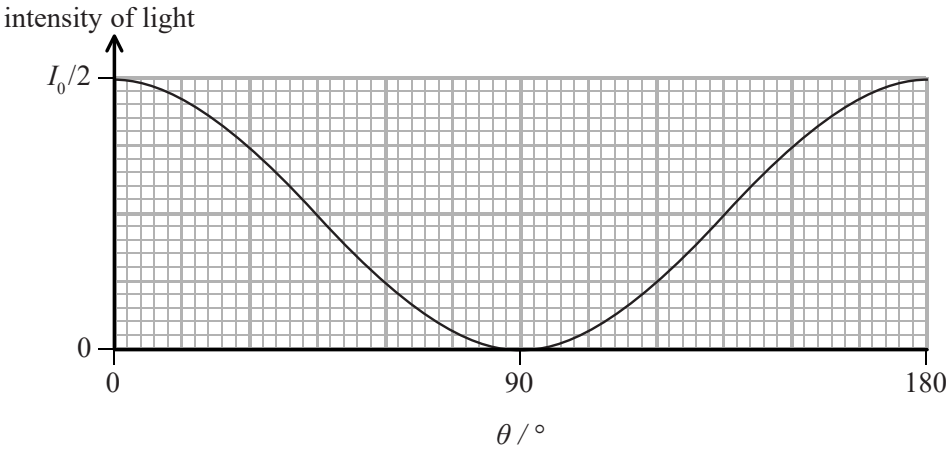
The arrows show the orientation of the plane of polarisation of the filters.

Light is incident on filter 1 and the intensity of the light is measured, using the light detector, when the filters are in the positions shown.

Filter 2 is then rotated and the intensity of light is measured for different angles of rotation θ.

The intensity of light measured with no filters present is I_0.

The results are shown on the graph.



Explain the effect of the filters on the intensity of light and why the intensity varies as shown.

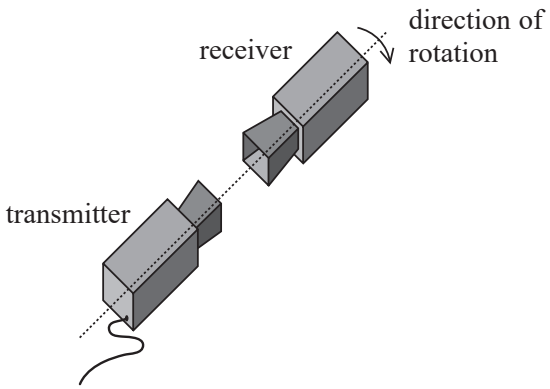
(6)

(Total for Question 15 = 6 marks)

10 Details supplied with a school microwave transmitter and receiver include the following information:

> Transmitter supplies a 10 GHz polarised EM wave.
> Receiver detects EM waves in a single plane containing the direction of propagation, producing an audible output proportional to the microwave intensity.

(a) The receiver and transmitter are initially set up, as shown in the diagram, so that a maximum audible output is produced.



The receiver is rotated through 180° relative to the transmitter.

Describe what is heard as the receiver is rotated.

(2)

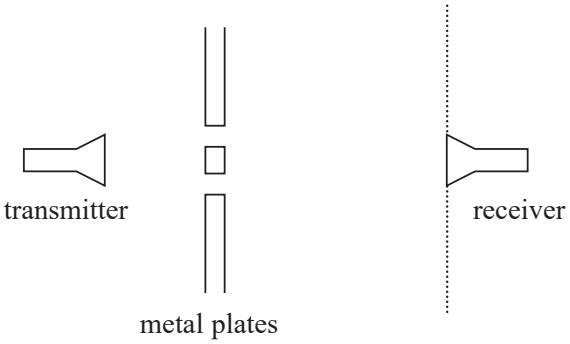
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(b) A student uses the microwave transmitter and receiver to investigate interference using the set-up shown.



As the receiver is moved along the dotted line, alternate points of maximum and minimum intensity are detected.

Explain why points of maximum and minimum intensity are detected.

(4)

(Total for Question 10 = 6 marks)

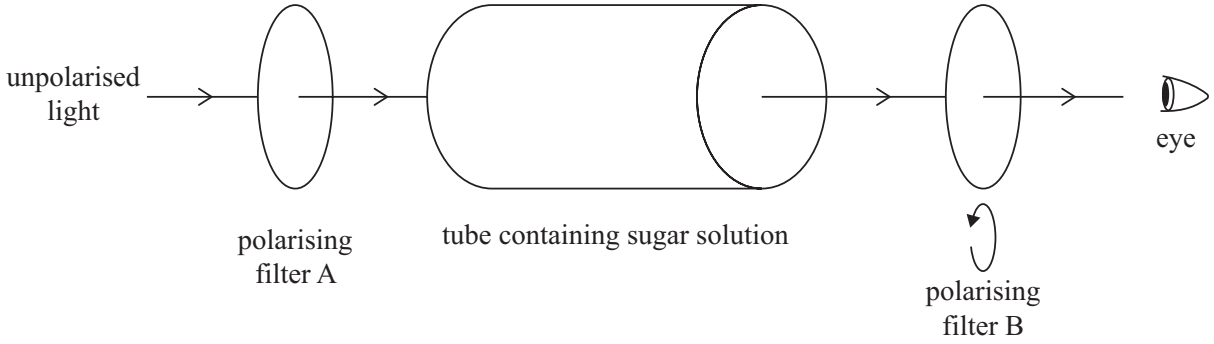
***13** A student views a laptop screen through a polarising filter. Initially the screen appears normal brightness. He rotates the filter to 90° and observes that the screen appears dark.

Explain what the student observes as he gradually rotates the filter to 180° and then to 270°.

(6)

(Total for Question 13 = 6 marks)

9 The concentration of a sugar solution can be determined using the apparatus shown.



Unpolarised light passes through polarising filter A. The transmitted polarised light then passes through a tube containing the sugar solution. This changes the plane of polarisation of the light.
Polarising filter B is rotated and the change in the angle of the plane of polarisation of the light is measured.

(a) Explain what is meant by the plane of polarisation of light.

(2)

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(b) (i) Initially the tube is empty. No light is observed.

Explain how A and B are aligned when no light is observed.

(2)

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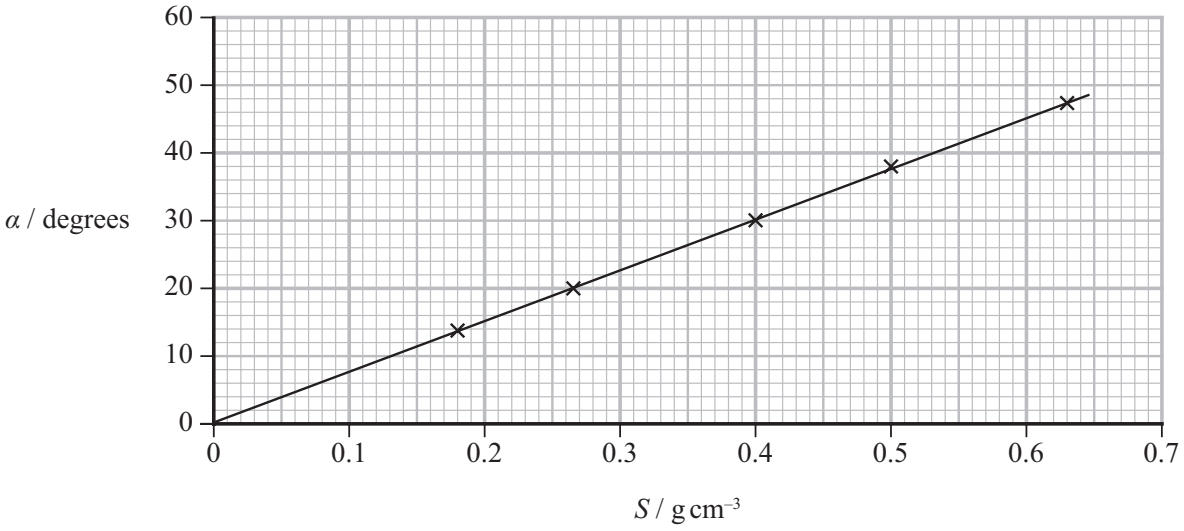
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(ii) A student filled a tube of length l with a sugar solution of concentration S. She observed some light transmitted by filter B. She then rotated filter B until no light was observed. The angle α through which the filter was rotated was recorded.

S was changed and the measurement repeated.

The student plotted a graph of α against S and drew a line of best fit, as shown.



A textbook states that S is related to α by the formula

$$\alpha = klS$$

where $k = 0.050$ degrees $\text{cm}^2\,\text{g}^{-1}$
$l = 15.0\,\text{cm}$

Deduce whether the student's results support this relationship.

(3)

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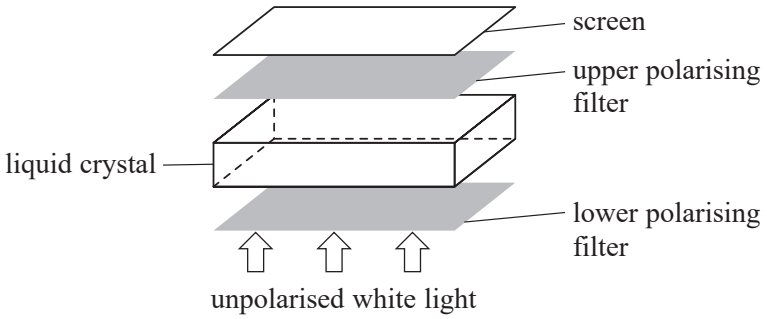
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(Total for Question 9 = 7 marks)

16 A liquid-crystal display uses a series of segments to form letters and numbers on a screen.

(a) The construction of a display segment is shown.



- Unpolarised white light passes through the lower polarising filter and becomes plane polarised.
- When there is no potential difference (p.d.) across the liquid crystal, the molecules in the liquid crystal rotate the plane of polarisation by 90°.
- Light then passes through the upper polarising filter and appears on the screen.
- When a p.d. is applied across the liquid crystal, the molecules no longer rotate the plane of polarisation. The light will not pass through the upper polarising filter and the screen appears dark.

(i) Describe what is meant by plane polarised light.

(2)

(ii) Explain the angle of polarisation of the upper polarising filter relative to the lower polarising filter.

(2)

(b) (i) The intensity of the emitted light at the surface of a display segment is $7.8\,W\,m^{-2}$. The segment has an exposed area of $1.8 \times 10^{-3}\,m^2$.

Calculate the power of the emitted light at the surface of the display segment.

(2)

Power of emitted light = ...

(ii) A light-emitting diode (LED) is used to provide the unpolarised white light for the liquid-crystal display.

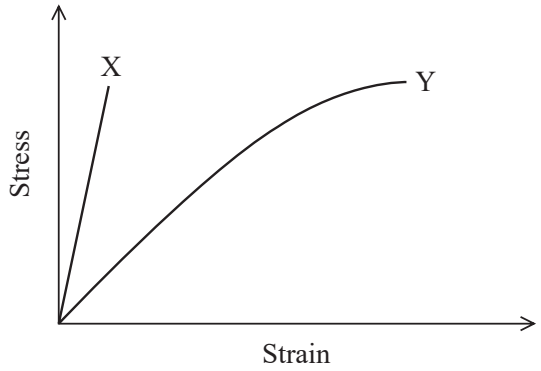
Calculate the efficiency of the liquid-crystal display segment.

(3)

current in LED = 20 mA
p.d. across LED = 3.6 V

Efficiency of liquid-crystal display segment = ...

(c) Manufacturers are developing new materials for flexible screens for liquid-crystal displays. The graph shows how stress varies with strain for two materials X and Y up to typical stresses that would be applied to the screens in normal use. Both materials behave elastically over the ranges shown.



Deduce which material would be more suitable to use for the flexible screen in liquid-crystal displays.

(4)

(Total for Question 16 = 13 marks)

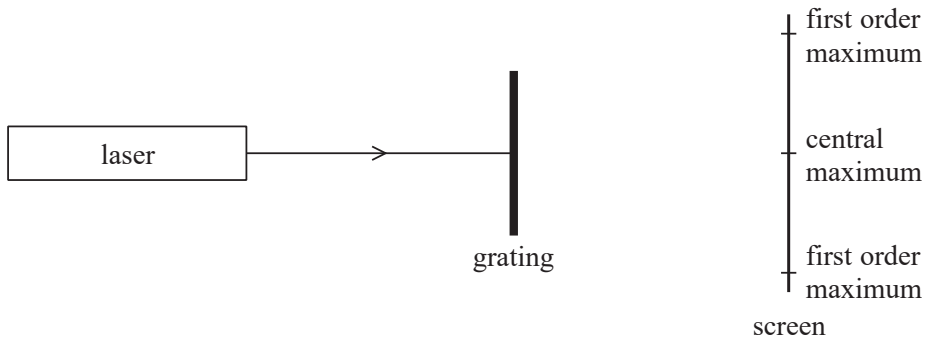
SUB-TOPIC 5.6

DIFFRACTION AND INTERFERENCE

Sub-topic 5.6 · 26 questions · 169 marks · lowest tariff first

10 A beam of light from a laser is directed at a diffraction grating.

The diagram shows the positions of the central maximum and the first order maxima on a screen.



Which of the following would cause the first order maxima to be closer to the central maximum on the screen?

- ☒ **A** moving the laser closer to the grating
- ☒ **B** moving the screen further from the grating
- ☒ **C** using a grating with more lines per metre
- ☒ **D** using laser light with a higher frequency

(Total for Question 10 = 1 mark)

3 In an experiment to determine the wavelength of light, a diffraction grating is illuminated with light from a monochromatic source. A series of bright spots is observed.

The experiment is repeated and the distance between consecutive bright spots increases.

Select the row of the table that gives two changes to the experimental set up which would both cause the distance between consecutive bright spots to increase.

	Number of slits per mm in the diffraction grating	Wavelength of the light source
☒ **A**	Increased	Increased
☒ **B**	Increased	Decreased
☒ **C**	Decreased	Increased
☒ **D**	Decreased	Decreased

(Total for Question 3 = 1 mark)

7 For two waves of light to be coherent the waves must

- ☒ **A** always have a phase difference equal to 0.
- ☒ **B** oscillate in the same plane.
- ☒ **C** have a similar amplitude.
- ☒ **D** originate from one source.

(Total for Question 7 = 1 mark)

10 A monochromatic beam of light of wavelength λ from a laser is directed at a diffraction grating of line spacing d.

A student calculates the value of d/λ in order to determine the expected number of visible maxima.

The calculated value of d/λ is 4.7

How many maxima are visible?

☒ **A** 4

☒ **B** 5

☒ **C** 9

☒ **D** 11

(Total for Question 10 = 1 mark)

8 In an experiment to determine the wavelength of light, three values for the wavelength are obtained and the mean value calculated.

Wavelength / nm	466	448	473
Mean wavelength / nm	462		

What is the uncertainty, in nm, in these results?

☒ **A** 25

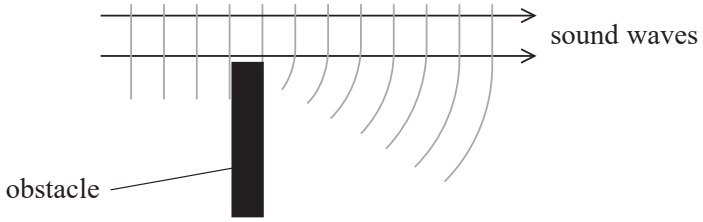
☒ **B** 18

☒ **C** 14

☒ **D** 11

(Total for Question 8 = 1 mark)

3 Sound waves can diffract around obstacles as shown in the diagram.



The diffraction effect is

- ☒ **A** greater for large amplitude sound waves.
- ☒ **B** greater for low frequency sound waves.
- ☒ **C** independent of the frequency of the sound waves.
- ☒ **D** independent of the speed of the sound waves.

(Total for Question 3 = 1 mark)

6 Monochromatic light of wavelength λ is incident normally on two slits, S_1 and S_2, producing an interference pattern on a screen as shown. V, W, X, Y and Z represent positions of adjacent maxima.



The distance from S_1 to X is represented as S_1X.

Which of the following expressions is equal to 2λ?

- ☒ **A** $S_1Z - S_2X$
- ☒ **B** $S_1V - S_2V$
- ☒ **C** $S_1Y - S_2Y$
- ☒ **D** $S_1W - S_2Y$

(Total for Question 6 = 1 mark)

1 The wavelength of light emitted from a laser can be determined using a diffraction grating. The equation used to calculate the wavelength is

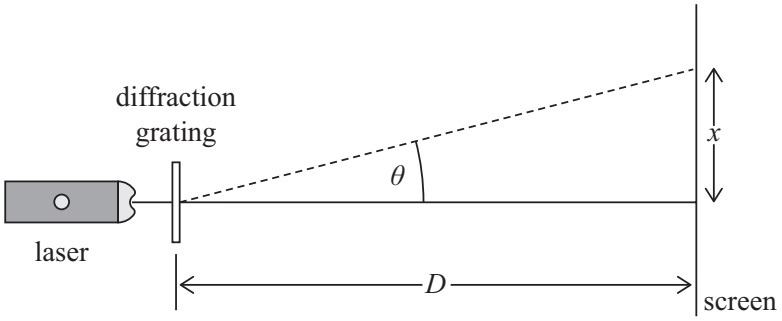
$$n\lambda = d\sin\theta$$

Which row of the table shows possible units for n and d?

		n	d
☒	**A**	no unit	mm^{-1}
☒	**B**	no unit	mm
☒	**C**	mm	no unit
☒	**D**	mm^{-1}	no unit

(Total for Question 1 = 1 mark)

2 A diffraction grating was illuminated with light from a laser, as shown.



A series of fringes was observed on the screen. x is the distance between the central maximum and a bright fringe.

The following measurements were recorded.

$D = 2.00\,\text{m}$
$x = 35.0\,\text{cm}$

Which of the following is the expression for the diffraction angle θ?

☒ **A** $\sin^{-1}\left(\frac{0.35}{2.00}\right)$

☒ **B** $\sin^{-1}\left(\frac{2.00}{0.35}\right)$

☒ **C** $\tan^{-1}\left(\frac{2.00}{0.35}\right)$

☒ **D** $\tan^{-1}\left(\frac{0.35}{2.00}\right)$

(Total for Question 2 = 1 mark)

4 Two waves of wavelength λ are produced from two coherent sources. The waves meet at a point X and constructively interfere.

Which of the following statements could describe the waves at X?

☒ **A** The phase difference of the waves is π.

☒ **B** The path difference of the waves is λ.

☒ **C** The frequency of the resultant wave is reduced.

☒ **D** The displacement of the resultant wave is 0.

(Total for Question 4 = 1 mark)

11 A student shone green light from a laser through a diffraction grating, producing a diffraction pattern on a screen. The student determined the angle of the third order maximum.

Calculate the wavelength of the green light.

angle of third order maximum = 73.3°
grating spacing = 1.67×10^{-6} m

.....

.....

.....

.....

Wavelength = ...

(Total for Question 11 = 2 marks)

11 Light can be modelled as a wave.

(a) Describe how light is transmitted as a transverse wave.

(2)

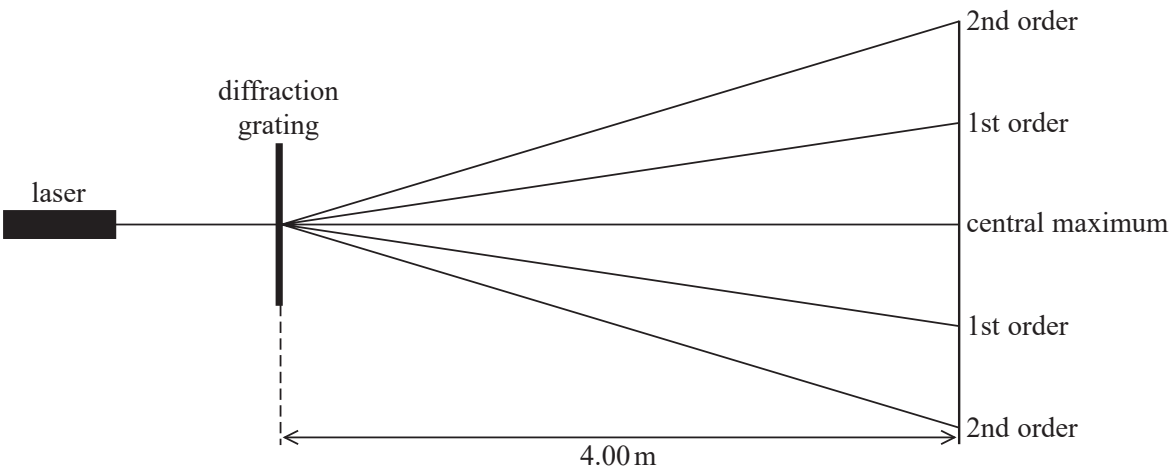
(b) Diffraction provides evidence for the wave nature of light.

Use Huygens' construction to describe what happens to light waves after passing through a narrow gap.

(3)

(Total for Question 11 = 5 marks)

9 A student used a diffraction grating to determine the wavelength of the light emitted by a laser. Light from the laser passed through the diffraction grating and the student observed a pattern on a wall 4 m away. The pattern consisted of a central maximum and 1st and 2nd order maxima as shown.



The student measured the distance between the central and a 2nd order maximum as 1350 mm. The diffraction grating had 300 slits mm^{-1}.

(a) The colours and corresponding wavelengths of light emitted by commonly used lasers are given in the table.

blue	450–490 nm
green	520–560 nm
red	635–700 nm

Deduce the colour of the laser light the student used in this experiment.

(4)

(b) Measuring the distance between the two 2nd order maxima would produce a smaller percentage uncertainty in the value of wavelength.

Give a reason why.

(1)

.....

.....

.....

(Total for Question 9 = 5 marks)

13 Huygens' principle states that every point on a wavefront is a source of wavelets which spread out at the same speed.

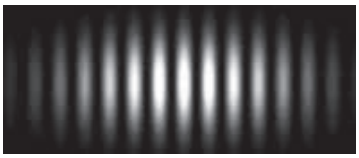
(a) State what is meant by a wavefront.

(1)

.....

.....

(b) In an experiment to demonstrate interference of light, monochromatic light from a laser is shone onto two narrow slits. A series of light and dark lines is observed on a screen placed a distance away from the slits.



(i) State one safety precaution that should be taken with this procedure.

(1)

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(ii) Thomas Young first demonstrated the principle of this experiment in 1803 in support of the theory that light behaves as a wave.

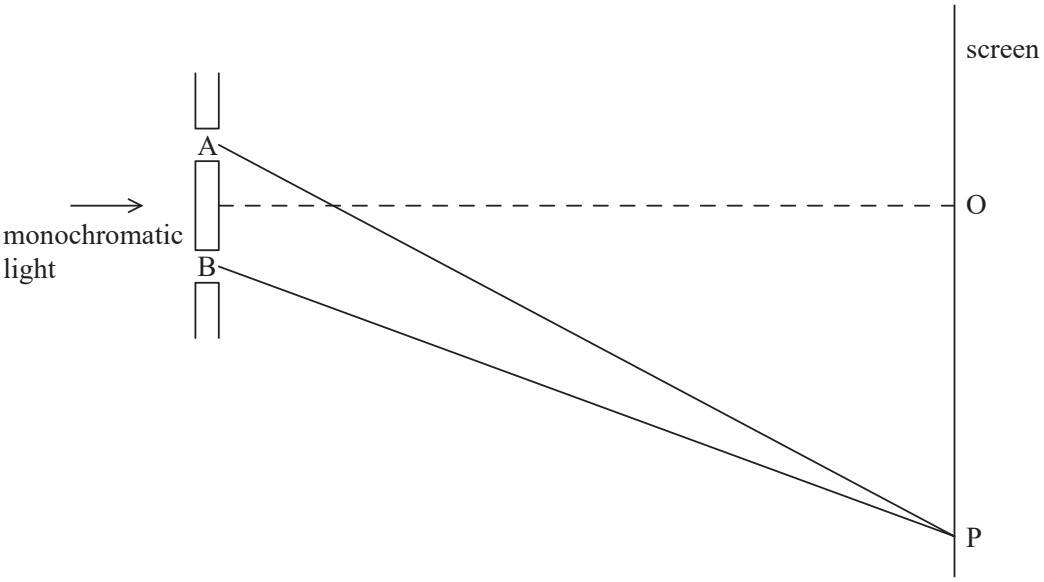
Give a reason why some scientists at the time did not accept the wave theory of light.

(1)

.....

.....

(c) The experiment was carried out with laser light of wavelength 600 nm. The diagram below shows two paths taken by the light after it has passed through the two slits A and B. The diagram is not to scale.



(i) Point O is a point equidistant from the two slits.

Explain why there is a bright line at this point.

(3)

(ii) The next bright line is observed on the screen at point P. Lines AP and BP show the path of the light from each slit to the screen at P.

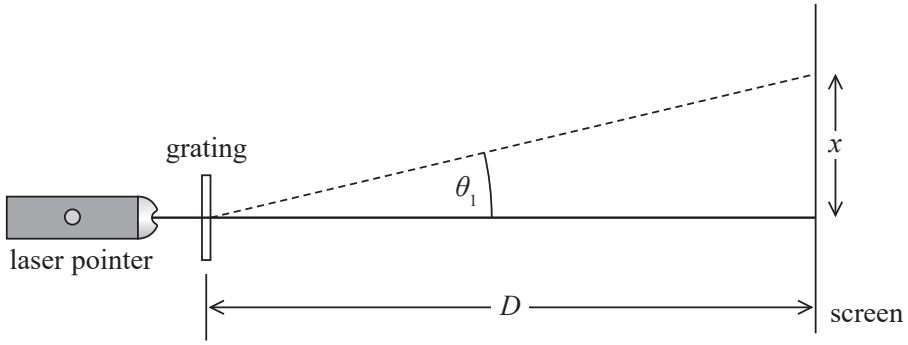
State the difference in the lengths of the paths AP and BP.

(1)

Difference in lengths of paths = ...

(Total for Question 13 = 7 marks)

1 A student used a laser pointer to direct monochromatic light normal to the plane of a diffraction grating as shown.



A diffraction pattern was produced on the screen. The distance between the first order maximum and the central maximum of the diffraction pattern was x. The distance between the diffraction grating and the screen was D.

(a) The diffraction grating had 300 lines per mm.
The laser pen was marked with $\lambda = 520\,\text{nm}$.

Determine whether the spacing of the diffraction pattern was consistent with these values.

$x = 43.5\,\text{cm}$
$D = 2.75\,\text{m}$

(4)

(b) The student wrote the following conclusion:

"The value of x was measured with a metre rule. A metre rule has a precision of 0.1 cm, so this value was determined with a high degree of accuracy."

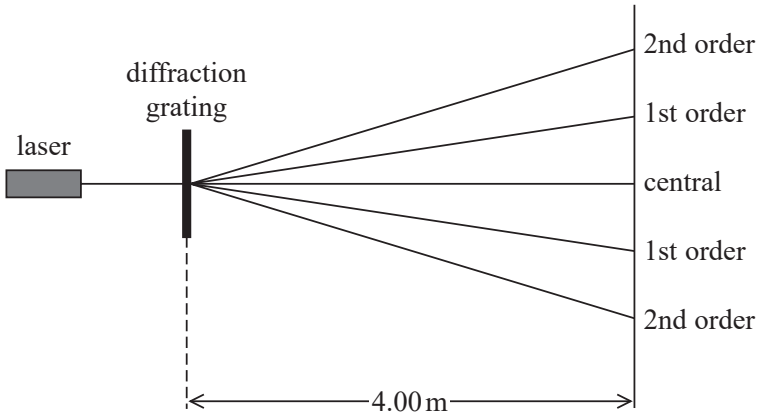
Comment on this conclusion.

(3)

(Total for Question 1 = 7 marks)

11 A technician shone light from a laser through a diffraction grating. A pattern was observed on a screen 4.00 m away. The pattern consisted of 5 maxima, as shown.

Not to scale



The diffraction grating has 4.00×10^2 lines per millimetre.

(a) The technician wanted to check that the wavelength emitted by the laser was within the range 450 nm ± 10 nm.

She measured the distance between the two second order maxima as 3.25 m.

Deduce whether the light from the laser was within the range 450 nm ± 10 nm.

(4)

(b) The electrons in an electron beam have a speed of approximately 10% of the speed of light. It is possible to demonstrate diffraction with this electron beam when the electron beam is incident on a graphite target.

If the spacing of the atoms in the graphite target were equal to the spacing of lines on the diffraction grating used by the technician, this electron beam would **not** show diffraction effects.

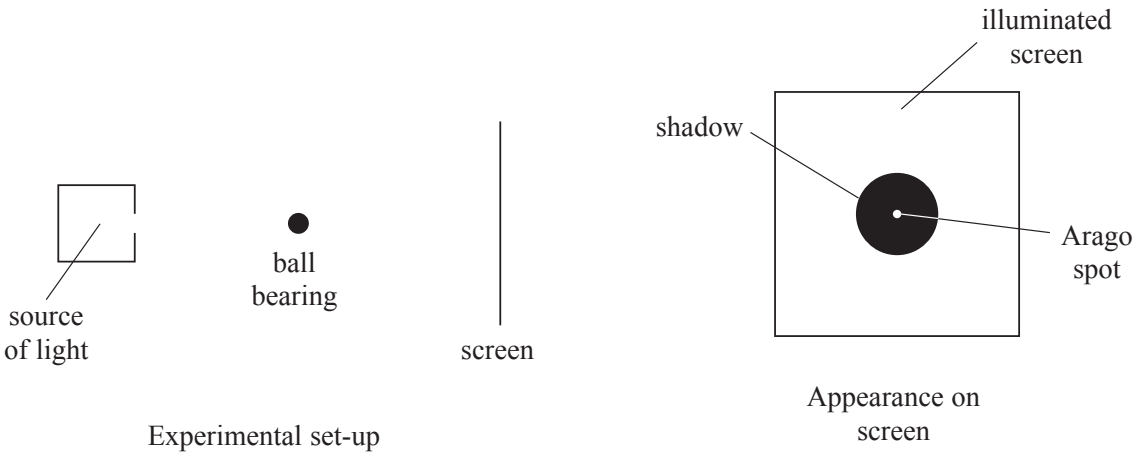
Explain why. Your answer should include calculations.

(4)

(Total for Question 11 = 8 marks)

11 The diagram shows a coherent beam of light incident on a metal ball bearing.

A dark shadow is seen on a screen behind the ball bearing. There is a small spot of light in the centre of the shadow. This spot of light is known as the Arago spot.



Experimental set-up

Appearance on screen

(a) Use Huygens' construction to explain the behaviour of light as it travels past the edge of the ball bearing.

(2)

(b) Explain why a spot of light is produced at the centre of the shadow.

(3)

(c) François Arago first demonstrated this experiment in 1818 for a group of eminent scientists, to show the behaviour of light.

State the model for the behaviour of light that this experiment demonstrated and explain why the scientific community accepted this model.

(3)

(d) The ball bearing shown in the experimental set-up has a diameter of about 1 cm.

Describe how the diameter could be measured accurately.

(2)

(Total for Question 11 = 10 marks)

15 The photograph shows an ultrasonic mouse repeller used in a house.



The mouse repeller produces ultrasound that repels mice but cannot be heard by humans.
The mouse hears ultrasound directly and by reflection from the walls.

The mouse repeller produces ultrasound of frequency 26.0 kHz.

speed of sound = 340 m s^{-1}

(a) Calculate the wavelength of the ultrasound produced.

(2)

Wavelength = ...

(b) State what is meant by superposition of waves.

(2)

(c) A student makes the following suggestion.

"If the ultrasound reflects off a wall directly opposite the mouse repeller a standing wave is formed, so there will be areas in the room where the mice will not hear the ultrasound."

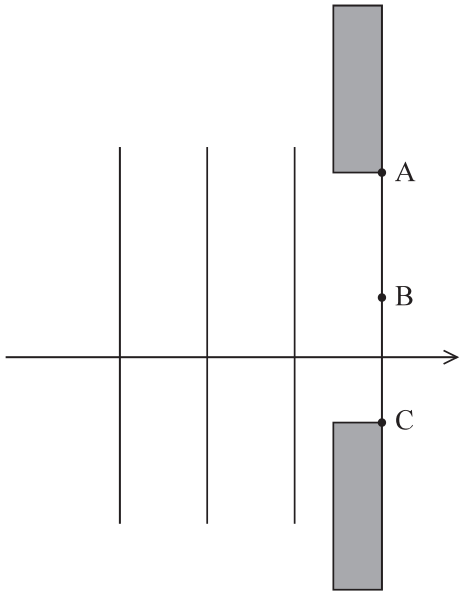
Evaluate this suggestion.

(6)

(Total for Question 15 = 10 marks)

13 The diffraction of light provides evidence for the wave theory of light.

(a) The diagram represents wavefronts of light, incident at a single slit. The points labelled A, B and C are points on the wavefront that has just passed through the gap.



(i) Describe what is meant by a wavefront.

(1)

(ii) Add to the diagram to show how Huygens' construction can be used to determine the shape of the next wavefront, after the wave has passed through the gap.

(3)

(b) A student carried out an investigation to determine the wavelength of the light emitted from a laser pen.

He shone the light from the laser pen so that it was incident perpendicularly on a diffraction grating. The diffraction grating had 200 lines per mm. He observed the diffraction pattern on a screen 3.00 m away from the grating. The pattern consisted of a series of bright dots.

(i) Give a reason why a laser is a suitable source of light to produce a diffraction pattern.

(1)

(ii) The student measured a distance of 102 cm between the central maximum and the centre of a third order maximum.

The table shows the range of wavelengths for each colour of the visible spectrum.

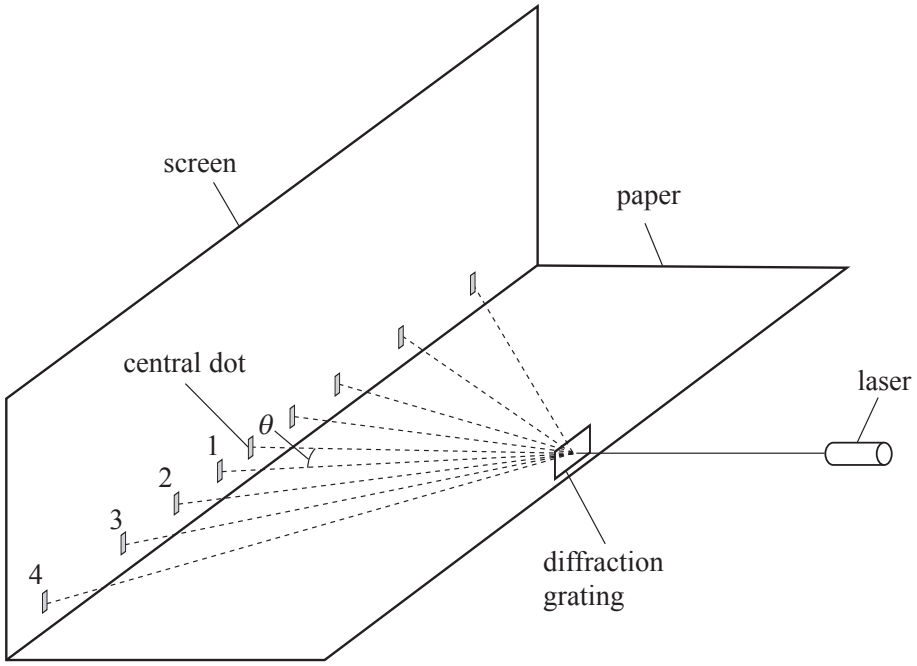
Colour	Range of wavelength / nm
violet	380–450
blue	450–495
green	495–570
yellow	570–590
orange	590–620
red	620–750

Deduce the colour of the light emitted from the laser pen.

(5)

(Total for Question 13 = 10 marks)

15 The arrangement shown was used to determine the wavelength of light emitted by a laser.



A laser light beam was shone at a diffraction grating. A series of dots of light was produced on a screen. The angles θ between the light ray to the central dot and the light rays to the dots labelled 1 to 4 were measured with a protractor.

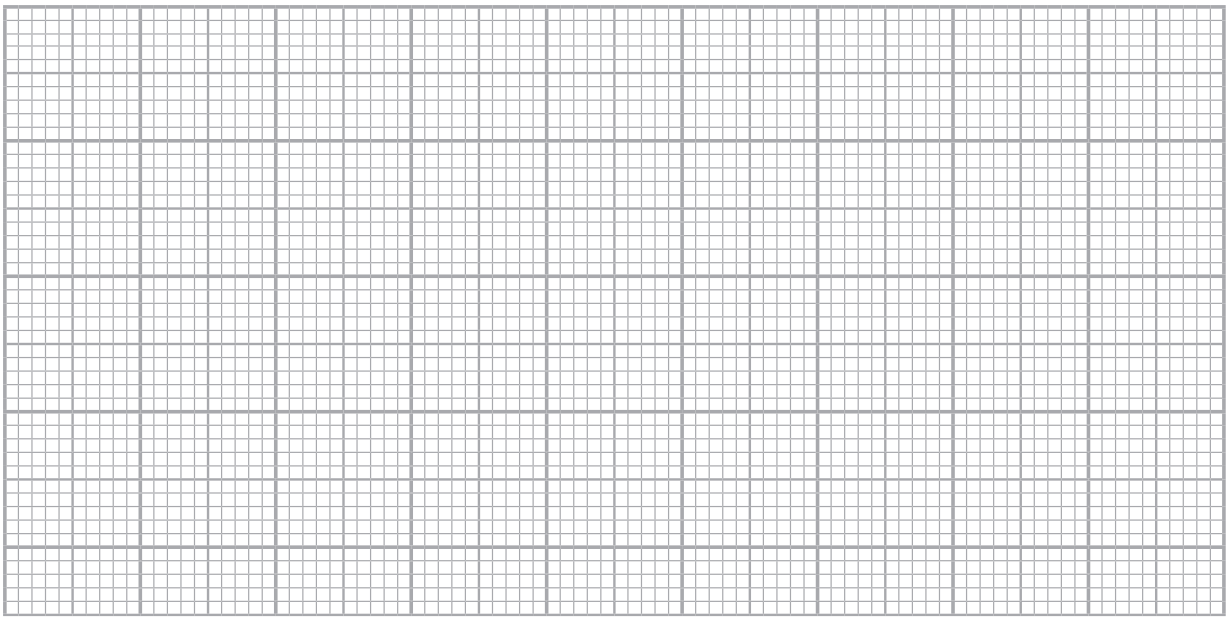
n	θ / °	$\sin\theta$
1	12	0.21
2	23	0.39
3	34	0.56
4	51	0.78

(a) Describe how the angle θ could be determined without using a protractor.

(2)

(b) Plot a graph of n against $\sin\theta$ on the grid below.

(4)



(c) The diffraction grating has 300 lines mm^{-1}.

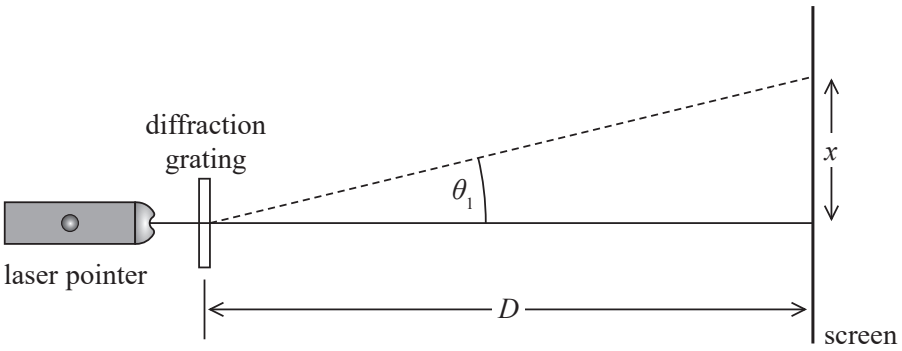
Determine the wavelength of the laser light.

(4)

Wavelength = ...

(Total for Question 15 = 10 marks)

11 Light from a laser pointer was passed through a diffraction grating. The light was perpendicular to the diffraction grating as shown. A diffraction pattern was produced on a screen.



The distance between the first order maximum and the central maximum of the diffraction pattern was x. The distance between the diffraction grating and the screen was D.

(a) Distance x was measured to be 0.500 m with a metre rule. The wavelength of light λ_1 from the laser pointer was 650 nm.

The laser pointer was replaced with one that produced light of a different wavelength. The new distance x was measured to be 0.400 m.

$D = 1.45$ m

Calculate the wavelength λ_2 of the light emitted by the replacement laser pointer.

(5)

$\lambda_2 =$ .....

(b) Explain one modification to this method that would decrease the uncertainty in the calculated value of λ_2.

(2)

(c) In another experiment, the light from the laser pointer was not quite perpendicular to the screen.

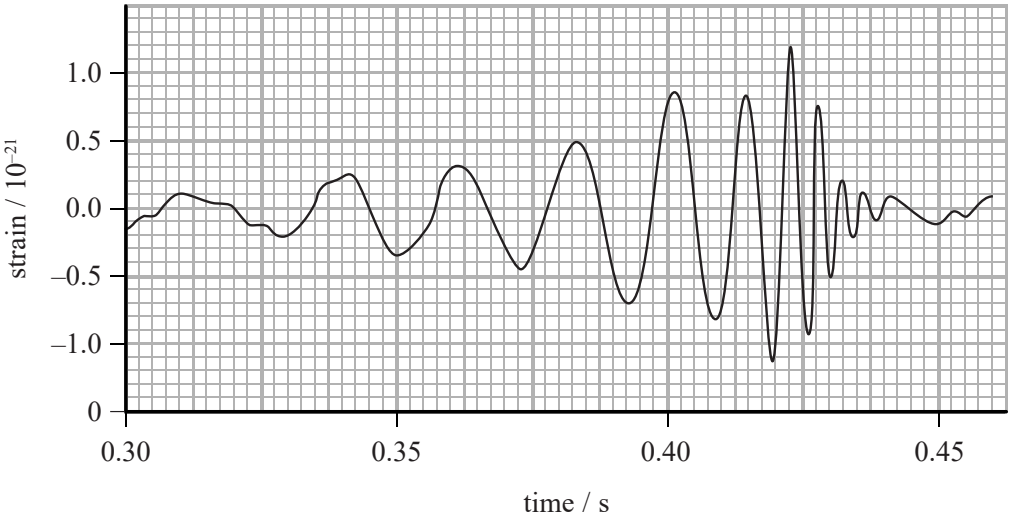
Explain how this would change the diffraction pattern produced on the screen.

(3)

(Total for Question 11 = 10 marks)

20 In 2016 scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) announced that gravitational waves had been detected.

The signal they detected is shown on the graph.



(a) Gravitational waves travel at the speed of light.

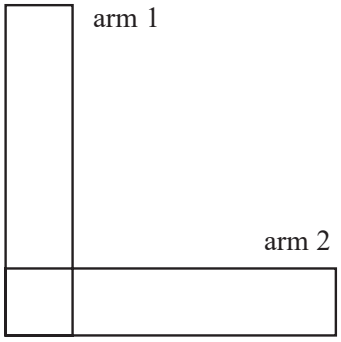
Determine the mean wavelength of the waves detected between 0.30 s and 0.35 s on the graph.

(3)

Mean wavelength = ...

(b) Gravitational waves alternately compress and stretch matter by very small amounts as they pass through.

The LIGO detector has two arms, at 90° to each other, each 4 km long. As a gravitational wave passes the detector, the arms change length. The detector continuously compares the lengths of the two arms.



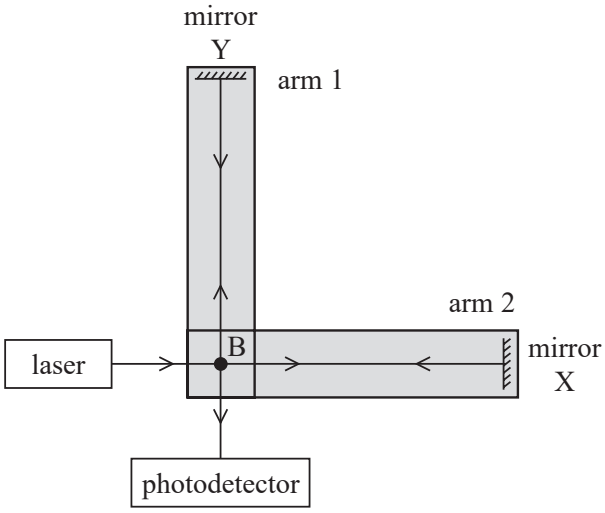
(i) An article states that 'the maximum change in the 4 km length of the arm is about 0.001 times the diameter of a proton'.

Determine whether this statement applies to the gravitational wave shown in the graph.

diameter of proton = 8.8×10^{-16} m

(3)

(ii) In the LIGO detector, any change in the lengths of the arms is detected using a laser beam and photodetector.



The laser beam is split into two at B, one beam travelling to one mirror and the other beam travelling to the other mirror. After reflection at the mirrors, the beams are recombined at B and reach the photodetector. The photodetector measures the intensity of the incident light.

The system is arranged so that when no gravitational waves are present, the beams have a path difference of half a wavelength at the photodetector.

Explain how the photodetector detects very small changes in the length of one arm, when the other arm stays the same length.

(4)

(iii) The system could be arranged so that when no gravitational waves are present, the beams have zero path difference at the photodetector.

Explain whether using an initial path difference of half a wavelength is a more sensitive way of detecting changes in length than having an initial path difference of zero.

(2)

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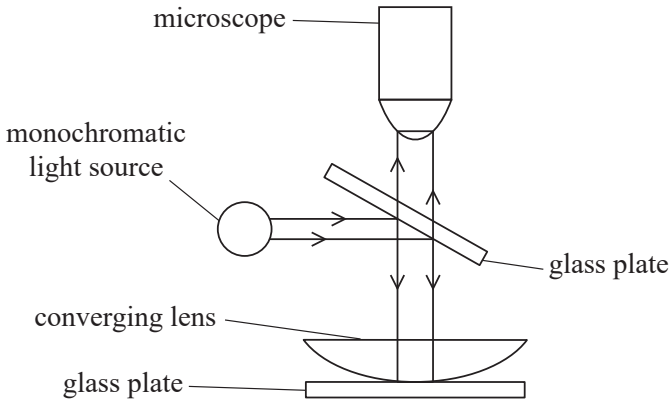
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(Total for Question 20 = 12 marks)

13 A method to determine the wavelength of light using a converging lens was first proposed by Sir Isaac Newton.

A converging lens is placed on a plane glass plate. The lens is illuminated from above with a parallel beam of monochromatic light, as shown.

Some of the light is reflected from the upper surface of the lower glass plate and some from the lower surface of the lens. Interference between these two reflected waves produces circular fringes. The pattern is viewed through a microscope.



Side view of apparatus



Pattern seen through microscope

The diameter D of each circular fringe, numbered N from the centre, is measured using the microscope. The data obtained from such an experiment is shown.

N	D / mm		
1	5.13		
2	7.08		
3	8.71		
4	10.23		
5	11.48		

(a) The relationship between N and D is of the form $D = pN^q$ where p and q are constants.

Determine p and q for this data using a graphical method. Use the additional columns for your processed data.

(8)

p = ...

q = ...

(b) The table below shows the readings from which the diameter of the first dark circle was calculated.

Position of left-hand side of circle / mm	Position of right-hand side of circle / mm	Diameter / mm
54.79	49.66	5.13

(i) Use these readings to estimate the percentage uncertainty in the diameter due to the resolution of the instrument.

(2)

.....

.....

.....

.....

Percentage uncertainty = ...

(ii) State why the actual percentage uncertainty would have been greater than the value calculated in (b)(i).

(1)

.....

.....

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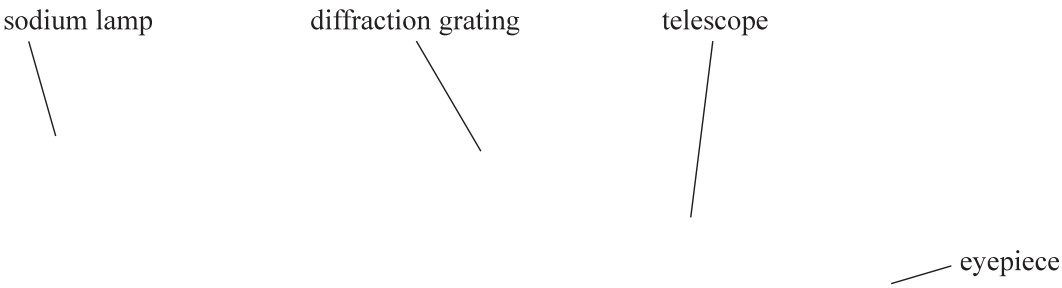
(c) When considering the principles of this experiment, a student suggests that interference fringes would only be produced with monochromatic light. This is because interference requires coherent light waves.

Discuss the validity of the student's suggestion.

(4)

(Total for Question 13 = 15 marks)

17 The photograph shows a school spectrometer.



The spectrometer allows parallel rays of light to be passed through a diffraction grating and the resulting angles of diffraction to be measured.

(a) In the telescope, light from the grating is focused to make a real image 16.7 mm in front of the eyepiece lens. The eyepiece lens then uses this real image as an object to produce a magnified virtual image for the observer.

Calculate the magnification produced by the eyepiece lens.

focal length of eyepiece lens = 17.9 mm

(3)

Magnification = ...

(b) The spectrometer and diffraction grating are used to analyse the light from a sodium lamp. In the sodium lamp, sodium is heated until it becomes a vapour and an electric current is passed through it. The vapour then emits light.

After the light passes through the diffraction grating a line spectrum is observed.

(i) Explain why only certain wavelengths are observed.

(6)

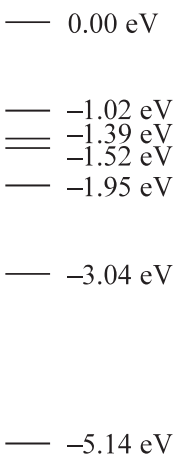
(ii) Diffraction gratings with the following spacings are available:

$d / 10^{-6}$ m	1.0	1.7	2.0	3.3

Explain which would be the best spacing to use to measure the diffraction angle for the third order maximum for yellow light of wavelength 589 nm.

(3)

(c) The diagram shows some of the energy levels in a sodium atom.



Add an arrow to the diagram to show the transition involved in the emission of yellow light of wavelength 589 nm.

Show your working below.

(4)

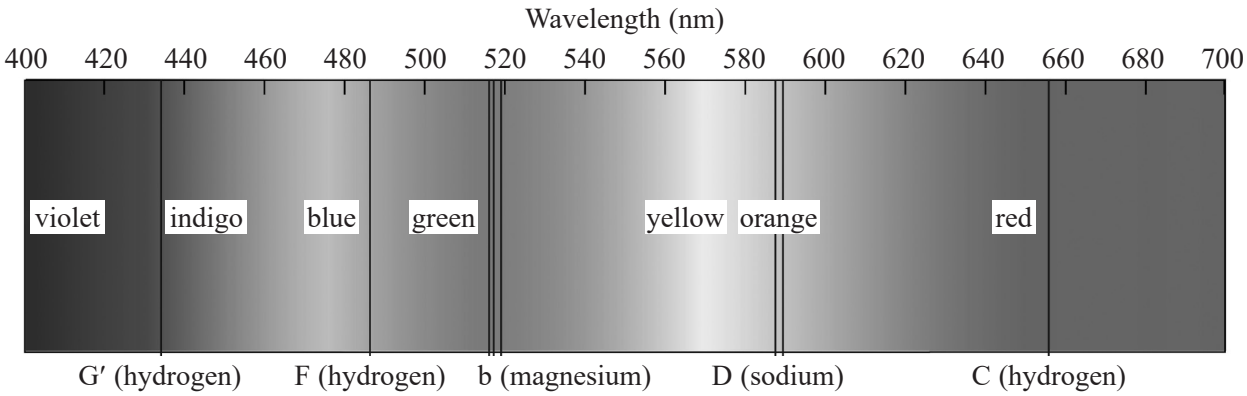
(Total for Question 17 = 16 marks)

17 Scientists can analyse light from stars that has passed through a diffraction grating.

*(a) Explain the pattern produced when a mixture of blue and red light, from the same source, passes through a diffraction grating.

(6)

(b) A spectrum of the visible light emitted by a particular star is shown.



(Source: © Universal Images Group North America LLC/Alamy Stock Photo)

(i) Light interacts with atoms as it passes through the atmosphere of the star.

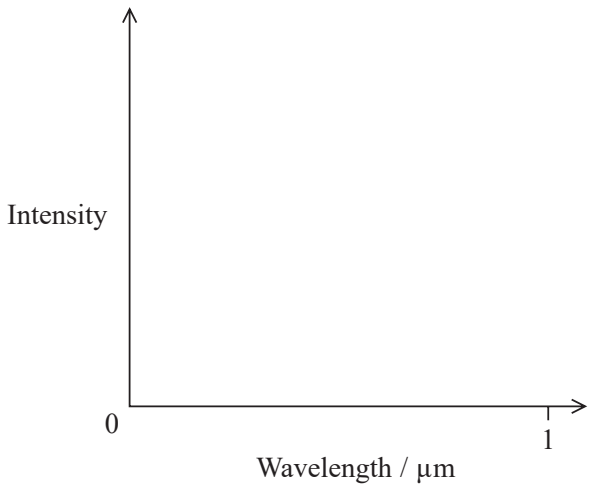
Explain how this leads to the formation of the dark lines within the spectrum.

(4)

(ii) The surface temperature of the star is 5800 K.

On the axes below, sketch a graph of the intensity of radiation against the wavelength of that radiation for this star.

(4)



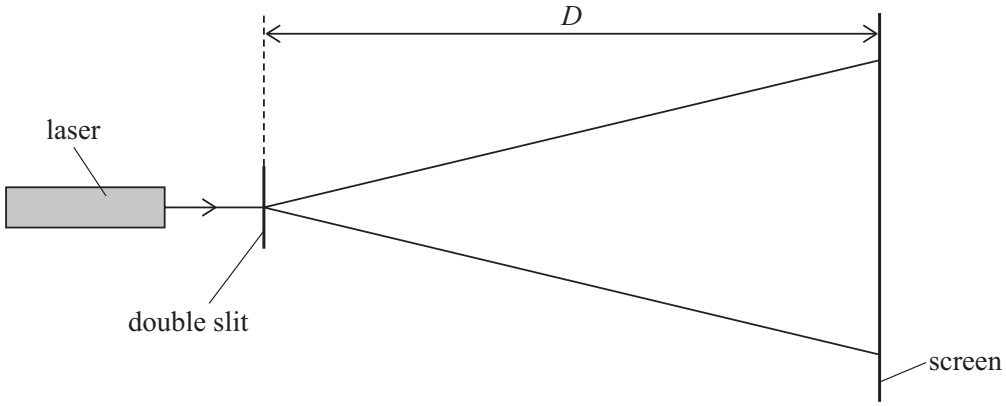
(iii) This star is a main sequence star.

Explain why main sequence stars do not collapse due to gravitational forces.

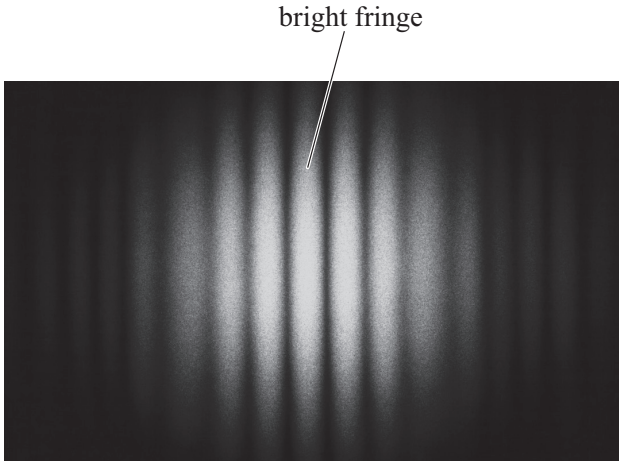
(2)

(Total for Question 17 = 16 marks)

16 A student directed light from a laser onto a double slit. The double slit consisted of two parallel narrow slits a distance s apart. The light spread out as it passed through the double slit and hit a screen a distance D away from the double slit, as shown.



The light produced a pattern of bright and dark fringes on the screen, as shown below.



(Source: © GIPhotoStock/SCIENCE PHOTO LIBRARY)

(a) The student used digital calipers to measure the separation of the fringes w by measuring between the centres of adjacent fringes.

Explain how the student could reduce the percentage uncertainty in his measurement of w.

(2)

(b) The student varied s for the double slit and recorded corresponding values of w. The results are recorded below.

s / mm	w / m	
0.10	0.0643	
0.20	0.0301	
0.30	0.0204	
0.40	0.0159	
0.50	0.0131	

(i) Plot a graph of s on the y-axis and $1/w$ on the x-axis using the grid opposite.

Use the additional column in the table for your processed data.

(5)

(ii) The following equation can be used to determine the wavelength λ of laser light for the experiment.

$$s = \frac{\lambda D}{w}$$

Calculate λ for the light used in this experiment.

$D = 9.00\,\text{m}$

(3)

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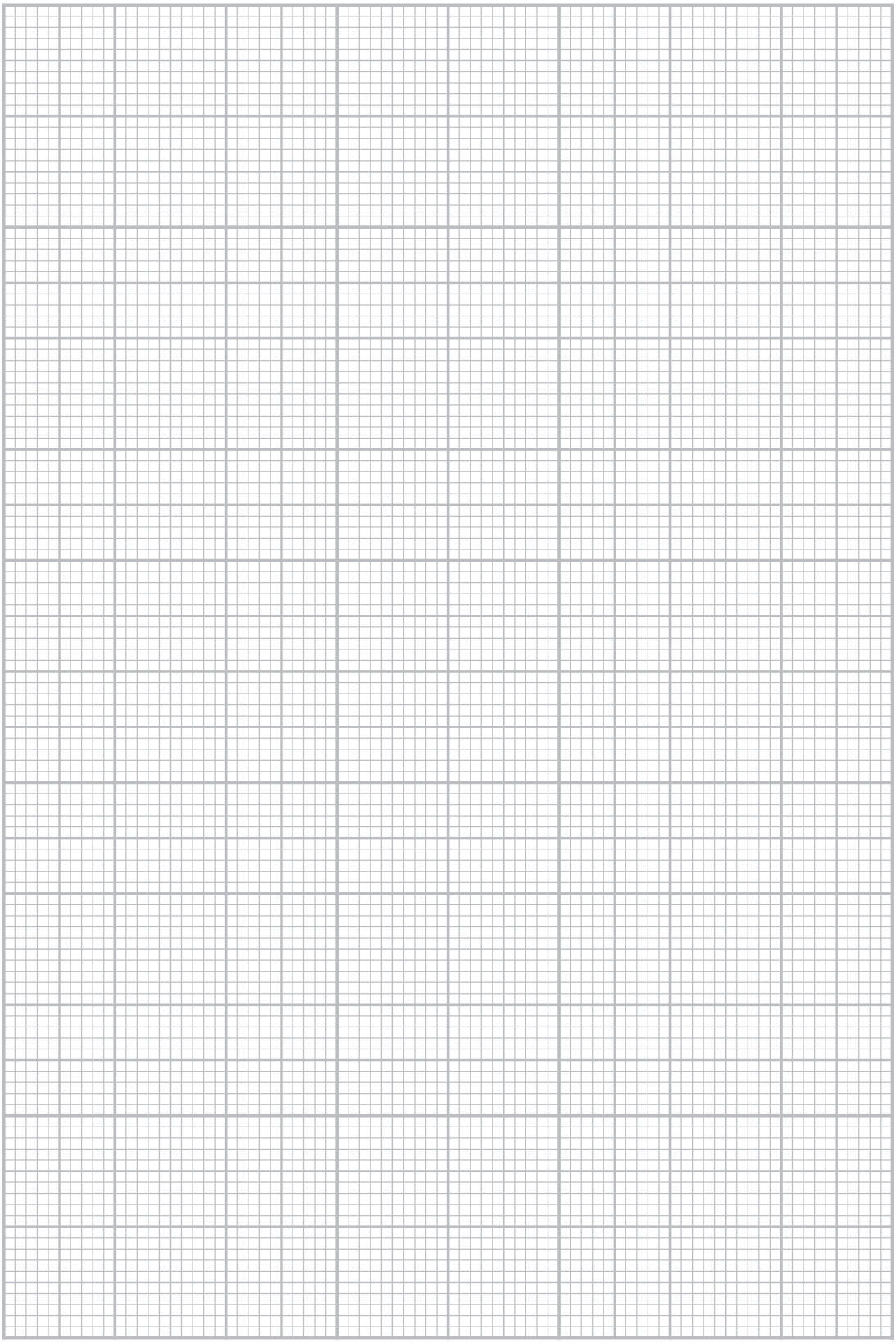
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$\lambda =$ .....



(c) Another student carried out the same experiment using a different laser labelled with a wavelength of 520 nm.

(i) She measured w several times for the same value of s. The results are recorded below.

w / mm				w_{mean} / mm
21	20	23	24	22

Calculate the percentage uncertainty in the value of w.

(2)

Percentage uncertainty in w = ...

(ii) Assess whether the student's results support the value of the wavelength of light given on the label.

$$s = \frac{\lambda D}{w}$$

$D = 9.00\,\text{m} \pm 0.01\,\text{m}$
$s = 0.20\,\text{mm} \pm 4\%$

(4)

(Total for Question 16 = 16 marks)

SUB-TOPIC 5.7

THE PHOTOELECTRIC EFFECT AND PHOTONS

Sub-topic 5.7 · 24 questions · 154 marks · lowest tariff first

6 When monochromatic light is incident on the surface of a metal, electrons are emitted by the photoelectric effect.

If other conditions are unchanged, the maximum kinetic energy of the electrons will be increased by

☒ **A** increasing the frequency of the incident light.

☒ **B** increasing the intensity of the incident light.

☒ **C** using a metal with a higher threshold frequency.

☒ **D** using a metal with a higher work function.

(Total for Question 6 = 1 mark)

4 Einstein's photoelectric equation states

$$hf = \phi + \frac{1}{2}mv^2_{max}$$

The quantity denoted by ϕ is the minimum

☒ **A** amount of energy of a photon needed to release an electron.

☒ **B** amount of energy of an electron needed to release a photon.

☒ **C** frequency of a photon needed to release an electron.

☒ **D** frequency of an electron needed to release a photon.

(Total for Question 4 = 1 mark)

6 When light is incident on the surface of a metal, electrons may be emitted by the photoelectric effect. Observations of the photoelectric effect helped to establish that light can exhibit particle behaviour.

Which of the following observations of the photoelectric effect could also be explained by light behaving as a wave?

☒ **A** Emission of photoelectrons occurs immediately the surface is illuminated.

☒ **B** Photoelectrons are only emitted when the frequency of the light is more than a certain minimum value.

☒ **C** The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

☒ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for Question 6 = 1 mark)

7 The photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Which of the following observations of the photoelectric effect could also be explained using the wave nature of electromagnetic radiation?

- ☒ **A** The emission of photoelectrons is instantaneous.
- ☒ **B** The maximum kinetic energy of photoelectrons depends on frequency.
- ☒ **C** The rate of emission of photoelectrons depends on intensity.
- ☒ **D** There is a minimum frequency for emission of photoelectrons to occur.

(Total for Question 7 = 1 mark)

1 Which of the following provides evidence for the particle model of electromagnetic radiation?

- ☒ **A** diffraction
- ☒ **B** interference
- ☒ **C** polarisation
- ☒ **D** visible line spectra

(Total for Question 1 = 1 mark)

5 The photoelectric effect provides evidence for the particle nature of electromagnetic radiation.

Which of the following is **not** observed in the photoelectric effect?

- ☒ **A** Photoelectrons are released instantly.
- ☒ **B** Photoelectrons are only released above a certain frequency of radiation.
- ☒ **C** The energy of the photoelectrons is determined by the intensity of the light.
- ☒ **D** The energy of the photons is proportional to the frequency of the radiation.

(Total for Question 5 = 1 mark)

2 Which of the following provides evidence for the particle nature of electromagnetic radiation?

- ☒ **A** diffraction
- ☒ **B** interference
- ☒ **C** photoelectric effect
- ☒ **D** polarisation

(Total for Question 2 = 1 mark)

6 A teacher demonstrates the photoelectric effect. Monochromatic radiation is incident on the surface of a metal and photoelectrons are emitted.

The intensity of the radiation is increased.

Which row of the table describes what now happens to the maximum speed of the photoelectrons and the number of photoelectrons emitted per second?

		Maximum speed of the photoelectrons	Number of photoelectrons emitted per second
☒	**A**	increases	increases
☒	**B**	increases	no change
☒	**C**	no change	increases
☒	**D**	no change	no change

(Total for Question 6 = 1 mark)

12 Study of the photoelectric effect leads to observations that cannot be explained by the wave theory of light.

When ultraviolet light is shone on a charged zinc plate, electrons are released.
When visible light is shone on the zinc plate, electrons are not released.

(a) (i) State what is meant by threshold frequency.

(1)

.....

.....

(ii) Explain why the observation of a threshold frequency is **not** consistent with the wave theory of light.

(2)

.....

.....

.....

.....

(b) The photoelectric effect can be explained using the idea of photons.

State what is meant by the term photon.

(1)

.....

.....

(Total for Question 12 = 4 marks)

13 A teacher demonstrated the photoelectric effect by illuminating a zinc plate with electromagnetic radiation.

When ultraviolet radiation of wavelength 320 nm was incident upon the zinc plate, electrons were emitted from the zinc surface.

When visible light of wavelength 420 nm was incident upon the zinc plate, no effect was observed.

Explain these observations. Your answer should include calculations.

work function of zinc = 3.74 eV

(Total for Question 13 = 5 marks)

15 A pulsar is a rotating neutron star. The pulsar emits electromagnetic radiation as it rotates.

Scientists have recently detected the highest ever energy gamma ray photons received from a pulsar.

(a) The energy of one of these gamma ray photons was determined to be 2.0×10^{13} eV.

Calculate the wavelength of these gamma rays.

(4)

Wavelength = ...

(b) The pulsar is estimated to be travelling away from the Earth with a velocity of $750\,m\,s^{-1}$.

State why this motion away from the Earth does not significantly affect the wavelength of radiation received at the Earth.

(1)

(Total for Question 15 = 5 marks)

***15** The behaviour of electromagnetic radiation can be described in terms of a photon model or a wave model.

In the photoelectric effect, electromagnetic radiation is incident on a metal plate and under certain conditions electrons are emitted.

It is observed that, for a given metal,

- no electrons are emitted if the frequency of the incident radiation is below a certain threshold frequency.
- electrons are emitted instantaneously if the frequency of the incident radiation is above a certain threshold frequency.
- the kinetic energy of the emitted electrons depends only on the frequency of the incident radiation.

Discuss how the photon model of electromagnetic radiation can explain these observations and why the wave model of electromagnetic radiation cannot.

(6)

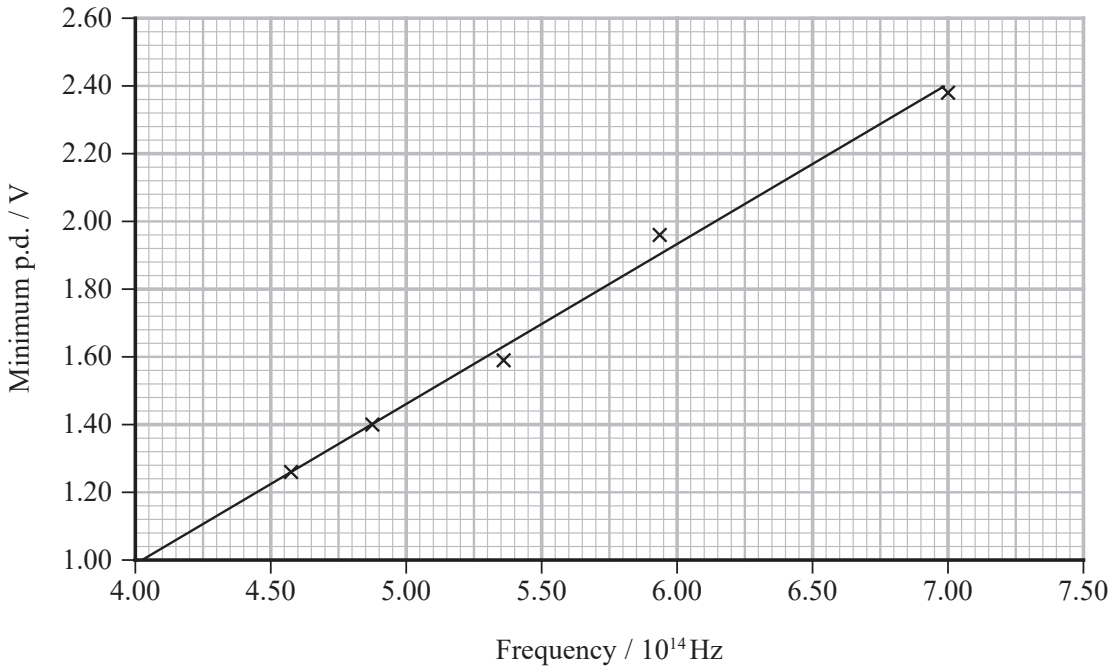
(Total for Question 15 = 6 marks)

16 The Planck constant can be determined in a school laboratory using light emitting diodes (LEDs).

An LED emits light when the potential difference (p.d.) across it is large enough to transfer sufficient energy to an electron to result in the emission of a photon. The electron must have energy greater than or equal to the photon energy.

The minimum p.d. required to produce light from LEDs emitting different frequencies was measured by increasing the p.d. from zero until light was first seen.

The graph shows the results.



(a) Determine the value of the Planck constant given by this graph.

(4)

Value of Planck constant given by graph = ...

(b) There are two problems with using LEDs to determine the Planck constant:

- when the p.d. is increased and the LED first emits light it is difficult to see
- the LEDs do not emit a single frequency but also light of frequencies slightly above and below the recorded frequency.

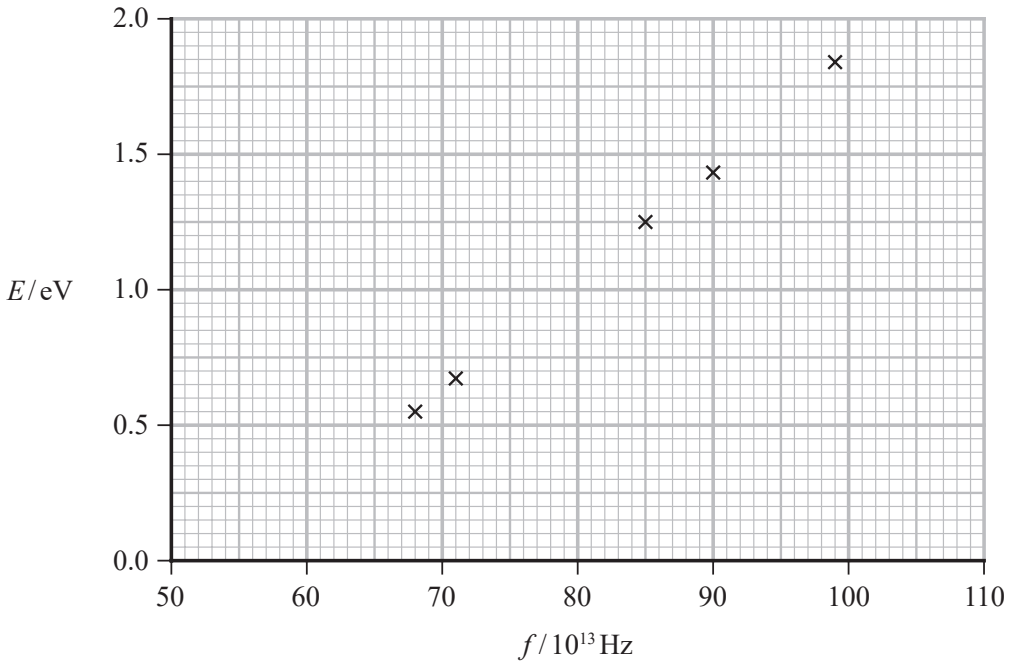
Discuss the extent to which these problems are consistent with obtaining a result from this graph for the Planck constant which is higher than the accepted value.

(3)

(Total for Question 16 = 7 marks)

16 In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



(a) Determine a value for the Planck constant, h, in J s.

(4)

h = ... J s

(b) The table gives data for different metal surfaces.

Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

(Total for Question 16 = 7 marks)

15 The Planck constant is an important universal constant used in the study of wave–particle duality.

(a) In a demonstration of the photoelectric effect, ultraviolet radiation with a frequency of 2.8×10^{16} Hz is incident on the surface of clean zinc. Electrons are released from the surface of the zinc.

Calculate the maximum velocity of the released electrons.

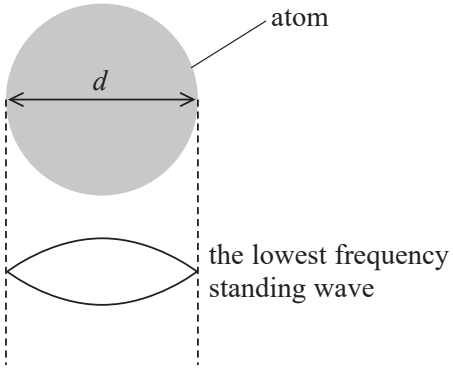
work function of zinc = 6.9×10^{-19} J

(2)

Maximum velocity = ...

(b) Atomic electrons are confined within the atom. One model of atomic electrons suggests that the wave associated with an atomic electron forms a standing wave that fits exactly into the diameter d of the atom.

(i) The diagram shows the lowest frequency standing wave that fits into the diameter of the atom.



Calculate the momentum of the electron.

$d = 2.00 \times 10^{-10}$ m

(3)

Momentum = ...

(ii) Electrons in an atom can only exist at discrete energy levels.

Explain how this standing wave model can account for this.

(2)

.....

.....

.....

.....

.....

(Total for Question 15 = 7 marks)

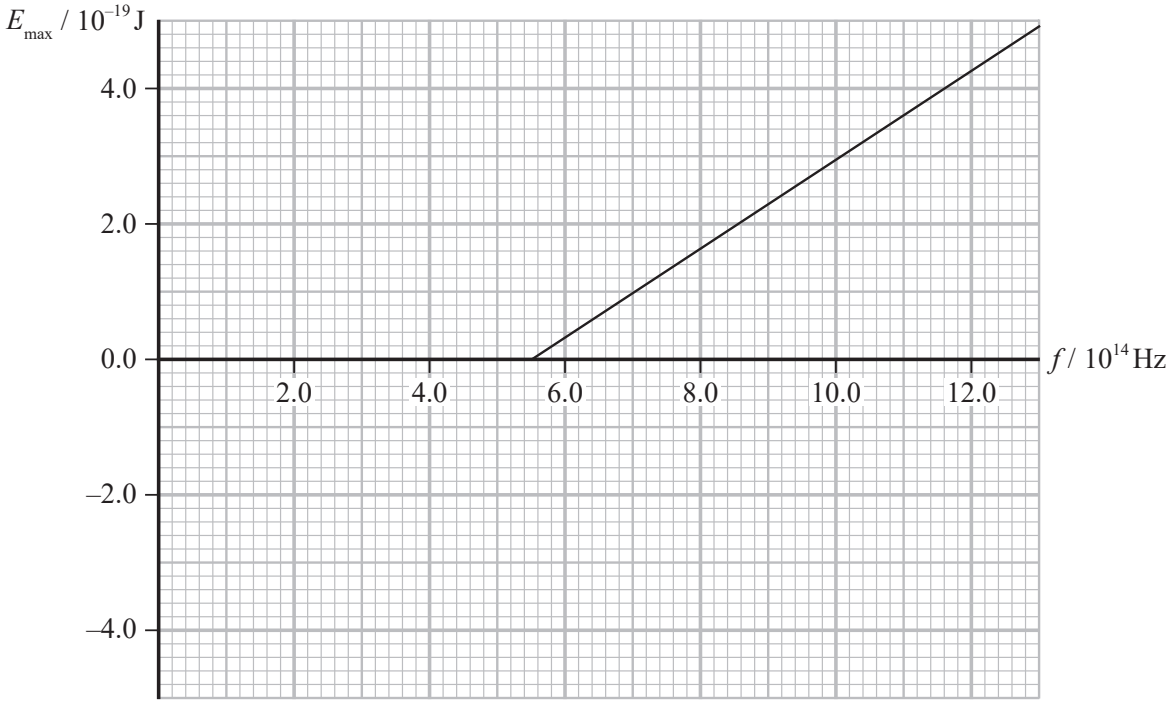
11 In a demonstration of the photoelectric effect, electromagnetic radiation of frequency f was incident on the surface of a metal. The maximum kinetic energy E_{max} of the emitted photoelectrons was determined for increasing values of f.

(a) No photoelectrons are emitted when the frequency of the radiation is below a certain value.

Explain why.

(3)

(b) The graph shows the variation of E_{max} with f.



(i) A photon with frequency 10.0×10^{14} Hz is incident on the metal surface causing a photoelectron to be released.

Calculate the maximum possible velocity v_{max} of the photoelectron.

(2)

v_{max} = ...

(ii) The table shows the work function ϕ for three metals.

Metal	ϕ / eV
caesium	2.2
zinc	4.3
beryllium	5.0

Deduce which metal was used in this demonstration.

(3)

(Total for Question 11 = 8 marks)

17 A coulombmeter is used to measure charge.



In a laboratory demonstration of the photoelectric effect, a sheet of zinc was placed on top of a coulombmeter and the zinc was given a negative charge.

*(a) The following observations were made:

- under normal lighting conditions the charge remained constant
- when the zinc was illuminated with ultraviolet light, the magnitude of the charge on the zinc decreased as time passed
- when a larger sheet of zinc was used the charge on the zinc decreased more rapidly.

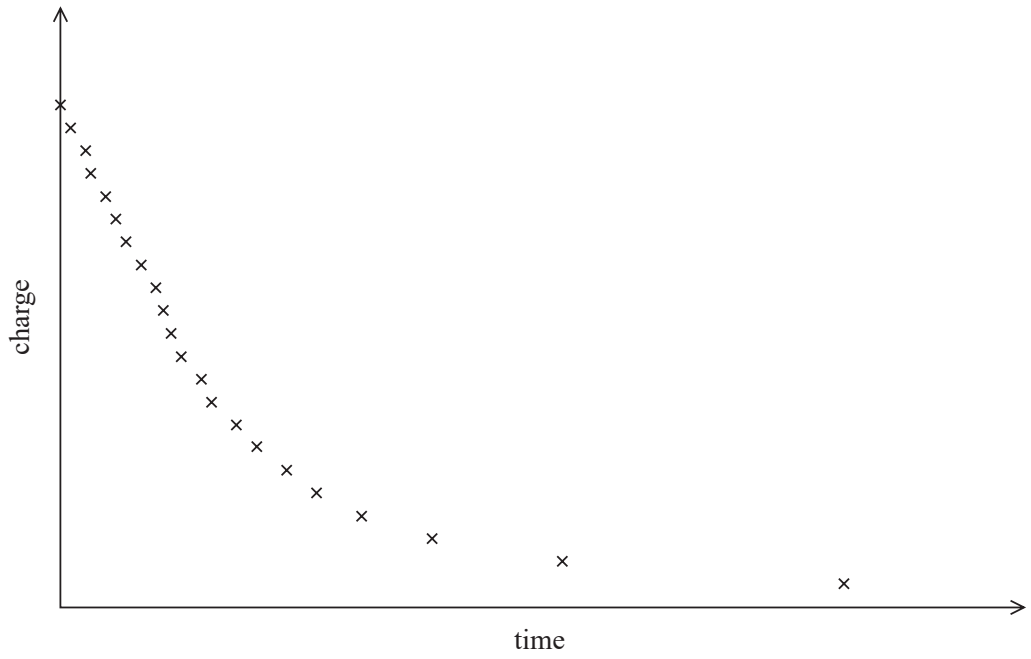
In each case the initial charge on the zinc was the same.

Explain these observations.

(6)

(b) For one sheet of zinc, the charge at different times was measured.

The following graph was obtained.



A student suggests that this is an exponential decay curve.
Explain how this suggestion could be tested.

(3)

(Total for Question 17 = 9 marks)

15 (a) Solar sails are a form of propulsion for spacecraft. The sail is made of a thin sheet of reflective material. When photons of light from the Sun reflect from the material a force is exerted on the sail. The photons reflect with a momentum equal to their initial momentum but in the opposite direction.

(i) Show that a single photon of frequency 1.5×10^{15} Hz has a momentum of about 3×10^{-27} N s.

(2)

.....

.....

.....

.....

(ii) Hence determine the momentum transferred to the solar sail by this photon.

(1)

.....

Momentum transferred = ...

(b) An alternative method of producing a momentum change is being investigated. Researchers have suggested that 'larger changes in momentum could be produced by directing laser light at graphene oxide'. Electrons are emitted from the graphene oxide surface, resulting in a force being exerted on the graphene oxide in the opposite direction.

A researcher has suggested that one possible mechanism for the emission of the electrons is the photoelectric effect.

(i) Show that the maximum velocity for a photoelectron emitted after absorption of a photon of light of frequency 1.5×10^{15} Hz is about 8×10^{5} m s^{-1}.

work function of graphene oxide = 6.7×10^{-19} J

(3)

(ii) Hence calculate the momentum of the photoelectron.

(2)

Momentum of photoelectron = ...

(c) Explain whether the suggestion in (b) that 'larger changes in momentum could be produced by directing laser light at graphene oxide' is true.

(2)

(Total for Question 15 = 10 marks)

13 Spacecraft in orbit will be exposed to ultraviolet radiation from the Sun. Due to the photoelectric effect they can become charged.

(a) Scientists have observed that one such spacecraft becomes charged when the frequency of the radiation is greater than 9.9×10^{14} Hz.

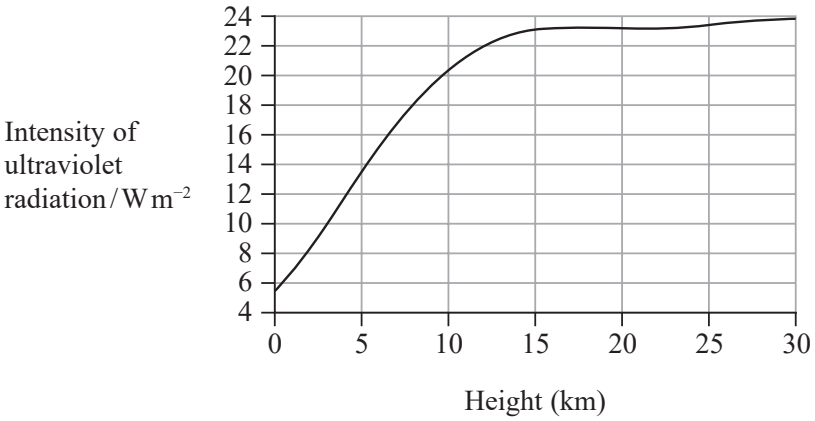
The table lists the work function of some metals.

metal	Work function eV
aluminium	4.1
caesium	2.1
nickel	5.0
platinum	3.3

Deduce the metal that covers the outside of the spacecraft.

(4)

*(b) The graph shows how the intensity of ultraviolet radiation varies with height above the surface of the Earth.



(Source: semanticscholar.org)

An aeroplane made of the same metal as the spacecraft is flying at a height of 10 km.

Explain why the aeroplane charges at a slower rate than the spacecraft due to the photoelectric effect.

(6)

(Total for Question 13 = 10 marks)

15 Read the following extract and then answer the questions that follow.

Powdery dust, the by-product of fearsome meteor storms that pounded the Moon, coats much of the lunar surface. A build-up of this dust could damage sensitive machinery.

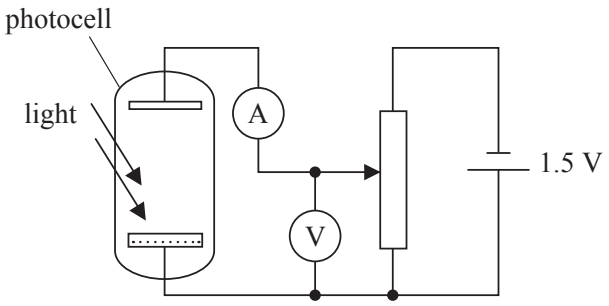
Scientists theorise that lunar dust must be electrostatically charged by ultraviolet solar radiation from the Sun. When ultraviolet radiation hits the Moon's "day side", the half that faces the Sun, it knocks electrons out of atoms in the lunar soil.

(a) Describe the particle model of ultraviolet radiation that explains how it can "knock electrons out of atoms".

(3)

(b) A teacher uses the arrangement below to demonstrate that electrons can be knocked out of a metal surface in a photocell by visible light.

The arrangement can also be used to measure the maximum kinetic energy of these electrons.



(i) Explain how the potential divider circuit can produce a range of values from 0 to 1.5 V on the voltmeter.

(3)

(ii) The potential difference on the voltmeter is increased until the ammeter reading is zero.
The voltmeter reads 0.6 V at this instant.
State the maximum kinetic energy of the electrons in eV.

(1)

Maximum kinetic energy = ... eV

(c) Discuss whether the photocell arrangement in part (b) gives a valid demonstration of how dust particles become charged on the Moon.

(4)

(Total for Question 15 = 11 marks)

9 A student has been learning about the photoelectric effect.

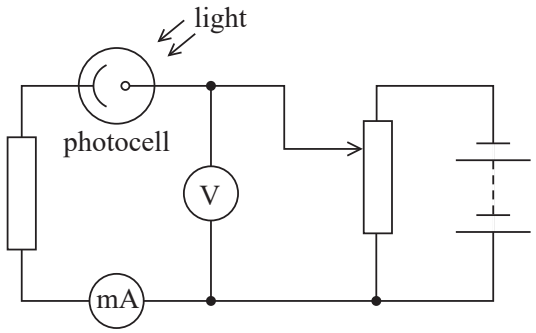
(a) The student was asked by his teacher to explain the photoelectric effect. He gave the following explanation:

Light above a certain threshold is able to free electrons from a metal, because the light gives energy to electrons in the metal.
Some of this energy is used to release the electrons from the metal and the rest becomes kinetic energy of the freed electron.

Discuss whether the student's answer fully explains the photoelectric effect.

(4)

(b) The student sets up a circuit to investigate the photoelectric effect.



The student illuminates the photocell with light of known frequency f. A current is produced in the circuit due to the emitted electrons. He adjusts the potential difference, using a potential divider, until the reading on the milliammeter is zero and records the corresponding reading V_s on the voltmeter. He repeats this procedure for other frequencies of light.

When the reading on the milliammeter is zero the maximum kinetic energy of the emitted electrons is given by eV_s.

Explain how the student can use his results to determine a value for the Planck constant h using a graphical method.

(5)

(c) This experiment demonstrates the particle nature of light.

Explain what is meant by the particle nature of light.

(2)

.....

.....

.....

.....

.....

(Total for Question 9 = 11 marks)

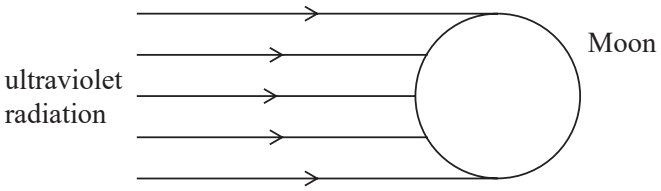
14 Read the extract and answer the questions that follow.

Scientists have observed small dust particles 'jumping' above the Moon's surface. Small particles on the surface of the Moon acquire a charge due to the photoelectric effect, caused by incident ultraviolet radiation from the Sun. Electrostatic forces between charged dust particles cause these particles to move. It is believed this is a mechanism by which dust particles can be transported across vast regions of the Moon.

(a) Explain how the incident ultraviolet radiation causes dust particles to become charged by the photoelectric effect.

(3)

(b) The angle at which the ultraviolet radiation is incident on the Moon varies across its surface, as shown.



The number of dust particles per unit area that become charged is greatest where the ultraviolet radiation is incident on the Moon's surface at 90°.

Explain why.

(3)

(c) The work functions of some minerals that have been found on the surface of the Moon are shown.

Mineral	Work function / eV
ilmenite	4.3
olivine	7.9
pyroxene	5.1

Ultraviolet radiation with a frequency of 2.0×10^{15} Hz is incident on a sample of one of these minerals and electrons are emitted by means of the photoelectric effect.

The released electrons have a maximum kinetic energy of 4.0 eV.

Deduce the mineral from which the photoelectron is released.

(3)

(d) The motion of a charged dust particle on the Moon is influenced by nearby charged dust particles as well as by the Moon's gravity. The lack of an atmosphere on the Moon means that the dust particles experience no resistive forces.

A particular dust particle experiences an electrostatic force of 8.2×10^{-17} N that is perpendicular to the gravitational force. The magnitude of the resultant force on the particle is 8.7×10^{-17} N.

Calculate the magnitude and direction of the acceleration of the particle.

gravitational field strength on the Moon = $1.6\,\text{N kg}^{-1}$
weight of dust particle on the Moon = 3.0×10^{-17} N

(5)

Magnitude of acceleration = ...

Direction of acceleration = ...

(Total for Question 14 = 14 marks)

15 Read the passage and answer the questions below.



© Reuters

The Solar Impulse 2 is a solar-powered plane that completed a round the world trip in 2016 without using fossil fuels.
The wings are covered in thin solar panels, keeping the total mass of the plane and pilot at 1600 kg. The need to reduce the weight limits the efficiency of the solar panels to 23%. However, in daylight, these panels generate enough energy to run the four 7.5 kW electric motors that keep the plane airborne and to fully charge the batteries that power the plane during the night. The batteries take about 6 hours to fully charge.
In daylight the plane flies at a height of 8500 m to harness the most sunlight, and at night descends to 1500 m. This descent makes use of the gravitational potential energy gained during the day to help the plane get through the night.
(Source: www.solarimpulse.com)

(a) The solar panels consist of a series of photocells connected to an external circuit that includes the batteries. When light strikes the photocells, electrons gain energy and are able to move through the external circuit so that the batteries charge up.

Explain why the batteries charge more quickly in high intensity light.

(4)

(b) The solar panels are illuminated with an average light intensity of 1300 W m^{-2} over an 8 hour period in any day.

Calculate the electrical energy generated by the solar panels in one day. (4)

upper area of wings = 200 m^2

Energy = ...

(c) During the night the motors are switched off for 4 hours.
Calculate the battery energy saved by switching off the motors. (2)

Battery energy saved = ...

(d) The plane flies at the greater height during the day. At night it glides down to the lower height over a period of 4 hours, with the motors switched off.

Calculate the change in gravitational potential energy as the plane glides down. (2)

Change in gravitational potential energy = ...

(e) After four hours the engines are switched on again.

Explain whether the plane should fly at a slower horizontal speed at its lower height.

(3)

(f) Comment on how projects such as the Solar Impulse 2 might be of benefit to society at large.

(1)

(Total for Question 15 = 16 marks)

17 In 1905 Einstein published his equation for the photoelectric effect.

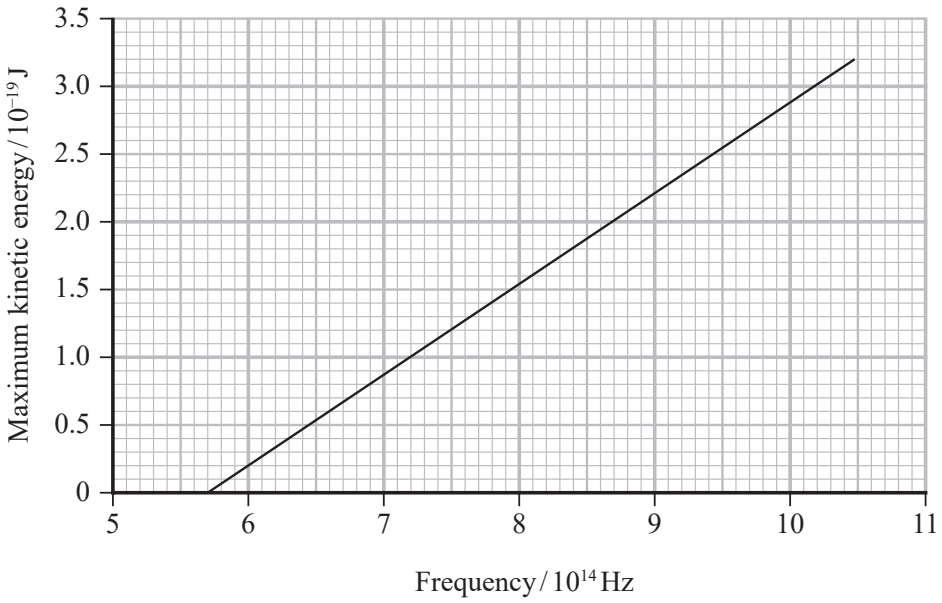
In 1916 Millikan demonstrated that the maximum kinetic energy of photoelectrons is consistent with Einstein's equation.

*(a) Discuss the extent to which our current understanding of observations of the photoelectric effect supports the idea that light behaves as photons rather than as waves.

(6)

(b) Millikan used his data to obtain a value of the Planck constant.

The following graph of maximum kinetic energy of photoelectrons against frequency was produced from his data for the photoelectric effect using lithium.



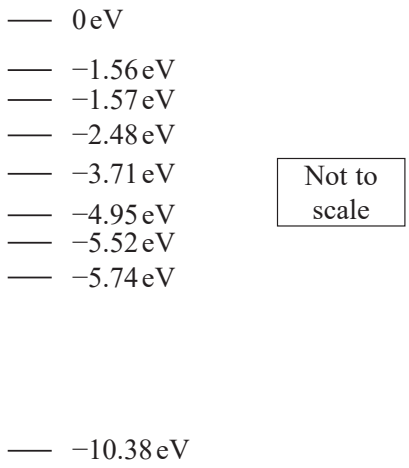
Millikan suggested that the uncertainty from his results for lithium was as little as 1%.

Determine whether the value of the Planck constant obtained from this graph is within 1% of the value stated on the data sheet for this examination paper.

(3)

(c) Millikan's experiments involved using different frequencies of light. These were obtained using a mercury vapour lamp which produced an emission spectrum with a specific number of known frequencies.

The diagram shows some energy levels for a mercury atom.



Determine which transition from the −3.71 eV energy level would produce light of wavelength 6.1×10^{-7} m.

(4)

Transition from −3.71 eV to .....

(d) Millikan used a device known as a monochromator to ensure that a single wavelength of light was used to illuminate the surface of the lithium.
A monochromator separates wavelengths using a diffraction grating.

Calculate the angle at which a diffraction grating would produce the most intense line at a single wavelength of 6.1×10^{-7} m.

number of lines per mm for grating = 600 mm^{-1}

(3)

Angle = ...

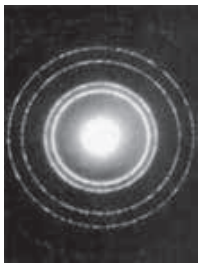
(Total for Question 17 = 16 marks)

SUB-TOPIC 5.8

ELECTRON DIFFRACTION AND WAVE-PARTICLE DUALITY

Sub-topic 5.8 · 10 questions · 40 marks · lowest tariff first

5 The image shows a diffraction pattern formed when a beam of electrons passes through thin metal foil.

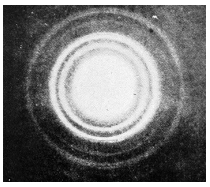


Which of the following would cause the diameter of the rings to increase?

- ☒ **A** Decreasing the number of electrons in the beam.
- ☒ **B** Decreasing the speed of electrons in the beam.
- ☒ **C** Increasing the number of electrons in the beam.
- ☒ **D** Increasing the speed of electrons in the beam.

(Total for Question 5 = 1 mark)

5 The image shows a diffraction pattern observed when a beam of electrons is fired at thin gold foil.



(Source: © The Reading Room/Alamy Stock Photo)

What property of electrons does this observation demonstrate?

☒ **A** they exist in discrete energy levels

☒ **B** they have a negative charge

☒ **C** their small mass

☒ **D** their wave nature

(Total for Question 5 = 1 mark)

7 An electron travels at a velocity v.

Which of the following is the correct expression for the de Broglie wavelength λ of the electron?

☒ **A** $\lambda = \dfrac{3.00 \times 10^{8}}{9.11 \times 10^{-31} \times v}$

☒ **B** $\lambda = \dfrac{9.11 \times 10^{-31} \times v}{3.00 \times 10^{8}}$

☒ **C** $\lambda = \dfrac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times v}$

☒ **D** $\lambda = \dfrac{9.11 \times 10^{-31} \times v}{6.63 \times 10^{-34}}$

(Total for Question 7 = 1 mark)

4 In an electron diffraction experiment, electrons are accelerated by a potential difference between a hot filament and an anode. The electron beam produced strikes a sample of crystalline material causing a diffraction pattern.

Which of the following would cause the angle of diffraction to increase?

- ☒ **A** decreasing the distance between the filament and the anode
- ☒ **B** decreasing the potential difference
- ☒ **C** increasing the filament temperature
- ☒ **D** using a crystalline material with a larger lattice spacing

(Total for Question 4 = 1 mark)

3 In the 19th century experiments with magnetic and electric field deflections were used to determine the charge to mass ratio of electrons.
Later experiments showed the diffraction of electrons as they passed through thin metal foils.
Deduce what these experiments tell us about electrons.

(3)

(Total for Question 3 = 3 marks)

9 In the 1920s Louis de Broglie proposed that an electron could behave as a wave.

Calculate the wavelength of an electron that is travelling at a speed of $2.2 \times 10^7 \text{ m s}^{-1}$.

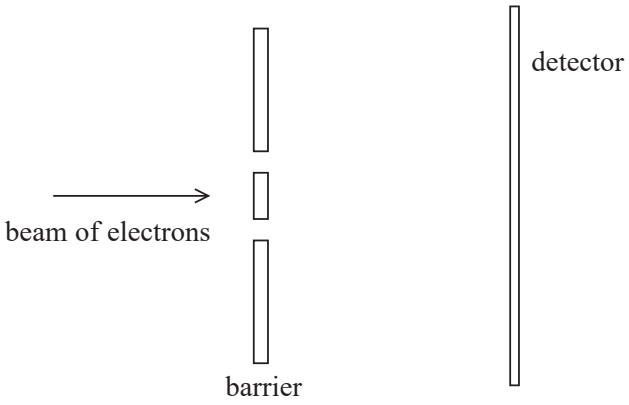
(3)

Wavelength = ...

(Total for Question 9 = 3 marks)

14 In 1965, Richard Feynman proposed a double slit experiment to investigate the wave properties of electrons.

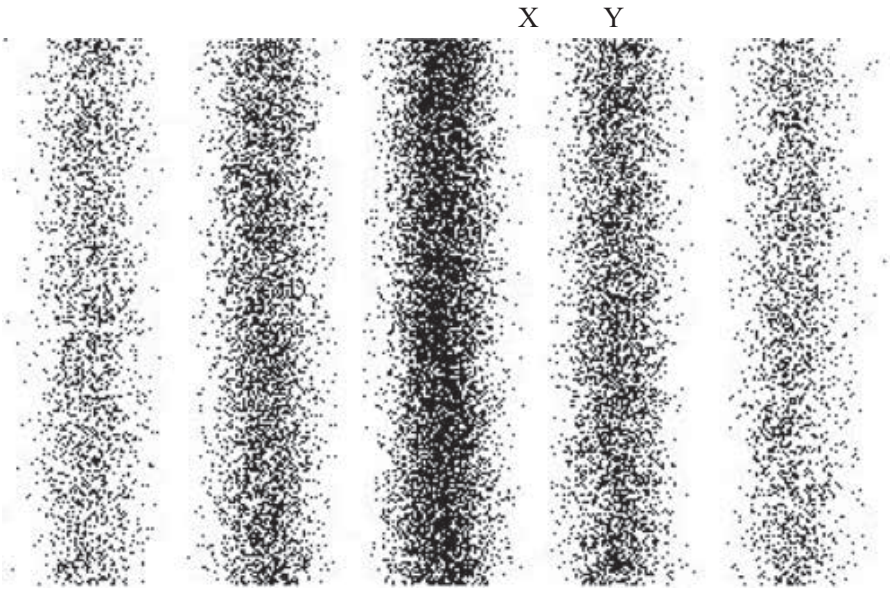
The experiment was later carried out using the arrangement shown.



A beam of electrons was directed at a barrier with two slits.

The detector recorded the positions where electrons arrived after passing through the slits.

The following pattern was obtained. Black dots represent points where electrons were detected. A band where electrons were not detected has been labelled X and a band where electrons were detected has been labelled Y.



The path difference for electrons arriving at band X from the separate slits was 2.5×10^{-11} m. For electrons arriving at band Y the path difference was 5.0×10^{-11} m.

Explain why this pattern is observed when the electron energy is 9.6×10^{-17} J.

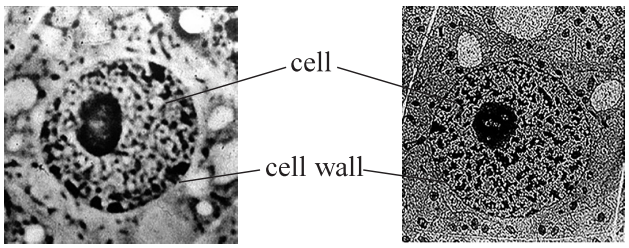
The electrons are travelling at non-relativistic speeds.

(6)

(Total for Question 14 = 6 marks)

14 An optical microscope uses a beam of visible light. An electron microscope uses a beam of electrons.

A biologist looked at an animal cell using both microscopes. The two images are shown; both have the same magnification.



using optical microscope using electron microscope

www.udel.edu

(a) An electron in the beam of the electron microscope has a velocity of 2% of the speed of light.

Calculate the de Broglie wavelength of the electron.

(3)

de Broglie wavelength = ...

(b) The image of the animal cell produced by the electron microscope is less blurred than the image produced by the optical microscope.

Explain why.

(2)

(c) The biologist measured the diameter of the cell from one of the images. He recorded four measurements. The image had a magnification of ×800.

Diameter of image /cm			
2.4	2.5	1.1	2.2

Determine a value for the diameter of the actual cell.

(2)

Diameter of cell = ...

(Total for Question 14 = 7 marks)

16 In 1930 Niels Bohr suggested that electrons in orbit in an atom exist at discrete energies. The scientist de Broglie suggested that an electron exhibits wave-like properties. This was used to explain why electrons exist at discrete energy levels.

(a) (i) The wave produced by the electron sets up a standing wave around the circumference of its orbit.

In the lowest energy state one wavelength fits into the circumference of the electron's orbit.

Calculate the wavelength at the lowest energy state.

radius of orbit of the electron = 5.3×10^{-11} m

(2)

.....

.....

.....

.....

Wavelength at the lowest energy state = ...

(ii) Explain how electron standing waves can exist at different discrete energy levels.

(2)

.....

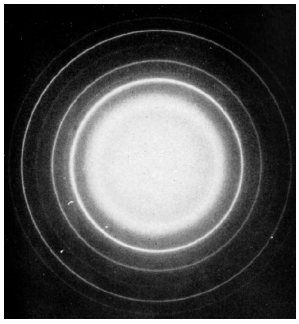
.....

.....

.....

(b) Electrons exhibit wave-like properties when they undergo diffraction.

The photograph shows a diffraction pattern observed when an electron beam is passed through a thin piece of graphite.



(Source: © Bookworm/Alamy Stock Photo)

(i) An electron in the beam travels at $5.9 \times 10^6\ \text{m s}^{-1}$.

Calculate the de Broglie wavelength of the electron.

(2)

de Broglie wavelength = ...

(ii) The diameters of the rings in the diffraction pattern decrease as the speed of the electron beam is increased.

Explain why.

(2)

(Total for Question 16 = 8 marks)

13 An electron beam is directed onto crystalline graphite. A fluorescent screen on the other side of the crystal shows the pattern in Figure 1. The brighter areas correspond to higher electron intensity.

The speed of the electrons is increased and the resulting pattern is shown in Figure 2.

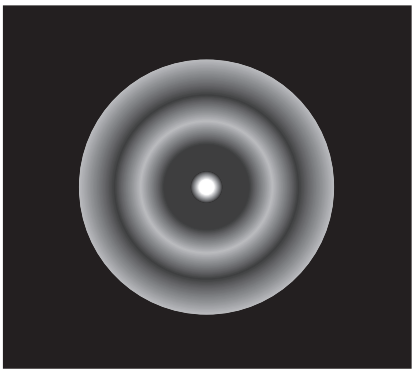


Figure 1

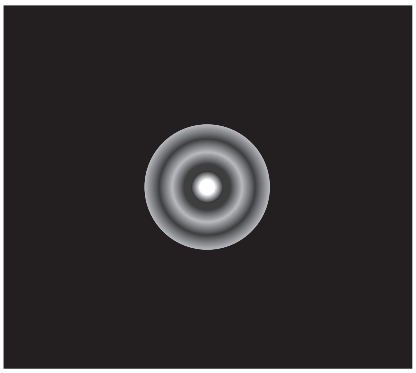
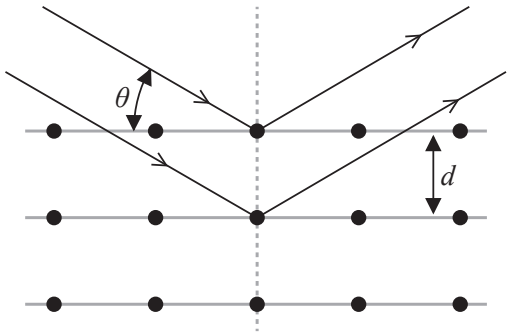


Figure 2

*(a) Discuss the conclusions that can be drawn from this information about the behaviour of electrons and the structure of graphite.

(6)

(b) An electron beam can be used to explore the structure of solid materials. The diagram shows an electron beam reflected by the top two layers of atoms within a material. The two layers are separated by a distance d.



(i) Show that the extra distance travelled by the electron beam reflecting off the second layer of atoms is given by $2d\sin\theta$.

θ is the angle between the beam and each layer of atoms.

You may add to the diagram.

(2)

(ii) Give one reason why there is more than one ring shown in both Figure 1 and Figure 2.

(1)

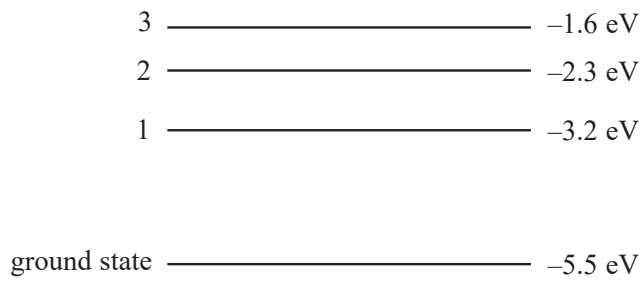
(Total for Question 13 = 9 marks)

SUB-TOPIC 5.9

ENERGY LEVELS AND ATOMIC SPECTRA

Sub-topic 5.9 · 11 questions · 86 marks · lowest tariff first

5 The diagram shows the lowest energy levels for a certain atom.



A photon with energy 3.2 eV is absorbed.

An electron could move from

☒ **A** ground state to level 1.

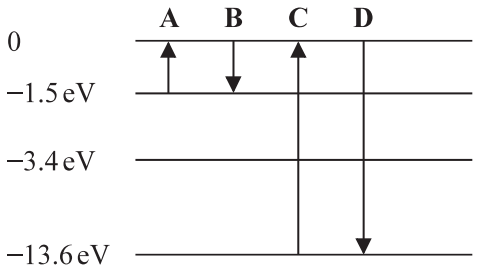
☒ **B** ground state to level 2.

☒ **C** level 1 to ground state.

☒ **D** level 2 to ground state.

(Total for Question 5 = 1 mark)

3 Some of the energy levels of an atom of a gas are shown.

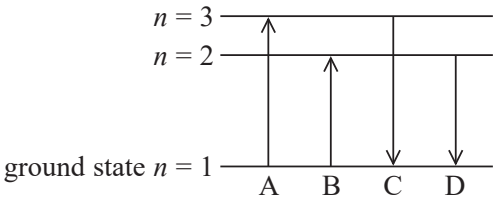


During which transition, A, B, C or D, is electromagnetic radiation with the shortest wavelength emitted?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 3 = 1 mark)

7 The energy level diagram shows four possible energy transitions for an electron in an atom.



Which arrow shows the transition made by the electron when the atom emits radiation with the longest wavelength?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 7 = 1 mark)

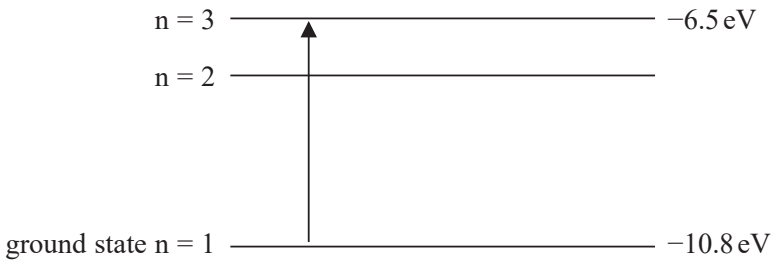
3 An electron in an atom absorbs energy E and is excited from one energy level to the next. When the electron returns to its original energy level a photon is emitted.

Which of the following is an expression for the wavelength of the emitted photon?

- ☒ **A** $\frac{hc}{E}$
- ☒ **B** $\frac{E}{hc}$
- ☒ **C** $\frac{Eh}{c}$
- ☒ **D** $\frac{c}{Eh}$

(Total for Question 3 = 1 mark)

11 An electron in its ground state absorbs electromagnetic radiation of wavelength λ.
The energy level diagram represents the resulting energy transition of the electron.



(a) Calculate the wavelength of radiation absorbed by the electron.

(3)

Wavelength = ...

(b) The electron eventually returns to its ground state.

Explain, with reference to the energy level diagram, how this may result in the emission of radiation with a longer wavelength than λ.

(3)

(Total for Question 11 = 6 marks)

12 In 1925 Franck and Hertz were awarded the Nobel Prize in Physics "for their discovery of the laws governing the impact of an electron upon an atom".
In one of their experiments, a beam of high-speed electrons is fired through mercury vapour.

An electron in the beam collides with a mercury atom, which becomes excited. The atom returns to its initial state by emitting electromagnetic radiation of a single frequency.

(a) Explain why excited atoms only emit certain frequencies of radiation.

(5)

(b) An electron travelling with a speed of 2.5×10^6 m s^{-1} collides with a stationary mercury atom and continues at a speed of 2.1×10^6 m s^{-1}.

The table gives a range of wavelengths for ultraviolet, visible and infrared radiation.

Type of radiation	Typical range of wavelengths / m
ultraviolet	2.0×10^{-7} to 4.0×10^{-7}
visible	4.0×10^{-7} to 7.8×10^{-7}
infrared	7.8×10^{-7} to 1.0×10^{-3}

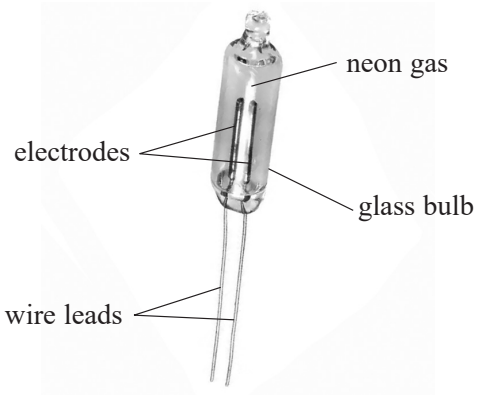
Deduce the type of radiation that is emitted by the stationary mercury atom.

(4)

Type of radiation .....

(Total for Question 12 = 9 marks)

7 The neon lamp shown is a glass bulb filled with neon gas at low pressure.



(Source: https://media.digikey.com/Photos/Visual%20Communications%20Company%20VCC/A1A.JPG)

*(a) When in use, the neon gas between the electrodes emits electromagnetic radiation.

Explain why this happens when there is an electric current between the electrodes.

(6)

(b) When light from the neon lamp is incident upon a metal surface, electrons with a maximum speed of $2.68 \times 10^5\,m\,s^{-1}$ are emitted from the surface.

The table shows the work functions of some metals.

Metal	Caesium	Potassium	Sodium
Work function / 10^{-19} J	3.36	3.68	3.84

Deduce which metal the light is incident upon.

frequency of light from the neon lamp = 5.56×10^{14} Hz

(4)

(Total for Question 7 = 10 marks)

16 Read the passage and answer the questions that follow.

Atoms can be promoted into an excited state when they absorb energy. This results in the release of radiation at a random time. When several atoms are close together a quantum effect can occur. When one atom emits radiation this affects all the other nearby excited atoms. The excess energy of many of the atoms is released simultaneously and an intense flash of light is produced. This effect is called superradiance and can be used to produce lasers that emit a narrower range of frequencies than conventional lasers.

(a) When superradiance occurs the atoms all absorb the same amount of energy.

Explain how this results in all the atoms emitting radiation of a particular frequency.

(5)

(b) Superradiance occurs when the distance between atoms is less than the wavelength of the emitted radiation.

An atom is in the ground state. The atom absorbs 6.2 eV of energy. The distance between neighbouring atoms is 140 nm.

Deduce whether superradiance can occur.

(3)

(c) Superradiant lasers are highly monochromatic.

Explain why a monochromatic light source is important in diffraction experiments.

(3)

(Total for Question 16 = 11 marks)

15 Read the extract and answer the questions that follow.

The MAVEN satellite orbits Mars, collecting data on the atmosphere of Mars. Analysis of the data has detected hydrogen atoms in the upper regions of the atmosphere.

It is thought that these atoms originate from water molecules that have risen from the surface of Mars. As the molecules ascend, the bonds between the oxygen and the two hydrogen atoms break.

A hydrogen atom with sufficient energy may escape the atmosphere of Mars.

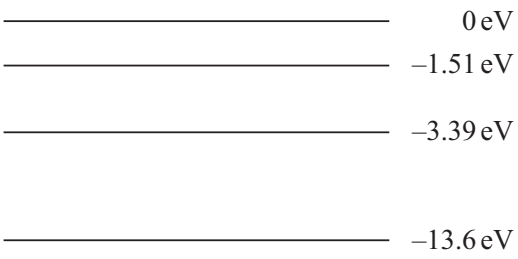
(a) Radiation from the Sun passes through the gases in the atmosphere of Mars.

The electron in a hydrogen atom absorbs and re-emits radiation. Emission line spectra are detected by the satellite.

(i) Explain how these emission spectra are created.

(4)

(ii) The diagram shows some of the energy levels for a hydrogen atom.



Deduce the transition which would result in the emission of light with a wavelength of 660 nm.

(4)

Transition ..... eV to ..... eV

(iii) The concentration of hydrogen atoms in the atmosphere of Mars is not constant.

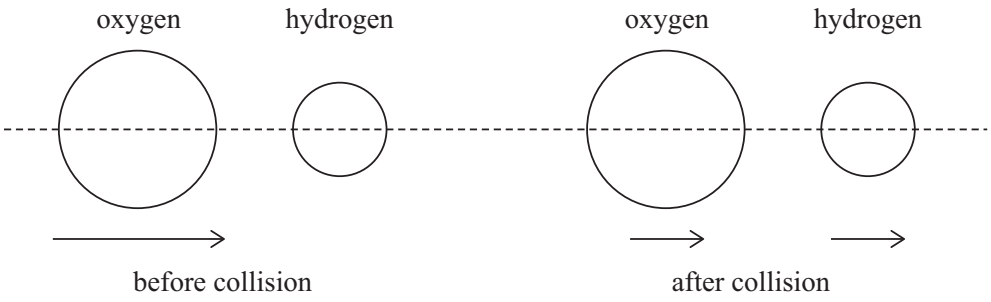
Explain why the intensity of the radiation received by the detectors on the satellite increases as the concentration of hydrogen atoms increases.

(2)

(b) Collisions between the atoms in the atmosphere of Mars cause the speed of these atoms to change.

An oxygen atom, travelling at 2210 m s^{-1}, collides with a stationary hydrogen atom. Following the collision, the oxygen atom continues at a speed of 1870 m s^{-1}. The hydrogen atom moves off in the same direction, as shown.

Not to scale



An atom can escape the atmosphere when it has a velocity of around 5000 m s^{-1}.

Deduce whether this hydrogen atom can escape the atmosphere of Mars.

mass of hydrogen atom = 1.67×10^{-27} kg
mass of oxygen atom = 2.66×10^{-26} kg

(4)

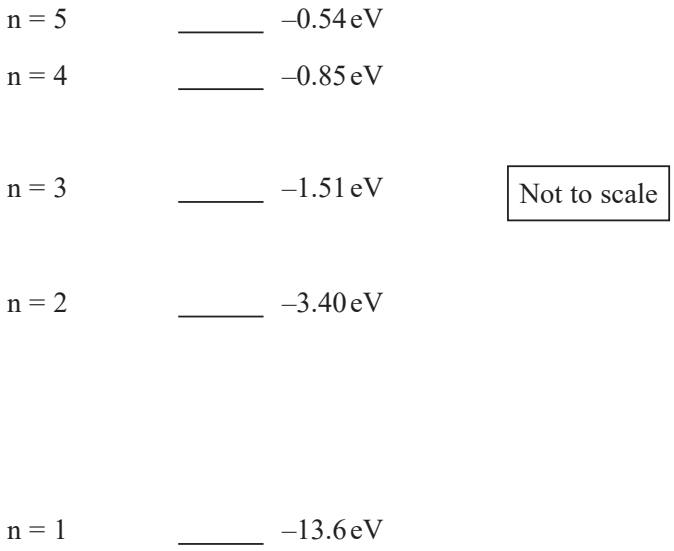
(Total for Question 15 = 14 marks)

18 In 1864, William Huggins and William Miller used dark lines in the spectrum of the Sun to identify elements in the Sun's atmosphere.

*(a) Explain how gases in the Sun's atmosphere cause dark lines in the spectrum corresponding to different elements.

(6)

(b) The diagram shows some energy levels of a hydrogen atom.



The absorption spectrum for hydrogen includes a set of lines that all derive from transitions involving the n = 2 energy level. One of these lines is known as the hydrogen-alpha line.

Deduce the transition involved in the formation of the hydrogen-alpha line.

wavelength of hydrogen-alpha line = 656.46 nm

(4)

(c) In 1868, William Huggins analysed light from the star Sirius A. The wavelength of the hydrogen-alpha line for light from Sirius A was slightly different from the hydrogen-alpha line observed from a source in a laboratory.

Huggins suggested that this difference could be explained using the Doppler effect and could be used to determine the speed and direction of the star's motion relative to the Earth.

(i) Assess Huggins's suggestion.

(3)

(ii) Sirius A has a component of velocity away from the Earth of $5.5\,\text{km}\,\text{s}^{-1}$.

The wavelength of the hydrogen-alpha line observed from a source in the laboratory is 656.46 nm.

Calculate the wavelength of the hydrogen-alpha line as seen in the spectrum of Sirius A.

(2)

Wavelength = ...

(Total for Question 18 = 15 marks)

12 Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

*(a) The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure.

Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases.

(6)

(b) The nuclear model of the atom was established following a series of experiments in which alpha particles were directed at thin gold foil.

(i) An alpha particle approaching a gold nucleus, $^{197}_{79}Au$, head-on will be brought to rest and returned along its original path.

Calculate the minimum distance between the alpha particle and the nucleus for alpha particles of energy of 5.5 MeV.

(4)

Minimum distance = ...

(ii) It is observed that electrons, with energy of 5.5 keV, are diffracted as they pass through the thin gold foil.

Explain a conclusion about the electrons that can be made from this observation.

(3)

(c) In the energy ladder model of the atom, electrons exist in a discrete number of allowed energy states. The collision of electrons with gold atoms may lead to the production of high frequency electromagnetic radiation.

Explain how high frequency electromagnetic radiation may be produced when electrons collide with atoms in a metal.

(4)

(Total for Question 12 = 17 marks)

MARK SCHEMES

official mark schemes

Question Number	Acceptable answers	Additional guidance	Mark
1	A Sound can travel through a solid.		**1**

Question Number	Acceptable answers	Additional guidance	Mark
2	C W m^{-2}		**1**

Question Number	Acceptable answers	Additional guidance	Mark
6	D 90 degrees		**1**

Question Number	Acceptable answers	Additional guidance	Mark
8	D transverse, longitudinal		**1**

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
4	**A** $\frac{2\pi t}{T}$	**1**
	Incorrect Answers: B – no factor of 2 C – incorrect substitution of f D – incorrect substitution of f and no factor of 2	

6	**D 4P Using $I = \frac{P}{A}$**	**1**
	Incorrect Answers: A – Incorrect arrangement of the equation B – Incorrect arrangement of the equation and incorrect use of πr^2 with $2r$ C - Incorrect use of πr^2 with $2r$	

8	**C the reflected pulse can be detected before the next pulse is transmitted**	**1**
	Incorrect Answers: A – incorrect B – This is limited by the wavelength D – Diffraction is affected by wavelength	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
2	**C** $t = \frac{90\times2}{1500}$	**1**
	Incorrect Answers: A -no factor of 2 B - no factor of 2 and incorrect equation D - incorrect equation	

6	**C** $-\frac{\pi}{5}$ $(\frac{1}{10} \times 2\pi)$	**1**
	Incorrect Answers: A – the waves would be in antiphase B – the waves would be a quarter of a wave out of phase D – the waves would be a 20^{th} of a wave out of phase	

Question Number	Answer	Mark
2	**C** $\frac{3.0\times10^{8}\times t}{2}$	**1**
	Incorrect Answers: A – incorrect factor of 2 B – incorrect factor of 2 and speed D – incorrect speed	

Question Number	Answer	Mark
6	**B** $2\pi tf$	**1**
	Incorrect Answers: A – incorrect expression C– incorrect expression D – incorrect expression	

Question Number	Answer	Mark
7	**B** fd	**1**
	Incorrect Answers: A – incorrect expression C – incorrect expression D – incorrect expression	

Question Number	Answer	Mark
3	**A**	**1**
	Incorrect Answers: **B** incorrect arrangement **C** incorrect formula for area of a circle **D** incorrect arrangement and incorrect formula for area of a circle	

6	**B**	**1**
	Incorrect Answers: **A** compression and rarefaction both occur at regions of 0 displacement **C** compression and rarefaction both occur at regions of 0 displacement **D** compression and rarefaction are labelled the wrong way round with respect to the direction of the positive displacement	

Question Number	Answer	Mark
1	The only correct answer is A because detail is improved by both decreasing pulse length and decreasing wavelength B increasing wavelength decrease detail C increasing pulse length decrease detail D increasing pulse length and increasing wavelength both decrease detail	1

Question Number	Answer	Mark
6	The only correct answer is D because there is relative motion of the objects away from each other so the wavelength is increased by the Doppler effect so the observed frequency is decreased A there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased B there is no relative motion for the objects so there is no observed change in wavelength or frequency C there is relative motion of the objects towards each other so the wavelength is decreased by the Doppler effect so the observed frequency is increased	1

7	**D –** both are moving up	**1**
	Incorrect Answers: A – incorrect answer B – incorrect answer C – incorrect answer	

8	**D** – $\frac{P}{\pi r^2}$	**1**
	Incorrect Answers: A – Incorrect equations B – Incorrect equation for area of a circle C – Incorrect equation	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
6	**C** $\frac{\pi\pi}{33}$	**1**
	Incorrect Answers: **A** – incorrect **B** – incorrect **D** – incorrect	

8	**D wavelength**	**1**
	Incorrect Answers: **A –** determined from the maximum displacement on y-axis **B –** determined from 1/time for one cycle **C –** determined from the time for one cycle on x-axis	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
3	**C** $\frac{1}{5 \times 50 \times 10^{-6}}$	1
	A – incorrect calculation B– incorrect calculation D– incorrect calculation	

Question Number	Answer	Mark
1	**The only correct answer is C** **A** *is not correct because* this is an eighth of a wavelength apart **B** *is not correct because* this is a quarter of a wavelength apart **D** *is not correct because* this is one wavelength apart	1

10	**The only correct answer is C,** Y leads X by 90° A is not correct because Y reaches a maximum displacement a quarter of a cycle ahead of X B is not correct because Y reaches a maximum displacement a quarter of a cycle ahead of X D is not correct because Y reaches a maximum displacement a quarter of a cycle ahead of X	**1**

Question Number	Answer	Mark
1	**C** $W m^{-2}$	1
	Incorrect Answers: A – Incorrect units B – Incorrect units D – Incorrect units	

Question Number	Answer	Mark
5	**D** $\frac{3\pi}{2}$	1
	Incorrect Answers: A – Incorrect phase difference B – Incorrect phase difference C – Incorrect phase difference	

Question Number	Acceptable Answers	Additional guidance	Mark
9(a)	• Use of $f = \frac{1}{T}$ with T = 125 μs (1) • 8000 Hz (1)	Example of calculation $f = \frac{1}{1.25\times10^{-8}\ \text{s}}$ = 8000 Hz	2
9(b)	• Fewer waves/cycles on screen (1)	Accept wavelength increases	1

(Total for question 9 = 3 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
10(a)	• Use of $v = \frac{s}{t}$ with a factor of 2 (1) **Either** • t = 125 μs • Comparison of their calculated value with 160 μs to reach a conclusion consistent with their answer (1) (1) **Or** • s = 0.256 m • Comparison of their calculated value with 0.2 m to reach a conclusion consistent with their answer (1) (1)	Example of calculation $s = \frac{3200\ \text{m s}^{-1} \times 1.25\times10^{-4}\ \text{s}}{2} = 0.2\ \text{m}$ $t = \frac{2 \times 0.2\ \text{m}}{3200\ \text{m s}^{-1}} = 250\ \mu\text{s}$ 125 μs < 160 μs so detected	**3**
10(b)	• Use of $\Delta E_{el} = \frac{1}{2}F\Delta x$ (1) • 0.026 J (1)	Example of calculation $\Delta E_{el} = \frac{1}{2} \times 130\ \text{N} \times 4.0 \times 10^{-4}\ \text{m} = 0.026\ \text{J}$	**2**

(Total for Question 10 = 5 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*10</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
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<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
Indicative Content
IC1 Pulses of light are emitted from laser/Earth or Pulses of light sent to the Moon/mirror
IC2 Light reflects from the mirrors
IC3 Measure the time taken for the reflected light to return
IC4 Calculate distance = speed x time
IC5 Use speed of light c
IC6 Measured time must be divided by 2
Or calculated distance must be divided by 2
</td>
<td>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

(Total for Question 10 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	• Use of $v = \frac{s}{t}$ with v = 340 m s^{-1} **(1)** • Use of correct factor of two **(1)** • 6.1 m **(1)**	Example of calculation s = 340 m s^{-1} × $\frac{36 \times 10^{-3}\text{ s}}{2}$ = 6.12 m	**3**
9(b)	**EITHER** • (as the bat gets closer) the reflected pulses take less time to return **(1)** • The bat reduces the time between emitted pulses **(1)** • So the bat can detect small changes in the moth's position/speed **Or** To give the bat more frequent updates **(1)** **OR** • At greater distances the reflected pulse takes a longer time to return **(1)** • The time between pulses needs to be longer **(1)** • So that the reflected pulse returns before the next pulse is emitted **(1)**		**3**

(Total for Question 9 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
10(a)	• Use of $s = ut$ **(1)** • Correct use of a factor of two **(1)** • Distance = 3.1 m **(1)**	Example of calculation $1500\ \text{m s}^{-1} = \frac{2s}{4.1 \times 10^{-3}\ (\text{s})}$ s = 3.08 m	**3**
10(b)	• So reflected pulse returns before next pulse is transmitted **(1)**		**1**
10(c)	• High frequency has a short wavelength **(1)** • Short wavelengths diffract less around smaller objects **Or** Greater amount of detail can be detected **(1)**		**2**

(Total for Question 10 = 6 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*10</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning.
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
Indicative content:

IC1 The soundwave is emitted in <u>pulses</u>
IC2 (The pulses) reflect from the seabed.
IC3 The reflected pulses are detected/received (by the transducer at sea level)
IC4 The time between the emission and detection (of the pulse) is measured/recorded
IC5 The distance travelled (by the pulses) is calculated by speed of sound (in water) × time taken to return
IC6 Depth of ocean is half the calculated distance
</td>
<td>
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
Accept a correct factor of 2
</td>
<td>6</td>
</tr>
</table>

(Total for Question 10 = 6 marks)

7(a)	An explanation that makes reference to the following: • The time interval is very short **(1)** • the idea of a high sample rate (with the datalogger) **Or** (Percentage) uncertainty in measurement would be small (when using the datalogger). **(1)**	MP2 examples: time interval between measurements is small Many recordings/sec	**2**
7(b)(i)	• Correct time(s) read from graph **(1)** • Use of $v = \frac{s}{t}$ **(1)** • $v = 5900\ (\text{m s}^{-1})$ **(1)**	<u>Example of calculation:</u> $t = (1400 - 1000) \times 10^{-6}$ s $v = \frac{2L}{t} = \frac{2 \times 1.18\ \text{m}}{400 \times 10^{-6}\ \text{s}} = 5900\ \text{m s}^{-1}$	**3**
7(b)(ii)	• Substitution into $E = v^2 \rho$ ecf from (b)(i) **(1)** • $E = 2.7 \times 10^{11}$ Pa **(1)**	MP2 accept N m^{-2} for units 'show that value' gives $E = 2.8 \times 10^{11}$ Pa <u>Example of calculation:</u> $E = v^2\rho = (5900\ \text{m s}^{-1})^2 \times 7850\ \text{kg m}^{-3}$ $\therefore E = 2.73 \times 10^{11}$ Pa	**2**

(Total for Question 7 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• He should have moved the microphone over more in-phase positions (to determine multiple wavelengths) • This would reduce the uncertainty in the value (for *d*) (dependent upon MP1)	(1) (1)	**Alternative:** MP1: move microphone between antiphase positions MP2: as it is easier to judge when waves are in antiphase (peak corresponds to a trough)	**2**
6(b)	• No of divisions read from oscilloscope trace • Use of time base setting • Use of $f = 1/T$ • Use of $v = f\lambda$ • $v = 340$ m s^{-1}	(1) (1) (1) (1) (1)	MP1: Must be for a recognised part of wave Example of calculation $T = 3 \times 0.20 \times 10^{-3}$ s $= 6.0 \times 10^{-4}$ s $f = \frac{1}{6.0 \times 10^{-4}\text{ s}} = 1.67 \times 10^{3}$ Hz $v = 1.67 \times 10^{3}$ s^{-1} $\times$ 0.205 m $= 342$ m s^{-1}	**5**

(Total for Question 6 = 7 marks)

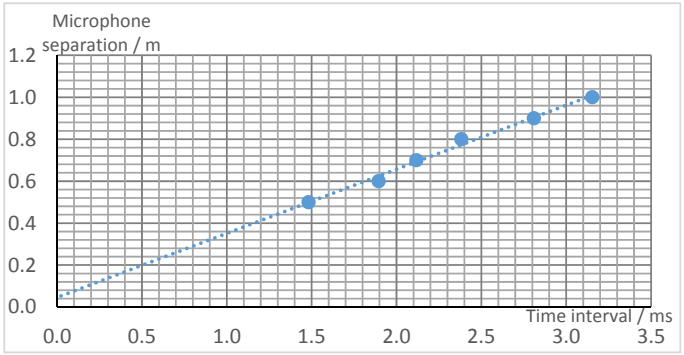
Question Number	Acceptable Answer		Additional Guidance	Mark
5(a)	• μ read from graph	**(1)**	Accept μ in the range 140 (m^{-1}) - 160 (m^{-1})	
	• Use of $I = I_0 e^{-\mu x}$	**(1)**		
	• I = 1.5 W m^{-2}	**(1)**	Accept answers that round to 1.4 W m^{-2} or 1.5 W m^{-2} dependent upon value of μ for MP3 Example of calculation: I=1.8 W m^{-2} × $e^{-150\ m^{-1} \times 1.4 \times 10^{-3}\ m}$ = 1.46 W m^{-2}	**3**
5(b)	• (for deoxygenated blood) μ is greater for red	**(1)**	Accept values for μ which show $\mu_{red} > \mu_{IR}$ for MP1	
	• hence more red is absorbed **Or** intensity is smaller for red **Or** $e^{-\mu x}$ is smaller for red	**(1)**	Allow numerical substitutions for MP2 and MP3	
	• So I/I_0 is smaller for red [dependent upon MP2]	**(1)**	Accept converse argument leading to same conclusion	**3**
5(c)	• Use of $\lambda_{max} T = 2.898 \times 10^{-3}$ m K	**(1)**	Ignore references to the wavelength of red light	
	• λ_{max} = 910 nm	**(1)**	Example of calculation: $\lambda_{max} = \frac{2.898 \times 10^{-3}\ \text{m K}}{3200\ \text{K}} = 9.06 \times 10^{-7}$ m	
	• Yes, because peak emission occurs at a wavelength close to 950 nm	**(1)**		**3**

(Total for Question 5 = 9 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
14(a)	• Use of $n = \frac{c}{v}$ (1) • Use of $n_1 sin\theta\theta_1 = n_2 sin\theta\theta_2$ (1) • Uses $\sin C = \frac{1}{n}$ (1) • Comparison of $C = 50°$ with 30° and conclusion (1)	Example of Calculation $n_{\text{(air-water)}} = \frac{3.0 \times 10^8}{2.25 \times 10^8} = 1.33$ $\sin 40 = 1.33 \sin\theta\theta_2$ $\theta\theta_2 = 29°$ At X: $\sin C = \frac{1}{1.33}$ C = 49° > 29° so refracted	4
(b)(i)	• Use of node to node distance = $\frac{\lambda}{2}$ (1) • Use of $v = f\lambda$ (1) • v = 340 m s^{-1} (1)	Example of Calculation λ = 2 x 0.86 m = 1.72 m v = 200 s^{-1} x 1.72 m = 344 m s^{-1}	3
(b)(ii)	• Wavelength is 1.7 m which is the same order of magnitude as 2 m (1) • Diffraction will take place so sound will be heard at Y (1)	Example of Calculation λ = 2 x 0.86 (m) = 1.7 m	2

(Total for Question 14 = 9 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>15(a)</td><td>• No repeats
Or range too small
Or readings should be repeated (and mean calculated)
Or separations less than 0.50 m should be used
Or separations greater than 1.00 m should be used
Or distances should be recorded to the nearest mm
Or smaller intervals (for the separation) should be used (1)</td><td>Do not credit:
more readings should be taken
references to the number of decimal places</td><td>1</td></tr>
<tr><td>15(b)(i)</td><td>• Axes labelled with quantities and units (1)
• Suitable scale (1)
• Correct plotting (1)
• Line of best fit (1)

<table><tr><th>Microphone separation/ m</th><th>Time interval / ms</th></tr><tr><td>1.00</td><td>3.2</td></tr><tr><td>0.90</td><td>2.8</td></tr><tr><td>0.80</td><td>2.4</td></tr><tr><td>0.70</td><td>2.1</td></tr><tr><td>0.60</td><td>1.9</td></tr><tr><td>0.50</td><td>1.5</td></tr></table></td><td> 

Graph may be landscape and axes either way round

MP2: Suitable scale – plotted points take up at least half the graph paper in both directions</td><td>4</td></tr>
</table>

15(b)(ii)	• Use of gradient **Or** use of 1/gradient (if axes swapped) **(1)** • Speed of sound = 280 - 310 m s^{-1} **(1)**	MP1: only award for a y/x calculation if the graph passes through the origin <u>Example of calculation</u> Speed of sound = $\frac{0.96\text{ m} - 0.04\text{ m}}{(3.0 - 0.0) \times 10^{-3}\text{ m}} = 307\text{ m s}^{-1}$	**2**
15(c)	• Value obtained is lower than accepted value **(1)** **Max 2** • Measured times are too small **(1)** • Large percentage uncertainty for time **(1)** • Parallax when reading from the metre rule **(1)** • The distance not measured to same position on each microphone **(1)**	MP1: accept answer consistent with calculated value but do not accept different for greater/lower Ignore references to temperature	**3**

(Total for Question 15 = 10 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
17(a)	• Increasing light intensity increases rate of photons/energy arriving at LDR (1) • More electrons gain enough energy to be released/free to conduct (1) • Greater number of conduction electrons per unit volume (1) • $I = nAvq$ so current increases and resistance decreases (1)		4
17(b)	• Use of $I = \frac{P}{A}$ **and** $P = \frac{E}{t}$ (1) • $E =$ 2.6 J (1)	Example of calculation $P = 1100\ \text{W m}^{-2} \times 4.0 \times 10^{-5}\ \text{m}^2 = 4.4 \times 10^{-2}\ \text{W}$ $E = 4.4 \times 10^{-2}\ \text{W} \times 60\ \text{s} = 2.64\ \text{J}$	2
17(c)	• Unpolarised light oscillates in many planes (1) • The light perpendicular to the plane of polarisation of the filter is absorbed **Or** only light parallel to the plane of polarisation of the filter is transmitted (1) • So polarised light oscillates in only one plane (1) • So light intensity is reduced (1)	dependent upon MP2 or MP3	4

(Total for Question 17 = 10 marks)

Question Number	Acceptable Answers		Additional guidance	Mark
16 (a)	• Use of $I = \frac{P}{A}$ • Use of $2.4\sin 50$ **or** $2.4\cos 40$ • P = 400 W	(1) (1) (1)	Example of Calculation P =1100 W m^{-2} × 2.4 sin 50 m^2 × 0.2 = 404 W	**3**
16(b)	• Uses ratio of resistances to pd's **Or** uses $I = \frac{V}{R_{total}}$ **and** $V = IR$ • Output pd =13.7 (V) • Compares their answer to 13 (V) with conclusion consistent with their answer	(1) (1) (1)	R_{total}=1750 Ω Example of Calculation $V_o = V_s\left(\frac{R_1}{R_1 + R_2}\right)$ $V_{LDR} = 24\text{ V}\left(\frac{1000\ \Omega}{750\ \Omega\ + 1000\ \Omega}\right) = 13.7\text{ V}$ 13.7 > 13 so motor is on	**3**

16(c)	**Max 6** **Similarities** • An electron absorbs a photon **Or** electrons gain energy from a photon (1) • photons need a minimum amount of energy (1) • So light must be above a certain frequency (1) • increasing the light intensity increases the number of electrons (released per sec) (1) • Evidence for the particle model of light (1) **Differences** • In the photoelectric effect electrons are released from the surface (1) • But electrons remain within the LDR (1) • Photoelectric effect occurs in metals **Or** LDR is a semiconductor (1)		**6**

(Total for Question 16 = 12 marks)

Question Number	Acceptable Answers		Additional guidance	Mark
17(b)	• Uses Pythagoras • Speed = 15 m s^{-1} • Uses trigonometry • Angle to N-S line = 53° **or** angle to E-W line = 27°	(1) (1) (1) (1)	Example of Calculation $v = \sqrt{12^2 + 9^2} = 15$ m s^{-1} $\tan\theta = \frac{12}{9} = 53°$ to N-S line accept vertical and horizontal for N-S and E-W respectively or labelled on diagram/sketch	**4**
17(c)(i)	• Recognises resultant force on raindrop = 0 **Or** Uses $W=F(+U)$ • Use of $F = 6\pi\eta r v$ • Use of U = weight of air displaced **Or** $U = \frac{4}{3}\rho_a \pi r^3 g$ **Or** $U = \rho_a V g$ **and** $V = \frac{4}{3}\pi r^3$ **Or** $U = mg$ **and** $\rho = \frac{m}{V}$ **and** $V = \frac{4}{3}\pi r^3$ **Or** states upthrust is negligible • v = 1.7 m s^{-1}	(1) (1) (1) (1) (1)	Example of Calculation $W=F+U$ $F = 6\pi \times 1.3 \times 10^{-5}\text{Nm}^{-2} \times 1.0 \times 10^{-4} \times v$ $= (2.45 \times 10^{-8}\, v)$ (N) $U = 1.225\text{ kg m}^{-3} \times \frac{4}{3}\pi(0.0001\text{ m})^3 \times 9.81\text{m s}^{-2}$ $= 4.9 \times 10^{-11}$ (N) $v = \frac{4.1\times10^{-8}\text{ N} - 4.9\times10^{-11}\text{ N}}{2.45\times10^{-8}} = 1.7$ m s^{-1}	**4**
17(c)(ii)	• turbulent flow • (so) Stokes law does not apply	(1) (1)	Accept not laminar flow Do not accept a counter-statement to that in question eg drop not spherical	**2**
	Total for question 17			**13**

Question Number	Acceptable Answers		Additional guidance	Mark
14(a)	• Sound travels as a longitudinal wave **Or** in a series of compressions **and** rarefactions • With oscillations/vibrations of (air) particles/molecules parallel to the direction of energy transfer	(1) (1)	Accept: Direction of energy transfer **Or** propagation of the wave **Or** direction of wave travel/motion	**2**
14(b)(i)	• the idea that there is a wide variation in the first two readings	(1)		**1**
14(b)(ii)	• uses $\frac{\text{half the range of values}}{\text{mean value}}$ • percentage uncertainty = 8.5%	(1) (1)	Example of Calculation $\frac{0.5 \times (0.51\text{ s} - 0.43\text{ s})}{0.47\text{ s}} \times 100\% = 8.5\%$ Accept calculations based on $\frac{\text{range of values}}{\text{mean value}}$ (17%)	**2**
14(b)(iii)	• attempt to calculate Δv • $\Delta v = 7.4\text{ m s}^{-1}$ or 8.0 m s^{-1}	(1) (1)	Example of Calculation $\frac{160\text{ m}}{0.46\text{ s}} - \frac{160\text{ m}}{0.47\text{ s}} = 7.4\text{ m s}^{-1}$ Use of 80 m (Δv =3.7) scores MP1 only	**2**
14(b)(iv)	**Max 2:** • insufficient number of results • identifies one other variable to take into account • difference (in t or v) could be due to human reaction times • uncertainty in results may account for the difference	(1) (1) (1) (1)	Do not accept take readings over more days MP2 examples:wind speed/direction, humidity, air pressure MP3 do not credit human error	**2**

14(c)(i)	• Amplitude/energy/intensity of the soundwave reduces with distance travelled **(1)** • Appreciate that at A **or** B two waves are interfering destructively **(1)** **Or** at A **and** B there are nodes • at B the waves have travelled similar distances so have similar amplitudes **(1)**	Assume they are talking about point B unless stated otherwise For MP3 Accept answers with respect to waves at point A having different amplitudes due to different distances	**3**
14(c)(ii)	• Uses graph to identify $\lambda = 0.16$ (m) **(1)** • Use of $v = f\lambda$ with a valid value from the graph **(1)** • v =320 m s^{-1} **(1)**	using $\lambda = 0.08$ gives v= 160 m s^{-1} MP2 only Example of Calculation $v = 2000\ \text{Hz} \times 0.16\ \text{m} = 320\ \text{m s}^{-1}$	**3**
	Total for question 14		**15**

(Total for Question 14 = 15 marks)

Question Number	Answer	Mark
2	**D Comparing to y=mx+c format with v as y and $\sqrt{T}$ as x**	**1**
	Incorrect Answers: A – this assumes T is proportional to $\sqrt{v}$ B – this assumes v is proportional to T C – this assumes $\frac{1}{T}$ is proportional to v	

Question Number	Answer	Mark
3	**D – Two points $\frac{\lambda}{2}$ apart oscillate with the same amplitude**	**1**
	Incorrect Answers: A – Points on a wave do not all oscillate in phase B – A node is formed from destructive interference C – Stationary waves may also be formed from longitudinal waves	

7	**B - $v = 2fl$**	**1**
	Incorrect Answers: A – wavelength is $2l$ C - wavelength is $2l$ D - wavelength is $2l$	

8	**C - $\mu = \frac{1}{\text{gradient}}$**	**1**
	Incorrect Answers: A – incorrect use of $v = \sqrt{\frac{T}{\mu}}$ B – incorrect use of $v = \sqrt{\frac{T}{\mu}}$ D - incorrect use of $v = \sqrt{\frac{T}{\mu}}$	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
4	**C**	**1**
	Incorrect Answers: **A** results in a higher value for *f* **B** results in a higher value for *f* **D** results in a higher value for *f*	

10	The only correct answer is C because decreasing the mass on the hanger decreases the tension in the string and, since $v = \sqrt{\frac{T}{\mu}}$, decreases the speed of waves on the string. $\lambda = v/f$ so the wavelength is shorter and a whole wavelength could fit in the original length A the wavelength at the original frequency is unchanged, so decreasing the length will not allow a whole wavelength B decreasing the frequency will increase the wavelength, since wave speed is unchanged, so this will not allow a whole wavelength D since $v = \sqrt{\frac{T}{\mu}}$, decreasing the mass per unit length will increase the wave speed, increasing the wavelength at the original frequency, so this will not allow a whole wavelength	**1**

(Total for Multiple Choice Questions = 10 marks)

Question Number	Answer	Mark
5	**D – increases non-linearly**	**1**
	Incorrect Answers: A – incorrect as $f \propto \sqrt{T}$ B – incorrect as $f \propto \sqrt{T}$ C – incorrect as $f \propto \sqrt{T}$	

Question Number	Acceptable answers		Additional guidance	Mark
11	• Thicker string has greater μ	**(1)**	Accept words or symbols, including ↑ and ↓ Could be answered using an equation of the form: $f = \frac{1}{\lambda}\sqrt{\frac{T}{\mu}}$ gives MP2	**4**
	• Refers to $v = \sqrt{\frac{T}{\mu}}$, so v is smaller **Or** states v is proportional to $\sqrt{\frac{1}{\mu}}$, so v is smaller	**(1)**		
	• Refers to $v = f\lambda$ with λ constant	**(1)**		
	• So thicker string has lower frequency Dependent on MP1and 2 or MP1 and 3	**(1)**		

(Total for Question 11 = 4 marks)

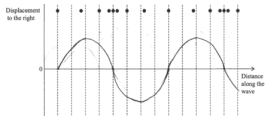
Question Number	Acceptable Answer	Additional Guidance	Mark
2	An explanation that makes reference to the following points: • Microwaves are reflected (from the metal plate) **(1)** • Superposition / interference occurs **Or** A standing wave is produced **(1)** • Maximum (intensity) where waves arrive in phase **Or** minimum (intensity) where waves arrive in antiphase **(1)** • Use of $v = f\lambda$ **(1)** • $\lambda = 2.8$ cm so separation of minima is 1.4 cm ≈ 1.5 cm **(1)**	For "in phase" accept phase difference $(2n)\pi$ or path difference $(2n)\lambda$ For "in antiphase" accept phase difference $(n+1)\pi/2$ or path difference $(n+1)\lambda/2$ May use 1.5 cm to calculate speed and then compare with 3.0×10^8 m s^{-1} or 10.7GHz <u>Example of calculation</u> $\lambda = \frac{v}{f} = \frac{3.0 \times 10^8 \text{ m s}^{-1}}{10.7 \times 10^9 \text{ Hz}} = 0.028 \text{ m}$ $\frac{\lambda}{2} = \frac{2.8 \text{ cm}}{2} = 1.4 \text{ cm}$	**5**

(Total for Question 2 = 5 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
12(a)	• Longitudinal wave **Or** Oscillations of air molecules are parallel to the direction of the energy transfer (1) • Creating compressions **and** rarefactions **Or** Creating regions where the molecules are close together **and** regions where they are further apart (1) • Molecules close together create higher pressure **Or** molecules further apart create lower pressure **Or** compressions are areas of high pressure **Or** rarefactions are areas of low pressure (1)		**3**
12(b)	• use of $v = f\lambda$ (1) • Path difference needs to be = $\left(n + \frac{1}{2}\right)\lambda$ **Or** Path difference needs to be $\frac{\lambda}{2}$ **Or** Length of chamber needs to be $\frac{\lambda}{4}$ **Or** See $\frac{2.4\text{ m}}{4}$ (1) • (so) waves meet in antiphase (1) • destructive interference (1)	Example of calculation $\lambda = \frac{340\text{ m s}^{-1}}{140\text{ s}^{-1}} = 2.43\text{ m}$ path difference = $2l = \frac{2.43\text{ m}}{2}$ $l = \frac{2.43\text{ m}}{4} = 0.61\text{ m}$	**4**

(Total for Question 12 = 7 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
14(a)	• There are points along the tube where the path difference between the incident wave and reflected wave is a whole number of wavelengths (1) • The waves meet in phase and constructive interference occurs (1) • There are points along the tube where the path difference between the incident wave and reflected wave is an odd number of half wavelengths (1) • the waves meet in antiphase and destructive interference occurs (1) • the piles of powder form at the points of destructive interference (1)	Accept: the length of tube is equal to an odd number of a quarter wavelengths	**5**
14(b)	• use of $v = f\lambda$ (1) • correct calculation of λ (1) • v = 360 m s^{-1} (1)	Example of calculation $\frac{\lambda}{2} = \frac{0.50}{5}$ λ = 0.20 m $v = 1800$ Hz $\times$ 0.20 m v = 360 m s^{-1}	**3**
	Total for question 14		**8**

Question Number	Acceptable answers	Additional guidance	Mark
11(a)	• sine wave drawn from first dotted line **(1)** • Min 1 wavelength with zero displacement at lines 5,9,(13) **(1)**	 [ignore their drawing between axis and first dotted line]	**2**
11(b)(i)	• $V = \pi r^2 \times L$ **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • $\mu = 0.00054$ (kg m^{-1}) **(1)**	[V= 1.5x10^{-7}] [No ue for show that] Example of calculation $m = \pi\left(\frac{7.6 \times 10^{-4}\ \text{m}^2}{2}\right)^2 \times 0.33\ \text{m} \times 1200\ \text{kg m}^{-3} = 1.8 \times 10^{-4}\ \text{kg}$ $\mu = \frac{1.8 \times 10^{-4}\ \text{kg}}{0.33\ \text{m}} = 0.00054\ \text{kg m}^{-1}$	**3**
11(b)(ii)	• Use of $v = \sqrt{\frac{T}{\mu}}$ **and** $v = f\lambda$ **(1)** **Or** Use of $f = \frac{1}{\lambda}\sqrt{\frac{T}{\mu}}$ **(1)** • Recognises $\lambda = 2L$ **(1)** • $\mu = 1.1 \times 10^{-3}$ (kg m^{-1}) so string 3 used	[Allow $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ for MP1 and MP2] [No ue] Example of calculation $2 \times 0.33\ \text{m} \times 277\ \text{s}^{-1} = \sqrt{\frac{3.9\ \text{kg} \times 9.81\ \text{m s}^{-1}}{\mu}}$ $\mu = 1.1 \times 10^{-3}$ kg m^{-1} string 3	**3**

(Total for Question 11 = 8 marks)

Question Number	Acceptable answers		Additional guidance	Mark
18 (a)(i)	• Use of $\rho = \frac{m}{V}$ with $V = \pi r^2 L$ • $\mu = 1.09 \times 10^{-3}$ (kg m^{-1})(to at least 3 sf)	**(1)** **(1)**	For MP1, accept use of ρA Example of calculation: $\mu = \frac{m}{L} = \frac{V\rho}{L} = \frac{\pi r^2 L\rho}{L} = \pi r^2 \rho$ $\therefore \mu = \pi\left(\frac{1.14 \times 10^{-3}\text{ m}}{2}\right)^2 \times 1070\text{ kg m}^{-3}$ $\mu = 1.09 \times 10^{-3}$ kg m^{-1}	**2**
18 (a)(ii)	• Use of $L = \frac{\lambda}{2}$ • Use of $v = f\lambda$ • Use of $v = \sqrt{\frac{T}{\mu}}$ • T = 140 N (ecf from (a)(i))	**(1)** **(1)** **(1)** **(1)**	Example of calculation: $\lambda = 2 \times 0.41\text{ m} = 0.82\text{ m}$ $v = 440\text{ Hz} \times 0.82\text{ m} = 361\text{ m s}^{-1}$ $361\text{ m s}^{-1} = \sqrt{\frac{T}{1.09 \times 10^{-3}\text{ kg m}^{-1}}}$ $\therefore T = (361\text{ m s}^{-1})^2 \times 1.09 \times 10^{-3}\text{ kg m}^{-3}$ T = 142 N	**4**
18 (b)	An explanation that makes reference to the following points: • (As the temperature increases,) E decreases • The tension in the string decreases • The wave speed decreases **and** the frequency decreases **Or** Wavelength is constant **and** the frequency decreases	**(1)** **(1)** **(1)**	MP2 accept "the string slackens", accept stress decreases	**3**

(Total for Question 18 = 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• (between f and 2f) there is no standing wave **Or** (between f and 2f) the amplitude (of the antinode) decreases **(1)** • At a frequency 2*f* there is a standing wave with 2 antinodes **(1)**		**2**
12(b)	• The vibrating string causes air molecules to oscillate/vibrate **Or** the vibrating string transfers energy to the air molecules **(1)** • Molecules are displaced from their (equilibrium) positions **(1)** • Where air molecules are close together the pressure is high **Or** where air molecules are far apart the pressure is low **(1)**		**3**
12(c)	**EITHER** • Equates $v = f\lambda$ and $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Uses $\lambda = 2l$ **(1)** • $l = 0.27$ m **(1)** • Comparison of their value of l to 0.21 and 0.63 m **and** conclusion consistent with their answer **(1)** **OR** • Equates $v = f\lambda$ and $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Uses $\lambda = 2l$ **(1)** • $f = 84$ Hz **and** 252 Hz **(1)** • Comparison of 196 Hz to their values of f **and** a conclusion consistent with their answer **(1)**	Example of calculation $l = \frac{1}{2\times196\text{ Hz}}\sqrt{\frac{56\text{ N}}{5\times10^{-3}\text{ Kg m}^{-3}}} = 0.27\text{ m}$	**4**

(Total for Question 12 = 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• Use a pulley and set of masses/weights hung on string **(1)** • Tension = weight (of set of masses) **Or** $T=mg$ **(1)**		**2**
12(b)	• Calculate missing $f^2 = 9025$ **(1)** • Plot missing point **(1)** • Draw line of best fit **(1)**	Plot (35, 9025) or their calculated value of f^2	**3**
12(c)	• Determines the gradient **(1)** • Equates $v = f\lambda$ and $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Uses $\lambda = 0.8$ (m) **(1)** • Mass per unit length μ = (6.0 to 6.2) x 10^{-3} (kg m^{-1}) **(1)** • Conclusion consistent with their value **(1)**	e.g. gradient= $\frac{(10200-0)}{(40-0)}$ =255 accept $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ $\mu = \frac{1}{255\text{Hz}^2\text{N}^{-1} \times 0.8^2\text{m}^2}$ =6.1 x 10^{-3} (kg m^{-1})	**5**

(Total for Question 12 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	**EITHER** • Waves are produced by the toothbrush and reflected (at the mass) **(1)** • Waves meet and superpose **(1)** • Constructive interference takes place where the waves are in phase **Or** Destructive interference takes place where the waves are in antiphase **(1)** • The string vibrates at the centre with maximum amplitude, forming an antinode in the centre **Or** The string here has zero/minimum amplitude, forming nodes at the ends **(1)** • Creating a standing/stationary wave **(1)** **OR** • The toothbrush causes the string to vibrate at its natural frequency **(1)** • There is a maximum/efficient transfer of energy from the toothbrush to the string **(1)** • Resonance occurs **(1)** • The string vibrates at the centre with maximum amplitude, forming an antinode in the centre **(1)** • Creating a standing/stationary wave **(1)**	Accept answer in terms of multiple ‘loops’ Accept reference to phase difference in terms of 2π, or 0 (radians) Accept reference to phase difference in terms of π (radians) Do not credit out of phase	**5**

15(b)	• Use of $W = mg$	**(1)**	Example of calculation $T = 0.010\ \text{kg} \times 9.81\ \text{N kg}^{-1} = 0.0981\ \text{N}$ $v = \sqrt{(0.0981\ \text{N} / 9.1 \times 10^{-4}\ \text{kg m}^{-1})} = 10.4\ \text{m s}^{-1}$ $\lambda = 0.69\ \text{m} / 2 = 0.345\ \text{m}$ $f = 10.4\ \text{m s}^{-1} / 0.345\ \text{m}$ $= 30\ \text{Hz}$	**5**
	• Use of $v = \sqrt{(T/\mu)}$	**(1)**		
	• Determination of wavelength	**(1)**		
	• Use of $v = f\lambda$	**(1)**		
	• $f = 30$ Hz	**(1)**		

(Total for Question 15 = 10 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*11(a)</td><td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><td>Number of indicative points seen in answer</td><td>Number of marks awarded for indicative points</td></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Indicative Content
• Two waves travelling in opposite directions
• Superpose / interfere (1)
• Constructive (interference) if waves in phase (1)
Or Constructive (interference) if path difference = nλ (1)
• Destructive (interference) if waves in antiphase (1)
Or destructive (interference) if path difference = (n + ½)λ (1)
• Nodes are formed from points of destructive (interference) or antinodes are formed from points of constructive (interference) (1)
• Nodes are points with min amplitude and antinodes are points with max amplitude (1)</td><td></td><td>6</td></tr>
</table>

11(b)	• the thicker string has a greater mass per unit length • wavelength is the same in each string • Valid assumption stated **Either** • Equate $v = \sqrt{\frac{T}{\mu}}$ and $v=f\lambda$ • Leading to $f \propto \frac{1}{\sqrt{\mu}}$ **or** $f = \frac{1}{\lambda}\sqrt{\frac{T}{\mu}}$ so f is lower **Or** • $v = \sqrt{\frac{T}{\mu}}$ so v is lower (as T constant) • $v=f\lambda$ so f is lower	(1) (1) (1) (1) (1) (1) (1) (1) (1)	A thicker string has a greater mass **Or** length of strings is the same	**5**

(Total for Question 11 = 11 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• There are nodes and antinodes on the plate	**(1)**	Allow "points with minimum/zero amplitude" for "nodes" and "points with maximum amplitude" for "antinodes" Accept "displacement" for "amplitude"	**3**
	• Sand is displaced away from the antinodes	**(1)**		
	• Sand collected/gathers at the nodes	**(1)**		
6(b)	• 1 full cycle read from oscilloscope trace 4.5 4.7 div	**(1)**	Example of calculation $T = 4.6 \text{ div} \times 0.5 \text{ ms div}^{-1} = 2.3 \text{ ms}$ $f = \frac{1}{2.3 \times 10^{-3} \text{ s}} = 435 \text{ Hz}$ $v = 435 \text{ s}^{-1} \times 0.32 \text{ m} = 139 \text{ m s}^{-1}$	**5**
	• Converts from div to s	**(1)**		
	• Use of $f = 1/T$	**(1)**		
	• Use of $v = f\lambda$	**(1)**		
	• v = 140 m s^{-1}, which is (much) less than 340 m s^{-1}	**(1)**	Allow "the speed of sound in air" for 340 m s^{-1}	
6(c)	**EITHER**			**3**
	• Plot a graph of L against $1/f$	**(1)**	Allow Plot a graph of L against $1/f$	
	• $L = \lambda/4$	**(1)**		
	• $L = \frac{v}{4f}$, so speed of sound = 4 × gradient	**(1)**	$v = \frac{4}{\text{gradient}}$	
	OR			
	• (Calculate λ using) $\lambda = 4L$	**(1)**		
	• Plot a graph of λ against $1/f$	**(1)**	Allow Plot a graph of f against $1/\lambda$	
	• Speed of sound = gradient	**(1)**		

(Total for Question 6 = 11 marks)

Question Number	Acceptable answers		Additional guidance	Mark
15(a)	• Waves are reflected at ends of strings • The reflected waves meet and superpose/interfere • Where they meet in phase constructive interference takes place producing points of maximum amplitude **Or** Where they meet in phase constructive interference takes place producing antinodes **Or** Where they meet in antiphase destructive interference takes place producing points of zero/minimum amplitude **Or** Where they meet in antiphase destructive interference takes place producing nodes	**(1)** **(1)** **(1)**		**3**
15 (b)(i)	• Wavelength = 44 cm	**(1)**		**1**
15(b) (ii)	• Use of $v = \sqrt{\frac{T}{\mu}}$ • Use of $v = f\lambda$ (ecf from (i)) • f = 320 Hz	**(1)** **(1)** **(1)**	Example of calculation $v = \sqrt{\frac{88.6\ \text{N}}{4.47 \times 10-3\ \text{kg m}-1}}$ = 141 m s^{-1} f = 141 m s^{-1} / 0.44 m = 320 Hz	**3**

15 (c)(i)	• Use of stress = F/A **(1)** • Use of Young modulus = stress / strain **(1)** • Use of strain = $\Delta x/x$ **(1)** • Extension = 0.053 m **(1)**	Example of calculation stress = 93.4 N / 6.6 $\times 10^{-7}$ m^2 = 1.42 $\times 10^8$ N m^{-2} strain = 1.42 $\times 10^8$ N m^{-2} / 1.8 $\times 10^9$ N m^{-2} = 0.0786 extension = 0.0786 × 0.68 m = 0.053 m	**4**
15 (c)(ii)	• Increase tension so increase wavespeed since $v = \sqrt{\frac{T}{\mu}}$ **Or** decrease μ so increase wavespeed since $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Since $v = f\lambda$ and wavelength unchanged, this increases frequency **(1)**		**2**
			(Total for Question 15 = 13 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
14(a)	• Recognises $\lambda = 2L$ (1) • Equates $v = f\lambda$ **and** $v = \sqrt{gh}$ (1) • $T = 5.9 \times 10^4$ s (1)	Example of calculation $T = \frac{L}{\sqrt{gh}} = \frac{2 \times 4.0 \times 10^5 \text{ m}}{\sqrt{9.81 \text{ m s}^{-1} \times 19 \text{ m}}} = 5.9 \times 10^4 \text{ s} = 16.4 \text{ h}$	**3**
14(b)	• Use of $F = 6\pi\eta r v$ (1) • Use of $U = mg$ **and** $\rho = \frac{m}{V}$ **and** $V = \frac{4}{3}\pi r^3$ (1) • Recognises $W = F + U$ (1) • Use of $v = \frac{s}{t}$ (1) **Either** (1) • $t = 1.7 \times 10^7$ s • comparison with 6 months and conclusion consistent with their answer (1) **Or** • $s = 3.3$ - 3.6 m • comparison with 4 m and conclusion consistent with their answer	Example of calculation $F = 6\pi \times 1.0 \times 10^{-3} \text{ kg m}^{-1} \text{ s}^{-1} \times 2.5 \times 10^{-7} \text{ m} \times v$ $V = \frac{4}{3}\pi(2.5 \times 10^{-7} \text{ m})^3 = 6.5 \times 10^{-20} \text{ m}^3$ $U = \rho_w V g = 1000 \text{ kg m}^{-3} \times 6.5 \times 10^{-20} \text{ m}^3 \times 9.81 \text{ m s}^{-1}$ $U = 6.4 \times 10^{-16}$ N $W = 2650 \text{ kg m}^{-3} \times 6.5 \times 10^{-20} \text{ m}^3 \times 9.81 \text{ m s}^{-1}$ $W = 1.7 \times 10^{-15}$ N $F = 1.7 \times 10^{-15}$ N - 6.4×10^{-16} N $F = 1.1 \times 10^{-15}$ N $v = \frac{1.1 \times 10^{-15} \text{ N}}{6\pi \times 1.0 \times 10^{-3} \text{kg m}^{-1}\text{s}^{-1} \times 2.5 \times 10^{-7} \text{ m}}$ $v = 2.3 \times 10^{-7} \text{ m s}^{-1}$ $t = \frac{4 \text{ m}}{2.3 \times 10^{-7} \text{ m s}^{-1}} = 1.7 \times 10^7$ s t =197 days which is 6.6 months accept 1 month = 28 to 31 days giving t = 6.3 to 7.0 months	**6**

14(c)	• Viscosity increases with decreasing temperature (1) **Or** Viscosity **or** viscous drag increases with depth • (so) rate at which the particle falls decreases with depth (1)	MP2 dependent on MP1	**2**
14(d)	• The idea that human reaction time is large (compared to the short time to be measured) • Giving a greater %U in measurements of time so not suitable		**2**

(Total for Question 14 = 13 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• (As the light from the lasers is coherent) there is a constant phase relationship for the two beams **(1)** • Waves (meet and) superpose / interfere **(1)** • Constructive interference if waves in phase **(1)** • Destructive interference if waves in antiphase **(1)** • Nodes are formed at points of destructive interference **Or** antinodes are formed at points of constructive interference **Or** waves in antiphase form nodes **Or** waves in phase form antinodes **(1)**		**5**
15(b)	• Use of $\tan\theta = \frac{o}{a}$ **(1)** • Use of $n\lambda = d\sin\theta$ with $n = 1$ **(1)** • 6.1×10^{-11} m **(1)**	Example of calculation $\tan\theta = \frac{5.5 \times 10^{-5}\text{ m}}{0.24\text{ m}} = 2.29 \times 10^{-4}$ $\theta = 0.013°$ $\lambda = \frac{5.32 \times 10^{-7}\text{ m}}{2}\sin 0.013° = 6.08 \times 10^{-11}$ m	**3**

15(c)	• (de Broglie) wavelength of electron is much less than the size/width of the gaps in diffraction grating **Or** (de Broglie) wavelength of electron is very much smaller than the wavelength of light **(1)** • So little / no diffraction **Or** no diffraction pattern is observed **(1)**		**2**

***15(d)**

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for structure and lines of reasoning

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

IC1 Electron energy levels are discrete
Or electrons can only have certain energy states

IC2 (An excited) electron falls back down (to a lower energy level)

IC3 A photon is emitted

IC4 The photon energy is equal to the difference in the energy between the energy levels

IC5 Only certain (energy level) transitions are possible, so only discrete amounts of (photon) energy are possible

IC6 Wavelength is inversely proportional to energy (difference), (So emitted photons have a limited range of wavelengths)
Or the wavelength emitted corresponds to the change in energy (So emitted photons have a limited range of wavelengths)

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Accept charge carriers for electrons and only penalise once for omission of charge carriers or lattice ions

Linkage marks

Number of indicative content points awarded	Possible linkage marks
0, 1	0
2, 3	1
4, 5, 6	2

6

(Total for Question 15 = 16 marks)

Question Number	Acceptable Answer	Additional Guidance	
13(a)	• Waves are reflected from the opposite bridge **(1)** • Waves meet in phase (at mid-point of wire) and superpose **(1)** • Constructive interference occurs giving a maximum displacement **(1)**		**3**
13(b)(i)	• Wear safety glasses (to protect eyes from breaking wire) **Or** wear suitable footwear (to protect feet from falling masses) **Or** place sand tray under masses (to catch them if they fall)		**1**
13(b)(ii)	• $\lambda = 2L$ substituted into $v = f\lambda$ **(1)** • v substituted into $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Correct re-arrangement into $y = mx + c$ format **(1)**	$v = f\lambda$ and $\lambda = 2L$ so $v = 2fL$ $v = \sqrt{\frac{T}{\mu}}$, so $4f^2L^2 = \frac{T}{\mu}$ $L^2 = \left(\frac{T}{4\mu}\right).\frac{1}{f^2}$, so gradient is $\frac{T}{4\mu}$	**3**
13(b)(iii)	• Gradient calculated **(1)** • Use of gradient = $\frac{T}{4\mu}$ **(1)** • $\mu = 1.8$ (g m^{-1}) **(1)** • SWG consistent with their calculated value of μ (24 swg) **(1)**	Example of calculation gradient $= \frac{(0.043 - 0)\text{m}^2}{(15.0 - 0.0) \times 10^{-6}\text{s}^2} = 2.87 \times 10^3\text{m}^2\text{s}^{-2}$ $\mu = \frac{2.1\text{ kg} \times 9.81\text{ m s}^{-2}}{4 \times 2.87 \times 10^3\text{m}^2\text{s}^{-2}} = 1.79 \times 10^{-3}\text{ kg m}^{-1}$ $\therefore \mu = 1.79\text{ g m}^{-1}$	**4**

13(c)(i)	An explanation that makes reference to the following points: **Either** • Take readings in different positions/orientations along the wire (and calculate a mean) **(1)** • As wire diameter may not be uniform **(1)** **OR** • Check (and correct for) for zero error **(1)** • Zero error reduces the accuracy of the measurement **Or** Zero error moves the value away from the true value **(1)**	**Accept:** use ratchet to close up micrometer to avoid squashing the wire MP2 accept cross section for diameter MP2: accept to reduce the effect of random error MP2 accept systematic error not changed by repeat measurements	**2**
13(c)(ii)	• Use of half range value to calculate % uncertainty in d **Or** use of max value from mean to calculate % uncertainty in d **(1)** • % uncertainty in area = 2 × (% uncertainty in d) **(1)** • Calculation of % uncertainty in density **(1)** • % uncertainty in density added to % uncertainty in area **(1)** • Use of $\mu = \frac{m}{L}$ with $\rho = \frac{m}{V}$ **(1)** • $\mu = 2.2 \times 10^{-3}$ kg m^{-1} ± 0.2×10^{-3} kg m^{-1}, so the stated value is supported by the student's data **(1)**	Example of calculation $\check{d} = \frac{(0.55 + 0.59 + 0.57 + 0.58)\text{ mm}}{4} = 0.57\text{ mm}$ % uncertainty in $d = \frac{0.02\text{ mm}}{0.57\text{ mm}} \times 100 = 3.5$ ∴ % uncertainty in area $= 2 \times 3.5 = 7.0$ % uncertainty in density $= \frac{200\text{ kg m}^{-3}}{8700\text{ kg m}^{3}} \times 100 = 2.3$ % uncertainty in μ = 2.3 + 7.0 = 9.3 $\mu = \frac{m}{L} = \frac{\rho AL}{L} = 8700\text{ kg m}^{-3} \times \pi \times \left(\frac{0.57 \times 10^{-3}\text{ m}}{2}\right)^2$ $\mu = 2.2 \times 10^{-3}\text{ kg m}^{-1}$ Range $= \pm\frac{9.3}{100} \times 2.2 \times 10^{-3}\text{ kg m}^{-1} = 2.05 \times 10^{-4}\text{ kg m}^{-1}$ So $2.0 \times 10^{-3}\text{kg m}^{-1} < \mu < 2.4 \times 10^{-3}\text{ kg m}^{-1}$	**6**

(Total for Question 13 = 19 marks)

4	The only correct answer is **B** because at angles less than or equal to the critical angle not all of the light is reflected internally such that angle of incidence is equal to the angle of reflection A is not correct because total internal reflection occurs at angles greater than the critical angle but at the critical angle the angle of refraction is 90 degrees, so the reflection is not total C is not correct because internal reflection is not total at angles less than the critical angle D is not correct because internal reflection is not total at angles less than the critical angle		**1**

Question Number	Answer	Mark
5	**B** $v_1 < v_2$ $n_1 > n_2$	**1**
	Incorrect Answers: A – incorrect equality for speed C – incorrect equality for speed and refractive index D – incorrect equality for refractive index	

Question Number	Answer	Mark
2	**B – TIR as angle of incidence is greater than the critical angle**	**1**
	Incorrect Answers: A – light is reflecting at an incorrect angle C – light is not refracted D – light is not refracted	

Question Number	Answer	Mark
3	**B** $\frac{1}{\sin 35}$	**1**
	Incorrect Answers: A – incorrect arrangement of equation C – incorrect arrangement of equation D – incorrect arrangement of equation	

Question Number	Answers	Mark
2	**The only correct answer is B** ***A*** *is incorrect because the relative refractive index for light travelling from glass to water is required* ***C*** *is incorrect because the relative refractive index for light travelling from glass to water is required* ***D*** *is incorrect because the relative refractive index for light travelling from glass to water is required*	**1**

Question Number	Answers	Mark
8	**The only correct answer is D** ***A*** *is incorrect because the angle of incidence must be greater than the critical angle* ***B*** *is incorrect because the angle of incidence must be greater than the critical angle* ***and*** $n_1 < n_2$	**1**
	C *is incorrect because the light must be incident upon the boundary in the medium with the larger refractive index*	

8	**The only correct answer is C** A is not correct as there is total internal reflection at the first surface as c = 42° B is not correct as there is total internal reflection at the first surface as c = 42° D is not correct as the angle of incidence is equal to the angle of reflection for internal reflection		**1**

Question Number	Answer	Mark
7	The only correct answer is A ***B*** *is not correct because ray z has increased in speed, as shown by refracting away from the normal* ***C*** *is not correct because ray z has increased in speed, as shown by refracting away from the normal* ***D*** *is not correct because in medium y the ray has slowed down as it has refracted towards the normal*	**1**

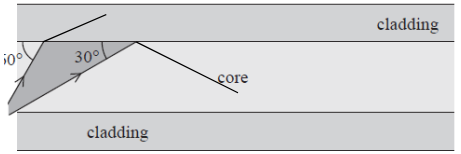
Question Number	Answer	Mark
3	**The only correct answer is B,** when ϑ is greater than c, then no light is transmitted. A is not correct because all light is reflected C is not correct because some light is reflected D is not correct because some light is transmitted	1

Question Number	Acceptable Answer	Additional Guidance	Mark
12	• Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$, with $n_1 = 1$ and $\theta_1 = 45$ **(1)** • Use of $n = \frac{c}{v}$ **(1)** • Ratio of speeds = 0.69 Or angle for red light = 22.2° **(1)** • 0.69 is less than 0.99, so angle is not accurate. **Or** 22.2° is less than 33 degrees, so angle is not accurate. **Or** Comparison of calculated value with value in question and consistent conclusion **(1)**	Example of calculation $n = \frac{c}{v}$, so $\frac{n_{red}}{n_{violet}} = \frac{v_{violet}}{v_{red}} = 0.99$ $n_{air} \sin 45^o = n_{violet} \sin 22^o$ $n_{air} \sin 45^o = n_{violet} \sin(22^o + 11^o)$ $n_{red} \sin 33^o = n_{violet} \sin 22^o$ $\frac{n_{red}}{n_{violet}} = \frac{\sin 22^o}{\sin 33^o} = 0.688$ For MP4 allow a conclusion based on candidate's calculated value of refractive index ratio [Alternative method: Use sin 45° / sin 22° to calculate n_{violet} 1.89 Using ratio of velocities = 0.99, n_{red} 1.87 Then calculated angle for red = 22.2° The red and violet lines would be very close together as the angular dispersion is negligible so diagram is incorrect" If students use this method and round to 2 sf then they will just get the angle for violet 22° ie same as red]	**4**

(Total for Question 12 = 4 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• Use of trigonometry to determine angle of ray to normal in liquid **(1)** • Use of n sin θ = constant **(1)** • n = 1.42 **(1)**	Example of calculation (10.2 – 4.0) ÷ 2 = 3.1 cm tan θ = 3.1 cm / 35 cm θ = 5.06° n = sin 7.2° / sin 5.06° n = 1.42	**3**
12 (b)	• Use of $n = c / v$ **(1)** • $v = 2.1 \times 10^8$ m s^{-1} (allow ecf from (a)) **(1)**	Example of calculation $v = c/n$ $= 3.00 \times 10^8$ m s^{-1} / 1.42 $= 2.11 \times 10^8$ m s^{-1}	**2**

(Total for Question 12 = 5 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	• Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **(1)** • Angle in cladding $\theta = 90(^o)$ **(1)** • Critical angle = 50.3(^{o}) **(1)**	Accept alternative method using $\sin c = \frac{1}{n}$ **and** $n = \frac{c}{v}$ to give $n = \frac{v_{cladding}}{v_{core}}$ **Or** $n = \frac{n_{core}}{n_{cladding}}$ Use of $\sin c = \frac{1}{n}$ with n=1.2 or 1.56 gains 1 mark Example of calculation e.g. $1.56 \sin\theta_1 = 1.20 \sin\theta_2$ $1.56 \sin c = 1.20 (\sin 90^o)$ $\sin c = \frac{1.20}{1.56}$ $c = 50.3(^o)$	**3**
9(b)	• Left hand side of beam refracts away from normal **(1)** • Right hand side of beam totally internally reflected **(1)** • State Student C is correct **(1)**	Ignore any line continued beyond cladding Ignore any reflection Reflection correct by eye Do not award if any line shown in cladding **(MP3 dependent on MP1 and MP2)**  Arrows on rays not needed	**3**

(Total for Question 9 = 6 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
12(a)	• An image formed from the apparent divergence of light rays from a single point **Or** an image that cannot be projected on to a screen **(1)**		**1**
12(b)	• Light is refracted as it passes into medium 2 • Angle of refraction may be calculated using $n_1\sin\theta_1 = n_2\sin\theta_2$ **(1)** • Angle of refraction = 89.81° **(1)** • Angle of <u>incidence</u> at layer 2-3 is greater than the critical angle **(1)** • So <u>total internal reflection</u> occurs (at layer 2-3 interface) **(1)** • So light/ rays appear to come from surface of road (so that observer sees mirage) **(1)**	MP2 see use of the equation MP5 accept totally internally reflected and TIR MP6 is not just for saying there is a mirage. <u>Example of Calculation</u> $\sin^{-1}\left(\frac{1.00032 \times \sin 89.59°}{1.00030}\right) = 89.81°$	**6**

(Total for Question 12 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• Use of $n = c / v$ **(1)** • $v = 2.0 \times 10^8$ m s^{-1} **(1)**	Example of calculation $1.52 = 3.00 \times 10^8$ m s^{-1} / v 1.97×10^8 m s^{-1}	**2**
12 (b) (i)	• the angle of incidence in an (optically) denser medium at which the angle of refraction (in the less dense medium) is 90° **(1)** **Or** • the greatest angle of incidence in an (optically) denser medium at which there is an emergent ray (into the less dense medium) **Or** • the greatest angle of incidence in an (optically) denser medium at which there is a refracted ray (in the less dense medium)	Other equivalent answers may be given Do not accept answers stating or implying that the critical angle is the smallest angle at which total internal reflection occur, e.g., 'The smallest angle at which t.i.r. takes place', but do not automatically exclude answers on the basis of mentioning internal reflection alone without the inclusion of 'total' 'The greatest angle before t.i.r. takes place' is not sufficient	**1**
12 (b) (ii)	• Use of sin $C = 1 / n$ **(1)** • $C = 41°$ **(1)**	Example of calculation sin $C = 1/1.52$ $C = 41.1°$	**2**
12 (c)	• Light strikes the edges of the long crystals at angles greater than the critical angle **(1)** • It is repeatedly totally internally reflected along the crystal **(1)**		**2**

(Total for Question 12 = 7 marks)

Question Number	Acceptable answers		Additional guidance	Mark
12(a)	• Use of $\sin C = \frac{1}{n}$ • $C = 38°$	**(1)** **(1)**	Example of calculation $\sin C = \frac{1}{1.63}$ $C = 37.84°$ [No ue as given in diagram and in (b)]	**2**
12(b)	• Use of $n = \frac{c}{v}$ • Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ with $\theta = 40°$ [$r = 24°$] • Uses geometry to determine angle of incidence at the glass-air interface [$\theta = 36.52°$] • Recognises that n(glass to air) = $\frac{1}{n(\text{air to glass})}$ • $\theta = 68°$	**(1)** **(1)** **(1)** **(1)** **(1)**	[1.58] e.g. Internal angles totalling 180° Accept answers using 1/(candidates value for n in MP1) [answer of 15° not MP4 and MP5 - has used 1.58 instead of 1/1.58 [accept answers written on diagram] [No ue] Example of calculation $n = \frac{3.0 \times 10^8}{1.9 \times 10^8} = 1.58$ At air-glass interface $\sin r = \frac{\sin 40}{1.58}$ $r = 24°$ At glass-air interface $i = 90 - (180 - (90 - 24) - 60) = 36°$ $\sin r = \frac{\sin 36}{(1/1.58)}$ $r = 68°$	**5**

(Total for Question 12 = 7 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
11(a)	**Max 2** • Use large angles of incidence **or** use a wide range of angles • Use narrowest possible ray • Repeat and calculate mean • Work in a dark room. • Use monochromatic light (2)		**2**
11(b)(i)	**Either** • Resolution of protractor 1° (1) • Recognises that the results are recorded to the same precision as the resolution of the protractor (1) **Or** • Resolution of protractor 0.5° (1) • Recognises that the results are not recorded to the same precision as the resolution of the protractor (1)	MP2 dependent on MP1	**2**
11(b)(ii)	• Use of percentage uncertainty equation with 0.5° as the resolution (1) • percentage uncertainty = 2% (1)	Example of calculation $\frac{0.5}{29} \times 100\% = 1.72\%$	**2**
11(c)(i)	• Appropriate line of best fit (1)		**1**
11(c)(ii)	• Calculates a gradient using at least half the drawn line (1) • η=1.37 to 1.47 (1) • leading to a conclusion that glass is silica (1) **Or** conclusion consistent with their value for η	Example of calculation $\frac{0.9-0.05}{0.58} = 1.47$ silica	**3**
	Total for question 11		**10**

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• Use of $n_1\sin\theta_1 = n_2\sin\theta_2$ **(1)** **Either** • Angle of refraction = 55° **(1)** • So radiation is refracted **(1)** **Or** • $C = 60°$ **(1)** • Angle of incidence is smaller than C so not total internal reflection **(1)**	<u>Example of calculation</u> $1.5\sin45° = 1.3\sin\theta_2$ $\theta_2 = 55°$	**3**
15(b)i	• Number of conduction electrons increases **(1)** • (so) LDR has a lower resistance **(1)** • Ratio of R_{LDR}/R decreases **or** ratio V_{LDR}/V_R decreases **(1)** • (Leading to) decreased pd across <u>motor</u> so speed of motor decreases **(1)**		**4**

15(b)ii	**Either** • Use of $R_T = R_1 + R_2$ **(1)** • Uses: ratio of pd across LDR to supply pd = ratio of resistance of LDR to total resistance **(1)** • Number of cells = 8 **(1)** **Or** • Use of $R = \frac{V}{I}$ • Use of $V_s = V_1 + V_2$ **Or** $R_T = R_1 + R_2$ • Number of cells = 8	<u>Example of calculation</u> $V_s = \frac{5\ V\ (270\ \Omega + 193\ \Omega)}{193\ \Omega} = 12\ \text{V}$ Number of cells = $\frac{12\ \text{V}}{1.5\ \text{V}} = 8$	**3**

(Total for Question 15 = 10 marks)

(Total for Section B = 24 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
16 (a)	• Experimental evidence became available (eg speed of light in water) **or** wave model could be used to explain other properties of light **or** Huygens' construction could be used to explain interference/diffraction (1) • further support for wave theory by other scientists (eg Thomas Young) **or** (younger) scientists were willing to accept new ideas (1)	MP1 the idea of evidence MP2 the idea of further support	**2**
16 (b)	• use of $n_1 sin\theta_1 = n_2 sin\theta_2$ **and** $n = \frac{c}{v}$ (1) • $v = 2.3 \times 10^8$ m s^{-1} (1) • conclusion comparing their answer to 3.0×10^8 m s^{-1} (1)	Accept use of $n_1 sin\theta_1 = n_2 sin\theta_2$ to establish that $n(water)>1$ with conclusion referring to $n=\frac{c}{v}$ Example of calculation $n(water) = \frac{\sin 35}{\sin 26} = 1.3$ $v(water) = \frac{3.0\times10^8 ms^{-1}}{1.3} = 2.3 \times 10^8$ m s^{-1}	**3**
16(c)	• calculates $\theta = 24°$ **and** $d = 3.3 \times 10^{-6}$ m • use of $n\lambda = dsin\theta$ • $6.7 - 6.8 \times 10^{-7}$ m	Example of calculation $\tan\theta = \frac{0.89\text{ m}}{2.0\text{ m}}$ $\theta = 24°$ $d = \frac{1\times10^{-3}}{300} = 3.3 \times 10^{-6}$ m $\lambda = \frac{3.3\times10^{-6}\text{ m} \times \sin 24}{2} = 678$ nm	**3**

16(d)	• one photon interacts with one electron (1) • when the energy of the photon is equal to or greater than the work function (of the metal) an electron is released (1) • energy of photon = hf so there is a minimum/threshold frequency (1)		**3**
16(e)	• Use of $\lambda = \frac{h}{p}$ **Either** • $h = 6.7 \times 10^{-34}$ (J s) • compares answer to 6.63×10^{-34} (J s) **Or** • $\lambda = 1.38 \times 10^{-10}$ (m) • compares answer to 1.40×10^{-10} (m)	<u>Example of calculation</u> $h = 1.4 \times 10^{-10}$ m $\times 4.8 \times 10^{-24}$ kg m s^{-1} $h = 6.7 \times 10^{-34}$ J s $\approx 6.63 \times 10^{-34}$ J s	**3**

(Total for Question 16 = 14 marks)

9	**C - 1.5** Incorrect Answers: all select incorrect data from question Correct method: image distance ÷ object distance A – uses focal length ÷ object distance B – uses object distance ÷ image distance D – uses object distance ÷ focal length	**1**

Question Number	Acceptable answers	Additional guidance	Mark
1	The only correct answer is **B** because the power of a diverging lens is negative, so the total power = 9.4 D – 4.2 D = 5.2 D A is not correct because the total power should be obtained from (9.4 D – 4.2 D), but this is (9.4 D + 4.2 D) C is not correct because this is (4.2 D – 9.4 D) using negative power for a converging lens and positive for a diverging lens where it should be the opposite so that (9.4 D – 4.2 D) is used D is not correct because – 13.6 D = − 9.4 D – 4.2 D, as if both lenses are diverging, which is not the case		**1**

9	The only correct answer is **D** because magnification is numerically equal to image distance divided by object distance A is not correct because magnification is numerically equal to image distance divided by object distance, but this is focal length divided by object distance B is not correct because magnification is numerically equal to image distance divided by object distance, but this is object distance divided by image distance C is not correct because magnification is numerically equal to image distance divided by object distance, but this is object distance divided by focal length		**1**

8	A	The only correct answer is **A** because a real image is produced at a distance of 30 cm from the lens B is not the correct answer because the object distance is less than the focal length so the image is virtual C is not the correct answer because diverging lenses produce virtual images with real objects D is not the correct answer because diverging lenses produce virtual images with real objects	**1**

Question Number	Answer	Mark
2	The only correct answer is C because 10 cm is more than the focal length from a converging lens A diverging lenses do not form real images from real objects B diverging lenses do not form real images from real objects D an object at less than the focal length from a converging lens will form a virtual image	1

9	**The only correct answer is C** ***A*** *is incorrect because the focal length of the lens increases* ***B*** *is incorrect because the focal length of the lens increases* ***D*** *is incorrect because lens power is the reciprocal of the focal length*	**1**

Question Number	Answer	Mark
4	**A 2.5 cm converging**	**1**
	Incorrect Answers: **B** – incorrect type of lens **C** – incorrect focal length **D** – incorrect focal length and type of lens	

Question Number	Answer	Mark
7	**D** 8D (4D +4D)	1

	A – incorrect calculation B – incorrect calculation C – incorrect calculation	

Question Number	Answer	Mark
2	**The only correct answer is D** **A** *is not correct because* this is the power of one converging lens **B** *is not correct because* this is the power of one diverging lens **C** *is not correct because* this is the power of two converging lenses	1

Question Number	Answer	Mark
4	**The only correct answer is B** **A** *is not correct because* a real image is not formed on the same side of the lens to the object **C** *is not correct because* both comments incorrect **D** *is not correct because* a virtual image cannot be produced on a screen	1

Question Number	Acceptable Answer		Additional Guidance	Mark
8(a)	• Use of $m = \frac{\text{image height}}{\text{object height}}$	(1)		3
	• Use of $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$	(1)	For MP2 allow ($u \approx f$, so) $v = f \times$ magnification	
	• $\therefore v = 28$ m	(1)	Example of calculation $\frac{v}{u} = \frac{h_i}{h_o} = \frac{0.75\text{ m}}{4.0\times10^{-3}\text{m}} = 187.5$ $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $\therefore \frac{v}{u} + 1 = \frac{v}{f}$ $\therefore v = (187.5+1)\times15.0\times10^{-2}\text{m} = 28.3$ m	
8(b)	**Either** • (Inverse square law states that) the intensity is inversely proportional to the square of the distance **Or** $I \propto \frac{1}{x^2}$ with symbols defined	(1)		2
	• So $I \rightarrow \frac{I}{4}$ and statement is incorrect **Or** intensity/brightness falls to one quarter and statement is incorrect	(1)		
	OR • The power is spread over 4 times the area	(1)		
	• So intensity/brightness falls to one quarter and statement is incorrect	(1)		

(Total for Question 8 = 5 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
4	• $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, re-arranged to make $\frac{1}{v}$ the subject	**(1)**	$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ $y = mx + c$	
	• Comparison with $y = mx + c$	**(1)**		
	• So intercept equals $1/f$	**(1)**		
	• Use the y intercept to calculate a value for f	**(1)**		
	• Comment on the agreement with the initial determination including an appropriate justification	**(1)**		
	OR			
	• Since $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, when $\frac{1}{u} = 0$, $f = v$	**(1)**		
	• When $\frac{1}{v} = 0$, $f = v$	**(1)**		
	• Use the y intercept to calculate a value for f	**(1)**		
	• Use the x intercept to calculate a value for f	**(1)**		
	• Comment on the agreement with the initial determination including an appropriate justification	**(1)**		
	OR			
	• Read a pair of corresponding values from the graph	**(1)**		
	• Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to calculate a value for f	**(1)**		
	• Read a second pair of corresponding values from the graph	**(1)**		
	• Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to calculate a second value for f	**(1)**		
	• Comment on the agreement with the initial determination including an appropriate justification	**(1)**		**5**

(Total for Question 4 = 5 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11 (a)	• Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ **(1)** • … with consistent units for u and f **(1)** • Use of displacement = $v - f$ **(1)** • Displacement of lens = 0.07 mm away from sensor **(1)**	Example of calculation $\frac{1}{25\times10^{-2}\text{ m}}+\frac{1}{v}=\frac{1}{4.25\times10^{-3}\text{ m}}$ $\therefore \frac{1}{v}=(235.3-4)\text{ m}^{-1}$ $\therefore v=\frac{1}{231.3\text{ m}^{-1}}=4.32\times10^{-3}\text{ m}$ Displacement of lens = (4.32 – 4.25) mm = 0.0735 mm	**4**
11 (b)	• Lens displacement is so minimal that v doesn't change much **Or** $u >> v$ so Δv doesn't change much **Or** $u >> f$ so displacement doesn't change much **Or** $u >> v$ so v approx. equal to f **Or** most object distances can be considered to be at infinity so will focus at about f **(1)**		**1**

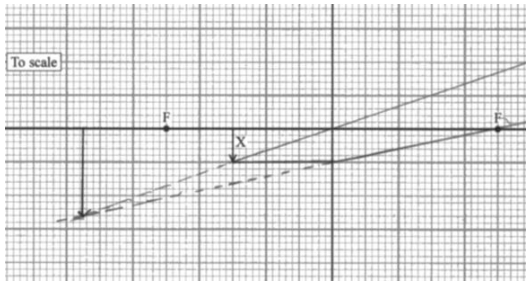
(Total for Question 11 = 5 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
11(a)	• **Two** straight lines drawn extrapolated from diverging rays meeting at a single point on the principal axis **(1)** • focal length = (-) 2.3 to 2.4 cm **(1)**	Accept dotted or solid lines	**2**
11(b)	• Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ **(1)** • Use of $P = \frac{1}{f}$ **(1)** • P = 46 D / Dioptre / dioptre **(1)**	Accept MP2 if you see $\frac{1}{25}$ or $\frac{1}{2.4}$ for $\frac{1}{f}$ Example of Calculation $\frac{1}{0.25}+\frac{1}{0.024} = 46$ D	**3**
11(c)	• increases the power (of the eye) **Or** to decrease the image distance **Or** to shorten the focal length (of the eye and lens) **Or** to the eye it makes the rays appear to come from an object further away **(1)**	If a candidate states that the image is formed at the focal point or that the retina is at the focal point do not award this mark	**1**

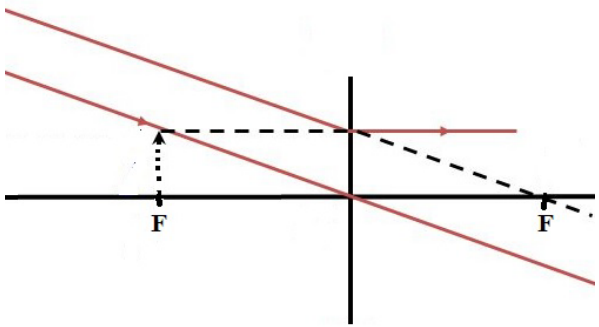
(Total for Question 11 = 6 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
12(ai)	For the 30-year-old • greater stress for a given strain **Or** greater Young Modulus **Or** stiffer **Or** max deformation of the 23-year-old lens is greater **Or** breaking stress of 30-year-old lens is greater (1)	Accept answers for the 23-year-old	**1**
12(aii)	• Reference to the graph consistent with their answer to **(ai)** (1)		**1**
12(b)	• Use of $m = \frac{v}{u}$ (1) • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ (1) • Use of $P = \frac{1}{f}$ (1) • Use of $P = P_1 + P_2$ = 5D therefore use one lens with power of 2 (D) and one with power of 3 (D) (1)	Example of Calculation v = 0.5 x 0.6 m = 0.3 m $\frac{1}{f} = \frac{1}{0.6\text{ m}} + \frac{1}{0.3\text{ m}}$ f = 0.2 m P = 1/0.2 m = 5D	**4**

(Total for Question 12 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	• Use of P = 1/f **(1)** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with u=∞ or very large **(1)** **Or** Rays from a distant point are parallel and converge at the focal point • Distance = 1.25 m **(1)**	Example of calculation $f = \frac{1}{0.8\ \text{D}} = 1.25$ m $\frac{1}{1.25\ m} = \frac{1}{\infty} + \frac{1}{v}$ v = 1.25 m	3
9(b)	• 2 rays drawn: Extended line joining centre of lens to tip of object **and** Horizontal line from tip of object to the lens, then an extended line joining the point on the lens where this line intercepts to the focal point on the right of the lens **(1)** • Image drawn where their two rays cross **(1)** • Use of $m = \frac{v}{u}$ **or** m= $\frac{\text{image height}}{\text{object height}}$ • m = (-) 2.3 – 2.7 **(1)**	Accept: line from focal point on the left hand side of lens through the tip of object to the lens, and then a parallel line joining the line from the lens through the left hand side of lens.  Example of calculation $m = \frac{v}{u}$ $m = \frac{7.5\ (\text{cm})}{3.0(\text{cm})} = (-)\ 2.5$	4

(Total for Question 9 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
16(a)	• Virtual **(1)**		**1**
16(b)	• Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ **(1)** • Use of $P=\frac{1}{f}$ **(1)** • $P = 2.5$ (D) **(1)**	Ignore use of sign convention for MP1 and MP2 Example of calculation $\frac{1}{0.25\text{ m}}+\frac{1}{-0.65\text{ m}}=\frac{1}{f}$ $\therefore \frac{1}{f} = 4.00 - 1.54 = 2.46\text{ m}^{-1}$ $\therefore P = 2.46$ D	**3**
16(c)	• One correct ray drawn **(1)** • Two correct rays drawn for a distant object **(1)** • Image upright and on same side of lens as object **(1)**	Accept diagram with rays drawn parallel to principal axis for MP1 and MP2  	**3**

(Total for Question 16 = 7 marks)

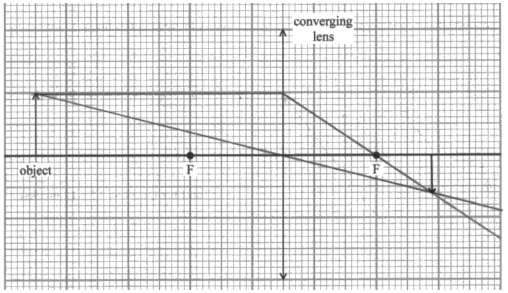
Question Number	Acceptable Answer		Additional Guidance	Mark
15(a)	• Use of $P = \frac{1}{f}$ • $P = 6.0$ D	(1) (1)	Example of calculation $P = \frac{1}{0.167} = 6.0$ D	2
15(b)	• Refractive index of the oil has decreased • Light refracts less (at boundaries of the lens) • Focal length increases • So light intensity at F decreases • The resistance of the LDR increases	(1) (1) (1) (1) (1)	MP4 dependent on MP2 or MP3 MP5 dependent on MP4	5

(Total for Question 15 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

Question Number	Acceptable Answers	Additional guidance	Mark
10(a)	• Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ (1) • f = 8.0× 10^{-2} m (1)	Example of calculation $\frac{1}{f} = \frac{1}{0.09\text{ m}} + \frac{1}{0.75\text{ m}}$ f = 8.00× 10^{-2}m	**2**
(b)	• Light rays pass through the image **Or** Light rays converge to a point where the image is formed (1)		**1**
(c)	• Use of $m = \frac{v}{u}$ (to calculate m) (1) • Use of $m = \frac{\text{image height}}{\text{object height}}$ to calculate distance between dots on screen (1) • Uses tan/sin **or** small angle approximation to calculate the angle (1) • Answer consistent with their calculation (1) • Comparison with 0.0003 radians **or** 0.017° and conclusion consistent with their value for θ (1)	Example of calculation $m = \frac{0.75\text{ m}}{0.09\text{ m}} = 8.3$ Image height = 8.3 x 0.005 m = 0.042 (m) $\tan(\frac{\theta}{2}) = \frac{0.042/2\text{ m}}{4.5\text{ m}}$ $\theta = 0.5° = \frac{0.5\pi}{180}$ rads = 0.0092radians 0.009 radians > 0.0003 radians so student can distinguish between the dots	**5**

(Total for Question 10 = 8 marks)

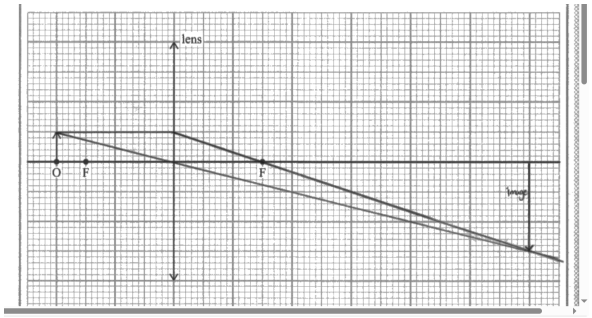
Question Number	Acceptable Answers	Additional guidance	Mark
15(a)	• two rays correctly drawn (1) • image drawn in correct position ±half square (1) • use of $m = \frac{v}{u}$ **or** $m = \frac{image\ height}{object\ height}$ (1) • m = 0.6 (1)	 Example of calculation $m = \frac{4.8\ \text{cm}}{8.0\ \text{cm}} = 0.6$	4
15(b)	• Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ **and** $P = \frac{1}{f}$ • Use of $P = P_1 + P_2$ • (−) 0.6 D • Diverging	MP4 dependent on MP3 Example of calculation Power of eye $P = \frac{1}{1.5\ (\text{m})} + \frac{1}{0.024(\text{m})} = 42.3$ D P of spectacles = 41.7 (D) – 42.3 (D) = -0.6 D diverging	4

(Total for Question 15 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
17 (a)(i)	• Object/star is at infinity, so (intermediate) image formed at focal length of objective lens **(1)** • (Final image at infinity), so object (intermediate image) must be at focal length of eyepiece lens **(1)** **Or** • Objective lens, $1/v + 1/u = 1/f$, and u = infinity, so $v = f$ • Eyepiece lens, $1/v + 1/u = 1/f$, v = infinity so $u = f$	Appropriate references to parallel rays may be equivalent to object/image at infinity Example Objective: $1/v + 1/u = 1/f$, $u = \infty$, so $1/v + 1/\infty = 1/f$ $1/v + 0 = 1/f$ $v = f$ Eyepiece: $1/v + 1/u = 1/f$, $v = \infty$, so $1/\infty + 1/u = 1/f$ $0 + 1/u = 1/f$ $u = f$ Note: If both lenses are considered, $1/v + 1/u = 1/f$ does not have to be quoted twice	**2**
17 (a)(ii)	• The rays cross over after the objective lens **Or** **(1)** • The objective lens inverts the image **Or** • The image formed by the eyepiece lens is on the same side as its object, so remains the same way up		**1**

17 (b)(i)	**Either** • Use of $n = \frac{c}{v}$ **(1)** • Use of $v = f\lambda$ (with v in coating) **(1)** • Use of path difference $= \frac{\lambda}{2}$ with factor of 2 **(1)** • $d = 9.1 \times 10^{-8}$ m **(1)** **OR** • Use of $v = f\lambda$ (with c in air) • Use of $n = \frac{\lambda_{air}}{\lambda_{\text{coating}}}$ • Use of path difference $= \frac{\lambda}{2}$ with factor of 2 $d = 9.1 \times 10^{-8}$ m	Example of calculation: $v = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{1.38} = 2.17 \times 10^{8}\ \text{m s}^{-1}$ $\lambda = \frac{2.17 \times 10^{8}\ \text{m s}^{-1}}{6.00 \times 10^{14}\ \text{Hz}} = 3.62 \times 10^{-7}\ \text{m}$ $d = \frac{\lambda}{4} = \frac{3.62 \times 10^{-7}\ \text{m}}{4} = 9.06 \times 10^{-8}\ \text{m}$	**4**
17 (b)(ii)	• Red and blue light do not interfere destructively, so remain in the reflected light **Or** If green light is cancelled/eliminated, then red and blue light will remain in the reflected light. **(1)**		**1**

(Total for Question 17 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14(a)	**Any two of the following rays drawn [maximum 2 marks for ray drawing]** • Continuous straight line joining the top of the object and the centre of the lens and extended to the right hand side of the lens. **(1)** • Straight line joining the top of the object and F on the left hand side of lens, extended up to the lens. Then continued parallel to the principal axis on the right hand side of the lens. **(1)** • Straight line drawn from the top of the object parallel to the principal axis up to the lens. Then continued through and beyond F on the right hand side of the lens. **(1)** • Correct image drawn in position consistent with their rays **and** within range 11-13 cm **(1)**		**3**
14(b)	• Use of $m = \frac{v}{u}$ **(1)** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ **(1)** • Use of $P = \frac{1}{f}$ **(1)** • Use of $P = P_1 + P_2$ **(1)** • Power of lens = 5.3 D so the student used lens X **(1)**	Example of calculation $v = 0.71 \times 20$ cm = 14.2 cm $P = \frac{1}{0.20\text{ m}} + \frac{1}{0.142\text{ m}} = 12.04$ D $P_2 = P - P_1 = 12.0\text{ D} - 6.7\text{ D} = 5.34$ D	**5**

(Total for Question 14 = 8 marks)
(Total for Section A = 58 marks)

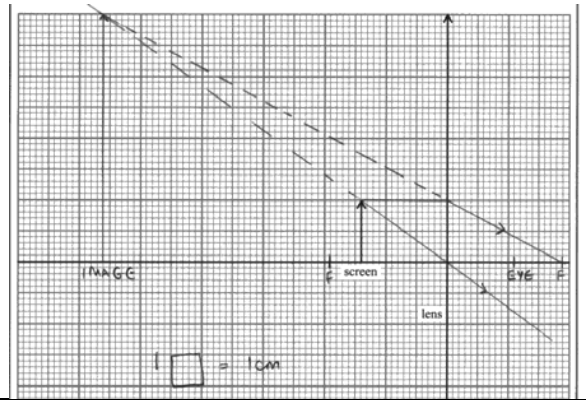
Question Number	Acceptable answers	Additional guidance	Mark
14(a)	• Use of $P = \frac{1}{f}$ **(1)** • 1220 (mm) **(1)**	Example of calculation 0.82 D = 1/*f* *f* = 1 / 0.82 D = 1.22 m Accept 122 (cm)	**2**
14(b)(i)	**Either** • Rays from (a point) on the moon are parallel **(1)** • So the rays converge to the principal focus **Or** so the image is formed at the principal focus **(1)** **Or** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with $u = \infty$ or very large • $f = v$ **(1)** **(1)**	Description of focal length as: the distance between the lens and point at which parallel rays will converge (after passing through lens), scores 2 Accept focal point for principal focus **(MP2 dependent on MP1)** **(MP2 dependent on MP1)**	**2**
14(b)(ii)	Real Diminished Inverted **(2)**	One/Two properties scores 1 mark Three properties score 2 marks Accept smaller Accept upside down	**2**

14(c)	• Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ with u = 100 and v = (−)300 • $f = 150$ (mm) • converging lens with focal length 150 mm	**(1)** **(1)** **(1)**	**(MP3 dependent on MP2)** <u>Example of calculation</u> $\frac{1}{f} = \frac{1}{100\text{ mm}} - \frac{1}{300\text{ mm}}$ $\frac{1}{f} = \frac{3-1}{300\text{ mm}}$ $f = 150\text{ mm}$ MP3 accept if annotated in question Accept convex for converging	**3**

(Total for Question 14 = 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14(a)	• Use of $1/f = P$ **(1)** • Use of $P = P_1 + P_2$ **(1)** • $P = 17$ (D) **(1)**	Example of calculation $P_1 = 1/0.1$ m $= 10$ D $P_2 = 0.15$ m $= 6.7$ D $P = 10$ D $+ 6.7$ D $= 16.7$ D $P = 1/0.1$ m $+ 1/0.15$ m for MP1 **and** MP2	**3**
14(b)	• Use of $1/v + 1/u = 1/f$ **Or** $1/v + 1/u = P$ **(1)** • $v = (-)$ 12 cm (ecf from a) **(1)**	Example of calculation $1/v + 1/(0.04$ m$) = 16.7$ D $v = -0.12$ m (Show that answer gives 20 cm)	**2**
14(c)	• Use of $M = v/u$ **(1)** • Use of M = (image height) / (object height) **(1)** • Image height = 4.2 cm (ecf from b) **(1)**	Example of calculation $M = 12$ cm $/ 4$ cm $= 3$ $I = 3 \times 1.4$ cm $= 4.2$ cm (Show that from (a) gives 7.0 cm)	**3**
14(d)	• Virtual **and** erect/upright **(1)**		**1**

(Total for Question 14 = 9 marks)

Question Number	Acceptable answers		Additional guidance	Mark
17(a)	• Two rays correctly drawn including extrapolation • Completes diagram with image at 10.6 cm (range 9.0 cm to 12.0 cm) • Magnification = 3.8 (3.5 to 4.0) • Conclusion consistent with values for distance and *M*	**(1)** **(1)** **(1)** **(1)**	Acceptable rays: • from arrowhead on object through the optical centre of the lens • from arrowhead on object parallel to the axis up to the lens and then through the principal focus on the other side • from the principal focus on the same side and through the arrowhead on the object to the lens and then parallel to the axis <u>Example of calculation</u> *M* = image size / object size (accept use of distances) = 8.0 cm / 2.0 cm = 4.0 	**4**

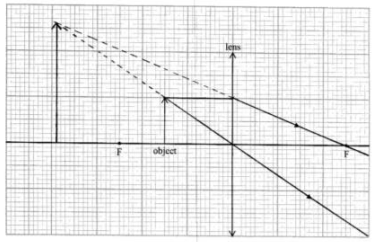
Question Number	Acceptable Answers		Additional Guidance	Mark
17 (b)(i)	• use of $n_1 \sin i_1 = n_2 \sin i_2$ • with angle of incidence in plastic = 28° • angle of deviation = angle of refraction – angle of incidence • angle of deviation = 16°	**(1)** **(1)** **(1)** **(1)**	<u>Example of calculation</u> $n_1 \sin i_1 = n_2 \sin i_2$ $1.47 \sin (90° - 62°) = 1.00 \sin i_2$ $i_2 = 43.6°$ angle of deviation = 44° − 28° = 16°	**4**
17 (b)(ii)	• Going from the centre of the lens towards the edge the angle of incidence in the plastic increases • The angle of deviation increases • (So) all rays cross (the axis) at the principal focus	**(1)** **(1)** **(1)**	Accept focal point for principal focus	**3**

(Total for Question 17 = 11 marks)

Question Number	Acceptable Answers		Additional guidance	Mark
15(a)	• Use of $m = \frac{image\ height}{object\ height}$ • Use of $m = \frac{v}{u}$ • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ • Use of $P = \frac{1}{f}$ • 19 D	(1) (1) (1) (1) (1)	Example of Calculation $m = \frac{3.5\times10^{-3}\text{ m}}{2.0\times10^{-4}\text{ m}} = 17.5$ $v = -17.5 \times 5.0 \times 10^{-2}\text{m} = -0.875$ (m) $\frac{1}{f} = \frac{1}{5.0\times10^{-2}\text{ m}} - \frac{1}{0.875\text{ m}}$ $f = 0.053$ m $P = \frac{1}{0.053\text{ m}} = 18.9$ D	**5**
15(b)(i)	• Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ using angle of incidence = 20° • $r(\text{blue}) = 31.3°$ **and** $r(\text{red}) = 31.1°$ **Or** Calculates difference between $r(\text{blue})$ and $r(\text{red}) = 0.2°$ • Compares their answer to an uncertainty of protractor of 0.5° with conclusion consistent with their answer	(1) (1) (1)	Example of Calculation $\sin r(\text{blue}) = 1.517\sin20 = 0.519$ r (blue)$=\sin^{-1}(0.519) = 31.3°$ $\sin r(\text{red}) = 1.509\sin20 = 0.516$ r (red)$=\sin^{-1}(0.516) = 31.1°$ 31.3° - 31.1° = 0.2° 0.2° < 0.5° so protractor unsuitable	**3**
15(b)(ii)	• Use of $\sin C = \frac{1}{n}$ • 41.5° • Compares their answer to 35° and concludes that red light is not totally internally reflected **or** conclusion consistent with their answer	(1) (1) (1)	$\sin C = \frac{1}{1.509} = 41.5°$ $C > 35°$ so red light is not totally internally reflected [Accept light is refracted linked to an appropriate comparison]	**3**
	Total for question 15			**11**

Question Number	Acceptable answers		Additional guidance	Mark
19 (a)(i)	• Use of $P = 1/f$ • $f = 8.47$ (mm)	**(1)** **(1)**	Example of calculation $f = 1 / 118$ D = 8.47 mm	**2**
19 (a)(ii)	• Use of $1/v + 1/u = 1/f$ (allow u and v reversed, but not f) • $u = 14.8$ mm (ecf for f from 19(a)(i))	**(1)** **(1)**	Example of calculation 1/20 mm + $1/u$ = 1/8.5 mm u = 14.8 mm	**2**
19 (a)(iii)	• (Freshwater has a lower refractive index than seawater, so) there will be greater refraction of light on entering the lens • This means that the power of the lens is greater in freshwater **Or** this means that the focal length is less in freshwater • This means that the shortest distance will be decreased	**(1)** **(1)** **(1)**		**3**
19 (a)(iv)	• Use of $n = c/v$ • $v = 2.2 \times 10^8$ m s^{-1}	**(1)** **(1)**	Example of calculation $1.37 = 3.00 \times 10^8$ m s^{-1} / v $v = 2.2 \times 10^8$ m s^{-1}	**2**
19(b)	**Either** • Polarised light is light where the oscillations are in a single plane • Which includes the direction of propagation **Or** • Polarised light is light where the oscillations are in a single direction • Which is perpendicular to the direction of propagation	**(1)** **(1)** **(1)** **(1)**		**2**

(Total for Question 19 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
13(a)	• Two rays drawn correctly **(1)** • Image drawn, enlarged, upright and 3.7 – 3.9 large squares to the left of lens **(1)**	Extended straight line passing through the centre of the lens and top of the object **and** line parallel to the principal axes from top of the object to the lens and then an extended straight line through F on RHS Accept ray from F on left hand side passing through the top of the object to the lens and continuing parallel to principal axis on RHS and extended back to the image position  	**2**

13(b)	• Use of magnification $= \frac{\text{image height}}{\text{object height}}$ **(1)** • Use of $P = \frac{1}{f}$ **(1)** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ **(1)** • Use of $m = \frac{v}{u}$ **(1)** • image height = 22×10^{-6} m with comparison to 0.1 mm and conclusion jeweller cannot see scratch **Or** m = 2.2 with comparison to their calculated value of m and conclusion jeweller cannot see scratch	<u>Example of calculation</u> Required magnification $= \frac{1 \times 10^{-4}\ \text{m}}{1 \times 10^{-5}\ \text{m}} = 10$ $45 = \frac{1}{0.012} + \frac{1}{v}$ v = (-)0.026 m $m = \frac{0.026}{0.012}$ = 2.2 < required magnification of 10 so jeweller cannot see scratch	**5**
13(c)	**EITHER** • Use of $n = \frac{c}{v}$ **(1)** • Use of $\sin C = \frac{1}{n}$ **(1)** • $C = 25°$ **(1)** • comparison of their calculated value of C with 40° and conclusion consistent with their comparison **(1)** **OR** • Use of $n = \frac{c}{v}$ **(1)** • Use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **(1)** • $\sin\theta_2 > 1$ **(1)** • There cannot be a refracted ray and so the ray must follow the path shown **(1)**	<u>Example of calculation</u> $n = \frac{3.0 \times 10^8\ \text{m s}^{-1}}{1.25 \times 10^8\ \text{m s}^{-1}} = 2.4$ $C = \sin^{-1}\frac{1}{2.4} = 24.6°$	**4**

Total for Question 13 = 11 mark

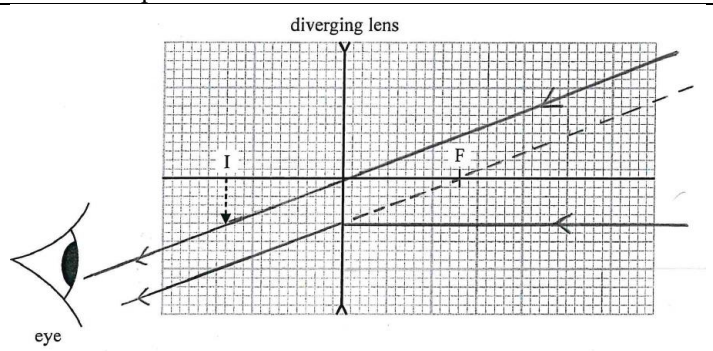
Question Number	Acceptable Answer	Additional guidance	Mark
14(a)(i)	• Use of $V = \frac{4}{3}\pi r^3$ **(1)** • Use of $\rho = \frac{m}{V}$ **and** $U = mg$ **(1)** • 1.73×10^{-5} (N) **(1)**	Example of calculation $U = \frac{4}{3}\pi\left(\frac{1.5 \times 10^{-3}}{2}\right)^3 \times 997 \times 9.81$ $U = 1.73 \times 10^{-5}$ N	**3**

Question Number	Acceptable answers	Additional guidance	Mark
18(a)	• use of $P = 1/f$ **(1)** • use of $P = P_1 + P_2$ etc **(1)** • total power = 63.8 (D) **(1)** • Comparative statement consistent with their values **(1)**	**MP4** An attempt at a % must be made and a clear comparison with the 80% must be made e.g % for cornea from 44.8 / 63.8 is 71% which is not 80% so no Example of calculation P_{cornea} = 1/ 0.0223 m = 44.84 D P_{lens} = 1/ 0.0527 m = 18.98 D Total power = 63.82 D	**4**
18(b) (i)	• use of $1/f = 1/u + 1/v$ **(1)** • u = 4.8 cm **(1)**	Example of calculation 1/1.6 cm = 1/u + 1/ 2.4 cm u = 4.8 cm	**2**
18(b)(ii)	• use of $n = c / v$ **(1)** • use of $n_1 \sin\theta_1 = n_2 \sin\theta_2$ **Or** n = sin i / sin r with correct angles **(1)** • $\theta = 11°$ **(1)**	Accept use of $v_2 \sin\theta_1 = v_1 \sin\theta_2$ for MP1 and MP2 but $v_1 \sin\theta_1 = v_2 \sin\theta_2$ scores neither Example of calculation $n = 3 \times 10^8$ m s^{-1} / 2.18×10^8 m s^{-1} = 1.376 $1 \times \sin 15° = 1.376 \times \sin\theta$ $\theta = 10.8°$	**3**
18(c)	• difference in speed for air to cornea much greater than difference in speed from water to cornea **Or** lower refractive index for water to cornea (= 1.03) **(1)** • so less refraction **Or** so power of eye/cornea reduced **Or** so focal length of eye/cornea increased **(1)** • if goggles worn the interface is with air and refraction is as normal **Or** if goggles worn the interface is with air and image focused on retina **(1)**	MP1: Seeing values of refractive index as 1.03 and 1.38 is not enough, a comparison is required.	**3**

(Total for Question 18= 12 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)	• Comparison with $y = mx + c$ **(1)** • Gradient is $1/f$ and constant [allow reference to m for "gradient"] **(1)**	$m = \frac{v}{f} - 1$ $m = \frac{1}{f}v - 1$	**2**
16(b)(i)	• m = 1.05 to 3 SF **(1)** • Axis labels and unit **(1)** • Scales **(1)** • Plots **(2)** • Line of best fit **(1)**	Example of calculation $m = \frac{h_i}{h_o} = \frac{2.15\text{ cm}}{2.04\text{ cm}} = 1.054$	**6**
16(b)(ii)	• Uses large triangle **(1)** • To determine gradient **(1)** • f in the range 16.5 – 17.4 cm to 2/3 SF **(1)**	Example of calculation Gradient = 0.0588 cm^{-1} $f = \frac{1}{\text{gradient}} = \frac{1}{0.0588\text{ cm}^{-1}} = 17.01\text{ cm}$	**3**
16(c)	An explanation that makes reference to the following points: • Only a real image will be produced on a screen **(1)** • The object cannot be closer than f for a real image **(1)** • Because light diverges after passing through the lens **(1)** **OR** • If object closer than f rays still diverge after passing though lens **(1)** • So a virtual image is formed **(1)** • which cannot be seen on a screen. **(1)**		**3**

(Total for Question 16 = 14 marks)

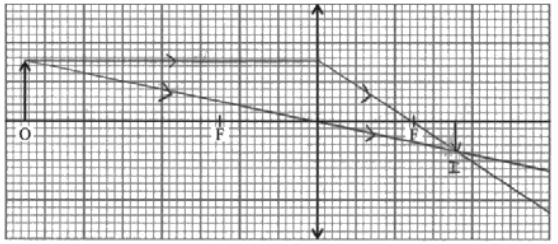
Question Number	Acceptable answers	Additional guidance	Mark
18(a)	An explanation that makes reference to the following points: • The rays must be parallel (to converge to the focal length) **(1)** • So the object must be a large distance away **(1)**	accept use of $1/u + 1/v = 1/f$ with indication that $v = f$ Accept at infinity	**2**
18(b)	• Virtual means that the ray(s) of light do not pass through (the image position) **Or** Virtual means the image cannot be produced on a screen **(1)** • Upright means that the image is the same way up as the original object being observed **(1)**	Accept same orientation (as original object) Accept right way up Do not accept 'not inverted'	**2**
18(c)	• Ray from top right through centre of lens and through arrowhead of image at I **(1)** • Ray (below and parallel to principal axis) refracted as if from focal point F **(1)** • Arrow on at least one ray towards eye **(1)**		**3**

18(d)	• Focal length of converging lens is length of telescope + focal length of diverging lens **or** focal length of converging lens = 90 cm + focal length of diverging lens **(1)** • fc = 100 cm **and** f_d = 10 cm **(1)**	Example of calculation: $10 = \frac{f_c}{f_d}$ $f_c = 90 + f_d$ $10 = \frac{90 + f_d}{f_d}$ f_d = 10 cm and fc = 100 cm Alternate method: $90 = f_c - f_d$ $90 = 10f_d - f_d = 9f_d$ f_d = 10 cm and fc = 100 cm accept f_d = −10 cm as it is a diverging lens	**2**
18(e)	• Converts hours to seconds **(1)** • Equates $F = \frac{GMm}{r^2}$ and $F = \frac{mv^2}{r}$ **(1)** **Or** Equates $F = \frac{GMm}{r^2}$ and $F = mr\omega^2$ **(1)** • Substitutes $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ **(1)** • $GM = \frac{4\pi^2 r^3}{T^2}$ derived and used • $M = 1.9 \times 10^{27}$ kg	Example of calculation: $171 \times 60 \times 60 = 615\,600$ s $\frac{GMm}{r^2} = \frac{mv^2}{r}$ and $v = \frac{2\pi r}{T}$ Leads to $GM = \frac{4\pi^2 r^3}{T^2}$ $M = \frac{4\pi^2 \times (1.07 \times 10^9\ \text{m})^3}{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2} (171 \times 3600)^2 (\text{s})^2}$ $M = 1.91 \times 10^{27}$ kg	**5**

	OR • Converts hours to seconds • Use $v = \frac{2\pi r}{T}$ or $\omega = \frac{2\pi}{T}$ • Equates $F = \frac{GMm}{r^2}$ and $F = \frac{mv^2}{r}$ **Or** Equates $F = \frac{GMm}{r^2}$ and $F = mr\omega^2$ • $GM = r^3\,\omega^2$ **Or** $GM = v^2\,r$ derived and used • $M = 1.9 \times 10^{27}$ kg	Alternative method: $171 \times 60 \times 60 = 615\,600$ s $$v = \frac{2\pi \times 1.07 \times 10^9\ m}{615600\ s}$$ $v = 10900$ ms^{-1} $$\frac{GMm}{r^2} = \frac{mv^2}{r}$$ $$GM = v^2 r$$ $$M = \frac{(10900\ \text{ms}^{-1})^2 \times 1.07 \times 10^9\ \text{m}}{6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}}$$ $M = 1.9 \times 10^{27}$ kg Alternative via $\omega = 1.02 \times 10^{-5}$ rad s^{-1}	

(Total for Question 18 = 14 marks)

TOTAL FOR PAPER = 90 MARKS

14(a)(i)	• One ray correctly drawn (1) • Second ray correctly drawn (1) • Completes diagram with image at position 3.6 to 3.8 cm and height of 0.7 to 0.8 cm (1)		**3**
14(a)(ii)	• Use of $m = \frac{v}{u}$ **or** $m = \frac{image\ height}{object\ height}$ using values from (a)(i) (1) • Magnification of 0.47 to 0.53 (1)	Example of Calculation $m = \frac{v}{u} = \frac{3.7}{7.5} = 0.5$	**2**
14(a)(iii)	• Real **and** image on different side of converging lens to object **Or** rays pass through the image (1)		**1**

14(b)(i)	• Focus image of distant/far object on to a screen (1) • Measure distance from lens to screen (1) **Or** • Use <u>parallel</u> rays of light (1) • Measure distance from lens to the point where the rays converge (1)	MP2 dependent on MP1	**2**
14(b)(ii)	• Greater <u>refraction</u> (1) • To converge (parallel) rays at a point closer to the lens (1)		**2**
14(b)(iii)	• Photograph 2 has a greater magnification (1) • so v is greater (1) • since u is constant (1) • So f is greater (1) • Hence photograph 2 taken with lens of focal length 200 mm (1)	MP5 dependent on MP2 and MP4	**5**
	Total for question 14		**15**

Question Number	Acceptable answers	Additional guidance	Mark
7	D oscillates in one direction, no light		1

Question Number	Answer	Mark
1	**C - polarisation**	**1**
	Incorrect Answers: A – diffraction is exhibited by sound waves B – interference is exhibited by sound waves D – refraction is exhibited by sound waves	

Question Number	Acceptable answer	Additional guidance	Mark
5	B	The only correct answer is **B**: light leaving Y is polarised in its plane of polarisation and 135° is perpendicular to the plane of Y, so there will be maximum absorption by filter Z A is not correct because Z is not perpendicular to the plane of Y so some light is transmitted C is not correct because Z is not perpendicular to the plane of Y so some light is transmitted D is not correct because Z is not perpendicular to the plane of Y so some light is transmitted	**1**

8	**D** Transverse waves are always plane polarised.	**1**
	Incorrect Answers: A – An unpolarised wave may be polarised on reflection from a surface. B – Longitudinal waves cannot be plane polarised. C – The vibrations in an unpolarised wave are in many directions.	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
2	**The only correct answer is A** B is not correct as the filter would be the same intensity as the first position if rotated through π C is not correct as the light is polarised D is not correct as the light is polarised		1

Question Number	Answer	Mark
5	**C** bright dark	1
	A - at 90° the lamp appears bright B - at 90° the lamp appears bright and at 180° the lamp appears dark D - at 180° the lamp appears dark	

Question Number	Answer	Mark
6	**D** unpolarised transverse waves	1
	A – this is not a stationary wave B – this is not a longitudinal wave C – this is not a polarised wave	

8	**The only correct answer is B** **A** *is not correct because* no light can be transmitted when the filters are perpendicular **C** *is not correct because* no light can be transmitted when the filters are perpendicular **D** *is not correct because* no light can be transmitted when the filters are perpendicular	**1**

(Total for Multiple Choice Questions = 8 marks)

9	**The only correct answer is C,** rotation of P_1 is $\pi/2$ rad and rotation of P_2 is π rad A is not correct because this has a net rotation of the filters of 45° B is not correct because this has a net rotation of the filters of 135° D is not correct because this has a net rotation of the filters of 180°	**1**

Question Number	Acceptable Answers	Additional Guidance	Mark
9	• Rotate filter or laptop and brightness of the screen varies (1) **Either** • When screen goes dark plane of polarised light is perpendicular to the plane of polarisation of the filter (1) • As polarised light from the screen is absorbed by the filter. (1) **Or** • When screen is brightest plane of polarised light is parallel to the plane of polarisation of the filter (1) • As polarised light from the screen is transmitted by the filter. (1)		**3**
	Total for question 9		**3**

Question Number	Acceptable Answers	Additional Guidance	Mark

15

This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

- Light from the source is unpolarised
  Or light from source has oscillations in all planes.
- Intensity is reduced to ½ by filter 1
- By absorbing the perpendicular components
  Or by transmitting the parallel components.
- At 0° / 180° filter 2 aligned with filter 1 so all light through filter 1 passes through filter 2
- As filter 2 is rotated only the component of the light from filter 1 in the plane of filter 2 is allowed through, so the intensity reduces.
- At 90°, all light is absorbed because their planes (of polarisation) are at right angles.

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Number of IC points awarded	**Possible linkage marks**
0,1	0
2, 3	1
4, 5, 6	2

IC3,6 allow, no light passes through, blocked by, stopped by

6

(Total for question 15 = 6 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
10(a)	• Intensity (of sound) varies **(1)** • (Intensity) is a minimum at 90° **and** a maximum at 180° **(1)**	For MP1 there must be an indication of intensity, volume, loudness or amplitude. Any reference to pitch changing means this mark cannot be awarded. MP2 can be awarded if answer only refers to audible output.	**2**
10(b)	• Waves (from gaps) superpose/interference **(1)** • Constructive (interference) when waves are in phase **Or** path difference is nλ **(1)** • Destructive (interference) when waves are in antiphase **Or** path difference is $(n+\frac{1}{2})\lambda$ **(1)** • Links constructive interference to maximum intensity **Or** links desructive interference with minimum/zero intensity **(1)**	Not superimpose MP3 Do not accept out of phase	**4**

(Total for Question 10 = 6 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*Q13</td>
<td>
This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Indicative content

At 180° the screen is normal/bright
When oscillations/vibrations are parallel to the filter all the light is transmitted
or
When oscillations/vibrations are parallel to the filter no light is absorbed
At 270° the screen is dark/darkest/black
When oscillations/vibrations are perpendicular to the filter all the light is absorbed
or
When oscillations/vibrations are perpendicular to the filter no light is transmitted
The idea of a gradual change as the filter is rotated
(as) Light from the screen is (partially) polarised

</td>
<td>
The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

(Total for question 13 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
9(a)	An explanation that makes reference to the following points: • (The plane that) contains the oscillations / vibrations (of the wave) **(1)** • (The plane) including the direction of propagation of the wave **(1)**		**2**
9(b)(i)	An explanation that makes reference to the following points: • (Planes of polarisation of filters are) at 90° **or** at right angles **or** perpendicular **(1)** • Light transmitted by the first filter is absorbed by the second **(1)**	[do not allow all light absorbed. Must refer to each filter absorbing different components of light]	**2**

9(b)(ii)	• Calculates gradient = 75 (degrees cm^3 g^{-1}) **(1)** **EITHER** • Calculates *kl* (0.75) **(1)** • Compares their gradient to *kl* (0.75) with conclusion consistent with their gradient **(1)** **OR** • Calculates *k* using their gradient **(1)** • Compares their value for *k* with 0.050 (degrees cm^2 g^{-1}) with conclusion consistent with their calculated *k* **(1)** **OR** • Calculates *l* using their gradient **(1)** • Compares their value for *l* with 15 (cm) with conclusion consistent with their calculated *l* **(1)**	[Accept 73 – 80] Example of calculation *kl* = 0.05 degrees cm^2 g^{-1} × 15 cm = 0.75 degrees cm^3 g^{-1}	**3**

(Total for Question 9 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)(i)	• Oscillations/vibrations (of the light) are in one plane only **(1)** • Plane includes the direction of energy transfer **Or** Plane includes the direction of travel/propagation **(1)**	Accept: • Oscillations/vibrations (of the light) are in one direction only • perpendicular to the direction of propagation/travel **Or** perpendicular to the direction of energy transfer Allow labelled diagrams for each marking point	**2**
16(a)(ii)	• The (angle of polarisation of the) filters are 90° to one another **(1)** **Either** • If plane of polarisation of light is rotated (by 90°) when it passes through the crystal (with no p.d. across it), it can still pass through the upper filter **(1)** **Or** • If plane of polarisation of light is not rotated (by 90°) when it passes through the crystal (with a p.d. across it), it cannot pass through the upper filter **(1)**	MP2: it must be clear as to whether the candidate is describing a light screen or a dark screen	**2**
16(b)(i)	• Use of $I = P/A$ **(1)** • $P = 0.014$ W **(1)**	Example of calculation $P = 7.8\ \text{W m}^{-2} \times 1.8 \times 10^{-3}\ \text{m}^2$ $P = 0.014$ W	**2**
16(b)(ii)	• Use of $P = VI$ **(1)** • Use of efficiency $= \frac{\text{useful power output}}{\text{total power input}}$ **(1)** • Efficiency = 0.19 or 0.20 or 19 % or 20 % **(1)**	Example of calculation Power input into LED $= 3.6\ \text{V} \times 20 \times 10^{-3}\ \text{A} = 0.072$ W Efficiency $= \frac{0.014\ \text{W}}{0.072\ \text{W}} = 0.194$ ecf from (b)(i) for the power output of LED	**3**

16(c)	• X is brittle at greater stresses/forces **(1)** • Y will deform plastically at greater stresses/forces **(1)** • The Young modulus for X is greater than Y **(1)** • A screen made from material Y would be more suitable as it is more flexible **(1)**	Accept converse for MP3 and MP4 MP4: accept less stiff for flexible.	**4**

(Total for Question 16 = 13 marks)

10	**D – using laser light with a higher frequency** Incorrect Answers: A – this would have no effect B – this would make the maxima further from the central maximum C − this would make the maxima further from the central maximum	**1**

(Total for Multiple Choice Questions = 10 marks)

<table>
<tr><th>Question Number</th><th>Answer</th><th>Mark</th></tr>
<tr><td>3</td><td>A Using nλ=dsin θ
<table>
<tr><td>Number of slits per mm in the diffraction grating</td><td>Wavelength of the light source</td></tr>
<tr><td>Increased</td><td>Increased</td></tr>
</table>
Incorrect Answers:
B – wavelength decreasing would cause d to decrease
C – number of slits/mm decreasing would cause d to decrease
D –both decreasing causes d to decrease</td><td>1</td></tr>
</table>

7	**D originate from one source**	**1**
	Incorrect Answers: A – coherence requires a constant phase difference not necessarily 0 B – planes not relevant C – amplitude not relevant	

10	The only correct answer is **C** because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order A is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, and there are that many orders either side of the maximum plus a central order, but this answer only gives the number of orders on one side of the central order B is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and doesn't consider the central maximum or that there are orders on either side D is not correct because the maximum order reached corresponds to the highest integer value less than or equal to line spacing divided by wavelength, which is 4, but this order rounds 4.7 to 5 and then adds the orders on the other side and the central maximum		**1**

(Total for Multiple Choice Questions = 10 marks)

8	**C** equal to the difference between the mean and 448	**1**
	Incorrect Answers: **A** this is equal to the range **B** this is equal to the difference between the values 448 and 466 **D** this is equal to the difference between the mean and 473	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answers	Mark
3	**The only correct answer is B** ***A*** *is incorrect because amplitude does not affect the diffraction effect* ***C*** *is incorrect because frequency affects the wavelength and hence the diffraction effect* ***D*** *is incorrect because the speed of sound affects the wavelength and hence the diffraction effect*	**1**

Question Number	Acceptable answers	Additional guidance	Mark
6	**The only correct answer is B** A is not correct as the corresponding maxima must be V or Z and only V is represented by the answer option B		1
	C is not correct as the corresponding maxima must be V or Z and only V is represented by the answer option B D is not correct as the corresponding maxima must be V or Z and only V is represented by the answer option B		

Question Number	Answer	Mark
1	**B** n no unit *d* mm	1
	A – *d* incorrect C – *n* and *d* incorrect D– *n* and *d* incorrect	

Question Number	Answer	Mark
2	**D** $\tan^{-1}\left(\frac{0.35}{2.00}\right)$	1
	Incorrect Answers: A – Incorrect use of trigonometry B – Incorrect use of trigonometry C – Values inverted	

Question Number	Answer	Mark
4	**B** The path difference of the waves is λ. Incorrect Answers: A – phase difference would be $2n\pi$ C – frequency of resultant wave is unchanged D – displacement of the resultant would be sum of the two waves	1

Question Number	Acceptable answers		Additional guidance	Mark
11	• Use of $n\lambda = d \sin\theta$	**(1)**	Example of calculation $3\ \lambda = d \times 1.67 \times 10^{-6}$ m × sin 73.3° $\lambda = 5.33 \times 10^{-7}$ m	**2**
	• $\lambda = 5.33 \times 10^{-7}$ m	**(1)**		

Total for Question 11 = 2 marks

Question Number	Acceptable Answers	Additional Guidance	Mark
11(a)	• Light is an electromagnetic wave **Or** light is oscillations of electric and magnetic fields (1) • Oscillations are perpendicular to the direction of energy transfer (1)		2
11(b)	• The wave spreads out (after passing through a gap) (1) • Each point on the wave acts as a source of secondary wavelets (1) • That interfere/superpose (1)		3
	Total for question 11		5

Question Number	Acceptable Answers	Additional guidance	Mark
9(a)	• Use of $\tan\theta\theta = \frac{x}{D}$ (1) • Use of $d = 1/300$ • Use of $n\lambda = d\sin\theta\theta$ (1) • $\lambda = 530$ (nm) with conclusion green (1) (1)	Example of Calculation $d = 1/(300 \times 10^{3}\text{m}^{-1}) = 3.33 \times 10^{-6}$ m $\theta\theta = \tan^{-1}\frac{1.35}{4.0} = 18.65°$ $\lambda = \frac{3.33 \times 10^{-6}\text{ m} \times \sin 18.65°}{2} = 5.32 \times 10^{-7}\text{m} = 532$ nm Green	4
9(b)	• The resolution would be the same but the distance measured is greater **Or** The uncertainty would be the same but is divided by a greater length (1)		1

(Total for Question 9 = 5 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
13 (a)	• Line/surface joining points on a wave that are in phase (1)		**1**
13(b)(i)	• Do not stare into laser (1)		**1**
13 (b)(ii)	• Lack of other evidence (supporting wave theory) **Or** Was yet to be reproduced **Or** There was support / evidence for the particle model (1)		**1**
13(c)(i)	An explanation that makes reference to the following: • Path lengths (A-O and B-O) are equal **Or** Path difference is zero (1) • Will arrive in phase **Or** phase difference is zero (1) • (Bright line is position of) <u>constructive</u> interference/superposition (1)		**3**
13(c)(ii)	• 600 nm **Or** 600 × 10^{-9} m **Or** 6.0 × 10^{-7} m **Or** one wavelength **Or** λ (1)	Do not accept (nλ**)** Accept any correct equivalent value	**1**
	Total for question 13		**7**

			Additional guidance	Mark

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Use of $\tan\theta = \frac{x}{D}$ **(1)** • Use of $d\sin\theta = n\lambda$ **(1)** • Use of $d = \frac{1}{\text{number of lines per metre}}$ **(1)** • λ = 520 nm so spacing of pattern was consistent **Or** x = 43.5 cm so spacing of pattern was consistent **Or** $d = 3.32 \times 10^{-6}$ m $\approx 3.33 \times 10^{-6}$ m, so spacing is consistent **Or** number of lines per mm = 301 ($\approx$300 mm^{-1}), so spacing is consistent **Or** $\theta = 8.97^{o} \approx 8.99^{o}$, so spacing is consistent **(1)**	Example of calculation $\tan\theta = \frac{0.435\text{ m}}{2.75\text{ m}} = 0.158$ $\theta = 8.99^{o}$ $d = \frac{1}{3 \times 10^{5}\text{ m}^{-1}} = 3.33 \times 10^{-6}\text{ m}$ $\lambda = 3.33 \times 10^{-6}\text{ m} \times \sin 8.99^{o} = 5.20 \times 10^{-7}\text{ m}$	**4**
1(b)	**MAX 3** • The metre rule has a resolution of 0.1 cm **Or** The metre rule has a resolution not a precision **(1)** • Precision is how closely grouped (repeated) readings are **(1)** • Accuracy is how close the measured value is to the actual value **(1)** • Systematic error may shift measured values away from the actual values **Or** It may be difficult to judge the positions of the maxima **(1)**	MP4 Accept an example of systematic error e.g. a zero error **Or** a reference to parallax error	**3**

(Total for Question 1 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
2(a)	• Use of $P = \frac{V^2}{R}$	(1)	Use of $P = VI$ and $R = \frac{V}{I}$ to calculate R scores MP1 Use of $V = \epsilon - Ir$ scores MP2 and MP3 Allow use of potential divider equation for MP2 and MP3 Example of calculation $R = \frac{(12\ \text{V})^2}{40\ \text{W}} = 3.6\ \Omega$ $I = \frac{12\ \text{V}}{(3.6 + 0.5)\ \Omega} = 2.93\ \text{A}$ $V = 2.93\ \text{A} \times 3.6\ \Omega = 10.5\ \text{V}$ Allow $V = \left(\frac{3.6\ \Omega}{3.6\ \Omega + 0.50\ \Omega}\right) \times 12\ \text{V} = 10.5\ \text{V}$	4
	• Use of sum of e.m.fs = sum of p.d.s	(1)		
	• Use of $R = \frac{V}{I}$ to calculate a p.d.	(1)		
	• $V = 10.5$ V	(1)		

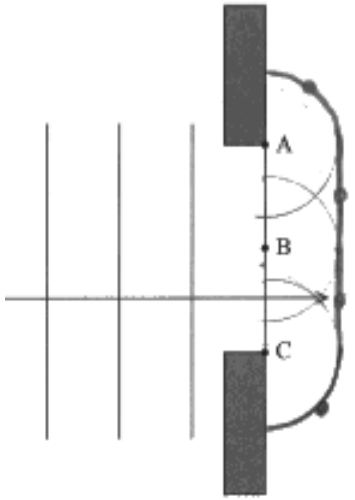
Question Number	Acceptable answers		Additional guidance	Mark
11(a)	• Use of correct trigonometry to determine θ	**(1)**		**4**
	• Uses $d = 1/400$	**(1)**		
	• Use of $n\lambda = d \sin\theta$ with $n = 2$	**(1)**	Example of calculation $\theta = \tan^{-1}\frac{3.25 \times 0.5}{4} = 22.1°$ $2 \times \lambda = 2.5 \times 10^{-6}$ m $\sin 22.1°$	
	• $\lambda = 470$ nm which is outside the range	**(1)**	$\lambda = 470$ nm	
11(b)	• Use of $\lambda = \frac{h}{p}$ **and** $p = mv$	**(1)**		**4**
	• Calculate 10% of c	**(1)**		
	• $\lambda = 2.4 \times 10^{-11}$ m	**(1)**		
	• $\lambda \ll$ than size of gap so little/no diffraction occurs	**(1)**	Example of calculation $\lambda = \frac{6.63 \times 10^{-34}\text{J s}}{9.11 \times 10^{-31}\text{kg} \times 0.1 \times 3.0 \times 10^{8}\text{ m s}^{-1}}$ $\lambda = 2.4 \times 10^{-11}$ m	

(Total for Question 11 = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11(a)	An explanation that makes reference to the following: • The light is diffracted **(1)** • (because) each point on wavefront acts as a source of secondary waves **Or** wavelets emitted (from points on the wavefront) **(1)**	Marks may be shown on a clearly labelled diagram	**2**
11(b)	An explanation that makes reference to the following: • Path lengths (to centre of shadow from edge of ball) are equal **Or** path difference (at spot) is zero **(1)** • Will arrive in phase **Or** phase difference is zero **(1)** • (Bright spot is position of) constructive interference/superposition **(1)**		**3**
11(c)	• Wave model **(1)** **Any two** • (Demonstration) provided experimental evidence (in support of wave model) **(1)** • (Demonstration) supported previous evidence **(1)** • (This demonstration was) reproducible **Or** (This demonstration) could be repeated by others **(1)**		**3**
11(d)	• (Vernier) callipers **Or** travelling microscope **Or** micrometer **(1)** • Measure diameter in different places **and** calculate mean **(1)**		**2**

(Total for Question 11 = 10 marks)

Question Number	Acceptable answers		Additional guidance	Mark
15 (a)	• Use of $v = f\lambda$ • λ = 0.013 m	**(1)** **(1)**	Example of calculation 340 m s^{-1} = 26.0 kHz × λ λ = 0.013 m	**2**
15 (b)	• Two or more waves meet • The (resultant) displacement (at a point) is the sum of the individual displacements from the individual waves	**(1)** **(1)**	Do not accept sum of amplitudes	**2**
15 (c)	• Wave and reflection will meet • Superposition / interference occurs • Where in antiphase, destructive interference • Zero/minimum amplitude at nodes – so mice won't hear **Either** • But node separation = ½ wavelength = (about) 7 mm • Too small a space for a mouse to avoid the ultrasound, so suggestion not correct **Or** (MP5 and 6) • Wall absorbs some ultrasound so reflected wave has smaller amplitude than incident wave • Incomplete cancellation, some ultrasound even at nodes, so suggestion (probably) incorrect **Or** (MP5 and 6) • Waves also arrive from other walls/floor/ceiling/multiple reflection • Complete cancellation unlikely so suggestion (probably) incorrect **Or** (MP5 and 6) • A standing wave will only be formed if the length of the room is a whole number of half wavelengths • Otherwise there will be no nodes so no silent spots where the mouse won't hear	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	Example of calculation λ/2 = 0.013 m / 2 = 0.0065 m	**6**
				(Total for Question 15 = 10 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
13(a)(i)	• A line/surface/plane along which all the points are in phase (1)		1
13(a)(ii)	• A wavelet drawn centred on any point on the line AC (1) • Minimum of three wavelets drawn (extending to right hand side) with radii equal (by eye) to distance between incoming wavefronts (1) • New wavefront drawn with correct shape and position along leading edge of wavelets (1)	Accept curved line, arc, circle or semicircle for wavelets 	3

13b(i)	Any one • Monochromatic **or** small range of wavelength / frequencies • Coherent • Little divergence of wave over a distance • Produces plane wavefronts		**1**
13b(ii)	• d = 0.005 mm **or** use of $d = \frac{1}{200\ \text{mm}^{-1}}$ (1) • Use of tan to find θ (1) • Use of $n\lambda = d\sin\theta$ with n = 3 (1) • $\lambda = 5.4 \times 10^{-7}$ (m) (1) • Concludes that the laser light is green **Or** conclusion consistent with their value of λ (1)	Example of Calculation $d = \frac{1}{200\ \text{mm}^{-1}} = 0.005$ mm $\theta = \tan^{-1}\left(\frac{1.02\ \text{m}}{3.0\ \text{m}}\right) = 18.8°$ $\lambda = \frac{(5\times10^{-6}\text{m})\times\sin 18.8°}{3} = 5.37 \times 10^{-7}\text{m}$ so light is green	**5**

(Total for Question 13 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• measure distance from grating to screen l and from centre to dot x **(1)** • use $\tan\theta = x / l$ to determine θ **(1)**		**2**
15(b)	• Axes with labels **(1)** • scales **(1)** • plots **(1)** • line of best fit **(1)**	**MP2**: scales only in 1,2,4,5 and must cover at least half of paper **MP3**: a 2 mm square tolerance, check all points	**4**
15(c)	• calculation of a gradient **(1)** • use gradient = d/λ **(1)** • use d = 0.001 / 300 **(1)** • wavelength = 6.3×10^{-7} m **(1)**	Example of calculation $\text{gradient} = \frac{4.0}{0.76} = 5.26$ $\frac{0.001}{300} = 5.26 \times \lambda$ wavelength = 6.3×10^{-7} m	**4**

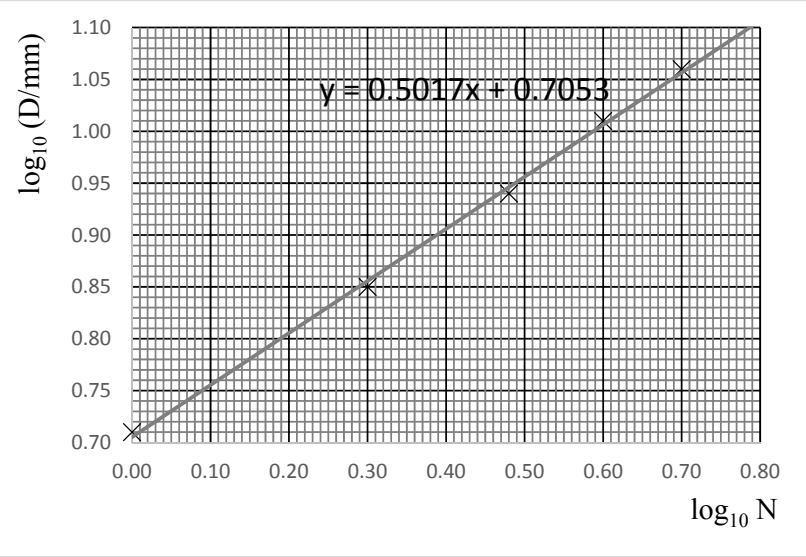
(Total for Question 15 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	• Use of trigonometry to determine θ **(1)** • Calculation of both angles **(1)** • Use of $d\ sin\theta = n\lambda_1$ to calculate d **(1)** • Use of $d\ sin\theta = n\lambda_2$ with d **(1)** • $\lambda_2 = 5.3 \times 10^{-7}$ m (530 nm) **(1)**	Example of calculation $\tan\theta = \frac{0.50\text{ m}}{1.45\text{ m}} \therefore\ \theta = 19.0^o$ $\tan\theta = \frac{0.40\text{ m}}{1.45\text{ m}} \therefore\ \theta = 15.4^o$ $d = \frac{650 \times 10^{-9}\text{ m}}{\sin 19.0^o} = 1.99 \times 10^{-6}\text{ m}$ $\lambda_2 = 1.99 \times 10^{-6}\text{m} \times \sin 15.4^o = 5.29 \times 10^{-7}\text{m}$	**5**
11(b)	An explanation that makes reference to the following points: • Measure the distance between the two 1st/2nd order maxima **Or** measure the distance from the 2nd order to the central maximum **Or** increase the distance from the grating to the screen • This increases the distance measured on the screen (and reduce the % uncertainty) **(1)** MP2 dependent upon MP1 **(1)**		**2**
11(c)	An explanation that makes reference to the following points: • Maxima on one side move closer to the central maximum **(1)** • Maxima on the other side move further away from the central maximum **(1)** • Intensity of maxima would be different on each side of central maximum **(1)**	Allow 1 mark for spacing of maxima on screen will change	**3**

(Total for Question 11 = 10 marks)

Question Number	Acceptable answers		Additional guidance	Mark
20(a)	• use of $f = 1/T$ • use of $v = f\lambda$ • wavelength = 7.5×10^{6} m	**(1)** **(1)** **(1)**	MP3: accept variations e.g. 1.75 waves or two wavelengths averaged with correct calculation Example of calculation 2 waves $2T = 0.05$ s $T = 0.025$ s $f = 1/0.025$ s $= 40$ Hz $\lambda = 3.00 \times 10^{8}$ m s^{-1} ÷ 40 Hz $= 7.5 \times 10^{6}$ m	**3**
20(b)(i)	• use of strain = extension / length • change in length = 4.8×10^{-18} (m) **Or** max strain for 0.001× proton size = 2.2×10^{-22} • comparison of their change in length to 8.8×10^{-19}(m) **Or** comparison of their max strain to 1.2×10^{-21}	**(1)** **(1)** **(1)**	Example of calculation Change in length = $1.2 \times 10^{-21} \times 4000$ m = 4.8×10^{-18} m Fraction of proton diameter = 4.8×10^{-18} m ÷ 8.8×10^{-16} m = 0.0055	**3**
20(b)(ii)	• half wavelength path difference means waves in antiphase • so destructive interference takes place • this results in zero amplitude, (so no signal detected) • a change in length will result in a change in path difference, so signal detected **Or** a change in length will result in a change in phase difference, so signal detected	**(1)** **(1)** **(1)** **(1)**	Do not accept 'out of phase' for MP1 Accept reference to being 'not out of phase' for MP4	**4**
20(b)(iii)	• if initially the path difference is zero there will be a maximum signal • a change from max amplitude would represent a much smaller percentage (therefore less sensitive)	**(1)** **(1)**	MP2 alternative**:** a change from minimum amplitude would represent a much larger percentage (therefore more sensitive) MP2 Accept 'it is easier to detect the change from no light to light' MP2 Accept suitable reference to uncertainty	**2**

(Total for Question 20 = 12 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>13(a)</td>
<td>
• Log values calculated in table (1)
• Axes correctly labelled (1)
• Suitable scales (1)
• All points plotted correctly (1)
• Line of best fit drawn (1)
• Determine gradient using large triangle (1)
• Intercept read from graph (1)
• $p = 5.0 – 5.2$ (mm)
Or $p = (5.0 – 5.2) \times 10^{-3}$ (m)
$q = 0.5$ (1)
</td>
<td>
Accept $\log_{10}$ or ln ($\log_e$)
<table>
<tr><th>$\log_{10}$ (D/mm)</th><th>$\log_{10}$ N</th></tr>
<tr><td>0.710</td><td>0.000</td></tr>
<tr><td>0.850</td><td>0.301</td></tr>
<tr><td>0.940</td><td>0.477</td></tr>
<tr><td>1.01</td><td>0.602</td></tr>
<tr><td>1.06</td><td>0.699</td></tr>
</table>
<table>
<tr><th>ln (D/mm)</th><th>ln N</th></tr>
<tr><td>1.64</td><td>0.000</td></tr>
<tr><td>1.96</td><td>0.693</td></tr>
<tr><td>2.16</td><td>1.10</td></tr>
<tr><td>2.33</td><td>1.39</td></tr>
<tr><td>2.44</td><td>1.61</td></tr>
</table>


</td>
<td>8</td>
</tr>
</table>

13(b)(i)	• absolute uncertainty in position × 2 **(1)** • % uncertainty = 0.2 % **(1)**	Example of calculation Absolute uncertainty = 2 × 0.005 mm = 0.01 mm $\therefore$% uncertainty= $\frac{0.01\text{ mm}}{5.13\text{ mm}} \times 100\% = 0.2\ \%$	**2**
13(b)(ii)	• The edges of the dark circle are not clearly defined **(1)**	Accept: the rings are not perfect circles	**1**
13(c)	• Coherent waves have a constant phase relationship **(1)** • Coherent waves have the same frequency **(1)** • However, for each frequency present the (two) reflected waves are coherent **(1)** • Hence with a non-monochromatic source, a set of dark rings for each frequency would be produced **(1)**	MP2-4: accept wavelength for frequency MP4: hence with a white light source you would see a set of coloured rings	**4**

(Total for Question 13 = 15 marks)

Question Number	Acceptable answers		Additional guidance	Mark
17 (a)	• Use of lens equation $1/f = 1/v + 1/u$ • Use of magnification = v/u • Magnification = 15	**(1)** **(1)** **(1)**	Example of calculation 1/17.9 mm = $1/v$ + 1/16.7 mm v = (-)249 mm magnification = 249 mm / 16.7 mm = 14.9	**3**
17 (b)(i)	• The electrons/atoms can only exist in discrete/specific energy levels (in the sodium atoms) • Electrons/atoms become excited **Or** Electrons/atoms move to higher energy levels • The electrons/atoms then move to lower energy levels, giving out energy in the form of photons • The energy of the photon is equal to the energy difference between the energy levels • $E = hf$ and $\lambda = c/f$ so wavelength depends on the photon energy • There are only certain energy transitions possible (between discrete levels) so only certain frequencies/wavelengths are visible.	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	accept $E = hc / \lambda$ MP6 – Allow reference to few or limited number for 'certain'. Allow reference to discrete differences in energy levels.	**6**

17 (b)(ii)	• Use of $n\lambda = d \sin\theta$ **(1)** • $d = 1.77 \times 10^{-6}$ m **(1)** • Choose $d = 2.0 \times 10^{-6}$ m as a smaller value than $d = 1.77 \times 10^{-6}$ m would cause greater diffraction angles so the third order would not be seen, but 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement **(1)** **Or** • Use of $n\lambda = d \sin\theta$ **(1)** • A correct value of $\sin\theta$ or θ $d = 1.0 \times 10^{-6}$ m → 1.77 $d = 1.7 \times 10^{-6}$ m → 1.04 $d = 2.0 \times 10^{-6}$ m → 0.88 62.° $d = 3.3 \times 10^{-6}$ m → 0.535 32.° **(1)** • Choose $d = 2.0 \times 10^{-6}$ m. 1.7×10^{-6} m would give a sine value greater than 1, so no 3rd order is visible, and 3.3×10^{-6} m would produce smaller angles than 2.0×10^{-6} m, causing larger relative uncertainty in measurement **(1)**	Example of calculation $3 \times 5.89 \times 10^{-7}$ m = $d \sin 90°$ $d = 1.77 \times 10^{-6}$ m	**3**
17 (c)	• Use of $E = hf$ and $c = f\lambda$ **(1)** • Convert J to eV **(1)** • 2.1 eV **(1)** • Arrow drawn on diagram from −3.04 eV to −5.14 eV **(1)**	Example of calculation $E = 6.63 \times 10^{-34}$ Js × 3.00×10^{8} m s^{-1} / 5.89×10^{-7} m $= 3.38 \times 10^{-19}$ J 3.38×10^{-19} J / 1.60×10^{-19} C = 2.11 eV	**4**

(Total for Question 17 = 16 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*17(a)</td>
<td>This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

Indicative content:

IC1 (Waves from different slits) undergo superposition/interference

IC2 Constructive (interference) where path difference = $n\lambda$
Or Constructive (interference) where in phase

IC3 (Bright) lines seen where constructive interference

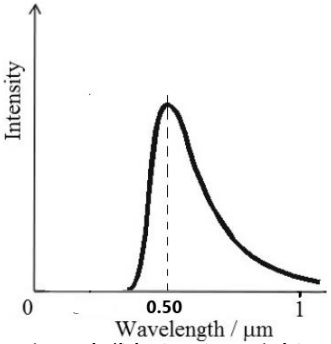
IC4 Central maximum/line due to mixture of red and blue light

IC5 $n\lambda = d\sin\theta$, so the angle/spacing of lines is larger for greater wavelength

IC6 Blue wavelength shorter than red, so next blue spot closer than red spot to centre spot</td>
<td>
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
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<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>

IC3 accept spots/lines/fringes maxima – colour reference to red/blue mix

IC4 accept purple/violet/magenta/mauve
</td>
<td>6</td>
</tr>
</table>

17(b)(i)	An explanation that makes reference to the following points: • Electrons / atoms exist in discrete/fixed/certain energy levels **Or** there are only a certain number of specific differences in energy levels of electrons / atoms **(1)** • (Absorbing) a <u>photon</u> causes an electron / atom to move to a higher energy level **Or** (Absorbing) a <u>photon</u> causes an electron / atom to become excited **(1)** • Photons are (only) absorbed when the <u>photon</u> energy is equal to the difference between energy levels **(1)** • <u>Photon</u> energy depends on frequency/wavelength, so photons of specific frequencies/wavelengths are absorbed, (producing dark lines) **(1)**	May refer to photon energy $E = hf$	**4**
17(b)(ii)	• Use of $\lambda_{max}T = 2.898 \times 10^{-3}$ m K **(1)** • $\lambda_{max} = 5.0 \times 10^{-7}$ (m) **(1)** • Curve with a peak at candidate's value of λ_{max} **(1)** • Black body asymmetric curve with intensity = 0 when wavelength = 0 **(1)**	<u>Example of calculation:</u> $\lambda_{max} = \frac{2.898 \times 10^{-3} \text{ m K}}{5800 \text{ K}}$ $= 5.0 \times 10^{-7}$ m  Meets x axis on left but not on right, steeper on the left than on the right and narrower on the left at every point than on the right	**4**

17(b)(iii)	An explanation that makes reference to the following points: • Fusion takes place (from hydrogen to helium) **(1)** • This releases energy and leads to an (outward) pressure/force which balances gravitational forces **(1)**	Accept high temperature for energy	**2**

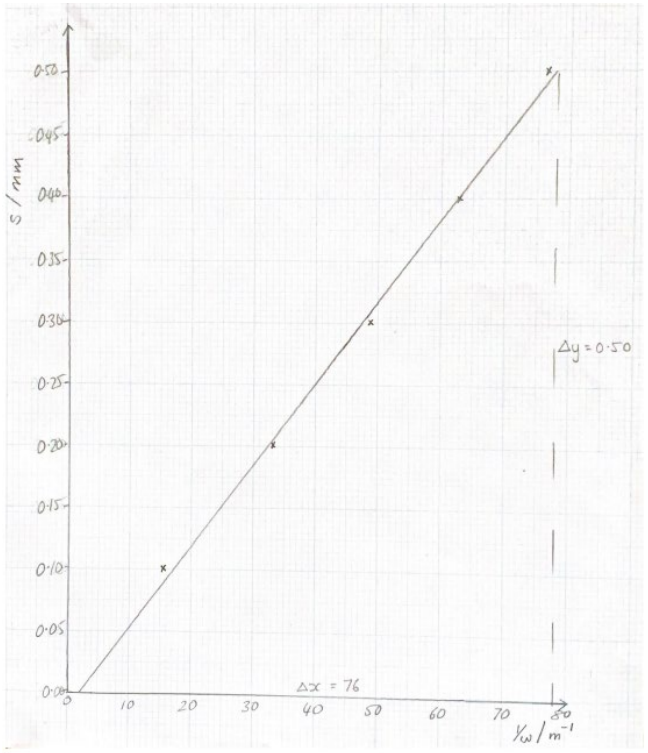
(Total for Question 17 = 16 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
16(a)	An explanation that makes reference to the following points: • Measure across n fringe separations and divide by n **(1)** **Or** Accept increase D (so w is larger) • The uncertainty stays the same but the measurement is larger (so the percentage uncertainty in w is decreased) **(1)**		**2**

16(b)(i)

- Values of 1/*w* given to 3 sf **(1)**
- Axes with labels & units **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**

s / mm	*w* / m	1/*w* / m^{-1}
0.10	0.0643	15.6
0.20	0.0301	33.2
0.30	0.0204	49.0
0.40	0.0159	62.9
0.50	0.0131	76.3



MP3 scales only in 1,2 and 5, and must cover at least half the grid

MP4 tolerance of ½ graph square, check all points.

5

16(b)(ii)	• Use of large triangle **(1)** • Use of gradient = λD **(1)** • λ in range 6.9 – 7.7 × 10^{-7} m to 2 or 3 significant figures **(1)**	<u>Example of calculation</u> Gradient = (0.50 − 0) × 10^{-3} / (78 – 2) = 6.6 × 10^{-6} λ = 6.6 × 10^{-6} / 9.00 = 7.3 × 10^{-7} m	**3**

16(c)(i)	• Use of ½ range **Or** Use of furthest from mean **(1)** • $\%U_f = 9\%$ **(1)**	Example of calculation $\%U_f = ½(24 - 20) \times 100 / 22 = 9\%$	**2**

16(c)(ii)	**EITHER** • Use of $s = \frac{\lambda D}{w}$ **(1)** • Percentage uncertainty calculated for D **(1)** • Percentage uncertainties for D, s and w added (ecf from (c)(i)) **(1)** • Upper limit of $\lambda = 5.52 \times 10^{-7}$ m which is greater than 520 nm so student's results are consistent with value on label **Or** Comparison of calculated value of relevant limit of wavelength with 520 nm and valid conclusion **(1)** **OR** • Maximum or minimum value calculated for s or w **(1)** • Calculation of upper or lower limit using maximum/minimum values **(1)** • Calculation of both limits using maximum and minimum values **(1)** • Upper limit of $\lambda = 5.55 \times 10^{-7}$ m which is greater than 520 nm and lower limit of $\lambda = 4.26 \times 10^{-7}$ m which is less than 520 nm so student's results are consistent with value on label **(1)**	Example of calculation $\lambda = (22 \times 10^{-3}\text{ m} \times 0.20 \times 10^{-3}\text{ m}) / 9.00 = 4.89 \times 10^{-7}$ m $\%U_D = 0.01 \times 100 / 9.00 = 0.1\ \%$ $\%U_\lambda = \%U_D + \%U_s + \%U_w$ $\%U_\lambda = 9\% + 0.1\% + 4\% = 13\%$ $U_\lambda = 0.13 \times 4.89 \times 10^{-7}\text{ m} = 6.36 \times 10^{-8}$ m Upper limit of $\lambda = 4.89 \times 10^{-7}\text{ m} + 6.36 \times 10^{-8}$ m Upper limit of $\lambda = 5.52 \times 10^{-7}$ m MP3 – accept ecf from c(i) Example of Calculation $s_{max} = 0.20 \times 10^{-3}\text{ m} \times 1.04 = 2.08 \times 10^{-4}$ m $w_{max} = 22 \times 10^{-3}\text{ m} \times 1.09 = 0.024$ m $\lambda_{max} = (0.024\text{ m} \times 2.08 \times 10^{-4}\text{ m})/(9.00-0.01)$ m $\lambda_{max} = 5.55 \times 10^{-7}$m $s_{min} = 0.20 \times 10^{-3}\text{ m} \times 0.96 = 1.92 \times 10^{-4}$ m $w_{min} = 22 \times 10^{-3}\text{ m} \times 0.91 = 0.020$ m $\lambda_{min} = (0.020\text{ m} \times 1.92 \times 10^{-4}\text{ m})/(9.00+0.01)$ m $\lambda_{min} = 4.26 \times 10^{-7}$m MP3 – accept ecf from c(i)	**4**

(Total for Question 16 = 16 marks)

6	The only correct answer is **A** because, using Einstein's photoelectric equation, $hf = \varphi + ½ mv^2_{max}$, since the work function is constant, an increase in frequency results in an increase in the maximum kinetic energy of the photoelectrons B is not correct because, using Einstein's photoelectric equation, $hf = \varphi + ½ mv^2_{max}$, intensity has no effect on the maximum kinetic energy of the photoelectrons, just the rate at which they are emitted C is not correct because , using Einstein's photoelectric equation, $hf = \varphi + ½ mv^2_{max}$, and since the work function is equal to (the Planck constant × threshold frequency), a higher threshold frequency will lead to a lower maximum kinetic energy of the photoelectrons D is not correct because, using Einstein's photoelectric equation, $hf = \varphi + ½ mv^2_{max}$, a higher work function will lead to a lower maximum kinetic energy of the photoelectrons		**1**

Question Number	Answer	Mark
4	**A – amount of energy of a photon needed to release an electron**	**1**
	Incorrect Answers: B- an electron does not release a photon C – reference to frequency incorrect D - reference to frequency incorrect and electron does not release a photon	

Question Number	Acceptable answer	Additional guidance	Mark
6	D	The only correct answer is **D**: a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	**1**

Question Number	Answer	Mark
7	The only correct answer is C because wave nature would predict a greater emission rate with a greater incident power A because instantaneous emission is only predicted by particle nature B because dependence of maximum kinetic energy on frequency is only predicted by particle nature D because minimum frequency for emission is only predicted by particle nature	1

Question Number	Answer	Mark
1	**D visible line spectra**	1
	Incorrect Answers: **A** – wave model **B** – wave model **C** – wave model	

5	**The only correct answer is C** **A** *is not correct because* photoelectrons are released instantly, so this statement is true **B** *is not correct because* there is a minimum frequency for photoelectrons to be released, so this statement is true **D** *is not correct because* the energy of a photon $E = hf$ so this statement is true	**1**

Question Number	Answer	Mark
2	**The only correct answer is C,** photoelectric effect A is not correct because this is a wave effect B is not correct because this is a wave effect D is not correct because this is a wave effect	1

6	**C** no change increases Incorrect Answers: A – both incorrect B – speed incorrect D – number of photoelectrons incorrect	**1**

Question Number	Acceptable answers	Additional guidance	Mark
12(a)(i)	• The (minimum) frequency at/above which electrons are released **(1)**	Accept frequency below which electrons are not released	1
12(a)(ii)	An explanation that makes reference to the following points: • With waves, energy would build up **(1)** • A photoelectron would (eventually have enough energy to) be emitted with any frequency, (which is not observed) **(1)**		2
12(b)	• A <u>quantum</u> of (electromagnetic) energy/radiation **Or** A <u>discrete</u> packet of (electromagnetic) energy/radiation **(1)**	Accept light for energy/radiation	1

(Total for Question 12 = 4 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
13	An explanation that makes reference to the following points: • Work function is the minimum (photon) energy for an electron to be emitted **Or** For an electron to be emitted, the frequency must be above a (minimum) value **Or** For an electron to be emitted, the wavelength must be below a (maximum) value **Or** At the threshold for emission kinetic energy of electrons is zero **(1)** • Use of $c = f\lambda$ **(1)** • Use of $E = hf$ **(1)** • Conversion between eV and J **(1)** • Comparison of λ / f / E for visible light with value for threshold case **and** comparison of λ / f / E for UV radiation with value for threshold **(1)**	Example of calculation $\phi = 3.74 \times 1.6 \times 10^{-19}\ \text{J} = 5.98 \times 10^{-19}\ \text{J}$ $f_0 = \frac{5.98 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 9.03 \times 10^{14}\ \text{Hz}$ $\lambda_{\text{max}} = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{9.03 \times 10^{14}\ \text{s}^{-1}} = 3.32 \times 10^{-7}\ \text{m} = 332\ \text{nm}$ Visible light wavelength is 420 nm > 332 nm and UV radiation wavelength is 320 nm < 332 nm $\phi = 3.74 \times 1.6 \times 10^{-19}\ \text{J} = 5.98 \times 10^{-19}\ \text{J}$ $f_0 = \frac{5.98 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 9.03 \times 10^{14}\ \text{Hz}$ Visible light, $f = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{4.2 \times 10^{-7}\text{m}} = 7.14 \times 10^{14}\ \text{Hz}$ $7.14 \times 10^{14}\ \text{Hz} < 9.03 \times 10^{14}\ \text{Hz}$ UV radiation, $f = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{3.2 \times 10^{-7}\text{m}} = 9.38 \times 10^{14}\ \text{Hz}$ $9.38 \times 10^{14}\ \text{Hz} > 9.03 \times 10^{14}\ \text{Hz}$ Visible light $f = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{4.2 \times 10^{-7}\text{m}} = 7.14 \times 10^{14}\ \text{Hz}$ $E = hf_0 = 6.63 \times 10^{-34}\ \text{J s} \times 7.14 \times 10^{14}\ \text{Hz}$ $E = 4.73 \times 10^{-19}\ \text{J}$ $E = \frac{4.73 \times 10^{-19}}{1.6 \times 10^{-19}\ \text{J}} = 2.96\ \text{eV} < 3.74\ \text{eV}$ UV radiation $, f = \frac{3.00 \times 10^{8}\ \text{m s}^{-1}}{3.2 \times 10^{-7}\text{m}} = 9.38 \times 10^{14}\ \text{Hz}$ $E = hf_0 = 6.63 \times 10^{-34}\ \text{J s} \times 9.38 \times 10^{14}\ \text{Hz}$ $E = 6.22 \times 10^{-19}\ \text{J}$ $E = \frac{6.22 \times 10^{-19}}{1.6 \times 10^{-19}\ \text{J}} = 3.89\ \text{eV} > 3.74\ \text{eV}$	**5**

(Total for Question 13 = 5 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
15(a)	• Conversion from eV to J **(1)** • Use of $E = hf$ **(1)** • Use of $c = f\lambda$ **(1)** • $\lambda = 6.2 \times 10^{-20}$ m **(1)**	Example of calculation $E = 2.0 \times 10^{13}$ eV $\times 1.60 \times 10^{-19}$ J eV^{-1} $= 3.2 \times 10^{-6}$ J 3.2×10^{-6} J $= 6.63 \times 10^{-34}$ J s $\times f$ $f = \frac{3.2 \times 10^{-6}\ \text{J}}{6.63 \times 10^{-34}\ \text{J s}} = 4.83 \times 10^{27}$ Hz $\lambda = \frac{3.0 \times 10^{8}\ \text{m s}^{-1}}{4.83 \times 10^{27}\ \text{Hz}} = 6.22 \times 10^{-20}$ m	**4**
15(b)	• The speed of the pulsar is negligible compared with the speed of light **(1)**	Attempt at calculation may result in this conclusion and so should gain mark Accept idea of speed being much smaller Accept comment that red shift is negligible/very small, if based on a calculation	**1**

(Total for Question 15 = 5 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answers</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*15</td>
<td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5-4</td><td>3</td></tr>
<tr><td>3-2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Particle model

One photon interacts with one electron
And each photon has energy proportional to the frequency, Or reference to $E=hf$
The electron is emitted (instantly) only if the energy of the photon is greater than the work function (of the metal)
Or The electron is emitted (instantly) only if the energy of the photon is greater than the energy needed for an electron to break free (from metal surface)
Any photon energy over and above the work function is gained by the electron as kinetic energy

Wave model

It would be expected that the energy of the electron would build up and eventually be emitted.
The (kinetic) energy of the (emitted) electrons would depend on the intensity of the wave (and not the frequency)

</td>
<td>The following table shows how the marks should be awarded for structure and lines of reasoning
<table>
<tr><td></td><td>Number of marks awarded for structure and lines of reasoning</td></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr>
</table>
Linkage marks
<table>
<tr><th>Indicative content points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6 with points from both models</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

(Total for Question 15 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16 (a)	• Substitute eV for $\frac{1}{2} mv^2_{max}$ in $hf = \phi + \frac{1}{2} mv^2_{max}$ **(1)** • Rearranges to identify gradient = h/e **(1)** • Attempt to find gradient using large triangle **(1)** • $h = 7.6 \times 10^{-34}$ J s **(1)** (range: 7.5×10^{-34} J s to 7.7×10^{-34} J s)	<u>Example of calculation</u> $hf = \phi + \frac{1}{2} mv^2_{max}$ $hf = \phi + eV$ $eV = hf - \phi$ $V = hf/e - \phi/e$ gradient = h/e gradient = (2.40 V – 1.00 V) ÷ (6.975×10^{14} Hz – 4.025×10^{14} Hz) gradient = 4.72×10^{-34} V s $h = 4.72 \times 10^{-34}$ V s × 1.6×10^{-19} C $h = 7.58 \times 10^{-34}$ J s	**4**
16 (b)	• (Faint and difficult to see, so may not be seen at the correct p.d. and) recorded p.d. could be too high **(1)** • (Range of frequencies could mean light is seen before the light at the stated frequency and) recorded p.d. could be too low **(1)** • Discussion of these points, e.g. opposite effects, could cancel or could be systematic errors and not affect gradient **(1)**		**3**

(Total for Question 16 = 7 marks)

Question Number	Acceptable answers		Additional guidance	Mark
16 (a)	• Line of best fit drawn • Gradient determined • Applies eV to J conversion factor • $h = 6.62 \times 10^{-34}$ J s (6.4×10^{-34} J s to 6.8×10^{-34} J s) MP4 dependent on calculation from graph	**(1)** **(1)** **(1)** **(1)**	<u>Example of calculation</u> Gradient = 4.14×10^{-15} $h = 4.14 \times 10^{-15}$ eV s $\times 1.6 \times 10^{-19}$ J eV^{-1} $h = 6.62 \times 10^{-34}$ J s	**4**
16 (b)	• x-intercept determined • Use of $\phi = h f_0$ • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a)) **OR** • Reads a pair of co-ordinates from graph • Use of $\phi = hf - E$ • $\phi = 2.3$ eV, so metal is (probably) caesium (allow ecf for h from (a))	**(1)** **(1)** **(1)**	MP2: allow use of standard value for h **or** value of h determined in (a) <u>Example of calculation</u> $f_0 = 55 \times 10^{13}$ Hz $\phi = 6.62\times10^{-34}$ J s $\times 55\times10^{13}$ Hz $= 3.64\times10^{-19}$ J $\phi = \frac{3.64 \times 10^{-19}\text{J}}{1.6 \times 10^{-19}\text{ J eV}^{-1}} = 2.28$ eV	**3**

(Total for Question 16 = 7 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
15(a)	• Use of $hf = \emptyset + \frac{1}{2}mv^2$ (1) • $v = 6.3 \times 10^6$ m s^{-1} (1)	Example of Calculation $E_k = (6.63\times 10^{-34}$ J s $\times 2.8 \times 10^{16}$ s^{-1}) - 6.9×10^{-19} (J) = 1.78712×10^{-17} J $v = \sqrt{\frac{2 \times 1.78712\times10^{-17}\text{J}}{9.11\times10^{-31}\text{ kg}}} = 6.26 \times 10^6$ m s^{-1}	2
(b)(i)	• Use of $\lambda = \frac{h}{p}$ (1) • recognise $\lambda = 2 \times$ diameter of atom (1) • 1.7×10^{-24} kg m s^{-1} (1)	Example of calculation $p = \frac{6.63 \times 10^{-34}\text{ (J s)}}{2\times 2.0\times10^{-10}\text{ (m)}} = 1.67\times 10^{-24}$ kg m s^{-1}	3
(b)(ii)	• A discrete number of half wavelengths fit into the diameter of an atom (1) • Reference to $E = \frac{hc}{\lambda}$ to link wavelength to discrete energy levels (1)	Accept reference to $E = \frac{hc}{\lambda}$	2

(Total for Question 15 = 7 marks)

(Total for Section A = 60 marks)

Question Number	Acceptable answers	Additional guidance	Mark
11(a)	• One electron absorbs one photon **(1)** • Photon energy is proportional to frequency **Or** Photon energy is equal to hf **(1)** • The (photon) energy is less than the work function of the metal (if frequency is below the threshold) **Or** electron gains insufficient energy to be released (if frequency is below a certain value) **(1)**		**3**
11(b)(i)	• Use of $E = \frac{1}{2}mv^2$ with $E = 2.9 - 3.0 \times 10^{-19}$ J **(1)** • $v = 8 \times 10^5$ m s^{-1} **(1)**	Example of calculation $v = \sqrt{\frac{2 \times 2.9 \times 10^{-19}\ \text{J}}{9.11 \times 10^{-31}\ \text{kg}}} = 7.98 \times 10^5$ m s^{-1}	**2**
11(b)(ii)	• Use of $hf_0 = \emptyset$ *with* $f_0 = 5.4 - 5.6 \times 10^{14}$ Hz **Or** Extrapolates graph to y axis **(1)** • Conversion between J and eV **(1)** • $\emptyset = 2.1$ to 2.4 eV **and** the metal was caesium **(1)**	Example of calculation $\emptyset = 3.6 \times 10^{-19}$ J $= (3.6 \times 10^{-19}\ \text{J}) / (1.6 \times 10^{-19}\ \text{C})$ $= 2.3$ eV	**3**

(Total for Question 11 = 8 marks)

17(a)

This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content

- photon energy $E = hf$
- photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
- UV photons have sufficient energy for photoemission but lab light photons do not
- one photon interacts with one electron
- with larger area more photons are absorbed/incident in a given time
- more electrons are emitted in a given time (so the charge is lost more quickly)

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once

Number of IC points awarded	**Possible linkage marks**
0,1	0
2, 3	1
4, 5, 6	2

6

17(b)	• would be of form $Q = Q_0 e^{-kt}$ **(1)** • plot ln charge against time **(1)** • if straight line with negative gradient it's exponential **(1)** **Or** • would be of form $Q = Q_0 e^{-kt}$ **(1)** • Calculate Q/Q_0 for pairs of values with same time interval t **Or** calculates $t_{1/2}$ at least twice **(1)** • If equal, then it's exponential **(1)**	MP3 accept some indication that gradient is negative For both MS options MP3 is dependent on MP2	**3**

(Total for Question 17= 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
15(a)(i)	• Use of $\lambda = h/p$ **and** $v = f\lambda$ **(1)** • Momentum of photon = 3.3×10^{-27} (N s) **(1)**	Example of calculation Momentum of photon = $p = hf/c$ = 6.63×10^{-34} J s × 1.5×10^{15} Hz ÷ 3.00×10^{8} m s^{-1} = 3.315×10^{-27} N s	**2**
15(a)(ii)	• Momentum transfer = 6.6×10^{-27} (N s) **(1)**	Ecf momentum from (i) in parts (a)(ii) and (c)	**1**
15(b)(i)	• Use of $hf = \varphi + ½ mv^2_{max}$ **(1)** • Use of $E_K = ½ mv^2$ **(1)** • $v = 8.4 \times 10^{5}$ (m s^{-1}) **(1)**	Example of calculation $hf = \varphi + ½ mv^2_{max}$ $hf = 6.63 \times 10^{-34}$ J s × 1.5×10^{15} Hz = 9.95×10^{-19} J $hf - \varphi = 9.95 \times 10^{-19}$ J − 6.7×10^{-19} J = 3.25×10^{-19} J 3.25×10^{-19} J = ½ × 9.11×10^{-31} kg × v^2 $v = 8.4 \times 10^{5}$ m s^{-1}	**3**
15(b)(ii)	• Use of $p = mv$ **(1)** • Momentum of photoelectron = 7.7×10^{-25} N s **(1)**	Example of calculation $p = 9.11 \times 10^{-31}$ kg × 8.4×10^{5} m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	**2**
15(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron **(1)** • so the (change in) momentum is much larger for the photoelectron than for the reflected photon **(1)**	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	**2**

(Total for Question 15 = 10 marks)

Question Number	Acceptable answers	Additional guidance	Mark
		12	

Question Number	Acceptable Answers	Additional Guidance	Mark
13(a)	• Use of $hf = \emptyset + \frac{1}{2}mv^2$ with $\frac{1}{2}mv^2 = 0$ (1) • Conversion between J and eV (1) • $\emptyset$ = 4.1 eV (1) • Compares their calculated energy with work function (J or eV) concluding aluminium (1)	Example of calculation $\emptyset = 6.63 \times 10^{-34}$ J s $\times 9.9 \times 10^{14}$ Hz $\emptyset = 6.6 \times 10^{-19}$ J $\emptyset = \frac{6.6 \times 10^{-19}\text{J}}{1.6 \times 10^{-19}\text{C}} = 4.1$ eV aluminium [MP4 is dependent on MP3]	**4**

13(b)

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative Content

IC1 Intensity of UV radiation decreases as altitude decreases
IC2 (because) UV radiation is absorbed in the atmosphere
IC3 E ∝ frequency so energy of photon unchanged at lower altitude (so photoelectric effect still occurs)
IC4 Links intensity of UV to number of photons/second
IC5 One electron to one photon
IC6 Resulting in a lower rate of electrons released at lower altitude

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Linkage marks

Number of indicative content points awarded	**Possible linkage marks**
0, 1	**0**
2, 3	**1**
4, 5, 6	**2**

6

	Total for question 13		**10**

Question Number	Acceptable answers	Additional guidance	Mark
15(a)	• (UV radiation consists of) photons **(1)** • One photon interacts with one electron **Or** energy of photon depends on frequency **(1)** • Electrons released if energy (of photon) greater than work function **Or** frequency is greater than threshold frequency **Or** <u>energy</u> supplied is sufficient to remove electron **(1)**	Accept quanta/packets of energy	**3**
15(b)(i)	• when slider at the bottom - reading on voltmeter is zero **Or** minimum resistance - reading on voltmeter is zero **(1)** • When slider at the top – reading on voltmeter is 1.5 V **Or** maximum resistance - reading on voltmeter is 1.5 V **(1)** • Potential difference split between top and bottom part of resistor (either side of slider) **Or** reading on voltmeter depends on the ratio of resistances (either side of slider) **Or** moving the slider changes the resistance that the voltmeter is across **(1)**		**3**
15(b)(ii)	Maximum Kinetic Energy of electron = 0.6 (eV) **(1)**		**1**

15(c)	**Max 4** Valid because: • Moon and photocell both have vacuum **(1)** • Both demonstration and theory use photoelectric effect **(1)** Not valid because: • Different wavelengths in each case **(1)** • On the moon there is dust not metal **(1)** • Dust is free to move but the metal plate is fixed **(1)** • On the moon UV removes electrons from (individual) <u>atoms</u> **and** in the demo light removes electrons from metal <u>surface</u> **(1)** • Demonstration is based on photoelectric effect but effect on moon could be ionisation **(1)**	Full marks can only be scored if a correct link is made between at least one physics point and the demonstration being valid or not valid Accept the same concept for photoelectric effect Accept one uses light the other UV Accept different materials for MP4	**4**

(Total for Question 15 = 11 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)	The student's answer should • Include the idea that 'threshold' refers to a (minimum) frequency **(1)** • state that <u>photons</u> have an energy given by hf **(1)** • recognise that the energy used to release electrons is called the <u>work function</u> **(1)** • include the idea that one <u>photon</u> is absorbed by one electron **(1)**	For MP1, accept that wavelength has to be below a certain 'threshold' **Max 3** if the response is not a discussion of the student's answer	**4**
9(b)	• Photoelectric equation stated in words **Or** $hf = \phi + \frac{1}{2}mv^2_{max}$ with ϕ defined **(1)** • Hence $eV_s = hf - \phi$ **Or** $E_{k\,max} = hf - \phi$ **and** $E_{k\,max} = eV_s$ **(1)** • Compare with $y = mx + c$ **(1)** • So plot a graph of V_s against f **Or** plot a graph of eV_s against f **(1)** • Gradient $= \frac{h}{e}$ **Or** gradient = h **(1)**	MP1: Accept hf_0 for ϕ [with f_0 defined], and $E_{k\,max}$ for $\frac{1}{2}mv^2_{max}$ MP2: eV_s does not have to be the subject of the equation MP5 is dependent upon MP4	**5**
9(c)	• Light consists of (particles called) <u>photons</u> **(1)** • These particles: are discrete packets of energy **Or** are quanta of energy **Or** have momentum **(1)**		**2**

(Total for Question 9 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
14(a)	An explanation that makes reference to the following points: • Electrons (in the dust particles) absorb the energy of photons (in UV ray) **(1)** • One photon interacts with one electron **(1)** • And the electron is released from the surface of the dust particle (leaving dust particle charged) **(1)**		**3**
14(b)	An explanation that makes reference to the following points: • (At 90°) the photons/UV spread over a smaller area (than at angles less than 90°) **Or** (At 90°) the intensity of the UV is higher **(1)** • (At 90°) there is a maximum/larger number of (incident) photons (per unit area per second) **(1)** • So a greater number of (photo)electrons are released (per unit area) **Or** More electrons absorb a photon (per unit area) **(1)**		**3**
14(c)	• Conversion between eV and J **(1)** • Use of $hf = \phi + \frac{1}{2}mv_{max}^2$ **(1)** • ϕ = 4.3 (eV) therefore the mineral is Ilmenite **(1)**	Example of calculation $\phi = \frac{6.63 \times 10^{-34}\text{J s} \times 2.0 \times 10^{15}\text{ Hz}}{1.6 \times 10^{-19}\text{ C}} - 4.0$ $\phi = 4.3$ eV	**3**

14(d)	• Use of $W = mg$ with $g = 1.6$ N kg^{-1} **(1)** • Use of $F = ma$ **(1)** • $a = 4.6$ m s^{-2} **(1)** • Use trigonometry to calculate θ **(1)** • $\theta = 70°$ to the vertical (downwards) **Or** $\theta = 20°$ to the horizontal (downwards) **(1)**	Example of calculation 3.0×10^{-17} N = $m \times 1.6$ N kg^{-1} $m = 1.9 \times 10^{-17}$ kg 8.7×10^{-17} N = 1.9×10^{-17} kg $\times a$ $a = 4.6$ m s^{-2} $\cos\theta = \frac{8.2\times10^{-17}\text{ N}}{8.7\times10^{-17}\text{ N}}$ $\theta = 70°$ to the vertical	**5**

(Total for Question 14 = 14 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
15(a)	• (High intensity of light means) <u>photons</u> strike the photocell at a greater rate (1) • One to one interaction between photons and electrons (1) • So Electrons released at a greater rate (1) • So greater current/charge/power in external circuit (1)		**4**
15(b)	• Use of $I = \frac{P}{A}$ (1) • Use of $P = \frac{E}{t}$ (1) • Multiply by 23% (1) • 1700 MJ (1)	<u>Example of Calculation</u> $E = 1300\ \text{Wm}^{-2} \times 200\ \text{m}^2 \times (8 \times 60 \times 60\ \text{s} \times 0.23)$ $E = 1700\ \text{MJ}$	**4**
15(c)	• Use of $E = Pt$ (1) • 430 MJ (1)	<u>Example of Calculation</u> $E = 4 \times 7500\ \text{W} \times (4 \times 60 \times 60)\text{s}$ E =432 MJ	**2**
15(d)	• Use of $E = mg\Delta h$ (1) • $E = 1.1 \times 10^8$ J (1)	<u>Example of Calculation</u> $E = mg\Delta h = 1600\ kg \times 9.81 ms^{-1} \times (8500 - 1500)m$ $E = 1.1 \times 10^8$ J	**2**
15(e)	• Drag increases as speed increases **Or** Drag increases as <u>density</u> of air increases (1) • Requiring a greater forward force (1) • So motors require more energy/power so plane should fly at a reduced speed (1)	Accept air resistance for drag	**3**
15(f)	**Max 1** (1) • Develops new technologies • Develops alternative energy sources • Raises public awareness • Secures funding for other projects		**1**
	Total for question 15		**16**

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*17(a)</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>
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<table>
<tr><th></th><th>Number of marks awarded for structure and lines of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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</table>

Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).
</td>
<td></td>
</tr>
</table>

	Indicative content Observations • Photoelectrons emitted instantaneously when radiation incident on surface • There is no photoemission below the threshold frequency • The maximum ke of the photoelectrons is independent of the intensity of the incident radiation • The rate of photoemission is proportional to the intensity of the incident radiation Models • One photon is absorbed by one electron **Or** all of the energy of one photon is transferred to one electron • With waves, energy can be supplied to the electron continuously **Or** with waves, energy can 'build up'	There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models. Two linkage marks can only be awarded if reference is made to both models and more than one observation	**6**

17 (b)	• Use of gradient **(1)** • h from graph = 6.74×10^{-34} J s **(1)** • Suitable percentage calculation allowing comparison with 1% and conclusion **(1)**	Example of calculation gradient = 3.00×10^{-19} J ÷ (10.15×10^{14} Hz – 5.70×10^{14} Hz) $h = 6.74 \times 10^{-34}$ J s percentage difference = (6.74×10^{-34} J s – 6.63×10^{-34} J s)/6.63×10^{-34} J s × 100% = 1.66% which is greater than 1% so it is not within 1% **Or** 6.63×10^{-34} J s × 101% = 6.70×10^{-34} J s which is smaller than 6.74×10^{-34} J s so it is not within 1%	**3**
17 (c)	• Use of $E=hf$ **(1)** • Use of $c = f\lambda$ **(1)** • Apply conversion factor of 1.6×10^{-19} for photon energy from J to eV **(1)** • Level = -5.74 (eV) **(1)**	Example of calculation $f = 3.00 \times 10^{8}$ m s^{-1} / 6.1×10^{-7} m = 4.91×10^{14} Hz $E = 6.63 \times 10^{-34}$ J s × 4.91×10^{14} Hz = 3.26×10^{-19} J 3.26×10^{-19} J / 1.6×10^{-19} C = 2.04 eV Level = -3.71 eV - 2.04 eV = -5.75 eV	**4**
17 (d)	• Use of d = 1 / no of slits per metre **(1)** • Use of $n\lambda = d \sin\theta$ **(1)** • $\theta = 21°$ **(1)**	Example of calculation d = 1 / 600 000 = 1.67×10^{-6} m^{-1} $n = 1$ 6.1×10^{-7} m = 1.67×10^{-6} m^{-1} sin θ $\theta = 21.47°$	**3**

(Total for Question 17 = 16 marks)

5	**B – decreasing the speed of the electrons in the beam**	**1**
	Incorrect Answers: A – the number of electrons does not affect the angle C - the number of electrons does not affect the angle D – increasing the speed would decrease the distance between the rings	

Question Number	Answer	Mark
5	**D**	**1**
	Incorrect Answers: **A** not demonstrated by this observation **B** not demonstrated by this observation **C** not demonstrated by this observation	

7	**C**	**1**
	Incorrect Answers: **A** Incorrect value for *h* **B** Incorrect arrangement and incorrect value for *h* **D** Incorrect arrangement	

Question Number	Answer	Mark
4	The only correct answer is B ***A*** *is not correct because this produces a beam of electrons with a shorter de Broglie wavelength, which produces a smaller angle of diffraction* ***C*** *is not correct because increasing the filament temperature would have no effect on the wavelength of the electron beam* ***D*** *is not correct because diffraction is maximised when the wavelength is similar to the gap size, increasing the gap size would decrease the angle of diffraction*	**1**

Question Number	Acceptable Answer	Additional Guidance	Mark
3	• The deflection/fields experiments indicate that electrons have a mass (and a charge) **Or** the deflection/fields experiments indicate that electrons have particle behaviour. **(1)** • The diffraction experiments indicate that electrons must have a wave nature **(1)** • Idea that a model of electron behaviour must include wave-particle duality **(1)**	In MP1 allow a description of deflection e.g. electrons are deflected by (electric and magnetic) fields indicating that they have a mass (and charge)	**3**

(Total for Question 3 = 3 marks)

Question Number	Acceptable Answers		Additional guidance	Mark
9	• Use of $p = mv$ using mass of electron • Use of $\lambda = \frac{h}{p}$ • $\lambda = 3.3 \times 10^{-11}$ m	(1) (1) (1)	Example of Calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\text{kg} \times 2.2\ \times 10^{7}\ \text{m s}^{-1}}$ $\lambda = 3.3 \times 10^{-11}$ m	3

(Total for Question 9 = 3 marks)

Question Number	Acceptable Answers	Additional guidance	Mark

Question Number	Acceptable answers	Additional guidance	Mark
14	• Use of $E_K = p^2 / 2m$ **(1)** • Use of $\lambda = h/p$ **(1)** • $\lambda = 5.0 \times 10^{-11}$ (m) calculated from E_K **Or** $E_K = 9.7 \times 10^{-17}$ (J) calculated from $\lambda = 5.0 \times 10^{-11}$ m **Or** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from E_K **and** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from $\lambda = 5.0 \times 10^{-11}$ m **(1)** • path difference at X is $\lambda/2$ **Or** path difference at Y is λ **(1)** • (electron) <u>waves</u> at X are in antiphase **Or** (electron) <u>waves</u> at Y are in phase **(1)** • at X destructive interference/superposition takes place **Or** at Y constructive interference/superposition takes place **(1)**	MP1 accept use of $p = mv$ **and** Use of $E_k = ½ mv^2$ MP4 accept (n + ½) λ or n λ respectively <u>Example of calculation</u> $p = \sqrt{(2 \times 9.11 \times 10^{-31} \text{ kg} \times 9.6 \times 10^{-17} \text{ J})}$ $p = 1.32 \times 10^{-23}$ kg m s^{-1} $\lambda = 6.63 \times 10^{-34}$ Js / 1.32×10^{-23} kg m s^{-1} $\lambda = 5.0 \times 10^{-11}$ m	**6**

(Total for Question 14 = 6 marks)

Question Number	Acceptable Answers	Additional guidance	Mark
14(a)	• Use of $p = mv$ with m= 9.11×10^{-31} **and** $v = 0.02 \times 3.0 \times 10^{8}$ (1) • Use of $\lambda = \frac{h}{p}$ (1) • $\lambda = 1.2 \times 10^{-10}$ m (1)	Example of calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\ \text{kg} \times 0.02\ \times 3.0 \times 10^{8}\ \text{m s}^{-1}}$ $\lambda = 1.2 \times 10^{-10}$ m	**3**
14(b)	**Either** • The wavelength of the electron is less than the wavelength of light (1) • (So) less diffraction (with the electron beam) (1) **Or** • The wavelength of the light is greater than the wavelength of the electrons (1) • (So) more diffraction (with light beam) (1)		**2**
14(c)	• Use of magnification $= \frac{\text{image height}}{\text{object height}}$ (1) • 3.0×10^{-5} m (1)	Example of calculation mean = $\frac{(0.024+0.025+0.022)\text{m}}{3}$ = 0.024 m Size of cell = $\frac{0.024\ \text{m}}{800}$ = 3.0×10^{-5} m	**2**

(Total for Question 14 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)(i)	• Use of $\lambda = 2\pi r$ **(1)** • 3.3×10^{-10} m **(1)**	Example of calculation $\lambda = 2\pi \times 5.3 \times 10^{-11}$ m $\lambda = 3.3 \times 10^{-10}$ m	**2**
16(a)(ii)	An explanation that makes reference to the following points: • The wavelength of the standing wave is determined by the energy of the electron **(1)** • The wavelengths are discrete and (to fit the circumference of the orbit) only certain orbits are possible **(1)**	[Accept reference to $E_k = \frac{h^2}{2m\lambda^2}$ to link wavelength to discrete energy levels]	**2**
16(b)(i)	• Use of $\lambda = \frac{h}{p}$ **and** $p = mv$ **(1)** • 1.2×10^{-10} (m) **(1)**	Example of calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{m}^2\ \text{kg}\ \text{s}^{-1}}{9.11 \times 10^{-31}\ \text{kg} \times 5.9 \times 10^{6}\ \text{m}\ \text{s}^{-1}} = 1.23 \times 10^{-10}$ m [no ue]	**2**

16(b)(ii)	An explanation that makes reference to the following points: • The (de Broglie) wavelength of an electron decreases (with increasing speed) **(1)** • Smaller wavelength means a smaller path difference for waves to be in phase (so smaller rings/pattern) **Or** The diffraction angle is smaller for shorter wavelengths (and the rings become smaller) **(1)**	[Accept $\lambda \propto \frac{1}{v}$ with terms defined] [Allow there is less diffraction]	**2**

(Total for Question 16 = 8 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr>
<td>*13(a)</td>
<td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

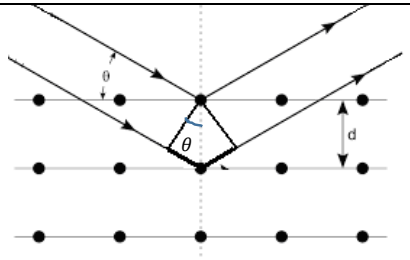
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</td>
<td></td>
</tr>
</table>

	Indicative content • This is a diffraction/interference pattern • Electrons behave as waves • As speed/momentum increases the circles get smaller • n$\lambda = d\sin\theta$ used to justify that as θ decreases λ decreases • Refers de Broglie equation ($\lambda = h/p$) to confirm that as speed/momentum increases, wavelength decreases. • Crystal has a regular/layered structure	**PP2** Do not credit 'electrons behave as waves or particles' on its own **PP3** accept circles get condensed for circles get smaller **PP4** do **not** credit use of equation to justify λ same size as gaps in crystal or to measure the gaps in the graphite **PP6** small gaps at uniform distances/lengths **Or** accept that graphite is made up of more than a single crystal	**6**

13(b)(i)	• Identification of θ between a wavefront and a vertical line **(1)** • Clear evidence of extra distance before **and** after reflection **(1)**		**2**
13(b)(ii)	• There is more than one order (of diffraction) **(1)**	Accept: path difference of one λ for 1st ring and 2 λ for 2nd ring rings occur for any whole number of wavelengths each ring corresponds to a different layer of atoms from which the electrons reflect.	**1**

(Total for Question 13 = 9 marks)

5	**B ground state to level 2**	**1**
	Incorrect Answers: A – incorrect change in energy C – incorrect change in energy and direction D – incorrect direction	

Question Number	Answer	Mark
3	**D**	**1**
	Incorrect Answers: A – absorption of the longest wavelength B – emission with the longest wavelength C – absorption of the shortest wavelength	

Question Number	Answer	Mark
7	**D shortest arrow pointing to ground state**	**1**
	Incorrect Answers: **A** – shortest wavelength absorbed	
	B – longest wavelength absorbed **C** – shortest wavelength emitted	

Question Number	Answer	Mark
3	**The only correct answer is A** **B** *is not correct because* the equation is arranged incorrectly **C** *is not correct because* the equation is arranged incorrectly **D** *is not correct because* the equation is arranged incorrectly	**1**

Question Number	Acceptable Answers	Additional guidance	Mark
11(a)	Use of $E = hf$ **and** $v = f\lambda$ (1) Conversion eV to J (1) $\lambda = 2.9 \times 10^{-7}$ m (1)	<u>Example of calculation</u> $\lambda = \frac{6.63\times10^{-34}\text{J s} \times 3.0\times10^{8}\text{m s}^{-1}}{4.3\text{ eV}\times 1.6\times10^{-19}\text{ C}} = 289$ nm	**3**
11(b)	electron falls back down energy levels emitting a photon (1) wavelength (of photon) is inversely proportional to the energy change (1) refers to energy transition n=3 to n=2 **or** n=2 to n=1 (1)		**3**

(Total for Question 11 = 6 marks)

Question Number	Acceptable Answers	Additional Guidance	Mark
12 (a)	• Electrons exist in discrete energy levels (1) • (After the mercury atom is excited) electrons move back to a lower energy level **Or** (After the mercury atom is excited) electrons move back down from a higher energy level (1) • <u>Photons</u> are emitted (1) • Frequency of emitted radiation / photons depends on the difference in energy between the energy levels **Or** reference to $\Delta E = hf$ (1) • Since there are only certain energy changes possible, only certain frequencies are possible (1)	Accept excited state for higher energy level Accept ground state for lower energy state	**5**
12 (b)	• Use of $E = \frac{1}{2}mv^2$ (1) • Use of $E = hf$ **and** $c = f\lambda$ (1) • $\lambda = (2.4 - 2.5) \times 10^{-7}$ (m) (1) • leading to a conclusion that radiation is ultraviolet **Or** conclusion consistent with their value for wavelength (1)	MP4 dependent on MP2 <u>Example of Calculation</u> $\Delta E_k = \frac{1}{2} \times 9.11 \times 10^{-31}\ \text{kg} \times ((2.5 \times 10^6 \text{m s}^{-1})^2 - (2.1 \times 10^6 \text{m s}^{-1})^2)$ $\Delta E_k = 8.4 \times 10^{-19}$ (J) $\lambda = \frac{6.63 \times 10^{-34} \text{J s} \times 3 \times 10^8 \text{ m s}^{-1}}{8.4 \times 10^{-19} \text{ J}}$ $\lambda = 2.4 \times 10^{-7}$(m)	**4**
	Total for question 12		**9**

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr>
<td>*7(a)</td>
<td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.

Indicative content:

IC1 The electric current is a movement of electrons (between the electrodes)
[Accept "charge carriers" for "electrons"]

IC2 The electrons collide with neon atoms
[Accept "interact" for "collide"]

IC3 Energy is transferred to the neon atoms (in the collisions)

IC4 Electrons in the neon (atoms) are promoted to higher energy states
Or electrons in neon (atoms) are excited

IC5 (After a short time) electrons in the neon (atoms) return to their normal/ground state
Or electrons in neon (atoms) de-excite

IC6 When an electron returns to a lower energy state it emits a photon (of electromagnetic radiation)</td>
<td>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5–4</td><td>3</td></tr>
<tr><td>3–2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>

<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>

Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning

<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

7(b)	• Use of $E = hf$ **(1)** • Use of $E_k = ½ mv^2$ **(1)** • Use of $hf = \phi + \frac{1}{2}mv_{max}^2$ **(1)** • $\phi = 3.36 \times 10^{-19}$ (J) so metal is caesium **(1)**		Example of calculation $E = hf = 6.63 \times 10^{-34}$ J s $\times 5.56 \times 10^{14}$ J $\therefore E = 3.69 \times 10^{-19}$ J Max $E_k = ½ mv^2$ $= 0.5 \times 9.11 \times 10^{-31}$ kg $\times (2.68 \times 10^5$ m s$^{-1})^2$ $= 3.27 \times 10^{-20}$ J $\therefore \phi = 3.69 \times 10^{-19}$ J $- 3.27 \times 10^{-20}$ J $\phi = 3.36 \times 10^{-19}$ J	**4**

(Total for Question 7 = 10 marks)

Question Number	Acceptable Answers		Additional guidance	Mark
16 (a)	• Atoms contain discrete energy levels • The atom loses energy and falls back down energy levels emitting a photon • with energy equal to the difference in energy levels • Energy of photon is proportional to frequency • So emitted frequency of radiation corresponds to the difference in energy levels of a particular atom	(1) (1) (1) (1) (1)	MP2 Accept it is deexcited **and** emits a photon	**5**
16(b)	• Use of $E = hf$ and $v = f\lambda$ • Converts between eV to J • $\lambda = 201$ nm **and** conclusion that superradiance can occur	(1) (1) (1)	Example of calculation E=6.2 eV $\times 1.6 \times 10^{-19}$ C $E = \frac{6.63 \times 10^{-34}\ \text{Js} \times\ 3.0 \times 10^{8}\ \text{ms}^{-1}}{\lambda}$ $\lambda = 201$ nm so superradiance can occur	**3**
16(c)	• emits a very small range of frequencies/wavelengths • so smaller variation at each diffraction angle • producing a clearer/sharper interference pattern	(1) (1) (1)	Accept short bandwidth / linewidth	**3**
	Total for question 16			**11**

Question Number	Acceptable Answers		Additional guidance	Mark
17(a)	• Use of $v = \frac{s}{t}$ with $v = 3.00 \times 10^{8}$ (m s^{-1}) • Correct use of factor of 2 • distance = 51000 m	(1) (1) (1)	Example of Calculation $s = \frac{3.00 \times 10^{8}\ \text{m s}^{-1} \times 3.4 \times 10^{-4}\ \text{s}}{2}$ s = 51000 m	**3**

Question Number	Acceptable answers	Additional guidance	Mark
15(a)(i)	An explanation that makes reference to the following points: • The electron in the hydrogen atom is excited **Or** the electron is promoted to a higher energy level **(1)** • (After a short time) the electron returns to its normal/ground state emitting a <u>photon</u> **(1)** • The energy of the photon is equal to the difference in the (discrete) energy levels of the atom **(1)** • Wavelength (of emitted photon) is inversely proportional to the change in energy **Or** Frequency (of emitted photon) is proportional to the change in energy **Or** Reference to $E = hf$ / $E = \frac{hc}{\lambda}$ **(1)**	[not promoted alone] [accept falls back down] [not de-excites alone] [must be a <u>change</u> in energy, allow ΔE]	**4**
15(a)(ii)	• Use of $E = hf$ **and** $v = f\lambda$ **(1)** • $\Delta E = (-)3.01 \times 10^{-15}$ J **(1)** • Conversion between eV and J **(1)** • (so) $\Delta E = (-)1.9$ (eV) means a transition of (−)1.51 eV to (−)3.39 eV **(1)**	<u>Example of calculation</u> $\Delta E = \frac{6.63 \times 10^{-34}\ \text{m}^2\ \text{kg}\ \text{s}^{-1} \times 3.00 \times 10^{8}\ \text{m}\ \text{s}^{-1}}{6.6 \times 10^{-7}\ \text{kg}}$ $\Delta E = -3.01 \times 10^{-15}$ J $= \frac{-3.01 \times 10^{-19}\ \text{J}}{1.6 \times 10^{-19}\ \text{J C}^{-1}} =$ -1.88 eV Transition -1.51 eV to -3.39 eV	**4**

15(a)(iii)	An explanation that makes reference to the following points: • One electron absorbs and re-emits one <u>photon</u> **(1)** • A greater rate of emitted <u>photon</u>s means a higher intensity radiation **(1)**	[Accept more photons means higher intensity]	**2**

15(b)	• Use of $p = mv$ **(1)** • Equates the total momentum before collision to total momentum after collision **(1)** • v of hydrogen = 5400 (m s^{-1}) **(1)** • Compares their calculated value with 5000 (m s^{-1}) with conclusion consistent with their calculated value **(1)**	Accept reverse calculations using v = 5000 m s^{-1} to calculate a minimum initial velocity of H and compare to 2210 m s^{-1} <u>Example of calculation</u> 2.66×10^{-26} kg $\times$ 2210 m s^{-1} = (2.66 $\times$ 10^{-26} kg $\times$ 1870 m s^{-1}) + (1.67 $\times$ 10^{-27} kg $\times$ v) v = 5416 m s^{-1} > 5000 m s^{-1} so can escape	**4**

(Total for Question 15 = 14 marks)

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td>*18(a)</td><td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.

<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td><td>
The following table shows how the marks should be awarded
<table>
<tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr>
<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
</table>
for structure and lines of reasoning.

Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).
</td><td></td></tr>
</table>

	Indicative content: IC1 Electrons are in (discrete) energy levels IC2 Absorption of (a single) photon causes an electron to move to a higher energy level IC3 Photon energy = hf **Or** photon energy is proportional to frequency IC4 Energy of (absorbed) photon must equal difference in energy levels IC5 The (changes in) energy levels are specific to each element IC6 Different wavelengths/frequencies of light are absorbed		**6**
18(b)	• Use of $c = f\lambda$ **(1)** • Use of $\Delta E = hf$ **(1)** • Use of 1 eV = 1.6 x 10^{-19} J **(1)** • Change in energy equal to 1.89 eV and transition from energy level 2 to energy level 3 **(1)**	<u>Example of calculation</u> $f = 3.00 \times 10^{8}$ m s^{-1} / 656.46×10^{-9} m $= 4.57 \times 10^{14}$ Hz $E = 6.63 \times 10^{-34}$ J s $\times 4.57 \times 10^{14}$ Hz $= 3.03 \times 10^{-19}$ J $= 3.03 \times 10^{-19}$ J / $1.60 \times 10^{-19} = 1.89$ eV 1.89 eV – 3.40 eV = – 1.51 eV = level 3	**4**

18(c)(i)	• (According to the Doppler effect) if the source is moving away from the observer the wavelength will increase **(1)** • (According to the Doppler effect) there is a change in wavelength proportional to velocity **(1)** • He is correct (as speed and direction can be determined). **(1)** MP3 dependent on MP1 and MP2	Allow converse statement i.e. If the source is moving towards the observer the wavelength will decrease	**3**
18(c)(ii)	• Use of $\Delta\lambda / \lambda_0 = v/c$ **(1)** • $\lambda = 656 \times 10^{-9}$ m **(1)**	Must see 656.46×10^{-9} m in denominator Example of calculation $\Delta\lambda = 656.46 \times 10^{-9}$ m $\times$ 5.5×10^{3} m s^{-1}/3.00×10^{8} m s^{-1} $= 0.012 \times 10^{-9}$ m Moving away, so add $\Delta\lambda$ $\lambda = 656.46 \times 10^{-9}$ m + 0.012×10^{-9} m $\lambda = 656.47 \times 10^{-9}$ m	**2**

(Total for Question 18 = 15 marks)

***12(a)**

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The table shows how the marks should be awarded for indicative content and structure and lines of reasoning.

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5–4	3
3–2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content:

1. As the temperature of the gas increases the (average) speed/E_k of the atoms increases
2. Greater speed/E_k so the momentum of the atoms increases
3. The rate/frequency of collision of atoms with the container walls increases **Or** the time between collisions with the walls decreases
4. The rate of change of momentum at the walls increases
5. Rate of change of momentum is equal to the force
6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater

IC Points	IC Mark	Max linkage mark avail.	Max final mark
6	4	2	**6**
5	3	2	**5**
4	3	1	**4**
3	2	1	**3**
2	2	0	**2**
1	1	0	**1**
0	0	0	**0**

IC3 and IC4 must include a mention of the walls/container

6

12(b)(i)	• Conversion of MeV to J **(1)** • See $Q_1 = 79 \times 1.6 \times 10^{-19}$ **and** $Q_2 = 2 \times 1.6 \times 10^{-19}$ **(1)** • Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ **and** $W = QV$ **(1)** • $r = 4.1\times10^{-14}$ m **(1)**	Example of calculation $E_\alpha = 5.5\times10^{6}\text{eV}\times1.6\times10^{-19}\text{J eV}^{-1} = 8.8\times10^{-13}\text{J}$ $8.8\times10^{-13}\text{J} = \frac{79\times1.6\times10^{-19}\text{C}\times2\times1.6\times10^{-19}\text{C}}{4\pi\times8.85\times10^{-12}\text{ F m}^{-1}\ r}$ $r = \frac{3.64\times10^{-26}\text{ N m}^2}{8.8\times10^{-13}\text{ J}} = 4.1\times10^{-14}\text{ m}$	**4**
12(b)(ii)	• Electrons are behaving like waves **(1)** • wavelength$= \frac{h}{\text{momentum}}$ **(1)** • Electron wavelength must be similar to the atomic spacing in the foil **(1)**	MP3: Accept electron wavelength must be similar to the distance between (adjacent) nuclei	**3**
12(c)	• Electrons are excited to higher energy states / levels (by incident electrons) **(1)** • An electron returns to the lower energy state / level resulting in the emission of a photon **(1)** • The energy of the photon is equal to the difference of the energy states / levels **(1)** • Large difference in energy states / levels so as $E = hf$, radiation is high frequency **(1)**	For MP1 and MP2 allow • Electrons knock electrons out of low energy levels • Electrons cascade down to fill up the levels	**4**

(Total for Question 12 = 17 marks)