Name: _____

Topic 5: Waves and Particle Nature of Light Part 3

Date:

Time:

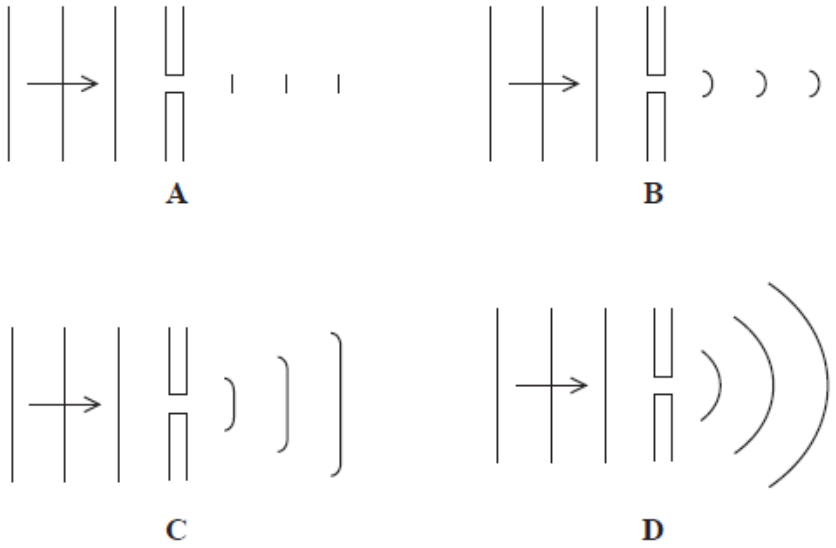
Total marks available:

Total marks achieved: _____

Questions

Q1.

Plane wavefronts pass through a gap in a barrier. The gap is much smaller than the wavelength of the wave.



Which diagram best shows the resultant shape of the wavefronts?

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for question = 1 mark)

Q2.

In a concert hall, sound waves produced by an instrument are reflected from different parts of the hall. Two coherent sound waves meet at a point where their phase difference is π.

What is the smallest possible path difference to produce this phase difference?

☒ **A** λ / 4

☒ **B** λ / 2

☒ **C** 3 λ / 4

☒ **D** λ

(Total for question = 1 mark)

Q3.

Which of the following wave properties demonstrates that electromagnetic waves must be transverse?

☒ **A** diffraction

☒ **B** interference

☒ **C** polarisation

☒ **D** refraction

(Total for question = 1 mark)

Q4.

A wave of wavelength λ and frequency f is travelling in a medium with wave speed v_1.
The wave passes into another medium with wave speed v_2.

The wavelength of the wave in the second medium is

☒ **A** $\frac{v_1}{f}$

☒ **B** $\frac{v_2}{f}$

☒ **C** $\frac{v_1}{v_2 f}$

☒ **D** $\frac{v_2 f}{v_1}$

(Total for question = 1 mark)

Q5.

In 2016 the Breakthrough Starshot initiative was announced. This project intends to send a fleet of small probes to Proxima Centauri, the nearest star to the Sun. This journey would take about twenty years.

The composition of a star can be determined by analysis of its absorption spectrum.

Explain why there are certain specific frequencies missing from the spectrum.

(5)

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(Total for question = 5 marks)

Q6.

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

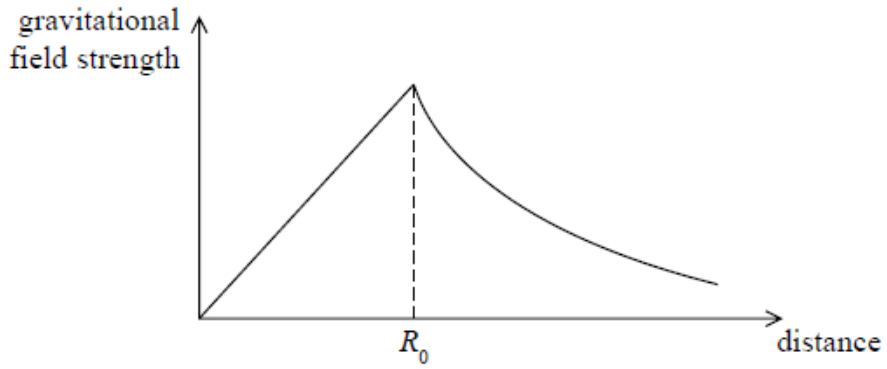
☒ **C** 9

☒ **D** 11

(Total for question = 1 mark)

Q7.

The graph shows the variation of the gravitational field strength with distance from the centre of the Earth. R_0 is the radius of the Earth.



A scientist suggests that the period of oscillation for a body dropped through the tunnel would be the same as the orbital period for a body orbiting just above the surface of the Earth. Its radius of orbit is assumed to be R_0.

(i) Derive an expression for the period of oscillation of the body dropped through the tunnel.

(4)

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(ii) Derive an expression for the orbital period for a body that is orbiting the Earth with radius R_0.

(3)

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(Total for question = 7 marks)

Q8.

A student has been learning about the photoelectric effect.

This experiment demonstrates the particle nature of light.

Explain what is meant by the particle nature of light.

(2)

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(Total for question = 2 marks)

Q9.

Pions (π^+, π^-, π^0) are created in the upper atmosphere when cosmic rays collide with protons. Pions are unstable and decay rapidly.

(a) Pions are the lightest of the hadrons. Charged pions (π^+ and π^-) decay to produce muons which then decay to positrons or electrons.

(i) A positive pion π^+ has a quark composition $u\bar{d}$.

State with a justification the possible quark compositions of a neutral pion π^0.

(2)

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(ii) Muons are examples of leptons whereas pions are examples of mesons.
State a structural difference between leptons and mesons.

(1)

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(b) Muons with a speed of 0.99*c* travel a distance of 15 km to reach the surface of the Earth from the upper atmosphere.

(i) Show that the time it takes a muon to travel this distance is about 51 μs.

(2)

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(ii) The muons are unstable particles.
Calculate the fraction of muons which would remain after a time of 51 μs.

half-life of muon = 2.2 μs

(4)

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Fraction = ...

(iii) In fact the fraction of muons reaching the surface of the Earth is about 0.1 Explain the discrepancy.

(4)

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(Total for question = 11 marks)

Q10.

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 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.

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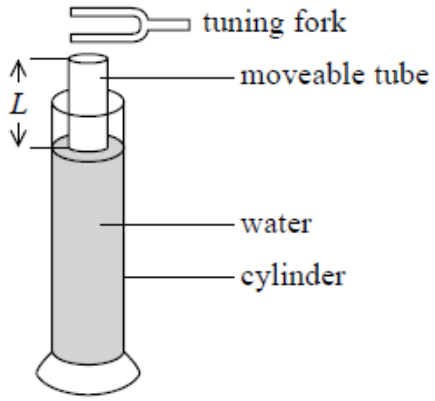
(Total for question = 6 marks)

Q11.

A set of tuning forks is used to find a value for the speed of sound in air.
A tuning fork is struck and then held near to the end of an air column formed by a moveable tube. The moveable tube is used to adjust the length, *L*, of the air column until a standing wave is set up in the tube and the loudest sound is heard. The experiment is repeated for a number of different tuning forks.



The following results are obtained by a student.

Fork frequency/Hz	Length, L/cm	Speed of sound/m s^{-1}
256	31.9	327
320	25.6	328
512	16.1	330

Student A says "These results show that the speed of sound increases as the frequency of the sound increases".

Student B says "The speed of sound should be the same for each frequency".

By estimating the uncertainties in these results, conclude which of these statements is valid.

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(Total for question = 4 marks)

Q12.

A book entitled *Interesting Projects with a Microwave Oven* suggests using chocolate to measure

the speed of light. The chocolate is placed on a non-metallic tray in the oven.
The oven is switched on and a pattern is observed in the melting chocolate.

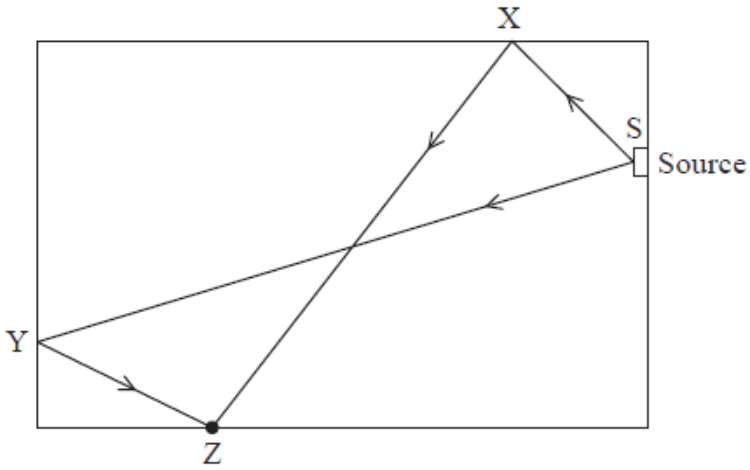
The photograph shows some lighter areas where the chocolate is melting and some darker areas where the chocolate remains hard.

The book states that microwaves are emitted from the source in the oven. The microwaves reflect off the metal walls so that the microwaves reaching any point arrive from different directions. The microwaves produce a standing wave pattern causing hot and cold areas in the oven.

The wavelength was determined to be 12 cm by measuring the distance between adjacent hot and cold areas.

(a) The diagram shows two different paths by which microwaves can reach the point Z.

Not to scale



SX = 9 cm, XZ = 23 cm, SY = 36 cm, YZ = 8 cm

Calculate the phase difference between microwaves from the source at S reaching point Z by the two different paths.

(2)

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Phase difference = ...

(b) Explain how a pattern of hot and cold areas is produced in the chocolate. You should assume that each point of the chocolate is reached by microwaves following two different paths only.

(4)

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(c) Explain why the microwaves reaching a point in the chocolate must be coherent for this effect to occur.

(2)

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(d) The microwave frequency is stated on the oven as 2450 MHz.

Evaluate the success of this experiment at determining the speed of light.

(3)

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(Total for question = 11 marks)

Q13.

* The photograph shows a pipe organ in a concert hall.

(Source: www.yucatanliving.com/article-photos/news/01042010/pipe-organ.jpg)

When the organ is played, sound travels through the air to a person in the audience as a wave. It is found that there are some positions in the concert hall where particular frequencies are quieter than others.

Explain why this might be the case and give an action that could be taken to eliminate this problem.

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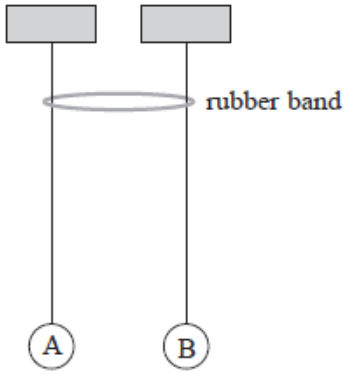
(Total for question = 6 marks)

Q14.

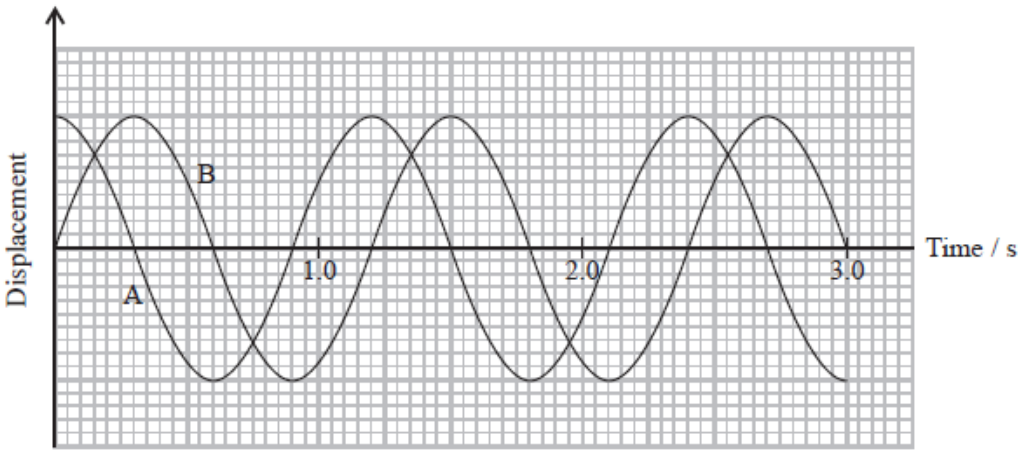
The diagram shows two identical pendulums, A and B, side by side with a rubber band placed over both strings.



Pendulum A is displaced and starts to oscillate. As pendulum A oscillates, pendulum B starts to oscillate with the same time period, its amplitude increasing as the amplitude of pendulum A decreases. At one stage pendulum A is no longer oscillating and pendulum B has its maximum amplitude. Then pendulum A starts to oscillate again with increasing amplitude, as the amplitude of pendulum B decreases.

The apparatus is adjusted so that the pendulums do not have the same length as each other. When the first pendulum is set into oscillation, the second pendulum starts to oscillate, but with very small amplitude; the first pendulum does not stop oscillating.

The graph shows how the displacement of each pendulum varies with time at one stage in the motion.



(i) State the phase relationship between the two pendulums.

(1)

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(ii) Determine the length of pendulums A and B.

(3)

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Length = ...

(Total for question = 4 marks)

Q15.

Which of the following phenomena does **not** occur with sound waves?

☒ **A** diffraction

☒ **B** interference

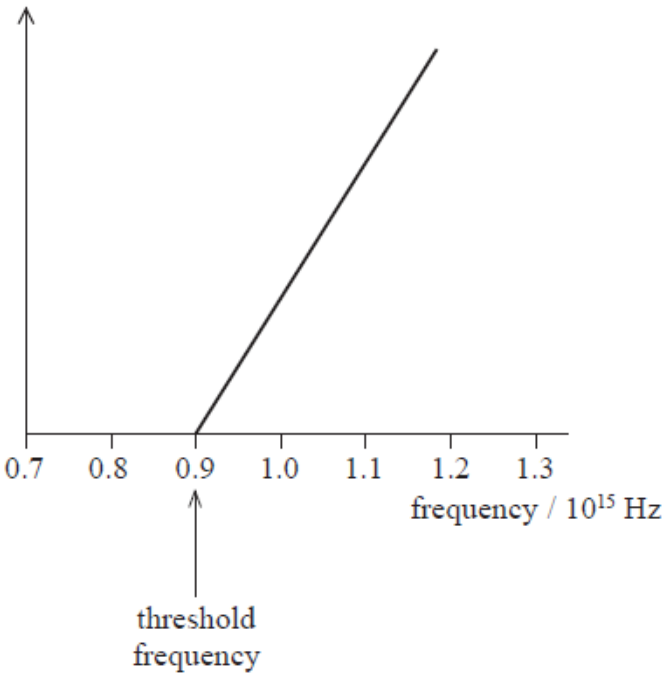
☒ **C** polarisation

☒ **D** refraction

(Total for question = 1 mark)

Q16.

The graph shows the results for an experiment to demonstrate the photoelectric effect by illuminating a clean metal sheet with light of increasing frequency.



(a) State a quantity, and its unit, which could have been plotted on the Y-axis to produce this graph.

(2)

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(b) The threshold frequency is shown on the graph.

Explain why there is a threshold frequency.

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(Total for question = 6 marks)

Q17.

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.

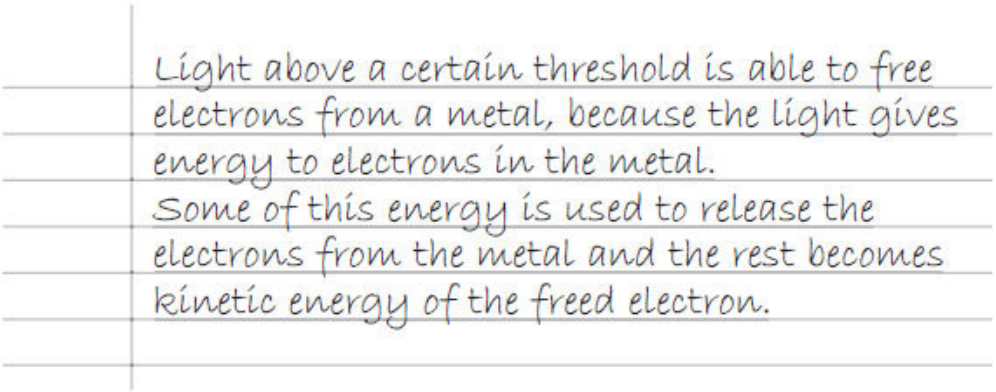
☒ **D** When the intensity of the incident light increases, photoelectrons are emitted at a greater rate.

(Total for question = 1 mark)

Q18.

A student has been learning about the photoelectric effect.

The student was asked by his teacher to explain the photoelectric effect. He gave the following explanation:



Discuss whether the student's answer fully explains the photoelectric effect.

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(Total for question = 4 marks)

Q19.

Answer the question with a cross in the box you think is correct ☒. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

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 = 1 mark)

Q20.

*****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.

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.

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(Total for question = 6 marks)

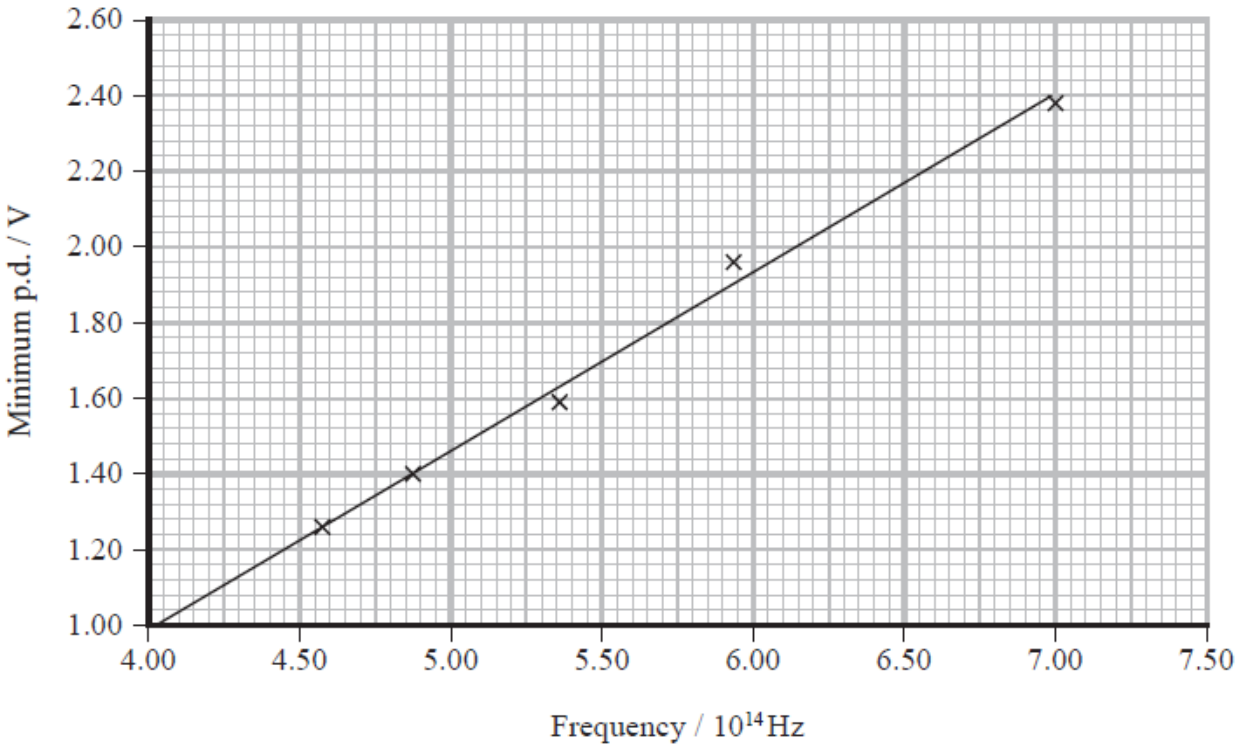
Q21.

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.



Determine the value of the Planck constant given by this graph.

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Value of Planck constant given by graph = ...

(Total for question = 4 marks)

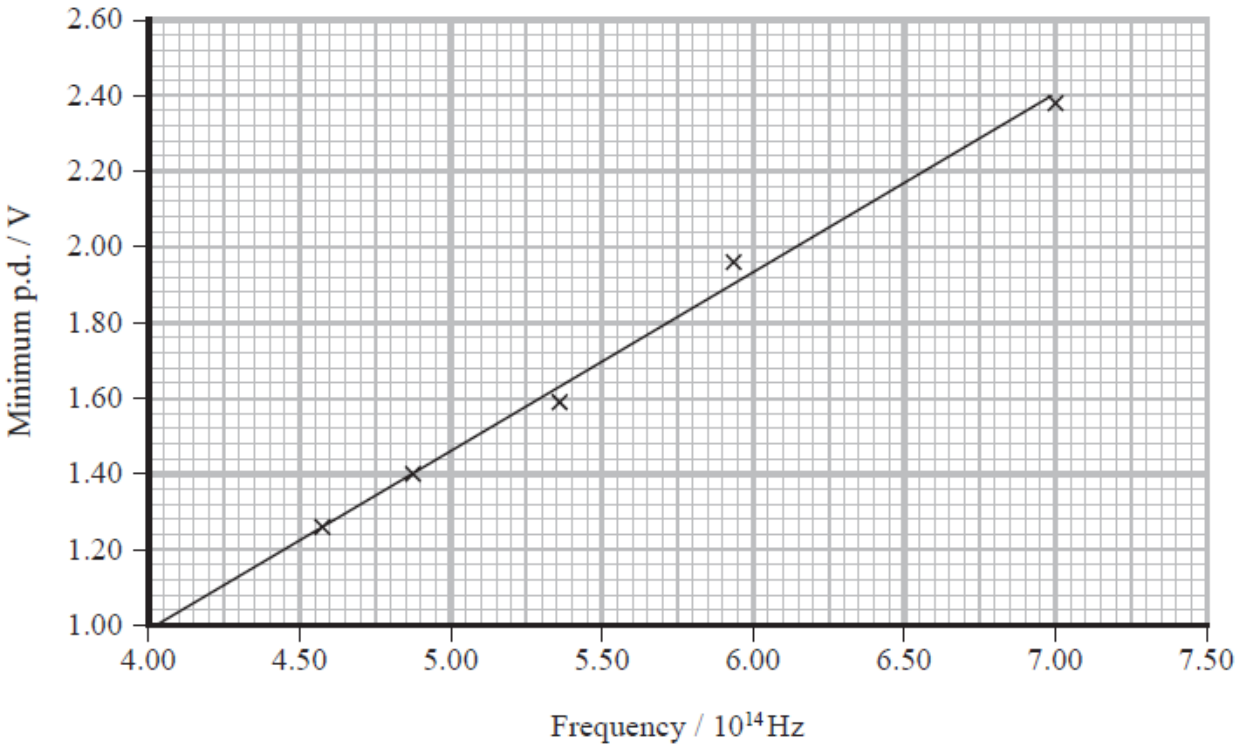
Q22.

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.



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.

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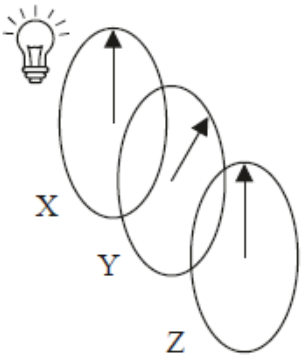
(Total for question = 3 marks)

Q23.

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 = 1 mark)

Q24.

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.

An octopus can detect the orientation of polarised light.

State what is meant by polarised light.

(2)

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(Total for question = 2 marks)

Q25.

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.

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

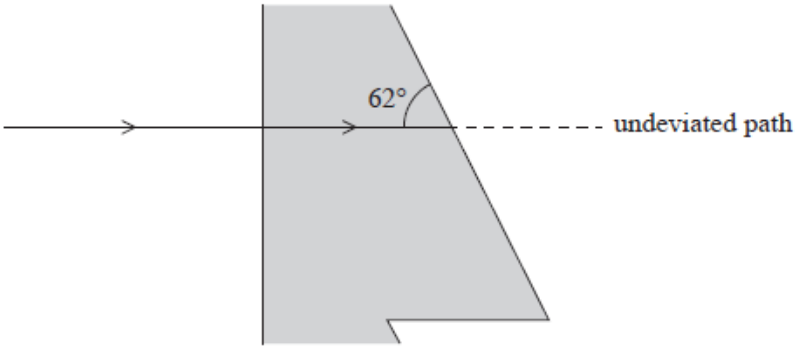

Figure 2

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

(4)

refractive index of plastic = 1.47

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Angle = ...

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

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(Total for question = 7 marks)

Q26.

Iceland spar is a crystalline form of calcite. An incident ray of unpolarised light is separated into two plane polarised rays by a sample of Iceland spar. The two rays of polarised light follow different paths.

(a) Explain the difference between polarised and unpolarised light.

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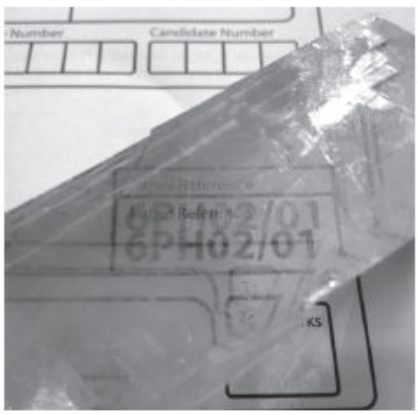
*(b) The photograph shows how the separate paths of light produce two images of an object behind the sample.



When a polarising filter is placed on the sample shown in the photograph only one image of 6PH02/01 is seen.

Explain why only one image is seen and describe what would be seen as the filter is rotated through 360°.

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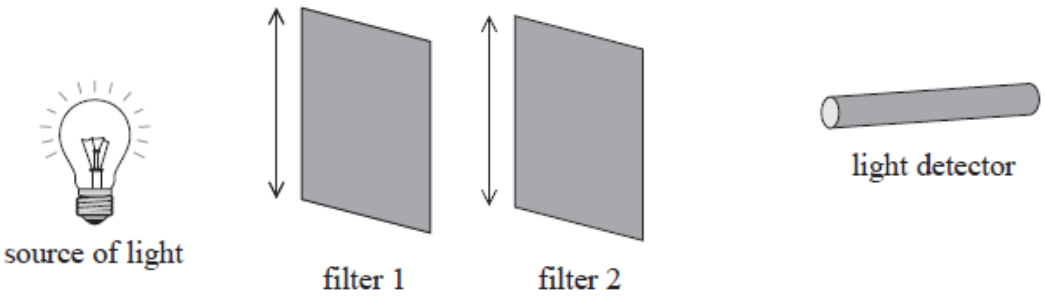
(Total for question = 7 marks)

Q27.

The diagram shows apparatus used to investigate polarising filters.

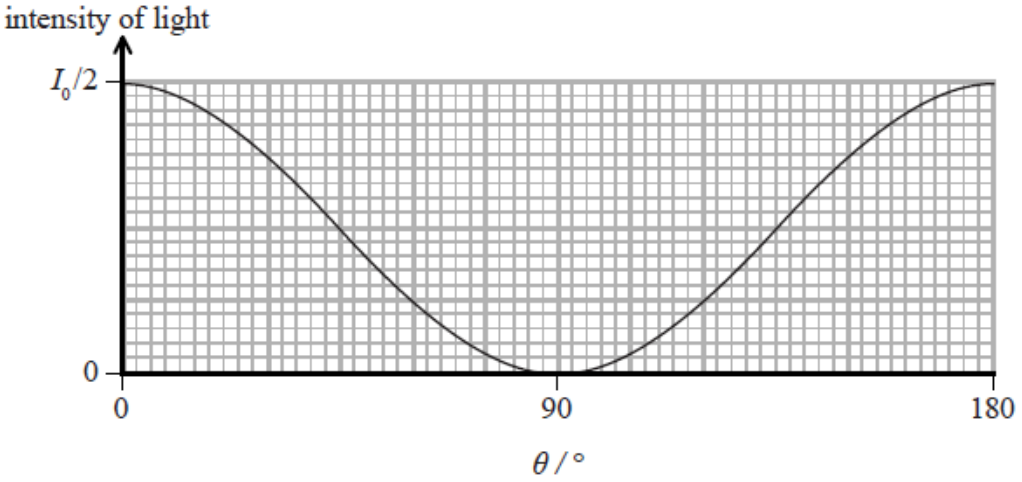


Light is incident on filter 1 and the intensity of the light is measured, using the light detector, when the filters are in the positions shown.

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.

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(Total for question = 6 marks)

Q28.

Answer the question with a cross in the box you think is correct (☒). If you change your mind about an answer, put a line through the box (☒) and then mark your new answer with a cross (☒).

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 mark)

Q29.

A converging lens has a focal length of less than 20 cm. The lens can be used to produce real images of an illuminated object. You are required to investigate how the image distance from the lens depends upon the object distance from the lens. Your method should lead to a graphical method to determine the focal length of the lens.

(a) Describe how you would obtain the data.

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(b) Explain how you would use your results to determine a value for the focal length of the lens.

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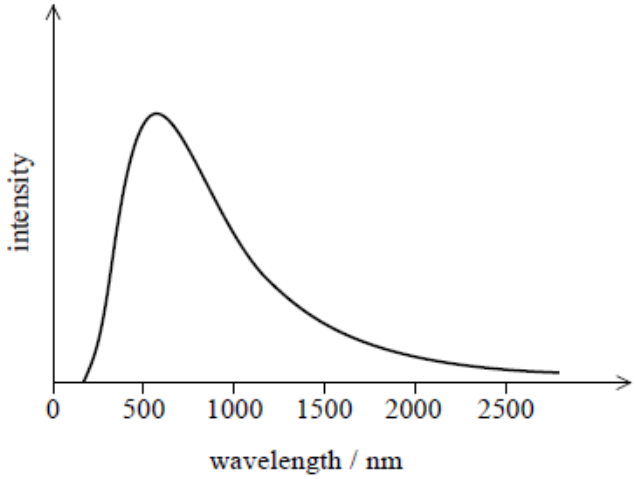
(Total for question = 7 marks)

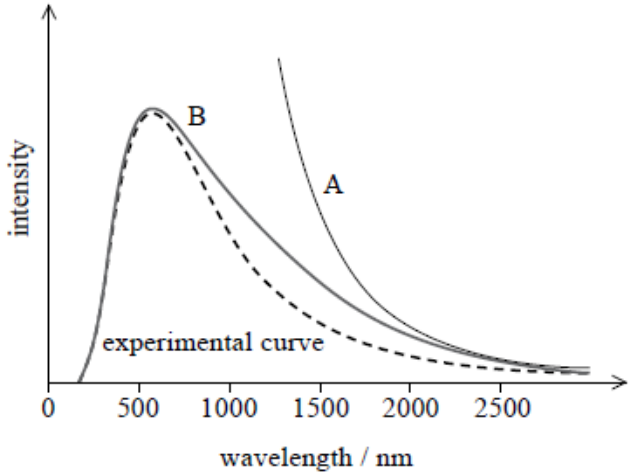
Q30.

The diagram shows the radiation curve for a black body radiator. The diagram was obtained from experimental data.



Experimental curve

In the late 19th century, scientists struggled to explain this experimental curve. One model used ideas of classical physics and produced curve A. Another model incorporated the idea of energy quantisation in the mechanism of energy emission and produced curve B. Both curve A and curve B are shown below, with the experimental curve for comparison.



(i) Explain how energy quantisation applies to the emission of radiation of energy from a black body radiator.

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(ii) Assess the extent to which each model is successful at explaining the experimental curve.

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(Total for question = 6 marks)

Mark Scheme

Q1.

Question Number	Answer	Additional guidance	Mark
	D		**(1)**

Q2.

Question Number	Answer	Additional guidance	Mark
	B	(λ / 2)	**(1)**

Q3.

Question Number	Answer	Additional guidance	Mark
	C	(polarisation)	**(1)**

Q4.

Question Number	Answer	Additional guidance	Mark
	B	$(\frac{v_2}{f})$	**(1)**

Q5.

Question Number	Acceptable Answers		Additional Guidance	Mark
	• atoms/electrons have fixed/discrete/specific energy levels	(1)	Answers in terms of emission spectrum can be awarded MP1, 4 and 5	5
	• electrons get excited by absorbing <u>photons</u>	(1)		
	• energy of <u>photon</u> absorbed = difference in energy levels	(1)		
	• only certain transitions possible, so only certain <u>photon</u> energies absorbed so only certain frequencies missing	(1)		
	• the set of frequencies absorbed depends on the element	(1)		

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	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

Q7.

Question number	Acceptable answers	Additional guidance	Mark
(i)	**Either** • When x = R_0, F = GMm/R_0^2 **(1)** • F = $GMmR_0/R_0^3$ so k = $m\omega^2 = GMm/R_0^3$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • From graph F=-(g/R_o)r **(1)** • From which $\omega = \sqrt{(g/R_0)}$ **(1)** • Use of $T=2\pi/\omega$ **(1)** • So $T = 2\pi\sqrt{(R_o^3/g)}$ **(1)**		**4**

Question number	Acceptable answers	Additional guidance	Mark
(ii)	**Either** Centripetal force = $mv^2/R_0 = GMm/R_0^2$ **(1)** • $4\pi^2 R_0^2/ T^2R_0 = GM/R_0^2$ **(1)** • $T^2 = 4\pi^2/\omega^2 = 4\pi^2 R_0^3/GM$ So $T = 2\pi\sqrt{(R_o^3/GM)}$ **(1)** **OR** • $mg = mv^2/R_0 = m\,\omega^2R_0$ **(1)** • So $\omega = \sqrt{(g/R_0)}$ **(1)** • $T = 2\pi/\omega = 2\pi\sqrt{(R_0/g)}$ **(1)**		**3**

Q8.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• Light consists of (particles called) photons **(1)** • These particles: are discrete packets of energy **Or** are quanta of energy **(1)** **Or** have momentum		**2**

Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)(i)	• a π^0 may be $u\bar{u}$ **Or** $d\bar{d}$ (1) • it must be a quark combined with its own antiquark so that overall charge is 0 (1) OR it can only contain up or down quarks (as it is not a strange particle)	Allow $s\bar{s}$	**(2)**
(a)(ii)	mesons are made up of quarks, whereas leptons are fundamental particles (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	• use of v = s/t (1) • t = 5.05 × 10^{-5} s (1)	Example of calculation: $t = \frac{s}{v} = \frac{15\times10^{3}\,\text{m}}{0.99\times3\times10^{8}\,\text{ms}^{-1}} = 5.05\times10^{-5}\text{s}$	**(2)**
(b)(ii)	• use of $\lambda t_{1/2} = 0.693$ (1) • λ = 3.15 × 10^{5} s^{-1} (1) • use of $N = N_0 e^{-\lambda t}$ (1) • $\frac{N}{N_0} = 1.23\times10^{-7}$ (1)	Example of calculation: $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{2.2\times10^{-6}\text{s}} = 3.15\times10^{5}\text{s}^{-1}$ $\frac{N}{N_0} = e^{-\lambda t} = e^{-3.15\times10^{5}\text{s}^{-1}\times5.05\times10^{-5}\text{s}} = 1.23\times10^{-7}$ $\frac{N}{N_0} = 1.1\times10^{-7}$ if "show that" value used	**(4)**
(b)(iii)	• This is much smaller than 10% indicating the muon lifetime is much greater than the expected value (1) • The high speed of the muon has led to relativistic effects (1)		**(2)**

Q10.

Question Number	Acceptable answers		Additional guidance	Mark
	• 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)**	Example of calculation $\lambda/2 = 0.013$ m / 2 $= 0.0065$ m	**6**

Q11.

Question number	Acceptable answers	Additional guidance	Mark
	• Sensible estimate of uncertainties from readings given **(1)** • Adds percentage uncertainties **(1)** • Hence calculates uncertainty in speed **(1)** • Candidate's conclusion must be supported by their estimate of the uncertainties **(1)**	Example of calculation: %U in L is (0.1/25.6) x 100 % = 0.4 % %U in F is (1/320) x 100 % = 0.3 % %U in speed is 0.7 % 328 x 0.007 = 2 Speed = 328 ± 2 All three results are within the calculated uncertainty so concludes student B is correct	**4**

Q12.

Question Number	Answer		Mark
(a)	Calculates path difference = 12 (cm) Phase difference 0, 360° or 2π **Or** Calculates number of wavelengths in two paths Phase difference 0, 360° or 2π	(1) (1) (1) (1)	**2**
(b)	Waves superpose **Or** interference between two waves takes place In phase constructive **Or** Antiphase destructive Links to <u>amplitude</u> maximum **Or** <u>amplitude</u> zero respectively In phase/constructive/max amplitude is where chocolate is hot with opposite at cold spots. **Or** Antiphase/destructive/min amplitude is where chocolate is cold with opposite at hot spots.	(1) (1) (1) (1)	**4**
(c)	Coherent means a constant phase relationship (If the relationship not constant) a point could sometimes be constructive and sometimes destructive	(1) (1)	**2**
(d)	Use of $c = f\lambda$ Calculates $c = 2.94 \times 10^8$ (m s^{-1}) **Or** $\lambda = 12.2$ (cm) **Or** $f = 2500$ (MHz) Sensible comment based on their calculated value. e.g. close to real value, so successful **Or** reference to uncertainty in data <u>Example of calculation</u> $c = 2.45 \times 10^9$ Hz $\times$ 0.12 m $c = 2.94 \times 10^8$ m s^{-1}	(1) (1) (1)	**3**
	Total for question		**11**

Q13.

<table>
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<tr><td>*</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></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>
</td><td>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>

<table>
<tr><th>Question number</th><th>Additional guidance</th><th colspan="2">Mark</th></tr>
<tr><td>* (continued)</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>
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</table>
</td><td></td><td></td></tr>
</table>

Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Indicative content** • Sound waves incident upon surfaces within the concert hall will be reflected. • Some frequencies will arrive from different directions with a phase difference of (any odd multiple of) π radians **(1) OR** path difference is odd number of half wavelengths • Destructive superposition/interference will occur, causing the waves with those frequencies to be quieter than others. • Other frequencies arrive with a phase difference of zero or (any multiple of) 2π radians **(1) OR** a whole number of wavelengths • Constructive superposition/interference will occur, causing waves with those frequencies to be louder than others. • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections.		**6**

Question Number	Acceptable answers	Additional guidance	Mark
* (continued)	**Alternative approach based on standing waves:** • Sound waves incident upon surfaces within the concert hall will be reflected. • Reflections from walls set up standing waves (in room) • Nodes and antinodes are formed for certain frequencies of sound • Nodes are areas of zero/low amplitude so the frequencies of those sound waves will be quieter than others • Antinodes are areas of maximum amplitude so the frequencies of these sound waves will be louder than others • Problem arises due to reflections from walls, so use absorbing material on surfaces to reduce reflections		

Q14.

Question Number	Acceptable Answers		Additional Guidance	Mark
(i)	• Pendulum A is π/2 ahead of pendulum B	(1)		1
(ii)	• $T = 1.2$ s from graph • Use of $T = 2\pi\sqrt{(l/g)}$ • $l = 0.36$ m	(1) (1) (1)	$T = 3.0$ s / 2.5 oscillations 1.2 s = $2\pi\sqrt{(l/9.81\ \text{N kg}^{-1})}$ $l = 0.36$ m	3

Q15.

Question Number	Answer	Mark
	C	1

Q16.

Question Number	Answer		Mark
(a)	max kinetic energy **Or** ke_{max}	(1)	
	joule/J **Or** electronvolt/eV	(1)	
	Or	(1)	
	stopping potential **Or** V_s volt/V	(1)	2
	(Unit mark can be scored if no quantity given. If incorrect quantity given no marks awarded but KE/energy in joules/eV scores MP2)		
(b)	Idea that one photon is absorbed by one electron	(1)	
	Photon energy given by $E = hf$ **Or** photon energy increases with frequency	(1)	
	The idea that there is a minimum energy needed for emission of a (photo)electron	(1)	
	(So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons	(1)	4
	Total for question		6

Q17.

Question Number	Acceptable answer	Additional guidance	Mark
	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

Q18.

Question Number	Acceptable Answer	Additional Guidance	Mark
	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**

Q19.

Question Number	Answer	Mark
	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**

Q20.

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<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>
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<td></td>
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	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

Q21.

Question Number	Acceptable answers	Additional guidance	Mark
	• 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 (range: 7.5×10^{-34} J s to 7.7×10^{-34} J s) **(1)**	Example of calculation $hf = \phi + \frac{1}{2} mv^2_{max}$ $hf = \phi + eV$ $eV = hf - \phi$ $V = hf/e - \phi/e$ 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

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
	• (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

Q23.

Question Number	Acceptable answer	Additional guidance	Mark
	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

Q24.

Question Number	Acceptable answers	Additional guidance	Mark
	Either • Polarised light is light where the oscillations are in a single plane **(1)** • Which includes the direction of propagation **(1)** **Or** • Polarised light is light where the oscillations are in a single direction **(1)** • Which is perpendicular to the direction of propagation **(1)**		2

Q25.

Question Number	Acceptable Answers		Additional Guidance	Mark
(i)	• use of $n_1 \sin i_1 = n_2 \sin i_2$	(1)	Example of calculation $n_1 \sin i_1 = n_2 \sin i_2$ $1.47 \sin (90° - 62°) = 1.00 \sin i_2$ $i_2 = 43.6°$ angle of deviation = $44° - 28° = 16°$	**4**
	• with angle of incidence in plastic = 28°	(1)		
	• angle of deviation = angle of refraction – angle of incidence	(1)		
	• angle of deviation = 16°	(1)		
(ii)	• Going from the centre of the lens towards the edge the angle of incidence in the plastic increases	(1)	Accept focal point for principal focus	**3**
	• The angle of deviation increases	(1)		
	• (So) all rays cross (the axis) at the principal focus	(1)		

Q26.

Question Number	Answer		Mark
(a)	Unpolarised – oscillations/vibrations in many directions	(1)	
	Polarised – oscillations/vibrations in single direction	(1)	
	oscillations/vibrations are perpendicular to direction of propagation	(1)	
	Or		
	Unpolarised – oscillations/vibrations in many planes	(1)	
	Polarised – oscillations/vibrations in single plane	(1)	
	Plane includes direction of propagation	(1)	3
(b)	(QWC- Work must be clear and organised in a logical manner using technical wording where appropriate.)		
	The idea that light transmitted only when in same plane/direction as plane/direction of polarisation of filter **Or** The idea that light not transmitted when plane/direction at 90° to plane/direction of polarisation of filter	(1)	
	Rays for each image are (polarised) in different planes/directions, (so only one image is seen)	(1)	
	When the (polarising) filter is rotated the image becomes fainter **Or** When the (polarising) filter is rotated the other image becomes visible	(1)	
	A statement correctly linking image(s) seen with angle. • at 90° only the other image is seen • at 180° only the 1st image is seen • at 270° only the other image is seen • at in between angles both images will be seen, (but neither at full intensity)	(1)	4
	Total for question		7

Q27.

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</table>
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.

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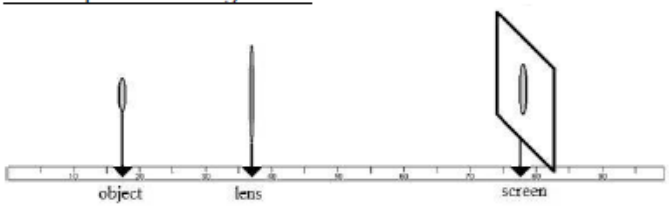
</table>
<table>
<tr><th>Number of IC points awarded</th><th>Possible linkage marks</th></tr>
<tr><td>0,1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
IC3,6 allow, no light passes through, blocked by, stopped by
</td>
<td>6</td>
</tr>
</table>

Q28.

Question Number	Acceptable answers	Additional guidance	Mark
	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

Q29.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• diagram with illuminated object, lens, screen and metre rule (1) • lens position adjusted until clear image located on screen (1) • object, image distances calculated from metre rule readings (1) • procedure repeated for at least 4 other positions of the lens (1)	Example of Diagram:  Example of calculation: $\frac{1}{u} = -\frac{1}{v} + \frac{1}{f}$ $y = mx + c$	**(4)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)	• $1/v$ plotted against $1/u$ and intercept(s) of line read off (1) • lens equation compared with equation of a straight line (1) • f = 1/intercept (1)	Question 5 to be marked holistically	**(3)**

Q30.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	An explanation that makes reference to: • quantisation of energy is the idea that energy is emitted/radiated in discrete packets/photons **(1)** • each photon has an energy which is related to frequency OR suitable reference to $E = hf$ **(1)**		**2**
(ii)	• Model A is successful at long wavelengths because the curve for model A follows the experimental curve **(1)** • But model A breaks down for short wavelengths, since it suggests that the intensity tends to infinity as the wavelength gets shorter **(1)** • Model B is successful for short wavelengths because curve B follows the experimental curve **(1)** • But model B indicates higher than expected intensities at larger wavelengths **(1)**		**4**