Name: ____

Topic 5: Waves and Particle Nature of Light Part 1

Date:

Time:

Total marks available:

Total marks achieved: ______

Questions

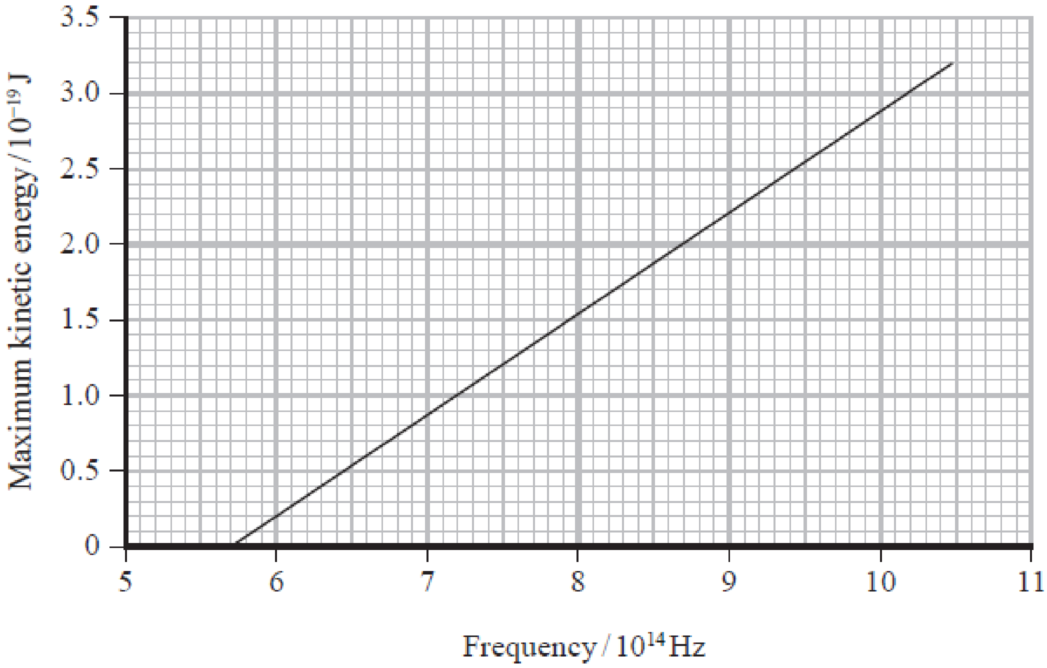
Q1.

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.

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)

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(Total for question = 3 marks)

Q2.

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.

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)

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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)

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(Total for question = 7 marks)

Q3.

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.

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)

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Angle = ...

(Total for question = 3 marks)

Q4.

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 ☒.

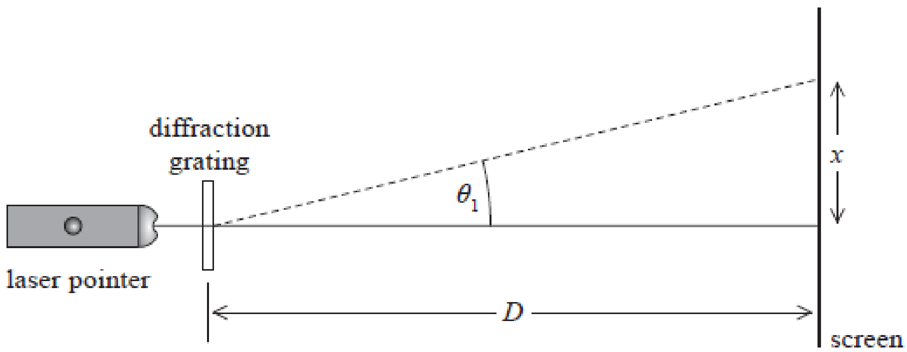
Which row of the table shows a base quantity and its base SI unit?

		Quantity	Unit
☐	**A**	charge	C
☐	**B**	length	m
☐	**C**	mass	g
☐	**D**	temperature	°C

(Total for question = 1 mark)

Q5.

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.

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)

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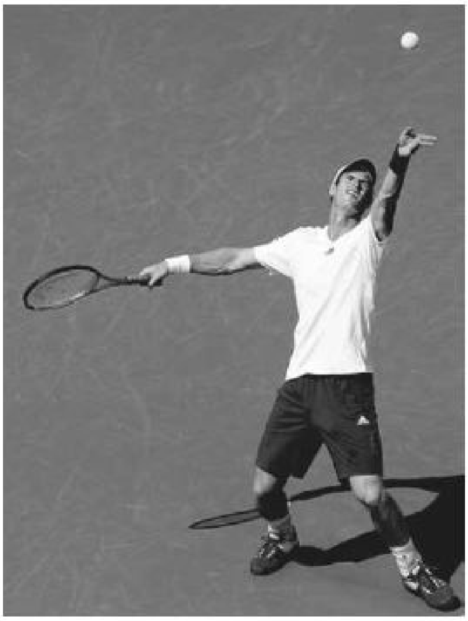
λ_2 = ...

(Total for question = 5 marks)

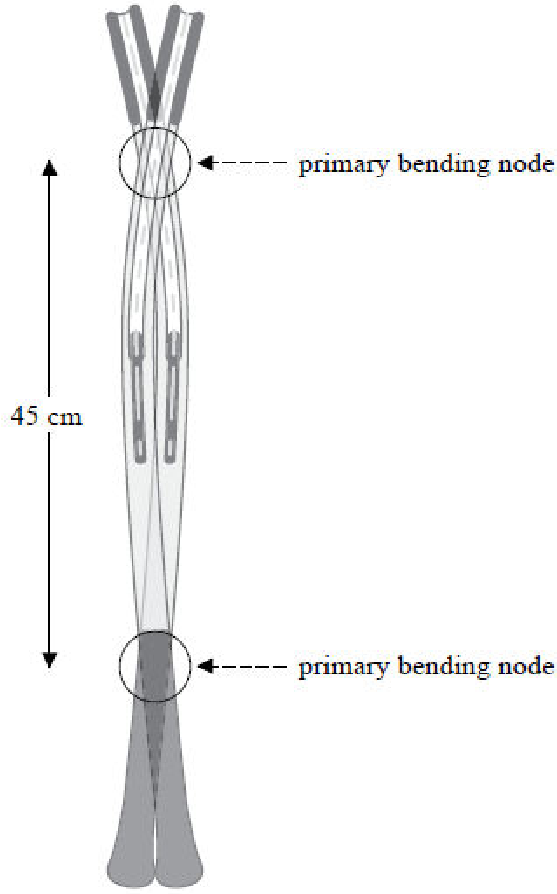
Q6.

A tennis player uses a racket to hit a ball over a net. When the racket strikes the ball the racket frame is set into oscillation.

The fundamental mode of oscillation is shown. Transverse waves travel along the length of the racket at a speed of 160 m s^{-1}.



© Getty images



Calculate the frequency of oscillation of the frame.

(3)

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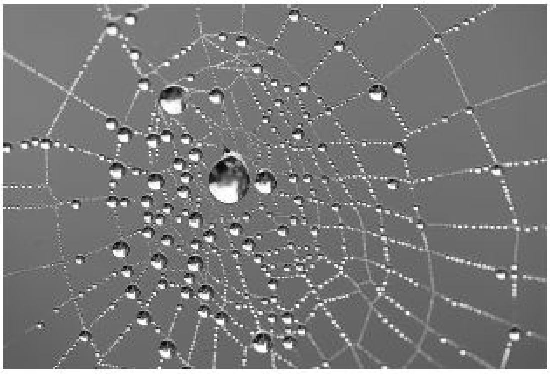
Frequency = ...

(Total for question = 3 marks)

Q7.

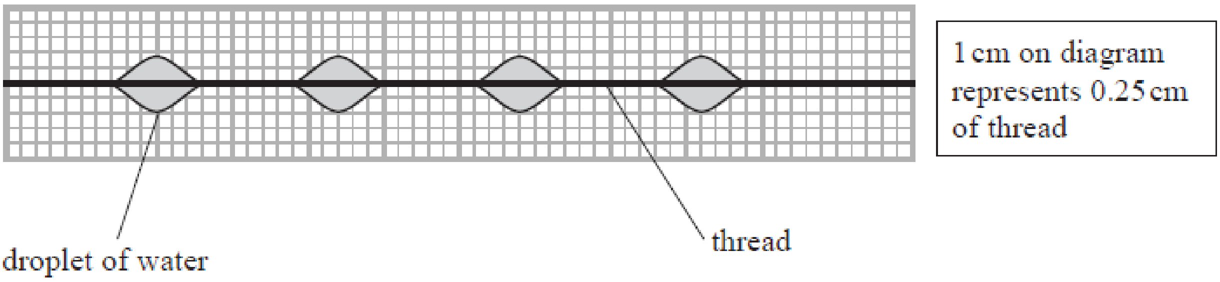
The photograph shows part of a spider's web where water droplets have collected at certain points. The web is made from spider silk which is made by the spider.



Spiders are almost completely dependent on vibrations transmitted through their web for receiving information about the location of trapped insects. When the threads are disturbed by the insects, progressive waves are transmitted along sections of the silk.

It has been suggested that the droplets of water collect at certain points on the web because stationary waves are formed.

The diagram shows water droplets on a single thread of spider silk when the frequency of waves is 7.9 Hz.



Further measurements are taken to test whether the observations are consistent with the presence of stationary waves in the threads.

diameter of the thread = 3.6×10^{-6} m

mass per unit length of the thread = 1.32×10^{-8} kg m^{-1}

Young modulus of spider silk = 1.2×10^{9} N m^{-2}

strain in the thread = 9.7×10^{-9}

Determine, by considering wave speed, whether the measurements are consistent with this suggestion.

(7)

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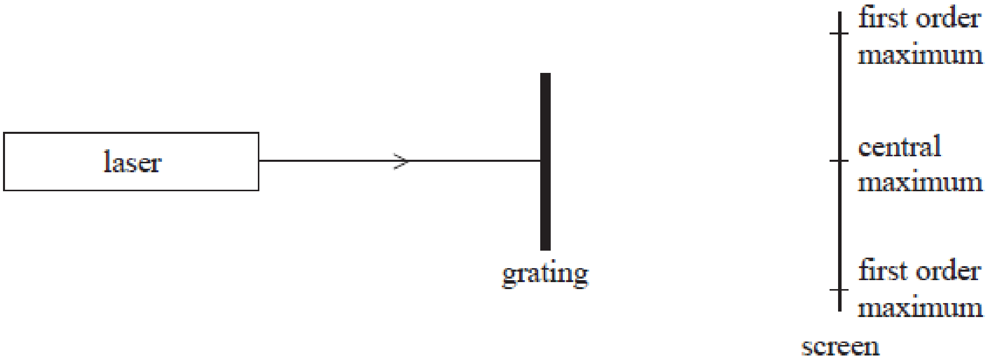
Q8.

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?

(1)

☐ **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 = 1 mark)

Q9.

Magnifying 'bug boxes' are used to observe small insects. One type consists of a clear plastic pot with a snap-on lid.

The lid acts as a converging lens of focal length 8.5 cm.

An insect inside the box appears to be 3.5 times bigger when viewed through the lid.

(i) Draw a ray diagram to show the formation of the image by the lens when used in this way.

(3)

(ii) Calculate the distance of the insect from the lid.

(3)

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(Total for question = 6 marks)

Q10.

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.

* 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)

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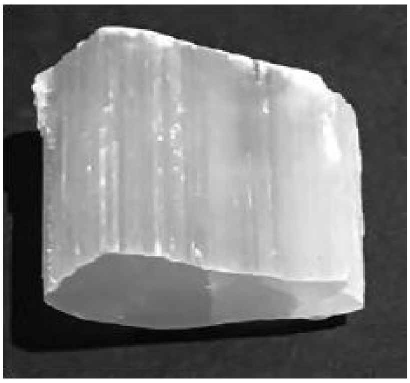
(Total for question = 6 marks)

Q11.

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

(i) State what is meant by critical angle.

(1)

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

(2)

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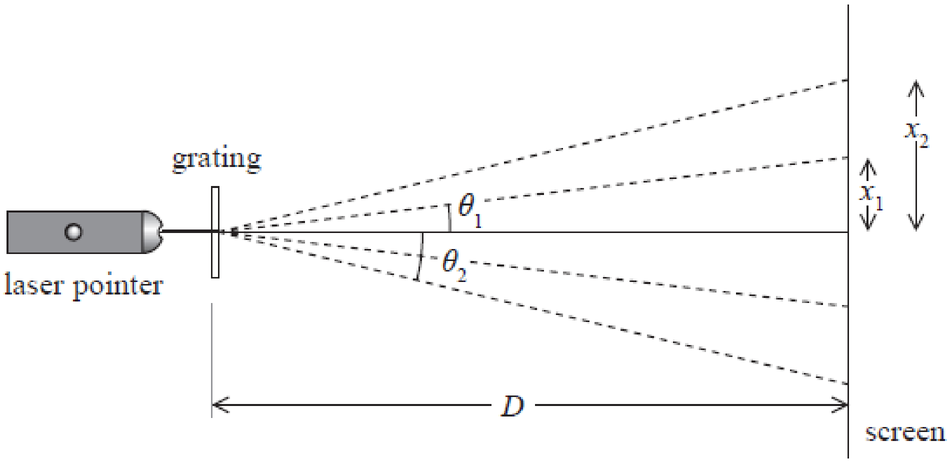
Critical angle for light in selenite = ...

(Total for question = 3 marks)

Q12.

A student is using a diffraction grating to determine the wavelength of the light emitted by a laser pointer. The light from the laser pointer is directed so that it is normal to the plane of the grating. The diffracted light is viewed on a screen a distance D from the grating.



The diagram shows the first two diffracted orders where x_1 and x_2 are the distances of the maxima for these orders from the central maximum of the diffraction pattern.

(a) Before carrying out the experiment, the student carries out a risk assessment to ensure that the experimental procedure is safe.

Explain one precaution that should be taken.

(2)

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(b) The student measures the distances from the central maximum of the diffraction pattern for various diffracted orders n, using a metre rule.

n	x_n / cm	θ / °	sin θ
0	0	0.00	0.000
1	35.5	11.4	0.20
2	74		
3	126.5	35.9	0.586
4	211	50.4	0.771

(i) Criticise the results that are recorded.

(1)

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(ii) Complete the data for the 2nd order maximum.

D = 1.750 m

(2)

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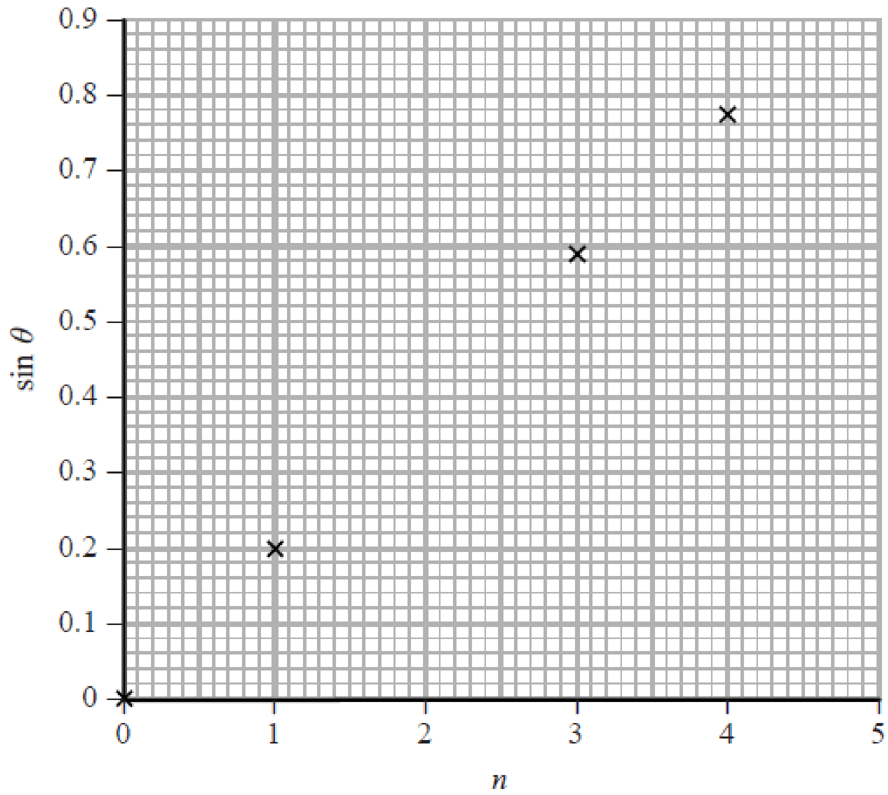
(iii) Add your data to the axes and draw a line of best fit.

(1)



(iv) Use your graph to determine a value for the wavelength of the laser light.
The grating has 300 lines per mm

(5)

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Wavelength = ...

(c) State and justify two modifications to the experimental method which would have improved the accuracy of the value obtained for the wavelength.

(4)

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(Total for question = 15 marks)

Q13.

Which variables are linked in the de Broglie equation?

☒ **A** frequency and wavelength of a photon

☒ **B** wavelength and momentum of a moving electron

☒ **C** energy and frequency of a photon

☒ **D** work function and threshold frequency of a metal

(Total for question = 1 mark)

Q14. The de Broglie wavelength for neutrons used to study crystal structure is 1.2 nm.
mass of a neutron = 1.67×10^{-27} kg

The speed of these neutrons would be

- ☒ **A** 3.0×10^{6} m s^{-1}
- ☒ **B** 3.3×10^{2} m s^{-1}
- ☒ **C** 3.0×10^{-3} m s^{-1}
- ☒ **D** 3.3×10^{-7} m s^{-1}

(Total for Question = 1 mark)

Q15. The de Broglie wavelength associated with electrons moving at 2.5×10^{6} m s^{-1} is

- ☒ **A** 2.9×10^{-4} m
- ☒ **B** 2.4×10^{-8} m
- ☒ **C** 2.9×10^{-10} m
- ☒ **D** 2.4×10^{-39} m

(Total for Question = 1 mark)

Q16.

The electron in a hydrogen atom can be described by a stationary wave which is confined within the atom. This means that the de Broglie wavelength associated with it must be similar to the size of the atom which is of the order of 10^{-10} m.

(a) (i) Calculate the speed of an electron whose de Broglie wavelength is 1.00×10^{-10} m.

(3)

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Speed = ...

(ii) Calculate the kinetic energy of this electron in electronvolts.

(3)

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Kinetic energy = ... eV

(b) When β radiation was first discovered, it was suggested that there were electrons in the atomic nucleus, but it was soon realised that this was impossible because the energy of such an electron would be too great.

Suggest why an electron confined within a nucleus would have a much greater energy than the energy calculated in (a)(ii).

(2)

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(Total for question = 8 marks)

Q17.

(a) State what is meant by the de Broglie wavelength.

(2)

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(b) An electron is accelerated from rest, in a vacuum, through a potential difference of 500 V.

(i) Show that the final momentum of the electron is about 1×10^{-23} N s.

(3)

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(ii) Calculate the de Broglie wavelength for this electron.

(2)

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de Broglie wavelength = ...

(Total for question = 7 marks)

Q18.

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)

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(Total for question = 3 marks)

Q19.

The photoelectric effect was discovered by Hertz who investigated the effect of ultraviolet radiation incident upon the surface of zinc. The effect was found to depend on the frequency of the radiation.

(a) State what is meant by threshold frequency.

(1)

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(b) Light of frequency 8.9×10^{14} Hz is incident upon the surface of a different metal.
The photoelectrons have a maximum speed of 6.7×10^{5} m s^{-1}.

Calculate the work function of the metal in eV.

(4)

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Work function = ... eV

(Total for question = 5 marks)

Q20.

The distance travelled by a wave during one oscillation may be described as

☒ **A** frequency.

☒ **B** period.

☒ **C** wavelength.

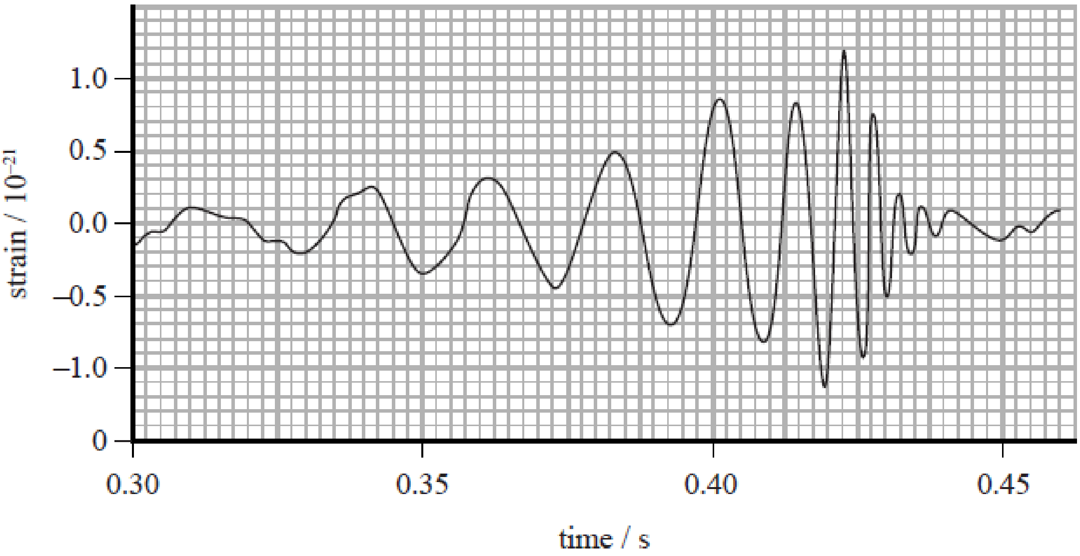
☒ **D** wave speed.

(Total for question = 1 mark)

Q21.

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.



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)

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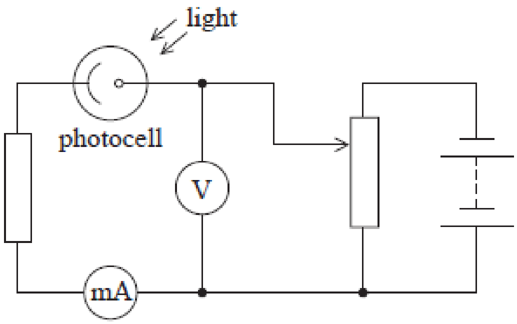
Mean wavelength = ...

(Total for question = 3 marks)

Q22.

A student has been learning about the photoelectric effect.

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)

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(Total for question = 5 marks)

Q23.

A beam of electrons spreads out into several distinct beams after passing through a crystalline material.

This demonstrates that

☒ **A** electrons behave as particles.

☒ **B** electrons behave as waves.

☒ **C** electrons exist in energy levels.

☒ **D** electrons have negative charge.

(Total for question = 1 mark)

Q24.

Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

A diffraction grating can be used to analyse the radiation emitted by a variety of sources.

(i) A diffraction grating of known grating spacing is used in a school laboratory to analyse the light emitted by a laser.

Describe how the diffraction grating is used and the measurements that should be taken.

(3)

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(ii) A diffraction grating with grating spacing of 2.2×10^{-6} m is used to determine the difference in wavelength for the spectral line emitted by Barnard's star.

Comment on the suitability of using a diffraction grating with this spacing. You should include appropriate calculations.

(4)

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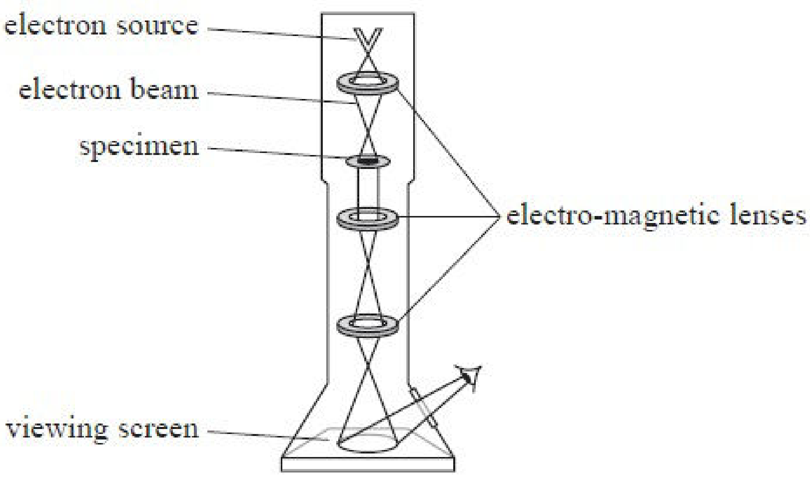
(Total for question = 7 marks)

Q25. A transmission electron microscope passes a beam of electrons through a tiny specimen to form an image on a viewing screen.



Due to the wave nature of electrons, diffraction occurs which can blur the image. To reduce this effect when viewing a smaller object the beam must contain

- ☒ **A** more electrons per second.
- ☒ **B** fewer electrons per second.
- ☒ **C** faster moving electrons.
- ☒ **D** slower moving electrons.

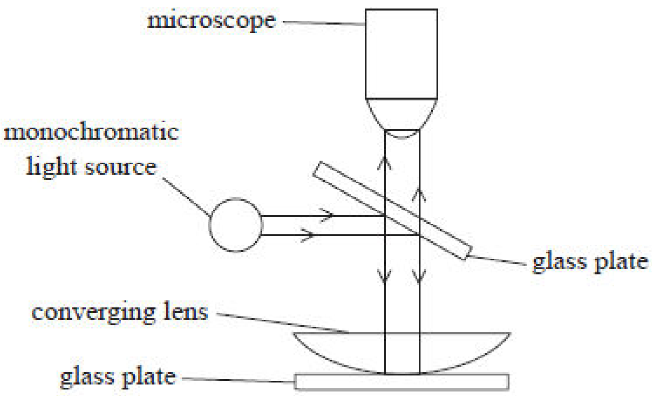
(Total for Question = 1 mark)

Q26.

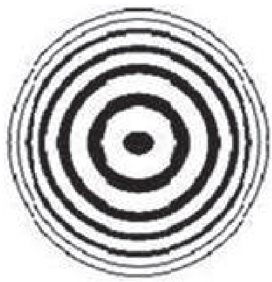
A method to determine the wavelength of light using a converging lens was first proposed by Sir Isaac Newton.

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

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.

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(Total for question = 4 marks)

Q27.

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

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)

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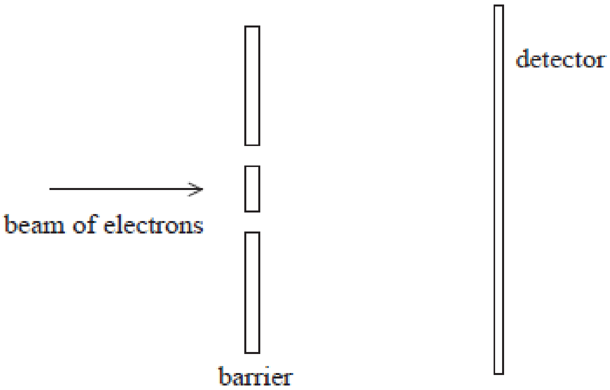
Distance between lens and screen = ...

(Total for question = 3 marks)

Q28.

In 1965, Richard Feynman proposed a double slit experiment to investigate the wave properties of electrons.

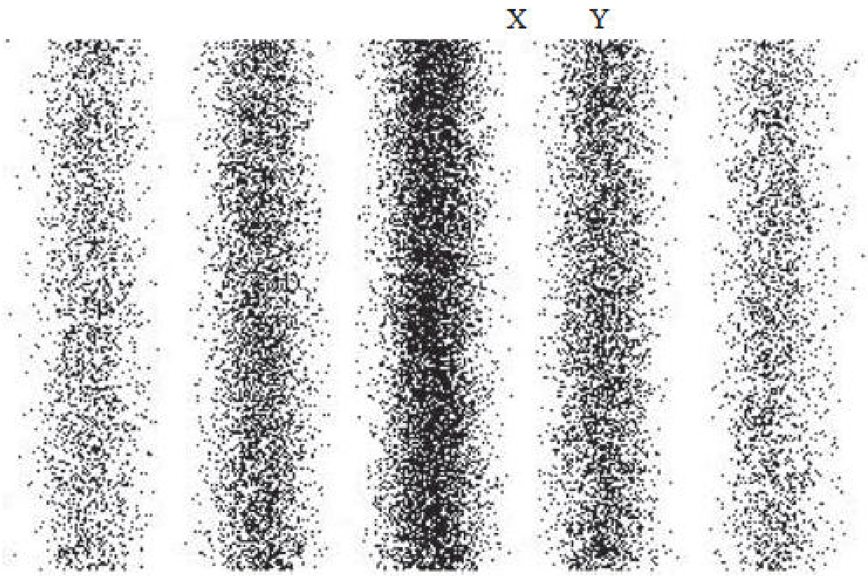
The experiment was later carried out using the arrangement shown.



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^{-1} m. For electrons arriving at band Y the path difference was 5.0×10^{-1} m.

Explain why this pattern is observed when the electron energy is 9.6×10^{-1} J.

The electrons are travelling at non-relativistic speeds.

(6)

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(Total for question = 6 marks)

Q29.

When a sound wave passes from water into air it slows down. As the wave crosses the boundary from water to air its

☐ **A** frequency decreases.

☐ **B** frequency increases.

☐ **C** wavelength decreases.

☐ **D** wavelength increases.

(Total for question = 1 mark)

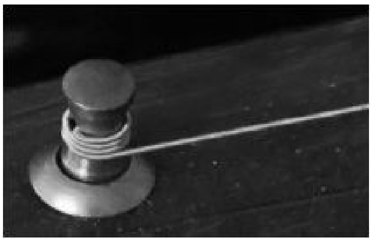
Q30.

The photograph shows a guitar.

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

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 = 1.8×10^9 N m^{-2}

cross-sectional area of string = 6.6×10^{-7} m^2

(4)

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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)

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(Total for question = 6 marks)

Mark Scheme

Q1.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of gradient (1) • *h* from graph = 6.74×10^{-34} J s (1) • Suitable percentage calculation allowing comparison with 1% and conclusion (1)	<u>Example of calculation</u> 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

Q2.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• Conversion of MeV to J • See $Q_1 = 79 \times 1.6 \times 10^{-19}$ **and** $Q_2 = 2 \times 1.6 \times 10^{-19}$ • Use of $V = \frac{Q}{4\pi\varepsilon_0 r}$ **and** $W = QV$ • $r = 4.1\times10^{-14}$ m	(1) (1) (1) (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
(ii)	• Electrons are behaving like waves • wavelength$=\frac{h}{\text{momentum}}$ • Electron wavelength must be similar to the atomic spacing in the foil	(1) (1) (1)	MP3: Accept electron wavelength must be similar to the distance between (adjacent) nuclei	3

Q3.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $d = 1$ / no of slits per metre • Use of $n\lambda = d \sin\theta$ • $\theta = 21°$	(1) (1) (1)	Example of calculation $d = 1 / 600\,000 = 1.67 \times 10^{-6}\text{ m}^{-1}$ $n = 1$ $6.1 \times 10^{-7}\text{ m} = 1.67 \times 10^{-6}\text{ m}^{-1} \sin\theta$ $\theta = 21.47°$	3

Q4.

Question Number	Acceptable answer	Additional guidance	Mark
	B	The only correct answer is **B** because m is the SI unit for length. A is not correct because C is not a base unit C is not correct because g is not a base unit D is not correct because °C is not a base unit	1

Q5.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• 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 $\tan\theta = \frac{0.50\text{ m}}{1.45\text{ m}}$ $\therefore\ \theta = 19.0°$ $\tan\theta = \frac{0.40\text{ m}}{1.45\text{ m}}$ $\therefore\ \theta = 15.4°$ $d = \frac{650 \times 10^{-9}\text{ m}}{\sin 19.0°} = 1.99 \times 10^{-6}$ m $\lambda_2 = 1.99 \times 10^{-6}\text{m} \times \sin 15.4° = 5.29 \times 10^{-7}\text{m}$	5

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	• Use of $L = \lambda/2$ **(1)** • Use of $v = f\lambda$ **(1)** • $f = 180$ Hz **(1)**	Example of calculation: $\lambda = 2 \times 0.45$ m $= 0.90$ m $f = v/\lambda = 160$ m s^{-1}/0.9 m $= 178$ Hz	3

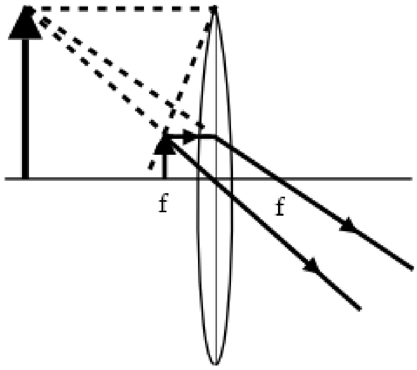
Q7.

Question Number	Acceptable answers		Additional guidance	Mark
	• states wavelength = 1.2 cm	(1)	Example of calculation:	
	• use of E = stress / strain	(1)	$\lambda = 4.8 \times 0.25$ cm = 1.2 cm $A = \pi d^2 / 4$ $= \pi(3.6 \times 10^{-6}$ m$)^2 / 4$ $= 1.012 \times 10^{-11}$ m^2	
	• use of $A = \pi\ d^2/4$	(1)	stress = strain × E = $9.7 \times 10^{-9} \times 1.2 \times 10^9$ N m^{-2}	
	• use of stress = F/A	(1)	= 11.64 N m^{-2} $T = F$	
	• use of $v = \sqrt{(T/\mu)}$	(1)	= stress × A = 11.64 N m^{-2} × 1.012×10^{-11} m^2 = 1.18×10^{-10} N	
	• use of $v = f\lambda$ with any two of the stated / measured / calculated values of v, f or λ to calculate the other	(1)	$v = \sqrt{(\ \div\ )} = \sqrt{8.92 \times 10^{-3}}$ = 0.094 m s^{-1} Using $v = f\lambda$, v = 7.9 Hz × 0.012 m = 0.0912 m s^{-1}	**7**
	• comparison of this calculated value of v, f or λ with the value obtained another way	(1)	Agree to within 3%, so suggests consistent	

Q8.

Question Number	Answer	Mark
	D – using laser light with a higher frequency	**1**
	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	

Q9.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	Two construction rays from: • ray from tip of object parallel to principal axis drawn then refracted through the focal point **(1)** • ray drawn from tip of object through centre of lens **(1)** • ray drawn from focal point through tip of object and then refracted parallel to the principal axis **(1)** **And** • rays extended back to locate tip of image on the same side as the object **(1)**	Example of diagram: 	**3**

Question Number	Acceptable answers	Additional guidance	Mark
(ii)	• Use of $m = v/u$ **(1)** • Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ and substituting for v or u **(1)** • $u = 6.1$ cm **(1)**	Example of calculation: $\frac{v}{u} = -3.5 \quad \therefore v = -3.5u$ $\frac{1}{u} + \frac{1}{-3.5u} = \frac{1}{8.5} \qquad \therefore \frac{3.5-1}{3.5u} = \frac{1}{8.5} \qquad \therefore \frac{3.5u}{2.5} = 8.5$ $u = \frac{8.5 \times 2.5}{3.5} = 6.07\,\text{cm}$	**3**

Q10.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
<tr><td></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

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)
</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>
IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once
<table>
<tr><td>Number of IC points awarded</td><td>Possible linkage marks</td></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></td><td>6</td></tr>
</table>

Q11.

Question Number	Acceptable answers		Additional guidance	Mark
(i)	• the angle of incidence in an (optically) denser medium at which the angle of refraction (in the less dense medium) is 90° **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)	**(1)**	Other equivalent answers may be given Do not accept answers stating or implying that the critical angle is the smallest angle at which <u>total</u> 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**
(ii)	• Use of $\sin C = 1 / n$ • $C = 41°$	**(1)** **(1)**	<u>Example of calculation</u> $\sin C = 1/1.52$ $C = 41.1°$	**2**

Q12.

Question Number	Acceptable Answer		Additional Guidance	Mark
(a)	• laser light should not be aimed directly into the eye • as concentrated beam can cause damage to the retina	(1) (1)		**(2)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(i)	<u>EITHER</u> • all x values should be recorded to the same number of decimal places, so x_2 and x_4 are incorrectly recorded (1) <u>OR</u> • all processed data should be recorded to the same number of significant figures, so sin θ for x_1 is incorrectly recorded	Do not award repeat readings, not appropriate in this experiment	**(1)**
(b)(ii)	• use of $\tan\theta = \frac{x}{D}$ [θ = 22.9°] (1) • sinθ = 0.390 (1)	<u>Example of calculation:</u> $\tan\theta = \frac{0.741}{1.75} = 0.423$ $\therefore \theta = 22.9°$ $\therefore \sin\theta = 0.3899$	**(2)**
(b)(iii)	point plotted correctly <u>and</u> best straight line drawn through points (1)		**(1)**

Question Number	Acceptable Answer	Additional Guidance	Mark
(b)(iv)	• $\sin\theta = \frac{n\lambda}{d}$, so gradient = $\frac{\lambda}{d}$ (1) • gradient = 0.194 (1) • use of d = 1/number of lines per mm (1) • d = 3.33 × 10^{-6} (m) (1) • λ = 6.5 × 10^{-7} m (1)	<u>Example of calculation:</u> $d = \frac{1}{3\times10^{5}\,\text{m}^{-1}} = 3.33\times10^{-6}\,\text{m}$ $\lambda = 3.33\times10^{-6}\,\text{m}\times0.194$ $= 6.47\times10^{-7}\,\text{m}$	**(5)**

Question Number	Acceptable Answer		Additional Guidance	Mark
(c)	An answer that makes reference to two of the following pairs: • use a Vernier scale to record *x* • so that data to the nearest 0.1 cm could be obtained to reduce the percentage uncertainty • use a larger grating to screen distance • so that all *x* values would be greater to reduce the percentage uncertainty • measure from nth order on one side to nth order on the other side • so that the distance measured is larger hence reducing the percentage uncertainty in x • use a grating with more lines per mm • so that values of *x* will be greater to reduce the percentage uncertainty	 (1) (1) (1) (1) (1) (1) (1) (1)	Do not award repeat readings, not appropriate in this experiment	**(4)**

Q13.

Question Number	Answer	Mark
	B	1

Q14.

Question Number	Answer	Mark
	B	**1**

Q15.

Question Number	Answer	Mark
	C	**1**

Q16.

Question Number	Answer		Mark
(a) (i)	Use of $\lambda = h/p$ and $p = mv$ **Or** $v = h/m\lambda$ Use of $m = 9.11 \times 10^{-31}$ kg $v = 7.28 \times 10^{6}$ m s^{-1} <u>Example of calculation</u> $\lambda = h/mv$ $v = 6.63 \times 10^{-34}$ J s /(9.11 × 10^{-31} kg × 1.0 × 10^{-10} m) $v = 7.28 \times 10^{6}$ m s^{-1}	**(1)** **(1)** **(1)**	**3**
(a) (ii)	Use of $E_k = \frac{1}{2} mv^2$ **Or** $E_k = p^2/2m$ **Or** see $E_k = 2.41 \times 10^{-17}$ J Divided by 1.60 × 10^{-19} E_k = 151 eV (accept values in range 150 – 152 eV) (ecf value of v from (a)) <u>Example of calculation</u> $E_k = \frac{1}{2}$ (9.11 × 10^{-31} kg)(7.28 × 10^{6} m s^{-1})^2 / (1.60 × 10^{-19} J eV^{-1}) E_k = 151 eV	**(1)** **(1)** **(1)**	**3**
(b)	The wavelength is similar in size to the nucleus The wavelength /nucleus is (much) smaller / 10^{-15}m / 10^{-14} m (if value is not given, 'wavelength is small' or 'wavelength is very small' is not sufficient)	**(1)** **(1)**	**2**

Q17.

Question Number	Answer		Mark
(a)	The wavelength (associated) with a particle/electron with a given momentum **Or** $\lambda = h/p$ all terms defined	(1) (1) (1) (1)	2
(b)(i)	Use of $E_k = eV$ Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ Momentum = 1.21×10^{-23} kg m s^{-1} <u>Example of calculation</u> $E_k = 1.6 \times 10^{-19}$ C $\times$ 500 V $p^2 = 2\,m\,E_k = 2 \times 9.11 \times 10^{-31}$ kg $\times$ ($1.6 \times 10^{-19} \times 500$) J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	(1) (1) (1)	3
(b)(ii)	Use of $\lambda = h/p$ $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (show that value gives 6.63×10^{-11} m) <u>Example of calculation</u> $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	(1) (1)	2
	Total for question		7

Q18.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• The deflection/fields experiments indicate that electrons have a mass (and a charge) **Or** the deflection/fields experiments indicate that electrons have particle behaviour. • The diffraction experiments indicate that electrons must have a wave nature • Idea that a model of electron behaviour must include wave-particle duality	(1) (1) (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

Q19.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Question Number	Acceptable answers		Additional guidance	Mark
(b)	• use of $\frac{1}{2} m v_{max}^2$ • use of $\varphi = hf$ – max ke • divides energy in joule by 1.6×10^{-19} C • $\varphi = 2.4$ eV	(1) (1) (1) (1)	Example of calculation: $E = 6.63 \times 10^{-34}$ J s $\times 8.9 \times 10^{14}$ Hz $= 5.9 \times 10^{-19}$ J $\frac{1}{2} m v_{max}^2 = \frac{1}{2} \times 9.11 \times 10^{-31}$ kg $\times (6.7 \times 10^5$ m s$^{-1})^2 = 2.045 \times 10^{-19}$ J $\varphi = 5.9 \times 10^{-19}$ J $- 2.045 \times 10^{-19}$ J $= 3.8 \times 10^{-19}$ J $= 1.8 \times 10^{-19}$ J $\div 1.6 \times 10^{-19}$ C $= 2.4$ eV	**(4)**

Q20.

Question Number	Answer	Mark
	C	1

Q21.

Question Number	Acceptable answers		Additional guidance	Mark
	• use of $f = 1/T$ • use of $v = f\lambda$ • wavelength $= 7.5 \times 10^6$ 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$^{-1} \div 40$ Hz $= 7.5 \times 10^6$ m	3

Q22.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Photoelectric equation stated in words **Or** $hf = \phi + \frac{1}{2}mv_{max}^2$ with ϕ defined	(1)	MP1: Accept hf_0 for ϕ [with f_0 defined], and $E_{k\,max}$ for $\frac{1}{2}mv_{max}^2$	
	• Hence $eV_s = hf - \phi$ **Or** $E_{k\,max} = hf - \phi$ **and** $E_{k\,max} = eV_s$	(1)	MP2: eV_s does not have to be the subject of the equation	
	• Compare with $y = mx + c$	(1)		5
	• So plot a graph of V_s against f **Or** plot a graph of eV_s against f	(1)	MP5 is dependent upon MP4	
	• Gradient = $\frac{h}{e}$ **Or** gradient = h	(1)		

Q23.

Question Number	Answer	Mark
	B	1

Q24.

Question Number	Acceptable Answer		Additional Guidance	Mark
(i)	• set up diffraction grating at right angles to light from laser **Or** set up grating parallel to screen	(1)	An annotated diagram could score these marks	
	• measure the distance between the diffraction grating and the screen	(1)	MP3 accept between other correct specified orders.	
	• measure the distance between 1st order images on the screen	(1)		3

Question Number	Acceptable Answer		Additional Guidance	Mark
(ii)	• use of $d\sin\theta = n\lambda$ • Calculation of one of the diffraction angles (for any n) • Attempt to calculate a difference in the angles **Or** statement that the two angles are very similar • So (accurate) measurement would be very difficult **Or** the difference in wavelength could not be determined with this grating	(1) (1) (1) (1)	MP4 dependent on MP3 Example of calculation: $\sin\theta_1 = \frac{656.2\times10^{-9}\text{ m}}{2.2\times10^{-6}\text{ m}}$ $\therefore \theta_1 = 17.354°$ $\sin\theta_2 = \frac{656.0\times10^{-9}\text{ m}}{2.2\times10^{-6}\text{ m}}$ $\therefore \theta_1 = 17.348°$ $\therefore \Delta\theta = 17.354° - 17.348° = 0.006°$	4

Q25.

Question Number	Answer	Mark
	C	**1**

Q26.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Coherent waves have a constant phase relationship • Coherent waves have the same frequency • However, for each frequency present the (two) reflected waves are coherent • Hence with a non-monochromatic source, a set of dark rings for each frequency would be produced	(1) (1) (1) (1)	MP2-4: accept wavelength for frequency MP4: hence with a white light source you would see a set of coloured rings	**4**

Q27.

Question Number	Acceptable Answer		Additional Guidance	Mark
	• Use of $m = \frac{\text{image height}}{\text{object height}}$ • Use of $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ • $\therefore v = 28$ m	(1) (1) (1)	For MP2 allow ($u \approx f$, so) $v = f \times$ magnification <u>Example of calculation</u> $\frac{v}{u}=\frac{h_i}{h_o}=\frac{0.75\text{ m}}{4.0\times10^{-3}\text{m}}=187.5$ $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ $\therefore \frac{v}{u}+1=\frac{v}{f}$ $\therefore v=(187.5+1)\times15.0\times10^{-2}\text{m}=28.3\text{ m}$	3

Q28.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $E_K = p^2 / 2m$	(1)	MP1 accept use of $p = mv$ **and** Use of $E_k = ½\ mv^2$	
	• Use of $\lambda = h/p$	(1)	MP4 accept (n + ½) λ or n λ respectively	
	• λ =5.0 × 10^{-11} (m) calculated from E_K **Or** E_K = 9.7 × 10^{-17} (J) calculated fro λ =5.0 × 10^{-11} m **Or** p = 1.3 × 10^{-23} (kg m s^{-1}) calculated from E_K **and** p = 1.3 × 10^{-23} (kg m s^{-1}) calculated from λ =5.0 × 10^{-11} m	(1)	Example of calculation $p = \sqrt{(2 \times 9.11 \times 10^{-31}\ kg \times 9.6 \times 10^{-17}\ J)}$ $p = 1.32 \times 10^{-23}$ kg m s^{-1} λ =6.63 × 10^{-34} Js / 1.32 × 10^{-23} kg m s^{-1} λ =5.0 × 10^{-11} m	6
	• path difference at X is $\lambda/2$ **Or** path difference at Y is λ	(1)		
	• (electron) waves at X are in antiphase **Or** (electron) waves at Y are in phase	(1)		
	• at X destructive interference/superposition takes place **Or** at Y constructive interference/superposition takes place	(1)		

Q29.

Question Number	Acceptable answers	Additional guidance	Mark
	C		**1**

Q30.

Question Number	Acceptable answers	Additional guidance	Mark
(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
(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