

PHYSICS



EXAM QUESTION PACK

MODULE 4 UNDERSTANDING PROCESSES

SCORE

/534

PERCENTAGE

%

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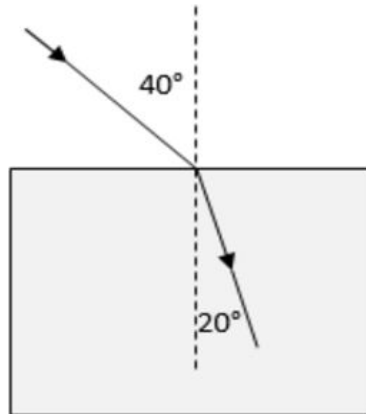
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- 1 A ray of light passes from air into a rectangular glass block.



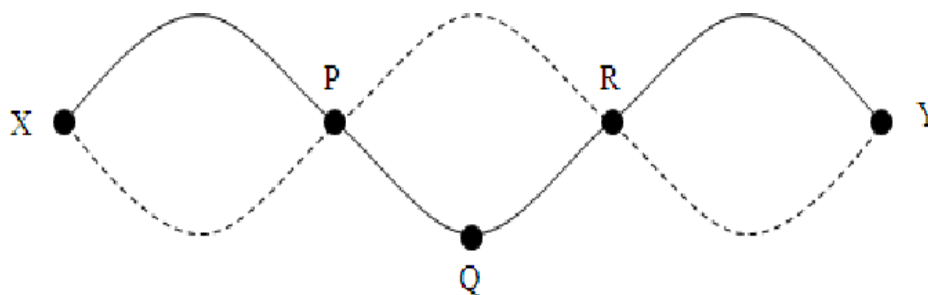
The refractive index of the glass is

- A 0.53
- B 0.82
- C 1.2
- D 1.9

Your answer

[1]

- 2 The solid line shows the standing wave pattern of a vibrating string which is fixed at ends X and Y. The broken line shows the position of the string half a cycle later. The displacement at point Q is a maximum.



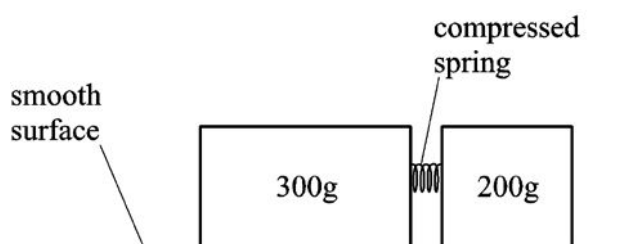
Which one of these statements is true?

- A The distance from P to R is one wavelength.
- B A short time later, the string at R will move up.
- C The lowest possible frequency for this string is one third of its current value.
- D The kinetic energy of the string has its maximum value.

Your answer ☐

[1]

- 3 The diagram shows two blocks of different masses resting on a smooth surface. They are held together so that a spring between them is in compression.



The blocks are released, and the spring pushes them apart.

The maximum speed of the 200 g mass is 4.2 ms^{-1} .

What is the maximum speed of the 300 g mass?

- A 6.3 ms^{-1}
- B 2.1 ms^{-1}
- C 2.8 ms^{-1}
- D 1.4 ms^{-1}

Your answer

[1]

- 4 A proton ${}^1_1\text{P}$ and a ${}^4_2\text{He}$ nucleus (alpha particle) are both accelerated from rest through a potential difference of 1000 V.

What is the ratio $\frac{\text{kinetic energy of the proton}}{\text{kinetic energy of the alpha particle}}$?

A $\frac{1}{4}$

B $\frac{1}{2}$

C $\frac{2}{1}$

D $\frac{4}{1}$

Your answer

[1]

- 5 A proton ${}^1_1\text{P}$ and a ${}^4_2\text{He}$ nucleus (alpha particle) are both accelerated from rest through a potential difference of 1000 V.

What is the ratio $\frac{\text{momentum of the proton}}{\text{momentum of the alpha particle}}$?

A $\frac{1}{2\sqrt{2}}$

B $\frac{1}{\sqrt{2}}$

C $\frac{\sqrt{2}}{1}$

D $\frac{2\sqrt{2}}{1}$

Your answer

[1]

6(a) Light of wavelength 633 nm passes through a diffraction grating.

The first order maximum is at an angle of 0.19 radian.

Show that the grating has about 300 lines per mm.

[3]

(b)

Calculate the number of orders of maximum that can be obtained from this grating with this light source.

[2]

- 7 The energy of photons released in the very early Universe has reduced by a factor of about 1000. Calculate the factor by which the wavelength of the photons has changed during this time.

[2]

8(a) This question is about the energy required to vaporise water.

A student performs a simple experiment in which she measures the change in mass of water as a kettle boils. The lid has been removed from the kettle so that the water vapour can escape.

These are her results:

mass of kettle and water at $t = 0$ s:	2.40 kg
mass of kettle and water at $t = 120$ s:	2.30 kg
power of kettle:	2100 W

She concluded that the energy required for one molecule to go into the vapour state is 7.5×10^{-20} J.

Show how the student reached this value.

molar mass of water = 18 g mol^{-1}

[3]

(b) Suggest and explain why her value of 7.5×10^{-20} J is larger than the expected value of 6.9×10^{-20} J.

[2]

- 9 This question is about the electron in the hydrogen atom. A simple model shown in Fig. 39.1 pictures the electron as a standing wave in a box of length equal to the diameter of the atom. The electron can be bound to the proton if the total energy of the electron (kinetic energy + potential energy) is less than zero.

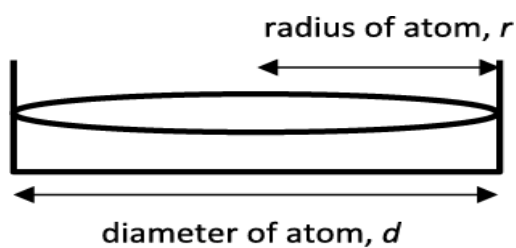


Fig. 39.1

- (i) Show that the kinetic energy of the electron in a box of diameter d is $\frac{h^2}{32mr^2}$.

[3]

- (ii) Calculate the kinetic energy of an electron trapped in a box of $r = 1 \times 10^{-10}$ m.

kinetic energy = _____ J [2]

- (iii) Calculate the electrical potential energy of an electron at a distance of 1×10^{-10} m from a proton. Use this value and your answer from (ii) to explain why an electron can be bound to a proton at this distance.

$$k = 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

[4]

10(a) A teacher uses strobe photography to demonstrate the motion of a tennis ball thrown under gravity. She opens the camera shutter in a darkened room and throws the tennis ball in front of the lens as the strobe flashes at 20 ± 2 Hz. Fig. 1 shows the result, superimposed on a metric grid.

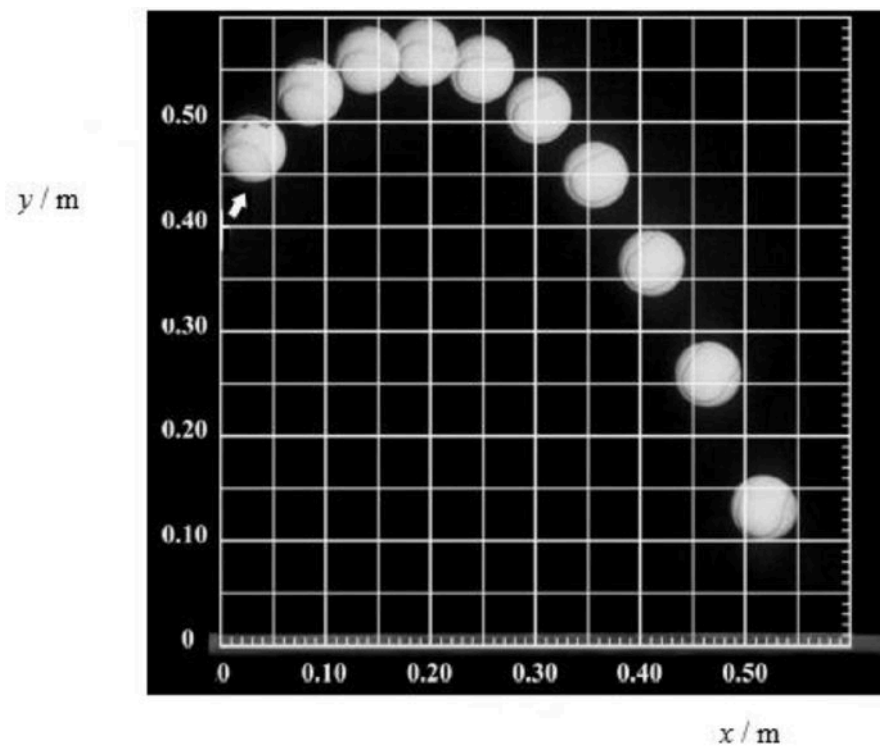


Fig. 1

A student takes measurements of the y position from Fig. 1, starting from the image centred on $x = 0.20$ m. He measures the y positions from the bottom of the ball and performs calculations; some are recorded in the table below. He concludes that g , the acceleration of gravity, is $9.2 \pm 0.4 \text{ ms}^{-2}$.

$t / \text{s} \pm 10\%$	$y / \text{m} \pm 0.005 \text{ m}$	$\Delta y / \text{m}$	$\Delta y / \Delta t / \text{ms}^{-1}$	$\Delta v / \text{ms}^{-1}$	$\Delta v / \Delta t / \text{ms}^{-2}$
0	0.54				
0.05	0.52	0.02	0.40		
0.10	0.48	0.04	0.80	0.40	
0.15	0.42	0.06	1.20	0.40	
0.20	0.33	0.09	1.80		
0.25	0.22	0.11	2.20		
0.30	0.10	0.12	2.40		

(i) Record further values in the spaces provided to complete the data in the table.

- (ii) Complete your own analysis of the data by calculating the mean value for g with an estimate of its uncertainty.

$$g = \text{-----} \pm \text{-----} \text{ ms}^{-2} \quad [2]$$

- (iii) You are planning to improve the accuracy of this experiment to estimate g . Suggest and explain which of the measured quantities is most worth improving to achieve this.

[2]

(b)

- (i) * It is suggested that the horizontal velocity component of the motion is constant at 1.0 ms^{-1} . Test this hypothesis, making your method clear. Explain your judgement and conclusion.

You may wish to use the table provided to record values taken from Fig. 1.

[6]

(ii) The teacher states that the vertical and horizontal components of the motion shown illustrate Newton's first two laws of motion.

Explain how the two components of the motion could illustrate these laws of motion.

[2]

11(a) The experiment illustrated in Fig. 2.1 is to be used to investigate aspects of the electric field between parallel plates. The charged ball bounces continuously between the plates.

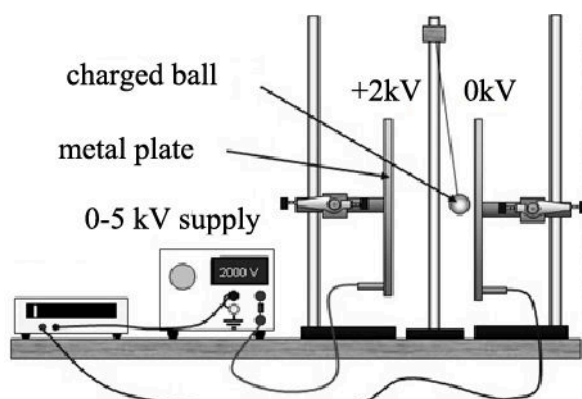


Fig. 2.1

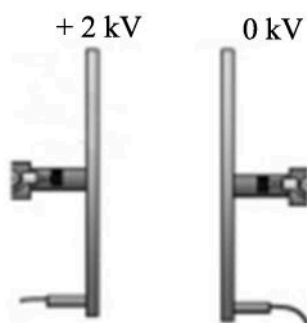


Fig. 2.2

- (i) Calculate the force on the ball when charged to +2.0 kV and placed between the plates with a p.d. of 2.0 kV.

radius of ball = 2.0×10^{-2} m

plate separation = 8.0×10^{-2} m

force = _____ N [3]

- (ii) Calculate or state the work done by the electric field per coulomb on the ball as the ball moves across half the separation of the plates.

work done per unit charge = _____ J C⁻¹ [1]

- (b) The ball bounces between the plates at a constant rate.

Explain why the ball bounces at a constant rate although it gains energy from the electric field each time it moves between the plates.

[2]

- 12 A converging lens is used to form a real image of an object on a screen. The object consists of a black line marked on a sheet of thin white paper illuminated from behind with red light as shown in Fig. 1.1.

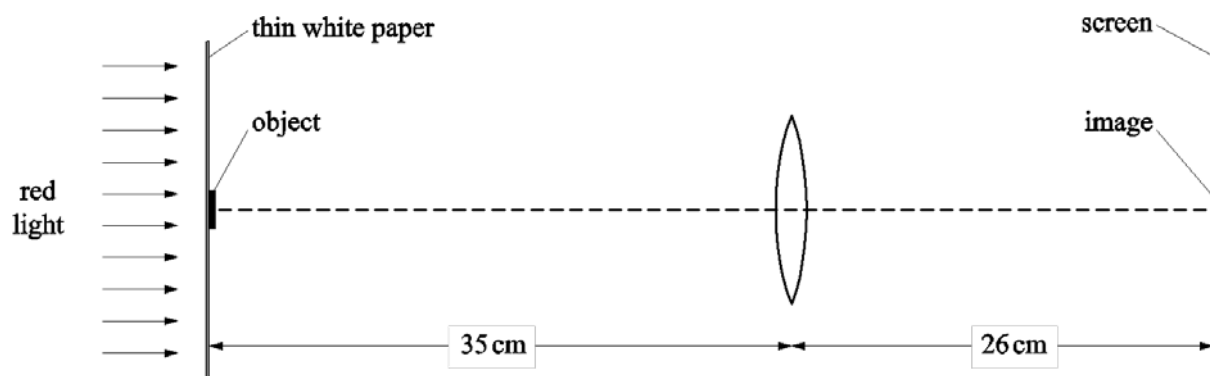


Fig. 1.1

When the red light is replaced with violet light, the position of the image moves 2.7 cm closer to the lens.

- (i) Show that the power of the lens is about 7% greater for violet light than for red light.

[2]

- (ii) Explain how this might affect a person wearing spectacles with lenses made from this glass.

[2]

13(a) This question is about the vertical forces and motion of an object floating in water. Fig. 5.1 shows a cylindrical rod of length L and cross-sectional area A floating vertically in water. The rod is weighted at the one end to ensure it floats vertically.

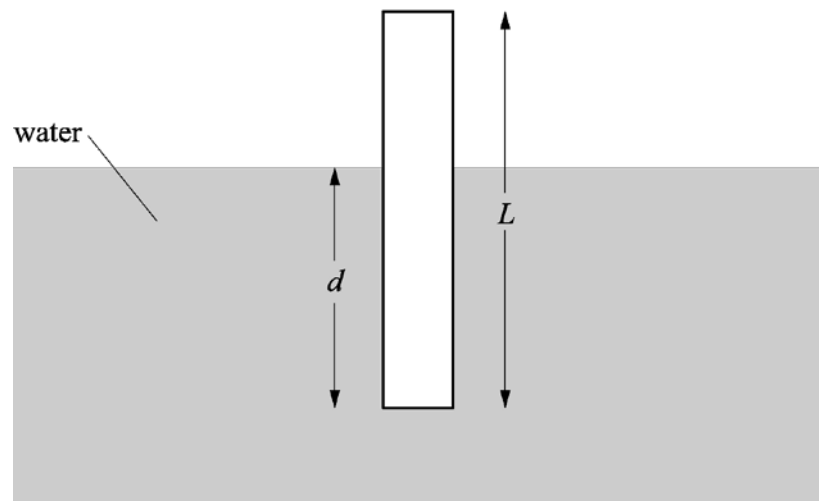


Fig. 5.1

Any object immersed in a fluid experiences an upwards force (upthrust) which is equal to the weight of the displaced fluid; in Fig. 5.1 this is the weight of water of volume Ad .

In equilibrium, the situation shown in Fig. 5.1, the distance between the water level and the base of the cylinder is d .

(i) Show that the depth d is given by

$$d = \frac{m}{A\rho_w}$$

where m is the mass of the cylindrical rod and ρ_w is the density of water.

[2]

(ii) Explain in terms of forces why a rod of mean density ρ_{rod} **cannot** float in water of density ρ_w if $\rho_{\text{rod}} > \rho_w$.

[2]

- (b) The rod is now pushed vertically down into the water by a distance s , where s is of the order of one or two cm. Show that the resultant acceleration a is given by

$$a = -\left(\frac{\rho_w g A}{m}\right)s$$

and explain why it would oscillate with simple harmonic motion of period T where

$$T = 2\pi\sqrt{\frac{m}{\rho_w g A}}$$

[5]

- Suggest and explain reasons why the pendulum method is likely to be chosen if a value of g with a small uncertainty is wanted.

In your answer you may wish to consider a pendulum of length 1m and a rod of mass 1 kg and cross sectional area 0.005 m^2 floating in water of density 1000 kg m^{-3} .

Blank lined paper for writing.

14 This question is about analysing the motion of sub-atomic particles.

Fig. 6.1 shows a collision of an alpha particle (α) with a stationary helium nucleus (He).
The paths of the alpha particle and the helium nucleus can be observed in a cloud chamber.
The velocities of the particles add as shown in Fig. 6.2.

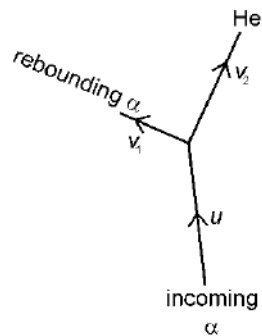


Fig. 6.1

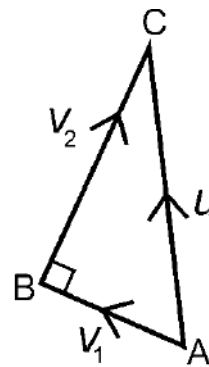


Fig. 6.2

- (i) Fig. 6.2 shows that
velocity u of α before collision = velocity v_1 of α after collision + velocity v_2 of He

Use the principle of conservation of momentum to explain why the velocities can only add in this way if the mass of an alpha particle, m_α , is the same as the mass of a helium nucleus, m_{He} .

[2]

- (ii) Fig. 6.2 also shows that the vector addition triangle **ABC** is a right-angled triangle.
Explain how this shows that the collision is elastic (there is no loss of kinetic energy).

[2]

- 15 The article describes the temperature of the solar corona as being far above that of the photosphere (line 13). The coronal X-rays detected by SOHO are in the wavelength range 0.10 nm to 10 nm.

Use these data to show how the temperature of the solar corona compares with that of the visible surface of the Sun (about 6000 K).

$$k = 1.4 \times 10^{-23} \text{ J K}^{-1}$$

[3]

16(a) This question is about an experiment to measure the speed of an air rifle pellet.

A student fires the rifle horizontally at a piece of Blu-tack suspended by a cord to form a pendulum, as shown in Fig. 13.1.

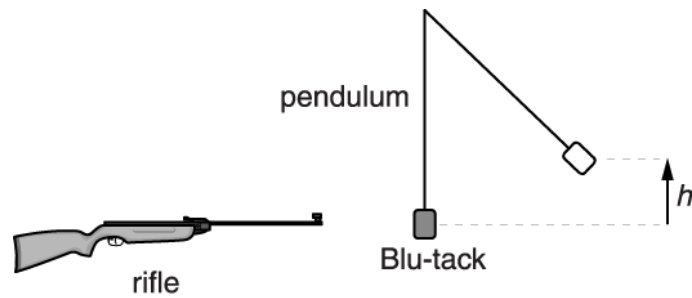


Fig. 13.1

The pellet becomes embedded in the Blu-tack which swings to the right, rising to a maximum height h of 0.23 m above its initial position.

Show that the kinetic energy of the Blu-tack and pellet, immediately after pellet impact, is about 0.2 J, stating clearly the assumptions that you have made.

mass of Blu-tack = 8.0×10^{-2} kg

mass of pellet = 1.0×10^{-3} kg

$g = 9.8 \text{ N kg}^{-1}$

- (b) Use momentum conservation and the answer to (a) to calculate the speed u of the pellet immediately before its impact with the Blu-tack. [3]

$u = \text{-----} \text{ m s}^{-1}$ [3]

(c) The student claims that kinetic energy is **not** conserved in the collision between the pellet and the Blu-tack.

(i) Show that the results of the experiment support the student's claim.

[2]

(ii) Describe where the missing energy has gone.

[2]

17 Which pair contains one vector and one scalar quantity?

- | | |
|------------------|--------------|
| A velocity | acceleration |
| B distance | force |
| C kinetic energy | power |
| D momentum | displacement |

Your answer

[1]

18 Suppose a certain atom has only four possible energy levels.

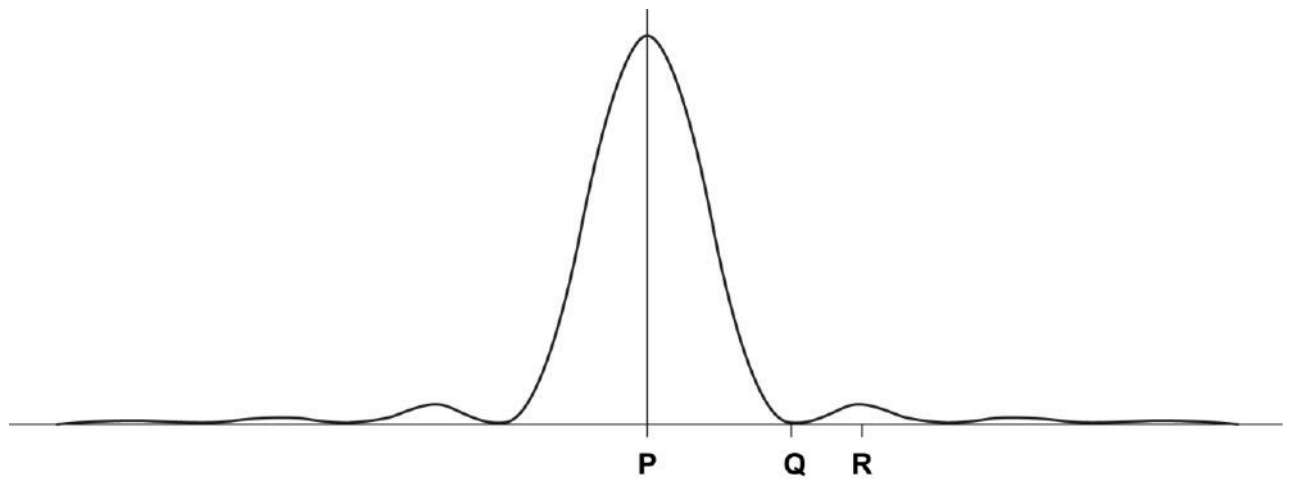
What would be the maximum number of different energies of photons that it could emit?

- A 3
- B 4
- C 6
- D 8

Your answer

[1]

- 19 Laser light is passed through a single slit onto a distant screen.
The graph illustrates the variation of intensity with position on the screen.



Which of the following statements about the positions **P**, **Q** and **R** on the screen is / are correct?

- 1 At **P** all the phasors from different positions across the slit line up to give a large resultant.
- 2 At **Q** phasors from different positions across the slit curl up to give zero resultant.
- 3 At **R** the probability of arrival of a photon will increase if the slit is made a little narrower.

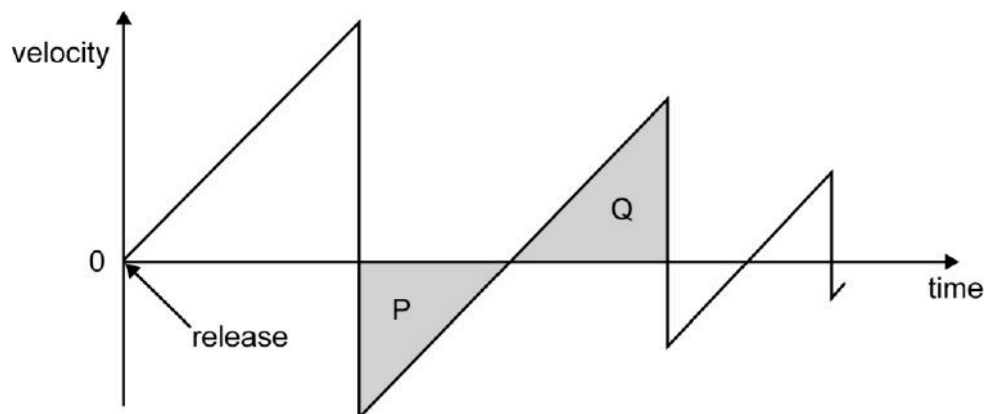
- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

Your answer

☐

[1]

- 20 A ball is released from rest above a horizontal surface and bounces.
The graph shows how the velocity of the ball varies with time.



Which statement best explains why areas **P** and **Q** equal?

- A The ball's acceleration is constant between bounces.
- B At each bounce the ball loses a fraction of its kinetic energy.
- C The ball rises and falls through the same distance between bounces.
- D After a bounce the ball leaves the surface with the same speed at which it hits the surface for the next bounce.

Your answer

[1]

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

- 1 It is reasonable to infer that both γ -rays and radio waves are electromagnetic because they both carry energy.
- 2 It is reasonable to expect to be able to polarise electromagnetic waves because they are transverse.
- 3 It is reasonable to expect to observe diffraction of electromagnetic waves of frequency 2×10^8 Hz by an object 1.5 m in diameter since electromagnetic waves travel at 3×10^8 m s⁻¹.

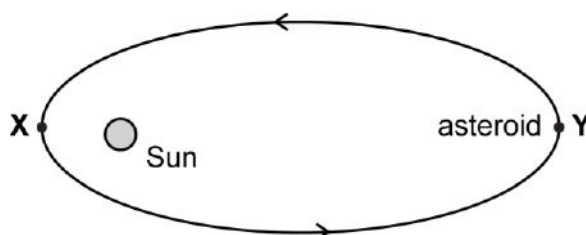
- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

Your answer

☐

[1]

- 22 An asteroid moves around the Sun in an ellipse, as shown. It is closest to the Sun at X and furthest from the Sun at Y.



Which one of the following quantities is greater at Y than at X?

- A the gravitational force on the asteroid due to the Sun
B the kinetic energy of the asteroid
C the speed of the asteroid in its orbit
D the gravitational potential energy of the Sun-asteroid system

Your answer

☐

[1]

23(a) In still water a boat can travel at 6.0 m s^{-1} . A river flows steadily at 2.0 m s^{-1} .

The boat must cross the river perpendicular to the banks as shown in Fig. 35.1.

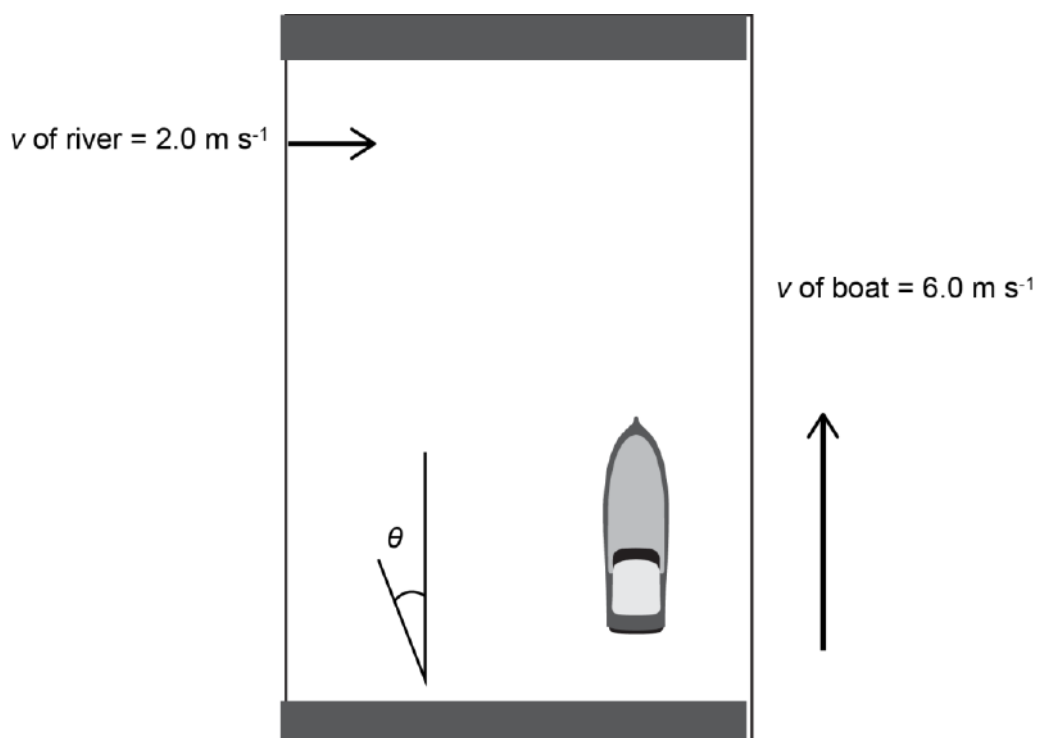


Fig. 35.1

Calculate the angle θ at which the boat should be steered to cross perpendicular to the banks.
Make your method clear.

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

(b) Calculate the magnitude of the velocity perpendicular to the banks.

$$\text{magnitude of perpendicular velocity} = \text{-----} \text{ m s}^{-1} \text{ [1]}$$

24(a) This question is about modelling projectile motion using iteration in discrete time intervals Δt .

Here $\Delta t = 0.1$ s and g is taken as 10 m s^{-2} . The first data row sets up initial conditions.

Then the rules in the column headings are applied using data from the previous row.

An analytical solution to the motion is also shown using kinematic equations.

iterative numerical solution				analytical solution
time lapsed t / s $t_{\text{new}} = t_{\text{old}} + \Delta t$	x displacement / m at constant v_x $x_{\text{new}} = x_{\text{old}} + v_x \Delta t$	$v_y / \text{m s}^{-1}$ $v_{\text{new}} \approx v_{\text{old}} - g \Delta t$	y displacement / m $y_{\text{new}} \approx y_{\text{old}} + v_y \Delta t$	$y = ut - \frac{1}{2}gt^2 / \text{m}$
0	0	4.0	0	0
0.1	$0 + (3 \times 0.1)$ = 0.3	$4 - (10 \times 0.1)$ = 3	$0 + (4 \times 0.1)$ = 0.4	$4 \times 0.1 - (5 \times 0.1^2)$ = 0.35
0.2	$0.3 + (3 \times 0.1)$ = 0.6	$3 - (10 \times 0.1)$ = 2	$0.4 + (3 \times 0.1)$ = 0.7	$4 \times 0.2 - (5 \times 0.2^2)$ = 0.6
0.3	$0.6 + (3 \times 0.1)$ = 0.9	$2 - (10 \times 0.1)$ = 1	$0.7 + (2 \times 0.1)$ = 0.9	$4 \times 0.3 - (5 \times 0.3^2)$ = 0.75
0.4	= 1.2	= 0		
0.5	= 1.5	= -1		
0.6	= 1.8	= -2	= 0.9	= 0.6
0.7	= 2.1	= -3	= 0.7	= 0.35
0.8	= 2.4	= -4	= 0.4	= 0

Air resistance effects have been ignored in these models.

(i) State how you recognize this for the v_y column.

-----[1]

(ii) State why there is a systematic difference between the y displacements in the iterative and analytical models.

-----[1]

(iii) State how the size of this systematic error can be controlled.

-----[1]

(iv) State why there is no systematic error in the x displacement column.

[1]

(b) Complete the table by writing in the missing numerical values.

[2]

(c) Fig. 37.1 shows parts of the (x, y) trajectory predicted by the models.

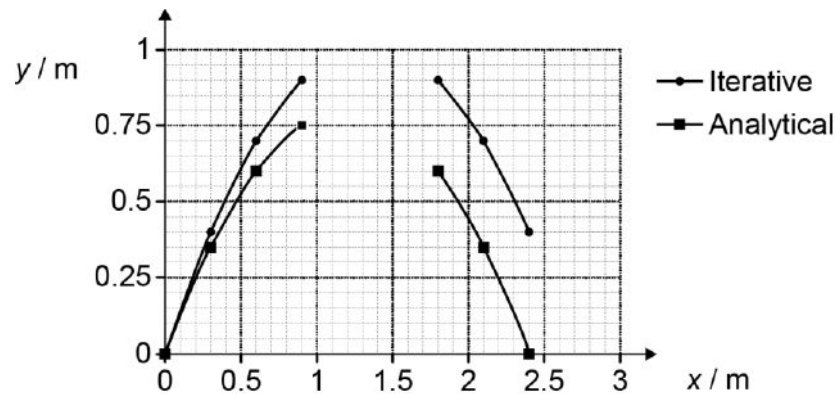


Fig. 37.1

(i) Add the missing data points you calculated in (b) to Fig. 37.1 and complete the two graphs.

[2]

(ii) State **one** similarity and **one** difference in the predictions of the two models.

similarity:

difference:

[2]

(d) Explain why scientists use approximate iterative models when analytical ones seem to give a better solution.

.....

[2]

25(a) This question considers how ideas about light have developed over time.

Huygens thought that each point on a light wavefront emitted secondary wavelets. Fig. 38.1 shows five secondary wavelets emitted from the original wavefront OO' . These wavelets add together a short time later to find the new position of the wavefront AA' .

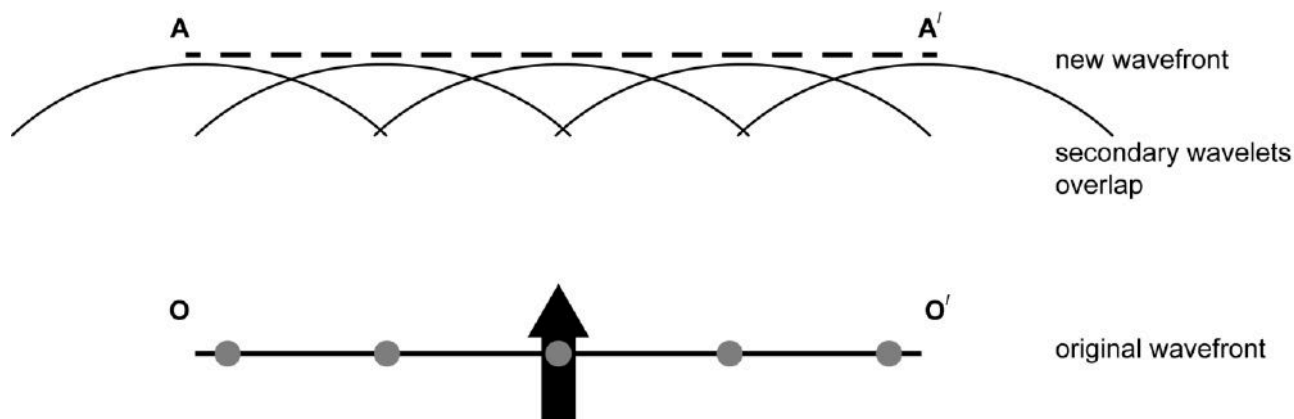


Fig. 38.1

- (i) State and explain the principle of wave behaviour that is equivalent to *adding secondary wavelets*.

----- [2]

- (ii) State a phenomenon that supports Huygen's idea of secondary wavelets.

----- [1]

- (iii) Huygens knew that light does not have infinite speed and requires time to travel.

Suggest the feature of Fig. 38.1 that supports this.

[1]

- (b) Huygens did not have access to diffraction gratings, but his ideas can help us to understand how they work. Fig. 38.2 shows a plane wave passing through part of a grating consisting of five slits.

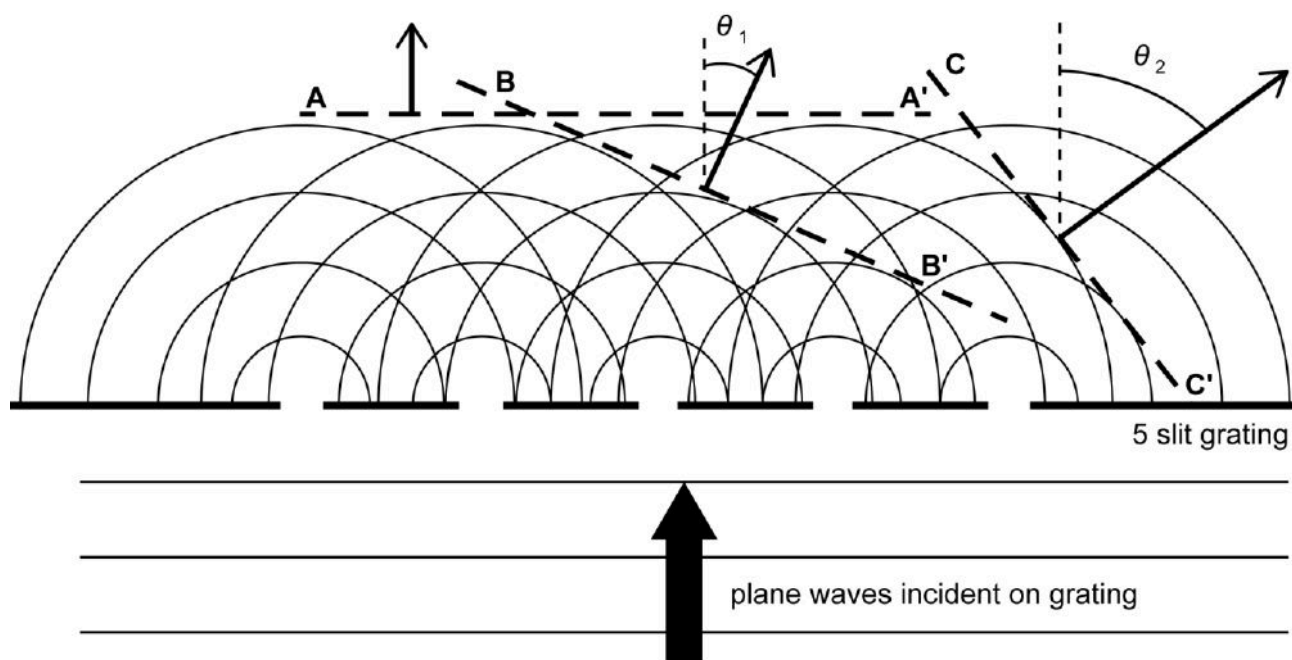


Fig. 38.2

The construction lines AA', BB' and CC', drawn on Fig. 38.2, represent some of the plane wavefronts that travel away from the grating at angles θ to the incident direction.

- (i) Suggest how Huygens might explain that the amplitude of the resultant waves along the wavefront BB' is particularly large.

[1]

- (ii) * For the grating shown in the diagram: $\frac{\text{wavelength, } \lambda}{\text{grating spacing, } d} = 0.40$ $\theta_1 = 24^\circ$ $\theta_2 = 53^\circ$.

Explain the values of these angles and how the diffraction grating works using modern wave and photon phasor models.

[6]

26(a) A student investigates how the resistance of an LDR varies with light intensity using a lux-meter and an ohm-meter capable of $\pm 1\%$ uncertainty. The teacher also advises her to calculate the conductance G of the LDR, and to plot the graphs shown below. Fig. 39.1, Fig. 39.2 and Fig. 39.3 show her incomplete practical results.

Light Intensity / lux	R_{LDR} / Ω	G / mS
15	13000	0.08
70	3450	0.29
150	1640	0.61
260	1070	0.93
500	530	
1000	270	
1500	186	
2000	150	

Fig. 39.1

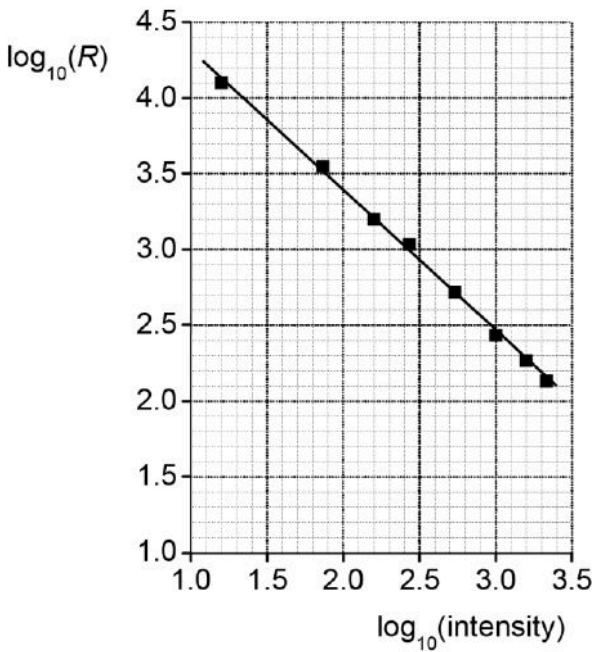


Fig. 39.2

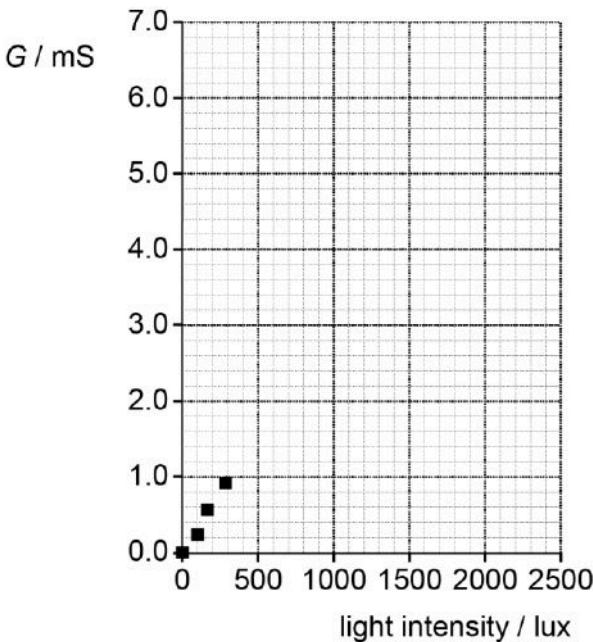


Fig. 39.3

- (i) Complete her table Fig. 39.1 for conductance G in mS.
 Plot the remaining data on her graph of Fig. 39.3 and draw a line of best fit.

[3]

- (ii) Explain why these graphs are more useful than a plot of R against light intensity, and state your conclusion about what they show.

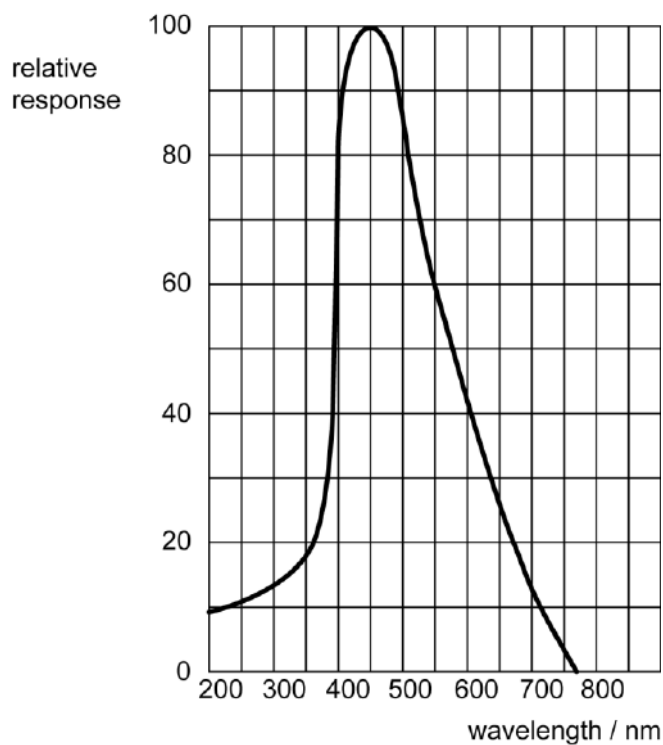
----- [3]

- (iii) The light sensitive material in the LDR is a semiconductor. It is suggested that the charge carrier density in the material is proportional to the light intensity shining on it.

Give a reason for this suggestion and evaluate it using the graphical evidence from part (i).

----- [2]

(b) The graph below shows the relative response to different wavelengths of light for the LDR.



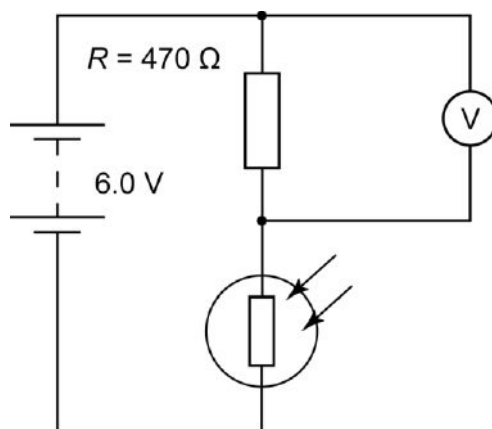
(i) State the feature of the graph that suggests a quantum process might be involved in changing charge carrier density when the LDR is illuminated.

----- [1]

(ii) Use a value from the graph to calculate the minimum energy for the quantum process.

energy = _____ J [2]

- (c) The LDR is set up in the potential divider circuit as shown with a 6.0 V supply and a fixed resistor of resistance 470 Ω .



Use data in Fig. 39.1 to calculate the p.d. measured by the voltmeter when the light intensity is 1000 lux.

p.d. = ... V [2]

27(a) Fig. 40.1 shows the gravitational potential V_g of the Earth from the surface out to 200 Mm. r is the distance measured from the centre of the Earth.

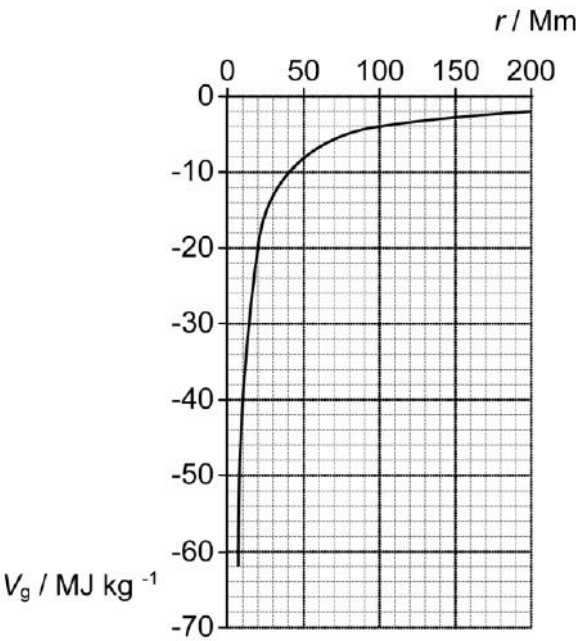


Fig. 40.1

(i) State why the potential is plotted as a negative value.

----- [1]

(ii) Calculate the launch velocity that is needed for a spacecraft to escape Earth's gravity.
Use data from the graph and make your method clear. You can ignore the effects of air drag.

velocity = ----- m s⁻¹ [2]

(b)

- (i) Show that the general equation for escape velocity is:

$$V_{\text{escape}} = \sqrt{\frac{2GM}{r}}$$

Make clear what the symbols M , G and r mean.

[3]

- (ii) For a spherical body of constant fixed density ρ and radius R show that the escape velocity v_{escape} can be calculated from the equation :

$$V_{\text{escape}} = \sqrt{\frac{8G\pi\rho}{3}} R$$

----- [1]

- (iii) A neutron star has a density $\rho \simeq 10^{17} \text{ kg m}^{-3}$. When $v_{\text{escape}} = c$ it will become a black hole.

Estimate the radius of the neutron star when it has an escape velocity of $c = 3 \times 10^8 \text{ m s}^{-1}$.

radius = ----- m [2]

28(a)

Radon decays by α -decay into polonium $^{218}_{84}\text{Po}$.

The α -particle in this decay always has kinetic energy of 5.5 MeV.

The table shows the precise masses of these nuclei in atomic mass units / u.

$$1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$$

nucleus	nuclear mass / u
Radon 222	221.9703
Polonium 218	217.9628
Helium (α) 4	4.0015

* Show that in this process the mass of the products is less than the mass of the original nucleus. Explain the term *binding energy* and show that the binding energy released is greater than the 5.5 MeV of the α -particle. Use ideas about forces and momenta during the α -decay to suggest why the α -particle does not take away all the energy from the decay.

[6]

(b) This part considers some algebraic reasoning to help to account for the difference between the energy of the α -particle and the binding energy released in (a).

(i)

$$m_{\alpha} v_{\alpha} = m_{\text{Po}} v_{\text{Po}} \rightarrow \frac{v_{\text{Po}}}{v_{\alpha}} = \frac{m_{\alpha}}{m_{\text{Po}}}$$

Where:

m_{α} = mass of α -particle,
 v_{α} = velocity of α -particle

m_{Po} = mass of polonium nucleus,
 v_{Po} = velocity of polonium nucleus.

State the physics principle used in this algebraic reasoning.

-----[1]

(ii) Use (i) to show that the ratio of

kinetic energy of the polonium nucleus
kinetic energy of the α -particle

is given by:

$$\frac{\frac{1}{2} m_{\text{Po}} v_{\text{Po}}^2}{\frac{1}{2} m_{\alpha} v_{\alpha}^2} = \frac{m_{\alpha}}{m_{\text{Po}}}$$

[1]

(iii) The fraction of total kinetic energy taken by α -particle = $\frac{1}{(1 + m_{\alpha} / m_{\text{Po}})}$

Use the equations above to calculate the kinetic energy of the α -particle and comment on the value.

kinetic energy of α particle = _____ MeV

 -----[3]

Fig. 1 shows a beam of light illuminating a reflection grating. A_1 , A_2 , A_3 and A_4 are four reflecting strips. Light reflected from the grating in the direction shown produces a bright image on a distant screen. The diagram also shows the wave crests of the light leaving A_1 .

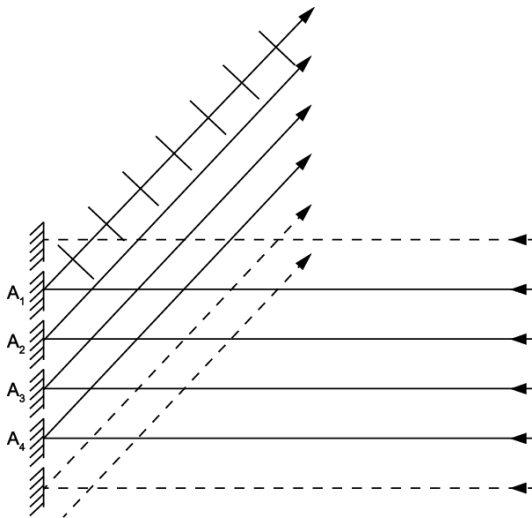


Fig. 1

- (i) On Fig. 1:
- 1 draw in the corresponding wave crests for the light leaving A_2 and A_4 , which give rise to the bright image

2 mark and label the path difference between adjacent beams
- [3]

- (ii) Explain:
- 1 why a bright image is seen on the screen at this angle

- 2 why the image is so bright.

[3]

(b)

- (i) Explain why spectra are seen when a CD is viewed in white light.

----- [2]

- (ii) The spacing of the reflecting strips on a CD is $1.6\text{ }\mu\text{m}$. Calculate the angle at which a bright image will be seen for light of wavelength 580 nm .

[2]

30(a) This question is about using airbags and seat belts to improve driver and passenger safety.

In a test laboratory, a car travelling at 11.0 m s^{-1} strikes a wall head-on and comes to rest in 0.12 s .

A crash test dummy of mass 72 kg is belted into the driver's seat of the car.

Calculate the change of momentum of the dummy in the crash.

change of momentum = _____ kg m s^{-1}

[2]

(b) In the crash, the dummy is brought to rest by the seat belt from a speed of 11.0 m s^{-1} in a time of 0.15 s .

Show that the average force on the dummy is between seven and eight times its weight.

[2]

(c) The seat belt does not stop the head of the dummy moving forward. With no airbag, the head could strike the steering wheel. Fig. 2.1 shows how the force on the dummy's head changes over time if it strikes the steering wheel. The area between the line and the time axis gives the impulse of the force.

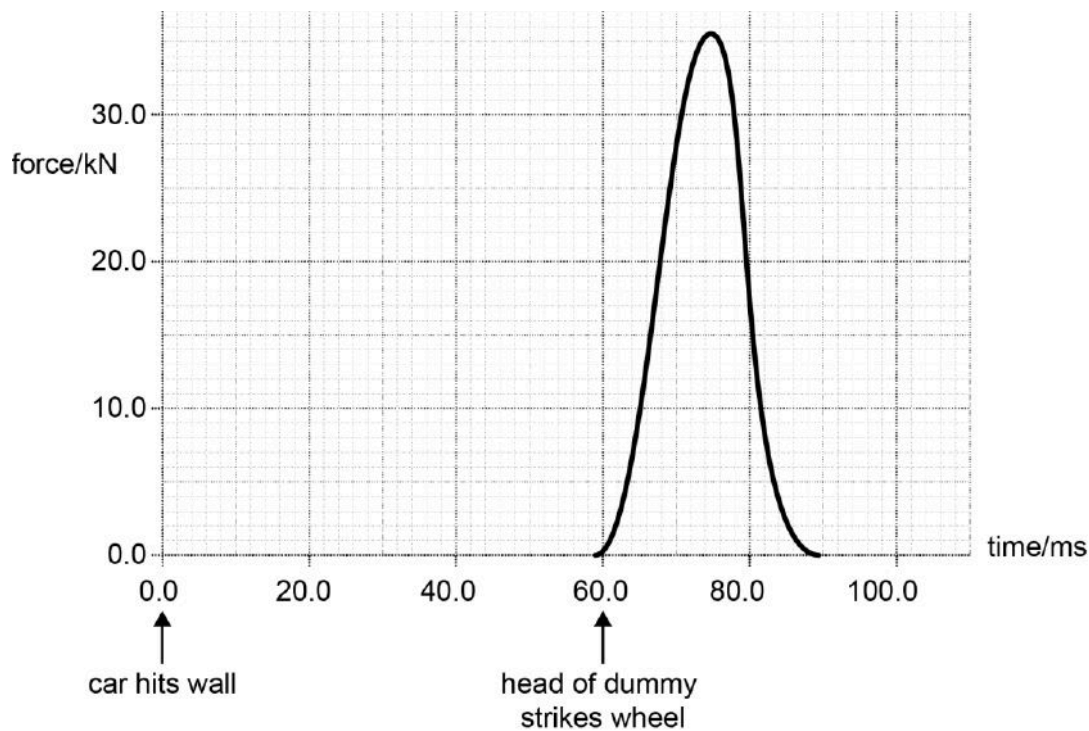


Fig. 2.1

- (i) If an airbag is installed it will begin to inflate from the steering wheel about 20 ms after the collision and takes a further 20 ms to fully inflate. Draw a second curve on the graph of Fig. 2.1 to show how the force on the head of the dummy will change over time when the airbag is present.

[2]

- (ii) State and explain how the graph is similar to the original curve and also how it differs from it.

----- [2]

- (iii) Airbags are designed to start deflating 40 ms after the collision. State and explain why this improves the protection that the airbag gives to the dummy.

----- [2]

- (i) A roughly-spherical asteroid has a radius of about 5×10^2 m and a mass of 3.0×10^{12} kg. Show that an 1100 kg spacecraft would have a weight of about 0.9 N on the surface of the asteroid.

[2]

- (ii) By equating the gravitational force on the spacecraft with the centripetal force required to keep the spacecraft on the surface of the asteroid, explain why the spacecraft cannot remain on the equator of the asteroid if the asteroid makes one revolution every 80 minutes.

[5]

- (iii) The gravitational potential energy of the spacecraft on the asteroid is about – 450 J.

Explain why this quantity is negative.

----- [2]

- (iv) Explain why the spacecraft will escape the asteroid if it is projected vertically upwards from the surface with a velocity greater than about 0.9 m s^{-1} .

----- [2]

32(a) Fig. 2.1 shows the layout of the apparatus required to observe the superposition of light from two sources.

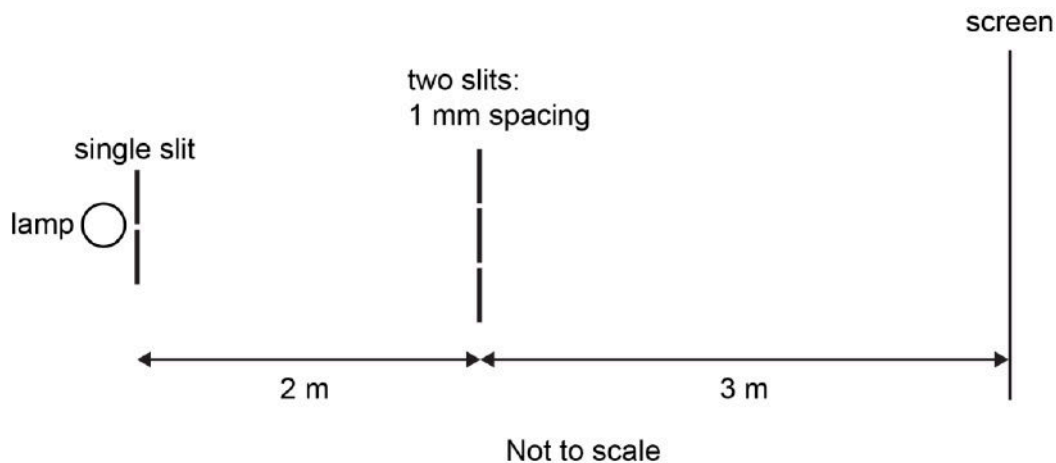


Fig. 2.1

In a laboratory experiment a vertical filament optics lamp and single slit were used as the light source placed 2 m away from a pair of slits. The slits were produced by painting a glass slide black and then scraping two lines in the paint using a pin.

(i) Suggest how the double slit spacing could be determined.

-----{1}

(ii) Explain why it is necessary to have a small slit spacing.

-----{2}

- (b) Fig. 2.2 shows the arrangement used to create the interference pattern on the screen. The slit separation is d and the distance from the slits to the screen is L . Point **O** shows the position of the central maximum and the distance to the adjacent maximum at point **P** is x .

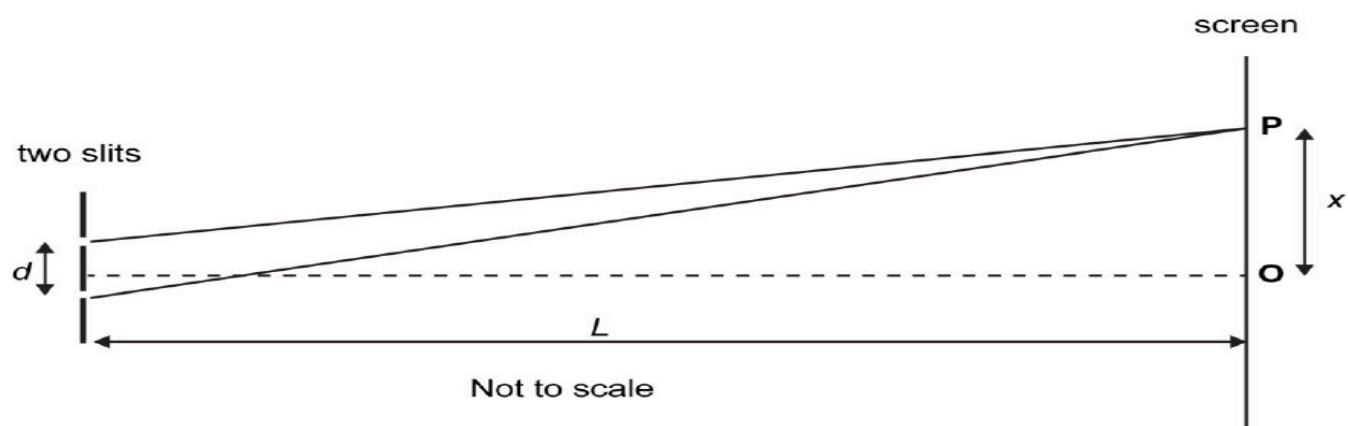


Fig. 2.2

Use the diagram to explain why

$$\lambda \approx \frac{xd}{L}.$$

[2]

- (c) Fig. 2.3 shows the pattern of light observed on the screen placed 3 m away from a pair of slits spaced 1 mm apart. The total width of the pattern shown was measured to be 1.3 cm.

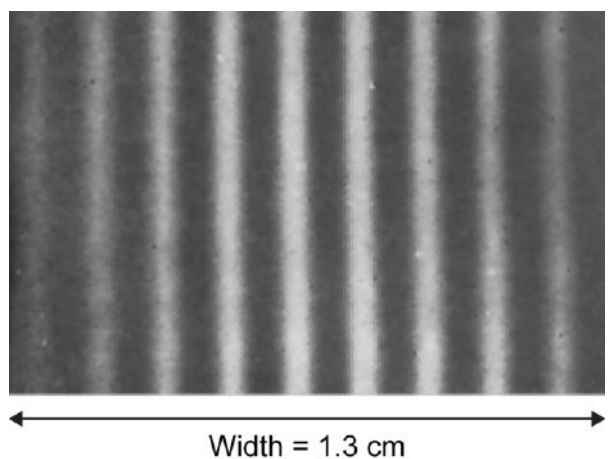


Fig. 2.3

Use data from Fig. 2.3 to estimate the wavelength, λ , of the light used in this experiment.

$\lambda =$ m [3]

(d) * Some changes were suggested to improve the experiment:

Increase the distance between the slits and the screen to increase the fringe spacing.

Increase the slit width to increase the intensity of light reaching the screen.

Reduce the distance between the light source and the slits to increase the intensity of the fringes.

Use coloured filters to enable the wavelengths of specific colours to be measured.

Comment on each of the proposals, pointing out any difficulties that may result from the changes mentioned.

[6]

- [6]

33(a) Fig. 4.1 shows the situation before and after the collision of two spacecraft in empty space.

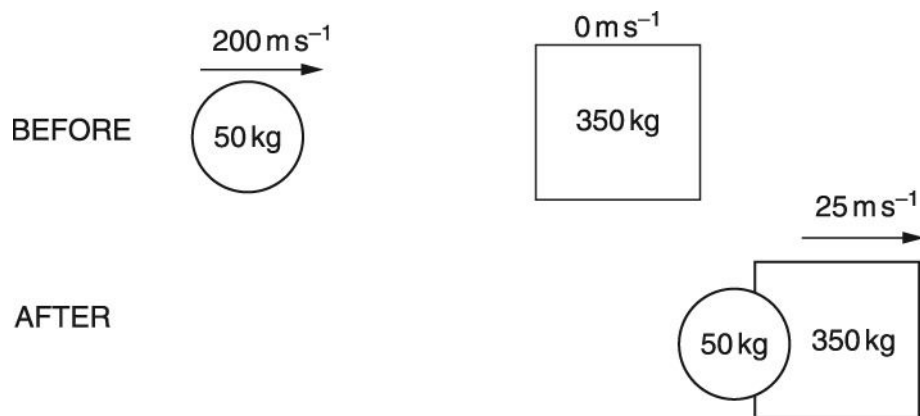


Fig. 4.1

Use calculations to show that the collision conserves momentum but does **not** conserve kinetic energy.

[3]

(b) Suggest why the collision does not conserve kinetic energy.

[1]

34(a) A student calculates the motion of a mass of 0.25 kg suspended by a spring of force constant 50 N m⁻¹. The mass is displaced vertically from equilibrium by 0.030 m at time $t = 0$ and released.

The student uses $\Delta v = -\frac{k}{m} x \Delta t$ followed by $\Delta x = v \Delta t$ to estimate the displacement of the mass at time $t = 0.10$ s.

Complete the table.

t/s	v/ms^{-1}	x/m	$\Delta t/\text{s}$	$\Delta v/\text{ms}^{-1}$
0.00	0.00	0.030	0.05	
0.05		0.015	0.05	-0.15
0.10	-0.45			

[3]

(b) The student uses the relationship $x = A \cos(2\pi ft)$ to calculate the displacement of the mass at $t = 0.10$ s as + 0.0047 m.

Why is this value different from that obtained from the method of (a)?

[1]

35(a) Here is a list of units.

J J C⁻¹ J s⁻¹ J m⁻¹ J kg⁻¹

Which unit from the list is a correct unit for:

force

----- [1]

(b) **absorbed** radiation dose

----- [1]

(c) potential in an electric field?

----- [1]

36 The kinetic energy E of a particle of mass m with momentum p is given by

$$E = \frac{p^2}{2m}.$$

Calculate the de Broglie wavelength of a proton of kinetic energy 2.8×10^{-15} J.

mass of proton = 1.7×10^{-27} kg

$h = 6.6 \times 10^{-34}$ J s

wavelength = _____ m [3]

37(a) This question is about a test of Special Relativity. In 1962 William Bertozzi designed an experiment which measured the velocity of electrons with a range of kinetic energies. He wanted to test Einstein's prediction that particles could not travel faster than the speed of light.

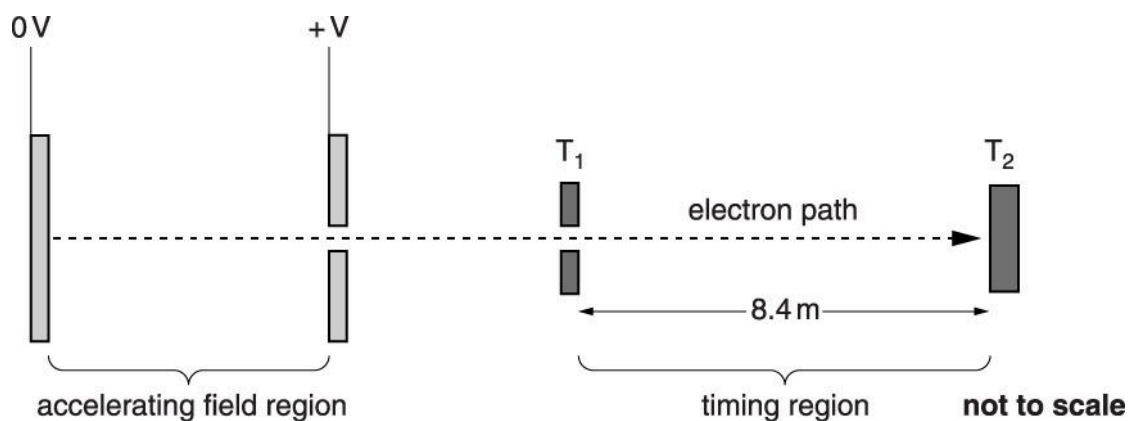


Fig. 12.1

Simplified experimental design of Bertozzi's experiment.

Electrons are accelerated in a region of uniform electric field. The time taken to travel the 8.4 m between timing sensors T₁ and T₂ is recorded. The experiment is carried out in a vacuum.

In the experiment, the 8.0×10^{-14} J electrons took 3.2×10^{-8} s to travel across the timing region. Show that the measured velocity of the electrons was 2.6×10^8 m s⁻¹.

[1]

(b)

- (i) Show that the kinetic energy $8.0 \times 10^{-14} \text{ J}$ is comparable to the rest energy of an electron. Hence calculate the relativistic factor γ .

speed of light = $3.0 \times 10^8 \text{ m s}^{-1}$

relativistic factor $\gamma =$ _____ [2]

- (ii) Use your value for the relativistic factor γ to calculate a value for the velocity of the electron when relativistic effects are considered.

velocity of electron = _____ m s^{-1} [2]

- (iii) Comment on your answer to d(ii).

[1]

38(a) Here is a list of units.

$\text{kg m}^{-1} \text{s}^{-2}$

kg m s^{-1}

$\text{kg m}^2 \text{s}^{-1}$

$\text{kg m}^2 \text{s}^{-2}$

Which **one** is a correct unit for momentum?

_____ [1]

- (b) Which **one** is a correct unit for pressure?

_____ [1]

- 39 A student does an experiment to verify that momentum is conserved when a pair of trolleys on a track collide head-on.

Fig. 5.1 shows the trolleys on a level track approaching each other.



Fig. 5.1

Fig. 5.2 shows the situation **after** the trolleys collide.



Fig. 5.2

Show that momentum is conserved in the collision.

[2]

40 This question is base on the insert.

In a typical scanning electron microscope, the electrons are accelerated from rest through a potential difference of 40 kV.

Some of the electrons' energy is carried away as x-rays (line 56). The maximum energy of an emitted x-ray photon is equal to that of the incident electron.

Calculate the minimum wavelength of the emitted x-rays.

electron energy $E = 6.0 \times 10^{-15} \text{ J}$

Planck constant $h = 6.6 \times 10^{-34} \text{ J s}$

speed of light $c = 3.0 \times 10^8 \text{ ms}^{-1}$

wavelength = _____ m

[2]

41 Which of the following pairs consist of one scalar and one vector?

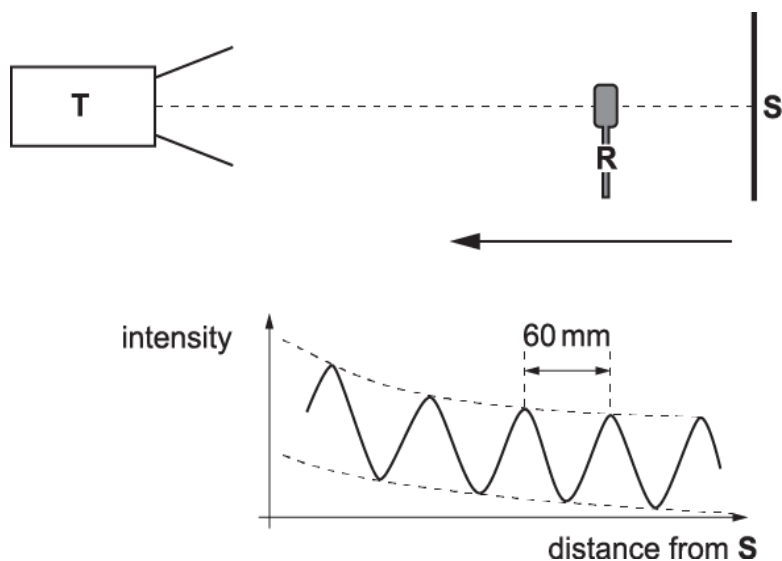
- | | | |
|---|--------------|--------------|
| A | acceleration | displacement |
| B | force | distance |
| C | temperature | energy |
| D | work | density |

Your answer

[1]

42 A microwave transmitter T is placed at a fixed distance from a flat reflecting surface S.

A receiver R is moved from S towards T. The signal received changes in intensity as indicated in the diagram.



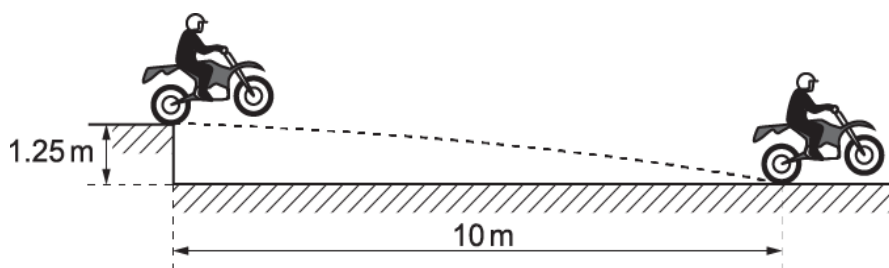
Which of the following statements is correct?

- A The receiver R is measuring the amplitude of a standing wave pattern.
- B The frequency of the microwaves is 2.5 GHz.
- C The wavelength of the microwaves is 6.0 cm.
- D The amplitudes of the transmitted and reflected waves at each position are equal.

Your answer

[1]

- 43 A motorbike launches horizontally from a point 1.25 m above ground, and lands 10 m away as shown.



What was the speed at launch?

- A 5 m s^{-1}
- B 10 m s^{-1}
- C 15 m s^{-1}
- D 20 m s^{-1}

Your answer

[1]

- 44 A motorist travelling at 10 m s^{-1} brings her car to rest in a braking distance of 10 m.

In what braking distance could she bring the car to rest from an initial speed of 40 m s^{-1} using the same braking force under the same road conditions?

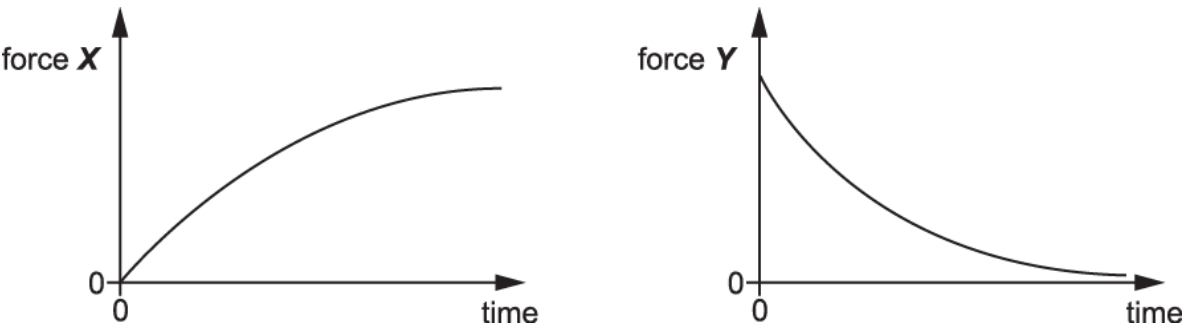
- A 20 m
- B 40 m
- C 80 m
- D 160 m

Your answer

[1]

45 A ball falls from rest through air. It reaches terminal velocity.

For this fall forces *X* and *Y* vary with time as shown.



What are the forces *X* and *Y*?

	Force <i>X</i>	Force <i>Y</i>
A	air resistance	resultant force
B	air resistance	weight
C	weight	resultant force
D	resultant force	weight

Your answer

[1]

46 A student makes measurements and calculates the speed of sound as 328.16 m s⁻¹.
The experimental uncertainty is ± 3%.

Which of the following expresses the result to an appropriate number of significant figures?

- A 300 m s⁻¹
- B 330 m s⁻¹
- C 328 m s⁻¹
- D 328.2 m s⁻¹

Your answer

[1]

47 10 kg of water at 90 °C is mixed with 30 kg of water at 30 °C in a warm bath.

Assume there is no energy transferred by heating to the surroundings.

Which of the following statements is/are correct?

- 1 Energy transferred by heating from the hotter water = energy transferred by heating to the cooler water.
- 2 The temperature drop of hotter water = 3 × temperature rise of cooler water.
- 3 The final temperature of the mixture will be 45 °C.

- A 1, 2 and 3 are correct
B only 1 and 2 are correct
C only 2 and 3 are correct
D only 1 is correct

Your answer

[1]

48(a) A glider on a friction free air track has a mass of 0.40 kg and a velocity of 0.36 m s^{-1} .
It has a collision with a stationary glider and they stick together and move forward.
After collision the combined gliders have a velocity of 0.16 m s^{-1} .

Calculate the mass of the stationary glider.

mass = _____ kg [2]

(b) Show that the magnitude of the impulse on one glider during the collision is less than 0.1 N s.

[2]

49(a) This question is about a simplified model of the refraction of light by the Earth's atmosphere.

The model assumes that the Earth's atmosphere is of uniform density and there is a sudden change of medium between the edge of the atmosphere and the vacuum of space. Fig. 34.1 shows this situation.

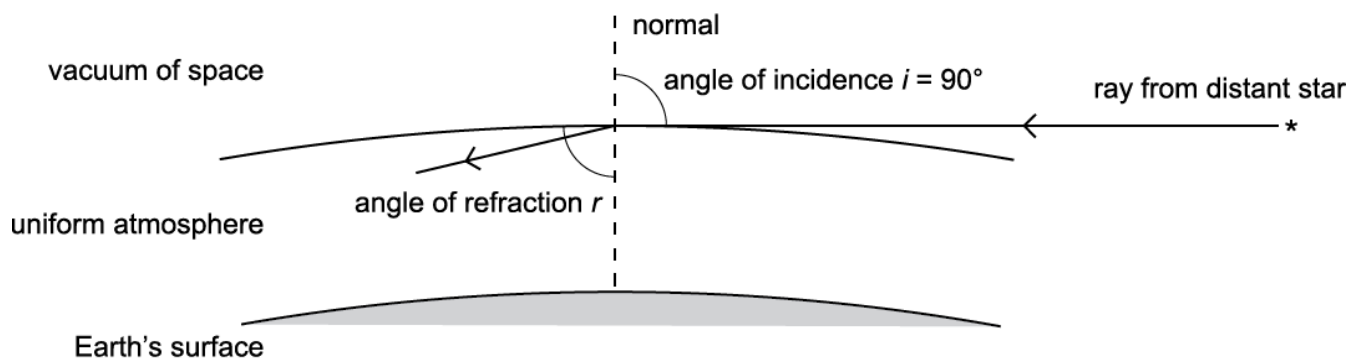


Fig. 34.1

A ray of light from a star arrives at the atmosphere at an angle of incidence i of 90° .
The refractive index n of the atmosphere is 1.00029.

Calculate the angle of refraction r inside the Earth's atmosphere.

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

- (b) Suggest and explain an effect that this refraction might have on the image of the setting Sun.

----- [2]

- (c) The refractive index of the Earth's atmosphere decreases exponentially with height. Suggest and explain an effect this would have on the path of the refracted ray in the atmosphere.

----- [2]

50(a) Fig. 37.1 shows a toy rocket of mass 0.030 kg about to be launched vertically from a compressed spring that obeys Hooke's Law.

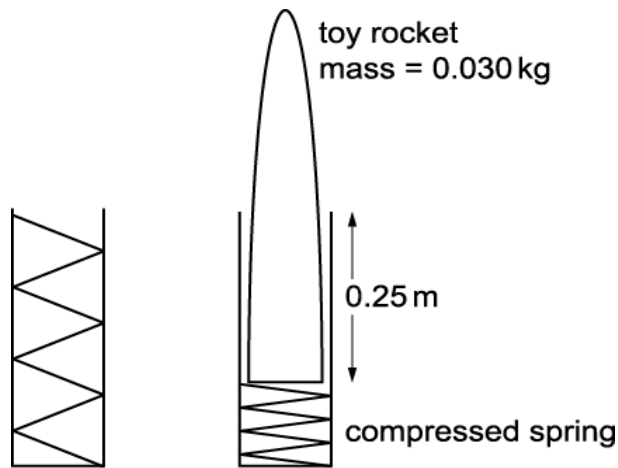


Fig. 37.1

The spring is compressed by 0.25 m by a force of 18 N.

Calculate the maximum height that the toy rocket could reach.
State any assumptions you make.

maximum height = _____ m [3]

- (b) In reality the toy rocket would not reach as high as you calculated in (a).
Suggest and explain one possible reason for this shortfall.

_____ [2]

- (c) The spring vertically launches a ball bearing of mass equal to the rocket.
Suggest and explain how the height reached by the ball bearing might be different to the rocket.

_____ [2]

51(a) This question is about an LED that produces orange light.

Light from the LED passes through a diffraction grating of 300 lines per mm.

The pattern of coloured dots produced on a screen beyond the grating is shown in Fig. 2.1. The variation in intensity of the light at the screen is shown in Fig. 2.2.

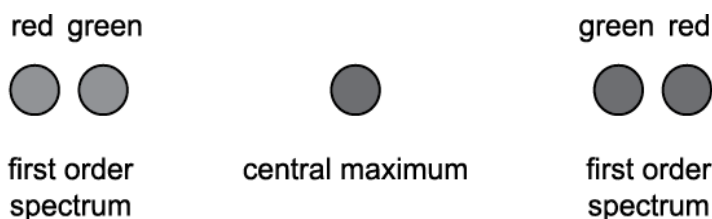


Fig. 2.1

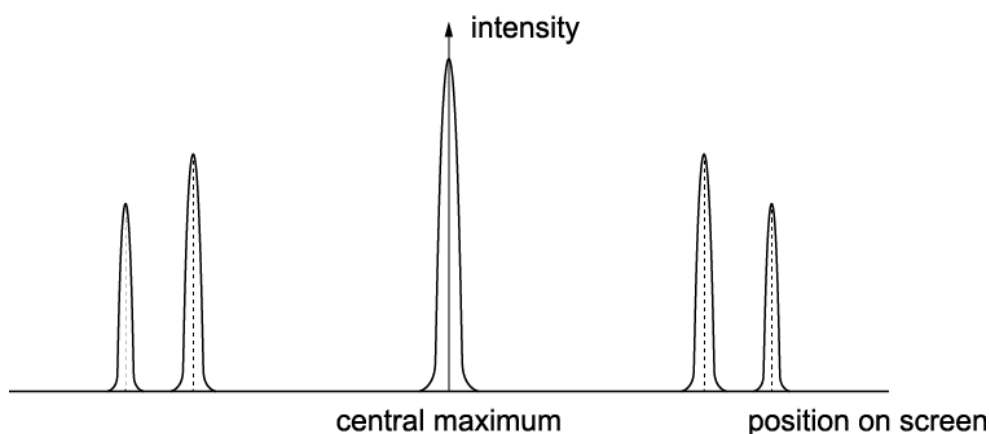


Fig. 2.2

- (i) State why the pattern shows that the orange light produced by the LED consists of only two colours.

----- [1]

- (ii) Suggest why the intensity of the central maximum is greater than the intensity of either the green or red dots in the first order spectrum.

----- [1]

(b)

- (i) Photons of red light are emitted with an energy of 1.9 eV. Calculate the angle to the first order maximum for red light.

angle = _____ ° [3]

- (ii) Use your answer to (i) and take measurements from Fig. 2.2 to calculate an estimate for the wavelength of the green light emitted from the LED.

wavelength = _____ m [2]

- (c) Explain why the diffraction grating produces more orders of maxima for green light than for red light.

----- [3]

52(a) This question is about the kinetic model of gas behaviour.

Consider a single particle of mass m moving directly towards the shaded face of the cube as shown in Fig. 4.1. The particle makes elastic collisions with the walls of the cube.

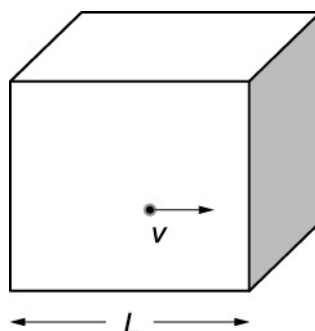


Fig. 4.1

Use the relationship $F = \frac{\Delta mv}{\Delta t}$ to show that the mean force F from repeated collisions of the particle with the shaded face is given by $F = \frac{mv^2}{L}$.

- (b) Explain why, if the cube contains N particles each of mass m moving in random directions, the pressure on any face is given by $p = \frac{1}{3} \frac{Nm \overline{c^2}}{V}$ where V is the volume of the cube and $\overline{c^2}$ is the mean square speed of the particles. [3]

[3]

(e) The root mean square speed of a gas molecule can be found using the equation

$$\text{root mean square speed} = 1.2 \times \text{most probable speed}$$

The most probable speed in Fig. 4.1 is 400 m s^{-1} .

The mass of a molecule of the gas is $4.7 \times 10^{-26} \text{ kg}$. Calculate the temperature of the gas.

temperature = _____ K [4]

53(a) Fig. 5.1 shows an experimental set-up which can be used to determine g .

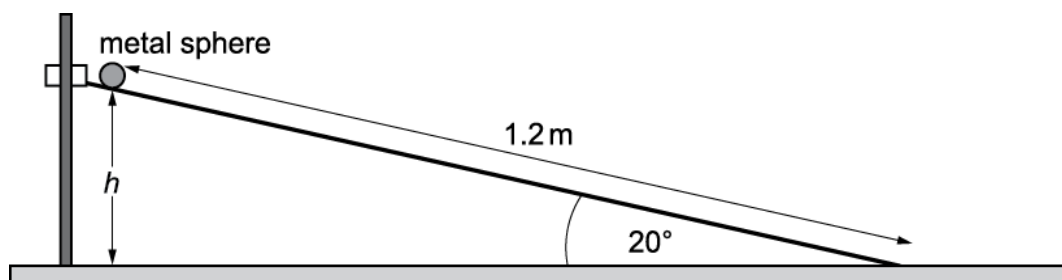


Fig. 5.1

*The metal ball was filmed as it was released and travelled down the slope. The time for the ball to travel down the slope was found using stop-frame analysis.

The time was recorded as $1.10\text{ s} \pm 0.05\text{ s}$.

Calculate the acceleration of the ball. Use the data given in the diagram to help explain why a student expected the journey time to be 0.85 s and suggest why the measured time was considerably longer.

[6]

- (b) Fig. 5.2 shows a slope of the same length and starting height h . The initial gradient of the slope is greater than in the first case.

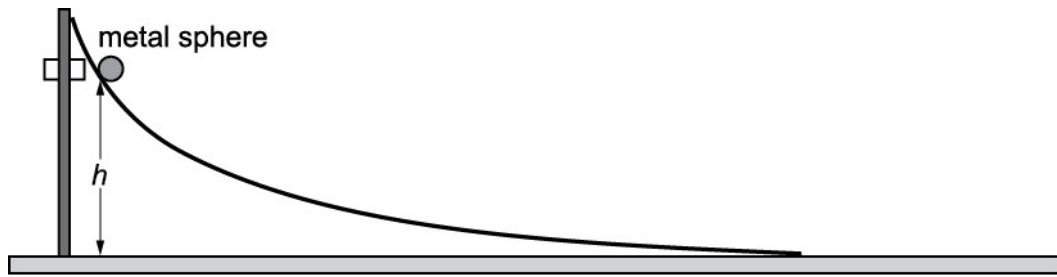


Fig. 5.2

A student says that she expects the ball to reach the end of the slope in less time **and** with greater final speed. Do you agree? Explain your reasoning and state any assumptions you have made.

[5]

54 The orbit of Mars is not circular. Its distance from the Sun varies between 2.1×10^{11} m at its closest and 2.5×10^{11} m at its most distant.

- (i) Show that the gravitational potential energy of the planet changes by about 7×10^{31} J between its furthest distance from the Sun and its nearest.

mass of Mars = 6.4×10^{23} kg

mass of Sun = 2.0×10^{30} kg

[3]

- (ii) At its furthest point from the Sun, Mars travels at a speed of 2.7×10^4 m s⁻¹.

Use your answer to (i) to calculate its speed at its closest approach to the Sun. Make your method clear.

speed at closest approach = _____ m s⁻¹ [3]

55(a) This question is about cobalt-60 used in radiotherapy (lines 11–14).

Show that 1 g of cobalt-60 will produce an activity of roughly 4×10^{13} Bq.

Molar mass of cobalt-60 = 60 g mol^{-1}

1 year = $3.2 \times 10^7 \text{ s}$

[3]

(b) Use calculations to estimate the power output of 1.0 g of cobalt-60. State any assumptions you make.

power output = _____ W [2]

56(a) This question is about a photomultiplier tube as shown in Fig. 2 in the article.

Photons of visible light of wavelength $4.2 \times 10^{-7} \text{ m}$ are emitted from the sodium iodide crystal.

Use the equation below to calculate the maximum possible work function ϕ of the surface of the photocathode for photoelectrons to be emitted.

$$\text{maximum k.e. of emitted photoelectron} = hf - \phi$$

work function = _____ J [2]

(b)

- (i) A photoelectron is released from rest at a the photocathode. Calculate its velocity just before it strikes the +100 V dynode, assuming non-relativistic behaviour.

$$\text{mass of electron} = 9.1 \times 10^{-31} \text{ kg}$$

velocity = _____ m s^{-1} [2]

- (ii) The rest energy of an electron is 0.51 MeV. Explain whether it is reasonable to ignore relativistic effects when an electron is accelerated through 100 V. You may include calculations in your explanation.

[2]

57 This question is about investigating the terminal velocity of paper cupcake cases.

A paper cupcake case is dropped from a height of 2.0 m and the time taken t to fall to the ground is recorded using a stopwatch.

Fig. 2.1 shows a dot-plot recording the values obtained for t .

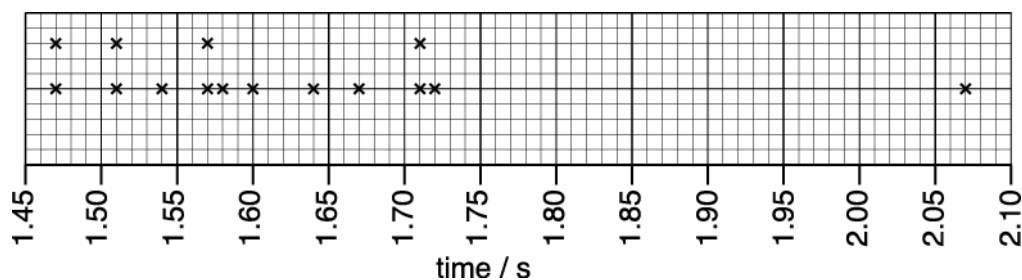


Fig. 2.1

Fig. 2.2 shows a sketch graph of velocity against time for the cupcake case.

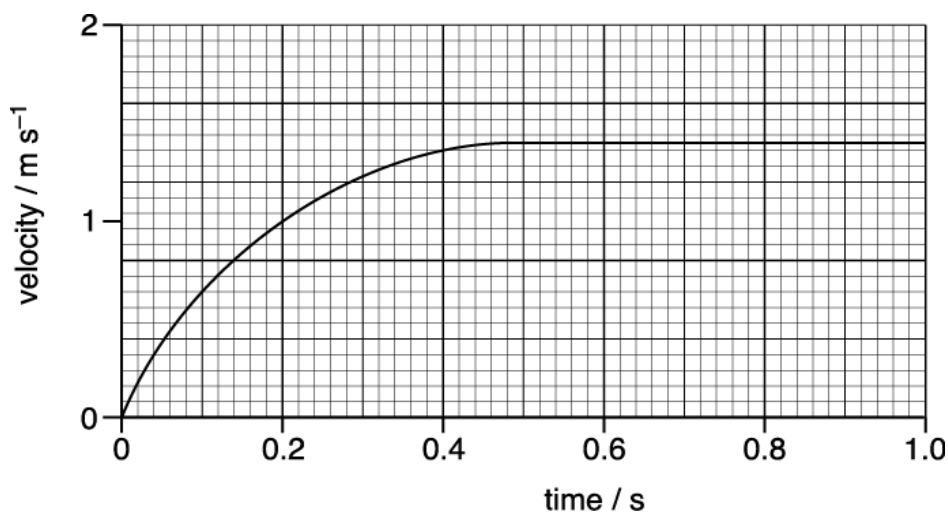


Fig. 2.2

(i) Explain the shape of the graph. Refer to the forces acting on the cupcake case in your answer.

41

- [2]

- STEMUP.CO.UK

[6]

Fig. 3.1 shows the circuit which is used in a school laboratory.

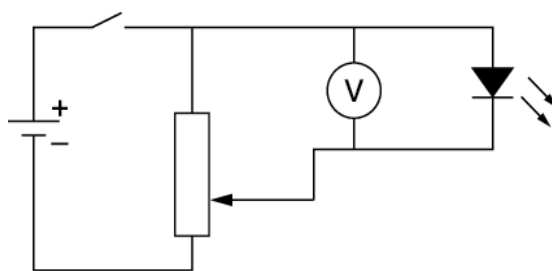


Fig. 3.1

The voltage across each LED is increased until the light emitted from the LED is just visible. This voltage V_t is recorded. V_t is found for seven LEDs emitting light of different wavelengths.

Fig. 3.2 shows a graph of V_t against $1/\lambda$ with uncertainty bars. The line of best fit has been drawn through the points. The gradient of the line is 2.0×10^{-6} .

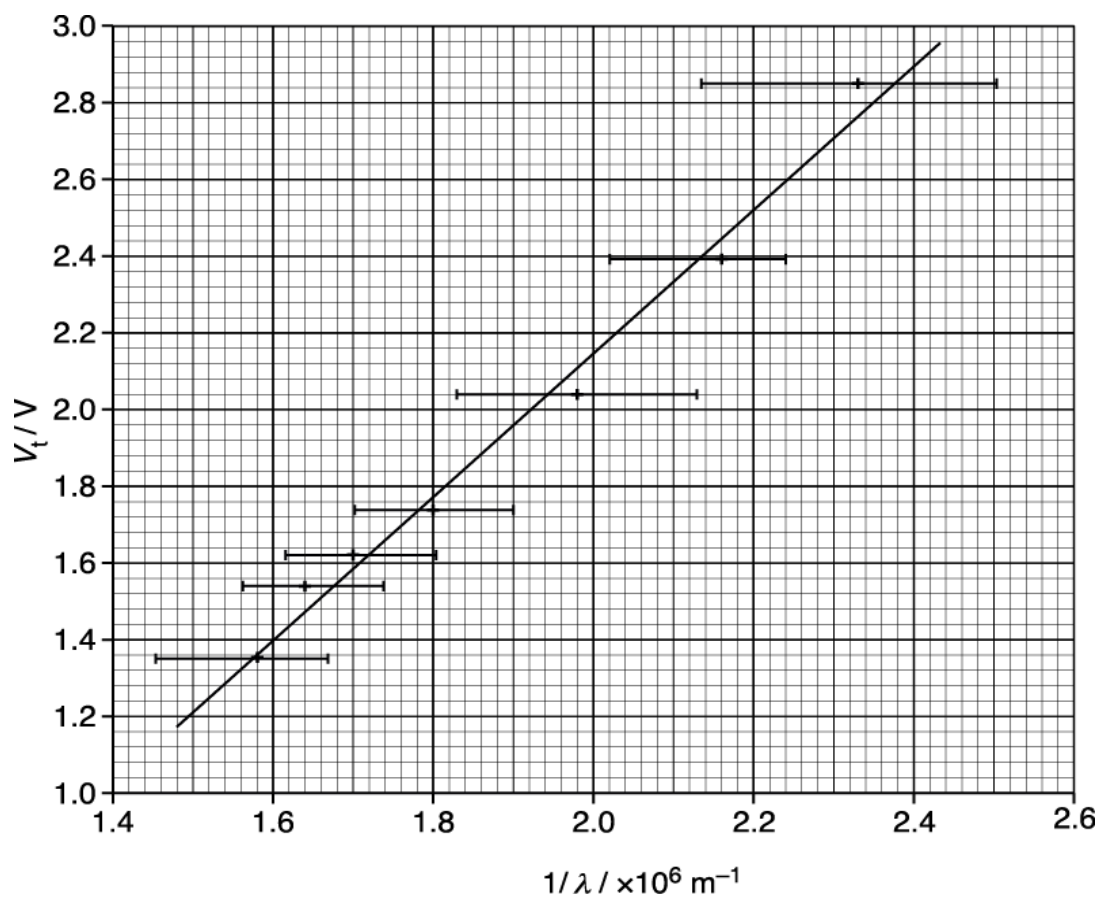


Fig. 3.2

- (i) Using the energy-frequency relationship for photons show that the gradient of the line represents

$$\frac{hc}{q}$$

where h is the Planck constant, c is the speed of light in a vacuum and q is the charge on the electron.

[2]

- (ii) Hence show that h is found to be about 1.1×10^{-33} J s.

[1]

- (iii) A *worst-fit* straight line is one which represents the steepest or least steep possible straight line to pass through all the uncertainty bars. Draw a worst-fit straight line on the graph and calculate a second value for the Planck constant.

[3]

- (iv) *Compare the calculated values for h with the accepted value (6.6×10^{-34} J s) and comment on the accuracy of the experiment. Describe the sources of uncertainty in the experiment and suggest improvements.

[6]

59(a) This question is about the force on a sail of a land yacht, a small vehicle that is powered by the wind.



Fig. 3.1

Explain how air particles exert a pressure on a sail and why, when no wind is blowing, the sail experiences the same pressure on both sides.

[3]

- (b) A constant force of 300 N strikes the sail of a land yacht at an angle of 50° to the direction of motion of the vehicle as shown in Fig. 3.2. The mass of the yacht and rider is 135 kg.

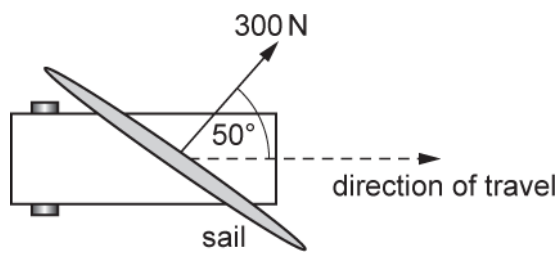


Fig. 3.2

Calculate the time for the land yacht to travel 50 m in the direction shown. The yacht starts from rest. Ignore resistive forces.

time = ----- s [4]

60(a) (See Insert for H557/02, Scientific literacy in physics (AS/A level), June 2017) This question is about an experiment to estimate the resolution of the human eye.

Two vertical, parallel black lines are drawn on a piece of card. The separation between the lines is 2.0 ± 0.5 mm. The card is fixed to a wall at head height.

A group of students look at the card whilst each covering one eye. They walk back from the card until they can no longer separate the two lines. The distance L between the eye and the card is measured.

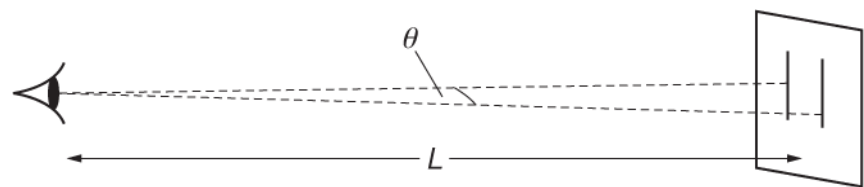


Fig. 9.1

Here are the results from five students:

student	A	B	C	D	E
maximum distance L /m	6.2	5.8	6.1	5.9	6.1

(i) State the spread of the distance values.

spread = $\pm$ m [1]

(ii) A student suggests that the uncertainty in the distance values can be ignored when calculating the minimum angle that can be resolved because of the uncertainty in the separation of the lines on the card. Comment on this suggestion, explaining whether or not you agree.

[2]

- (iii) Calculate a value for the minimum angle that can be resolved. Include an estimate of the uncertainty in your value. Explain how you estimated the uncertainty.

minimum angle that can be resolved = ... $\pm$ rad [3]

- (b) An approximate value for the minimum resolvable angle $\theta_{\min}$ can be obtained from the equation

$$\theta_{\min} = \frac{\text{wavelength of light}}{\text{diameter of pupil of the eye}}.$$

The students estimated the diameter of the pupil to be 3 mm and the wavelength of light to be 5×10^{-7} m. Use the data to estimate the minimum resolvable angle and compare your answer with the value obtained in (a)(iii).

minimum angle that can be resolved = ... rad [2]

- 61 (See Insert for H557/02, Scientific literacy in physics (AS/A level), June 2017) Explain why turbulence in the atmosphere limits the resolution of ground-based optical telescopes (lines 7–39).

[2]

- 62 Which pair contains one vector and one scalar quantity?

- | | | |
|---|----------------|--------------|
| A | Velocity | acceleration |
| B | displacement | force |
| C | kinetic energy | work done |
| D | Momentum | distance |

Your answer

[1]

- 63 Electrons accelerated through a potential difference V pass through a thin layer of graphite. The beam forms a diffraction pattern of rings on a fluorescent screen.

When V is made larger the diameter of the rings get smaller and they also become brighter.

Which **one** of the following statements about this experiment is correct?

- A The power delivered to the fluorescent screen decreases as V increases.
- B The diameter of the diffraction rings is independent of the interatomic spacings in graphite.
- C The wavelength of the electrons decreases as their kinetic energy increases.
- D The momentum of the electrons decreases as V increases.

Your answer

[1]

64 Which **one** of the following statements about photons is correct?

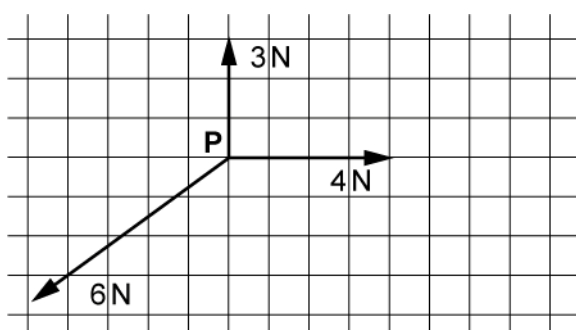
The probability of arrival of a photon at a position

- A is proportional to the amplitude of the waves arriving at that position.
- B is greater if the phasor amplitudes for paths from the source to that position “curl up” when they are added.
- C is proportional to the (resultant phasor amplitude)² for all photon paths from the source to that position.
- D is proportional to the phasor amplitude for the photon path straight from the source to that position.

Your answer

[1]

65 The three forces in this vector diagram act in one plane on an object **P**.



What is the magnitude and direction of the resultant?

- A 1 N ↙
- B 1 N ↗
- C 1 N ←
- D 11 N ↙

Your answer

[1]

66 A car travelling at 10 m s^{-1} is brought to rest in a braking distance of 10 m.

Using the same average braking force, in what distance can the car be brought to rest from a speed of 40 m s^{-1} ?

- A 20 m
- B 40 m
- C 80 m
- D 160 m

Your answer

[1]

67 The drag force F of the air on a train is

$$F \approx 10v^2$$

where F is in newtons and the speed v is in m s^{-1} .

What **power** must be delivered by the engine to keep the train travelling at a constant 50 m s^{-1} ?

- A 25 kW
- B 125 kW
- C 1.25 MW
- D 2.5 MW

Your answer

[1]

68 Which of the following statements about the α -particle and the β -particle is correct?

- A If both have the same kinetic energy, the speed of the β -particle is less than that of the α -particle.
- B If both have the same momentum, the de Broglie wavelength of the α -particle must be the same as that of the β -particle.
- C If both have the same momentum, the kinetic energy of the α -particle is greater than that of the β -particle.
- D The rest energies of both the α -particle and the β -particle are the same.

Your answer

[1]

69(a) This question is about refractive index.

For light passing from a vacuum into a medium, the refractive index is

$$n_{\text{medium}} = \frac{c}{c_{\text{medium}}}$$

Complete this line of algebraic reasoning.

$$n_{\text{glass}} = \frac{c}{c_{\text{glass}}}, \quad n_{\text{water}} = \frac{c}{c_{\text{water}}} \rightarrow \frac{n_{\text{glass}}}{n_{\text{water}}} = \frac{\quad}{\quad} = \frac{c_{\text{water}}}{c_{\text{glass}}}$$

[1]

(b) Fig. 32.1 shows a ray of light going from glass into water at an angle of incidence $i = 30^\circ$.

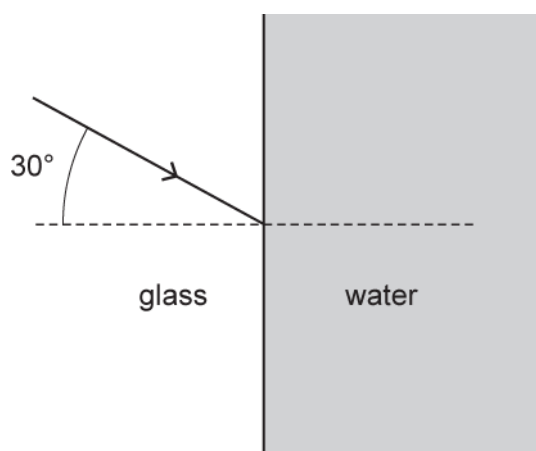


Fig. 32.1

Calculate the angle of refraction r in the water.

$$n_{\text{glass}} = 1.6$$

$$n_{\text{water}} = 1.3$$

$$r = \dots\dots\dots^\circ \quad [2]$$

70 Fig. 38.1 shows a displacement s against time t graph for the motion of a swing in simple harmonic motion.

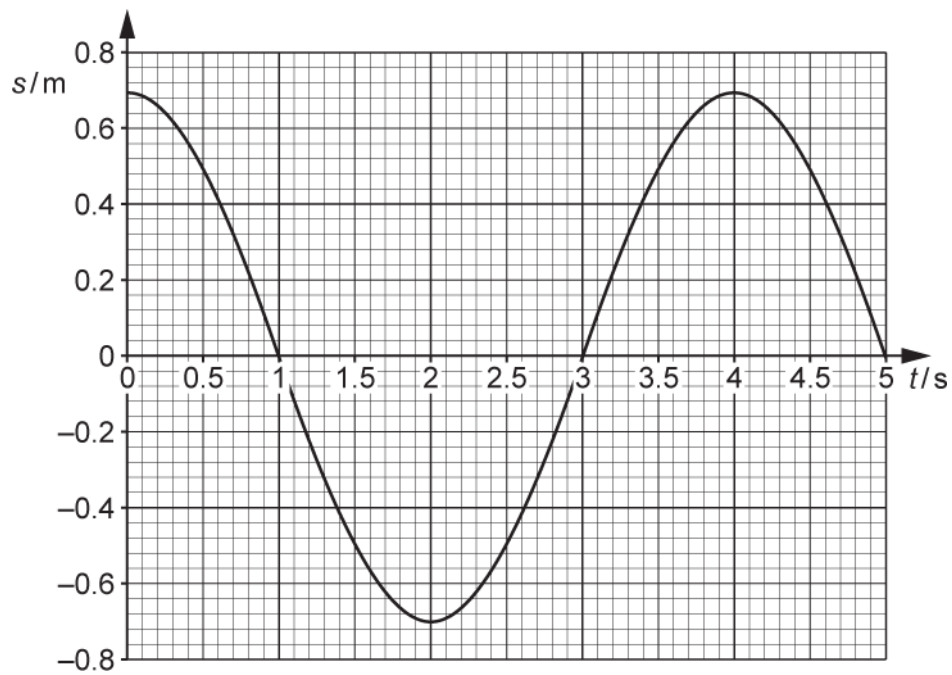


Fig. 38.1

Use Fig. 38.1 to find the magnitude of the maximum velocity of the swing. Make your method clear.

velocity = _____ m s⁻¹ [2]



Fig. 41.3 shows the electrical potential V and the magnitude of the electric field E against distance R for an isolated -1 C charge.

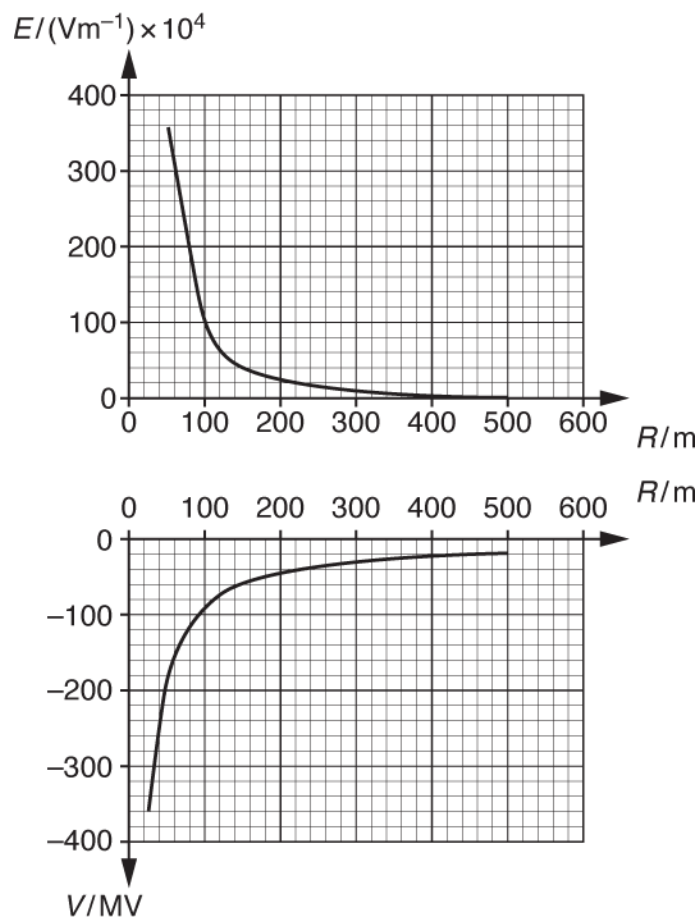


Fig. 41.3

By considering a unit positive charge being moved from $R = 100\text{ m}$ to 300 m explain the relationship between the electric field and the electric potential.

You may annotate the graphs in Fig. 41.3 if it is helpful.

[6]

72(a) This question is about notes produced by a flute.

A flute is an instrument that produces standing waves with displacement antinodes (A) at both ends. The nodes (N) and antinodes for the lowest note possible for a flute of length L are shown in Fig. 1.1.

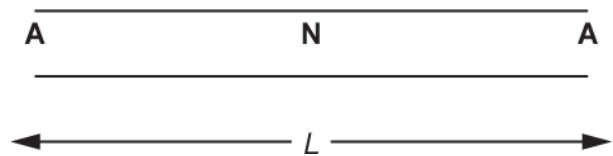


Fig. 1.1

Explain how standing waves are formed in air.

[3]

- (b) Mark the antinodes and nodes on Fig. 1.2 for a note of **twice** the frequency of the note indicated in Fig. 1.1.
Explain your answer.

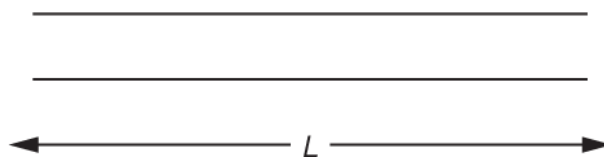


Fig. 1.2

[2]

- (c) The velocity of sound in air v is given by the equation $v = \sqrt{\frac{kp}{\rho}}$ where p is the pressure of the gas, ρ is the density of the gas and k is a constant.

Use the expression $pV = nRT$ and the expression for density, $\rho = \frac{m}{V}$, to show that $v = \sqrt{\frac{kRT}{M}}$ where $M = \frac{m}{n}$ is the mass of one mole of air.

[2]

- (d) A flute of length L sounds a note of 262 Hz at a temperature of 293 K. Calculate the frequency of the note from the same length flute when the temperature of the air in the flute has increased to 303 K. The change in length of the flute caused by this temperature rise is negligible.

frequency at 303 K = ----- Hz [3]

- 73 This question is about the measurement of the **B**-field between a pair of slab magnets.
- Fig. 3.1 shows the arrangement of the apparatus used in the experiment. It consists of a pair of slab magnets, with opposite poles facing one another, fixed onto a piece of U- shaped soft iron.
- The magnet assembly sits on top of an electronic balance. A rigidly fixed wire is shaped to carry a current I between the magnetic poles. The force created alters the balance reading.

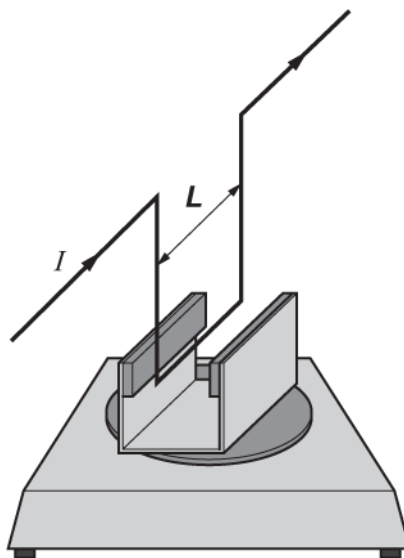


Fig. 3.1

Fig. 3.2 shows a section through the magnet assembly. The dot in the centre represents the wire.

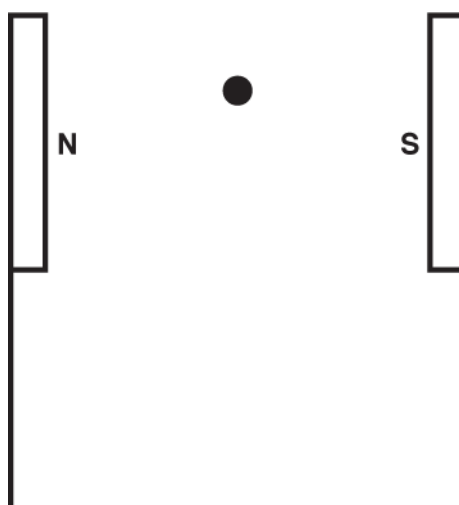


Fig. 3.2

(i) Draw, on Fig. 3.2, at least **three** lines to represent the magnetic field in the region between the magnetic poles when the current in the wire is zero. [2]

(ii) Explain why the balance reading changes to a new value when the wire carries a current.

----- [2]

74(a) An asteroid is tracked from the Earth by radar pulses.

A pulse places it at a distance of 44.444 light-minutes from Earth.

After 24 hours a second pulse places it 44.204 light-minutes from Earth.

Use this data to calculate the average velocity of approach of the asteroid relative to Earth.

relative velocity = _____ m s^{-1} [2]

- (b) The path of the asteroid is shown in Fig. 36.1. After 24 hours the angular shift in position of the asteroid relative to Earth is 1.8 mrad.

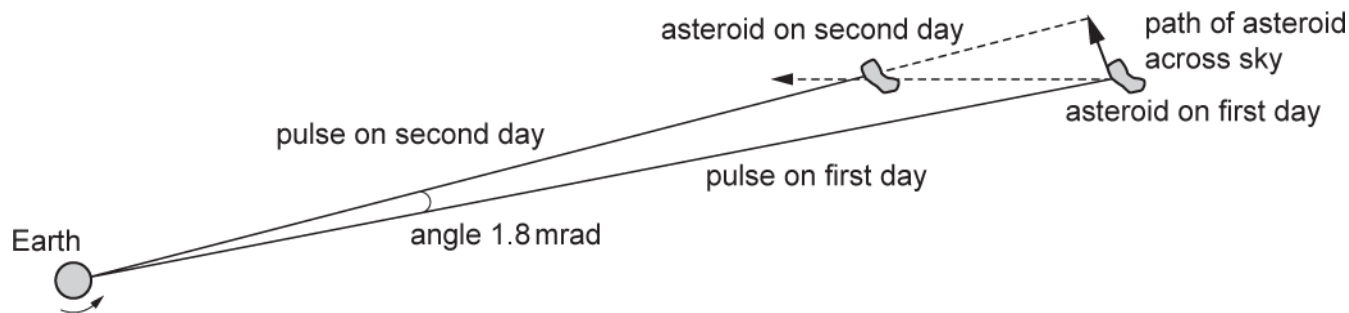


Fig. 36.1 (not to scale)

Estimate the velocity component of the asteroid perpendicular to its direction from Earth. Make your method clear.

perpendicular velocity = _____ m s^{-1} [3]

75(a) A ball bearing of diameter 12 mm was dropped through a tube of glycerol (a viscous liquid).
 The tube was next to a millimetre scale as shown in Fig. 37.1. The ball bearing was dropped from rest at the surface of the liquid. It was filmed using a video camera.

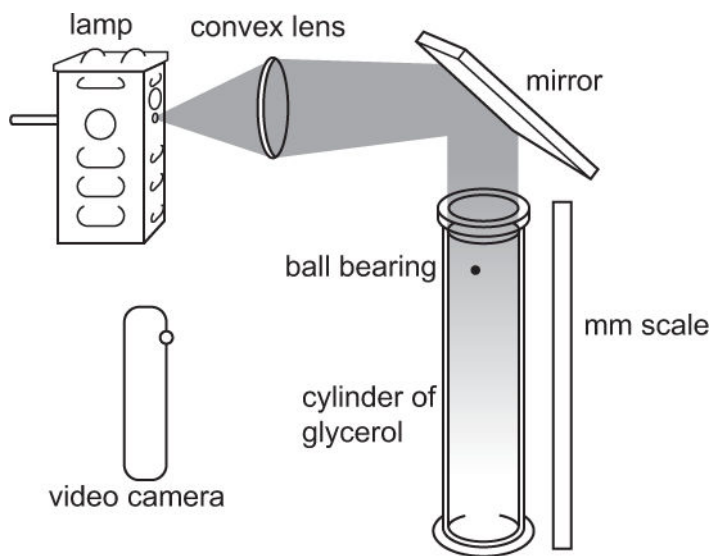


Fig. 37.1

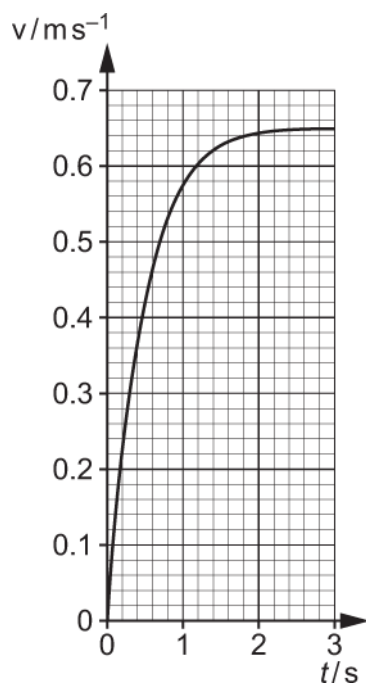


Fig. 37.2

Fig. 37.2 shows the graph of velocity against time obtained by analysing the video recording. This method has an uncertainty of about $\pm 3\%$ for velocity measurement.

Use data from Fig. 37.2 and the measurement precision to calculate the terminal velocity of the ball bearing and its absolute uncertainty.

terminal velocity = _____ $\pm$ _____ ms^{-1} [2]

- (b) Describe the motion shown in the graph at time $t = 0.5$ s and explain it by reference to the forces acting on the ball bearing.

----- [2]

(c)

- (i) The investigation is extended to see how the terminal velocity v_T varies with ball bearing diameter D .

Identify and justify **one** other variable that you would control during this investigation.

[2]

- (ii) This table shows the data obtained in the extended investigation.

Diameter D / mm	Terminal velocity $v_T / \text{m s}^{-1}$
12.0	0.65
10.0	0.49
6.0	0.25
4.0	0.11
2.4	0.04

For a sphere falling through a viscous medium it is suggested that

$$v_T \propto D^2$$

Use data points from the table to propose and carry out a test of this relationship and state your conclusion.

proposal	working	conclusion

[5]

76(a) In 1917 Robert Millikan investigated the motion of tiny oil drops in an electric field and used this to determine the charge on the electron. He sprayed tiny oil drops between two parallel metal plates connected to a high voltage power supply and observed their motion. The experiment was set up as shown in Fig. 3.

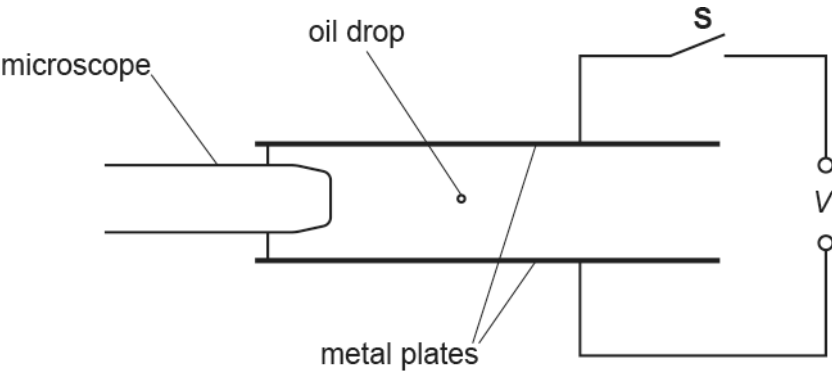


Fig. 3

As the oil drops are forced through a spray nozzle they become negatively charged.
With switch S open there is no potential difference between the plates and the oil drop is observed to be falling at constant velocity through the air.

Explain why the oil drop falls at constant velocity through the air.

[3]

- (b) The switch **S** is closed and the potential difference is adjusted until the oil drop remains stationary between the two parallel plates.

The following data are recorded:

potential difference $V = 390 \text{ V}$

distance between the plates $d = 6.0 \text{ mm}$

mass of an oil drop $m = 2.15 \times 10^{-15} \text{ kg}$.

- (i) Calculate the electric field strength E between the two parallel plates.
Include a suitable unit.

$E = \text{----- unit -----} \quad [2]$

- (ii) Calculate the charge q carried by each oil drop.

$q = \text{----- C} \quad [3]$

- (iii) This calculation does not take into account the effect of buoyancy from the displaced air.
This effect produces an additional upwards force on the oil drop. Explain what effect this would have on the value calculated for charge.

----- [2]

(c) The charge on the parallel metal plates is reversed. Explain the effect this has on the motion of the oil drop.

----- [2]

77(a) This question is about objects falling in a gravitational field.

In 1589, the Italian physicist Galileo Galilei is said to have dropped different masses from the top of the Leaning Tower of Pisa (Fig. 4.1) to show that all objects accelerate towards the Earth at the same rate.



Fig. 4.1

- (i) The height of the Leaning Tower is 56 m. Calculate the time for a mass to fall to the ground when released from rest at the top of the tower. Ignore the effects of air resistance.

time = ----- s [2]

- (ii) Explain why two objects of different masses dropped from the top of the tower should accelerate at the same rate if air resistance is ignored.

[2]

- (b) If Galileo had used two objects with very different masses, he would have observed that they did not both fall with the same acceleration. The air exerts a drag force on falling objects, decreasing their acceleration.

Taking into account the effects of drag, the acceleration a of an object falling through air at velocity v can be modelled using the equation

$$a = 9.81 \text{ ms}^{-2} - Kv^2 \text{ where } K \text{ is a constant for the object.}$$

- (i) The motion of a falling object, taking account of drag forces, can be modelled iteratively as shown below:

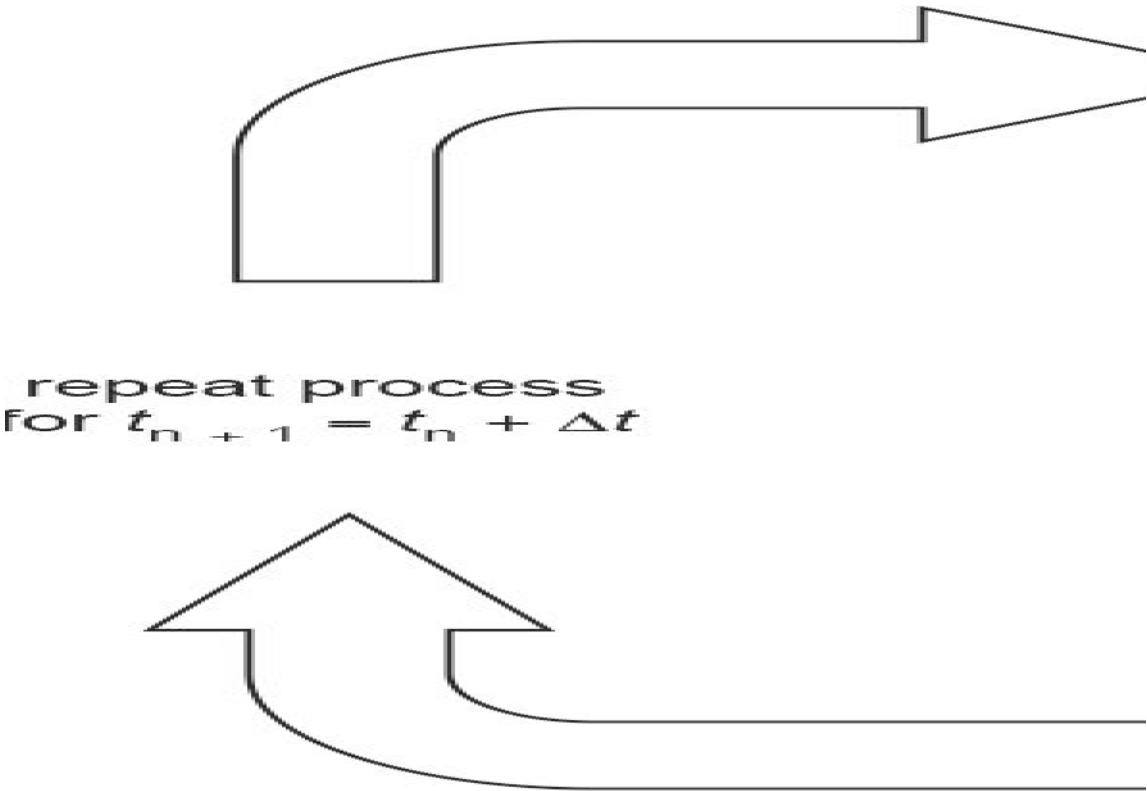


Fig. 4.2

The table below is for a ball with $K = 3.40 \times 10^{-3} \text{ m}^{-1}$, using $\Delta t = 0.200 \text{ s}$. Complete the table.

n	t/s	a/ms^{-2}	$\Delta v/\text{ms}^{-1}$	v/ms^{-1}	$\Delta s/\text{m}$	s/m
0	0.000	9.81	–	0.00	–	0.00
1	0.200	9.81	1.96	1.96	0.00	0.00
2	0.400					

[3]

(ii)



Further iterations of the calculation produce the graph in Fig. 4.3.

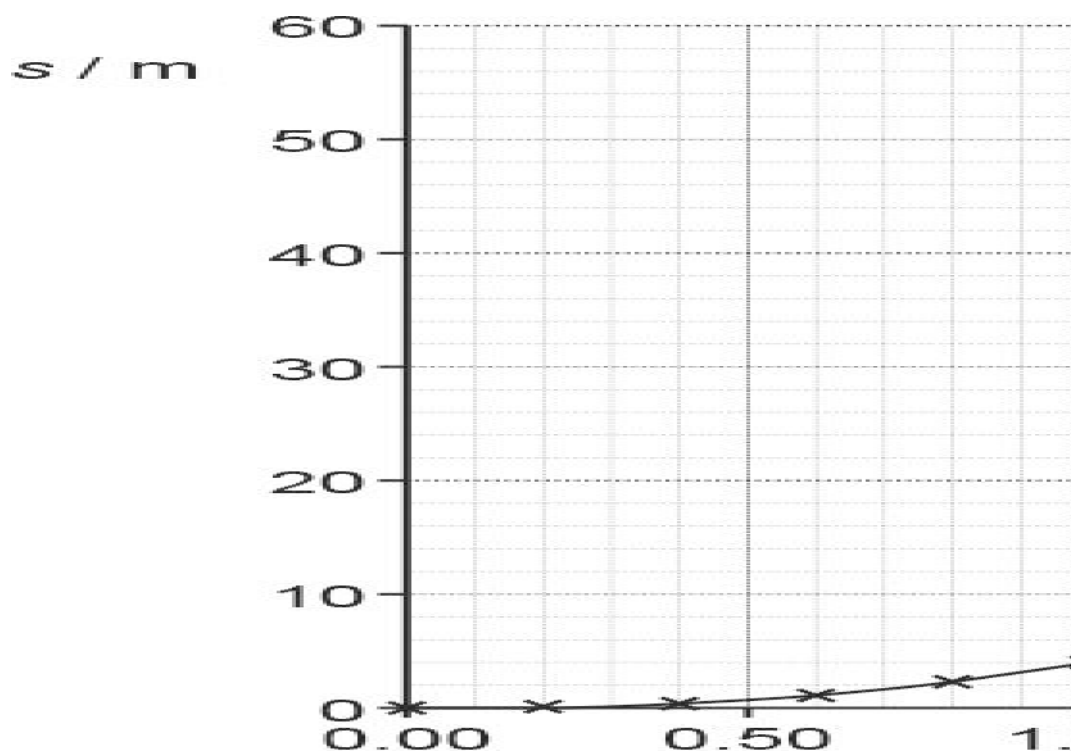


Fig. 4.3

Use data from the graph to estimate the time for this ball to fall from the top of the Leaning Tower to the ground.

Explain why the model may not give an accurate result and how the model could be improved.

Compare your estimate with your value from (a)(i) and use this to suggest and explain whether observers in 1589 would have been able to distinguish between the time of fall of relatively similar masses from the top of the tower.

[6]

Handwriting practice lines consisting of 15 sets of three horizontal dashed lines.

In 1909, a team led by Ernest Rutherford fired alpha particles at a thin sheet of gold. Most of the alpha particles passed through the sheet with little deflection but about one alpha particle in ten thousand ‘bounced back’.

[3]

Calculate the distance of closest approach of a 4.5 MeV alpha particle (${}^4_2\text{He}$) to a gold nucleus (${}^{197}_{79}\text{Au}$) and explain why the use of more energetic alpha particles would result in a different value for the radius of the gold nucleus.

[3]

- (b) Accelerated electrons can also be scattered by atomic nuclei.

The electrons are diffracted by the nuclei giving a minimum at angle θ where $\sin \theta = \frac{\lambda}{d}$ and d is the diameter of the nucleus and λ is the de Broglie wavelength of the electrons.

- (i) Show that the velocity of an electron accelerated through 1.5×10^8 V is very close to the velocity of light.

rest energy of electron = 0.51 MeV

[4]

- (ii) Calculate the angle of the diffraction minimum for a beam of electrons accelerated through 1.5×10^8 V scattered from a nucleus of diameter 3.0×10^{-14} m.

For relativistic particles, momentum = $\frac{E}{c}$ where E is the energy of the particle and c is the velocity of light.

minimum angle = ----- ° [4]

- (c) Electron scattering experiments show that the radius r of a nucleus of nucleon number A is proportional to $\sqrt[3]{A}$.

This relationship suggests that the radius of a silver nucleus ($^{107}_{47}\text{Ag}$) is about four-fifths the radius of the gold nucleus. However, calculations similar to those in (a)(ii) suggest that the maximum radius of the silver nucleus is smaller than this.

Use the relationship $r \propto \sqrt[3]{A}$ to calculate the ratio $\frac{\text{radius of silver nucleus}}{\text{radius of gold nucleus}}$ and show that it is significantly greater than the ratio given by the closest approach method used in (a)(ii).

[4]

79(a) (See Article in Insert for H55702, June 2018) In 1905, Einstein explained the photoelectric effect using the equation

$$\text{maximum kinetic energy of photoelectrons emitted from a surface} = hf - \phi$$

where h is the Planck constant, f is the frequency of light incident on the surface and ϕ is the work function of the surface. Fig. 7.1 shows this relationship for the metal rubidium.

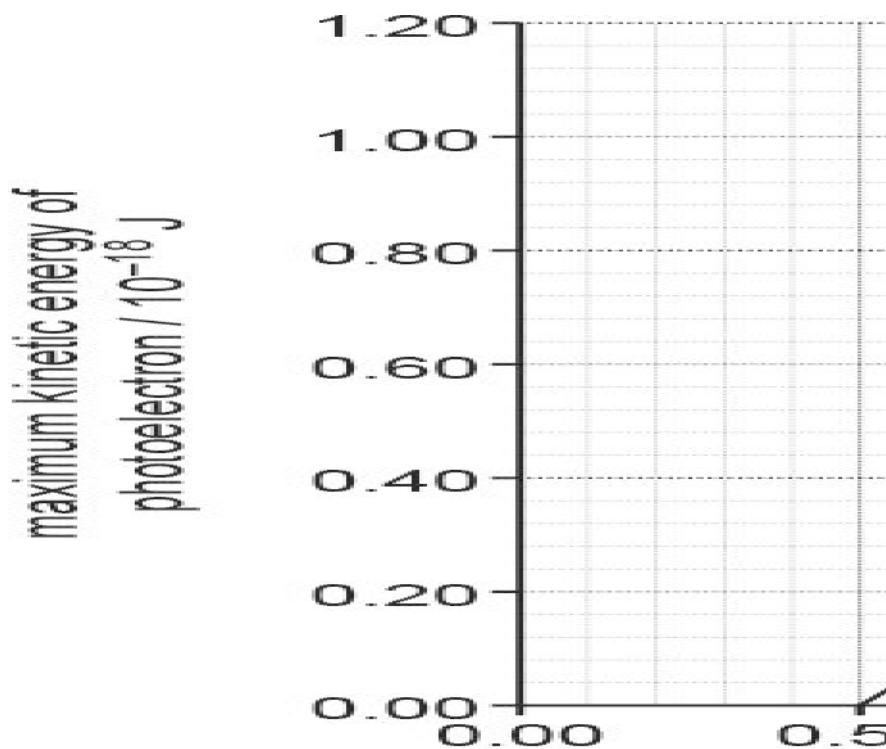


Fig. 7.1

(i) Use the graph in Fig. 7.1 to find the work function of the metal.

work function =----- J [2]

- (ii) Explain the meaning of the term *work function* and explain why Einstein's equation gives the **maximum** kinetic energy of the electrons emitted for a particular frequency of incident light (lines 14 – 17 in the Article).

[2]

- (b) Add a second line to the graph of Fig. 7.1 for a metal surface with a work function which is double that of the work function for rubidium.

[2]

80 (See Article in Insert for H55702, June 2018)



The upper surface of a solar cell is represented in Fig. 8.1.

Use ideas about superposition of waves to explain why a transparent layer of silicon monoxide about 100 nm thick reduces the amount of reflection of light of wavelength 613 nm and increases the efficiency of the solar cell (lines 29 – 30 in the Article).

[6]

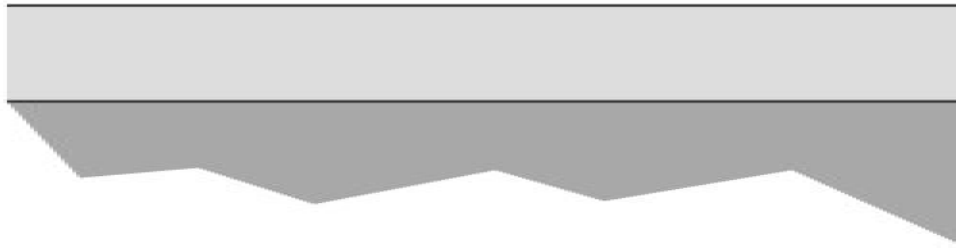
[illegible]

Fig. 9. shows a simplified situation in which a space probe of mass m sweeps around a planet of mass M .



Fig. 9.1

Show that the change in momentum of the space probe = $2 m (V_m + V_M)$.

[2]

- (b) The planet has a much greater mass than the space probe. Use the principle of conservation of momentum to describe the effect that the slingshot will have on the motion of the planet.

[2]

82 (See Article in Insert for H55702, June 2018) Solar Impulse 2 recharges its batteries during the day as it climbs from 1500 m to 8500 m. The solar cells produce an output power of 62.1 kW.

Use data from page 3 of the Article to show that the energy produced by the solar cells over eight hours of daylight is sufficient to lift the plane from 1500 m to 8500 m and fully recharge the batteries.

Make your reasoning clear.

[4]

- 83 (See Article in Insert for H55702, June 2018) The intensity of solar radiation at 1 AU from the Sun is 1.4 kW m^{-2} . At a distance of 5.2 AU from the Sun, the solar cells on the Juno probe produce a power of 500 W. Use data from page 4 of the Article to calculate an estimate of the efficiency of the solar cells.

efficiency =----- % [3]

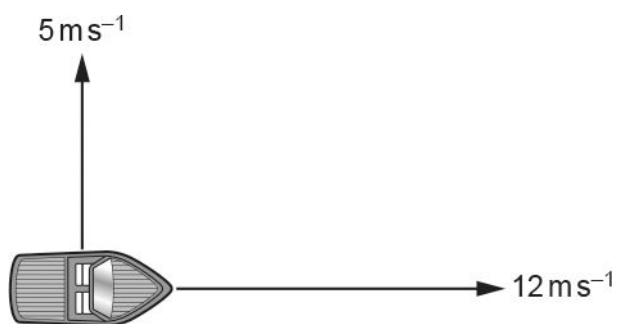
- 84 Which expression gives a quantity that can be expressed in joules?

- A $F v$ where F is the force causing a body to move and v is its speed
- B $I^2 R$ where I is the current flowing through a resistance of value R
- C $m v$ where m is the mass of a body moving with velocity v
- D $V I t$ where V is the potential difference across a conductor and I is the current in it for time t .

Your answer

[1]

- 85 A boat travels eastwards with a velocity of 12 m s^{-1} .
A current from the south pushes the boat northwards at a velocity of 5 m s^{-1} .



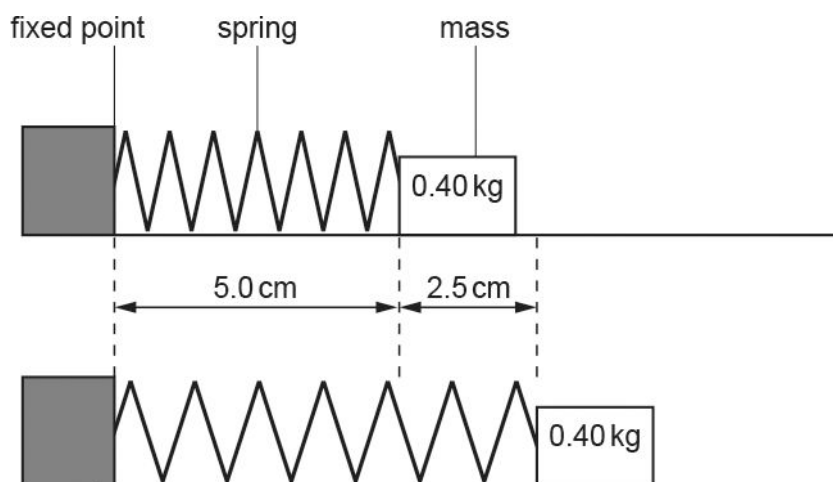
What is the magnitude of the resultant velocity of the boat?

- A 7 m s^{-1}
- B 13 m s^{-1}
- C 17 m s^{-1}
- D 169 m s^{-1}

Your answer

[1]

- 86 The spring in this diagram has a spring constant of 20 N m^{-1} .
The mass is pulled away from the fixed point. The spring stretches by 2.5 cm .
The mass is then released.



What is the maximum speed reached by the mass?

- A 0.18 m s^{-1}
- B 0.53 m s^{-1}
- C 1.25 m s^{-1}
- D 3.75 m s^{-1}

Your answer

[1]

- 87 An electron is travelling at a speed of $3.1 \times 10^5 \text{ m s}^{-1}$.
What is its kinetic energy in electronvolts?

- A $4.4 \times 10^{-20} \text{ eV}$
- B $8.8 \times 10^{-7} \text{ eV}$
- C 0.27 eV
- D 500 eV

Your answer

[1]

88 A ball is kicked from horizontal ground at a velocity of 15 m s^{-1} at an angle of 20° to the horizontal.

How long will the ball remain in the air before hitting the ground?

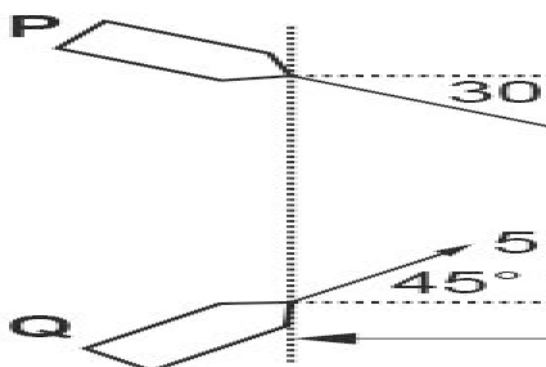
Ignore any effects of air resistance.

- A 0.5 s
- B 1.0 s
- C 1.4 s
- D 2.9 s

Your answer

[1]

89 The diagram shows two boats **P** and **Q** sailing at constant velocity towards the finish line.



Which statement is correct?

- A Boat **P** wins by 1.4 s.
- B Boat **Q** wins by 29 s.
- C Boat **P** wins by 59 s.
- D Boat **Q** wins by 198 s.

Your answer

[1]

90(a) This question is about a model of an atom with one electron.
 The electron is trapped in a box as shown in Fig. 35.
 Possible electron kinetic energy levels are plotted as shown.

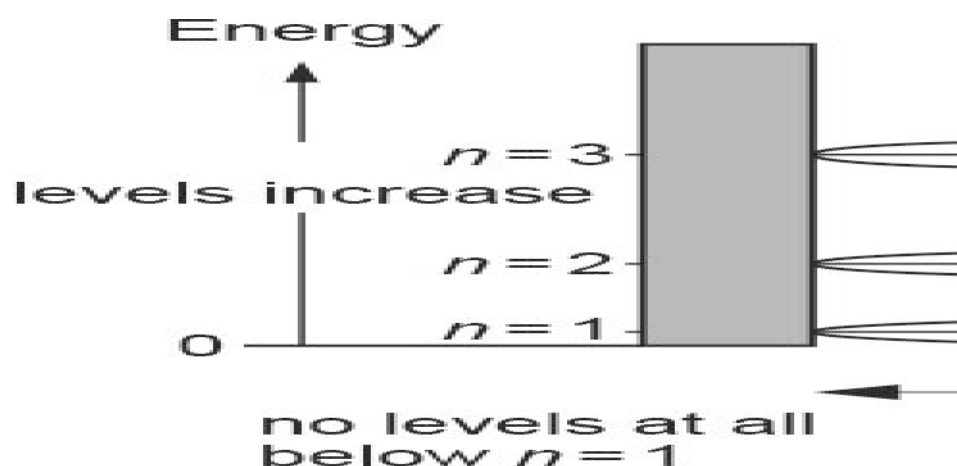


Fig. 35

Explain how this model gives rise to discrete quantised energy levels for the atom.

----- [2]

(b) The distance d between the walls of the box is about atomic size ≈ 0.10 nm.

Calculate the frequency of the most energetic photon that this model atom could emit.

frequency = ----- Hz [3]

91(a) This question is about propulsion systems for spacecraft.

A solar sail uses the momentum of photons in solar radiation for propulsion.



Fig. 37.1

Relativity shows that a photon of energy E has momentum $p = \frac{E}{c}$.

- (i) Show that $\frac{E}{c}$ has the units of momentum.

[1]

- (ii) The total photon power of the radiation received from the Sun on a 1.0 m^2 area of solar sail is P .

Show that the thrust force T from photon reflection is given by $T = \frac{2P}{c}$.

Assume that the Sun's rays are normal to the sail and all the radiation is reflected.

[3]

- (iii) The total photon power density is 1400 W m^{-2} . The 1.0 tonne spacecraft has a 10^6 m^2 solar sail.

Calculate the acceleration of the spacecraft.

acceleration = ----- ms^{-1} [2]

- (b) An ion drive uses the momentum of ions for propulsion. It ionises a gas and uses an accelerating field to accelerate the positive ions to a high velocity.



Fig. 37.2

- (i) A positive ion of charge Q and mass m is accelerated through a p.d. V . Show that the momentum per unit

mass $\frac{p}{m}$ it gains is given by the expression

$$\frac{p}{m} = \quad .$$

[2]

- (ii) Discuss an advantage of using ions of hydrogen $^1\text{H}^+$ as propellant instead of xenon $^{130}\text{Xe}^+$.

----- [2]

(iii) An ion drive with accelerating p.d. $V = 2000 \text{ V}$ must produce a thrust of 0.24 N .

Show that the mass flow rate $\frac{\Delta m}{\Delta t}$ is less than $4 \times 10^{-7} \text{ kg s}^{-1}$.

$\frac{Q}{m}$ for ${}^1\text{H}^+$ ions = $9.6 \times 10^7 \text{ C kg}^{-1}$.

[2]

92(a) A student performs Young’s double slit experiment as shown in Fig. 38.1.



Fig. 38.1

The student investigates how the fringe spacing y varies with the distance L from slits to screen.
The student measures the slit separation $d = 0.5 \pm 0.1 \text{ mm}$.
Fig. 38.2 shows the data obtained with uncertainties.

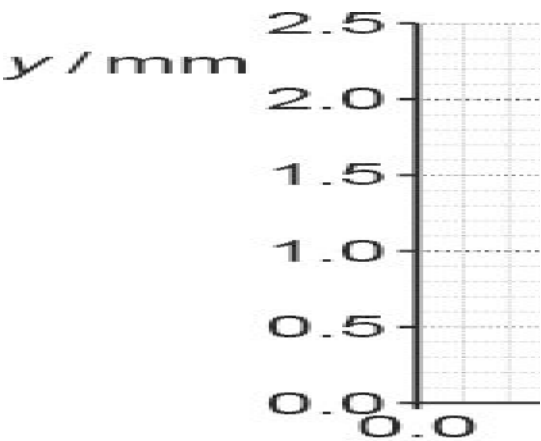


Fig. 38.2

Suggest a reason why only uncertainties in the fringe spacing are shown on the graph.

----- [1]

(b) Draw a line of best fit on the graph and measure its gradient with an uncertainty estimate.

gradient =----- ± ----- [3]

(c) Use the gradient to estimate an average wavelength for the light together with an uncertainty estimate. Make your method clear.

wavelength =----- ± -----m [3]

(d) State **one** way in which you could refine or develop this practical design or procedure to reduce uncertainty.

----- [1]

Here are some data about trace gases in the atmosphere:

H₂ molar mass 2 grams

Xe molar mass 132 grams

(i) Calculate the ratio: $\frac{\text{speed of hydrogen}}{\text{speed of xenon}}$.

Make your reasoning clear.

ratio = ----- [3]

(ii) The escape velocity for planet Earth is 11.2 km s⁻¹.

Use the Boltzmann factor to estimate the number of H₂ molecules per mole with sufficient energy to escape the atmosphere and the Earth's gravitational field at a temperature of 288 K.

number = ----- mole⁻¹ [4]

Three protons are positioned as shown in Fig. 41.2. Imagine a third proton is positioned as shown in Fig. 41.2.

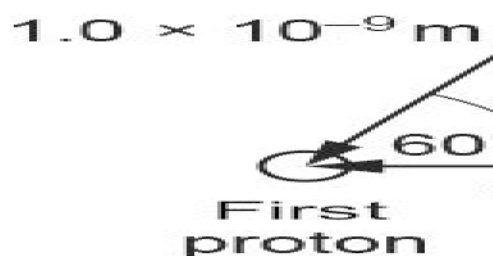


Fig. 41.2 not to scale

- (i) Show that the resultant force F on the third proton is about $4 \times 10^{-10} \text{ N}$ in the direction shown. Explain your reasoning. You may include a diagram in your answer.

[4]

- (ii) The separation of protons in a lithium ${}^6_3\text{Li}$ nucleus is of the order of 10^{-15} m . Estimate the magnitude of the resultant electric force on a proton in the nucleus if the protons are arranged symmetrically as in Fig. 41.2.

force = ----- N [2]

95(a) A block of mass 0.20 kg has velocity $+1.8 \text{ m s}^{-1}$. It collides with a stationary block of mass 0.30 kg. The two blocks stick together after the impact.

- (i) Calculate the velocity of the two blocks after impact. Ignore the effects of friction.

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

- (ii) Show that kinetic energy is **not** conserved in this collision.

[2]

- (iii) The collision took place over time, Δt . By calculating the change of momentum of both blocks, show that the force on one block is equal and opposite to the force on the other block, an example of Newton's third law of motion.

[3]

- (b) In a crash test, a driverless car strikes a wall and stops. The graph in Fig. 1.1 shows the variation of the force on the car over the time of the collision.

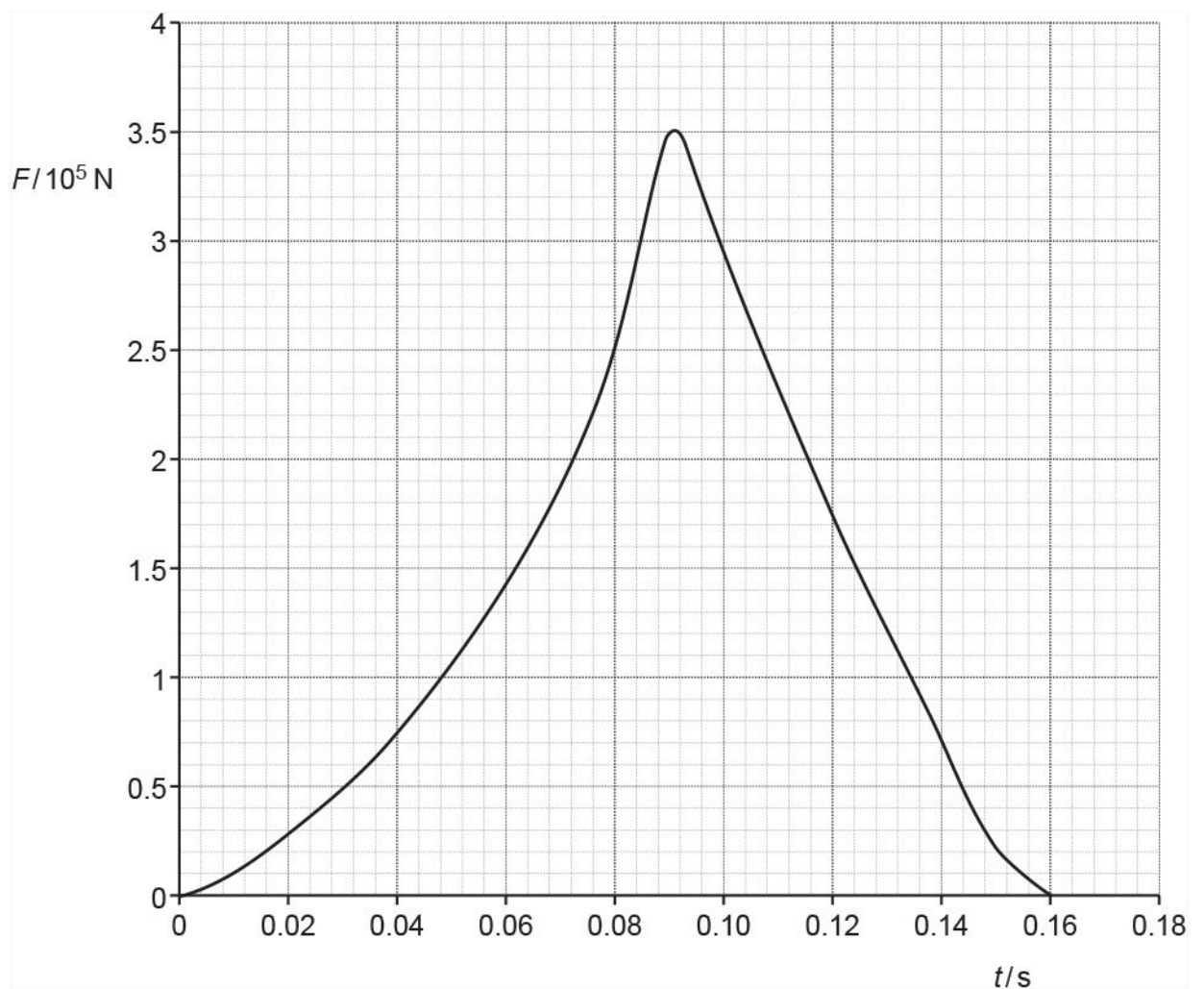


Fig. 1.1

The impulse on the car is given by the area under the curve. Use data from the graph to calculate the initial velocity of the car. Explain your method and reasoning.

mass of car = 1400 kg

initial velocity of car = ... m s⁻¹ [3]

96(a)

- (i) An electron is accelerated through a p.d. of 4.3 kV. Calculate the velocity of the accelerated electron. Ignore relativistic effects.

velocity = ... m s⁻¹ [2]

- (ii) Explain whether it is reasonable to ignore relativistic effects in the calculation in (i). Include a calculation in your explanation.

[3]

- (iii) Calculate the de Broglie wavelength of the accelerated electron.

wavelength = ... m [1]

- (b) Accelerated electrons can be diffracted by layers of graphite in a very similar way to light diffracted through a grating. When electrons are accelerated in a glass vessel and pass through graphite, they diffract and form circular rings on a fluorescent screen. Each electron striking the screen emits a tiny flash of light.

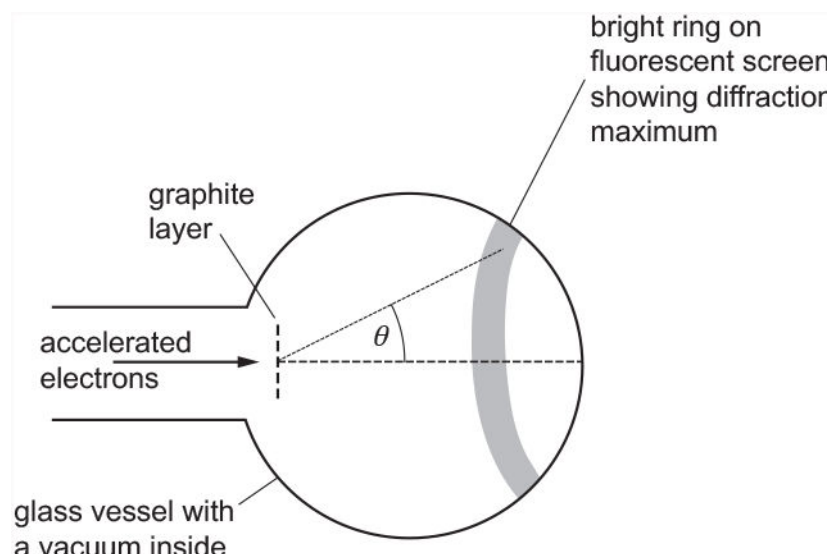


Fig. 4.1

Explain why the rings on the screen become smaller and brighter when the accelerating p.d. the electrons pass through is increased.

[3]

(c) * Explain how this demonstration shows that electrons can be considered as ‘quantum particles’ showing both wave-like and particle-like behaviour. Your answer should describe which aspects of the demonstration show each type of behaviour and explain how diffraction effects can be explained using ideas about phasors.

[6]

97(a) Manufacturers of spectacles (glasses) are keen to develop new materials for lenses. The refractive index of such materials is an important property to consider.

This question is about a method to determine the refractive index of a transparent polymer.

A ray box is used to shine a narrow beam of light through a block of the polymer. Fig. 1 shows the path of the light.

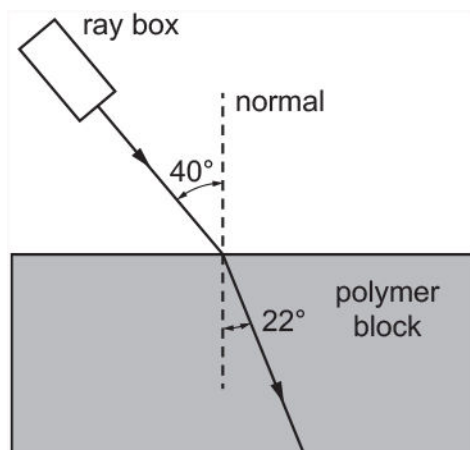


Fig. 1 (not to scale)

The angle of incidence is 40° and the angle of refraction is 22° .

- (i) Calculate the refractive index n of the polymer.

$n = \dots\dots\dots$ [2]

- (ii) The absolute uncertainty in the measurement of each angle is $\pm 4^\circ$.

Complete the table below with maximum and minimum values of the measured angles, and hence determine the absolute uncertainty in the calculated value of refractive index n .

Angle	Maximum value/°	Minimum value/°
angle of incidence, i		
angle of refraction, r		

absolute uncertainty in $n = \pm \dots\dots\dots$ [3]

(b) * Describe the method which could be used in this experiment to reduce the uncertainty in the calculated value of the refractive index of the polymer.

In your answer, include details of the experimental procedure and the analysis of data.

[6]

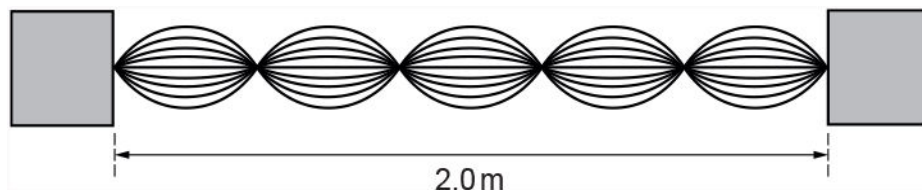
98 Which quantity is followed by a reasonable estimate of its order of magnitude?

- | | | |
|---|--|----------------------------|
| A | momentum of a bee in flight | 10^0 kg m s^{-1} |
| B | speed of an air molecule at room temperature | 10^6 m s^{-1} |
| C | wavelength of red light | 10^{-6} m |
| D | wavelength of X-rays | 10^{-15} m |

Your answer

[1]

99 The diagram shows a sketch of a wave pattern on a vibrating string.



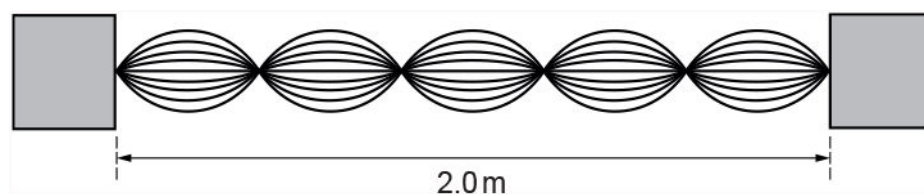
Which description of this wave is correct?

- A The wave is longitudinal, has a wavelength of 40 cm and is stationary.
- B The wave is transverse, has a wavelength of 40 cm and is stationary.
- C The wave is transverse, has a wavelength of 80 cm and is progressive.
- D The wave is transverse, has a wavelength of 80 cm and is stationary.

Your answer

[1]

100 The diagram shows a sketch of a wave pattern on a vibrating string.



The frequency of the wave shown in the diagram is 3.0 Hz.

What is the wave speed on the string?

- A 1.2 m s^{-1}
- B 2.4 m s^{-1}
- C 3.8 m s^{-1}
- D 7.5 m s^{-1}

Your answer

[1]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1			D	1	
			Total	1	
2			C	1	
			Total	1	
3			C	1	
			Total	1	
4			B	1	
			Total	1	
5			A	1	
			Total	1	
6	a		$6.33 \times 10^{-9} = d \times \sin(0.19)$ (1) $d = 3.4 \times 10^{-6}$ (1) working though to lines per mm (298) (1)	3	Bald answer not acceptable
	b		$n\lambda = d \sin\theta$. Recognition that $\sin\theta = 1$ (1) $n = 3.4 \times 10^{-6} / 6.33 \times 10^{-7} = 5.4 = 5$ orders (1)	2	
			Total	5	
7			$\lambda = hc/E$ rearrangement (1) By calculation or simple ratio, increase in λ = 1000 times (1)	2	
			Total	2	
8	a		energy supplied = 252000 J (1) energy supplied / mol = 45 360 J (1) energy per molecule = 7.53×10^{-20} J (1)	3	credit reverse argument. Clear working required. number of molecules evaluated as 3.3×10^{24}
	b		Not all energy transferred from heater to water (1) Alternative destination of energy transfer or vapour recondensing into kettle (1)	2	
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9		i	$ke = p^2/2m$ (1) $p^2 = h^2/\lambda^2$ (1) $\lambda = 4 r$ (1) therefore $E = h^2/32mr^2$	3	Some steps can be in different order but the derivation must be clear. Allow starting point of $\lambda = h / mv$ and $ke \frac{1}{2}mv^2$ to reach same conclusion.
		ii	$ke = ((h^2/(32 \times 9.1 \times 10^{-31} \times 1 \times 10^{-20})))$ (1) 1.5×10^{-18} (J) (1)	2	
		iii	potential energy = $-8.9 \times 10^9 \times (1.6 \times 10^{-19})^2/1 \times 10^{-10}$ (1) $= -2.3 \times 10^{-18}$ (1) Total energy = -0.8×10^{-18} J (1) This is negative, hence electron bound to proton. (1)	4	Must include negative sign for second marking point.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance										
10	a	i	<table><tr><td>0.40</td><td>8.0</td></tr><tr><td>0.40</td><td>8.0</td></tr><tr><td>0.60</td><td>12.0</td></tr><tr><td>0.40</td><td>8.0</td></tr><tr><td>0.20</td><td>4.0</td></tr></table> 3 Δv values correct 5 $\Delta v/\Delta t$ values correct	0.40	8.0	0.40	8.0	0.60	12.0	0.40	8.0	0.20	4.0	2	Correct values entered into table
0.40	8.0														
0.40	8.0														
0.60	12.0														
0.40	8.0														
0.20	4.0														
		ii	$g = (\Delta v/\Delta t)_{\text{average}} (\pm \frac{1}{2} \text{ range})$ $= 8.0 \checkmark$ $\pm 4 \text{ (ms}^{-2}\text{)} \checkmark$	2	accept $\pm 2 / 3 / 4 \text{ (ms}^{-2}\text{)}$ on uncertainty estimate										
		iii	Δt from strobe is $\pm 10\%$ (and is used twice to find $\Delta v/\Delta t$)$\checkmark$ may contribute up to about $\pm 20\%$ and is largest % uncertainty $\checkmark$	2	accept improve y measurement because $\pm \%$ on Δy varies between $\pm 5\%$ when y smallest to $\pm 1\%$ when y largest, (but lower y values could be ignored) both required										

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	* Level 3 (5–6 marks) Test carried out with at least 3 evaluations to check constancy. Complete answer with conclusion yes $v_{\text{horizontal}}$ sensibly constant (within limits of position measuring precision from image, about ± 0.5 cm uncertainty / 50 cm max displacement at best) <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) proposed test: Δx check constant or $x \propto t$ or $x / t = \text{constant}$ (if measuring from left edge of ball). Test carried out with at least 2 evaluations to check constancy <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) $v_{\text{horizontal}}$ in range $1.1 \pm 0.1 \text{ ms}^{-1}$ scores 2 transfers data from graph to table scores 1 <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	
		ii	Laws: identifies 1st law with constant $v_{\text{horizontal}}$ and links constant $v_{\text{horizontal}}$ to lack of $F_{\text{horizontal}}$ ✓ identifies 2nd law with constant a_{vertical} and links a_{vertical} to constant F_{vertical} or constant weight ✓	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	14	
11	a	i	$F = E Q = VQ / d$ ✓ $= V^2 r / kd$ ✓ $= 2000^2 \times 0.02 / (9.0 \times 10^9 \times 0.08) = 1.1 \times 10^{-4} \text{ (N)}$ ✓	3	apply uniform field equation combine with $V = k Q / r$ algebraic manipulation / numerical evaluation
		ii	1000 (J C ⁻¹) ✓	1	accept half the p.d. across the plates or complete calculation of $Fd / Q = 1000 \text{ (J C}^{-1}\text{)}$
	b		The ball can lose k.e. at each bounce to sound or heat and to the air by air resistive drag forces ✓ so ball accelerates until energy gained per passage = energy lost per passage (between the plates) ✓	2	alternative Allow credit for same charge transferred each time Thus experiences the same accelerating force
			Total	6	
12		i	New $P = 1/0.35 - 1/(0.26 - 0.027) = 7.2 \text{ D}$ ✓ Percentage increase = $[(7.2 \text{ D} - 6.7 \text{ D})/6.7 \text{ D}] \times 100\% = 7.5\% (\approx 7\%)$ ✓	2	Allow use of unrounded figures for both P s, gives 6.6% 7.46 or 7.5 gains both marks
		ii	different colours will be imaged at different places ✓ so objects emitting / reflecting light of several colours will not be seen sharply / will be fuzzy / will have coloured edges ✓	2	
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a	i	(upthrust = weight so) $A\rho_w g = mg$ ✓ $d = mg/A\rho_w g = m/A\rho_w$ ✓	2	
		ii	maximum upthrust = $LA\rho_w g$ and weight of rod = $LA\rho_{rod}g$ ✓ if $\rho_{rod} > \rho_w$ then weight > upthrust so it will sink ✓	2	can be done without algebraic treatment by referring to the maximum upthrust being the weight of a volume of water equal to the volume of the rod ✓ which must be less than the rod's weight if the density of water is greater than that of the rod ✓
	b		upwards force = $\rho_w(d + s)Ag$ and downwards force is still $mg = \rho_w Adg$ ✓ so resultant force $F = \rho_w Asg$ and acceleration = $F/m = \rho_w Asg/m$ ✓ $a \propto -s$ so this is simple harmonic motion ✓ $a = -\omega^2 s$ so $\omega^2 = \rho_w Ag/m$ ✓ $T = 2\pi/\omega$ ✓ (= $2\pi\sqrt{(m/\rho_w Ag)}$)	5	allow reference to additional weight of water displaced when moved from equilibrium. accept in the opposite direction for (–) sign Full credit for corresponding alternative with $2\pi f$ for ω

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	*Level 3 (5–6 marks) Both methods compared and advantages of SP and disadvantages of FR identified. Qualitative comparison of uncertainties of the different methods made, even if not completely successful, linking to value for g. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Compares both methods and identifies some advantages of SP method. Partial attempt to quantify differences. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes direct comparison between at least one shortcoming of FR method and an advantage of SP method. No attempt to quantify uncertainty. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: floating rod method • Method is indirect • Rod may oscillate in different directions • Damping will stop oscillations • Difficult to time a large number of oscillations to reduce ΔT • Water surface will move making it hard to judge position of rod • Use of the formula in the form $g = \frac{4\pi^2 m}{T^2 \rho_w A}$ • Percentage uncertainty in m and A are small compared with T • T will be of the order of 1 s • $\Delta T/T$ significantly larger than for pendulum • logical argument linking uncertainties in measurement through to value of g simple pendulum method • Method is indirect • Can time a large number of oscillations to reduce ΔT • May be systematic error in measuring L • Use of dense bob and light, flexible thread minimises frictional losses • Easy to judge position of bob e.g. passing through centre • Use of the formula in the form $g = \frac{4\pi^2 l}{T^2}$ • T will be of the order of 2s • $\Delta T/T$ significantly smaller than for floating rod • logical argument linking uncertainties in measurement through to value of g
		Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14		i	Conservation of momentum requires that vector addition of $m_{\alpha}v_1$ & $m_{\text{He}}v_2$ will give $m_{\alpha}u$ ✓ For the masses to cancel $m_{\alpha} = m_{\text{He}}$ ✓	2	allow suitable alternative wording
		ii	Pythagoras' theorem gives $(v_1)^2 + (v_2)^2 = (u)^2$ ✓ As $m_{\alpha} = m_{\text{He}} = m$: $\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 = \frac{1}{2}mu^2$ ✓	2	
			Total	4	
15			$hc / \lambda = kT \Rightarrow T = hc / k\lambda$ ✓ $T = 6.6 \times 10^{-34} \times 3 \times 10^8 / (\lambda \times 1.4 \times 10^{-23})$ Gives range of 1.4×10^6 K to 1.4×10^8 K ✓ Compares with T of photosphere, e.g. at least $200 \times$ higher temperature ✓	3	Accept other sensible Boltzmann approximations e.g. $3/2 kT$ Accept Boltzmann factor considerations leading to lower temperatures
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16	a		$m = 8.0 \times 10^{-2} + 1.0 \times 10^{-3} (= 8.1 \times 10^{-2} / 0.081\text{kg});$	1	ECF incorrect $m = 8.0 \times 10^{-2}$ kg for [1]
			$\text{KE} = 8.1 \times 10^{-2} \times 9.8 \times 2.3 \times 10^{-1} = 1.83 \times 10^{-1} \text{ J};$	1	0.183 = [2] 0.18: Check to ensure the masses were added for [2]
			Assumption: $\text{KE}_{\text{initial}} = \text{GPE}_{\text{final}} / \text{KE}_{\text{lost}} = \text{GPE}_{\text{gained}} / \text{KE} + \text{GPE} = \text{constant} / \Delta \text{KE} = \Delta \text{GPE};$ $(= 8.1 \times 10^{-2});$	1	Reject any reference to a collision or energy lost in the collision or energy lost when the gun is fired. Accept no air resistance / no transfer to heat in the air / surroundings Ignore: Energy is conserved / $\text{KE} = \text{GPE}$ / no energy lost as heat. Examiner's Comments Answered well. Many candidates got the first 2 marks but seemed to forget to include any assumptions made. It does suggest that candidates answer the question as they see it, and then never spent the short time to just re-check that they have complete the question fully. Such discipline would potentially, raise the marks awarded.
	b		$v = \sqrt{\frac{2E_K}{m}} = 2.12 \text{ m s}^{-1};$	1	Allow ECF for incorrect value of v . For example, if $v = 4.5(08) \text{ m s}^{-1}$ leads to $u = 365 \text{ m s}^{-1}$. [2]
			final momentum = 0.172 N s;	1	Using $\text{KE} = 0.2 \text{ J}$ $v = 2.22 \text{ m s}^{-1}$
			$u = 0.172 / 1.0 \times 10^{-3} = 1.7 \times 10^2 \text{ m s}^{-1};$	1	final momentum = 0.18 Ns $u = 180 \text{ m s}^{-1}$ [3] Examiner's Comments Well answered. A small number of candidates seemed confused about which mass(es) had which velocities and this led to some unlikely values for the velocity of the pellet and compounded problems when calculating its KE in (c).
	c	i	initial KE of pellet = $\frac{1}{2}mv^2 = 14.5 \text{ J};$	1	Accept any value for KE between 14J and 16J ECF: From u in (b).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	which is (much) greater than 2×10^{-1} J final KE;	1	There must be a comparison between the (correct) initial and final KE values. Reject: The two KEs are different / unequal / not the same. Examiner's Comments Most candidates did not consider it necessary to state that <i>KE</i> was not conserved. The few that calculated a gain in <i>KE</i> during the collision expressed no concern. Some did not realise that they had already calculated the final energy in (a).
		ii	any two of the following, [1] each KE (of the pellet) is lost due to ... • ...raises temperature of pellet/blutak / heat transferred to pellet/blutac; • ...deforming / changing shape of the pellet / bluetac • ...sound / vibrations (in the pellet / blutac)	2	Ignore: references to friction. Reject: bald <i>transferred to heat</i>. Accept: pellet embedding in the blutac. ANY reference to energy losses that occur before the collision itself (e.g., sound from the gun) scores 0/2. Examiner's Comments This question was generally well answered but the level of response was low. There were too many references to energy lost "... as heat and sound", without any reference to where the energy was actually lost. A small number of candidates did seem to misunderstand the question and discussed energy losses when the pellet was fired.
			Total	10	
17			B	1	
			Total	1	
18			C	1	
			Total	1	
19			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20			C	1	
			Total	1	
21			C	1	
			Total	1	
22			D	1	
			Total	1	
23	a		$\theta = \sin^{-1}(2/6)$ ✓ $= 19^\circ$ ✓	1 1	method accept correctly labelled vector Δ evaluation accept 19.4(7) ° or 19.5° not 20° RE(rounding error)
	b		$= 6 \times \cos(19.5^\circ) = 5.7(\text{ms}^{-1})$ ✓ or $= \sqrt{6^2 - 2^2} = 5.7 (\text{m s}^{-1})$	1	evaluation accept by components or Pythagoras allow ecf on $\cos\theta$ from (a) accept if scaled vector Δ answers in range 5.5 to 5.9 (m s^{-1})
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance						
24	a	i	$\Delta v = g \Delta t$ this only recognises gravitational acceleration there is no term involving the force of drag and the acceleration it would produce ✓	1	accept the only acceleration is due to gravity						
		ii	iterative model assumes v_y remains constant during Δt instead of continuously changing, so y values are always bigger than reality ✓	1	not just V_y or y overshoots						
		iii	by making Δt smaller and doing more iterations per time interval we can make the process as ✓	1							
		iv	V_x really is constant (ignoring air resistance) so no $\approx$ or approximation is involved ✓	1	accept there is no horizontal acceleration / force acting						
	b		<table border="1"><thead><tr><th>y / m</th><th>analytic</th></tr></thead><tbody><tr><td>1</td><td>0.8</td></tr><tr><td>1</td><td>0.75</td></tr></tbody></table> ✓✓	y / m	analytic	1	0.8	1	0.75	2	one mark for each correct column
y / m	analytic										
1	0.8										
1	0.75										
	c	i	✓✓	2	one mark for each correct graph with points allow small plotting errors or small calculation errors ecf (b)						
		ii	general shape is parabolic / both have same x values at same times ✓	1	similarity accept any sensible answer not start at same angle of projection						
		ii	iteration reaches higher y -value / peaks later in time / analytical reaches larger downward velocity ✓	1	difference accept any sensible answer not iteration reaches further						
	d		not every problem has an analytical solution / but many can be modelled by iteration and predictions can be made / approximations or models can be improved in the light of more real world data ✓✓	1 1	accept any two sensible points						
			Total	12							

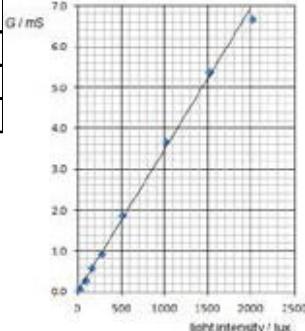
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
25	a	i	(wave) superposition ✓	1	accept (wave) interference accept when a wave crest/trough meets another wave
		i	(when waves from two or more sources overlap), the resultant displacement (at a given instant and position) is equal to the sum of the individual displacements ✓	1	crest/trough a large crest/trough forms called constructive interference and If a wave crest meets a wave trough, the waves cancel each other out momentarily called destructive interference. accept labelled diagrams
		ii	diffraction by single slit with ripple tank / light / μ -waves can show circular / sideways spreading of wave energy ✓	1	accept spreading of waves through a slit occurs at any point along an interrupted wavefront as if circular spreading was occurring from all points on the wavefront
		iii	wavelets spread on circular arcs of fixed radius = $c \Delta t$ ✓	1	
	b		wavefronts of wavelets line up along BB' with waves from successive slits being delayed by one cycle / one λ ✓ Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: • using grating equation for spectral orders • explain grating using wave ideas • explain grating using phasor ideas <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for level 3.	1 6	not just wavelets line up Indicative scientific points may include: Grating equation for spectral orders • recognising that $n = 1$ is first order at θ_1 or that $n = 2$ is second order at θ_2 • use of $\sin\theta = n\lambda / d$ with $n = 1 \Rightarrow \theta_1 = 23.6^\circ$ or use of $\sin\theta = n\lambda / d$ with $n = 2 \Rightarrow \theta_2 = 53.1^\circ$ ORA Explain grating using wave ideas • path difference between consecutive slits = $d \sin\theta$ • if path difference is an integer number of λs then waves at angle θ are in phase and will constructively interfere to give a high intensity at that angle or • if path difference is an odd number of $\frac{1}{2} \lambda$s then waves at angle θ are in antiphase and will destructively interfere to give a zero intensity at that

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			<i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit		angle Explain grating using phasor ideas - photons are emitted and detected discretely - description of phasor arrow rotating at f to describe every possible path and find phasor angle for each - add phasor arrows tip to tail to get phasor resultant for all possible paths between emission and detection - phasors near straight line paths “line up” and contribute most to resultant amplitude and probability away from the straight line path phasors “curl up” and contribute little to resultant amplitude and probability - probability of photon arrival at this detection point $\propto$ (resultant phasor amplitude)² - repeat for all possible detection points - sum probabilities and normalise so that total probability is 1 i.e. photon arrives somewhere accept well labelled diagrams throughout for credit if integrated into the explanation
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance				
26	a	i	✓✓ <table border="1"><tr><td>1.89 or 1.9</td></tr><tr><td>3.70 or 3.7</td></tr><tr><td>5.38 or 5.4</td></tr><tr><td>6.67 or 6.7</td></tr></table> ✓✓ 	1.89 or 1.9	3.70 or 3.7	5.38 or 5.4	6.67 or 6.7	1	G / mS values in table allow 2 or 3 S.F.
			1.89 or 1.9						
			3.70 or 3.7						
			5.38 or 5.4						
6.67 or 6.7									
1	G values plotted correctly allow ecf on wrong values								
1	best fit line must show proportionality for mark								
1									
		ii	R vs Intensity both variables change over about 2 orders of magnitude / by about $\times 100$ / graph is highly curved ✓	1	accept log / log graphs compress large ranges of data				
		ii	both graphs give linear best fit graph / test a functional relationship ✓	1	accept straight line graphs are only function that can be judged by eye				
		ii	straight log / log graph shows a power law $R \propto I^n$ (gradient = $n \approx -1$) ✓	1	accept $R \propto 1 / I^n$ ($n \approx 1$) or $G \propto I$				
		iii	photons give energy to electrons and free them into the conduction band ✓	1	reason				
		iii	$G \propto$ carrier density and $G \propto I$ so expect $I \propto$ carrier density (provided electrons drop back into bonds / recombine with holes) ✓	1	evaluation				
	b	i	threshold λ above which process of freeing electrons does not occur or ✓ threshold f or E below which electrons are not freed from bonds	1					
		ii	$E = hc / \lambda = 6.6 \times 10^{-34} \times 3 \times 10^8 / 770 \times 10^{-9}$ ✓	1	must have threshold λ not peak λ				
		ii	$= 2.6 \times 10^{-19} \text{ (J)}$ ✓	1					
	c		$V = 6 \times R / (R + R_{\text{LDR}})$ or $6 \times 470 / (470 + 270)$ ✓	1	method				
$= 3.8 \text{ (V)}$ ✓			1	evaluation					
			Total	14					

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
27	a	i	gravitational force is always attractive so potential energy per kg increases as body is lifted above the Earth's surface, towards zero at ∞ by convention ✓	1	accept arbitrary zero of potential is at ∞ separation, so as bodies approach, potential energy decreases below zero hence negative
		ii	to launch $\frac{1}{2} v^2 = 62 \times 10^6 \text{ J kg}^{-1}$ or $v = \sqrt{(124 \times 10^6)}$ ✓	1	method accept energy per kg or for mass m which cancels in words / algebra / numbers
		ii	$v = 1.1(1) \times 10^4 \text{ (ms}^{-1}\text{)}$ ✓	1	evaluation
	b	i	(k.e. lost = p.e. gained) $\Rightarrow$ ✓	1	
		i	$\frac{1}{2} v^2 = GM/r \Rightarrow v = \sqrt{(2GM/r)}$ ✓	1	
		i	where M is mass of spherical body of radius r that you are trying to escape and G is the gravitational constant ✓	1	
		ii	$v = \sqrt{(2G \frac{4}{3} \pi R^3 \rho) / R} \Rightarrow v = \sqrt{(8/3 G \pi \rho)}$ ✓	1	algebraic reasoning accept $M = 4/3 \pi R^3 \rho$
		iii	$R = \sqrt{(3/8 G \pi \rho) c}$ or $= \sqrt{(3 / (8 \times 6.7 \times 10^{-11} \times \pi \times 10^{17})) \times 3 \times 10^8}$ ✓	1	method change subject of equation and sub for c in algebra / numbers
		iii	$= 4.0 \times 10^4 \text{ (m)}$	1	evaluation
			Total	9	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
28	a	Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: • change in mass • binding energy equivalent • forces and momentum <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for level 3. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks <i>No response or no response worthy of credit</i>	6	Indicative scientific points may include: Change in mass • protons and neutrons in a nucleus are bound by the strong nuclear force, which is a short-range attractive force sufficient to overcome the electrostatic repulsion between the protons in a nucleus. • For a nucleus with Z protons and N neutrons • $\Delta m = \text{mass of nucleus} - (Z m_p + N m_n)$ OR • change in mass = $221.9703 - (217.9628 + 4.0015) = 0.0060 \text{ (u)}$ Binding energy equivalent • to pull nuclei apart requires energy called the binding energy of the nucleus • binding energy of a nucleus can be calculated from the difference in mass between the nucleus and its separate neutrons and protons • binding energy = $\Delta m c^2$ • rest energy of the nucleus is less than that of its constituent particles. Since the rest energy • $E_{\text{rest}} = m c^2$, the mass of the nucleus is also less than • that of its constituent particles. • $\Delta E = \Delta m C^2 = 0.0060 \times 1.661 \times 10^{-27} \times (3.00 \times 10^8)^2$ $= 8.969 \times 10^{-13} \text{ (J)}$ $= 8.969 \times 10^{-13} / (1.6 \times 10^{-19} \times 10^6) = 5.61 \text{ (MeV)}$ • OR accept knowledge of $1 \text{ u} = 931 \text{ MeV}$ Forces and momenta • during emission α and remnant nucleus repel with equal and opposite

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					electrostatic forces (for equal times) or $F = k Q_1 Q_2 / r^2$ • by Newton's 3rd Law nucleus recoils • so impulses are equal and opposite on α and nucleus • so gaining equal and opposite momenta • nucleus carries away some k.e. from binding energy released • accept well labelled diagrams throughout for credit if integrated into the explanation
	b	i	conservation of momentum	1	accept momentum before = momentum after = zero or equal magnitude opposite direction for two particles momenta
		ii	$= m_{po} V_{po}^2 / m_{\alpha} V_{\alpha}^2 = m_{po} m_{\alpha}^2 / m_{\alpha} m_{po}^2 = m_{\alpha} / m_{po}$	1	mid step must be clear for mark
		iii	= 0.98(2) ✓	1	accept evaluation of energy or fractional energy
		iii	5.61 MeV $\times$ 0.982 = 5.5(1) MeV ✓	1	allow nuclear fraction of total k.e. = 0.018 or nuclear recoil k.e. = 0.10(1) MeV
		iii	value of α k.e. 5.5 MeV agrees at 2 S.F. level ✓	1	comparison of energy to actual value
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a	i	Wave crests from A_2 and A_4 in phase with those from A_1 ✓ One extra wave crest from A_2 and three extra wave crests from A_3 with correct separation ✓ Path difference correctly shown ✓	3	
		ii	1 With a path difference of a whole number of wavelengths ✓ the waves superpose in phase ✓	2	
		ii	2 The image is bright because light from many slits superposes in phase ✓ (producing a superposition of high amplitude)	1	
	b	i	Any two from: • White light composed of many wavelengths ✓ • Different wavelengths require different path differences to meet in phase ✓ • The angle for a maximum is wavelength dependent λ ✓	2	
		ii	$\sin \theta = 5.8 \times 10^{-7} / 1.6 \times 10^{-6} \checkmark = 0.36(25)$ $\theta = 21^\circ \checkmark$	2	Accept second order value of 46°
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance						
30	a		$\Delta p = m\Delta v = 72 \text{ kg} \times -11 \text{ m s}^{-1} \checkmark = -790 \text{ kg m s}^{-1} \checkmark$	2	Accept -792 kg m s^{-1}						
	b		force/weight = $(790 \text{ kg m s}^{-1}/0.15\text{s})/(72 \text{ kg} \times 9.8 \text{ N kg}^{-1}) \checkmark$ $= 7.5 \checkmark$	2	No s.f. penalty on answer.						
	c	i	Any two from: F rises before 60.0 ms $\checkmark$ area under graph is similar (by eye) F_{max} is less than the original and occupies a longer time $\checkmark$	2							
		ii	Any two from: F starts earlier because bag is closer to head than wheel is $\checkmark$ F_{max} is (much) less because dp/dt is less $\checkmark$ area same because momentum is conserved $\checkmark$	2							
		iii	any pair of effect of deflation + its implication <table border="1"><tr><td>effect of deflation</td><td>implication for dummy/person</td></tr><tr><td>head will not bounce $\checkmark$</td><td>smaller momentum change on head $\checkmark$</td></tr><tr><td>head moves further (as it pushes out the air) $\checkmark$</td><td>longer collision time and so smaller $F \checkmark$</td></tr></table>	effect of deflation	implication for dummy/person	head will not bounce $\checkmark$	smaller momentum change on head $\checkmark$	head moves further (as it pushes out the air) $\checkmark$	longer collision time and so smaller $F \checkmark$	2	
effect of deflation	implication for dummy/person										
head will not bounce $\checkmark$	smaller momentum change on head $\checkmark$										
head moves further (as it pushes out the air) $\checkmark$	longer collision time and so smaller $F \checkmark$										
			Total	10							

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
31		i	$F = -6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2} \times 3 \times 10^{12} \text{ kg} \times 1100 \text{ kg} / (5 \times 10^2 \text{ m})^2 \checkmark$ $= 0.88 \text{ N} \sim 0.9 \text{ N} \checkmark$	2	Must have own answer and show working
		ii	$\frac{mv^2}{r} = \frac{GMm}{r^2} \checkmark$ Maximum velocity $= \sqrt{\frac{GM}{r}} \checkmark$ $= 0.63 \text{ m s}^{-1} \checkmark$ $\frac{2\pi}{80 \times 60} = 0.65 \text{ m s}^{-1} \checkmark$ Comparison of speeds and clear conclusion $\checkmark$	5	Alternative approaches possible, e.g. $\frac{mv^2}{r} = \frac{GMm}{r^2} \checkmark$ $T^2 = \frac{4\pi^2 r^3}{GM} \checkmark$ $T = \sqrt{\frac{4\pi^2 r^3}{GM}} (= 2\pi \sqrt{\frac{r^3}{GM}})$ $T = 4955 \text{ s} \checkmark$ $= 83 \text{ min} \checkmark$ Comparison of times and clear conclusion $\checkmark$
		iii	Zero of potential energy defined at infinity $\checkmark$ Need to supply energy to remove L.P from surface/ reference to gravitational potential well AW $\checkmark$	2	
		iv	Calculation of k.e. at about 450 J $\checkmark$ This is sufficient to escape potential well AW $\checkmark$	2	Need clear link with energy required to leave potential well.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
32	a	i	Place glass slide on a microscope slide with a piece of graph paper as a reference scale. ✓	1	Credit plausible alternatives
		ii	Reference to $\lambda = dx / L$ ✓ Smaller slit spacing gives larger fringe spacing ✓	2	Allow use of $n\lambda = d \sin\theta$
	b		$\lambda/d = \sin \theta$, $x/L = \tan \theta$ ✓ if $L \gg \lambda$, $\sin \theta \approx \tan \theta \approx \theta$ (if θ is measured in radians) ✓ $\lambda/d \approx x/L$	2	Both equations should be seen. Accept if $d > \lambda$ OR if there are many wavelengths between the slits and the screen.
	c		Fringe spacing = $1.3/8 = 0.16 \text{ cm}$ ✓ $\lambda = d \sin\theta = 1 \times 10^{-3} \times 0.16 \times 10^{-2} / 3$ ✓ $= 5.4 \times 10^{-7}$	3	OR $\lambda = dx / L$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		Level 3 (5-6 marks) ✓✓ Addresses all four points with reasoned comments regarding practicality and disadvantages. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) ✓✓ Addresses each point but may not appreciate the associated difficulty in some cases <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1-2 marks) ✓✓ Comments on at least two points with a least one difficulty described. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	e.g. Increasing the distance between slits and screen will have the desired effect of increasing the fringe spacing but the intensity of the fringes may become so low that fewer if any are clearly visible, making measurement difficult. Increasing the slit width to increase the intensity of light reaching the screen will allow more light to reach the screen but the larger slits will allow less diffraction to occur at each slit so the waves from each slit are less likely to superimpose and fringes will not be formed. Reduce the distance between the light source and the slits increase the intensity of the fringes. More diffraction at first slit will be required in order for both the secondary slits to be illuminated. Therefore narrower slit required and lower light intensity will result. Use coloured filters to enable the wavelengths of specific colours to be measured. A useful improvement but filters will reduce the intensity of light reaching the screen so the fringes may not be visible.
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33	a		initial KE = $\frac{1}{2} 50 \times 200^2 = 1.00 \times 10^6 \text{ J}$;	1	accept $1 \times 10^6 \text{ J}$
			final KE = $\frac{1}{2} (350 + 50) \times 25^2 = 1.25 \times 10^5 \text{ J}$	1	look for full working in calculations, not just final value accept 400 as final mass if $350 + 50$ shown elsewhere
			$\approx 1.3 \times 10^5 \text{ J}$; initial momentum: $50 \times 200 = 1.0 \times 10^4 \text{ kg m s}^{-1}$, final momentum = $(350 + 50) \times 25 = 1.0 \times 10^4 \text{ kg m s}^{-1}$	1	look for words like initial/before and final/after as labels to calculations of energy or momentum accept alphabetic suffixes e.g. i, b, f or a to p and E as labels Examiner's Comments This question required candidates to show that momentum was conserved but kinetic energy was not. The few candidates who simply wrote out the calculations with no supporting words of explanation earned very few marks. The calculations were not difficult, but needed to be in a structure of words to explain what the candidate was trying to show. Many strong candidates lost a mark by failing to show why the final mass of the object was 400 kg.
	b		work done deforming the spacecraft;	1	accept transfer to heat or thermal energy, ignore sound Examiner's Comments Although about half of the candidates were able to give a correct reason for the non-conservation of kinetic energy, very many forgot about the context and stated that the "missing" energy had become sound.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
34	a		-0.3(0);	1	
			-0.3(0);	1	allow ecf if $v = \text{incorrect } \Delta v$
			$(0.015 - 0.05 \times 0.45) = -0.0075 \approx -0.008$		no ecf for incorrect v
	b		any of the following: • formula has effectively infinite number of steps • not enough steps in the iterative calculation • time interval too long in iterative calculation • each iteration assumes constant speed	1	accept step-widths of zero time ignore constant acceleration other than zero acceleration Examiner's Comments This question was about an iterative calculation for an object in SHM. Although most candidates were able to complete the first two rows correctly, only a minority managed the calculation for the third row. Only a minority of strong candidates were able to explain why the values from the iterations were different from those obtained from a formula.
			Total	4	
35	a		J m^{-1}	1	Examiner's Comments This is a straightforward opening to the paper. The only problem here was recognising that the unit of force can be written as Jm^{-1} .
	b		J kg^{-1} (1)	1	
	c		J C^{-1} (1)	1	Examiner's Comments This is a straightforward opening to the paper. The only problem here was recognising that the unit of force can be written as Jm^{-1} .
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
36			$\lambda = \frac{h}{\sqrt{2 m E}}$ Either: (1) $= 6.6 \times 10^{-34} / (2 \times 1.7 \times 10^{-27} \times 2.8 \times 10^{-15})^{0.5}$ (1) $= 2.1(4) \times 10^{-13} \text{ m}$ (1) Or: calculate momentum to $3.09 \times 10^{-21} \text{ kg m s}^{-1}$ (1) $\lambda = 6.6 \times 10^{-34} / 3.09 \times 10^{-21}$ (1) $= 2.1(4) \times 10^{-13} \text{ m}$ (1)	3	Accept correct bald answer. Accept answers in the range $2.1 - 2.2 \times 10^{-13}$ Examiner's Comments This question was answered correctly by most candidates, gaining the correct value of $2.1 \times 10^{-13} \text{ m}$ through a direct rearrangement of the equation given, or by working through to an intermediate value of momentum ($3.09 \times 10^{-21} \text{ kg m s}^{-1}$)
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
37	a		$V = 8.4/3.2 \times 10^{-8} \text{ (1)} = 2.6 \times 10^8$	1	Examiner's Comments Similarly, this part was a very easy calculation of velocity giving the result of $4.2 \times 10^8 \text{ m s}^{-1}$.
	b	i	$m_e c^2 = 8.19 \times 10^{-14} \text{ J (1)}$ $\gamma = (8.0 \times 10^{-14} + 8.19 \times 10^{-14}) / 8.19 \times 10^{-14} = 1.98 \text{ (1)}$	2	Don't accept calculation of gamma from velocity calculated in (c) 1 mark max for rounding incorrectly to 1.97 Accept '2 x rest energy/ rest energy = 2' and similar arguments for second mark. Rest energy must be calculated for both marks Examiner's Comments This part of the question required candidates to calculate the rest energy of an electron and from this the gamma factor of the accelerated particle. This was more challenging to the weaker candidates. Some just divided kinetic energy by rest energy, others attempted to calculate the gamma factor through another method and could not gain the mark for calculating the rest energy of the electron.
		ii	substitution of γ value into $= 1/(1-v^2/c^2)^{0.5}$ or into a correctly rearranged formula (1) $V = 2.6 \times 10^8 \text{ (1)}$	2	Ecf from d(i) Evidence of calculation required. Bald answers score zero in this part of the question Examiner's Comments This was more challenging again. Only the top 40% gained both marks, reaching a value of $2.6 \times 10^8 \text{ m s}^{-1}$. Many came unstuck in attempting to rearrange the gamma factor equation and missed a relatively easy mark (no pun intended) for substituting the gamma factor correctly into the equation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Agrees with measured velocity (so supports Einstein's prediction) (1)	1	Do not accept 'they are the same' as it is not clear which velocities are being referred to. No ecf. Examiner's Comments The comments on the value obtained in (ii) were often too broad to gain credit 'less than too broad to gain credit 'less than the speed of light' was a common response.
			Total	6	
38	a		kg m s ⁻¹	1	
	b		kg m ⁻¹ s ⁻²	1	Examiner's Comments This was the usual units question to start off the paper. Very few candidates were unable to identify the correct SI unit for momentum. The equivalent unit for pressure proved to be more difficult, with many weak candidates clearly guessing instead of trying to work it out.
			Total	2	
39			initial momentum = $1.6 \times 0.56 - 2.4 \times 0.41$ = -0.088 N s;	1	look for some working as well as value (2 s.f.) for each mark accept either direction as positive accept 11/125 as value of total momentum Examiner's Comments It was good to see that most candidates were able to use the data provided to show that momentum was conserved in the collision.
			final momentum = $-1.6 \times 0.55 + 2.4 \times 0.33$ = -0.088 N s;	1	
			Total	2	
40			$\lambda = \frac{6.6 \times 10^{-34} \times 3.0 \times 10^8}{6 \times 10^{-15}} \quad (1)$ = 3.3×10^{-11} m (1)	2	Calculation of $f = 9.09 \times 10^{18}$ Hz worth one mark Correct bald answer worth two
			Total	2	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
41			B	1	
			Total	1	
42			B	1	
			Total	1	
43			D	1	
			Total	1	
44			D	1	
			Total	1	
45			A	1	
			Total	1	
46			B	1	
			Total	1	
47			A	1	
			Total	1	
48	a		$0.40 \times 0.36 = M_{\text{TOTAL}} \times 0.16 \checkmark$ $M_{\text{TOTAL}} = 0.90 \text{ kg} \therefore M_{\text{STAT}} (= 0.90 - 0.40) = 0.50 \text{ kg} \checkmark$	L M	method must use / imply conservation of momentum
	b		moving glider $F \Delta t = m \Delta v = 0.40 \times [0.16 - 0.36] \checkmark$ $= -0.08 \text{ (N s)} \checkmark$ OR state glider $m \Delta v = 0.50 \times [0.16 - 0] = +0.08 \text{ (N s)}$	M M	method must use / imply impulse = change in momentum evaluation for show that ignore signs $\pm$ magnitude only required
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
49	a		$\sin r = \sin 90^\circ / 1.00029 \checkmark$	S&C	method S&C because such unusual context, application and precision
			$r = 88.6(2^\circ) \checkmark$	S&C	evaluation
	b		Sun will be seen above the horizon when actually below $\checkmark$	M	accept virtual image of Sun seen above its real position /
			Because the light from below is refracted/bent so that it appears to come from above	H	Sun sets late accept diagram
	c		ray would curve / bend downwards $\checkmark$	M	accept it would curve, refracting more closer to Earth
			because it meet denser more refractive layers of Earth's atmosphere $\checkmark$	H	
			Total	6	
50	a		gravitational E_p gained = elastic E_p in spring $\checkmark$	L	principle make conservation of energy clear accept correct ref to E_k or to work done
			$h = Fx / [2mg] = 18 \times 0.25 / [2 \times 0.030 \times 9.81] \checkmark$	M	accept $mgh = (\frac{1}{2} mv^2) = \frac{1}{2} Fx$
			$= 7.7 \text{ (m)} \checkmark$	M	evaluation
	b		spring contains some E_k at point of launch / some E_k of rocket transferred to air by air resistance / friction against walls of tube results in temperature increase $\checkmark$	L	not just all energy is not transferred must identify the energy transfer
			So less energy transferred to E_p and so height less $\checkmark$	L	accept work done against air resistance.
	c		EITHER ball bearing reaches higher $\checkmark$ because smaller surface area / less air resistance / less energy transferred to air by air resistance $\checkmark$	M	ignore has same launch velocity
			OR lower because larger surface area / less streamlined $\checkmark$ more air resistance / more energy transferred or work done against air resistance $\checkmark$	M	
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
51	a	i	If there were more colours in the orange light, more colours would be observed in the diffracted image. AW ✓	1	Allow the red and green combine to create the orange light
		ii	Both red light and green light are in phase at central maximum AW ✓	1	Accept other correct suggestions, e.g. each 1 st order maximum has only one of the two wavelengths, or the intensity at this point is lower as it is convoluted with the single-slit diffraction envelope
	b	i	wavelength = hc/E $= 6.6 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1} / (1.6 \times 10^{-19} \text{ J} \times 1.9)$ $= 6.5 \times 10^{-7} \text{ m}$ ✓ $\sin \theta = 6.5 \times 10^{-7} \text{ m} \times 300 \times 10^3 \text{ m}^{-1} = 0.195$ ✓ $\theta = 11^\circ$ ✓	3	no s.f. penalty Accept bald correct answer for 3 marks
		ii	By ratio, angle to 1 st order for green = 9° ✓ wavelength = $\sin 9^\circ / 300 \times 10^3 \text{ m}^{-1} = 5.2 \times 10^{-7} \text{ m}$ ✓	2	Accept answers in range $5.1 - 5.3 \times 10^{-7} \text{ m}$ Accept bald correct answer for 2 marks
	c		$n = d \sin \theta / \lambda$, $\sin \theta \leq 1$ ✓ therefore, number of orders possible = d / λ ✓ λ_{green} is smaller than λ_{red} so d / λ gives larger ratio AW ✓	3	Allow argument by calculation. Each step must be clear Allow attempted calc. of θ for $n = 5$ and 6 for each wavelength for full marks if correct conclusion drawn
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
52	a		$\Delta mv = 2 mv \checkmark$ $\Delta t = \frac{2L}{v} \checkmark$ $F = \frac{\Delta mv}{\Delta t} = \frac{2mv}{(2L/v)} = \frac{mv^2}{L} \checkmark$	3	
	b		Statement showing that 1/3 of the velocity components of the N molecules will be perpendicular to a given face. $\checkmark$ Force on face $F = \frac{1}{3} \frac{Nmc^2}{L} \checkmark$ $P = F/A = \frac{1}{3} \frac{Nmc^2}{L \times L^2} = \frac{1}{3} \frac{Nmc^2}{V} \checkmark$	3	
	c		One from: • Particles have range of energies because of the range of speeds • Particles collide with one another • Energy exchanged in collisions To gain energy much greater than 'average' requires many consecutive collisions in which the molecule gains energy AW $\checkmark$ This is unlikely hence few molecules will gain sufficient energy to have much greater velocities $\checkmark$	3	
	d		$\frac{1}{3} Nm \overline{c^2} = NkT \Rightarrow m \overline{c^2} = 3kT \checkmark$ kinetic energy $= \frac{1}{2} m \overline{c^2} = \frac{3}{2} kT \checkmark$	2	
	e		r.m.s speed $= 1.2 \times 400 \text{ m s}^{-1} = 480 \text{ m s}^{-1} \checkmark$ $E_k = \frac{1}{2} \times 4.7 \times 10^{-26} \text{ kg} \times (480 \text{ m s}^{-1})^2 = 5.4 \times 10^{-21} \text{ J} \checkmark$ $T = 2 \times 5.4 \times 10^{-21} \text{ J} / (3 \times 1.38 \times 10^{-23} \text{ J K}^{-1}) \checkmark = 260 \text{ K} \checkmark$	4	Allow alternative correct methods
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
53	a		Level 3 (5–6 marks) Marshals argument in a clear manner, proceeding from correctly calculating acceleration of ball to an explanation that this is lower than expected acceleration = $g \sin \theta$. Considers possible reason for discrepancy in expected and recorded times its consequent effect. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Correctly calculates acceleration of the ball and makes considered statements about discrepancies in expected and recorded times. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Either correctly calculates acceleration of the ball OR makes valid suggestion as to why the recorded time was more than the expected time but does not provide any supporting reasoning. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points may include: - Acceleration of ball stated as $2s/t^2$ (or numerically) - Acceleration calculated as 1.98 m s^{-2} - Statement that student might expect $a = g \sin \theta$ $a = g \sin \theta = 9.81 \times \sin 20 = 3.35 \text{ m s}^{-2}$ - Expected acceleration using 0.85s calculated at 3.35 m s^{-2} - Suggested acceleration leading to a journey time of $(2.4/3.35)^{0.5}$ - Suggested journey time calculated at $0.846 \text{ s} \sim 0.85 \text{ s}$ - Some p.e. transferred to rotational k.e. or work done against friction - Clear reasoning to explain lower acceleration for example: energy transfer from ball will give lower k.e and thus lower velocity at the bottom of the ramp so the journey time will be longer than expected. (AW)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		Any five points from: • Change in p.e. the same in both cases • Therefore, final k.e. the same • Therefore, final velocity the same • Initial acceleration greater for the second slope • greater average velocity • therefore, time to reach the end of the slope will be less. • Assuming that the effects of energy loss/friction are the same for both tracks	5	
			Total	11	
54		i	$\Delta V_g = -GMm \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \checkmark$ $= -6.7 \times 10^{-11} \times 6.4 \times 10^{23} \times 2 \times 10^{30}$ $\left(\frac{1}{2.5 \times 10^{11}} - \frac{1}{2.1 \times 10^{11}} \right) \checkmark$ $= 6.5(3) \times 10^{31} \text{ J } \checkmark$	3	Correct bald answer gains three marks Other methods acceptable. One mark for calculating p.e. at greatest distance (aphelion) = $-2.3 \times 10^{32} \text{ J}$ One mark for calculating p.e. at smallest distance (perihelion) = $-2.98 \times 10^{32} \text{ J}$
		ii	k.e. of Mars at aphelion = $2.3 \times 10^{32} \text{ J } \checkmark$ k.e. at perihelion = $2.3 \times 10^{32} + 6.5 \times 10^{31}$ = $2.95 \times 10^{32} \text{ J } \checkmark$ velocity at perihelion = $3.1 \times 10^4 \text{ m s}^{-1} \checkmark$	3	Ecf from c (i) if answer to c(i) rounds to 7×10^{31} If 7×10^{31} used, $v = 3.1 \times 10^4 \text{ m s}^{-1}$ ($3.06 \times 10^4 \text{ m s}^{-1}$)
			Total	6	
55	a		Decay constant = $4.1 \times 10^{-9} \text{ s}^{-1} \checkmark$ Number of nuclei present = $1 \times 10^{22} \checkmark$ Activity $1 \times 10^{22} \times 4.1 \times 10^{-9} = 4.1 \times 10^{13}$ (Bq) $\checkmark$	3	Alternative methods possible, must show working and own answer.
	b		Total energy of gamma rays = $1.17 + 1.33 \text{ MeV } \checkmark$ power = $2.50 \times 10^6 \times 1.6 \times 10^{-19} \times 4.1 \times 10^{13} = 16 \text{ (W) } \checkmark$	2	
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
56	a		maximum work function = $6.6 \times 10^{-34} \times 3 \times 10^8 / 4.2 \times 10^{-7} \checkmark$ = $4.7 \times 10^{-19} \text{ (J)} \checkmark$	2	correct bald answer gains both marks
	b	i	$v = (100 \times 1.6 \times 10^{-19} \times 2 / 9.1 \times 10^{-31})^{1/2} \checkmark$ = $5.9 \times 10^6 \text{ m s}^{-1} \checkmark$	2	correct bald answer gains both marks
		ii	Gamma factor = $(5.1 \times 10^5 + 1 \times 10^2) / 5.1 \times 10^5 \checkmark$ = 1.0002 which is almost unity, so relativistic effects can be ignored. $\checkmark$	2	'gamma factor will be roughly one so relativistic effects can be ignored' gains one mark
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
57		i	Any four from: ✓✓✓✓ Initial acceleration is 9.81 ms^{-2}; No air resistance/only weight acting*; Velocity increases with decreasing acceleration; Because net downwards force = weight – air resistance and air resistance force increases with velocity*; Velocity eventually reaches terminal (constant) velocity; When weight is equal and opposite to air resistance*.	4	References to forces* must link to the relevant points to gain credit.
		ii	Initial start point and gradient same as original line ✓	1	
		ii	Terminal velocity at larger value and flattening out at a later time ✓	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Level 3 (5-6 marks) ✓✓ Detailed description of procedure, measurements, calculations and mitigation of uncertainty for at least two methods. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.</i> Level 2 (3-4 marks) ✓✓ Some description of procedure, measurements and calculations for at least two methods. OR Detailed description of procedure, measurements, calculations and mitigation of uncertainty for one method. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1-2 marks) ✓✓ Limited description procedure, measurements and calculations for one method. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative Scientific points may include: Visual timing • Metre rule & stopclock • Time from different heights • Plot average velocity against height • Identify trend • Reduce parallax Time lapse photography. • Ruler/tape measure as backdrop • Measure distance travelled between successive shots • Divide by time between shots. • Use value of velocity once it becomes constant. • Dark background easier to see against • Use high frame rate Use of video • Ruler and stopwatch in shot • Replay in slow motion • Record time to travel through a measured distance. • Don't use the acceleration part of trajectory/Start timing some distance below release point with pointers. • Dark background easier to see against • Use high frame rate Use of data logger • an ultrasound motion sensor connected to a below falling case. • Diagram of set up • Motion sensor records distance between sensor and cupcake case • Obtain plot of distance against time and find gradient for velocity.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
58		i	Combining $E = V q$ and $c = f \lambda$ with $E = h f$ to give $V q = h c / \lambda$ ✓	1	
		i	Hence $V = (h c / q) (1 / \lambda)$, (so gradient = $h c / q$) ✓	1	
		ii	Hence $h = \text{gradient} \times q / c$ ($= 2.0 \times 10^{-6} \times 1.6 \times 10^{-19} / 3.0 \times 10^8$) = $1.07 \times 10^{-33} \text{ J s}$. ✓	1	
		iii	Second line drawn within all horizontal error bars ✓	1	
		iii	Gradient calculated correctly from two read offs ✓	1	
		iii	Value for h calculated from gradient value ✓	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Level 3 (5-6 marks) ✓✓ Detailed quantitative comparison, explanation of the sources of error and improvements. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear relevant and substantiated.</i> Level 2 (3-4 marks) ✓✓ Some quantitative comparison, explanation of the sources of error and improvements OR detailed quantitative comparison and explanation of the sources of error or improvements OR detailed explanation of the sources of error and improvements. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1-2 marks) ✓✓ Limited quantitative comparison OR explanation of the sources of error OR improvements. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.	6	Indicative Scientific points may include: Comparison of values: - Percentage difference calculated - Compare with percentage differences in V and λ. Sources of error - Difficult to tell exactly when LED turns on. - Eye may be more sensitive to some colours than others. - Uncertain of precise wavelength will be emitted when just visible. Improved technique - Use a darkened room/tube to view - Record V against I for each LED - Plot values of V and I on graph to find a better value for threshold value. - Sketch graph showing V-I characteristics for LED and how to find threshold voltage from graph.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
59	a		First two marking points, any two from: - air particles in random motion - when particles collide with sail the particles / sail experience change of momentum - Force on sail is rate of change of momentum - Pressure is force per unit area Third marking point: As large numbers of particles involved, force is the same on both sides.	3	Accept 'transfer of momentum' for change of momentum Accept equal numbers of collisions on both sides of sail Examiner's Comments This question was about air pressure and dynamics. It focused largely on topics covered in the first year of the course. This part asked for a particulate explanation of air pressure. Whilst many candidates gained one or two marks for this part, relatively few gained all three marks. Once again, this was often due to leaping over steps in an argument. For example, writing 'air particles collide with the sail and exert a force' is correct, but does not explain the situation in sufficient depth as it misses the discussion of momentum changes (i.e. 'how' the particles exert a force). Weaker answers ignored the requirement to give a particle explanation and described the situation in terms of bulk forces.
	b		accelerating force = $300 \cos 50^\circ$ ✓ = 193 N ✓ $t = \sqrt{\frac{2 \times 50}{193/135}} \text{ ✓}$ = 8.4 s ✓	4	Correct bald answer gains four marks If $\sin 50^\circ$ used, 2 marks max : $t = \sqrt{\frac{2 \times 50}{230/135}} \text{ ✓}$ t = 7.7 s ✓ (7.66) Examiner's Comments This part was accurately and clearly answered by the majority of the candidates.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
60	a	i	0.2 m ✓	1	Examiner's Comments This question was about the resolution of the eye. Part (a)(i) required candidates to give the spread of a group of data. A sizeable minority of responses confused spread with range.
		ii	One mark from: % uncertainty in distance measurement ~ 3% ✓ uncertainty in separation = 25% ✓ Second mark: both uncertainties correctly given and sensible comparison drawn.	2	ECF from (a) (i): 0.4 m give % uncertainty ~ 7% Examiner's Comments Part (a)(ii) involved comparing uncertainties. To gain marks in this question the candidates had to give at least one percentage uncertainty. Many did not do this and gave rather descriptive responses that did not have sufficient merit to be awarded a mark.
		iii	Minimum angle = $(2 \times 10^{-3} \text{ m}) / (6 \text{ m}) = 0.0003 \text{ rad}$ ✓ Uncertainty of the order $\pm 0.0001 \text{ rad}$ ✓ Evidence of how uncertainty estimated ✓ SF penalty if uncertainty s.f. not consistent with value s.f. of angle.	3	Look for calculating maximum and / or minimum possible final values. Accept argument from % uncertainty Examiner's Comments Part (a) (iii) proved to be challenging. Many candidates did not use radian angles directly but calculated an angle in degrees before converting it to radians. This could still gain a mark if the answer was correct but it is, at best, an inelegant method. The better responses described how the percentage uncertainty was used to find the absolute uncertainty or how the range of angles was found from the spread of the data. Lastly, many candidates failed to gain the third mark through giving the uncertainty with excessive significant figures.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		Calculation of resolution to 0.0002 radian✓ (1 sf) Comment: suggests better resolution than eye but agree to 1 sf with smallest angle from experimental data (with uncertainty taken into account) ✓	2	Ignore s.f. error Second point needs to make a clear link to range of experimental results. Examiner's Comments Part (b) was also challenging. Once again, the calculation was straightforward and the candidates performed it with ease. Linking the results to the experimental data was rarely clearly described, with most responses merely pointing out the difference rather than considering the reason.
			Total	8	
61			Different parts of the atmosphere will have different refractive indices ✓ Leading to changing direction of light as it travels through the atmosphere and therefore a distorted image AW✓	2	Accept different air densities cause refraction. Second mark dependent on first. Examiner's Comments This question asked candidates to explain why turbulence in the atmosphere limits resolution. Although this was answered correctly by about half the candidates many responses confused refraction and diffraction effects.
			Total	2	
62			D	1	Examiner's Comment This question to select a pair of vector and scalar quantities was well answered by the vast majority of candidates.
			Total	1	
63			C	1	Examiner's Comment This question concerned selecting a correct statement about electron diffraction. A good majority of candidates were successful.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
64			C	1	Examiner's Comment Candidates had to select a correct statement about the probability of arrival of a photon at a position. The vast majority were successful in selecting answer C: proportional to (resultant phasor amplitude) ² .
			Total	1	
65			A	1	Examiner's Comment This question involved the addition of three scaled vector forces. The vast majority of candidates were successful. The most common incorrect answer was B, a vector of correct magnitude but pointing in the opposite direction.
			Total	1	
66			D	1	Examiner's Comment Candidates had to predict the braking distance of a car with quadrupled speed. Most chose correctly. The most common error B was to assume that the distance also quadrupled, instead of increasing sixteen-fold (distance $\propto$ speed ²).
			Total	1	
67			C	1	Examiner's Comment The vast majority of candidates correctly realised that the power $\propto v^3$ and correctly chose C. The most common error was B which assumed power $\propto$ force $\propto v^2$, as in the given equation for drag force.
			Total	1	
68			B	1	Examiner's Comment Most candidates could select the correct statement comparing the α -particle and the p-particle.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
69	a		$\frac{c/c_{\text{glass}}}{c/c_{\text{water}}} \checkmark$	1	Examiner's Comment In this part nearly all candidates could complete the algebraic reasoning for the refractive index from glass to water which was pleasing.
	b		$n_w = 1.3 / 1.6 = 0.81(3) \checkmark$ $r = \sin^{-1}(\sin 30^\circ / 0.813) = 38^\circ \checkmark$ OR $n_1 \sin \theta_1 = n_2 \sin \theta_2$ method $r = \sin^{-1}(\sin 30^\circ \times 1.6 / 1.3) \checkmark = 38^\circ \checkmark$	1 1	first mark for evaluating / using correct index not 24 ° have inverted the index only if this method is clear allow $n_1 / n_2 = 1.6 / 1.3 = 1.2(3)$ for first mark Examiner's Comment This part was much more discriminating, as candidates are more used to handling refraction from air to glass (or water). The majority used the inverse of the correct refractive index, despite their reasoning in (a), and got the incorrect refraction angle of 24°. Candidates should have been expecting: angle $r >$ angle i given that the light was entering a less optically dense medium. The ratio of refractive indices from air to medium, method or the $n \sin (\theta) = \text{constant}$ method, were credited provided the candidates got the correct angle of refraction at (38°).
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
70			draw tangent and suitable large Δ at $t = 1$ or 3 s ✓	1	method accept tangent and $\Delta s / \Delta t = 1.6 / 1.5$ ignore signs here award magnitude
			1.1 (m s ⁻¹) ✓ OR identifying $A = 0.70$ m $f = 1/4$ Hz $v_{\text{max}} = A \omega$; $= 0.7 \times 2\pi \times \frac{1}{4} = 1.1$ (m s ⁻¹)	1	evaluation accept in range 1.0 to 1.2 (m s ⁻¹) alternative method for two marks Examiner's Comment This was a straightforward question on S.H.M. but was well answered by the majority and gave good discrimination. In part (a) candidates could draw a tangent to the curve and find the gradient (maximum velocity when displacement is zero), or calculate using $v = A \omega$ with values read from the graph ($A = 0.70$ m, $\omega = 2\pi / 4$ rad / s). Both methods give the velocity at (1.1 m / s) and a tolerance ± 0.1 m / s was allowed for graph method, here sign was ignored and only magnitude inspected. The most common error for the graphical method was for candidates to take too small a triangle for the gradient and estimate outside the acceptable range, they should be encouraged to take the maximum triangle they can fit in when applying this method (either full Δy or Δx range) to minimise reading uncertainties.
			Total	2	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
71	Level 3 (5–6 marks) Marshals argument in a clear manner and includes clear explanation of three strands: • work done • area under $E(R)$ field graph • gradient of $V(R)$ potential graph <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Shows clear understanding of at least two of the three strands above to the argument or covers all three at a superficial manner and does not include enough indicative points for level 3. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Makes at least two independent points that are relevant to the argument but does not link them together and shows only superficial engagement with the argument. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response worthy of credit scores zero No response record NR	6	Look for number of strands attempted to help decide the Level, then look at quality. Do not penalise incorrect signs in this answer. Indicative scientific points may include: work done • work W is done against electrical attraction of + and – charges which increases the electrical potential energy of the system • + charge is worked on in raising it up the potential well • of the – charge • $W_{\text{total}} = \Sigma \Delta W = 2 F \Delta s = 2 F \Delta R$ area under $E(R)$ graph: accept algebraic or numerical reasoning • $W_{\text{total}} = 2 \Delta W = 2 \Sigma \Delta s = 2 \Sigma \Delta R$ only credit once • $E_{\text{field}} = F / q$ but test charge is unit charge $q = 1 \text{ C}$ • in this example $E_{\text{field}} = F$ • $\therefore W = \text{Area under the field graph}$ • $15 \text{ squares} \times 4 \times 10^6 \text{ J per square} = 60 \text{ MJ C}^{-1} \text{ or MV}$ • agrees with increase in potential from (–90 to –30) MV • recognising that $E = k Q / R^2$ gradient of $V(R)$ graph • $E_{\text{field}} = - \text{gradient of } V(R) = - dV / dR = - \Delta V / \Delta R$ • tangent to graph drawn and shown = field • e.g. at $R = 200 \text{ m}$ grad = $(120 \text{ MV}) / 600 \text{ m} = 2 \times 10^5 \text{ V m}^{-1}$ • agrees with the field at $R = 200 \text{ m}$ of $20 \times 10^4 \text{ V m}^{-1}$ • recognising that $V = k Q / R$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					check graphs for annotation credit Examiner's Comment The final LOR question part (d) saw candidates given graphs of the field and potential near an isolated -1 C charge. They were asked to explain the relationship between electric field and electric potential by considering movement of a unit $+1\text{ C}$ charge from $R = 100\text{ m}$ to 300 m. This was a deliberately testing question on a challenging aspect of A level physics, some candidates were running short on time, although very few made no attempt at all. The majority gained some credit, many made one or two isolated points reaching L1, (commonly recognising the appropriate shapes of the graphs as $1/R^2$ and $1/R$) and fewer reached L2 and L3. Again candidates limited the scope of the level reached by missing one or more of the strands that they should have covered: the work done, the area under the $E(R)$ field graph and the gradient of the $V(R)$ potential graph. Better candidates drew potential gradients, estimated values and showed equivalence to the field at a point, and / or numerically integrated (by counting about 15 squares under the field graph) between the suggested R values showing the change in potential to be 60 MV, which agreed with the change on the potential graph from going from -90 MV to -30 MV. Candidates should be encouraged that writing good technical physics with equations, quantitative estimates, diagrammatic reasoning and explanation will all be credited, some seem to think that only prose is acceptable for this type of question.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
72	a		Any three from: • Waves reflect from the ends of the tube • superpose when they pass through one another • A formed when waves superpose in phase • N formed when waves superpose in antiphase	3	'Reflection' alone insufficient for first marking point. Accept 'interference' or 'superimpose' for 'superposition'. Do not credit 'constructive interference' for 'in phase' or 'destructive interference' for 'in antiphase' Examiner's Comments This question was about standing waves in air. This is an area that has been frequently examined in Advancing Physics in the past. Part (a) required candidates to explain the formation of standing waves in a tube. Although most were familiar with the concept and gained a mark for correct use of the term 'superposition', few gained all three available marks. This was, for the most part, due to lack of precision in language. For example, stating that the waves in the tube were 'reflecting' without giving an indication of where the reflection took place. It may be helpful to remind candidates to include any relevant information in their answers which is not in the stem of the question and to ensure that their explanations clearly move from one statement to the next.
	b		Even pattern: A N A N A✓ Explanation: same velocity so half wavelength gives twice frequency✓	2	Must make it clear that the relationship between wavelength and frequency depends on constant velocity. Quoting $v = f\lambda$ not sufficient without clear statement of constant v. Examiner's Comments Part (b) asked candidates to draw the next possible standing wave. This was answered confidently by the majority. However, many candidates failed to get the second mark as they assumed that the velocity remaining constant was a given that did not need to be stated. This omission rendered their explanation incomplete.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\frac{pV}{\rho} = \frac{nRTV}{m} \checkmark$ $\frac{p}{\rho} = \frac{RT}{M} \checkmark$ $\text{As } v = \sqrt{\frac{kp}{\rho}}, v = \sqrt{\frac{kRT}{M}}$	2	Other routes acceptable. Clear and unambiguous working required. Look carefully for confusion between similar symbols. Examiner's Comments Part (c) asked candidates to rearrange some equations to reach a given relationship and was performed clearly by most.
	d		$\frac{f_{303}}{262} = \sqrt{\frac{303}{293}} \checkmark$ $\frac{f_{303}}{262} = 1.017 \checkmark$ frequency = $1.017 \times 262 = 266 \text{ Hz} \checkmark$	3	Correct bald answer gains three marks Credit $f \propto \sqrt{T}$ one mark Value 271 Hz gains zero marks Examiner's Comments Part (d) was a little more challenging as candidates had to use the dependency on the square root of temperature revealed in (c) and needed greater mathematical competence. Weaker responses used incorrect equations or ignored the square root in the relationship.
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
73		i	Minimum of three equally spaced horizontal lines between poles. Arrows on lines N to S	1 1	Lines should be perpendicular to magnet surface and start and touch (or finish close to) surface. Accept curved lines to show edge effects. Ignore field lines outside of the magnet assembly. Examiner's Comments Part (a)(i) was well answered, with nearly all candidates showing the correct direction of the magnetic field. Some lines were badly drawn (without a ruler) or were not equidistant. There tended to be a larger gap between the lines near the position of the wire. A few candidates attempted to draw the field lines when the wire carried a current.
		ii	Interaction between magnetic field of wire and permanent magnetic field gives rise to a (vertical) force on the wire; which produces a (reaction) force on the magnets (hence balance reading changes)	1 1	Reference to Newton's third law. Examiner's Comments In part (ii) reference to $F = BIl$ was insufficient to gain the mark, as they needed to refer to the interaction of the two magnetic fields. Few candidates included any explanation of the action/reaction pair of forces.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
74	a		$v = 0.24 \times 60 \times 3 \times 10^8 / \{60 \times 60 \times 24\} \checkmark$	1	accept $\{ 4.32 \times 10^9 \text{ m} \div 8.64 \times 10^4 \text{ s} \}$ Examiner's Comment In this part although a straightforward velocity = change in displacement / time calculation there was plenty of scope for error with the rather complex units, as displacements were given in light-minutes, separated by one whole day. These needed to be converted to metres by multiplying by , the speed of light, then subtracted to find the change in displacement and then divided by the number of seconds in one day. With all these pitfalls it was pleasing that the majority of candidates achieved both marks for the answer (50 km/s).
			$= 5.0 \times 10^4 \text{ (m s}^{-1}\text{)} \checkmark$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		range $R = 44.444 \times 60 \times 3 \times 10^8 = (8.0 \times 10^{11} \text{ m}) \checkmark$ $V_{\text{perp.}} = R \omega = 8.0 \times 10^{11} \times 1.8 \times 10^{-3} / (24 \times 3600) \checkmark$ $= 1.66 \times 10^4 \text{ (m s}^{-1}\text{)} \checkmark$ OR alternative method for last 2 marks $s_{\text{perp.}} \approx R \theta = 8 \times 10^{11} \times 1.8 \times 10^{-3} = (1.44 \times 10^9 \text{ m})$ $v_{\text{perp}} = s_{\text{perp}} / t = 1.44 \times 10^9 / (24 \times 3600)$ $= 1.66 \times 10^4 \text{ (m s}^{-1}\text{)}$	1 1 1	accept ranges based on either time or mean time of signal travel all give range $= 8.0 \times 10^{11} \text{ m}$ (2 S.F.) method evaluation method accept $\sin \theta \approx \tan \theta \approx \theta$ for small angle θ n.b. $s_{\text{perp}} = 0.08$ light minutes can be credited more method & evaluation allow answers close to 280 m s^{-1} to score 2/3 marks because light mins treated as light secs so 1/60 of correct answer so one small error Examiner's Comment This part was even harder and more discriminating to find the asteroid velocity component perpendicular to the line of sight. The neatest solution was to use $v = R \omega$ since the angular position shift of the asteroid in the day was given at 1.8 mrad. Where R is the range, either min. max or mean over the one day period makes negligible difference to the answer (17 km / s). Some candidates did a full analysis of the triangular geometry using the cosine rule and got the correct answer - well done, but must have taken more time. The most common error was to incorrectly treat the tiny angular shift 1.8 mrad as the angle of the asteroid's velocity to the line of sight and then solve using $\sin \theta$ or $\tan \theta$ or θ (small angle) which gave an answer far too small, of about (90 m / s). It was pleasing also that the vast majority of candidates were prepared to have a go at this novel question using small angles in radians.
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
75	a		$v_{\text{terminal}} = 0.65 \text{ (m s}^{-1}\text{)} \checkmark$	1	v_{terminal} read from graph accept in range 0.64 to 0.66 (m s ⁻¹)
			$\pm 0.02 \text{ (m s}^{-1}\text{)} \checkmark$	1	uncertainty estimate apply SF penalty for 2 or 3 SF e.g. 0.019 or 0.0195 (m s ⁻¹) scores 0 Examiner's Comment A good majority of candidates could read the terminal velocity from the graph in part (a). About half went on to estimate the uncertainty in it given $\pm 3\%$ uncertainty in velocity measurement. (0.65 $\pm$ 0.02 m/s). The most common error was to quote the uncertainty as ± 0.0195 m/s which was penalised as a S.F. error, as it shows a lack of appreciation of significance.
	b		(at $t = 0.5 \text{ s}$) ball is accelerating (and a is decreasing) $\checkmark$	1	credit numerical estimates of acceleration $\approx 0.55 \text{ m s}^{-2}$
			because downwards weight is larger than upwards drag force $\checkmark$	1	accept in algebra $W > D$ or $> (D + U)$ accept if upthrust U is overlooked / air resistance or friction for drag not U confused with D not just because net force is downwards Examiner's Comment In this part nearly all got the first mark for saying the ball-bearing was still accelerating, but only half went on to correctly account for this using a resultant force argument. (There was no need for them to consider the upthrust of the fluid to gain full credit here).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	temperature should be monitored or held constant ✓ since the viscosity / drag force will depend on T ✓	1 1	accept density of the glycerol ; as it will affect upthrust accept viscosity of the glycerol ; as it will affect drag accept purity of the glycerol ; as moisture affects viscosity accept density of ball bearing ; as it will affect the weight accept mass of ball bearing ; as it will affect the weight not height drop or air bubbles in glycerol or keep same liquid ignore edge effect Examiner's Comment This part was well answered by most, who named and could explain a control variable for the experiment to see how terminal velocity depends on the diameter of ball-bearings. A suggestion that was not accepted was the height of drop of the ball-bearing above the surface. In part (ciii) there was an opportunity to run a data test on some values to test for $v \propto D^2$.

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Question			Answer/Indicative content	Marks	Guidance
		ii	$D^2 / v_T = \text{constant}$ OR $v_T / D^2 = \text{constant}$ ✓ D^2 / v_T values: 144, 145, 144, 204, 221 ($\text{mm}^2 \text{m}^{-1} \text{s}$) ✓ ✓ OR v_T / D^2 values (6.9, 6.9, 6.9, 4.9, 4.5) $\times 10^{-3} (\text{m s}^{-1} \text{mm}^{-2})$ ✓ ✓	1	proposal if $v_T / D^2 = \text{constant}$ accept log / log graph allow $V_T = k D^2$
			noticing smallest three b.bs have almost constant k / largest two b.bs have a different sensible constant / smallest and largest b.bs k not constant consideration of quantitative uncertainty in k $D^2 / V_T = 144, 145, 144$ constant to $\pm 0.3\%$ / $= 204, 221$ constant to $\pm 4\%$ correct statement about their test showing proportionality or not showing proportionality If graphs sketched 2 marks from: sketches of log / log graph or sketches of V_T vs D^2 correct comment on gradient or linearity of their graph	2	working expect at least 2 data tests for credit 1 mark and all 5 data tested for 2 marks accept table of D^2 values (for v_T vs D^2 sketch graph) accept calculated log V_T and log D values same rule on data conclusions 2 marks available for any sensible test involving 2 or more data points accept any two or all three of smallest b.bs have almost constant k accept largest two b.bs have sensible constant k (if only 2 tested) accept use of 3% uncertainty based on the uncertainty in V_T from (a) OR comment on differences in their k values 144, 221 show increase in k of about 50% / decrease of about 35% for graph method candidates Examiner's Comment Candidates should be advised to run a quick numerical test on all the data offered (not just 2 or 3 data points in case there is a trend upon which they could comment).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Here looking for $D^2 / v = \text{constant}$ or the inverse is quick and easy on a calculator. Some candidates go to the trouble of plotting a graph and looking for proportionality, but if graph paper is not offered this is probably not advisable due to inherent inaccuracy of judgement by eye. Some even sketched a log / log graph, but the time taken must be considerable. All these methods if correctly applied were fully credited. This was a 5 mark question so there is time to invest in getting a good quick test and reaching a sound conclusion. The first mark was for the proposed data test, the next for testing two data sets, and another for testing all data sets. Finally two marks for reaching a full conclusion. Here the three smallest ball-bearings did show a consistent constant ($D^2 / v \approx 144$) but the larger two bearings have higher values (204, 221). Then comment on the initial proposal so not proportional across the whole range, or on the repeatability of the constant value for the last two marks. This part was well answered, the most common errors were to only test two datum points and to under-conclude and thus score only one of the two marks available in both cases.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
76	a		When (apparent) weight force is equal and opposite to air resistance/drag force ✓ no <u>resultant/net</u> force ✓ there is no acceleration ✓	3	IGNORE any reference to electric force $F = Eq$ ALLOW forces are in equilibrium for second marking point. ALLOW it is travelling at <u>terminal</u> velocity for third marking point. Examiner's Comments Most candidates achieved at least one mark here for stating that the oil drop reached terminal velocity. The other two marks were more challenging as it was necessary to state that the force from air resistance was equal and opposite to the weight, so therefore the resultant force is equal to zero. Candidates needed to correctly define the two forces and more often than not, the word 'opposite' was omitted. A few candidates did not realise that there was no electric force at this point. Exemplar 3 As the drop is very small, its terminal velocity in air is very low due to resistive forces, therefore it reaches this speed very easily. So inside the experiment the drop will fall at constant speed. This response gains one mark for stating that the oil drop reaches terminal velocity. However there is no mention of the weight of the oil drop being equal and opposite to the air resistance force, thereby giving a resultant force equal to zero.
	b	i	Field strength = $V \div d = 390 \div 6 \times 10^{-3}$ $= 6.5 \times 10^4$ ✓ $V \text{ m}^{-1}$ or $N \text{ C}^{-1}$ ✓	2	Examiner's Comments Most candidates were able to perform this relatively straightforward calculation, with a minority giving an incorrect unit or making a power of ten error.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$F = Eq$ or $F = mg$ ✓ Equate forces and rearrange to give $q = mg \div E$ ✓ Charge q ($= 2.15 \times 10^{-15} \times 9.81 \div 6.5 \times 10^4$) $= 3.2 \times 10^{-19} \text{ C}$ ✓	3	ALLOW ecf of incorrect value for E from part (i). Second mark can be implicit in the calculation Bald correct answer gains three marks <u>Examiner's Comments</u> This calculation proved to be slightly more challenging than part (ii). A few candidates attempted to use an incorrect equation, such as the force between two point charges.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Causing apparent weight of the oil drop to be less than actual weight / electric force can be smaller ✓ Calculated value is higher than actual value.✓	2	ALLOW $F_E + F_B = mg$ / $F_E = mg - F_B$. ALLOW actual charge is lower or calculated charge is too high. Examiner's Comments There were several confusing responses to this question. Candidates needed to be precise about which force was which and they needed to be clear about whether they were talking about the calculated value for charge or the actual charge in order to gain the marks. Exemplar 4 Smaller force required by the electric field (as buoyancy is the same direction) to equal downward force of mg. So $F = mg - B$ force from buoyancy, so $q = \frac{mg - B}{E}$, so charge is smaller. This response has stated that the electric field strength would be less than that calculated, which is incorrect as the electric field strength is only dependent on the potential difference and the distance between the two plates. It is the electric force which now needs to be smaller, and as the field strength is the same, this means that the value calculated for charge was too large. This response gets one mark.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		The weight and the electric forces are acting downwards/in the same direction. ✓ Oil drop will accelerate towards bottom/positive plate. ✓	2	ALLOW The oil drop will reach a higher/faster terminal velocity. <u>Examiner's Comments</u> Responses to this question also needed to be specific. Candidates who just stated that the oil drop would move towards the bottom plate were not credited, as it was necessary to state that it would accelerate downwards. The other marking point was for clearly stating that both the electric force and the weight were acting in the same direction, so candidates who just said that the electric force was now downwards did not gain the mark.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
77	a	i	$t = \sqrt{(2s/a)} = \sqrt{(2 \times 56/9.8)} \checkmark$ $= 3.4 \text{ s (2 s.f.) } \checkmark$	2	Accept 3.38 s Examiner's Comments Nearly all the candidates reached the correct value of 3.4 s
		ii	Force on body of mass $m = mg$ Acceleration $a = F/m = mg/m \checkmark$ $mg/m = g$ independent of mass $\checkmark$ AW	2	m.p.1 is for $W=mg$ and $F=ma$ m.p.2 is for equating these and eliminating m Arguing that $g = (-)GM/r^2$, independent of mass m gives one mark. Can gain both marks for clearly expressed non-algebraic reasoning. Examiner's Comments This question was discriminating. Lower ability candidates simply stated that the acceleration due to gravity is independent of mass – which is given in the stem of the question. The best answers showed a clear understanding of the proportionality of the weight with mass and the inverse proportionality of acceleration and mass. This could be expressed algebraically or in words.
	b	i	$a = 9.80 \text{ (m s}^{-2}\text{)} \checkmark$ $v = 3.92 \text{ (m s}^{-2}\text{)} \checkmark$ $s = 0.39 \text{ (m)} \checkmark$	3	Unrounded value is 9.7969... Unrounded value is 3.922 Unrounded value is 0.392 Do not penalise excessive sig. figs. in this question Examiner's Comments Nearly all candidates gained marks on this part. 9.81 was a common and incorrect value given for acceleration.

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Question			Answer/Indicative content	Marks	Guidance
		ii	Level 3 (5–6 marks) Marshals argument in a clear manner. Makes clear, unambiguous comparison of results. Clearly explains the limits of iterative modelling and explains how the model can be improved. Shows understanding of the observational situation and the limits of precision of simple observation. Clearly draws all the ideas together to a logical conclusion. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Correctly retrieves data from graph and shows some understanding of limits of iterative modelling but this understanding may be incompletely expressed. Makes correct statements of the observational situation but does not draw these together into a reasoned conclusion. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Retrieves data from graph and makes sensible comparison between the two predicted times. May make a superficial comment about iterative modelling but does not drill down to the fundamental reason for the inaccuracy. May make a superficial comment about the observational situation. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points may include: Model: - time to fall = 3.85 to 3.90 s - model holds acceleration / velocity constant over each time interval - holding acceleration constant will suggest higher average velocity - model underestimates time of fall - model can be improved by reducing time intervals - reducing time interval between calculations produces a model closer to continually varying acceleration. Observational situation: - less than one second/about $\frac{1}{2}$ second difference between model without drag and model including drag. - Time difference (of about $\frac{1}{2}$ s) could be to be detected (if balls dropped simultaneously) - If balls not dropped simultaneously, timing technology insufficiently accurate to distinguish drop times. - Difference in time for fall between similar (but different) masses difficult to observe if K values similar - Observations would be naked eye/not have modern equipment (video etc) - Subjective element in observational judgements. <u>Examiner's Comments</u> This is the first of three Level of Response questions. The question requires candidates to consider the use of iterative modelling and its limitations and explain whether the difference in time of fall of different masses would be observed in 1589. The majority of candidates produced Level 2 or Level 3 responses. The data from the graph was correctly interpreted in most responses and the limitations of iterative

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Question	Answer/Indicative content	Marks	Guidance
			modelling were clearly described by most candidates. It was pleasing to see that many responses showed clear structure, linking the difference in time between the calculation in 4 (a) (i) with the value from the graph and considering this in terms of measurements in 1589. The better responses commented on the difference between the two values being less than would be observed for two masses with similar drag coefficients. Exemplar 6 1. Use data from the graph to estimate the time for this ball to fall from the top of the Leaning Tower to the ground. 2. Explain why the model may not give an accurate result and how the model could be improved. 3. Compare your estimate with your value from (a)(i) and use this to suggest and explain whether observers in 1589 would have been able to distinguish between the time of fall of relatively similar masses from the top of the tower. [6] 1. Using the graph, the time taken to fall 56m is $\sim 3.86s$. 2. The model may not give an accurate result because it assumes that during the interval of Δt, the acceleration is constant and that the velocity only changes at the start (and end) of each interval. This may be inaccurate because in reality the acceleration and velocity are constantly changing. In order to improve the model, small intervals of Δt could be used, eg 0.1s and this means taking more iterations. This improves the accuracy since it means that the acceleration has a small error and difference between the real and constant value. This means that the final velocity is more accurate and so the path of the displacement will be more close to the real world data. 3. The graph suggests that it would take 3.86s but the calculation suggests it ~~will~~ take 3.88s however the value in (a)(i) does ~~not~~ factor in the effects of air resistance which explains why it suggests that a shorter time is needed. Assuming that a massive object would have air resistance but a light object would have negligible, then would be able to see the difference of 0.4s over large ~~short~~ heights like 56m. (For similar masses they would not be able to if air resistance was the same). This is a good example of a Level 3 response. The first thing to notice is that the candidate has annotated the question with '1', '2' and '3' to help him/her to cover

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Question			Answer/Indicative content	Marks	Guidance
					all the points in the answer. The time of fall is correctly stated followed by a clear explanation of the limitations of the iterative model. This explanation includes an understanding of the constantly changing acceleration of the falling mass. The final paragraph clearly states that the time interval between the two values could be determined by observers at the time and comments that the time difference for similar masses would be more difficult to determine. There was not enough explanation of the last point to gain 6 marks for the response so the response gained 5 marks. Other responses to this question included comments about the value of K for different masses.
			Total	13	

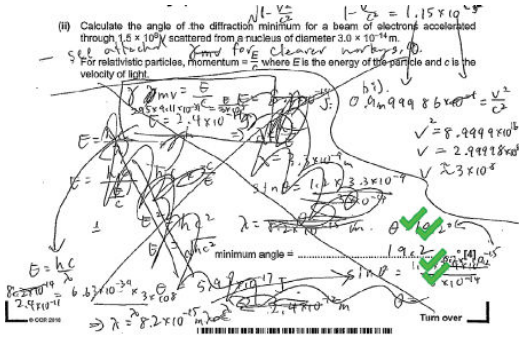
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
78	a	i	Any three from: Evacuating apparatus reduces interactions (over a given path length) ✓ Deflections can affect outcome of experiment ✓ Alpha particles highly ionising ✓ So lose their energy in a short distance through interactions with air particles ✓	3	AW throughout. Or 'no particles in their way' Examiner's Comments This question required candidates to show an understanding of the properties of alpha particles. Nearly all responses gained at least one mark. Some of the marking points were missed by many candidates; for example, few responses considered energy loss in interactions. More encouragingly, a good proportion of candidates made well-argued comments for the effect of deflections on the experimental results.
		ii	$r = 79 \times 1.6 \times 10^{-19} \times 2 \times 1.6 \times 10^{-19} \times 9 \times 10^9 /$ $4.5 \times 10^6 \times 1.6 \times 10^{-19} \checkmark$ $= 5.056 \times 10^{-14} \text{ m} = 5.1 \times 10^{-14} \text{ m} \checkmark$ Smaller r because a more energetic alpha particle would get closer to the nucleus before its electric potential energy is equal to its initial k.e. AW ✓	3	Accept $5.0 \times 10^{-14} \text{ m}$ Correct bald answer gains m.p.1 & m.p.2 Not just 'smaller r'. Examiner's Comments This is a standard calculation and most responses reached the correct value for closest approach. Common errors included using the nucleon number in the calculation rather than the proton number and using r^2 as the denominator rather than r. The third marking point required candidates to explain why the value of the radius (closest approach) changes. The best answers showed understanding of the physics of the situation and linked initial kinetic energy to the electrical potential energy at closest approach. As in other questions, some responses did not explain the result but merely stated it; 'r decreases' was not enough for the mark.

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	b	i	Gamma factor = $(150 \text{ MeV} + 0.51 \text{ MeV})/0.51 \text{ MeV}$ ✓ $= 295$ ✓ $v = 3 \times 10^8 \times \sqrt{(1 - 1/295^2)}$ ✓ $= 3.00 \times 10^8$ to 3 s.f. (calculator value = 2.99998×10^8) ✓	4	Ecf within question. If rest energy from numerator omitted, gamma factor = 294. Two marks maximum for the question. Must show clear working credit mp4 for e.g. $\sqrt{(1 - 1/295^2)} = 0.999994 \approx 1$ <u>Examiner's Comments</u> This question requires understanding of the gamma factor as well as the ability to identify the rest energy and kinetic energy of the electron from the data given. Successful responses worked through to the value of 295 for the gamma factor using 0.51 MeV and 150 MeV as rest energy and kinetic energy. Other candidates reached the value of 295 after unnecessarily converting the energies into joules. An incorrect gamma factor of 294 was commonly found. In such cases candidates had misinterpreted the equation 'total energy = gamma factor × rest energy' to mean 'kinetic energy = gamma factor × rest energy'. Such responses often gained the last two marking points of the calculation. A significant number of responses did not gain any marks for this question, perhaps due to its unstructured nature.

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	ii $p = 1.5 \times 10^8 \times 1.6 \times 10^{-19} \text{ J} / 3.00 \times 10^8 \text{ m s}^{-1} = 8.03 \times 10^{-20} \text{ N s} \checkmark$ $\lambda = h/p = 6.63 \times 10^{-34} \text{ J s} / 8.03 \times 10^{-20} \text{ N s} = 8.25 \times 10^{-15} \text{ m} \checkmark$ $\sin \theta = 1.2 \times 8.25 \times 10^{-15} \text{ m} / 3 \times 10^{-14} \text{ m} = 0.33 \checkmark$ $\theta = 19^\circ (.4) \checkmark$	4	ECF within question Correct bald answer gains all four marks Algebraic reasoning that $\lambda = hc/E$ gains credit for first mark. Examiner's Comments This is the second fourmark, unstructured calculation in the question. Although the stem of the question gives both the equations required to reach a value for minimum angle the question proved challenging. The best responses showed clarity and confidence in the calculation, often performing the calculation in one step having clearly written down the equation and showing the values used. Less impressive responses could still gain marks by correctly working out an angle from an incorrect value for wavelength. These marks were missed by candidates who chose not to show clear working or whose calculated wavelength value led to a value of sine of more than unity. Exemplar 7 

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Question	Answer/Indicative content	Marks	Guidance
			5 biii: $\gamma m v = \frac{E}{c}$ $E = \gamma m v c = 295 \times 9.11 \times 10^{-31} \times (3 \times 10^8)^2$ $= 2.4 \times 10^{-11} \text{ J}$ $E = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{2.4 \times 10^{-11}} = 8.2 \times 10^{-15} \text{ m}$ $\Rightarrow \sin \theta = \frac{1.2 \times 8.2 \times 10^{-15}}{3 \times 10^{-14}}$ $\sin \theta = 0.33$ $\theta = 19.2^\circ$ $\theta \approx 19^\circ$ (2sf) This response shows conciseness and accuracy. Exemplar 8 For relativistic particles, momentum = $\frac{E}{c}$ where E is the energy of the particle and c is the velocity of light. $\lambda = \frac{h}{p} \quad \lambda = \frac{hc}{E} \quad \lambda = \frac{(6.63 \times 10^{-34}) \times (3 \times 10^8)}{2.4 \times 10^{-11}}$ $\lambda = 8.3 \times 10^{-15} \text{ m}$ $\theta = \sin^{-1} \left(\frac{1.2 \times (8.3 \times 10^{-15})}{3 \times 10^{-14}} \right)$ $\theta = 19.4$ minimum angle = 19.4° This response is clear, accurate and concise. Exemplar 9 For relativistic particles, momentum = $\frac{E}{c}$ where E is the energy of the particle and c is the velocity of light. $\sin \theta = \frac{1.2 \lambda}{d}$ $d = (3.0 \times 10^{-14})$ $\lambda = \frac{hc}{p}$ $h = 6.63 \times 10^{-34}$ $p = \frac{E}{c}$ $E = \gamma E_{\text{rest}}$ $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $\gamma = 12.257$ $E = 12.257 \times 8.16 \times 10^{-14}$ $E = 1 \times 10^{-12}$ $\lambda = \frac{6.63 \times 10^{-34}}{\frac{1 \times 10^{-12}}{3 \times 10^8}}$ $\lambda = 1.989 \times 10^{-41}$ minimum angle = This response shows a common lack of detail in the third marking point. This gives a description of the change in value of the gold nucleus rather than an explanation.

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Question			Answer/Indicative content	Marks	Guidance
	c		via diffraction, $\text{Ag radius/Au radius} = (107/197)^{1/3} \checkmark$ $= 0.82 \checkmark$ via closest approach, $\text{Ag radius/Au radius} = \text{Ag nuclear charge/Au nuclear charge}$ $= 47/79 \checkmark$ $= 0.59 \text{ (which is significantly } < 0.82) \checkmark$	4	Algebraic reasoning gains first and third marks. Working must be shown. Allow complete calculations. Do not credit 0.81. (rounding error) <u>Examiner's Comments</u> This question requires candidates to compare ratios of atomic radii using electron scattering relationships and Rutherford scattering relationships. Many responses reached the expected ratio of 0.82 for electron scattering, although a significant minority lost marks by giving the ratio as 0.81 – a rounding error. Surprisingly, only the highest ability candidates calculated the ratio of radii from Rutherford scattering from the ratio 'nuclear charge on silver/nuclear charge on gold nucleus'. A more common, complicated and error-prone method involved making a calculation of the distance of closest approach of a 4.5 MeV alpha particle to a silver nucleus and finding the ratio of this value to the value calculated in (a) (ii).
			Total	18	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
79	a	i	$0 = hf_0 - \phi \Rightarrow \phi = h f_0 \checkmark$ $\phi = 6.63 \times 10^{-34} \text{ J s} \times 0.5 \times 10^{15} \text{ Hz} = 3.3 \times 10^{-19} \text{ J} \checkmark$	2	Allow f_0 in the range $(0.47 - 0.52) \times 10^{15} \text{ Hz}$ giving $3.12 \times 10^{-19} \text{ J} \leq \phi \leq 3.45 \times 10^{-19} \text{ J}$ Accept bald answer in range <u>Examiner's Comments</u> This is a standard calculation and most candidates answered it correctly. This area of physics was flagged up in lines 14 – 17 of the article.
		ii	Work function is (minimum) energy required for an electron to escape (the surface) AW $\checkmark$ Not all photons interact with electrons on the surface (those 'deeper' in the metal require more energy to escape) AW $\checkmark$	2	<u>Examiner's Comments</u> Although most responses correctly gave the meaning of the term work function, a much smaller proportion gained the second mark, that photons might not be interacting with electrons on the surface of the metal and that these 'deeper' electrons will require more energy to escape. Any discussion of the concept of minimum energy to escape linking to maximum kinetic energy of the ejected electrons would gain the mark.
	b		Same gradient $\checkmark$ x-intercept at $1.0 \times 10^{15} \text{ Hz} \checkmark$	2	Allow f_0 in the range $(0.94 - 1.04) \times 10^{15} \text{ Hz}$ <u>Examiner's Comments</u> Most candidates gained both marks for this question. A common incorrect response was to draw a line of different gradient but with the same x-axis intercept. Some candidates were penalised for sloppy line drawing, when the line had the correct intercept but was not quite parallel to the first line. This was a wasted mark for these candidates.
			Total	6	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
80	Level 3 (5–6 marks) Marshals argument in a clear manner. All technical vocabulary is used with accuracy and clarity. Makes relevant calculations which are clearly linked to the argument. Recognises reduction in reflected light implies greater transmission, increasing efficiency. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Describes superposition in terms of path difference between light reflecting from the two surfaces and considers effect of change of medium on velocity and/or wavelength of light. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Attempts description of superposition but does not consider the thickness of the layer nor the effect on the efficiency/ or considers effect of change of medium on velocity and wavelength of light. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points may include: • Reflection on boundaries introduces a path difference • Reflected light from boundaries superposes • Principle of superposition stated • reflected waves meeting in antiphase cancel • antiphase if path difference = $(n + \frac{1}{2})\lambda$ • velocity of light reduced when entering a region of higher refractive index • wavelength reduced in material of higher refractive index • velocity in silicon monoxide layer = $2 \times 10^8 \text{ m s}^{-1}$. • wavelength of light in monoxide layer = $613 \text{ nm}/1.5 = 410 \text{ nm}$ • path difference = 200 nm • path difference $\sim \frac{1}{2} \lambda$ • reduced reflected intensity • greater proportion of incident light transmitted • greater proportion of incident light interacts with electrons in silicon layer Examiner's Comments This last Level of Response question proved to be the most difficult on the paper. Many candidates concentrated on the refractive indices given in the diagram rather than the superposition at the upper surface from reflected waves at both surfaces. The indicative points listed in the mark scheme allowed such responses to gain merit but to reach the higher levels required an explanation of the physics of superposition in the context of the question. Common errors included making the assumption that standing waves are set up in the silicon monoxide layer and that refraction in the layer somehow focuses and hence intensifies the light reaching the silicon layer.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					The best answers calculated the wavelength of light in the silicon monoxide, showed that the layer was about one quarter of a wavelength thick and concluding that this introduces a path difference of half a wavelength at the surface. Exemplar 11 The superposition of waves means that waves in antiphase, a phase difference of π or $\frac{1}{2}$ will interfere destructively and have a very small amplitude, so the waves cancel out. If they have a phase difference of 0 or 1 then they will move in phase. A small amplitude means that there is a small probability of it occurring as probability $\propto A^2$ and so more of the light ~~will~~ be reflected but instead absorbed. As $\lambda = 615 \times 10^{-9} \text{ m}$, and the refractive index is 1.5, λ inside the silicon monoxide will be $\frac{\lambda}{1.5} = 4.09 \times 10^{-7} \text{ m}$. In order to produce a phase difference of $\frac{1}{2}$, the thickness should be $\frac{\lambda}{4}$ in order get $\frac{\lambda}{4} + \frac{\lambda}{4}$ each way (before and after reflection). Therefore the optimum thickness for reducing reflection is $\frac{4.09 \times 10^{-7}}{4} = 1.02 \times 10^{-7} \text{ m} \approx 100 \text{ nm}$ Decreasing the reflection again means that there is antiphase $\frac{1}{2}$ so the probability of arrival is low. Therefore none of the light will be absorbed, making the cell more efficient because none of the light's energy is transformed into the cell to be converted into the electricity. a greater intensity means more electrons are excited, producing a greater charge and so greater efficiency. This is an example of a high level response from a candidate who scored highly on the paper. A simple description of superposition and path difference is given as an introduction. The wavelength of the light in silicon monoxide is correctly calculated. The thickness of the monoxide layer is shown to provide a path difference of half a wavelength. The link between reduced reflection and increased absorption is made, though not particularly clearly. Finally, the candidate links this to the increased efficiency of the solar cell. The argument is clearly presented throughout.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
81	a		Change in velocity $\Delta v = V_m + 2V_M - (-V_m) = 2V_m + 2V_M \checkmark$ Change in momentum $= m \Delta v = m \times 2V_m + 2V_M \checkmark$ $(= 2m(V_m + V_M))$	2	Can argue directly from momentum but vector nature must be clear. (e.g., original momentum of probe is negative if final momentum positive) Examiner's Comments Candidates who recognised the vector nature of momentum and velocity were able to answer this question in a couple of lines of reasoning. Those candidates who didn't recognise that the final velocity of the probe is negative if the initial velocity is positive (or vice versa) could not gain marks. The question was highly discriminating with candidates who scored highly on the paper overall gaining both marks and less able candidates not scoring.
	b		Any two points from: • Change of momentum of planet $= -[2m(V_m + V_M)]$ • Negligible change in velocity of planet (AW) • (As the) planet is so much more massive than the spaceprobe ($M \gg m$). $\checkmark$	2	Or equal and opposite to answer to (a)/same magnitude as (a) Examiner's Comments Most responses to this part gained 1 or 2 marks. Some responses showed confusion between change in velocity and velocity; it was not uncommon to read that the planet would go backwards 'a little'. Once again, this question tested candidates' ability to use fundamental ideas from the course in a new context.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
82			Energy produced by solar cells over 8 hours $= 62\,100\text{ W} \times (8 \times 3600)\text{ s} = 1.788 \times 10^9\text{ J}$ ✓ Energy to lift plane $= 2300\text{ kg} \times 9.81\text{ N kg}^{-1} \times 7000\text{ m}$ $= 1.58 \times 10^8\text{ J}$ ✓ Energy to charge batteries $= 9.4 \times 10^5\text{ J kg}^{-1} \times 630\text{ kg}$ $= 5.92 \times 10^8\text{ J}$ ✓ $1.58 \times 10^8\text{ J} + 5.92 \times 10^8\text{ J}$ $= 7.5 \times 10^8\text{ J} < 1.788 \times 10^9\text{ J}$ ✓	4	Accept arguments showing power required during day is less than useful power received from the Sun. Accept $1.57 \times 10^9\text{ J}$ (using 9.8 N kg^{-1}) <u>Examiner's Comments</u> Candidates answered this question with more confidence than they showed in the previous question. Nearly all gained some marks and approached the problem in the same manner as the mark scheme. Some responses calculated the power required during the day and compared this to the useful power received from sunlight. Both approaches could gain four marks. The most common error was to ignore the energy required to charge the batteries, thus limiting the possible marks to 2. This is another example of applying standard physics to new contexts and taking the question step by step.
			Total	4	
83			Intensity at 5.2 AU $= 1.4\text{ kW m}^{-2} / (5.2)^2 = 0.052\text{ kW m}^{-2}$ ✓ Incident power $= 0.052\text{ kW m}^{-2} \times 60\text{ m}^2 = 3.1\text{ kW}$ ✓ Efficiency $= (500\text{ W} / 3100\text{ W}) \times 100\%$ $= 16\%$ ✓	3	ecf throughout <u>Examiner's Comments</u> This is a relatively straightforward question to finish the paper. The only common cause of error was miscalculating the intensity at 5.2 AU. This error would only cost one mark if the candidate clearly and correctly worked through to a value based on the error earlier in the question. Unfortunately, some responses continued to show errors beyond the first marking point, or did not clearly show how the final value was reached.
			Total	3	
84			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
85			B	1	<u>Examiner's Comments</u> This elementary application of Pythagoras Theorem was correctly answered by almost every candidate.
			Total	1	
86			A	1	<u>Examiner's Comments</u> Higher ability candidates realised that they had to apply an energy equation to a mass on a spring problem, kinetic energy gained = potential energy lost ($\frac{1}{2} m v^2 = \frac{1}{2} k x^2$) to find the maximum velocity reached.
			Total	1	
87			C	1	<u>Examiner's Comments</u> The working shown by some candidates who did not gain credit suggested that they may not have been aware that the value of electron mass is given in the data booklet.
			Total	1	
88			B	1	
			Total	1	
89			C	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
90	a		electron forms a <u>standing wave</u> of <u>integer</u> numbers of <u>$\lambda/2$ loops</u> ✓	M	accept λ is quantised in $\lambda/2$ loops of standing wave ignore mention of harmonics
			λ determines (mv and hence kinetic) energy ✓	M	accept k.e. = $h^2/2m\lambda^2$ not $E = hc/\lambda$ <u>Examiner's Comments</u> This question asked for an explanation of the discrete energy levels in the "model atom". Successful responses explained the importance of $\lambda/2$ loops fitting into a fixed distance, or the need for nodes at the barriers, in setting up a standing wave. Less able candidates gained a mark for recognising that wavelength determines kinetic energy but some incorrectly used $E=hc/\lambda$.

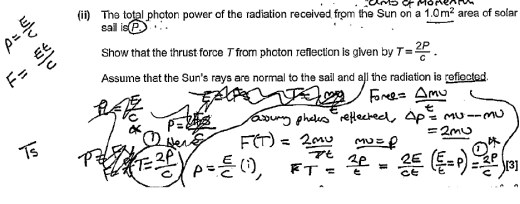
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		max photon energy $\Delta E = E_3 - E_1$ ✓ $\frac{h^2}{2m[2d/3]^2} - \frac{h^2}{2m[2d]^2} = hf$ OR 4.8×10^{-17} (J) ✓ $f = 7.3 \times 10^{16}$ (Hz) ✓	S&C S&C S&C	accept if substituted into numbers select correct levels 3 and 1 OR $\Delta E = (5.4 - 0.60) \times 10^{-17}$ (J) method accept alternative levels of highest level and 0 energy if λ correctly substituted gives 5.4×10^{-17} J OR (8.1 OR $8.2) \times 10^{16}$ Hz for 1 mark max evaluation $f = h \{ \frac{9}{8} - \frac{1}{8} \} / [md^2] = 6.6 \times 10^{-34} / \{ 9.1 \times 10^{-31} \times [10^{-10}]^2 \}$ = 7.3×10^{16} (Hz) Examiner's Comments This part of the question asked candidates to calculate the frequency of the most energetic photon this "atom" could emit. As this was designed for three stretch and challenge marks no hints about how to proceed were given. For those answers that did not arrive at the correct value of 7.3×10^{16} Hz, candidates could gain credit by selecting the correct energy levels E3 and E1, or by finding the energy difference Δ between them (4.8×10^{-17} J). One mark was also allowed for the energy or frequency of a jump from L3 to an invented zero level. The most common misconception was to treat the electron matter wave as an electromagnetic wave of that wavelength and find the corresponding photon frequency, this gave 4.5×10^{16} Hz (a close answer) but earned no credit due to the error of Physics.
			Total	5	

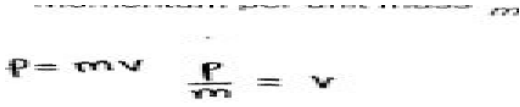
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
91	a	i	p has $\text{kg m s}^{-1} = E/c$ has $\text{kg m}^2 \text{s}^{-2} / \{\text{m s}^{-1}\}$ ✓	L	allow cancellation as implicit allow use of J for unit of energy leading to Ns for momentum accept algebra that mixes units and symbols <u>Examiner's Comments</u> The majority of candidates recognised that energy has unit of $\text{kg m}^2 \text{s}^{-2}$, speed has units of ms^{-1} and cancelled to give the unit of momentum as kg m s^{-1} for full credit. Credit was also given for the small number of candidates who used an alternative approach using J as the unit for energy leading to Ns for momentum.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	ii $T = \text{rate of change of momentum OR} = \Delta p / \Delta t$ ✓ factor $\times 2$ because $mv - \{-mv\} = 2mv$ ✓ $T = 2n \Delta\{E/c\} / \Delta t = 2n \Delta E / c \Delta t = 2P / c$ ✓	L M M	allow introduction of $\times 2$ at appropriate stage not $P = Fv$ accept momentum is reversed no credit for just $\times 2$ with no explanation must include n number of photons ($\text{m}^{-2} \text{s}^{-1}$) in calculation for third mark Examiner's Comments The most able candidates were able to manipulate algebraic expressions to show that the thrust from the solar sail $T = 2P / c$ where P is the total power density incident normally. They were then able to argue the momentum change per reflected photon is $2E / c$, and then relate the power of photon flux to the energy carried by n photons per $\text{m}^2 \text{s}^{-1}$. Other candidates got the first mark for stating that thrust was rate of change of momentum, but could not get much further. A common mistake was to confuse power, P, with the momentum symbol, p which led to confused and incorrect answers. Other errors were to introduce $P = Fv$ or $E = mc^2$ which are not appropriate for photons or to omit the number of photons from the calculation. Exemplar 7  This candidate has correctly used $F = \Delta mu / t$ and recognised that there is a change of $2mu$ on reflection to progress as far as $T = "P / c$ but has omitted the number of photons from the final step.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$a = T \times A / m = 2 P \times A / mc$ OR ✓ $= 2 \times 1400 \times 10^6 / \{10^3 \times 3 \times 10^8\}$ ✓ $9.3 \times 10^{-3} \text{ m s}^{-2}$ ✓	 M M	accept in algebra or numbers accept 9.3 mm s^{-2} <u>Examiner's Comments</u> This part of the question required candidates to use the equations given in part (ii) to calculate the acceleration of a 1 tonne spacecraft using a 1 km^2 solar sail as 9.3 mm s^{-2} . Many candidates did this successfully even if they had not gained credit in part (ii).
	b	i	k.e. gained = e.p.e. lost OR $\frac{1}{2} m v^2 = Q V$ ✓ $\{mv\}^2 = 2 m Q V \rightarrow mv / m = \sqrt{2 VQ / m}$ OR $mv / m = \sqrt{2 m V Q / m^2} \rightarrow v = \sqrt{2 VQ / m}$ ✓	 L H	energy conservation in words / algebra allow momentum per unit mass = velocity and subsequent derivation of v <u>Examiner's Comments</u> Exemplar 8  This part required algebraic reasoning and was often omitted by less able candidates. Those that were successful, as in exemplar 8, started from the equation for accelerated ions $QV = \frac{1}{2} m v^2$ and manipulated it to show that the momentum transfer per unit mass in the ion drive $p / m = \sqrt{2 VQ / m}$. Alternatively, some candidates realised that momentum per unit mass is in fact velocity for the ions and went on to derive v for full credit.

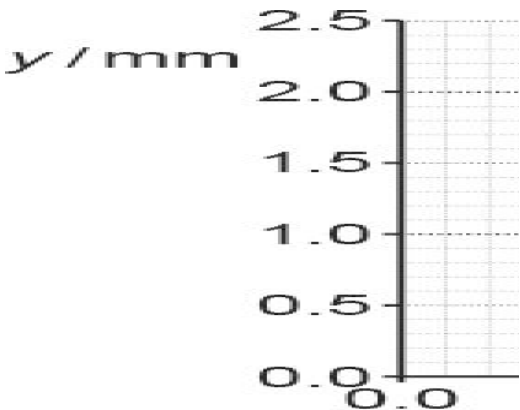
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	H^+ has highest Q / m ✓ so best momentum transfer / larger p/m ✓	S&C S&C	ignore Xe^+ is safer / energy to lift mass of H from Earth expect momentum comment <u>Examiner's Comments</u> Candidates were asked to compare the effectiveness of using $^1H^+$ and $^{130}Xe^+$ ions in the ion drive. Many gave trivial answers about availability and scored zero, but more able candidates gained full credit for arguing that $^1H^+$ has the largest charge mass ratio (Q / m) and hence the largest momentum transfer per unit mass.
		iii	$T = \Delta p / \Delta t = \Delta p / \Delta m \times \Delta m / \Delta t$ OR $\Delta m / \Delta t = T / \{\Delta p / \Delta m\} = 0.24 / \sqrt{2 \times 2000 \times 9.6 \times 10^7}$ ✓ $= 3.87 \times 10^{-7} \text{ kg s}^{-1} (< 4 \times 10^{-7} \text{ kg}^{-1})$ ✓	S&C S&C	No credit for only working out velocity of ions <u>Examiner's Comments</u> Successful candidates were able to recognise that thrust, $T = \Delta p / \Delta t$ and therefore $T = \Delta p / \Delta m \times \Delta m / \Delta t$. They could then re-arrange this and use the equation $p / m = \sqrt{2 V Q / m}$ given in part (i) to show that mass transfer rate was the thrust divided by momentum per unit mass, and hence that a 2000 V accelerator uses propellant at less than $4 \times 10^{-7} \text{ kg s}^{-1}$ to produce 0.24 N thrust.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
92	a		% uncertainties in L << % uncertainties in y ORA ✓	L	accept % uncertainties in L are negligible on this scale accept estimates e.g. 1 in 1000 mm << ½ in 2 mm expect percentage / relative / estimated uncertainties not just uncertainty is less ignore comments on <i>d</i> <u>Examiner's Comments</u> Successful candidates recognised that percentage or relative uncertainty in L is much smaller than that in y. A common feature of weaker responses was to state that the uncertainty in the distance L is much less than the uncertainty in fringe spacing y; these responses did not gain credit since the uncertainty of both could be a similar size of ± 1 mm.

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
b		best fit line expect through the origin but accept lines starting at (0.5,0.5) ✓	L	 accept ecf on POT error on gradient i.e. missing $\times 10^{-3}$ can still score uncertainty mark e.g. 1 ± 0.2
		accept intercepts up to +2 squares on y-axis or +1 square on x-axis	M	
		gradient of best fit line = $(2.25 \times 10^{-3} / 2.2) = 1.0 \times 10^{-3}$ accept in range $\{0.9 \text{ to } 1.2\} \times 10^{-3}$ (round their values to 1dp) ✓	H	
		penalise POT error on gradient accept y/x for proportional graphs expect evidence of $\Delta y / \Delta x$ for graphs not through (0,0)		allow a little pessimism comparing to max or min gradients through data
		uncertainty by graph of max OR min gradient or by $\pm \%$ (max gradient = 1.2×10^{-3} , min gradient = 0.7×10^{-3}) accept in range $\pm \{0.10 \text{ to } 0.5\} \times 10^{-3} / \pm \{10 \text{ to } 50\} \%$		Examiner's Comments Successful candidates gained the mark for a correct straight line of best fit and went on to calculate the gradient of their line and estimate the uncertainty from the error bars on the graph. Power of ten errors were common where candidates missed the "milli" multiplier on the mm axis. Candidates adopted a range of methods of estimating uncertainty and a wide range was accepted for credit to accommodate a variety of "worst fit" lines that could be drawn using the error bars.

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	$\lambda = d \times \text{grad} = 0.50 \times 10^{-3} \times 1.03 \times 10^{-3} = 5.15 \times 10^{-7} \text{ (m)}$ ✓ accept values in the range 450 to 600 nm and consistent with their gradient from (b) relative uncertainty in d expressed as $\pm 20\% / \pm 0.2$ ✓ evaluation combining uncertainties from grad and d to get overall uncertainty. Credit values in range of $\{\pm 30\% \text{ to } \pm 70\%\}$ of their λ estimate overall uncertainty in range $\pm 150 \text{ nm to } \pm 360 \text{ nm}$ ✓	M H H	allow ecf on gradient value from (ii) accept 515 nm accept use of $\lambda = d \times \sin \theta$ (with $n = 1$) accept ecf grad $\pm\%$ from (ii) accept absolute uncertainty in d is 0.1 mm if used in max/min calculation of λ large pessimistic % due to uncertainty in grad up to $\pm 50\%$ ignore method of combining large % uncertainties (several methods are used ours include extreme limits) so $5.2 \pm \{1.5 \text{ to } 3.6\} \times 10^{-7} \text{ (m)}$ Examiner's Comments Successful candidates were able to use the gradient calculated in (b) to find the wavelength of light, using $\lambda = d \times \text{gradient}$, in the range 450 to 600 nm. Examiners allowed errors in (b) to be carried forward without penalty. More able candidates went on to express the uncertainty in d, either as $\pm 20\%$ or ± 0.2 and combine uncertainties to give an estimate; a wide range of $\pm 150 \text{ nm to } \pm 360$ was allowed for credit due to the range of gradients permissible in part (b) and several methods that may be used to estimate the uncertainty.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		refine design: use travelling microscope to measure d or y or both more precisely ✓ OR refine procedure: repeat measurements (to improve cluster and improve precision)	L	accept other sensible improvements in apparatus e.g. increase L so y is larger OR measure a larger number of fringes / increase d to see more fringes / decrease d to increase fringe separation (changing d needs justification for credit) not just measure d or y more precisely OR make y larger accept use of tube to exclude background light / use of brighter lamp / use of collimator round lamp to improve fringe contrast <u>Examiner's Comments</u> Candidates usually gained this mark by naming an item of equipment with better resolution – for example a travelling microscope or micrometer – but those candidates who just made a simple statement about measuring more precisely did not gain credit. More detailed responses that were accepted included repeating measurements to look for cluster giving greater precision, using a brighter light source, screening from background light and measuring multiple fringes.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
93		i	$\{ \frac{1}{2} m \overline{c^2} \}_{\text{Xe}} = \{ \frac{1}{2} m \overline{c^2} \}_{\text{H}_2} \checkmark$	M	method or justification accept equipartition of energy OR average k.e of two species of molecules is equal OR $c_{\text{r.m.s.}}$ is speed of molecule with average kinetic energy not just $\sqrt{\{m_{\text{Xe}} / m_{\text{H}_2}\}}$ OR $\sqrt{\{132 / 2\}}$
			$\sqrt{\{ \overline{c^2}_{\text{H}_2} / \overline{c^2}_{\text{Xe}} \}} = \sqrt{\{m_{\text{Xe}} / m_{\text{H}_2}\}} \checkmark$	M	
			$= \sqrt{66 / 8.1(2)} \quad \checkmark$	M	

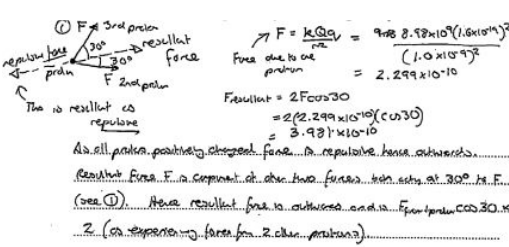
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	number = $N_A \times e^{-E/kT}$ ✓	H	method accept {Boltzmann factor expressed in recognisable algebra / numbers} x Avogadro's number
			where $E = \frac{1}{2} m_{H_2} v_{\text{Escape}}^2 / 2.1 \times 10^{-19} \text{ J}$ ✓	H	E of H molecule part evaluation accept $m_{H_2} = 2 \times m_p$
			Boltzmann exponent = $E/kT =$	S&C	or accept BF calculated at 3.2×10^{-23}
			$\frac{1}{2} \times 2 \times 10^{-3} \times [11.2 \times 10^3]^2 / [6 \times 10^{23} \times 1.4 \times 10^{-23} \times 288] = 51.8$		
			number = $N_A \times e^{-E/kT} = 6 \times 10^{23} \times e^{-51.8} = 19 \text{ (mole}^{-1}\text{)}$ ✓	S&C	correct evaluation scores full marks ignore fractions of molecules accept range between 8 and 52 (mole^{-1}) – extra sf in data book can give a large range of number of molecules since the answer is very sensitive to the value in the exponent
Examiner's Comments					
Exemplar 10					
Use the Boltzmann factor to estimate the number of H_2 molecules per mole with sufficient energy to escape the atmosphere and the Earth's gravitational field at a temperature of 288 K. $f_B = e^{-\frac{E}{kT}}$ $= e^{-\frac{\frac{1}{2} \times 2 \times 10^{-3} \times (11.2 \times 10^3)^2}{6.02 \times 10^{23} \times 1.4 \times 10^{-23} \times 288}}$ $= 1.70 \times 10^{-23}$ $6.02 \times 10^{23} \times 1.7 \times 10^{-23} = 10.2$ $\therefore \text{number} = \frac{10}{1} \text{ (mole}^{-1}\text{)}$					
This part asked candidates to find the number of hydrogen molecules per mole of particles with sufficient energy to reach the Earth's escape velocity (11.2 km s^{-1}) at a temperature of 288 K. They were advised to use the Boltzmann factor but otherwise given no further structure, so this was a stretch and challenge question. The Boltzmann factor containing a negative inverse exponent is very sensitive to exponent value, the values of the physical constants used, and to rounding. As a result, answers in the range 8 to 52 molecules were accepted if the calculations were justified for the full four					

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					marks as in this exemplar. Part marks were credited for setting up the calculation as number of molecules = $N_{\text{Avogadro}} \times e^{-E/kT}$ and for recognising the E as the kinetic energy of one hydrogen molecule travelling at the escape velocity (2.1×10^{-19} J) or for getting as far as calculating the Boltzmann exponent (-52) or Boltzmann factor (3.2×10^{-23}). Common errors included writing down the Earth's gravitational potential (unnecessary because escape velocity given), finding the kinetic energy for one mole of hydrogen gas with escape velocity (rather than a single molecule) or forgetting to multiply the Boltzmann factor by the Avogadro number. Candidates who confused grams and kg in expressing molar mass had a resulting power of ten error (of 1000) in the exponent. This yields an error message on most calculators, which typically only handle numbers down to 10^{-99} in size, confusing some candidates.
			Total	7	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
94	i Force on third proton due to one other in triangle = $(9 \times 10^9 \times (1.6 \times 10^{-19})^2) / (1 \times 10^{-9})^2$ ✓ = 2.3×10^{-10} N ✓ horizontal components will cancel (can show on diagram) ✓ sum of vertical components = $2 \times 2.3 \times 10^{-10} \times \sin 60^\circ = 3.98 \times 10^{-10}$ (N) ✓	M M H H	Look for final answer and if not correct work through scheme to credit each marking point achieved. accept shown by vector addition triangle or use of $\cos 30^\circ$ or $\sin 60^\circ$ accept use of $\cos 30^\circ$ accept 4.0×10^{-10} (N) in this instance <u>Examiner's Comments</u> Exemplar 12  In this part of the question the resultant electrical force on a third symmetrically placed proton was considered. Many candidates were able to score full marks for showing the size of the force is about 4×10^{-10} N. Two marks were credited for candidates who were able to calculate the force on the third proton due to one other proton as 2.3×10^{-10} N. A third mark was gained, as in this exemplar, by those who, by showing the vector addition of the two forces on a diagram or by using “vertical” components $\cos 60^\circ$ or $\sin 30^\circ$ of this force, demonstrated that the horizontal components of the forces cancel.

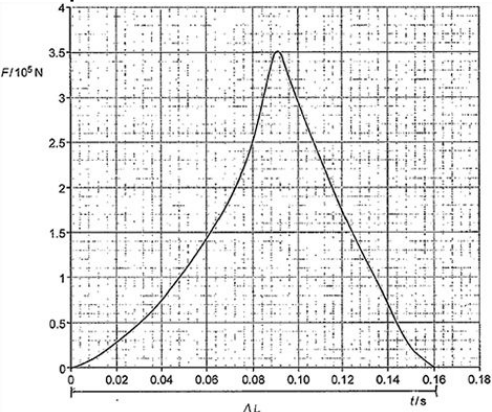
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$\text{Force} = 3.98 \times 10^{-10} \text{ N} \times (1 \times 10^{-9})^2 / (1 \times 10^{-15})^2$ ✓	H	accept 4.0×10^{-10} (N) or ecf from b(i) accept force scaled up $\times \{10^{-9} / 10^{-15}\}^2 = 10^{12}$
			$= 398 \text{ (N)}$ ✓	S&C	accept 400 (N) <u>Examiner's Comments</u> Many lower ability candidates omitted this final stretch and challenge question. Candidates were asked to consider the three protons in a ${}^6\text{Li}_3$ nucleus and the electrical force of repulsion on them. Better candidates realised it was the same problem as in part (i) only scaled down in distance by 10^{-6} so they could reason that, as the force goes up with $1/R^2$ and it therefore scaled by $1 / (10^{-6})^2 = 10^{12}$. Errors carried forward from part (i) were allowed as was the use of the "show that" value given of 4×10^{-10} N to obtain an answer of 400 N.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
95	a	i	$v = (0.20 \text{ kg} \times 1.8 \text{ m s}^{-1}) / 0.50 \text{ kg} \checkmark$ $= 0.72 \text{ m s}^{-1} \checkmark$	2	Correct bald answer gains both marks Accept 0.7 ms^{-1} Examiner's Comments This is a standard calculation that proved accessible to most candidates. The rare candidates that made errors divided the initial momentum by 0.3 kg rather than 0.5 kg, showing a lack of understanding of the conservation of momentum.
		ii	initial k.e. = $0.324 \text{ J} \checkmark = 0.32 \text{ (J)}$ final k.e. = $0.1296 \text{ J} \checkmark = 0.13 \text{ (J)}$	2	ecf from (a)(i) on final k.e. (0.36 J from $v = 1.2 \text{ m/s}$ from (i)) accept 0.216 J for final k.e. if this follows from mass and velocity error from (a) (i) Examiner's Comments A second straightforward calculation to begin the paper.
		iii	Change of momentum of 0.2 kg mass $= 0.20 \text{ kg} \times (0.72 - 1.8) \text{ m s}^{-1} = -0.216 \text{ kg m s}^{-1} \checkmark$ Change of momentum of 0.3 kg mass $= 0.30 \text{ kg} \times (0.72 - 0) \text{ m s}^{-1} = (+) 0.216 \text{ kg m s}^{-1} \checkmark$ Force on 0.2 kg mass = $-0.216 \text{ kg m s}^{-1} / \Delta t$ Force on 0.3 kg mass = $(+)0.216 \text{ kg ms}^{-1} / \Delta t \checkmark$	3	Ecf from (a) (i) (Commonly giving 0.12 kg m s^{-1} for one momentum and 0.36 kg m s^{-1} for the other) Must show working and one value of Δp is positive and the other is negative Accept use of 0.7 ms^{-1} Last marking point is independent and is for recognition that the two changes occur over (the same) time Δt. Examiner's Comments This part of the question was more challenging. Although most responses showed that the magnitude of the momentum change is the same for both blocks, a proportion did not give the vector sense of the answer (not stating that one block had a momentum change of $+0.216 \text{ Ns}$ and the other a change of -0.216 Ns). The third marking point, linking equal and opposite momentum changes to equal and opposite forces as the time of interaction for both bodies is the same, was often missed.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
b	Clear attempt at finding whole area under the line ✓ Impulse evaluated using $F\Delta t$ leading to impulse of 2.0×10^4 N s to 2.3×10^4 N s ✓ Answer in the range (-) 14.3 m s^{-1} to 16.4 m s^{-1} ✓	3	Ecf from impulse for third mark Examiner's Comments Most responses showed an attempt to calculate the whole area under the line. However, many of the values obtained were inaccurate. Candidates commonly assumed that the area was a triangle and calculated accordingly. Other incorrect responses missed the 10^5 factor of the force values. A more interesting error was to find the initial area under the graph (e.g. the area between 0.00 and 0.02s). It is assumed that the candidates who made this error missed the point that the car had zero momentum after 0.16 s of the collision so the change of momentum is equal to the initial momentum. Exemplar 1  Fig. 1.1 The impulse on the car is given by the area under the curve. Use data from the graph to calculate the initial velocity of the car. Explain your method and reasoning. mass of car = 1400 kg impulse = ~~Area~~ change in momentum. final momentum = 0 impulse = $\frac{1}{2} \times \text{area} = \frac{1}{2} \times \Delta t \times F = \frac{1}{2} \times 0.16 \times 3.5 \times 10^5$ = 28,000 N s change in momentum = initial momentum - 0 initial velocity = $\frac{28,000}{1400} = 20 \text{ ms}^{-1}$ initial velocity of car = 20 ms⁻¹ [3] This candidate lost one mark by assuming that the area was that of a simple triangle. The candidate gained the final mark through error carried forward.
Total		10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
96	a	i	$E_k = eV = 1.60 \times 10^{-19} \text{ C} \times 4.3 \times 10^3 \text{ V} (= 6.88 \times 10^{-16} \text{ J}) \checkmark$ $v = \sqrt{2 E_k / m}$ $= \sqrt{(2 \times 6.88 \times 10^{-16} \text{ J} / 9.11 \times 10^{-31} \text{ kg})} = 3.9 \times 10^7 \text{ m s}^{-1} \checkmark$	2	Correct bald answer gains both marks Examiner's Comments This standard calculation was accessible to most candidates. The main source of error was in rearranging the kinetic energy equation. Some candidates gave velocity values far greater than c – perhaps showing a lack of thought about what their calculators showed them.
		ii	rest mass of electron = 512 keV / $8.20 \times 10^{-14} \text{ J} \checkmark$ Gamma factor = $(4.3 \text{ keV} + 512 \text{ keV}) / 512 \text{ keV} = 1.008(4) \checkmark$ Not much bigger than 1, therefore reasonable to ignore. $\checkmark$	3	Accept calculation of gamma from $\frac{1}{\sqrt{1 - \frac{(3.9 \times 10^7)^2}{(3 \times 10^8)^2}}} \checkmark (= 1.0086) = 1.009 \checkmark$ Allow ecf of speed from (a)i If simply stated that relativistic effects can be ignored because velocity is about 0.1 c, one mark. Examiner's Comments Another accessible, familiar calculation. Some candidates did not perform a calculation but gained a mark for stating that the velocity of the electron is about 0.1 c and linking this to the statement that it is reasonable to ignore relativistic effects at this speed. The majority of correct answers were based on calculating the gamma factor through the Lorentz equation rather than using the rest energy and k.e. of the particle.
		iii	$\lambda = 6.63 \times 10^{-34} \text{ J s} / (9.11 \times 10^{-31} \text{ kg} \times 3.9 \times 10^7 \text{ m s}^{-1})$ $= 1.87 \times 10^{-11} \text{ m} \checkmark$	1	Allow ecf from a)i Examiner's Comments A third standard calculation which only caused difficulties to the weakest candidates.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		(higher energy electrons have) shorter wavelength✓ Angle to first order maximum decreases as wavelength decreases✓ More energetic electrons produce more photons when they strike the screen. ✓	3	Stating or implying that the electron energy is given by $E = \frac{hc}{\lambda}$ negates first mark Accept 'shorter wavelengths diffract less' or reference to equation Accept 'smaller rings giving more concentrated release of photons/ more intense light'/ electrons strike smaller area of screen <u>Examiner's Comments</u> Many responses correctly linked increasing velocity to decreasing wavelength and then made the link between wavelength and angle of diffraction, often quoting the diffraction grating equation which, although the situation is not the one-dimensional phenomenon the equation relates to, nonetheless shows an understanding of the essential physics. Candidates found it more difficult to account for the brightening of the rings. Many candidates suggested that released photons had more energy (individually) rather than a greater number of photons released. Another error was to think that more electrons struck the screen per second. Relatively few candidates suggested that more photons are released – the more common accepted answer was that as the rings are smaller the electron-screen collisions are more densely packed.

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	Level 3 (5–6 marks) <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Marshals argument in a clear manner. Clearly explains evidence for wave-like properties, evidence for particle-like properties and explains phasor model in context. Level 2 (3–4 marks) <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Gives a clear explanation of two of the three strands to the question but may ignore one strand. Or, gives a less detailed explanation of all strands but misses out vital links in the explanations. Level 1 (1–2 marks) <i>There is an attempt at a logical structure with a line of reasoning. The information is for the most part relevant. Explains one strand clearly and completely, or two strands in a less complete manner.</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points may include: Wave-like behaviour • Diffraction usually (classically) considered a wave property • Explained by waves superposing • Producing areas/places of maximum and minimum amplitude • Dependent on the phase relationship of the superposing waves Particle-like behaviour: • Electrons producing (discrete) flashes of light is evidence of particle like behaviour • Flash suggests discrete/point-like interactions with the screen • rather than the energy of each electron spread across the screen in the manner expected of waves • electrons have been accelerated (without changing medium) Phasor model • phasors described as rotating arrows (representing phase and amplitude) accept rotating vectors • electron (or electron phasor) explores all possible paths • between (e.g.) graphite layer and screen • resultant phasor is the sum of all the phasor amplitudes (added tip to tail) • Probability of electron detected at a given position can be calculated from the square of the resultant phasor <u>Examiner's Comments</u> The majority of the responses gained Level 2 or 3 on this level of response question. Most candidates clearly stated the link between diffraction and wave-like behaviour, the better responses explaining diffraction in terms of wave superposition. The description and explanation of particle-like behaviour were less secure – few

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			responses used the 'tiny flash of light' described in part (b) as an identifier of quantisation whereas a good number of responses stated that waves cannot be accelerated – this was accepted by the examiners as the situation under consideration has the electrons travelling through a uniform medium (so waves would travel at constant speed through the medium). The phasor explanation was often attempted and the best responses showed a solid understanding of the model and were clear and detailed. Exemplar 6 <i>The wavelike properties are shown in its ability to diffract, as particles do not do so under normal conditions, and its particle like behaviour is shown by how they can be accelerated as if they were solid entities, as waves can increase frequency and length but are restricted in speed as they must travel at the speed of light (max universal speed)</i> <i>Phasors help to explain the phenomenon of both behaviours as they use rotating vectors to show formation of maxima (bright areas) and minima (areas of no light), but can also have direction and magnitude with these values being easily changeable by applied forces ~~as~~ like particles would.</i> This Level 2 response includes a number of the indicative points suggested in the mark scheme but does not develop the ideas. In particular, there is no discussion of superposition of waves or addition of phasor amplitudes.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 7 This demonstration suggests electrons have wave-like behaviour because they display properties of waves - namely, they diffract around the graphite. When electrons are accelerated through the graphite layer, electron waves hit through the graphite and explore all possible paths. At some parts of the screen, the resultant phase from all the different electrons and their paths is zero - all the individual phases cancel out and cancel the probability of an electron arriving (resultant phase amplitude). This means that there is a zero probability of arrival, so there is a dark ring. On other parts, the resultant phase is larger, so the phases from all different paths line up, so the probability of arrival of an electron is much larger. If electrons were waves, however, a smooth image would build up - instead it is spiky and grainy. This shows the particle-like behaviour of electrons - a grainy image means that individual electrons are hitting the screen, slowly building up the image of concentric rings. Therefore electrons must have wave and particle-like behaviour. This Level 3 response shows understanding of the wave-like and particle-like behaviour of electrons, includes sufficient detail and is a well-constructed piece of writing.
			Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
97	a	i	$(n = \sin i \div \sin r =) \sin 40 \div \sin 22$	1	If radians are used answer = -84 (award 1 mark for correct method even if working is missing). Answer correct to 2sf. Don't penalise 1.71. Raw answer of 1.7 gains both marks. <u>Examiner's Comments</u> This seemed a straightforward start for most candidates. Nearly all got this correct; with only a handful of candidates using their calculator in radians mode and hence getting an incorrect value for refractive index.
			$(n =) 1.7(2)$	1	

Mark Scheme

Question			Answer/Indicative content			Marks	Guidance							
		ii	<table><tr><td>angle</td><td>Maximum value/°</td><td>Minimum value/°</td></tr><tr><td>angle of incidence, <i>i</i></td><td>44</td><td>36</td></tr><tr><td>angle of refraction, <i>r</i></td><td>26</td><td>18</td></tr></table>	angle	Maximum value/°	Minimum value/°	angle of incidence, <i>i</i>	44	36	angle of refraction, <i>r</i>	26	18	1	All 4 values needed for the mark.
angle	Maximum value/°	Minimum value/°												
angle of incidence, <i>i</i>	44	36												
angle of refraction, <i>r</i>	26	18												
			Find max value of $n = \sin 44 \div \sin 18$ (= 2.248) AND/OR Find min value of $n = \sin 36 \div \sin 26$ (= 1.3408)	1	Allow ecf of incorrect max and/or min values of angles from table.									
			Uncertainty = 2.25 – 1.72 = 0.53 [max value – 1.7] OR Uncertainty = 1.72 – 1.34 = 0.38 [1.7 – min value] OR Uncertainty = $\frac{1}{2}(2.25 - 1.34) = 0.46$ or 0.45 (depending on rounding) [$\frac{1}{2}(\text{max} - \text{min})$]	1	ALLOW correct use of the their max and/or min values and value of n calculated in part (i). eg. $\sin 44 \div \sin 26 = 1.6$ and $\sin 36 \div \sin 18 = 1.9$, so uncertainty = 0.2 or 0.1. ALLOW answers to 1sf. Do not credit a raw answer of 0.5, which can be achieved by adding percentage uncertainties of angle <i>i</i> and angle <i>r</i> – an incorrect method. <u>Examiner's Comments</u> Nearly all candidates completed the table correctly. Most candidates used the correct combination of angles to find the largest and/or smallest values possible for n and then correctly found the absolute uncertainty. Common errors were to use an incorrect pair of angles, for example the largest value for angle of incidence with the largest value for angle of refraction. Others just tried adding percentage uncertainties of the angles, without any reference to finding the sine of the angle.									
	b		Level 3 (5-6 marks) ✓ ✓ Detailed description of experimental procedure and/or analysis with meaningful description of the other strand. For example, a response having a detailed description of the analysis but only limited experimental procedure can get a level 3. <i>There is a well-developed line of reasoning</i>	1 x 6	Indicative scientific points may include: Experimental procedure: • vary angle of incidence and measure angle of refraction • angle of incidence goes up increments (eg 5° or 10°) • draw round block on paper and mark path of light with points, then draw lines									

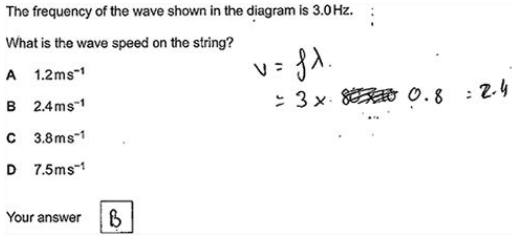
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	<i>which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) ✓ ✓ Workable description of experimental procedure and/or analysis. <i>There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.</i> Level 1 (1-2 marks) ✓ ✓ Limited description of experimental procedure and/or analysis. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.		through points with ruler (especially inside block) • place block on top of large protractor • measure angles when light enters and when light leaves rectangular block (as a repeat) • use set square/protractor to mark normal • use a large/higher resolution protractor to measure angles or trigonometry (measure length of opposite side) • use a very narrow ray of light with parallel sides or laser • dark room and/or bright light source • use monochromatic light source Analysis: • calculate $n = \sin i \div \sin r$ • <u>compare</u> values of n from different values of i. • plot graph of $\sin i$ against $\sin r$ • draw straight line of best fit • find gradient of line and hence refractive index • use 'large triangle' to find gradient • add error bars to plotted points • draw 'worst-fit' lines • use gradient of 'worst-fit' lines to find min and max values of n. <u>Examiner's Comments</u> Many candidates showed little knowledge of practical techniques which could be employed to measure the angles of incidence and refraction in this experiment. Many did suggest using a monochromatic laser and a digital angle measurer, without any reference as to how these would be used in practice. They do still need to record the path of a ray of light whether it is a laser beam or a narrow beam from a ray-box and many candidates omitted any such method. A detailed method which would help someone with some science knowledge to carry out the experiment could achieve Level 3. Some candidates did correctly suggest that a number of different values for angle of incidence

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					should be used, and the corresponding values of refraction recorded, but only some of these went on to suggest that a graph should be plotted. A level 3 response should suggest plotting a graph of $\sin i$ against $\sin r$ and calculating a gradient to find refractive index as well as some discussion of how to find uncertainty in the calculated value. Exemplar 1 <i>Place the polymer block on A3 paper. Draw an outline of the block and place it there. Use a thin slit and a ray box to produce as narrow a beam of light as possible. Use a set square to accurately draw ~~the~~ normals from the outline. ~~Remove~~ Turn off the lights of the room in order to remove as much background lighting as possible. Draw over the incident ray of light and the refracted ray leaving the block. Draw normals at these points of intersection. Use a protractor to measure the angles between the lines and the normals. ~~Take~~ Make the angles of incidence as large as possible to reduce the percentage uncertainty of the angles. Calculate the refractive index. Draw a line between the two intersections to find the angle of refraction. Calculate the refractive index using $n_1 \sin \theta_1 = n_2 \sin \theta_2$. Place the polymer block such that the ray will travel along the furthest distance in the block to further reduce uncertainty of the angles. Repeat readings and take readings from a wide range of values. Calculating their respective refractive indices and then find an average.</i> This candidate has described a practical method for finding the angles. It includes drawing the normal lines using a set square and marking the paths of the rays of light as they travel through the block. The suggestion of dimming the lights will also aid the process. The candidate also explains how to calculate the refractive index and suggests repeating readings and using a range of values for the angle of incidence. This is a Level 2 response. In order to get up to Level 3, it needed to include a graphical method to find refractive index.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
98			C	1	Examiner's Comments About half of candidates recognised the correct estimate as that of the wavelength of red light, but the range of other responses selected suggests that many candidates are not familiar with estimated order of magnitudes of everyday quantities as section 2(c)(iii) of the specification requires.
			Total	1	
99			D	1	Examiner's Comments A common error was to correctly identify that the wave is transverse and stationary but incorrectly calculate the wavelength as 40cm instead of 80cm.
			Total	1	
100			B	1	Examiner's Comments Exemplar 1  The frequency of the wave shown in the diagram is 3.0Hz. What is the wave speed on the string? A 1.2ms⁻¹ B 2.4ms⁻¹ C 3.8ms⁻¹ D 7.5ms⁻¹ Your answer 2.4 Whilst working is not required or credited, successful candidates, as in this exemplar, often showed their working for multiple-choice questions that involved calculations.
			Total	1	