SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided.
Where an answer box is provided, write your final answer in the box.
If an answer box has a unit printed in it, give your answer in that unit.
In questions where more than one mark is available, appropriate working **must** be shown.
Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
Take the value of g to be 9.8 m s^{-2}.

Question 1 (3 marks)

Two small charges, A and B, are placed 6.0 cm apart in a straight line, as shown in Figure 1.

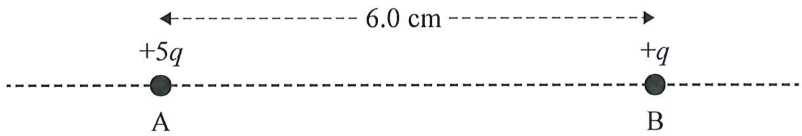

Figure 1

Charge A has a magnitude of $+5q$ coulombs and charge B has a magnitude of $+q$ coulombs.

If the force exerted by charge A on charge B is 5.1×10^{-24} N to the right, determine the value of q.

$F = k\frac{q_1 q_2}{r^2}$ $\quad 5.1\times10^{-24} = 8.99\times10^{9} \times \frac{5q^2}{0.06^2}$ (1)

$q = \sqrt{\frac{5.1\times10^{-24}\times 0.06^2}{5\times 8.99\times10^{9}}} = 6.39\times10^{-19}$ (1)

(1)

6.4×10^{-19} C

Question 2 (3 marks)

A positively charged particle carrying a charge of $+1.5 \times 10^{-8}$ C enters a region between two large, charged plates with opposite charges, as shown in Figure 2.

The potential difference between the plates is 2.0 kV, and the kinetic energy of the charged particle as it enters the hole is 2.8×10^{-5} J. Ignore gravitational effects and air resistance.

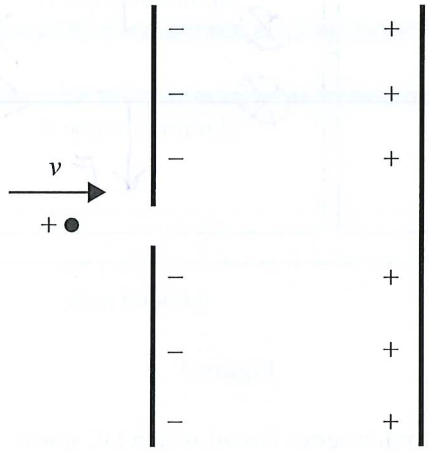

Figure 2

Ariel and Jamie discuss what they think will happen to the particle after it enters the region between the two equally but oppositely charged plates.

Ariel says that the particle has insufficient kinetic energy to reach the positively charged plate and will travel part of the way before returning towards the negatively charged plate.

Jamie says that the particle will collide with the positively charged plate and then head back towards the negatively charged plate.

Evaluate Ariel and Jamie's statements, giving clear reasons for your answer.

$E_K = qV$ when particle stop (1)

$V = \frac{2.8 \times 10^{-5}}{1.5 \times 10^{-8}} = 1.87 \times 10^3$ (1)

As $1.87 < 2$ particle will momentarily stop before reaching positive plate and then will move towards negative plate. (1)

Ariel is correct, Jamie is wrong.

SECTION B – continued
TURN OVER

Question 3 (3 marks)

Two thin, light aluminium tubes, A and B, are supported in a vertical wooden rack, as shown in Figure 3. Both of the aluminium tubes rest horizontally on wooden pegs.

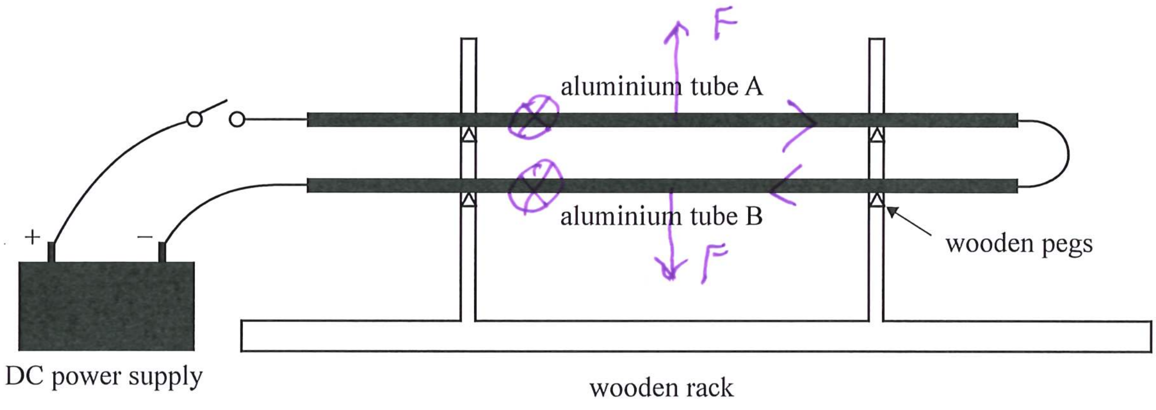

Figure 3

The two thin, light aluminium tubes form a series circuit with a DC power supply. It was observed that one of the tubes jumped upwards when the DC power supply was switched on.

Identify which tube jumped upwards and explain why this occurred.

Aluminium tube A (1)

As current in tubes is in the opposite directions, they will repel (1) as magnetic fields are directed into the page so force on A is ↑, on B is ↓ as shown on the picture. (1)

DO NOT WRITE IN THIS AREA

Question 4 (4 marks)

Two electrons, e_1 and e_2, are emitted, one after the other, from point P in a uniform magnetic field, as shown in Figure 4.

Both electrons travel perpendicular to the magnetic field, but in opposite directions. Throughout their journey, both electrons remain within the magnetic field.

Electron e_1 travels at twice the speed of e_2. Relativistic effects can be ignored as both electrons are travelling at low speeds. Electrostatic effects at point P can be ignored as the two electrons are emitted at different times.

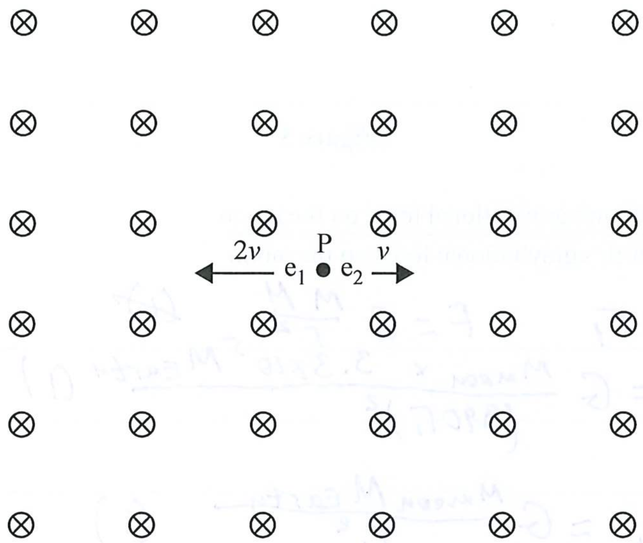

Figure 4

Which one of the following three outcomes occurs?

- Outcome 1 – Electron e_1 returns to point P in the shortest time.
- Outcome 2 – Electron e_2 returns to point P in the shortest time.
- Outcome 3 – Both electrons take the same time to return to point P.

Outcome $\boxed{3}$ (1)

Explain your answer.

$F = \frac{mv^2}{r} = qvB \qquad v = \frac{2\pi r}{T}$ (1)

$\frac{mv}{r} = qB \qquad \frac{v}{r} = \frac{2\pi}{T}$

$\frac{2\pi m}{T} = qB$

$T = \frac{2\pi m}{qB}$ (1) T is independent of v, so Outcome 3.

Question 5 (3 marks)

Figure 5 shows the sun, the moon and Earth.

The mass of the sun is approximately 3.3×10^5 times the mass of Earth.

The distance from the sun to the moon is approximately 390 times the distance from Earth to the moon.

Figure 5

Calculate $\dfrac{\text{magnitude of the sun's gravitational force on the moon}}{\text{magnitude of Earth's gravitational force on the moon}}$.

$r_2 = 390 r_1 \qquad F = G\dfrac{M M}{r^2}$ ~~(1)~~

$F_{sun} = G\dfrac{M_{moon} \times 3.3\times10^5 M_{Earth}}{(390 r_1)^2}$ (1)

$F_{Earth} = G\dfrac{M_{moon} M_{Earth}}{r_1^2}$ (1)

$\boxed{2.2}$

$\dfrac{F_{sun}}{F_{Earth}} = \dfrac{3.3\times10^5}{390^2} = 2.2$ (1)

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Question 6 (5 marks)

Measuring very small changes in Earth's surface mass, the 600 kg satellite GRACE-FO1 is in a circular orbit around Earth at an altitude of 500 km. The radius of Earth is 6.37×10^6 m.

a. Calculate the magnitude and direction of the satellite's centripetal acceleration. Give your answer correct to three significant figures. 3 marks

$g = \frac{GM}{r^2}$

$g = \frac{6.67\times10^{-11} \times \cancel{6.37\times10^{6}}\ 5.98\times10^{24}}{(6.37 + 5\times10^{5})^2}$ (1)

$= 8.45$

8.45 m s^{-2}	Inwards (1)

(1)

b. Figure 6 shows a graph of the gravitational force that would act on GRACE-FO1 for a range of altitudes.

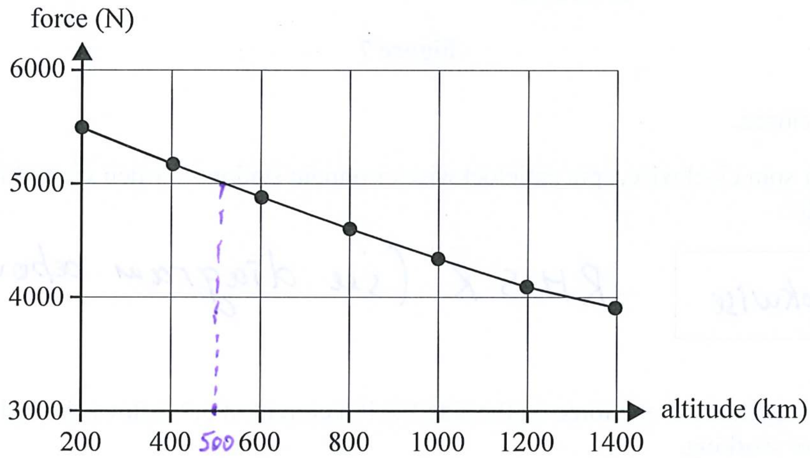

Figure 6

Estimate the energy required to lift the satellite from its present orbit at an altitude of 500 km to a new orbit at an altitude of 1400 km. 2 marks

$E_{gp} = \text{Area} = \frac{5000+3900}{2} \times 900\times10^3$

$= 4.0\times10^9$ (1)

$E_K = \frac{GMm}{2r}$ $\Delta E_K = \frac{GmM}{2}\left(\frac{1}{(6.87\times10^6)} - \frac{1}{(7.77\times10^6)}\right) =$

$= \frac{6.67\times10^{-11}\times600\times5.98\times10^{24}}{2}\left(\frac{1}{6.87\times10^6} - \frac{1}{7.77\times10^6}\right) =$

$= (6.67\times600\times5.98\times10^{24}\times10 \ldots$

$= 2.02\times10^9$ J

1.98×10^9 J

(1)

$E = (4.0 - 2.02)\times10^9$

$\approx 1.98\times10^9$ J

Question 7 (3 marks)

Figure 7 shows a schematic diagram of a simple DC motor, powered by a battery.

The motor has a rectangular coil, WXYZ, consisting of 45 turns. The side WX has a length of 6.0 cm and the side XY has a length of 4.0 cm. The coil is connected to a split-ring commutator. Two permanent magnets provide a uniform magnetic field of 80 mT. Both the coil and the commutator are free to turn.

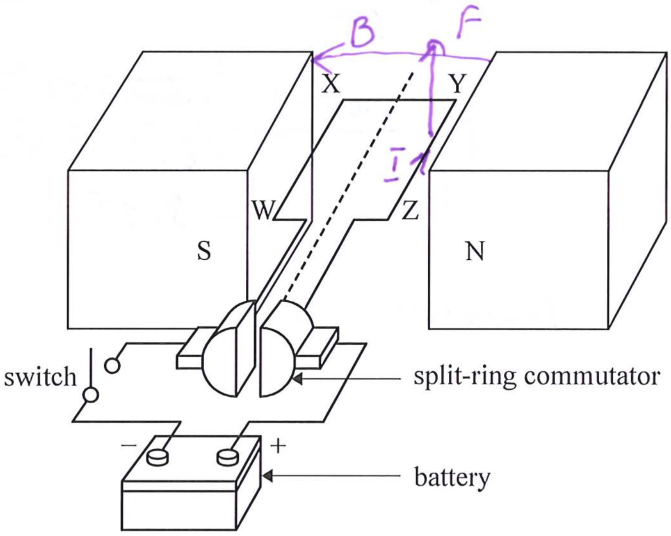

Figure 7

The switch is now closed.

a. Will the motor spin clockwise, spin anticlockwise or remain stationary when viewed from the battery side? 1 mark

Anticlockwise

RHSR (see diagram above)

b. Calculate the magnitude of the force on the side YZ if a current of 3.2 A flows through the coil. Show your working. 2 marks

$F = nIBL = 45 \times 3.2 \times 0.08 \times 0.06$ (1)

$= 0.69$ N (1)

0.69 N

Question 8 (7 marks)

Sarah and Raminda construct a simple alternator, as shown in Figure 8.

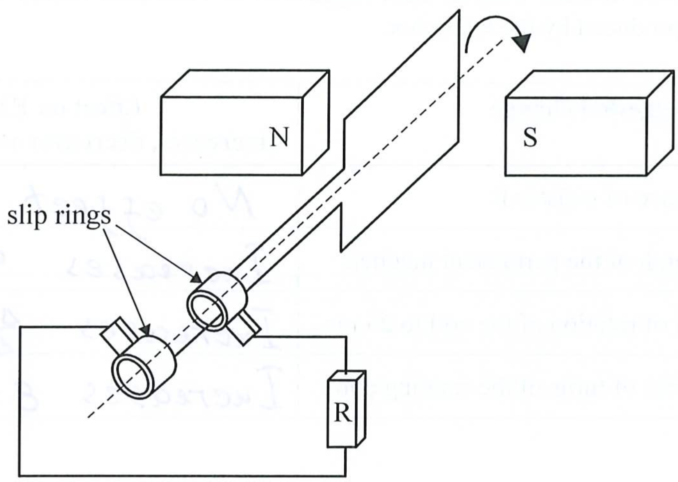

Figure 8

When the coil is rotating steadily, it takes 50.0 ms to complete one revolution and the peak EMF generated is 4.30 V.

a. Calculate the frequency of the alternator. 1 mark

$f = \frac{1}{T} = \frac{1}{0.05}$

20 Hz

b. Calculate the EMF, V_{RMS}, generated. Show your working and give your answer correct to three significant figures. 2 marks

$V_{RMS} = \frac{V_{peak}}{\sqrt{2}} = \frac{4.3}{\sqrt{2}} = 3.04$

(1) (1)

3.04 V

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c. To increase the magnitude of the EMF produced by the alternator, Raminda suggests making a number of changes to the alternator.

Sarah insists that each change be investigated one at a time.

In the spaces provided, indicate whether each suggestion will increase, decrease or have no effect on the EMF produced by the alternator. 4 marks

Suggested change	**Effect on EMF (increases, decreases or has no effect)**
reduce the resistance of resistor R	No effect
increase the strength of the permanent magnets	Increases $\Phi \uparrow, \Delta\Phi \uparrow$
reduce the period of rotation of the coil to 25 ms	Increases $\frac{\Delta\Phi}{\Delta t} \uparrow$
increase the number of turns of the rotating coil	Increases $\varepsilon = n\frac{\Delta\Phi}{\Delta t}$

Question 9 (7 marks)

A local community wishes to power its town hall using hydro-electricity. A waterfall drives an AC generator, with power delivered to the hall via transmission lines, as shown in Figure 9. The generator has an RMS power output of 4.2 kW when operating normally.

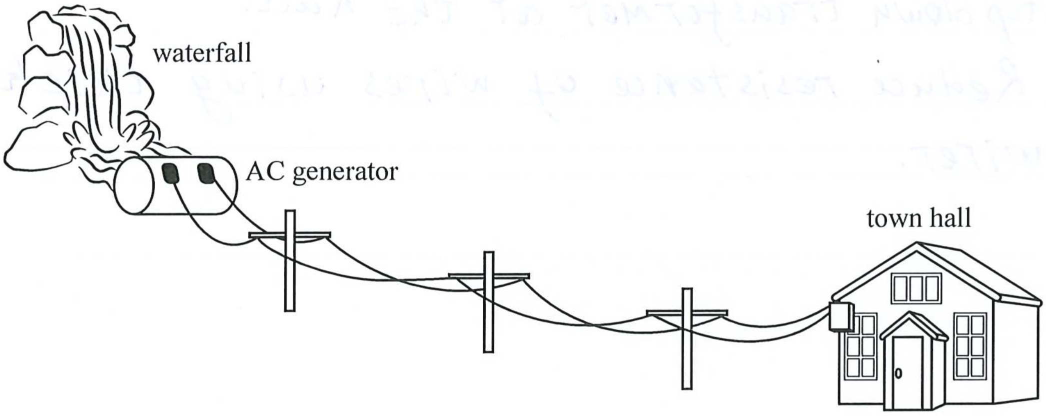

Figure 9

The town hall's electrical loads have a total resistance of 20 Ω and require 2.6 kW of RMS power when operating normally.

a. Calculate the RMS voltage at the town hall under these conditions. Show your working. 2 marks

$P = \frac{V_{RMS}^2}{R}$

$V_{RMS} = \sqrt{2.6 \times 10^3 \times 20}$ (1)

$= 228$

228 V

b. Calculate the resistance of the transmission lines. 3 marks

$P_{LOSS} = 4200 - 2600 = 1600\ W$ (1)

$I = \frac{V_{RMS}}{R} = \frac{228}{20} = 11.4A$ (1)

$P_{LOSS} = I^2 R \quad R = \frac{P_{LOSS}}{I^2} = \frac{1600}{11.4^2} = 12.3\Omega$ (1)

12.3 Ω

c. Suggest two changes the community could make to the system that would reduce power losses without changing the output of the AC generator or the load at the town hall. 2 marks

1. Add step up transformer at the generator and step down transformer at the hall.

2. Reduce resistance of wires using thicker wirer.

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Question 10 (6 marks)

A single rectangular loop of wire containing a cut out section labelled EF moves to the right at a constant speed of 2.4 m s^{-1}, as shown in Figure 10a. At time $t = 0$, the right-hand edge of the loop enters a constant magnetic field into the page.

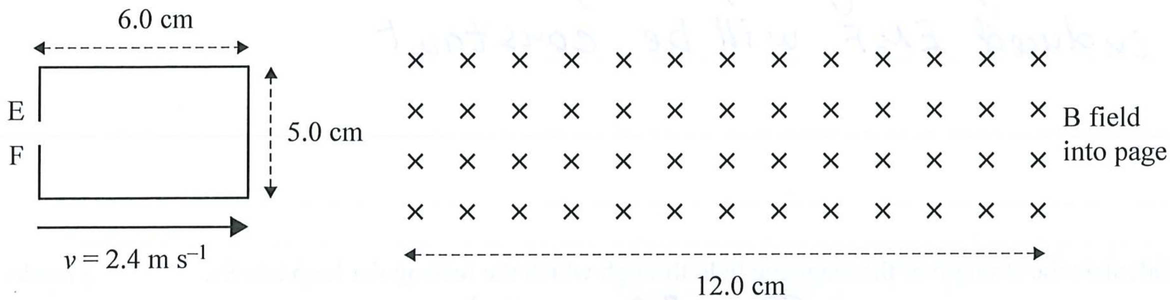

Figure 10a

The induced EMF produced as a function of time is shown in the graph in Figure 10b.

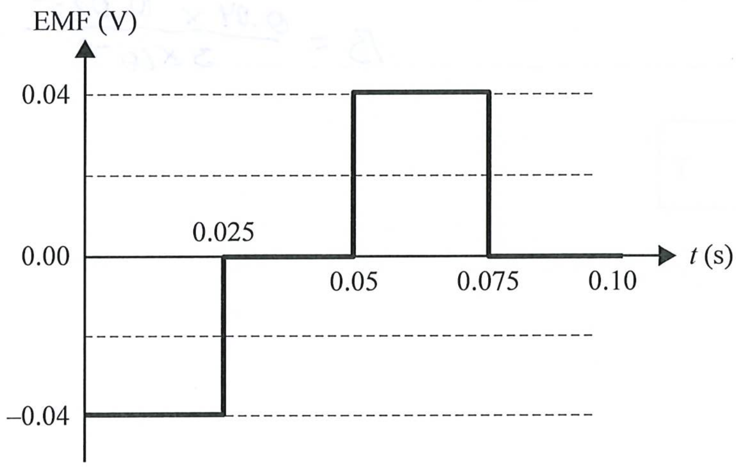

Figure 10b

While the loop enters, and is partially within, the field, an EMF is generated between points E and F.

a. Which point, E or F, is positive? 1 mark

E

Magnetic field into the page and flux ↑, so induced field is out of the page. Using RHGR current in the loop from F to E so if it will be connected to outside circuit current will be in the external circuit from E to F. ∴ E "+"

b. Explain why the induced EMF is constant during the time period 0.00 s to 0.025 s. 2 marks

As loop travels at constant speed
rate of change of the flux and so
induced EMF will be constant.

c. Calculate the strength of the magnetic field through which the rectangular loop travels. 3 marks

$\varepsilon = \frac{\Delta \Phi}{\Delta t} = \frac{BA}{\Delta t}$ (1)

$0.04 = \frac{B \times 3\times10^{-3}}{0.025}$ (1)

$B = \frac{0.04 \times 0.025}{3\times10^{-3}} = 0.33$ (1)

0.33 T

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Question 11 (9 marks)

Lee ties a small ball of mass 100 g to a string and rotates it in a vertical circle, as shown in Figure 11a. Assume that the ball is rotated at a constant speed of 3.0 m s^{-1}. The radius, r, of the circle is 0.60 m. Figure 11b shows a side view.

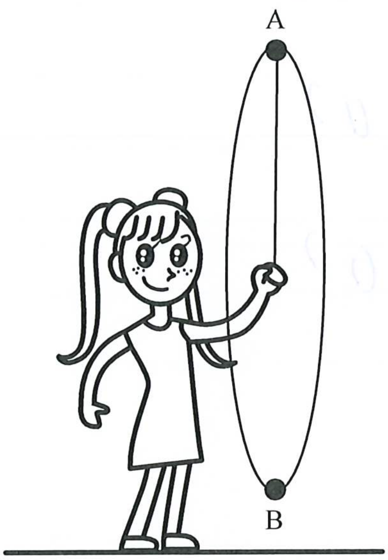

Figure 11a

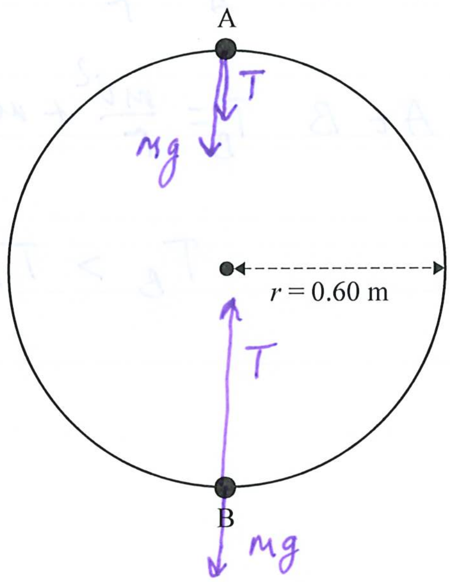

Figure 11b

a. On Figure 11b, draw arrows to represent each of the forces acting on the small ball at position A, at the top of the circle, and at position B, at the bottom of the circle. Label each arrow clearly and use the lengths of the arrows to show the relative approximate magnitudes of the forces. No calculations are required. 4 marks

b. Calculate the tension force in the string when the ball is at position B. Use $g = 10$ m s^{-2}. 2 marks

$T - Mg = \frac{mv^2}{r}$

$T = Mg + \frac{mv^2}{r} = 0.1 \times 10 + \frac{0.1 \times 3^2}{0.6}$ (1)

$= 2.5$ (1)

2.5 N

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c. Lee now increases the speed of the ball to a new constant speed, which is greater than 3.0 m s^{-1}, and notices that the string breaks when the ball is at position B.

Explain why the string is more likely to break at position B than at position A. 3 marks

At A $T_A = \frac{mv^2}{r} - mg$ (1)

At B $T_B = \frac{mv^2}{r} + mg$ (1)

$T_B > T_A$ (1)

Question 12 (8 marks)

Two students investigate the physics of long jumps. They analyse a video of their friend Jemina as she runs along a track and then jumps. She lands in a sand pit that is level with the track.

Jemina's horizontal speed at the moment she jumps is 8.0 m s^{-1}. She is in the air for 0.6 s before landing in the sand pit. The students use $g = 10$ m s^{-2} for their calculations. The motion is modelled as that of a point mass, as shown in Figure 12.

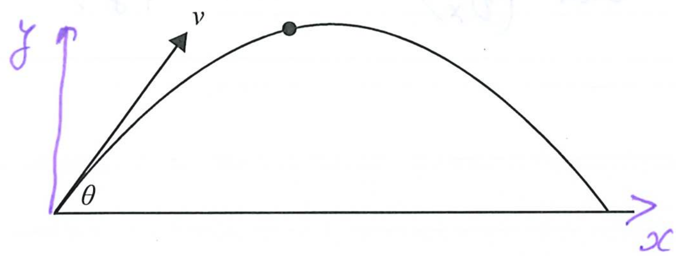

Figure 12

a. Calculate the horizontal distance that Jemina would be expected to travel if her motion were modelled as a projectile with point mass as shown in Figure 12. Show your working. 2 marks

$s = V_x t = 8 \times 0.6$ (1)

$= 4.8$ (1)

4.8 m

b. Calculate Jemina's vertical speed as she takes off from the track. Show your working. 2 marks

At the top $V_y = 0$. Time to the top 0.3 s.

$V = u + at$

$0 = u_y - gt$ (1) $u_y = 10 \times 0.3 = 3$

3 m s^{-1}

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c. Calculate Jemina's velocity as she launches. Include both the magnitude and the angle from the horizontal of her velocity at take-off. 3 marks

$v = \sqrt{v_x^2 + v_y^2} = \sqrt{8^2+3^2} = 8.54\ \text{m s}^{-1}$

(1) (1)

$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(\frac{3}{8}\right) = 21$

8.5 m s^{-1}	21 °

d. The students use a tape measure to check the horizontal distance that Jemina actually jumps, and find that it is less than the distance they calculated in **part a.**

Suggest **one** possible reason for this. 1 mark

Air resistance will slow her down so ~~time in the~~ her both vertical and horisontal velocities will be less and so range and hight will be less.

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Question 13 (13 marks)

As part of their practical investigations, two Physics students, Chris and Arya, investigate changes in gravitational potential energy and elastic potential energy for a 2.0 kg mass initially hanging on a spring.

The spring has an unstretched length of 1.0 m, as shown at position P in Figure 13a.

The 2.0 kg mass is placed by Arya on the unstretched spring and it hangs stationary at position Q in Figure 13b.

Their Physics teacher tells them that they can use $g = 10$ m s^{-2} for their calculations.

a. Show that the spring constant of the spring, k, is 20 N m^{-1}. 1 mark

$mg = kx$

$k = \frac{2 \times 10}{1} = 20$ N m^{-1}

Chris then pulls the mass down a further 1.0 m below position Q, to position R, and releases it so that it oscillates between positions R and P, as shown in Figure 13c.

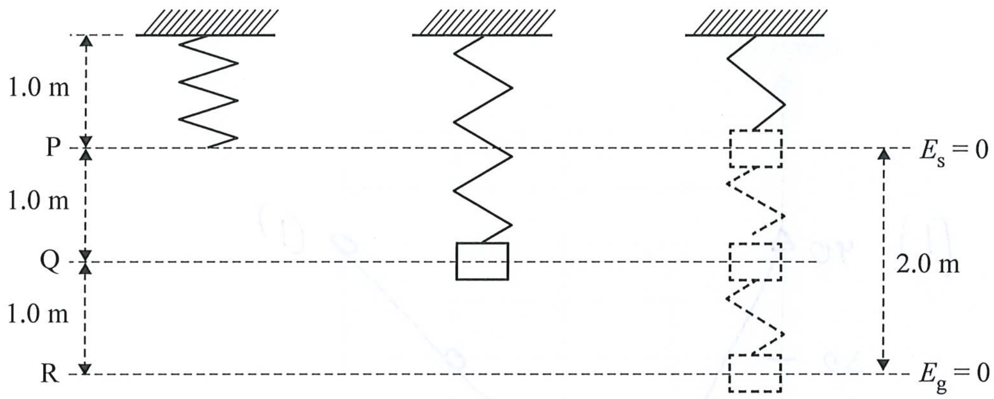

Figure 13a **Figure 13b** **Figure 13c**

The students decide that the gravitational potential energy, E_g, is zero at position R, and that they can use the formula for gravitational potential energy, $E_g = mg\Delta h$, where Δh is the height above position R.

The students also decide that the elastic potential energy is zero at the top position P, and that they can use the elastic potential energy formula $E_s = \frac{1}{2}k(\Delta x)^2$, where Δx is the extension of the spring beyond its unstretched length.

Arya enters the following information into a table.

Position	h (m)	E_g (J)	Δx (m)	E_s (J)
P	2.0	40.0	0	0
	1.5	30.0	0.5	2.5
Q	1.0	20	1.0	10.0
	0.5	10.0	1.5	22.5
R	0	0	2.0	40.0

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b. Using the formulas for E_g and E_s, verify that Arya's $E_s = 10$ J at position Q is correct and fill in the missing data points in the table. Show your working for each calculation. 3 marks

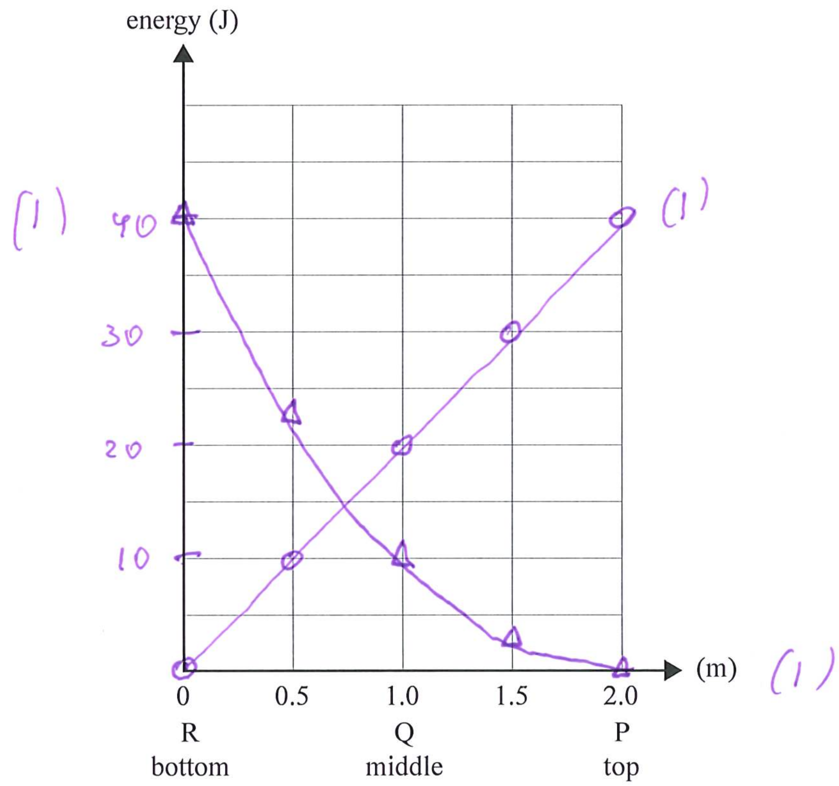
$E_s = \frac{20 \times 1^2}{2} = 10$ J

At Q $E_g = mgh = 2 \times 10 \times 1 = 20$ J

Between Q and R $E_s = \frac{20 \times 1.5^2}{2} = 22.5$ J

c. On the axes below, plot the E_g and E_s versus position data for the oscillating mass. On your graph:

- choose an appropriate scale and numbers for the *y*-axis
- use small circles for the E_g data and small triangles for the E_s data
- draw a line/curve of best fit through the plotted points for the E_g data
- draw a line/curve of best fit through the plotted points for the E_s data. 4 marks



d. Determine the speed of the mass as it goes through position Q. Show your working. 3 marks

$E_{total} = mgh = 2 \times 10 \times 2 = 40\ J$ (1)

At Q : $\frac{mv^2}{2} + mg \times 1 + \frac{k \times 1^2}{2} = 40$

$\frac{2v^2}{2} + 2 \times 10 + \frac{20 \times 1^2}{2} = 40$ (1)

$v^2 = 10$

$\boxed{3.2\ \text{m s}^{-1}}$ (1)

e. Arya and Chris discuss the graphs that they have drawn. Chris says that their calculation must be wrong because the graphs should add up to a constant amount – the total energy of the system. However, Arya says that the graphs are correct.

Explain why Chris is incorrect. 2 marks

He is incorrect as he did not account for kinetic energy. If he will take it into consideration total energy will be constant.

Question 14 (4 marks)

A spaceship of length 71 m, measured when stationary on Earth, is travelling horizontally past an observer on Earth at a speed of 0.80c.

a. The spaceship emits a beam of light towards the observer.

State the speed of the light as measured by the observer on Earth. Justify your answer. 2 marks

$v = 3 \times 10^8\ m\ s^{-1}$ (1)

According to the first Einstein's postulate speed of light is same for all observers

b. Calculate the length of the spaceship as measured by the observer on Earth. 2 marks

$L = \frac{L_0}{\gamma} = \frac{71}{(\sqrt{1-(0.8)^2})^{-1}} = 42.6\ m$ (1)

(1)

SECTION B – continued

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Question 15 (6 marks)

Nialle is standing between two loudspeakers on the school oval, as shown in Figure 14. Sound of a single frequency of 200 Hz is being emitted equally from both speakers. The distance between the speakers is 7.2 m.

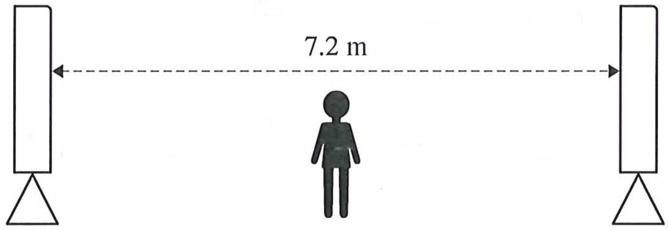

Figure 14

When Nialle stands exactly halfway between the speakers, the sound is quite loud. Nialle begins to walk towards one speaker and notices that the sound gets quieter and then louder.

a. Calculate the wavelength of the 200 Hz sound, taking the speed of sound to be 360 m s^{-1}. 1 mark

$\lambda = \frac{v}{f} = \frac{360}{200} = 1.8$

1.8 m

b. Nialle decides that this observation must be due to interference.

Explain how interference accounts for the loud and quiet points. 3 marks

Sound wave is a series of compressions (high pressure) and rarefactions (low pressure) (1) When 2 compressions or 2 rarefactions meet there will be constructive interference (loud point) (1) When compression meet rarefaction destructive interference (quiet point) forms (1) based on the path difference from each loudspeaker.

c. Calculate the spacing between two adjacent quiet points. 2 marks

$\frac{\lambda}{2}$ (1) $\frac{1.8}{2} = 0.9$

0.9 m

Question 16 (3 marks)

Priya and Dan are playing music in a soundproof recording room. Priya leaves the room while Dan is still playing. She notices that when she is standing at point X with the door open, as shown in Figure 15, she can still hear the music. The music is not only softer, but some of the frequencies also seem to be relatively much softer. The door to the recording room is 1 m wide.

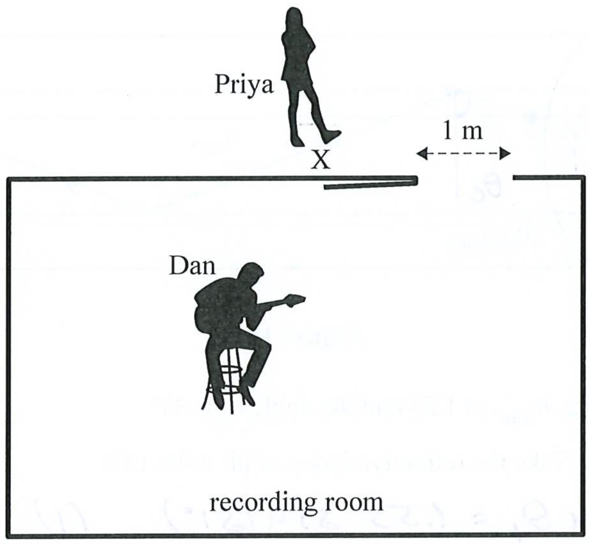

Figure 15

Outline in what way the music sounds different to Priya and explain why.

Priya will hear low frequencies but not high (1). This is the result of diffraction (spreading out of sound waves when they travel throug the opening) (1). As amount of diffraction is proportional to $\frac{\lambda}{w}$ lower frequencies will spread more. (1)

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Question 17 (5 marks)

An optical fibre consists of a transparent cylindrical glass core surrounded by transparent glass cladding. A ray of monochromatic light is incident on an optical fibre at an angle θ_1. It refracts to an angle θ_2 inside the fibre. It then travels in the core until it reflects at the critical angle at the interface between the core and the cladding, as shown in Figure 16.

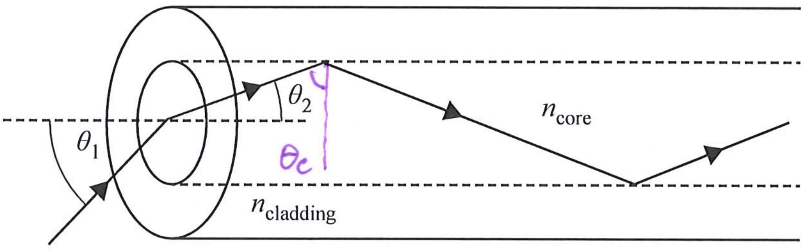

Figure 16

The refractive index of the core, n_{core}, is 1.55 and the angle θ_2 is 31°.

a. Calculate the value of θ_1. Take the refractive index of air to be 1.00 — 2 marks

$\sin\theta_1 = 1.55\sin(31°)$ (1)

$\theta_1 = \sin^{-1}(1.55\sin(31°))$

$\boxed{53°}$

b. Calculate the refractive index of the cladding. — 3 marks

$\theta_c = 90° - \theta_2 = 59°$ (1)

$\theta_c = \sin^{-1}\left(\frac{n_{cladding}}{n_{core}}\right)$

$n_{cladding} = n_{core}\sin(\theta_c)$ (1)

$= 1.55\sin(59°)$

$= 1.33$ (1)

$\boxed{1.33}$

Question 18 (6 marks)

Students carry out a Young's double-slit experiment using the experimental set-up shown in Figure 17. Laser light passes through two closely spaced narrow slits and forms a pattern of light and dark bands on a screen. The bands are numbered – the even numbers are bright bands and the odd numbers are dark bands. The band spacing is X. Band 6 is equidistant from each of the two slits.

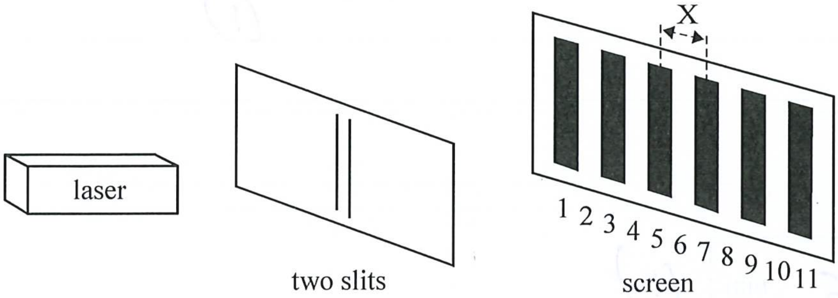

Figure 17

a. Using a wave model of light, explain why Band 3 is dark. 2 marks

The path difference between light travelling from each slit to band 3 equal 1.5λ (1) so this will result in the destructive interference and so dark band.

DO NOT WRITE IN THIS AREA

b. The two slits are 1.00 m from the screen. The wavelength of the laser is 600 nm. The spacing between the two slits is 0.100 mm.

Calculate the band spacing, X, in millimetres. 2 marks

$\Delta x = \frac{\lambda L}{d} = \frac{600 \times 10^{-9} \times 1}{1 \times 10^{-4}} = 0.006$

(1)

6 mm (1)

c. The whole apparatus is now immersed in an insulating liquid of refractive index 1.2. The spacing of the bands changes.

Explain why the spacing of the bands changes and include a calculation of the new band spacing. 2 marks

Wavelength will decrease 1.2 times (1)

$\frac{600}{1.2} = 500$ nm

As everything else is constant

$\Delta x = \frac{6}{1.2} = 5$ mm (1)

Question 19 (4 marks)

In an experiment on the photoelectric effect, Sam shines ultraviolet light onto a zinc plate and ejects photoelectrons, as shown in Figure 18.

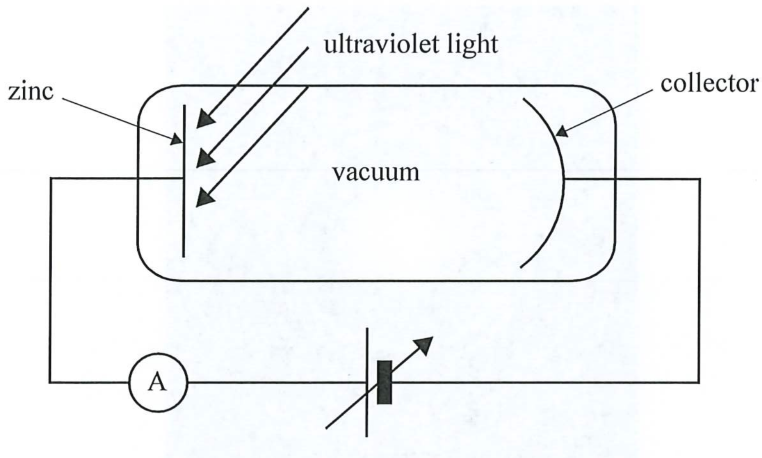

Figure 18

a. The work function of zinc is 4.30 eV.

Calculate the minimum frequency of the ultraviolet light that could eject a photoelectron. 2 marks

$W = hf_0$

$f_0 = \frac{W}{h} = \frac{4.3}{4.14 \times 10^{-15}}$ (1)

$= 1.04 \times 10^{15}$ (1)

$\boxed{1.04 \times 10^{15} \text{ Hz}}$

b. Sam wants to produce a greater photocurrent – that is, to emit more photoelectrons. He considers using a much brighter red light instead of the original ultraviolet light source used in **part a.**

Is Sam's idea likely to produce a greater photocurrent? Explain your answer. 2 marks

No (1)

Red light has lower frequency so photons will not have enough energy to ~~produce~~ release electrons (1)

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DO NOT WRITE IN THIS AREA

Question 20 (5 marks)

A beam of electrons, each with a momentum 4.60×10^{-24} kg m s^{-1}, is passed through a salt crystal to produce a diffraction pattern, as shown in Figure 19.

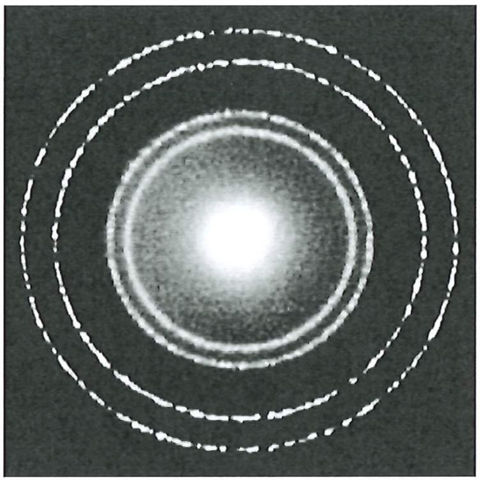

Figure 19

a. Calculate the de Broglie wavelength of the electrons. Show your working. 2 marks

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4.6 \times 10^{-24}}$ (1)

$= 1.44 \times 10^{-10}$ (1)

1.44×10^{-10} m

b. Explain why electron diffraction patterns from salt crystals provide evidence for the wavelike nature of matter. 3 marks

A diffraction pattern is a result of the interference which is a wave phenomena (1) So as electron ~~beeing~~ produce such pattern it is an evidence that they have wave preperties