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Draw a cross through the box (☒) if you have NOT written in this booklet

SCHOLARSHIP EXEMPLAR

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Scholarship 2023
Physics

Time allowed: Three hours
Total score: 32

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should answer ALL the questions in this booklet.

For all 'describe' or 'explain' questions, the answers should be written or drawn clearly with all logic fully explained.

For all numerical answers, full working must be shown and the answer must be rounded to the correct number of significant figures and given with the correct SI unit.

Formulae you may find useful are given on page 3.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–24 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (AREA DO NOT WRITE). This area may be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

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The assessment starts on page 4.

The formulae below may be of use to you.

$v_f = v_i + at$ $d = v_i t + \frac{1}{2}at^2$ $d = \frac{v_i + v_f}{2}t$ $v_f^2 = v_i^2 + 2ad$ $F_g = \frac{GMm}{r^2}$ $F_c = \frac{mv^2}{r}$ $\Delta p = F\Delta t$ $\omega = 2\pi f$ $d = r\theta$ $v = r\omega$ $a = r\alpha$ $W = Fd$ $F_{net} = ma$ $p = mv$ $x_{COM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\alpha = \frac{\Delta\omega}{\Delta t}$ $L = I\omega$ $L = mvr$ $\tau = I\alpha$ $\tau = Fr$ $E_{K(ROT)} = \frac{1}{2}I\omega^2$ $E_{K(LIN)} = \frac{1}{2}mv^2$ $\Delta E_p = mg\Delta h$ $\omega_f = \omega_i + \alpha t$ $\omega_f^2 = \omega_i^2 + 2\alpha\theta$ $\theta = \frac{(\omega_i + \omega_f)}{2}t$ $\theta = \omega_i t + \frac{1}{2}\alpha t^2$	$T = 2\pi\sqrt{\frac{l}{g}}$ $T = 2\pi\sqrt{\frac{m}{k}}$ $E_p = \frac{1}{2}ky^2$ $F = -ky$ $a = -\omega^2 y$ $y = A\sin\omega t \quad y = A\cos\omega t$ $v = A\omega\cos\omega t \quad v = -A\omega\sin\omega t$ $a = -A\omega^2\sin\omega t \quad a = -A\omega^2\cos\omega t$ $\Delta E = Vq$ $P = VI$ $V = Ed$ $Q = CV$ $C_T = C_1 + C_2$ $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$ $E = \frac{1}{2}QV$ $C = \frac{\varepsilon_o \varepsilon_r A}{d}$ $\tau = RC$ $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$ $R_T = R_1 + R_2$ $V = IR$ $F = BIL$ $V = BvL$ $F = Bqv$ $F = Eq$ $E = \frac{V}{d}$	$\phi = BA$ $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $E = \frac{1}{2}LI^2$ $\tau = \frac{L}{R}$ $I = I_{MAX}\sin\omega t$ $V = V_{MAX}\sin\omega t$ $I_{MAX} = \sqrt{2}\, I_{rms}$ $V_{MAX} = \sqrt{2}\, V_{rms}$ $X_C = \frac{1}{\omega C}$ $X_L = \omega L$ $V = IZ$ $f_0 = \frac{1}{2\pi\sqrt{LC}}$ $v = f\lambda$ $f = \frac{1}{T}$ $n\lambda = \frac{dx}{L}$ $n\lambda = d\sin\theta$ $f' = f\frac{V_W}{V_W \pm V_S}$ $E = hf$ $hf = \phi + E_K$ $E = \Delta mc^2$ $\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$ $E_n = -\frac{hcR}{n^2}$

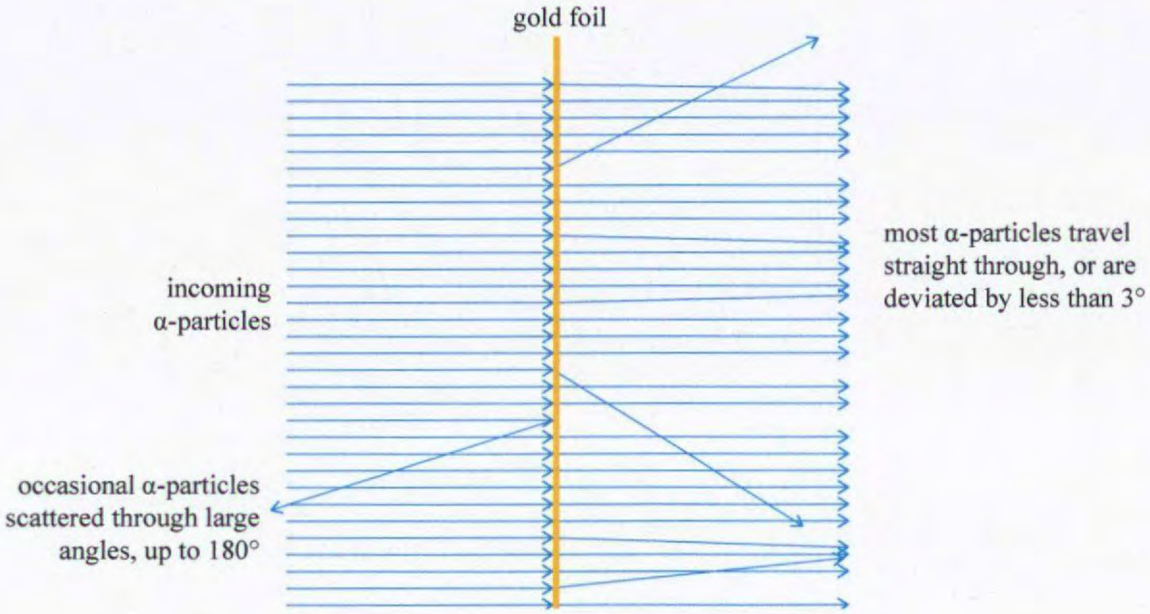
QUESTION ONE: THE DISCOVERIES OF ERNEST RUTHERFORD

Atomic number of gold = 79
Charge of an electron = -1.60×10^{-19} C

Ernest Rutherford won a Nobel Prize in 1908 for work on understanding radioactive decay and for discovering α-particles. Later, he and his fellow researchers used α-particles in two famous experiments.

Experiment 1: Scattering of alpha particles by gold foil

When Rutherford fired α-particles at a thin foil of gold, he observed that most went straight through or deviated by less than 3 degrees. However, the researchers were surprised to see occasional α-particles were scattered through large angles, some even returning in the direction from which they had come.



(a) Explain how these results were consistent with the model of the atom that Rutherford proposed.

~~Because~~ alpha particles consist of two protons and two neutrons (i.e. a helium nucleus). If the model of the atom previously proposed, the plum pudding model (~~positive~~ negative charges scattered throughout a negative body), had been accurate, the alpha particles would have been able to pass through the gold foil with minimum, or no, ~~deflection~~ deviation. However, the large angle/ scattering reflections were not consistent with this model. ~~AB~~ Rutheford proposed that the atom instead consisted of a small, dense, positively charged nucleus surrounded by orbiting

~~a~~ to the nucleus, and the angle at which it approached.

electrons. Therefore, according to Rutherford's model most of the atom is empty space, allowing most of the alpha particles to pass straight through, expiaing why it was observed that most ~~would~~ go straight through. However occasionally an alpha particle would encounter a ~~small~~ nucleus, and the dense, positively charged nucleus ~~positive charges~~ would repel the positive alpha partice, causing either a large angle deviation or reflection, depending upon ~~the~~ how close the alpha paticle got ~~a~~

(b) The electrostatic potential energy between two charges, of magnitudes q_1 and q_2, and separated by distance r, is given by $E_p = \frac{kq_1q_2}{r}$, where $k = 8.99 \times 10^9$ N m² C⁻².

An α-particle of mass m, velocity v, and charge $2e$, travels directly towards a nucleus that remains stationary at all times. The charge on the stationary nucleus is Ze, where Z is the atomic number of the stationary nucleus, and e is the charge of an electron.

(i) Show that the distance of closest approach, D, is given by:

$$D = \frac{4kZe^2}{mv^2}$$

Explain your reasoning.

$k = 8.99 \times 10^9 \text{ Nm}^2\text{C}^{-2}$ $\quad E_p = \frac{kq_1q_2}{r}$

The alpha particle will be at the closest point when all its kinetic energy is converted to electrostatic potential energy.

$E_{k_i}(a) = \frac{1}{2}mv^2 \quad E_p = \frac{k(2e)(Ze)}{r}$

~~$\frac{1}{2}mv^2$~~ Therefore, when $E_{k_i}(a) = E_p$, $r = D$

$\frac{1}{2}mv^2 = \frac{k(2e)(Ze)}{D}$

$\frac{Dmv^2}{2} = 2kZe^2$

$Dmv^2 = \cancel{2}\ 4kZe^2$

$D = \frac{4kZe^2}{mv^2}$

(ii) Calculate the distance of closest approach of a 4.78 MeV α-particle travelling directly towards a gold nucleus, which is fixed in position.

$eV = 1.6 \times 10^{-19}$ J $\qquad D = \dfrac{4kZe^2}{mv^2}$

$Z = 79$

$\cancel{E_{Ki}(a) = \frac{1}{2}m(4.78 \times 10^6 \times 1.6 \times 10^{-19})}$

$E_{Ki}(a) = (4.78 \times 10^6 \times 1.6 \times 10^{-19})$ J

$E_{Ki}(a) = 7.648 \times 10^{-13}$ J

$7.648 \times 10^{-13} = \dfrac{k(2e)(79e)}{D} \qquad E_p = \dfrac{kq_1q_2}{r}$

$e = 1.6 \times 10^{-19}$ C

$\cancel{D = (8.99 \times 10^9)(3.2 \times 10^{-19})} \qquad k = 8.99 \times 10^9\ \text{Nm}^2\text{C}^{-2}$

$D = \dfrac{(8.99 \times 10^9)(3.2 \times 10^{-19})(126.4 \times 10^{-19})}{(7.648 \times 10^{-13})}$

$D = 4.755 \times 10^{-14}$ m $\qquad D = 4.75 \times 10^{-14}$ m

(c) If a nucleus of charge *Ze* were free to move, as would occur if it were in the gaseous state for example, would the distance of closest approach be the same, greater, or less than given by the equation in part (b)(i)?

Explain your answer using physical principles. $\quad (+)\rightarrow \quad (+)\rightarrow$

No calculation is required.

If the nucleus of charge Ze were free to move, as the positive alpha particle approached it the positive charge on the alpha particle would repel the nucleus (as the nucleus is also positively charged and like charges repel). The electrostatic potential energy between the alpha particle and the nucleus ~~[illegible]~~ caused by the approach of the alpha particle ($E_p = \frac{kq_1q_2}{r}$), would convert to kinetic energy ~~in the initially~~ for the nucleus, so it would gain velocity in the ~~other~~ same direction as the alpha particle. (unless it initially had v in the direction ~~However, the~~ of the α particle, in which case it would first slow down then accelerate in the other direction). However, as the alapha particle ~~was~~ ~~initially had kinetic energy in the~~ for alredy

✱ (see back)

(d) **Experiment 2: Bombardment of nitrogen gas by high-energy alpha particles**

Rutherford and his fellow researchers fired high-energy, 7.70 MeV, α-particles at a container of nitrogen gas and were surprised to see that protons, ${}^{1}_{1}H$, were emitted. At the time, the researchers knew that a nuclear reaction had occurred, but they did not know what the reaction was. Two possible nuclear reactions are:

${}^{14}_{7}N + {}^{4}_{2}\alpha \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$	Reaction 1
${}^{14}_{7}N + {}^{4}_{2}\alpha \rightarrow {}^{13}_{6}C + {}^{1}_{1}H + {}^{4}_{2}\alpha$	Reaction 2

(i) Using your knowledge of binding energy per nucleon, explain which reaction, Reaction 1 or Reaction 2, is more likely.

Reaction 1 is more likely. This is because both ~~reaba~~ Oxygen and Nitrogen are before Fe on the & Oxygen is further along than Nitrogen. periodic table. This means that when Nitrogen fuses with the alpha particle binding energy per nucleon will decrease, providing a loss in energy per nucleon greater than the energy required to overcome the repulsion between the alpha particle and Nitrogen nucleus. As such, the Oxygen nucleus is more stable and & (see back)

(ii) Explain why it was necessary to use high-energy α-particles for this experiment.

Because, although reaction 1 is energetically favourable as the Oxygen nucleus is more stable than the Nitrogen nucleus, the alpha particle still needs to overcome the repulsion ~~between~~ from the Nitrogen nucleus (like charges) in order to fuse with it. As the alpha particle ~~gets closer the~~ needs to get very close to the Nitrogen nucleus for nuclear strong force between the protons and neutrons to take over and fuse the alpha particle and Nitrogen nucleus together, there will be a strong electrostatic repulsion ($E_p = \frac{kq_1q_2}{r}$) and r is very small.
& (see back)

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QUESTION TWO: AXE THROWING

Acceleration due to gravity = 9.81 m s^{-2}

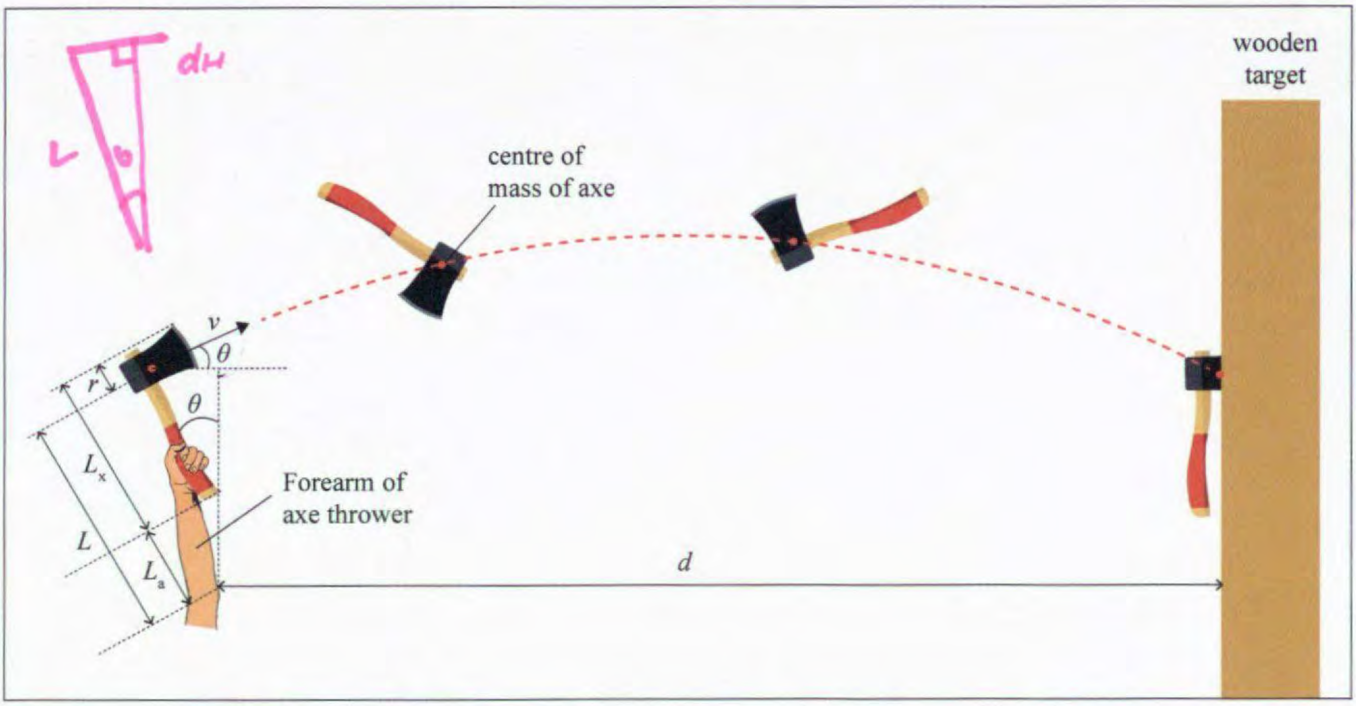
Axe throwing is a traditional sport that has become more popular recently. It involves throwing an axe at a wooden target. The path of the axe can be described with the physics of projectile motion and of rotational motion. If the axe is thrown correctly, it rotates after it is thrown so that it is vertical as it reaches the target, allowing the blade to stick in the target.

Source: www.sydney.com/destinations/sydney/sydney-west/penrith/attractions/throw-axe

Although everybody will throw the axe in a slightly different way, we can describe the throw as follows.

- The axe is held so that the forearm and the axe handle form a straight line, as shown in the diagram below.
- The throw is made by keeping the upper arm still and swinging the forearm from the elbow.

The axe is released at an angle θ, so that its centre of mass has a velocity, v. The axe is thrown from the same height as the target. The axe completes just over one full rotation as it travels from the release point to the target. The centre of mass of the axe finishes up level with the surface of the target, as shown in the diagram below.



The velocity of the centre of mass at release is v.

r = distance from the end of the axe to centre of mass

L_x = total length of axe

L_a = length of axe thrower's forearm

The length from the centre of mass to the elbow is, $L = L_a + L_x - r$

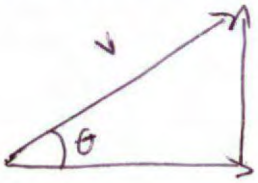
d = distance of axe thrower's elbow from the target

$x = L\sin\theta$

(a) An analysis of the projectile motion of the axe can be used to show that the time of flight of the axe, from the time it is released to when it strikes the target at exactly the same height, is $t = \dfrac{2v\sin\theta}{g}$.

Show that the initial velocity, v, required for the axe to strike the target successfully is given by:

$$v = \sqrt{\frac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}}$$



$v = \sqrt{\dfrac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}}$

Clearly show your working.

$v_{Hi} = v\cos\theta$

$v_{vi} = v\sin\theta$

$a_v = \cancel{9.8}\ g$

$v_{vf} = -v\sin\theta$

$t = \dfrac{2v\sin\theta}{g}$

$\dfrac{2v\sin\theta}{g}$

$v_f = v_i + at$

$d_{HORIZONTAL} = d + L\sin\theta$

$d = d + L\sin\theta$

$v_H = v\cos\theta \qquad v = \dfrac{d}{t}$

$\cancel{v}\cos\theta \times \dfrac{2v\sin\theta}{g} = d + L\sin\theta$

$\cancel{v\cos\theta = g(d + L\sin\theta)}$

$\dfrac{2v^2\cos\theta\sin\theta}{g} = d + L\sin\theta$

$v^2 = \dfrac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}$

(b) The angular velocity of the axe is given by $\omega = \dfrac{v}{L}$. For a successful throw that ends up with the axe rotating and sticking in the target, as shown in the diagram opposite, show that the ratio of $\dfrac{d}{L}$ is given by:

$$\frac{d}{L} = (\theta + 2\pi)\cos\theta - \sin\theta$$

$d = L\sin\theta + d$

$\omega = \dfrac{v}{L}$

$\theta = (\theta + 2\pi)$

$\omega = \dfrac{\Delta\theta}{\Delta t}$

$\dfrac{\sqrt{\dfrac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}}}{L} = \dfrac{g(\theta + 2\pi)}{2v\sin\theta}$

$\omega = \dfrac{(\theta + 2\pi)}{\dfrac{2v\sin\theta}{g}}$

$2v^2\sin\theta = Lg(\theta + 2\pi)$

$\omega = \dfrac{g(\theta + 2\pi)}{2v\sin\theta}$

$\cancel{2}\left(\dfrac{\cancel{g}(d + L\sin\theta)}{\cancel{2}\sin\theta\cos\theta}\right)\sin\theta = L\cancel{g}(\theta + 2\pi)$ (see back)

$\dfrac{\cancel{\sin\theta}(d + L\sin\theta)}{\cancel{\sin\theta}\cos\theta} = L(\theta + 2\pi)$

(c) In axe throwing, the angle θ is usually small.

Derive a simplified form of the equation in part (b), for a small angle θ.

Clearly show your working and state any assumptions made.

If the angle is small you can assume $L = L\cos\theta$

$\frac{d}{L} = (\theta + 2\pi)\cos\theta - \sin\theta$

$d = L\cos\theta(\theta + 2\pi) - L\sin\theta$

$d = L(\theta + 2\pi) - L\sin\theta$

$\frac{d}{L} = (\theta + 2\pi) - \sin\theta$

(d) Axe throwers have limited scope to vary their angle of release, and can throw from any distance, provided they stay behind a line marked on the ground.

(i) Mika throws an axe with a larger total length, L_x.

What other adjustment can she make to ensure that her throw still hits the target successfully?

A larger total length means that L increases. Apart from moving back to maintain the ratio of d/L, and with limited scope to change the angle, Mika needs to maintain the same θ (ie. rotational distance). ~~[illegible]~~ With d held constant, $v \uparrow$ when $L \uparrow$ ($v = \sqrt{\frac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}}$. * (see back)

(ii) Giving reasons, explain which aspects of the axe's flight would change, and which would stay the same, if Mika were throwing an axe on the Moon, where the acceleration due to gravity is less than on Earth.

Both the total velocity of the axe and therefore also the angular velocity of the axe would decrease ($\omega = v/L$) with L, ~~&~~ the d & θ held constant. Its time of flight would subsequently also increase ($t = \frac{2v\sin\theta}{g}$) and $v = \sqrt{\frac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}}$. $d = \frac{v_i + v_f}{2} t = vt$ (by $v_f = -v_i$). Therefore, $d = \frac{2v^2\sin\theta}{g}$

so $d = \frac{L\sin\theta}{\cos\theta - 1}$, which means d will stay constant, assuming L & θ remain constant, because time increases proportionately to the velocity decrease.

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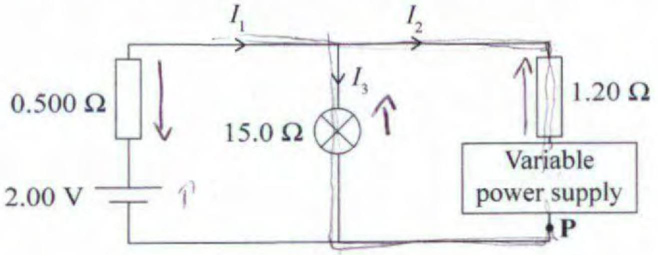
QUESTION THREE: DC AND DOPPLER

A circuit is set up with two power supplies. One supplies a constant EMF of 2.00 V, the other is a variable power supply that can provide a continuous range of EMFs.



(a) In addition to Ohm's Law, describe two other key circuit rules that could be applied to determine currents and potential differences in a circuit like this, and state the fundamental physics principles these rules are based on.

Kirchoffs voltage law and Kirchoffs current law (ie. Kirchoffs loop laws). These are based of the principle that all of the voltage in a loop add to 0V, and that the current into a junction equals the current out of a junction

(b) The orientation and EMF of the variable power supply are adjusted until no current flows through the 15 Ω lamp, and it does not light up.

(i) Calculate the EMF of the variable power supply when the lamp does not light up, and clearly state whether point **P** shown on the diagram is the positive or negative end of the variable power supply.

~~$I_1 = I_2$~~ ~~$3\ Emf - 1.2I_1 - V_L = 0$~~

~~$2 - 0.5I_1 - 1.2I_1 - Emf = 0$~~

~~$2 - 0.5I_1 = V_L$~~ ~~$V_L = 2 - 0.5I_1$~~

~~$Emf = 2 - 1.7I_1$~~

~~$Emf - V_L - 1.2I_1 = 0$~~

~~$Emf = V_L + 1.2I_1$~~

~~$2 - 1.7I_1 = 2 - 0.5I_1 + 1.2I_1$~~

P is the positive ~~negative~~ end

(see back)

(ii) With the variable power supply still set so the 15.0 Ω lamp does not light up, the lamp is replaced by another lamp with a lower resistance.

Explain whether the new lamp with lower resistance will light up or not.

The lamp would light up because Emf would then be greater than the voltage ~~of~~ lost across the lamp, so current would be able to flow and the lamp would light up.

(c) A moving car, with a horn emitting sound with frequency, f, starts from rest and accelerates with constant acceleration, a, towards a stationary observer a distance, d, away.

Show that the observer will eventually hear a frequency of $2f$ only if $d > \frac{v_w^{\ 2}}{8a}$, where v_w is the speed of sound.

$V_w \qquad a = \frac{v}{\frac{d}{v}} = \frac{v^2}{d} \qquad f' = f\frac{V_w}{V_w - v}$

$a = \frac{\Delta v}{\Delta t}$

$d = v \times t \qquad d = v \times t \qquad 2f = f\left(\frac{V_w}{V_w - \sqrt{ad}}\right)$

$t = d/v \qquad a = \frac{v}{t}$

$a = v \div \frac{d}{v} \qquad t = \frac{v}{a} \qquad 2(V_w - \sqrt{ad}) = V_w$

$a = \frac{v^2}{d} \qquad t = \frac{d}{v} \qquad 2V_w - 2\sqrt{ad} = V_w$

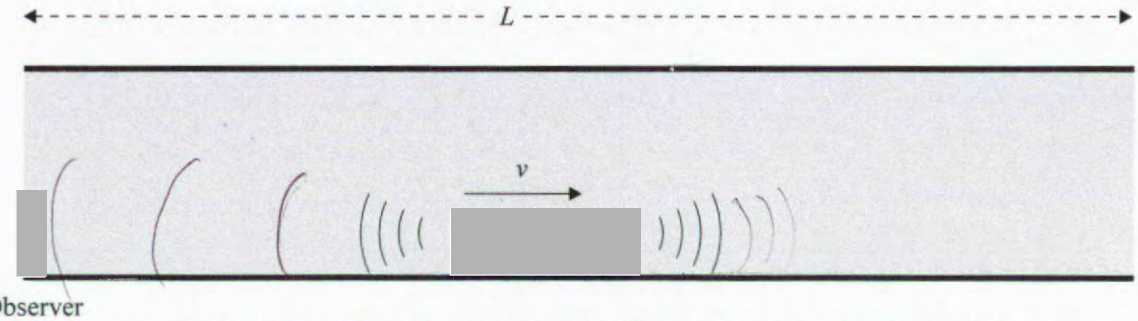
$a = \frac{v^2}{d} \qquad 2\sqrt{ad} = V_w$

$\sqrt{ad} = v \qquad v = \sqrt{ad} \qquad \sqrt{ad} = \frac{V_w}{2}$

* (see back) $\qquad ad = \frac{V_w^2}{4}$

(d) A car travels through a tunnel at a constant speed. The car horn emits sound at a constant single frequency. When sound reaches one of the open ends of the tunnel it is reflected and travels back along the tunnel in the other direction.

The size of the car is small compared to the diameter of the tunnel, so that the presence of the car does not affect the sound travelling through the tunnel.



Sources: https://signalvnoise.com/posts/920-car-design-the-side-crease-is-in
https://www.istockphoto.com/photo/casual-man-side-view-gm183765770-15426060

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An observer standing at one of the open ends of the tunnel will hear two distinct frequencies from the car horn.

(i) Explain why the observer hears two distinct frequencies from the car horn.

Because, the ~~wal~~ sound waves emitted behind the car will stretch behind it as the car moves away from each wavefront it emits. This increases the apparent wavelength of the sound waves from the car horn, ~~increasing~~ decreasing apparent f $\left(f' = \frac{V_w}{V_w + V_{car}}\right)$. ~~this~~ * (see back)

(ii) The car travels through the tunnel at a constant speed, *v*, while the horn emits sound at a constant frequency, *f*, so that both the 20th and 21st harmonics resonate in the tunnel. These harmonics cause a beat frequency of 4.76 Hz at the end of the tunnel.

Speed of sound = 343 m s^{-1}

Calculate the speed of the car, *v*, AND the frequency of the horn, *f*.

v

f

$\lambda = \frac{2L}{n}$

$f' = \frac{343}{\frac{2L}{21}}$

$f' = f\frac{V_w}{V_w \pm v}$

$v = f\lambda$

$f = \frac{v}{\lambda}$

$= \cancel{343}$

$$f\left(\frac{343}{343 - v}\right) - f\left(\frac{343}{343 + v}\right) = 4.76$$

$$\frac{f\,343}{343 + v} = \frac{343}{\frac{2L}{20}} \qquad \frac{f\,343}{343 - v} = \frac{343}{\frac{2L}{21}}$$

$$f\frac{343}{343 + v} = \frac{3430}{L} \qquad f\,343 = \frac{343(343 - v)}{\frac{2L}{21}}$$

$$f = \frac{3430(343 + v)}{343L} \qquad f\,343 = \frac{360.5(343 - v)}{L}$$

$$f = \frac{10(343 + v)}{L} \qquad f = \frac{10.5(343 - v)}{L}$$

4

* (see back)

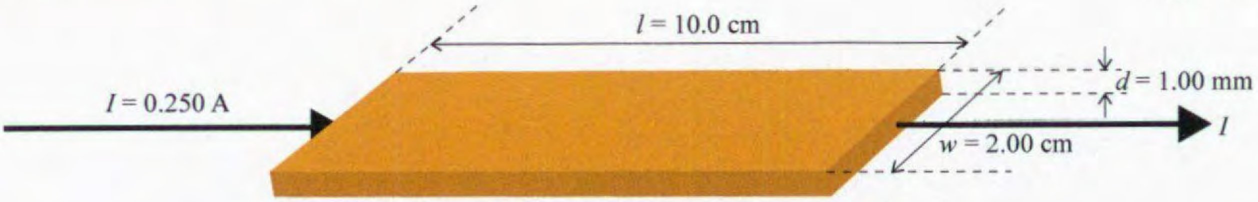
QUESTION FOUR: HALL EFFECT

Charge of an electron = -1.60×10^{-19} C

When charge flows through a conductive material, e.g. a metal, only some of the electrons are free to move. A conductor has a fixed number of free electrons per unit volume, n.

For copper metal, $n = 8.49 \times 10^{28}$ electrons m^{-3}

1m = 0·1cm



(a) (i) A piece of copper metal 10.0 cm long, 2.00 cm wide, and 1.00 mm thick has a current of 0.250 A flowing through it.

By first calculating the amount of free charge in the piece of copper, determine the average speed of a free electron as it flows through the piece of copper.

$V = w \times l \times h$

$= 0{\cdot}1 \times 0{\cdot}02 \times 0{\cdot}001$

$= 2 \times 10^{-06}\ m^3$

$n = 8{\cdot}49 \times 10^{28} \times 2 \times 10^{-06}$

$n = 1{\cdot}698 \times 10^{23}$ elecdons

1A = 1C per second

$1{\cdot}698 \times 10^{23} \times 1{\cdot}6 \times 10^{-19}$

= 27168 C

$I = qV$ $\quad 0.25 = 27168 \times V$

$V = 9{\cdot}202 \times 10^{-06}\ ms^{-1}$

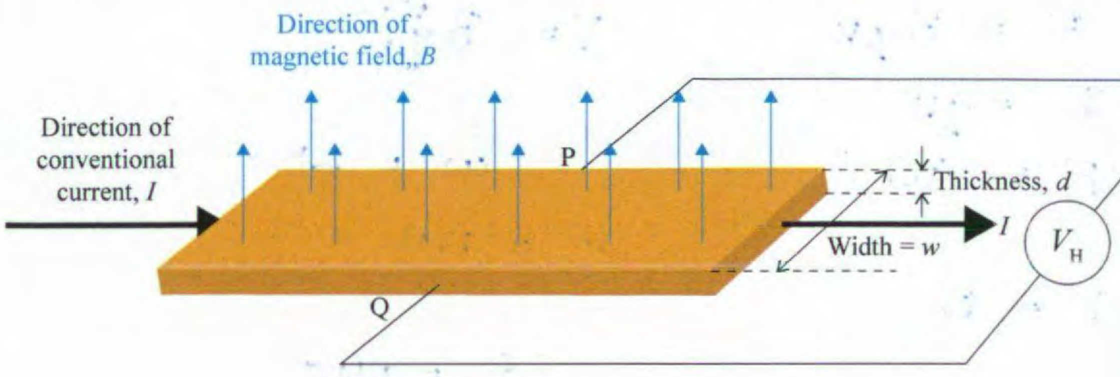
(ii) The current flowing through a conductor is given by the relationship:

$$I = neAv_d$$

where e is the charge of an electron, A is the cross-sectional area of the conductor, and v_d is the average drift velocity of a free electron.

Show that the relationship above is dimensionally consistent.

When charge flows through a conductor which is inside a uniform magnetic field, a sideways force is exerted on the moving electrons that pushes them to one side of the conductor. This makes one side of the conductor positively charged and the opposite side negatively charged. This separation of charge produces a potential difference, known as a Hall Voltage, V_H, across the two sides of the conductor.



(b) By considering the magnetic force acting on an electron moving through the conductor, state which side of the conductor, P or Q, is positively charged.

Your answer must include a description of how you made your selection.

~~Q is positively charged as the electrons are~~ ~~the electrons are moving to the~~ Conventional current is flowing to the right, so positive charge is "flowing" to the right (ie. electrons are flowing left causing a charge separation), and the magnetic ~~[illegible]~~ field acts upwards, so the force on the positive charges must be towards Q, using the ~~flat~~ right hand slap rule. ~~Therefore, the force on flow~~ if conventional current (the charge) is flowing right, electrons must be flowing left, so they electrons experience a force towards P, using right hand slap with charge flowing in the opposite direction, or using the back of my hand instead.

(c) (i) When a steady current is flowing, the sideways forces acting on an electron moving through the conductor are balanced.

Explain the origin of the force that balances the magnetic force on a moving electron.

Because, as the electrons are pushed towards P, a charge separation occurs and the side Q becomes positively charged. This induces a voltage (ie. V_H) / a potential difference, that attracts the electrons ~~[illegible]~~ towards Q, thus balancing the forces on the electrons.

Question Four continues on the following page.

(ii) By considering the sideways forces acting on a moving electron, show that the Hall Voltage, V_H, is given by the expression:

$$V_H = \frac{BI}{nde}$$

$F = Bqv$ $V = B\frac{v}{q}L$

$I = qv$

$F = BIL$ $w = d$

$q = ne$

$F = B$

$ld = area$

$L = w$

$V = F$

$B\cancel{v}L = Be\cancel{v}$

$F =$

(d) Measuring the Hall Voltage is a commonly used method for determining the strength of a magnetic field.

Describe the conditions necessary to achieve the most precise measurement of the strength of a magnetic field, and any practical limitations to achieving these conditions.

0

3

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q1. c) had velocity towards the ~~alph~~ nucleus, the alpha particle will have a greater velocity than the nucleus (as E_k (nucleus) $= \Delta E_p$, whereas $E_k(a) = E_{k i(a)} - E_p$) ~~as long as~~ ~~$E_p \nless E_{ki}(a)$~~ Therefore, the alpha particle will continue to get closer to the nucleus, increasing E_p. This increases the kinetic energy and therefore velocity of the nucleus. This will continue until E_p is such that the velocity of the nucleus and the alpha particle are ~~such~~ ~~that~~ equal, such that E_p ~~and~~ and a therefore the E_k of each remains constant. However, because the mass of the alpha particle is less than that of the nucleus this occurs when the kinetic energy of the nucleus is greater than the kinetic energy of the alpha particle ($E_k = \frac{1}{2}mv^2$). Consequently ~~the most~~ most of the alpha particles kinetic energy will have been converted to E_p, but no all. Therefore, the alpha particle will get less close at its distance of closest approach, because when the ~~nucleus~~ nucleus Ze is held in place all of the alpha particles kinetic energy will have been converted to E_p, so E_p will be greater for the same E_k, so with k, ze, Ze, m, v held constant, because $D = \frac{4kZe^2}{mv^2}$, D will be greater with the nucleus not free to move.

See

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q1. d)i) energetically favourable compared to the Nitrogen nucleus. The carbon nucleus, however, is lower than Nitrogen on the periodic table and subsequently has a higher ~~BE~~ binding energy per nucleon, is therefore ~~not~~ less energetically ~~stable~~ favourable, and less energy is released from the fusion than required to overcome the repulsion between the carbon nuclei and alpha particle so it won't occur spontaneously.

Seen

Q1. d)iii) Therefore, it needs to have a kinetic energy greater than the very high electrostatic potential energy, as once $E_k = E_p$ the alpha particle will stop moving and then accelerate away from the Nitrogen nuclei. Thus, the high kinetic energy needed mean the alpha particles must be high energy (7.70 MeV).

Seen

Q2. b) $\dfrac{d + L\sin\theta}{\cos\theta} = L(\theta + 2\pi)$

Seen

$d + L\sin\theta = L(\theta + 2\pi)\cos\theta$

$d = L(\theta + 2\pi)\cos\theta - L\sin\theta$

$\dfrac{d}{L} = (\theta + 2\pi)\cos\theta - \sin\theta$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q2.d)i) $\omega = \frac{\Delta\theta}{\Delta t}$. With v_x increased, for the same d, t↓. Therefore, in order to maintain $\Delta\theta$, ω needs to increase. As such, I would suggest she holds the axe further away from the COM, so as to exert a greater torque on the axe, ($\tau = I\alpha = Fr$) Thus increasing α and therefore ω.

Seen

$$\frac{2\left(\frac{g(d + L\sin\theta)}{2\sin\theta\cos\theta}\right)\sin\theta}{g}$$

$$d = \frac{2 \cdot d + L\sin\theta}{\cos\theta}$$

$$d\cos\theta - d = L\sin\theta$$

$$d = \frac{L\sin\theta}{\cos\theta - 1}$$

Q3. b)i) $2 - 0.5I_1 - 1.2I_1 + \varepsilon_{mf} = 0$

$\varepsilon_{mf} = 1.7I_1 - 2$

Seen

$\varepsilon_{mf} = V_L$

$2 - 0.5I_1 - \varepsilon_{mf} = 0$

$\varepsilon_{mf} = 2 - 0.5I_1$

$1.7I_1 - 2 = 2 - 0.5I_1$

$1.2I_1 = 4$

$I_1 = 3\frac{1}{3}$ A

$\varepsilon_{mf} = \frac{1}{3}$ V

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q3. c) $2f = f \frac{Vw}{Vw - V}$

$v = \sqrt{ad}$

$\frac{2f}{f} = \frac{Vw}{Vw - \sqrt{ad}}$

$2(Vw - \sqrt{ad}) = Vw$

$2Vw - 2\sqrt{ad} = Vw$

$2\sqrt{ad} = Vw$

$\sqrt{ad} = \frac{Vw}{2}$

$ad = \frac{Vw^2}{4}$

$d = \frac{Vw^2}{4}$

Seen

∴ once the driver has travelled $\frac{Vw^2}{4a}$ m, a frequency of 2f will be heard

so $d > \frac{Vw^2}{4a}$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Q3. d) i) ~~this~~ The observer is standing directly behind the car, so this is the frequency they will hear. However, the sound waves infront of the car will compress as the car moves towards each wavefront it emits, decreasing apparent wavelength and increases apparent f. These compressed wavefronts will travel down the tunnel infront of the car, then reflects back, constructively ~~interfe~~ interfering with itself (open end tunnel), towards the observer. The observer will also therefore hear this ~~also~~ increased apparent frequency. Because we hear the increased and decreased apparent f we will hear 2 distinct frequencies.

Seen

Q3. d) ii)

$$10(343 + v) = 10.5(343 - v)$$

$$\frac{343 + v}{343 - v} = 1.05$$

$$343 + v = 360.15 - 1.05v$$

$$2.05v = 17.15$$

$$v = 8.37\,ms^{-1}$$

Seen.

$$f\left(\frac{343}{343 - 8.37} - \frac{343}{343 + 8.37}\right) = 4.78$$

$$f\,0.0488 = 4.78 \qquad f = 97.5\,Hz$$

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Extra space if required.
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QUESTION NUMBER

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QUESTION NUMBER

93103

Scholarship

Subject: Physics

Standard: 93103

Total score: 21

Q	Score	Marker commentary
1	08	Outstanding scholarship responses for all details of this question. Grasp of the Rutherford model, order of magnitude calculations and the consequences of collisions are all well demonstrated.
2	06	A clear grasp of the physical situation allowed the straightforward derivation of complex expressions. After failing to show that if cos theta approaches 1 then sin theta must approach zero, the candidate, while showing good understanding of the proposed situations, did not adequately identify the key cause of the alterations.
3	04	Lack of understanding of circuitry shown. Incomplete response to the first part with confusion in the application of Kirchhoff's Laws and little understanding of the implications of zero potential difference were disappointing. Especially when followed up with a pleasing demonstration of Doppler effect understanding marred only by a peculiar algebraic error.
4	03	With no real attempt shown for half this question it is below a scholarship level result. Lack of clarity affected the result of two determinations while a good understanding of the consequences of the motion of charges was demonstrated.