SECTION ONE: Short Response

30% (54 marks)

This section has 14 questions. Answer all questions.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

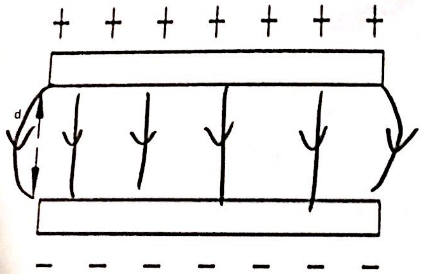
Additional working space pages at the end of this Question/Answer booklet are for planning or continuing an answer. If you use these pages, indicate at the original answer, the page number it is planned/continued on and write the question number being planned/continued on the additional working space page.

Suggested working time: 50 minutes.

Question 1

(3 marks)

Two charged metal plates are separated by a distance "d" as shown below. There is a constant potential difference applied between the plates.



Shape 1

Arrows 1

Sketch the electric field lines between the plates on the diagram above.

What would happen to the spacing of these lines if d is increased?

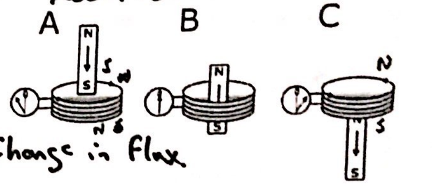
Increase 1

SHOULD ARGUE CURRENT BUT GENEROUSLY ACCEPTED EMF....

Question 2

(3 marks)

Explain the different galvanometer readings at A, B and C as the magnet falls through the coil.



Faraday's Law – Change in Flux

Lenz's Law – B from Induced current opposes

So A & C opposite.

Flux not changing in B.

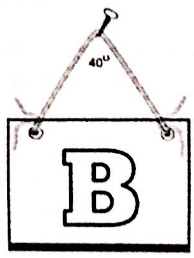
All points logically linked

3

Question 3

(3 marks)

A Biology teacher, Mr Mezcal, is hanging a "B for biology" sign. At the point where the nail is in contact with his dodgy shoe lace, the angle is 40°. The sign has a strangely large mass of 40.0 kg. The shoe lace can only be tensioned to 205 N. Show whether the dodgy lace will support the sign.



With max – 205 N

$T_v = T\cos 20° = 193\text{ N}$

$2T_v = 386\text{ N.}$

$F_g = 40 \times 9.8 = 392\text{ N}$ so No.

OR

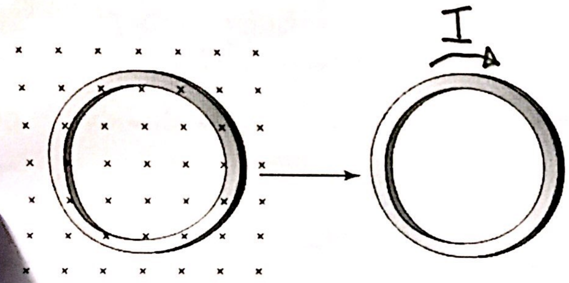
Required.

209 N > 205 N

Question 4 **(4 marks)**

Peta is experimenting with electromagnetic principles. In one experiment, she places a conducting loop in a magnetic field. She then turns off the magnetic field.

(a) Indicate with an arrow, the direction of induced current flow in the loop. (1 mark)

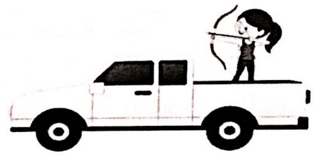


(b) State three ways that Peta could increase the size of the current induced. (3 marks)

↑ Area
B
Turns
Time of field.

Question 5 **(3 marks)**

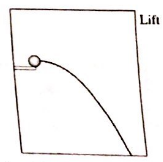
Eloise is firing an arrow above the horizontal from the back of a moving truck. The truck is travelling in the direction that she is firing her arrow at 95 kmh^{-1}. Compared to firing from the back of a stationary truck, and ignoring the effects of air resistance, circle the correct word to indicate the effect of the truck's velocity on:



The time of flight of the arrow	~~increased~~	decreased	no change
The range of the arrow along ground	increased	decreased	no change
The maximum height of the arrow	~~increased~~	decreased	no change

Question 6 **(2 marks)**

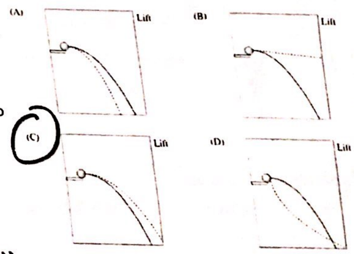
A projectile was launched horizontally inside a lift in a building. The diagram shows the path of the projectile when the lift was stationary.



?

The projectile was launched again with the same velocity. However, this time the lift was slowing down as it approached the top floor of the building.

Which diagram correctly shows the new path of the projectile (dotted line) as observed in the lift, relative to the path created in the stationary lift (solid line)? Explain clearly why you chose your answer.



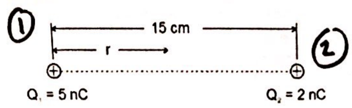
Answer: ____

Explanation:

Initial upward velocity

Question 7 **(5 marks)**

Two positive charges are 15 cm apart as shown below.



On the line joining their centres, there is a point where the net force on a test charge would be zero.

Calculate the distance, r, that this point is from Q_1.

$$F_{\text{on from } ①} = F_{\cancel{\text{on}} \text{ from } ②} \qquad 1$$

$$\frac{1}{4\pi\varepsilon_0}\frac{q\, 5\times10^{-9}}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{q\, 2\times10^{-9}}{(0.15-r)^2} \qquad 1$$

$$\text{so } \frac{5}{r^2} = \frac{2}{(0.15-r)^2} \qquad 1$$

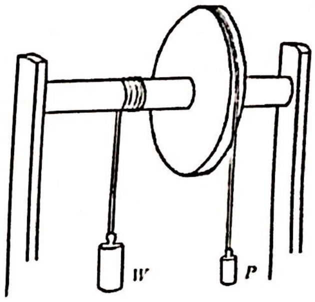
$$\sqrt{} \quad \frac{\sqrt{5}}{r} = \frac{\sqrt{2}}{0.15-r} \qquad 1$$

$$r = 9.19 \text{ cm} \,! \qquad 1$$

Question 8 **(3 marks)**

The frictionless wheel and axle in the diagram is stationary (not rotating).

Explain why this is the case given that W is much heavier than P.



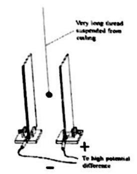
Torques must be balanced. 1

Weight of W acts on smaller radius. 1
(or converse for P)

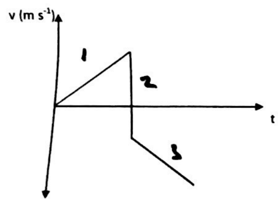
So $\tau = Fr$ means force larger for same torque. 1

Question 9 (4 marks)

Kasun is conducting an experiment on electric fields. He suspends a table tennis ball from a piece of string and suspends it between two parallel metal plates, 20.0 cm apart. The plates are connected to high voltage DC source. He then pulls the ball so that it touches the negative plate. The ball is then observed to bounce between the plates.



Kasun recorded the motion of the ball on his phone and later analysed it using software on his computer. He produced the following velocity-time graph for the ball as it moves away from the negative plate, bounces off the positive plate and returns to the negative plate.



Explain the motion of the ball illustrated by the graph.

1 – Ball charge -ve & repelled. ✓

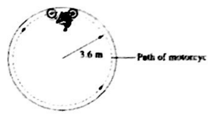
2 – Ball strikes + plate and bounces (changes direction) ✓ ✓

3 – Ball now + and repelled from + plate. ✓

Particle accelerator!

Question 10 (3 marks)

Aleksy is performing a dangerous stunt on his motorbike. He is attempting to complete a vertical circular loop-the-loop without his bike losing contact with the track. Aleksy and his motorbike have a combined mass of 225 kg. Find the minimum velocity that Aleksy and his bike must have at the top of the loop to maintain the circular path.



$R \downarrow \downarrow mg$

✓ $\frac{mv^2}{r} = mg + R$

✓ $R = 0$ for min v

$g = \frac{v^2}{r}$. $v = \sqrt{rg} = 5.94\ ms^{-1}$ ✓

Question 11 (5 marks)

NASA Scientists have recently discovered a new solar system: The Trappist-1 System. Trappist-1 is a red dwarf star (a star nearing the end of its life) and it has seven planets. One of the planets: "Trappist-f" has an orbital period of 9.21 "Earth days" about Trappist-1, has an assumed mass of 0.68 "Earth" masses and a radius 1.04 that of the Earth. The mean orbital radius of Trappist-f about Trappist-1 is 5.54×10^9 m.

(a) Find "g" the acceleration due to gravity on the surface of planet Trappist-f. (2 marks)

$g = \frac{GM}{r^2} = \frac{6.67\times10^{-11} \times 4.0696\times10^{24}}{6624800^2}$

$= 6.17\ ms^{-2}$

(b) Use Kepler's Third Law to find the mass of the red dwarf star, Trappist-1. (3 marks)

$T^2 = \frac{4\pi^2}{GM} r^3$

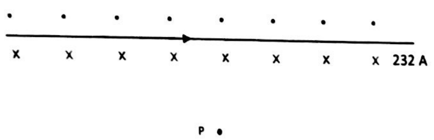
$= \frac{4\pi^2 (5.54\times10^9)^3}{6.67\times10^{-11} (795744)^2}$ — 9.21 Days

$= 1.59 \times 10^{29}$ kg.

Question 12

(4 marks)

The diagram below shows a conductor carrying a 232 A DC conventional current through an overhead cable.



(a) On the diagram, show the direction of the magnetic field surrounding the conductor due to the current. (1 mark)

Students should be using the conventional notation for representing fields going into or coming out of a page. Given the wording of the question, it was sufficient to show one pair of symbols, but the intention of the question was to show the magnetic field direction along the length of the cable.
Drawing circles with arrows (or 'springs') around the wire is insufficient, particularly if it is not possible to unambiguously interpret the which part of the circle/spring is in front of the cable and which is behind.
Statements like 'clockwise looking at the end of the cable' are also ambiguous unless it is clearly specified which end of the cable is referred to.

(b) Point P is 3.12 m below the conductor. Find the magnetic field intensity at P due to the current carrying conductor and state its direction. (3 marks)

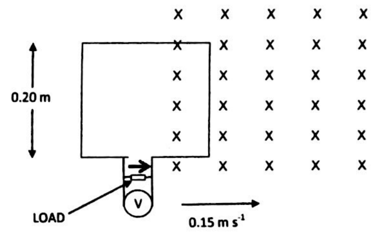
$B = \frac{\mu\ I}{2\pi\ r}$

$= \frac{4\pi \times 10^{-7} \times 232}{2\pi \times 3.12}$ **(1 mark)**

$= 1.49 \times 10^{-5}$ T **(1 mark)** into the page **(1 mark)**

Question 13 **(5 marks)**

A square flat coil of insulated wire is moving through a region of perpendicular magnetic field of strength 0.150 T, as shown in the diagram below. The square coil consists of 1150 turns, has a side length of 0.20 m and is moving at 0.15 m s^{-1} in the direction shown. There is a small load placed across the terminals of the voltmeter to ensure that current can flow.



(a) Show that the reading on the voltmeter is approximately 5.2 V. (2 marks)

emf = NBℓv
= 1150 turns x 0.150 T x 0.20 m x 0.15 m s^{-1} **(1 mark)**
= 5.18 V
≈5.2 V **(1 mark)**
i.e. need to show that the answer is <u>approx</u>. 5.2 V, not that it is <u>equal</u> to 5.2 V

(b) Indicate the direction of induced current through the load with an arrow above it. (1 mark)

Many had direction of current shown correctly in other parts of the coil – but with no arrow placed as directed!

(c) It is noticed that a little later when the coil is completely immersed in the magnetic field, that the reading on the voltmeter drops to zero. Explain this observation. (2 marks)

When the coil is immersed in the field there is no change in magnetic <u>flux</u> **(1 mark)**
As per Faraday's Law, if there is no change in flux, no current will be induced **(1 mark)**

Question 14 **(7 marks)**

The figure below shows a 115 tonne aeroplane flying in a horizontal circle of radius 2,130 m.

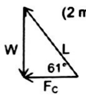
(a) Show clearly as a third arrow, the direction of the "net force" acting on the plane. Label this force F_{net}. **(1 mark)**

Arrow must go along existing dotted line and must be labelled. Strictly speaking it should also be a dotted line since this is not a real force.

(b) Explain how the lift force keeps the plane in a horizontal circle. **(2 marks)**

The lift force has a horizontal component which is directed towards the centre of the circular flight path **(1 mark)**
Since this force is unbalanced, it supplies the centripetal (net) force which maintains the aeroplane in a circular flight path. **(1 mark)**

(c) Find the magnitude of the lift force "L". **(2 marks)**



$\sin(61°) = W/L$
$L = (1.15 \times 10^5 \times 9.80)/\sin(61°)$ **(1 mark)**
$= 1.29 \times 10^6$ N **(1 mark)**

(d) Find the speed of the aeroplane. **(2 marks)**

$F_C = mv^2/r = mg/\tan(61°) = 6.247 \times 10^5$ N **(1 mark)**

$v = \sqrt{6.247 \times 10^5 \text{ N} \times 2130 \text{ m}/1.15 \times 10^5 \text{ kg}}$

$= 108$ m s^{-1} **(1 mark)**

End of Section One

SECTION TWO: Problem-solving **50% (90 marks)**

This section has **six (6)** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

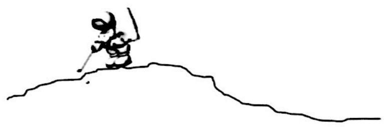
When estimating numerical answers, show your working or reasoning clearly. Give final answers to a maximum of **two** significant figures and include appropriate units where applicable.

Additional working space pages at the end of this Question/Answer booklet are for planning or continuing an answer. If you use these pages, indicate at the original answer, the page number it is planned/continued on and write the question number being planned/continued on the additional working space page

Suggested working time: 90 minutes.

Question 15 **(14 marks)**

Neil decides to hit a golf ball while visiting the Moon. He is standing on a small mound and he hits the ball from a point 2.35 m above the lunar surface that he is hitting the ball toward. The ball leaves the ground travelling at 35.0 m s^{-1} at an angle of 17° to the horizontal.



(a) In the diagram below, the ball has just left the club face. Show clearly as labelled arrows, all forces acting on the ball at this instant. **(1 mark)**

1 mark for weight force; less one mark for any spurious forces shown

(b) Find the maximum height gained by the ball above the mound. **(3 marks)**

$u_v = \sin(17°) \times 35.0$ m s^{-1} = 10.23 m s^{-1} up **(1 mark)**; $a = -1.62$ m s^{-2}; $v_v = 0$ m s^{-1}
$v^2 = u^2 + 2as$
$s = (0 - 10.23^2)/(2 \times -1.62)$ **(1 mark)**
$= 32.3$ m above the mound **(1 mark)**

(c) What is the ball's speed at its maximum height? (2 marks)

cos(17°) x 35.0 m s^{-1} **(1 mark)**
= 33.5 m s^{-1} **(1 mark)**

no need to state direction for a scalar quantity

(d) What is the ball's acceleration at its maximum height? (1 mark)

1.62 m s^{-2} down (direction must be given; accept -1.62 m s^{-2})

(e) Calculate the total time of flight for the ball. (3 marks)

Time to top of flight:
t = (v-u)/a
= (0-10.23)/-1.62
= 6.32 s **(1 mark)**

Final speed:
$v^2 = u^2 + 2as$
v = √(0 +2 x -1.62 x (−32.32 + -2.35)
= 10.599 m s^{-1}

Time from top of flight:
t = (v-u)/a
= (0-10.599)/-1.62
= 6.54 s **(1 mark)**

Total time = 6.32 + 6.54
= 12.86 s
= 12.9 s **(1 mark)**

(f) Find the horizontal range of the golf shot. (2 marks)

$s_x = u_x$ x t
= cos(17°) x 35.0 m s^{-1} x 12.86 s **(1 mark)**
= 430 m **(1 mark)**

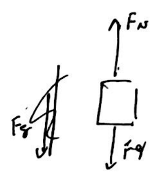
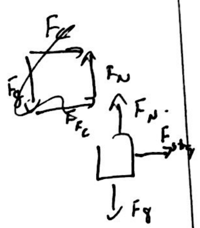
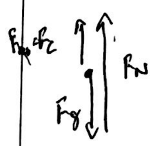
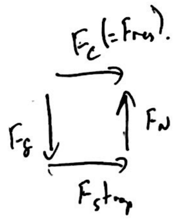
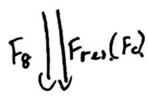
As long as method was correct, follow through marks were allowed for use of incorrect horizontal speed from (c), and/or incorrect time from (e).

(g) Explain why the range calculated in part (f) above, is approximately six times further than the same shot on the Earth. (2 marks)

gravity on earth = -9.82/-1.62 = 6.06 times gravity on the moon **(1 mark)**
Flight time is inversely proportional to a (from t = (v_y-u_y)/a), so for a given initial velocity, a projectile on the moon will have a flight time of ~6 times that on Earth.
Since horizontal range is proportional to flight time (from v_x = s_x x t), a projectile on the moon will have a range which is ~6 times further than on earth. **(1 mark)**

NB: Difference in gravity needs to be calculated rather than simply stating that Earth has 6x as much gravity.

a) Complete the table, for each contestant you must select the position number (as shown on the diagram) at which you believe they will fail (**each ninja will fall at a different position**), draw the associated free body and force vector diagrams for the contestant. (9 marks)

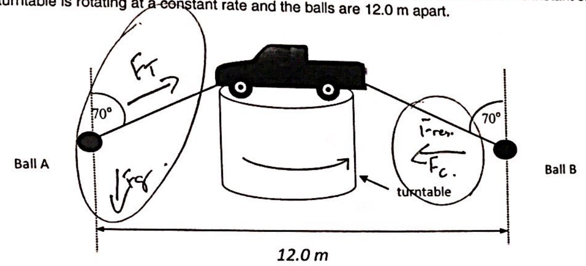
Position 1	Position 2	Position 3
Contestant. (A,B or C) A	Contestant. C	Contestant. B
Free body diagram. 	Free body diagram. 	Free body diagram. 
Force Vector Diagram 	Force Vector Diagram 	Force Vector Diagram 

b) Give the order in which the contestants will finish. Ninja who lasts longest to who falls first. (3 m

C B A. 3.
C B A 2.
B B A — 1

Question 17 **(14 marks)**

A recent television commercial shows a utility (light truck) rotating on a turntable with heavy iron balls attached to either end of the vehicle. Each of the balls has a mass 152 kg and is attached to the utility by identical cables. Each cable makes a 70° angle to the vertical. At the instant shown the turntable is rotating at a constant rate and the balls are 12.0 m apart.



(a) Show as clearly labelled arrows, all forces acting on the ball A. (2 marks)

(b) Show the net force acting on the ball B as a clearly labelled arrow. Label this arrow F_{net}. (1 mark)

(c) Show that tension in each cable is approximately 4350 N. (3 marks)

F_T ✓ $\cos 70 = \frac{F_g}{F_T}$

70° F_g F_c

$F_T = \frac{mg}{\cos 70} = \frac{152 \times 9.8}{\cos 70} = 4.36\ kN.$

(d) Find the centripetal force acting on each of the steel balls. (2 marks)

$\cancel{\sin}\ \tan 70 = \frac{F_c}{F_g}$

$F_c = mg \tan 70.$

$= 4.09\ kN$

(e) Calculate the speed of each of the steel balls. (2 marks)

$F_c = \frac{mv^2}{r}$

$v = \sqrt{\frac{r F_c}{m}} = \sqrt{\frac{6 \times}{152.}}$

$= \cancel{13.1}\ 12.7\ m/sec.$

(f) Find the rate of rotation of the turntable. Express your answer in revolutions per minute. (4 marks)

$\frac{s}{t} = v = 2\pi r f.$ ✓

$f = \frac{v}{2\pi r} = \frac{}{2\pi \times 6} = .337\ Hz$ ✓

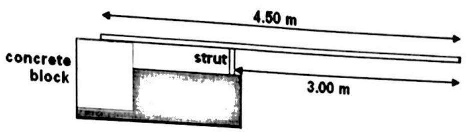
$= \cancel{60.} \times 60\ RPM$ ✓

$= 20.2\ RPM.$

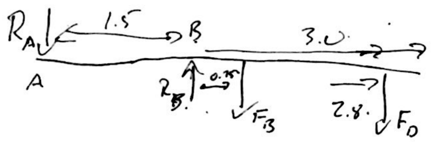
Question 18:

(14 marks)

A uniform diving board has one end firmly fixed by bolts through its end into a concrete block, it is also supported by a single iron strut as shown in the diagram below. The board has a mass of 65.5 kg and is 4.50 m long. An 85.0 kg diver is standing 0.200 m from the end of the board ready to dive in.



a. Draw a labelled diagram showing all the forces acting on the board including the diver. (3 marks)



b. Calculate the force acting on the bolts on the concrete block when the diver is standing 0.200 m from the end. (5 marks)

$\sum M_B = 0 = -R_A \times 1.5 + 65.5 \times 9.8 \times 0.75 + 85 \times 9.8 \times 2.8$

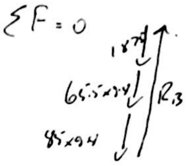
$R_A = 1876$ N. — This is force on Block.

Bolts are in tension ∴ Force is up on Bolts.

$\boxed{-1 \text{ max. For } 2 \text{ directions in "b" or "c"}}$

c. Determine the force on the strut. (3 marks)

$\sum F = 0$

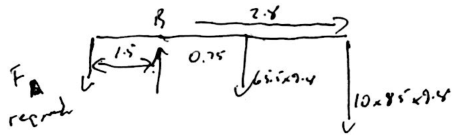


$R_B = 1876 + 642 + 833$

$= 3351$ N.

∴ Force on strut $= \cancel{3351} \cdot$ 3.35 kN ↓.

d. A safety margin built into the attachment at the concrete block would allow for a force 10 times that of the 85.0 kg diver to be standing 0.200 m from the end of the board. Calculate the mass of the concrete block to allow for this safety margin? (3 marks)



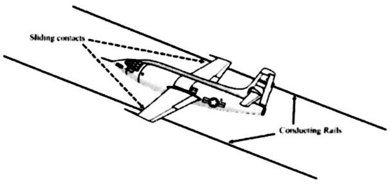
$\sum \tau_B = 0 = 65.5 \times 9.8 \times 0.75 + 10 \times 85 \times 9.8 \times 2.8 - R_A \times 1.5$

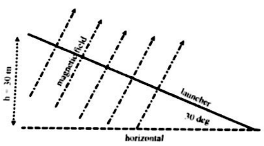
F_A : $R_A = 15970$ N.

mass required $= \frac{F_A}{9.8} = 1.63 \times 10^3$ kg.

Question 19 **(17 marks)**

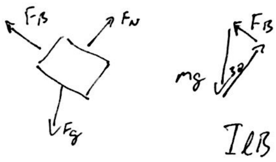
A proposed new design to save fuel during the launch of a rocket plane (mass = 6000kg) is shown below. A large current is to be passed through the wings which will run along frictionless conducting rails with a high voltage between them. Strong electromagnets generate a field which is perpendicular to the rails as shown in the side view and the rocket engines start as the plane leaves the launcher. The distance between the rails is 15.0 m and the current is to be 1000 Amps.





Side View

i) What magnetic field strength will be required to **just** hold the plane in position on the rails ready to launch? (4 marks)



F

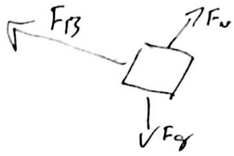
$\sin 30 = \frac{F_B}{mg}$

$ILB = F_B = mg\sin 30$

$B = \frac{6000 \times 9.8 \times \sin 30}{1000 \times 15}$

$= 1.96T$

ii) The current is increased to accelerate the plane up the ramp. Draw a Free Body Diagram for the plane as it travels up the launcher. (3 marks)



iii) Calculate the resultant force required to produce the design acceleration of 50m/sec^2 up the launcher. (2 marks)

why oh why so easy.

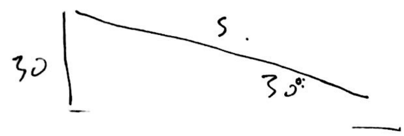
$F = ma$

$= 6000 \times 50$

$= 300\ kN$.

iv) What is the launch speed for the plane?

(4 marks)



$\sin 30 = \frac{30}{s}$

$s = \frac{30}{\sin 30} = 60\,m.$

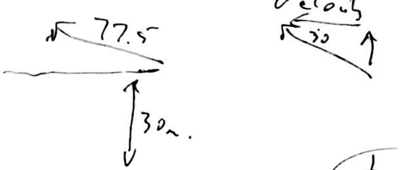
$v^2 = u^2 + 2as.$

$v = \sqrt{2as}$

$= \sqrt{2 \times 50 \times 60} = 77.5\,m/sec$

v) If the rocket motor fails then the plane will take a parabolic path and crash. What will be the maximum time the pilot will have to eject before the plane hits the ground should this happen?

(4 marks)



$\tan 30 = \frac{u_y}{77.5}$

$u_y = 77.5 \tan 30$

$=.$

$s = ut + \frac{1}{2}at^2$

(time to ground $-30 = u_y t - 4.9t^2$ solve.

$t = 8.61$

or. $v_y^2 = u_y^2 + 2(-9.8)(-30$

$= .$

$= (-)$

$v_y = u_y + (-9.8)t$

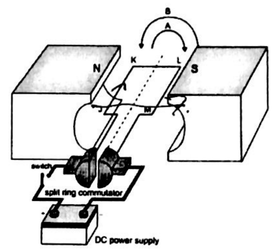
$t = \frac{v_y - u_y}{-9.8} = 8.61$

24

PHYSICS

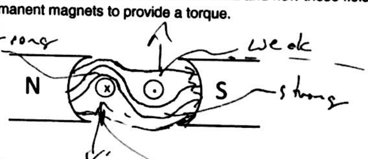
Question 20 (19 marks)

The figure below shows a simple DC motor. The coil JKLM consists of 200 turns. JK and LM are 12.5 cm in length and KL and JM are both 8.0 cm long. The two permanent magnets provide a magnetic field of intensity 1.6×10^{-3} T.



(a) The motor is initially not spinning. In which direction A (clockwise) or B (anticlockwise) will the motor rotate when the switch is closed? (1 mark)

(b) The figure below shows the end view of sides JK and ML, at the position shown above. Show the fields produced by the conductors JK and ML and how these fields interact with the field from the permanent magnets to provide a torque. (2 marks)



(c) When the motor first started spinning, the current flowing was initially measured to be 2.2 A. It then dropped to 0.15 A as the motor reached a constant speed. Explain why the current dropped by making reference to Lenz's Law. (3 marks)

As the motor accelerates it acts as a generator. ~~which is accord.~~ Back emf ✓ reduces cur

Lenz – says

(d) Find the maximum torque produced by the motor when the current flowing is 0.15 A. (3 marks)

$\tau_{max} =$ allow for turns $F = IlB$

$F = 0.15 \times (200 \times .125) \times 1.6 \times 10$

$=$ N ✓

$\tau = F \times \text{diameter} = \times 0.04$ ✓

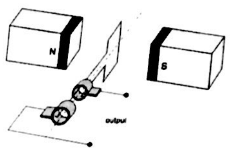
$= 4.8 \times 10^{-4}$ Nm ✓

(e) Explain why the torque produced fluctuates during each revolution and suggest how the design of the motor could be modified to achieve a more constant torque. (2 marks)

Something about radius of action.

Increase number of coils (splits)

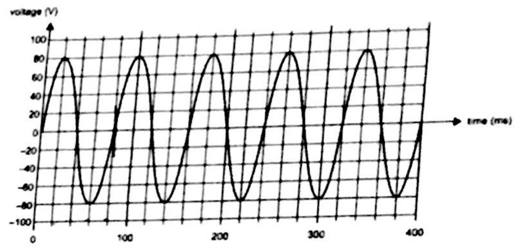
The diagram below shows a simplified ac generator (alternator), the rotating coil is square with a side length of 0.25 m and consists of 1000 turns.



(f) State a feature of the design of the above device that shows it would produce an AC and not DC output. (1 mark)

Slip rings.

The graph below shows how the output from the alternator varies with time:



(g) State the maximum emf produced by the alternator and hence find the average (rms) value of the output. (2 marks)

$\mathcal{E}_{max} = 80$ V.

$\mathcal{E}_{RMS} = \frac{80}{\sqrt{2}} = 56.6$ V

(h) Show that the frequency of rotation of the alternator is approximately 12 Hz. (2 marks)

From graph $T = 80 \times 10^{-3}$ sec.

$F = \frac{1}{T} = \frac{1}{80 \times 10^{-3}} = 12$ Hz.

(i) Find the magnetic field intensity provided by the permanent magnets in the alternator. Express your answer in mT. (3 marks)

$EMF_{max} = 2\pi NBAf$

$B = \frac{80}{2\pi \times 1000 (0.25^2) 12.5}$

$= \cancel{0.017\,T}$ 16.3

or $\cancel{17.0\,mT}$ 16.3 mT.

End of Section Two

Scanned by CamScanner

a. List the variables for this experiment. (4 marks)

Independent variable: Size / magnitude of the current (I) ✓

Dependent variable: Force between the wires ✓

Control variables: – Thickness of wires ✓
– Length (ℓ) of the wires ✓
– Same material for wires ✓
– Distance (d) between wires ✓
(Any two suitable answers for 2 marks)

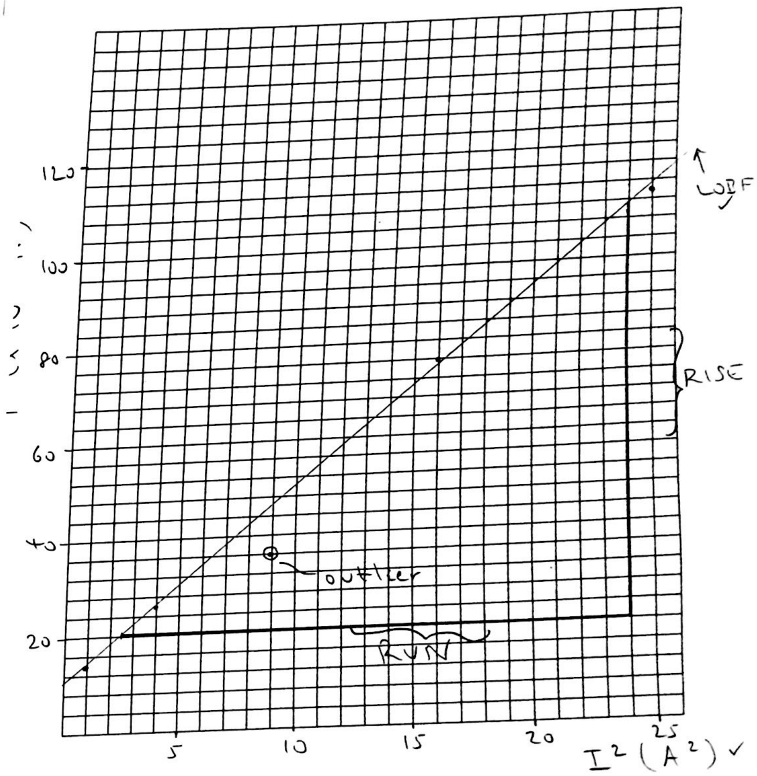
b. Using the equation given, complete the results table below to allow a linearized graph of the data to be drawn. (2 marks)

$$\frac{F}{\ell} = \frac{\mu_o I^2}{2\pi d}$$

I (Amps)	F (x 10^{-7}) (N)	I^2 (A^2)
1.00	13.94	1.00
2.00	26.01	4.00
3.00	36.10	9.00
4.00	76.24	16.0
5.00	109.97	25.0

Correct data ✓
Preferably 3sf ✓

c. On the graph paper below draw a graph of the linearized data including line of best fit. (5 marks)



Relationship between force on wires and applied current ✓
(TITLE)

– Points plotted correctly ✓

d. Calculate the gradient (with units) of the graph. The method (as demonstrated by your working) and the precision (in accordance with the graph drawn) of your result will be considered in marking.

(5 marks)

Gradient = $\frac{\text{rise}}{\text{run}}$ ✓ ✓

$= \frac{(108 - 20) \times 10^{-7}}{24 - 2.5}$

$= \frac{88 \times 10^{-7} \text{ N}}{21.5 \text{ A}^2}$ ✓

$= 4.1 \times 10^{-7} \text{ NA}^{-2}$ ✓ ✓ (estimate

e. Calculate the value of μ_0 including units.

(2 marks)

$\frac{F}{l} = \frac{\mu_0 I^2}{2\pi d}$

$\frac{F}{I^2} = \frac{\mu_0 l}{2\pi d}$

slope

$\therefore 4.09 \times 10^{-7} = \frac{\mu_0 (0.2)}{2\pi (0.01)}$

$\mu_0 = 1.3 \times 10^{-7} \text{ NA}^{-2}$ ✓ ✓

(estimate)

* Note: Answer to (e) is $0.1 \times$ actual μ_0 value due to small $d = 0.01$ m

(−2) Marks if axes were reversed!

(a) Why do the engines give the spacecraft "an enormous shove at the beginning of its journey"?

(2 marks)

– So that most of the initial energy is in the form of KE. ✓

– Maximises velocity, so that the 'escape velocity' can be reached. ✓

(b) Use the expression given for gravitational potential energy and the usual formula for kinetic energy to rewrite the formula for the total energy of the spacecraft.

(2 marks)

$E_T = E_P + E_K$ ✓

$\therefore E_T = -\frac{GMm}{r} + \frac{1}{2}mv^2$ ✓

(c) Use the formula for the total energy of the spacecraft from part b) to derive the formula for the escape velocity, which is when the total energy equals zero.

(3 marks)

$0 = -\frac{GMm}{r} + \frac{1}{2}mv^2$

$\frac{GM\cancel{m}}{r} = \frac{1}{2}\cancel{m}v^2$ ✓

$v^2 = \frac{2GM}{r}$ ✓

$\therefore v = \left(\frac{2GM}{r}\right)^{\frac{1}{2}}$ ✓

(d) The escape velocity of a spacecraft is the same as that of a molecule. Explain why.

(1 mark)

According to (c), the escape velocity (v) is independent of the mass (m) of the actual object. ✓

(e) Some commentators have proposed firing payloads into deep space by using massive cannons at the Earth's surface. Calculate the escape velocity needed by a projectile which is fired from such a cannon at the surface of the Earth. (3 marks)

$$v = \left(\frac{2GM_e}{r_e}\right)^{\frac{1}{2}}$$

$$= \left(\frac{2 \times 6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.37 \times 10^{6}}\right)^{\frac{1}{2}} \checkmark$$

$$= 1.12 \times 10^{4} \text{ ms}^{-1} \checkmark \checkmark \quad \approx 40250 \text{ km/h!}$$

(f) A spacecraft is in a stable circular orbit 330 km above the surface of the Earth. What gain in speed would the spacecraft need to achieve in order to leave Earth orbit and escape the gravitational field of the Earth? (4 marks)

At 330 km height

$$v = \left(\frac{GM}{r}\right)^{\frac{1}{2}}$$

$$= \left(\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.37 \times 10^{6}) + 330000}\right)^{\frac{1}{2}} \checkmark$$

$$= 7.71 \times 10^{3} \text{ ms}^{-1} \checkmark \quad (2)$$

(g) In the last paragraph it states "if a spacecraft's speed is below the escape velocity, it may have sufficient speed to go into a stable orbit". What percentage of the escape velocity is the speed for a stable circular orbit at any given orbital radius? (3 marks)

$$v_{escape} = \left(\frac{2GM}{r}\right)^{\frac{1}{2}} \qquad = 1/\sqrt{2} \checkmark$$

$$v_{orbital} = \left(\frac{GM}{r}\right)^{\frac{1}{2}} \qquad \therefore \frac{v_o}{v_e} = 0.707 \checkmark$$

$$= 70.7\% \checkmark$$

OR (from (f))

$$\checkmark \frac{7710}{10903} \checkmark \times \frac{100\%}{1} = 70.7\% \checkmark$$

End of Questions

Additional Working Space

Total v required at 330 km height

$$v = \left(\frac{2GM}{r}\right)^{\frac{1}{2}}$$

$$= \left(\frac{2 \times 6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.37 \times 10^{6}) + 330000}\right)^{\frac{1}{2}}$$

$$= 10903 \text{ ms}^{-1} \checkmark \quad (1)$$

$\therefore$ Gain in speed required $= 10903 - 771$

$$= 3.19 \times 10^{3} \text{ ms}^{-1} \checkmark$$

Equation (2) — (1)