PHYSICS

YEAR 12

UNIT 3

Name: SOLUTIONS

Teacher: ___________________________

TIME ALLOWED FOR THIS PAPER

Reading time before commencing work: Ten minutes

Working time for the paper: Three hours

MATERIALS REQUIRED/RECOMMENDED FOR THIS PAPER

To be provided by the supervisor:

- This Question/Answer Booklet; ATAR Physics Formulae and Data Booklet

To be provided by the candidate:

- Standard items: pens, pencils, eraser or correction fluid, ruler, highlighter.

- Special items: Calculators satisfying the conditions set by the SCSA for this subject.

IMPORTANT NOTE TO CANDIDATES

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short answer	14	14	50	54	30
Section Two: Extended answer	6	6	90	90	50
Section Three: Comprehension and data analysis	2	2	40	36	20
			Total	180	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2016.* Sitting this examination implies that you agree to abide by these rules.

2. Write answers in this Question/Answer Booklet.

3. 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.

4. You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.

5. 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.
   - Planning: If you use the spare pages for planning, indicate this clearly.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Refer to the question(s) where you are continuing your work.

Section One: Short response 30% (54 marks)

This section has **fourteen (14)** questions. Answer **all** questions. Write your answers in the space 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.

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.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page

Suggested working time for this section is 50 minutes.

Question 1

An aeroplane is being flown with a horizontal speed of 400 kmh^{-1} at an altitude of 1500 m. A piece of the plane becomes dislodged and drops off it whilst it is in motion.

Ignoring air resistance, calculate the velocity of this piece of the plane when it lands on the ground.

(4 marks)

$v^2 = u^2 + 2as; u = 0\ ms^{-1}, a = 9.80\ ms^{-2}, s = 1500m$

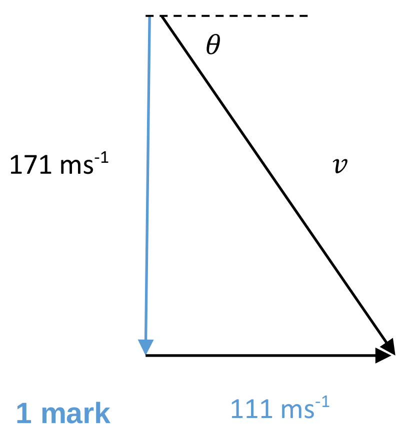
$v^2 = 0 + 2\ x\ 9.8\ x\ 1500$

$v_v = 171\ ms^{-1}$ **1 mark**

$u_h = \frac{400}{3.6} = 111\ ms^{-1}$ **1 mark**

$v^2 = 171^2 + 111^2$

$v = 204\ ms^{-1}$ **1 mark**

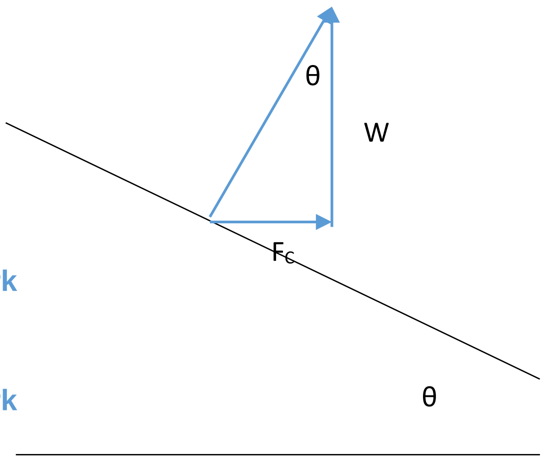


$\theta = tan^{-1}\left(\frac{171}{111}\right) = 57.0^0\ below\ the\ horizontal$ **1 mark**

Question 2

The banking of roads can help cars navigate high speed bends safely. Calculate the angle to the horizontal that a road should be inclined for a 1500 kg car to negotiate a horizontal circular path with a radius of 250 m at 110 kmh^{-1}.

(3 marks)



$v = \frac{110}{3.6} = 30.6\ ms^{-1}$

$\tan\theta = \frac{F_c}{W} = \frac{mv^2}{r}\Big/mg = \frac{v^2}{gr}$ 1 mark

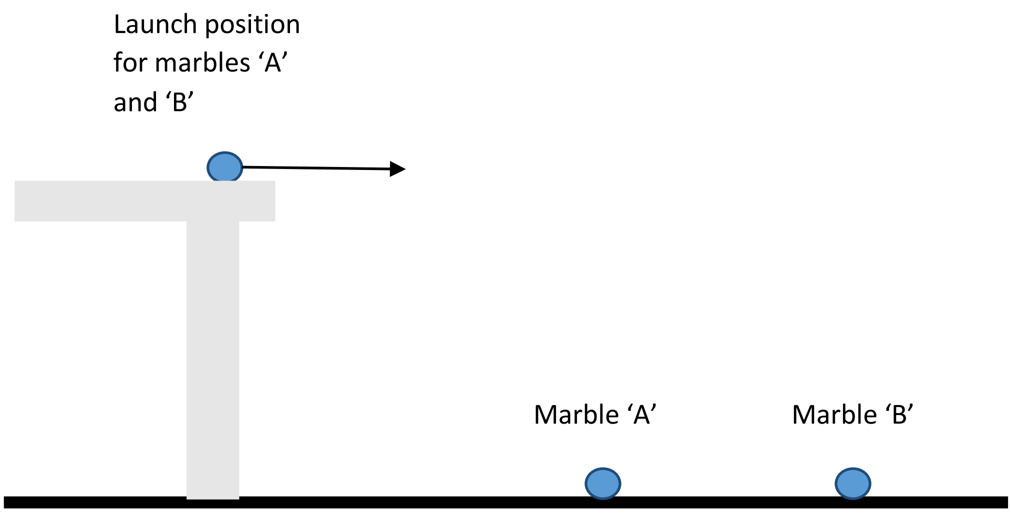
$\therefore \tan\theta = 30.6^2/(9.8\ x\ 250)$ 1 mark

$\theta = 20.9^o$ 1 mark

Question 3

Two marbles ('A' and 'B') are rolled off a horizontal table separately and fall through the same vertical height to the floor below. Their landing positions are shown on the diagram below.

(4 marks)



Which one of the following statements correctly describes the motion of marbles 'A' and 'B'? Briefly explain the reasons for your choice in the space provided.

A 'B' hits the ground before 'A' because it is further from the launch site.

B 'B' has a larger launch velocity than 'A'.

C 'A' and 'B' hit the ground simultaneously with the same velocity.

D 'B' lands before 'A' due to its larger launch velocity.

ANSWER: **B** **1 mark**

EXPLANATION: 1 mark for each (max 3) acceptable explanation points:

- **Both marbles have an initial vertical velocity of 0 ms^{-1}.**
- **Both marbles accelerate vertically at the same rate (9.8 ms^{-2})**
- **Both marbles hit the ground at the same time**
- **Horizontal displacement for marble B is greater than horizontal displacement for marble A.**
- **∴ marble B's initial horizontal velocity is greater than marble A; hence, marble B's launch velocity is greater than marble A.**

SEE NEXT PAGE

Question 4

A baseball player is sprinting around second base after hitting the ball to the outfield. Essentially, the player is undertaking a circular path around the base at high speed.

Whilst doing this, the player appears to be leaning over towards the centre of his circular path. With the aid of a diagram, explain why leaning is essential to cause this circular motion.

(3 marks)

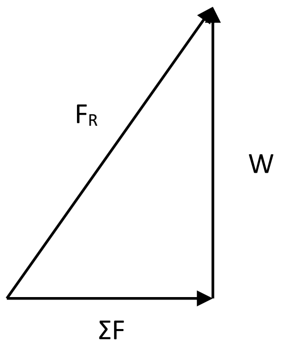


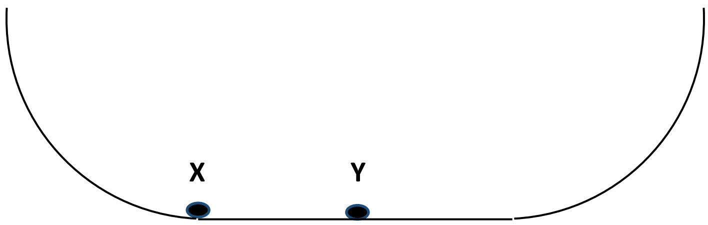
Diagram or Free body diagram– 1 mark

By leaning over the player is introducing a frictional force that acts horizontally 1 mark

The friction is the necessary centripetal force to cause circular motion 1 mark

Question 5

The diagram below shows the cross-sectional structure of a skateboard halfpipe. Two points 'X' and 'Y' are marked at two different positions on the halfpipe ('X' is at the bottom of the curved section of the halfpipe; 'Y' is on the flat section).



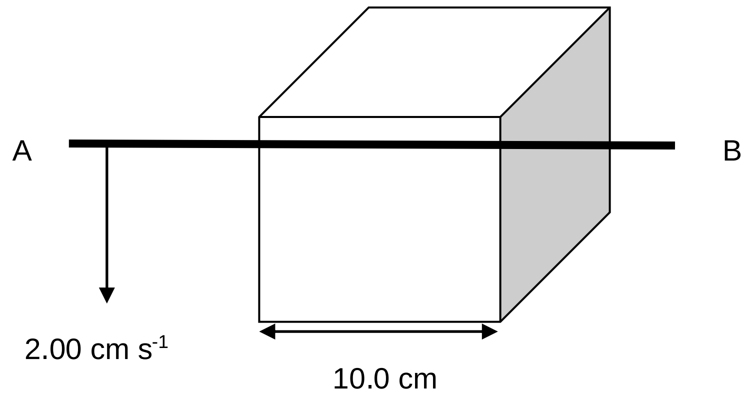
Compare the forces experienced by a skateboarder at these two positions. At which point is this force greatest? Assume the skateboarder's speed is the same at both points. With reference to relevant formulae, explain your choice.

(4 marks)

- **Force at X › force at Y** **1 mark**
- **At Y, F_Y = weight = mg** **1 mark**
- **At X, at the bottom of the vertical circular path** $F_X = \frac{mv^2}{r} + mg$ **1 mark**

Question 6

An insulated copper wire is pulled downwards across the face of one of the poles of a bar magnet (as shown below). It is moved with an average velocity of 2.00 cm s^{-1} and the width of the bar magnet's face is 10.0 cm.



The end of the copper wire marked 'B' gains a net negative charge and the wire generates a small emf with an average value of 2.74 mV.

a) Using the information above, determine the polarity of the face of the bar magnet shown (North or South).

(1 mark)

NORTH **1 mark**

b) Assuming the magnetic field near the magnet's face is uniform, calculate the density of the magnet's magnetic field near its face.

(2 marks)

$\boldsymbol{emf = lvB}$

$\boldsymbol{2.74\ x\ 10^{-3} = 0.100\ x\ .0200\ x\ B}$ **1 mark**

$\boldsymbol{B = 1.37\ T}$ **1 mark**

Question 7

A current-carrying straight conductor is placed in a magnetic field and experiences a magnetic force equal to 75% of the maximum value this force could be in this field. Calculate the size of the angle 'θ' between the conductor and the magnetic field. Show working.

(3 marks)

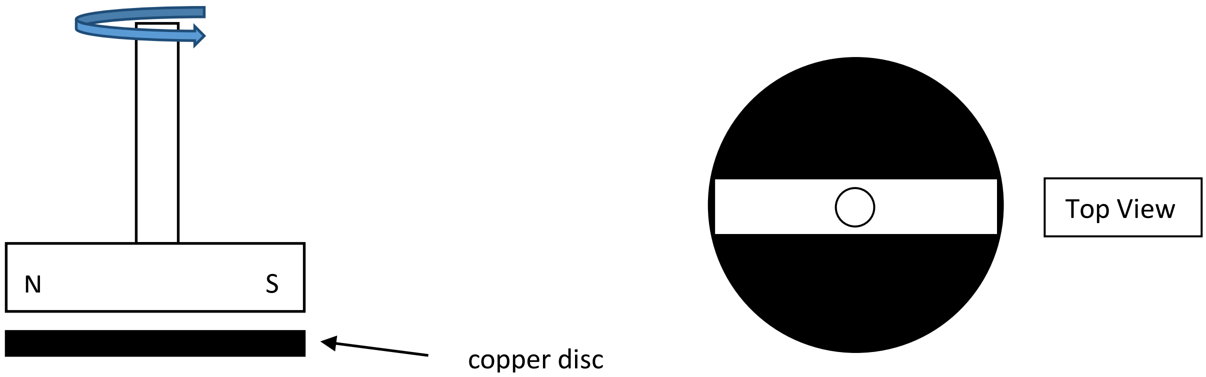
$\boldsymbol{F = IlBsin\theta}$ **1 mark**

$IlB\ \sin\theta = IlB\ x\ 0.75;\ \therefore\ \sin\theta = 0.75$ 1 mark

$\therefore\ \theta = 48.6^{o}$ 1 mark

Question 8

A car speedometer utilises magnetic properties in its operation. Essentially, its main components consist of a rotating bar magnet adjacent to a round, copper disc (see the diagram below).



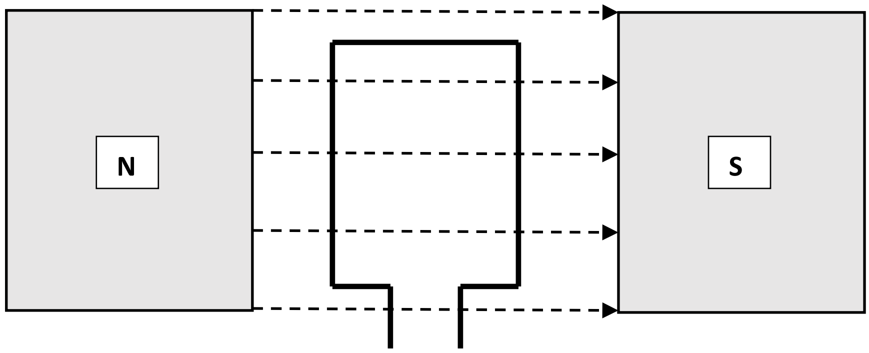
As the bar magnet rotates in the manner shown, the copper disc follow it by rotating in the same direction. Explain why.

(4 marks)

- The rotating bar magnet causes a $\Delta\Phi$ across the surface of the copper disc. 1 mark
- $\therefore$ eddy currents are induced on the surface of the copper disc. 1 mark
- The direction of the eddy currents opposes the motion of the rotating bar magnet (Lenz's Law).
  OR
- The direction of the current creates its own field that opposes the change in flux (Lenz's Law).
  1 mark
- Hence, the copper disc rotates with the bar magnet due to the attraction forces between the two fields. 1 mark

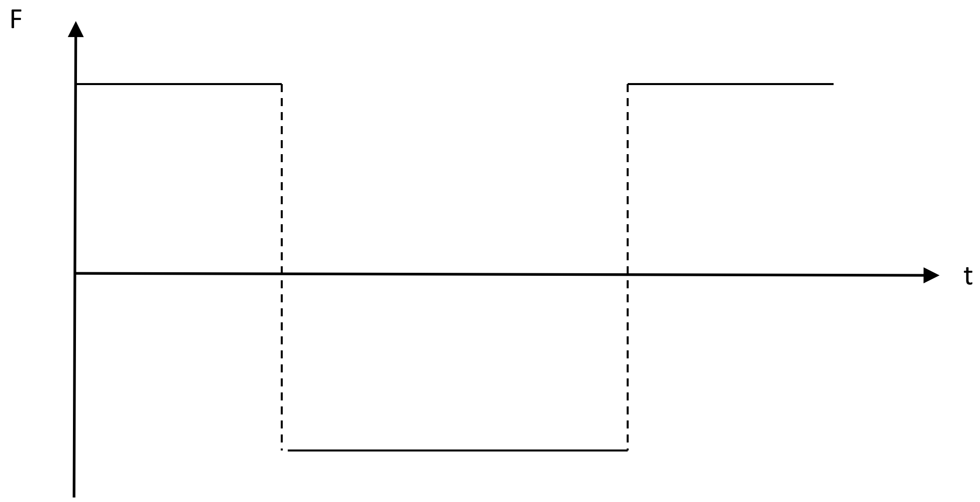
Question 9

The diagram below shows the structure of a simple DC motor (i.e.: a coil connected to a split ring commutator and a DC emf source).



a) On the set of axes below, show how the magnetic force acting on one side of the coil varies over ONE complete rotation, starting from the position shown in the diagram.

(3 marks)

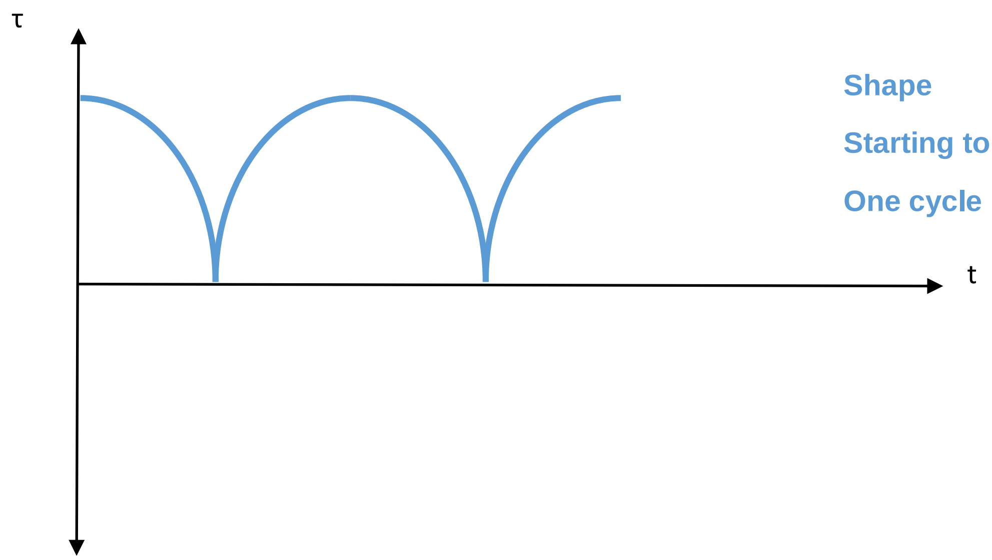


Constant values (not sinusoidal)	1 mark
Force suddenly swaps to negative at some point in time	1 mark
Same shape as shown in answer (or inversed)	1 mark

Question 9 continued on next page

b) On the set of axes below, show how the torque (τ) acting on the coil varies over ONE complete rotation. Assume the coil starts in the position shown.

(3 marks)



Shape 1 mark

Starting torque value 1 mark

One cycle 1 mark

Question 10

A coil of area 25.0 cm^2 is made of 200 turns of wire. The coil is placed at right angles to a magnetic field of strength 175 μT.

a) Calculate the amount of flux passing through the coil.

(2 marks)

$Area = 25.0cm^2 = \frac{25.0}{100^2}\ m^2 = 2.50 * 10^{-3}\ m^2$ 1 mark

$\emptyset = BA$

$\emptyset = 175\ x\ 10^{-6}\ x\ 2.50\ x\ 10^{-3} = 4.38\ x\ 10^{-7}\ Wb$ 1 mark

b) If the field collapses to zero in 25.0 ms, calculate the average emf generated in the coil in this time.

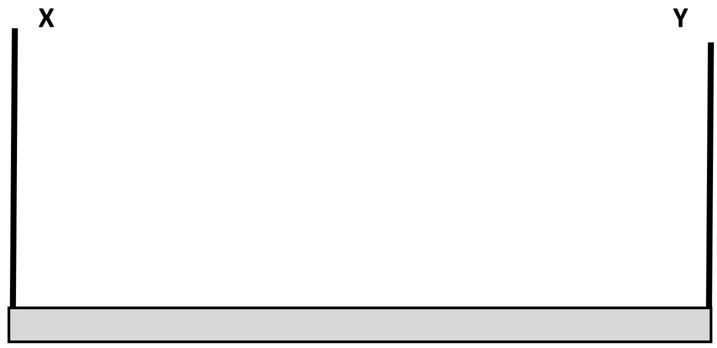
(2 marks)

$average\ emf = \frac{-N\Delta\emptyset}{t}$ 1 mark

$average\ emf = \frac{200\ x\ 4.38\ x\ 10^{-7}}{25\ x\ 10^{-3}} = 3.50\ x\ 10^{-3}$ 1 mark

Question 11

A uniform, 35.0 kg horizontal platform is supported by two vertical steel cables ‘X’ and ‘Y’ situated 10.0 m apart as shown. A person with a mass of 85.0 kg stands 3.00 m from ‘X’.



With the person in the position stated, calculate the tension in cables ‘X’ and ‘Y’.

(4 marks)

$Take\ moments\ around\ 'X';\ \Sigma M = 0;\ \Sigma M_C = \Sigma M_A$ **1 mark**

$(85\ x\ 9.8\ x\ 3) + (35\ x\ 9.8\ x\ 5) = F_Y\ x\ 10$ **2 marks**

$\therefore\ F_Y = 421\ N\ up$

$\Sigma F = 0;\ \Sigma F_{UP} = \Sigma F_{DOWN};\ \therefore\ F_X = (85\ x\ 9.8) + (35\ x\ 9.8) - 421 = 755\ N\ up$ **1 mark**

Question 12

a) Calculate the magnetic field strength at a distance of 20.0 cm from a long straight conductor carrying a current of 550 mA. The experiment is performed in air.

(2 marks)

$$B = \frac{\mu_0}{2\pi}\frac{I}{r} = \frac{4\pi\ x\ 10^{-7}}{2\pi}\ x\ \frac{550\ x\ 10^{-3}}{0.20} = 5.50\ x\ 10^{-7}\ T$$ **2 marks**

b) The magnetic constant, μ_0, is also known as “the magnetic permeability of free space”. The magnetic permeability of water is slightly lower than the value for free space. If the experiment in part a) was conducted in water, explain how that would change the result calculated in air.

(2 marks)

- **Magnetic field strength (B) is directly proportional to permeability of medium (μ).**

1 mark

- **μ for water is less than μ for free space; hence, B will be less in water medium if all else remains the same.**

1 mark

Question 13

Khai has a study lamp that uses a 35 W globe that operates at 24 V_{RMS}. The lamp plugs into the mains 240 V_{RMS} power supply; consequently, it has a transformer placed in its base that allows the lamp to transform the voltage to the required value. The transformer can be assumed to be ideal. The secondary coil has 30 turns.

a) Calculate the number of turns on the primary coil.

(2 marks)

$\frac{V_P}{V_S} = \frac{N_P}{N_S}; \frac{240}{24} = \frac{N_P}{30}$ **1 mark**

$\therefore N_P = 300 \text{ turns}$ **1 mark**

b) Calculate the RMS current flowing in the primary coil of the lamp when it is operating.

(3 marks)

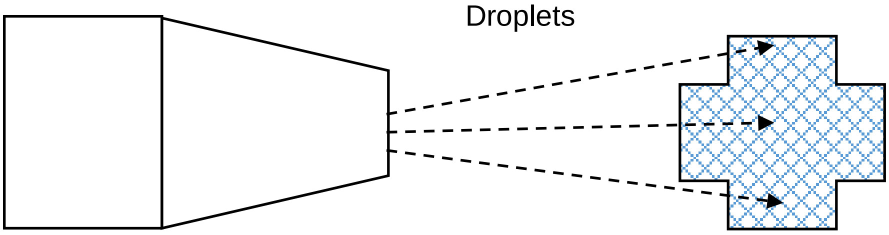
$\text{Ideal transformer}: P_P = P_S = 35.0\, W$ **1 mark**

$240 \times I_P = 35.0$ **1 mark**

$\therefore I_P = \frac{35.0}{240} = 0.145\, A$ **1 mark**

Question 14

In an electrostatic spray painting system, droplets of paint are ejected from a positively charged spray gun to the object to be painted, which is negatively charged.



The magnitude of the charge on each droplet is 2.00 x 10^{-10} C and they a diameter of 150 µm.

a) State whether electrons were added to or removed from the droplets of paint by the spray gun.

(1 mark)

REMOVED **1 mark**

b) Calculate the electrostatic force acting between adjacent droplets if they are virtually touching each other.

(3 marks)

Assuming the droplets can be modelled as point charges,

$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$$ **1 mark**

$$= \frac{1}{4\pi \, x \, 8.85 \, x \, 10^{-12}} \, x \, \frac{2 \, x \, 10^{-10} \, x \, 2 \, x \, 10^{-10}}{(150 \, x \, 10^{-6})^2} = 1.6 \, x \, 10^{-2} \, N$$ **2 marks**

End of Section One

Section Two: Problem-solving 50% (90 Marks)

This section has **six (6)** questions. You must answer **all** questions. Write your answers in the space provided.

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.

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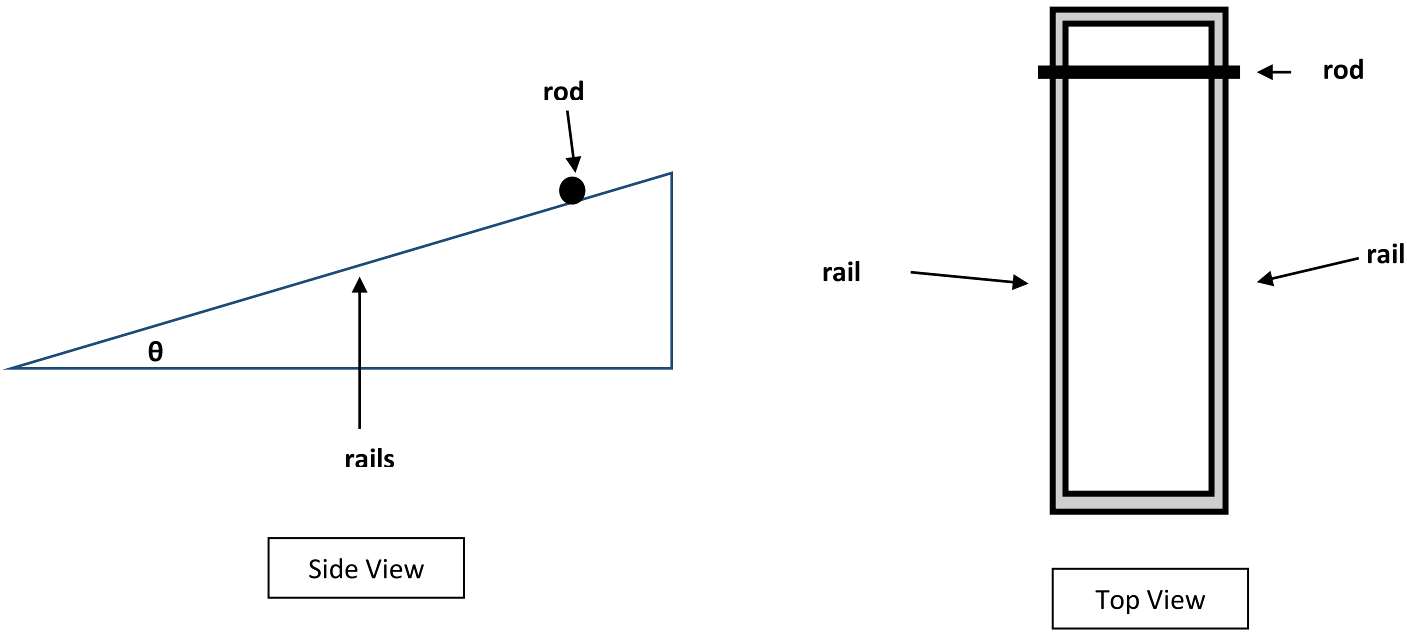
Suggested working time for this section is 90 minutes.

Question 15 (19 marks)

Some Year 12 Physics students conducted an experiment investigating the link between the angle of an incline and the velocity of an object free to move down the incline.

The students placed a conducting rod on an inclined plane. The rod started from rest and was allowed to roll freely down the slope on some conducting rails which have negligible friction.



a) After the bar has rolled 1.00 m down the ramp, show that the velocity of the rod is equivalent to $v = \sqrt{2gsin\theta}$.

(2 marks)

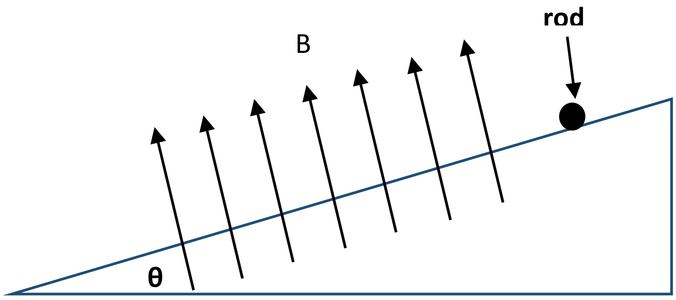
$v^2 = u^2 + 2as$ 1 mark

$where\ u = 0, a = gsin\theta\ and\ s = 1.00\ m$ 1 mark

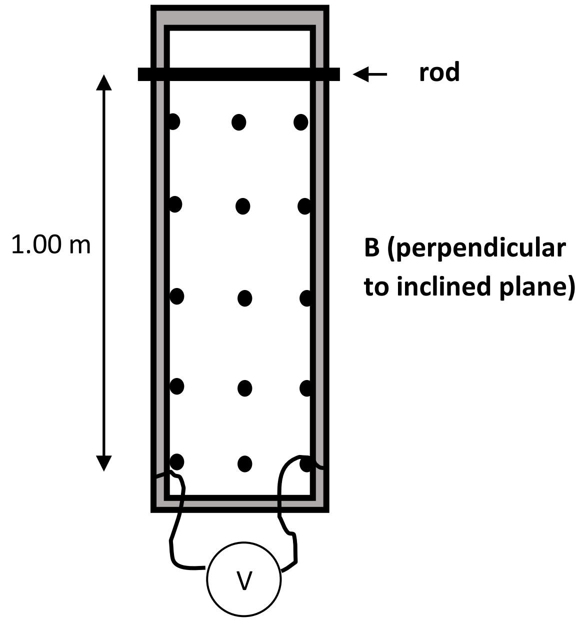
$v^2 = 0 + 2gsin\theta * 1.00$

$v = \sqrt{2gsin\theta}$

The students attempted to build a device capable of determining the velocity of the rod 1.00 m down the rails from its starting position. They established a uniform magnetic field perpendicular to the plane of the inclined rails. The terminals of a voltmeter were connected to the rails, 1.00 m from the starting position of the rod so that as the rod rolled over this point, the emf of the rod could be measured.



Side View



Top View

The following controlled variables were measured by the students:

- Initial velocity of rod, u = 0 ms^{-1}
- Distance rolled down the inclined plane, s = 1.00 m
- Mass of rod, m = 45.0 g
- Magnetic field strength, B = 0.500 T
- Distance between rails (ie – length of conducting rod), *l* = 10.0 cm

b) Describe how knowledge of the voltmeter reading would allow the students to determine the velocity of the rod 1.00 m from its starting position.

(2 marks)

As the rod cuts across flux lines it will have an emf induced across it. 1 mark

The magnitude of the emf is given by $emf = vBl$ hence $v = \frac{emf}{Bl}$ 1 mark

They gradually increased the angle (θ) the plane made with the horizontal and recorded the value of the emf across the rod, measured by the voltmeter. Their measured values, including the calculated velocity from the emf reading are shown in the table below.

θ	$sin\ \theta$	$\sqrt{sin\theta}$	emf (× 10^{-2} V)	$v\ (ms^{-1})$
10º	0.17	0.41	7.80	1.56
20º	0.34	0.58	11.0	2.20
30º	0.50	0.71	13.0	2.60
40º	0.64	0.80	15.0	3.00
50º	0.77	0.88	16.4	3.28
60º	0.87	0.93	17.4	3.48
70º	0.94	0.97	18.1	3.62

a) Complete the table by filling in the missing values.

(3 marks)

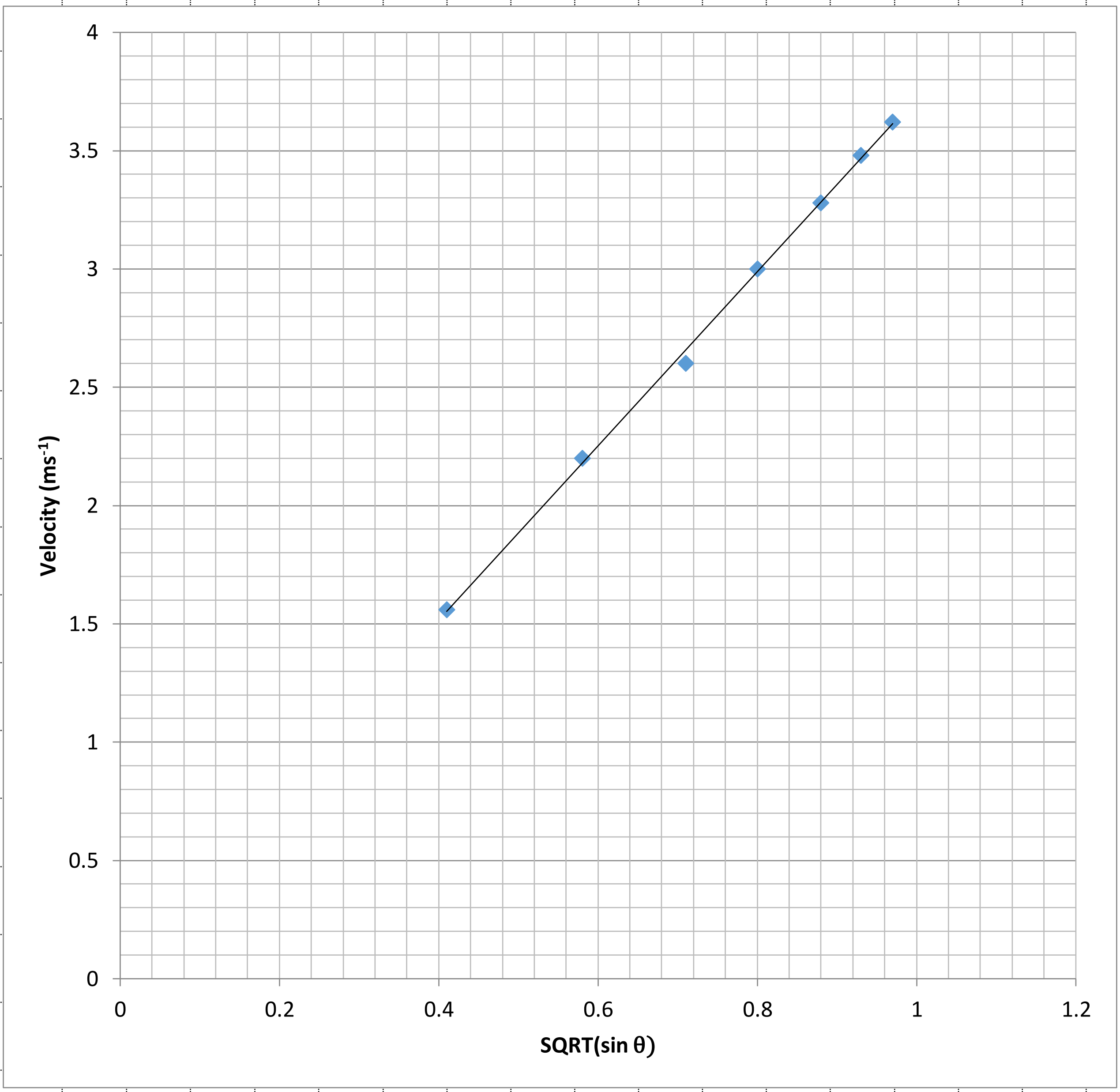
1 for each entry

b) On the grid provided on the next page, draw a graph of $\sqrt{sin\theta}$ and v. Place $\sqrt{sin\theta}$ on the horizontal axis. Draw a line of best fit through the data.

(5 marks)

Labelled axes 1
Units 1
Suitable scale 1
Accuracy of plotted points 1

Line of best fit 1


Velocity (ms-1)
SQRT(sin θ)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2

c) Find the slope of your line of best fit.

(2 marks)

$grad = \frac{rise}{run} \approx 3.7$

2 marks for clearly using graph data to find gradient

1 mark **only** if table data is used to find gradient

d) Use your value from c) and the relationship $v = \sqrt{2gsin\theta}$ to calculate an experimental value for the value of 'g'. Show working.

(2 marks)

$grad = \sqrt{2g}$ 1 mark

$g = \frac{grad^2}{2} \approx \frac{3.7^2}{2} \approx 6.8\, ms^{-2}$ 1 mark

e) You should have found that your experimental value for 'g' is significantly less than the accepted value. Explain why this should be the case.

(3 marks)

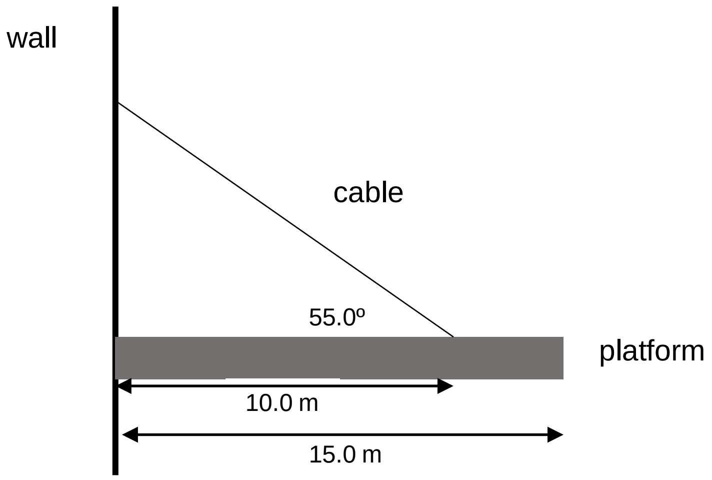
As the rod cuts through the flux lines, there is an induced emf (faraday's law) which drives a current around the rod and rails. 1 mark

The magnetic field produced by this current will oppose the change in flux, causing a retardation force to be applied to the rod. 1 mark

This will reduce the acceleration cause by the gravitational force acting on the rod. 1 mark

Question 16 (17 marks)

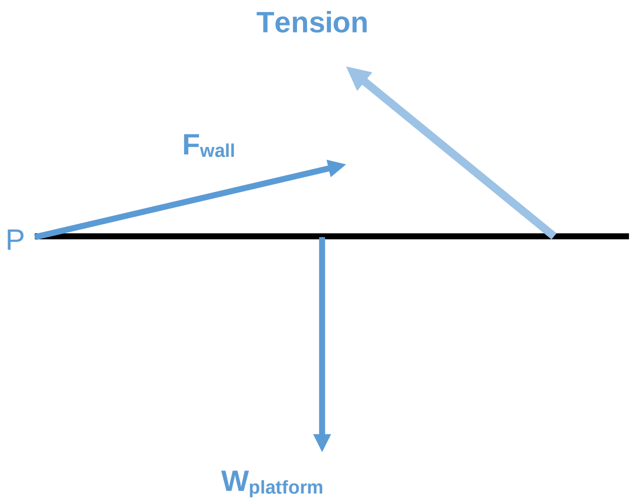
A nature lookout consists of an elevated concrete walkway high above the ground. A uniform platform has been constructed so people can walk out over a gorge and view it. The entire platform structure is shown in the figure below.



The uniform platform is designed to support a load of 8.50 tonnes in addition to its own 0.700 tonne mass. and is 15.0 m long. A single steel cable supports the platform, attached 10.0 m from the end at 55.0° as shown in the figure. The steel cable shown has a maximum tensile strength of 1.50 x 10^5 N.

a) Draw a free-body diagram below, showing all of the forces acting on the platform when in it is an **unloaded** state. Label the forces appropriately.

(3 marks)



- **Three forces are shown** **1 mark**
- **Forces labelled correctly** **1 mark**
- **No forces are missing; no unnecessary forces are shown** **1 mark**

b) Show that with the maximum load acting through the platform's midpoint, the cable will be able to support the platform. Support your answer with calculations.

(5 marks)

$\textit{Take moments about P}; \Sigma M = 0; \Sigma M_c = \Sigma M_A$ 1 mark

$8500 x\, 9.8\, x\, 7.5 + 750\, x\, 9.8\, x\, 7.5 = (T\ \sin 55^o)\, x\, 10.0$ 3 marks

$\therefore T = 8.25\, x\, 10^4\ N$

$T < 1.5\, x\, 10^5\ N, \therefore \textit{cable does not break}$ 1 mark

c) Hence, calculate the magnitude of the force that the wall exerts on the platform when fully loaded. If you could not calculate an answer for part a), use a value of 9.00 x 10^4 N for the tension in the cable.

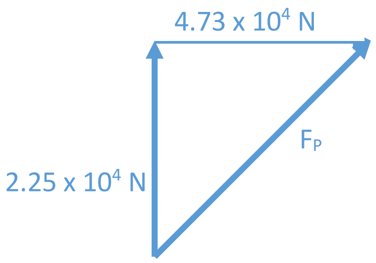
(4 marks)

$\Sigma F_{UP} = \Sigma F_{DOWN}$ and $\Sigma F_{LEFT} = \Sigma F_{RIGHT}$ 1 mark

$F_{wall\ up} = (8500 + 700) x\, 9.8 - 8.25\, x\, 10^4\ \sin 55^o = 2.25\, x\, 10^4\ N\ up$ 1 mark

$\Sigma F_{LEFT} = \Sigma F_{RIGHT}$

$F_{wall\ right} = 8.24\, x\, 10^{-4}\ \cos 55^o = 4.73\, x\, 10^4\ N\ right$ 1 mark



${F_P}^2 = \left(2.25\, x\, 10^4\right)^2 + \left(4.73\, x\, 10^4\right)^2$ 1 mark

$$F_P = 5.24\, x\, 10^4\ N$$

d) If the maximum load of 8.50 tonnes is gradually moved towards the end of the platform, describe what happens to the magnitude of the force you calculated in part c).

(2 marks)

- **As load moves to the end of the platform, ΣM_C increases, hence, tension in cable increases.**

  1 mark

- **Hence, force at wall will increase to balance this increase in tension.**

  1 mark

e) If the maximum load continues to move towards the end of the platform, the cable will eventually exceed its load limit and snap. Calculate how far from the the edge of the wall the load can move before the tensile strength limit on the wire is exceeded.

(3 marks)

$$(700 \; x \; 9.8 \; x \; 7.5) + (8500 \; x \; 9.8 \; x \; r) = 1.5 \; x \; 10^{-5} \; x \; \sin 55^{o} \; x \; 10.0$$

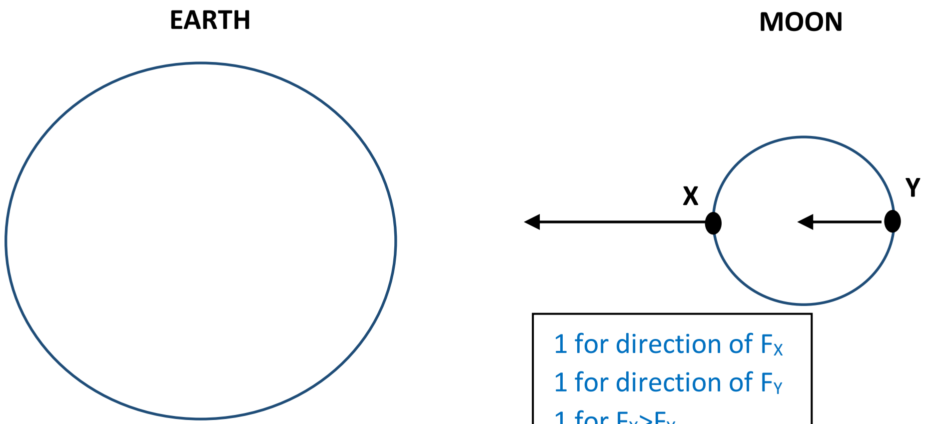
$$r = 14.1 \; m$$

3 marks (1 for each torque term)

Question 17 **(15 marks)**

In astrophysics, the 'Roche Radius' is the distance within which a celestial body (e.g.: the Moon) will disintegrate (get pulled apart) due to a second celestial body (e.g.: the Earth) which exerts a large 'tidal force' on the first. A tidal force is the **difference** in the gravitational force acting on the close and far sides of the first celestial body (point X and Y in the diagram below). The Roche Radius for the Moon orbiting around the Earth is 9492 km.

a) The diagram below shows the Moon in space near the Earth. Consider the two points shown: 'X' and 'Y'. On the diagram, draw vectors showing the magnitude and direction of the Earth's gravitational force acting on these points on the Moon. (3 marks)



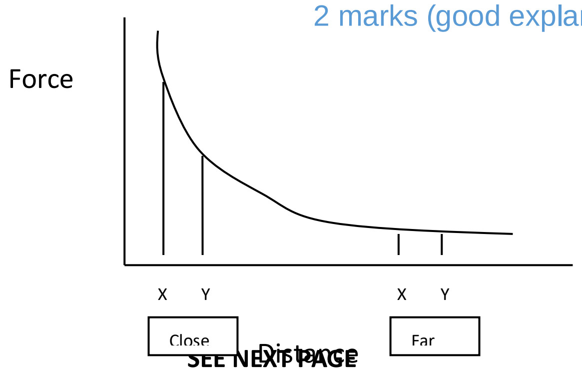
1 for direction of F_X
1 for direction of F_Y
1 for $F_X > F_Y$

b) The Moon is not disintegrating in its current orbit as it is outside the Roche Radius. Explain why the tidal force (**difference** in gravitational force between close and far sides) gets larger the closer the Moon gets to the Earth. Diagrams and/or graphs may help your explanation. (4 marks)

Gravitational force follows the inverse square law ($F \propto 1/r^2$) 1 mark

At close distances the gravitational force is dropping off faster than at larger distances 1 mark

When the Moon is close, the gravitational force acting on point X (close side) will be significantly higher than the force on side Y (far side). When the Moon is far, there is very little difference in the force felt on either side of the Moon. 2 marks (good explanation and/or diagram)



c) Calculate the Earth's gravitational field strength at position 'X' (g_x) and position 'Y' (g_y) if the Moon was orbiting at the Roche Radius.

(5 marks)

$$g_x = \frac{Gm}{r^2} = \frac{6.67 \, x \, 10^{-11} \, x \, 5.97 \, x \, 10^{24}}{(9492 \, x \, 10^3 - 1.74 \, x \, 10^6)^2}$$ **2 marks**

$$= 6.63 \, ms^{-2}$$ **1 mark**

$$g_y = \frac{Gm}{r^2} = \frac{6.67 \, x \, 10^{-11} \, x \, 5.97 \, x \, 10^{24}}{(9492 \, x \, 10^3 + 1.74 \, x \, 10^6)^2}$$ **1 mark**

$$= 3.16 \, ms^{-2}$$ **1 mark**

d) Calculate the velocity of the Moon if it orbits at the Roche Radius.

(3 marks)

Do not penalise for **not** converting to metres if already penalised in part c)

$$T^2 = \frac{4\pi^2}{GM} \, x \, r^3$$ **1 mark**

$$T = \sqrt{\frac{4\pi^2}{GM} \, x \, r^3} = \sqrt{\frac{4\pi^2}{6.67 * 10^{-11} \, x \, 5.97 * 10^{24}} \, x \, (9492 \, x \, 10^3)^3} = 9.208 \, x \, 10^3 \, s$$ **1 mark**

$$v = \frac{2\pi r}{T} = \frac{2\pi \, x \, 9492 * 10^3}{9.208 * 10^3} = 6.48 \, x \, 10^3 \, ms^{-1}$$ **1 mark**

OR

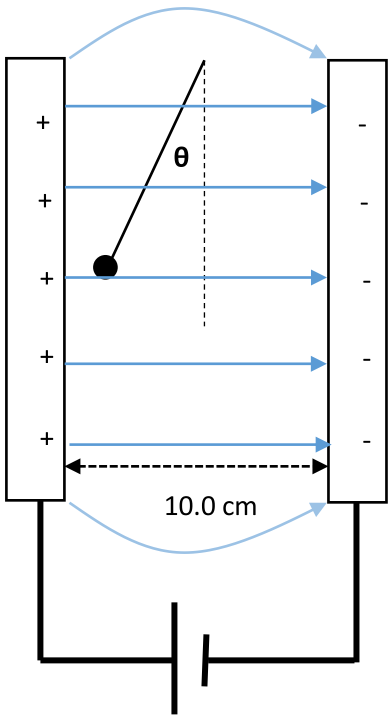
$$F_c = F_g$$ **1 mark**

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

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67 * 10^{-11} \, x \, 5.97 * 10^{24}}{9492 \, x \, 10^3}} = 6.48 \, x \, 10^3 \, ms^{-1}$$ **2 marks**

Question 18 (12 marks)

A small charged object of mass 0.500 mg is suspended from a 25.0 cm long piece of string made of insulating material. The charge on the object is 25.0 nC.



a) On the diagram above, draw the electric field between the charged plates.

(3 marks)

- **Direction of field** **1 mark**
- **Uniform shape** **1 mark**
- **Bowed at edges** **1 mark**

b) Is the object positively or negatively charged? Explain your choice (2 marks)

- **Negative charge** **1 mark**
- **Attracted to positively charged plate and/or repelled by negatively charged plate**
  1 mark

c) Calculate the electric field strength between the two charged plates.

(2 marks)

$E = \frac{V}{d}; \therefore E = \frac{500}{0.10}$ **1 mark**

$E = 5000\ Vm^{-1}$ **1 mark**

SEE NEXT PAGE

d) Hence, calculate the electrostatic force acting on the charged object. If you could not calculate an answer to part a), use E = 5500 Vm^{-1}.

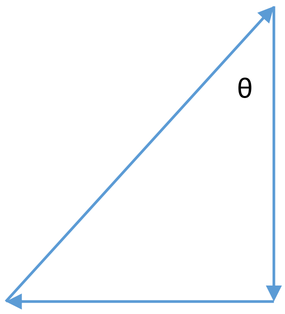
(2 marks)

$E = \frac{F}{q}; F = Eq = 5000 \, x \, 25 \, x \, 10^{-9}$ **1 mark**

$\therefore F = 1.25 \, x \, 10^{-4} \, N$ **1 mark**

e) Calculate the size of the angle 'θ'. Show all working. If you could not calculate an answer for part (d), use $F_E = 1.40 \times 10^{-4}$ N.

(3 marks)



W = mg

= 0.5 x 10^{-3} x 9.8

= 4.9 x 10^{-3} N

- **Weight calculation 1 mark**

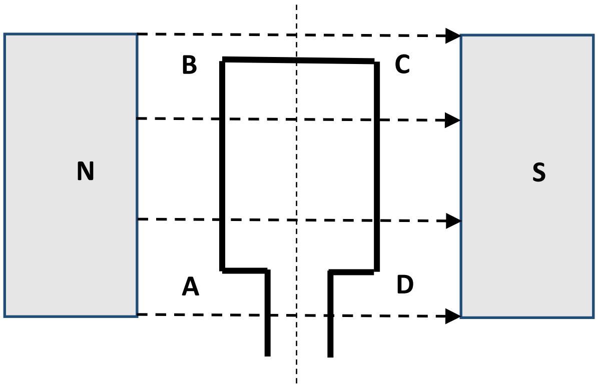
F_E = 1.25 x 10^{-4} N

$\tan \theta = \frac{1.25 \, x \, 10^{-4}}{4.9 \, x \, 10^{-3}}$ **1 mark**

$\theta = 1.46^o$ **1 mark**

Question 19 **(15 marks)**

The diagram below shows the structure of a simple AC generator.



The coil ABCD consists of 30 turns, is pivoted around its central axis, and has dimensions AB = CD = 20.0 cm and AD = BC = 10.0 cm. It lies in a uniform magnetic field of strength 0.400 T. At the moment in time shown, side AB is rotating out of the page. The coil is rotating at rate of 600 revolutions per minute.

a) As the coil rotates from this position, an emf is induced. Which side (A or D) develops a positive polarity?

(1 mark)

ANSWER: **D** **1 mark**

The coil is used in a generator that rotates at rate of 600 revolutions per minute.

b) Calculate the maximum emf generated by the coil. As part of your description, state the amount of flux that passes through the coil at this instant.

(5 marks)

$\boldsymbol{Max\ emf = -2\pi\ NBA\ f}$ **1 mark**

$\boldsymbol{= -2\ \pi\ x\ 30\ x\ 0.4\ x\ 0.2\ x\ 0.1\ x\ \frac{600}{60}}$ **2 marks**

$\boldsymbol{= -15.1\ V}$ **1 mark**

$\boldsymbol{Amount\ of\ flux\ passing\ through\ the\ coil, \emptyset = BA = 0\ Wb}$ **1 mark**

c) Hence, calculate the RMS voltage (V_{RMS}) when the generator is operating. (2 marks)

$\boldsymbol{V_{peak} = \sqrt{2}\ V_{RMS}}$ **1 mark**

$\boldsymbol{\therefore\ V_{RMS} = \frac{15.1}{\sqrt{2}} = 10.7\ V}$ **1 mark**

d) The source of mechanical energy that keeps the coil rotating in the generator needs to work harder while the generator is connected to an external circuit but not while the generator is disconnected. Explain why.

(3 marks)

- **As the coil rotates, the induced emf and resulting current will produce a magnetic field that opposes the change in flux, causing a retardation force on the rotation of the coil (Lenz's Law).**

2 marks

- **While the external circuit is disconnected there is no current, hence no induced field that will slow the coil rotation. 1 mark**

e) Commercial AC power stations must generate far higher power than this simple generator. Hence, their generators have some design modifications.

Name two (2) such modifications. Explain how these enable the commercial power stations to generate greater quantities of power.

(4 marks)

- **Modification 1: Use stronger permanent magnets.**

Explanation: Maximum emf = -2π NBAf; electromagnets can produce much stronger magnetic fields than permanent magnets.

- **Modification 2: Larger coils are used (larger number of turns 'N' or larger cross-sectional area 'A').**

Explanation: Maximum emf = -2π NBAf; Increasing 'N' and 'A' will produce a larger induced emf.

- **Modification 3: Induction and field coils wrapped around iron cores.**

Explanation: Maximum emf = -2π NBAf; Iron cores produce much stronger magnetic fields and a larger induced emf.

- **Modification 4: Rotate the coil at a higher frequency.**

Explanation: Higher frequency rotation increases the rate of change of flux through the coil and, hence, the induced emf.

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- **Explanation 1 mark each**
- **Modification 1 mark each**

Question 20 (15 marks)

Our Sun is a medium sized star that is part of a spiral galaxy called the Milky Way. Like all spiral galaxies, the stars in the Milky Way rotate around a galactic centre.

Our Sun's orbit is virtually circular with an orbital radius of 2.50 x 10^{20} m; its average orbital speed is 2.20 x 10^5 ms^{-1}.

a) Calculate the orbital period of the Sun around the galactic centre of the Milky Way (in years).

(4 marks)

$v = \frac{2\pi r}{T}$; $\therefore T = \frac{2\pi r}{v}$ **1 mark**

$T = \frac{2\pi \; x \; 2.50 \; x \; 10^{20}}{2.20 \; x \; 10^5}$ **1 mark**

$\therefore T = 7.14 \; x \; 10^{15} \; s$ **1 mark**

$= 2.26 \; x \; 10^8 \; years$ **1 mark**

b) Calculate the gravitational field strength due to the Milky Way galaxy at the Sun's distance from the galactic centre.

(3 marks)

$g = a_c = \frac{v^2}{r}$ **1 mark**

$\therefore g = \frac{(2.20 \; x \; 10^5)^2}{2.50 \; x \; 10^{20}}$ **1 mark**

$= 1.94 \; x \; 10^{-10} \; ms^{-2}$ **1 mark**

c) Calculate the mass of the Milky Way by assuming that this mass is located at the galactic centre. If you could not calculate an answer to part b), use 1.90 x 10^{-10} ms^{-2}.

(3 marks)

$g = \frac{GM}{r^2}$ **1 mark**

$1.94 \ x \ 10^{-10} = \frac{6.67 \ x \ 10^{-11} \ x \ M}{(2.5 \ x \ 10^{20})^2}$ **1 mark**

$\therefore M = 1.82 \ x \ 10^{41} \ kg$ **1 mark**

d) If the mass of our Sun can be considered to be an average mass for the stars in our galaxy, calculate how many stars are inside our Sun's orbit in the Milky Way.

(2 marks)

$Number \ of \ stars = \frac{1.81 \ x \ 10^{41}}{1.99 \ x \ 10^{30}}$ **1 mark**

$= 9.12 \ x \ 10^{10}$ **1 mark**

End of Section 2

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Section Three: Comprehension and Data Analysis 20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided.

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.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.

Suggested working time for this section is 40 minutes.

Question 21 (18 marks)

"How do gravitational slingshots work?"

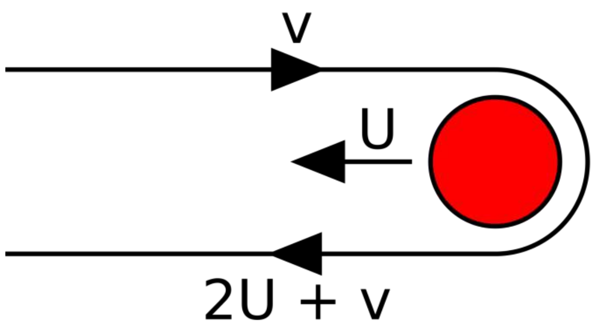
Adapted from an article by Fraser Cain (From Universe Today Astronomy and News, http://www.universetoday.com/113488/how-do-gravitational-slingshots-work/)

A "gravitational slingshot" is a gravity assist that will speed up an actual spacecraft. For example, when Voyager was sent out into the Solar System, it used gravitational slingshots past Jupiter and Saturn to increase its velocity enough to escape the Sun's gravity.

So how do gravitational assists work? You probably know this involves flying your spacecraft dangerously close to a massive planet. But how does this help speed you up? Sure, as the spacecraft flies towards the planet, it speeds up. But then, as it flies away, it slows down again. Sort of like a skateboarder in a half pipe; speeding up on the way down but slowing down on the way up.

At first glance, you may imagine the slowing down process cancels out the speeding up process, with no overall increase in velocity as your spacecraft falls into and out of the gravity well. So how does the spacecraft end up with an overall change in velocity? Here's the trick; Each planet has an orbital speed, travelling around the Sun, which also affects the change in velocity of the spacecraft.

As the spacecraft approaches the planet, its gravity pulls the much lighter spacecraft so that it catches up with the planet in orbit, gaining some of the planet's kinetic energy. The closer it can fly, the more kinetic energy it receives, and the faster it flies away (up to twice the speed of the planet) from the encounter.



Simplified model of an ideal gravitational slingshot, showing the speed of:

- Planet
- Spacecraft on approach
- Spacecraft on departure

It is also possible to perform a gravitational slingshot maneuver that will cause the spacecraft to slow down. Spacecrafts launched from Earth, on approach to Mercury, are moving far too quickly to be captured by Mercury's gravitational field. The spacecraft is slowed down using gravitational slingshot maneuvers around Mercury itself, to slow the spacecraft down enough to remain in orbit around Mercury. During such maneuvers the spacecraft slows down a lot and Mercury speeds up a little.

These gravitational slingshot maneuvers all obey the conservation of energy. Part of the usefulness of the maneuvers is that the difference in mass between the spacecraft and planet is so large that there is no noticeable change in the planet's velocity. However, if you did enough gravitational slingshots, such as several zillion zillion slingshots, you could cause the planet to spiral in towards the Sun.

a) Explain why a spacecraft like Voyager needs to achieve a minimum speed to escape the Solar System.

(2 marks)

The Sun's gravitational field applies a force on the spacecraft, pulling it towards the centre of the system. 1 mark

If the spacecraft travels too slowly as it leaves the system , it will stop, then fall back towards the Sun. 1 mark

b) Describe how a spacecraft like Voyager might achieve this minimum speed despite being launched from Earth with a relatively low speed and was not built with any engines or thrusters.

(2 marks)

Using the gravitational slingshot maneuver. 1 mark

SEE NEXT PAGE

The spacecraft gains velocity/kinetic energy from a planet that it flies very close too.

1 mark

c) Consider a spacecraft on a gravity assist maneuver moving at 2.30×10^3 ms^{-1}, approaching Earth which orbits the Sun at 30.0×10^3 ms^{-1}. Calculate the largest speed at which the spacecraft could leave Earth's gravitational field.

(3 marks)

$final\ v = initial\ v + 2U$ (reference to diagram formula) 1 mark

$v = 2.30\ x\ 10^3 + 2\ x\ 30.0\ x\ 10^3 = 62.3\ x\ 10^3\ ms^{-1}$ 2 marks

d) Calculate the change in velocity that would be experienced by the Earth during the gravity assist maneuver described in part c). The spacecraft has a 260 kg mass. If you could not obtain an answer to part c) you may use the change in velocity of the spacecraft as 58.0×10^3 ms^{-1}.

(4 marks)

$KE\ gained\ by\ spacecraft = KE\ lost\ by\ planet$ 1 mark

$\frac{1}{2}\ x\ 260\ x\ (60.0 * 10^3)^2 = \frac{1}{2} * 5.97 * 10^{24} * v^2$ 2 marks

$v = 3.96\ x\ 10^{-7}\ ms^{-1}$ 1 mark

e) It's possible that if a spacecraft performs enough 'gravitational slingshot' maneuvers around a planet like Earth that it could cause the planet to move closer to the Sun and possibly spiral into it. Explain why this would occur.

(4 marks)

When the spacecraft maneuvers around the planet, the planet loses some kinetic energy. 1 mark

The centripetal force required decreases as the velocity decreases $F_c = \frac{mv^2}{r}$ 1 mark

The amount of gravitational force acting between Earth and Sun remains unchanged, thus the Earth is pulled towards the Sun with more force than what is required for circular motion, causing it to move towards the centre of its orbit (the Sun). 2 marks

f) Would it be possible to cause Mercury to crash into Earth using (possibly many) spacecrafts to perform gravity slingshot maneuvers around Mercury? Justify your choice.

(3 marks)

Yes 1 mark

If the slingshot maneuver is used to slow down the spacecraft, this causes Mercury to speed up. 1 mark

As the speed of Mercury increases, it will move further away from the Sun, possibly crashing into Earth. 1 mark

If student argues "no" apply follow through marks based on suitable reasoning. (e.g.: 2 marks for "Mercury can only fall towards the Sun as it slows down during each slingshot maneuver")

Question 22 **(18 marks)**

"Tesla turns in his grave: Is it finally time to switch from AC to DC?'

By John Hewitt, from ExtremeTech, 10/12/2012

Paragraph 1

AC power transmission losses are greater than DC losses. That is hardly an industry secret. At the Three Gorges Dam in China, high voltage DC transmission lines were chosen to bring the power to the people for a variety of reasons. Many power companies are now starting to rethink the decisions that made AC transmission the obvious choice in the previous era.

Paragraph 2

At a mains power frequency of 50 or 60 hertz, the skin effect, where the majority of the current travels only on the surface of the conductor, starts to become important. If most of the current is travelling in only a portion of the total cross section available, it will see an effectively higher resistance. To combat the skin effect, more expensive, multi-stranded wire must be used.

Paragraph 3

So why do we use AC? To begin with, it typically comes hot off the presses as AC. In other words, it is most efficiently produced in this form by three-phase-alternators (three coils offset at an angle of 120 degrees to each other) at the power station's turbines. If you then want to transmit power any significant distance from the point of generation, you need to step up the voltage quite a bit just to get something worthwhile on the other end. If, for example, you are starting with 20 volts and are dropping one volt every mile because of the resistance of the wire alone, 20 miles out you will have next to nothing. Actually the losses will diminish a little less than linearly but you get the idea.

Paragraph 4

Transforming to higher voltages is simple for AC, you use a transformer; but for DC, it typically means using motor-generator sets or other fancy elaborations. When you then manage to get some power transmitted, your biggest customer might very well be a large motor that compresses, pumps, or other moves stuff, and runs on, you guessed it, AC power. The three-phase AC induction motor, first envisioned by Tesla, is far and away the most efficient way to convert electricity into mechanical power. DC motors, until recent times, required graphite brushes for commutation which severely restrict maximum RPM, reliability, and lifespan.

Paragraph 5

To transmit power, voltage is king. The same power transmitted at a higher voltage requires less current. In fact a whole lot less current, and therefore less of that expensive copper, or aluminum as the case may be in high voltage wires. Less metal will make cables lighter and thinner. Support towers can therefore be shorter since current-laden wire won't lengthen and couple to the ground when unable to sufficiently disperse its heat.

Paragraph 6

There is a limit though, to how high of a voltage your system would still see benefit. Above a few hundred kilovolts or so, coronal loss, due to the high voltage ionizing air molecules begins to occur.

Paragraph 7

Some new projects, such as the Three Gorges Dam in China (pictured below), undersea transmission lines and longer spans in the western US are now planning to use DC transmission. The question is how far will this new trend go? It would sure be convenient to do away with all those DC wall chargers for phones and computers, so why not run the DC to the doorstep? Instead of three lines for three-phase industrial power, business would only need one power line in addition to ground.

Questions

a) "AC power transmission losses are greater than DC losses. One of the reasons for this statement is outlined in the article – the "skin effect" (Paragraph 2) Using physics concepts, explain these losses and why they make AC power transmission less efficient than DC power.

(2 marks)

- **The skin effect means that the alternating current flows through a much smaller cross-sectional area of the wire.**

1 mark

- **Resistance is inversely proportional to the cross-sectional area of the wire; hence, power losses are increased.**

1 mark

b) When describing reasons why AC power transmission is still mostly used instead of DC power transmission, paragraph 3 states "it typically comes hot off the presses as AC."
What does this statement mean?

(1 mark)

- **Generators naturally produce AC within their rotating coil** **1 mark**

c) Describe one other reason described in the article for the popularity of AC transmission?

(2 mark)

Power losses are reduced when power is transmitted at high voltages. **1 mark**

It is easier to step up an AC voltage than it is DC. **1 mark**

Alternatively:

The biggest customers require AC **1 mark only**

d) "Voltage is king." (Paragraph 3) At the Muja power station in South-Western Australia, power can be generated at 200 MW and 16000 V RMS. For transmission, a step-up transformer increases the voltage to 330 kV.

(i) Calculate the transmission current (I) after the voltage is stepped up.
(1 mark)

$I = \frac{P}{V} = \frac{200 \ x \ 10^6}{330 \ 000} = 606 \ A$ **1 mark**

(ii) If the total resistance of the transmission lines to the next substation are 10.0 Ω, calculate the radiative (heat) power losses and the voltage drop in those lines. [If you could not calculate an answer for part d) (i), use a value of 600 A]

(4 marks)

$P_{loss} = I^2R = 606^2 \ x \ 10$ **1 mark**

$= 3.67 \ x \ 10^6 \ W$ **1 mark**

$V_{drop} = IR = 606 \ x \ 10$ **1 mark**

$= 6060 \ V$ **1 mark**

(iii) Hence, calculate the efficiency of the transmission system when the transmission voltage is 330kV.

(2 marks)

$P_d = 200 \ x \ 10^6 - 3.67 \ x \ 10^6 = 1.96 \ x \ 10^8 \ W$ **1 mark**

$\% \ efficiency = \frac{1.96 \ x \ 10^8}{200 \ x \ 10^6} \ x \ 100\% = 98.2\%$ **1 mark**

e) If high voltages increase the efficiency of transmission why is power not transmitted at higher voltages than 330kV?

(1 mark)

Above this voltage, the coronal losses/ionisation of air will cause more power losses.

f) In paragraph 4, the article talks about “commutation” in DC motors using “graphite brushes”. Discuss what “commutation” means and the role that graphite brushes plays in this process.

(3 marks)

- **Commutation in DC motors is where the current in the rotating coil is reversed every half turn. 1 mark**

- **This is done to ensure that the torque acting on the coil is on one direction.**

  1 mark

- **The graphite brushes act as the conducting input between the DC power supply and the rotating coil.**

  1 mark

g) Paragraph 7 states that DC transmission would only require a single line rather than the three lines used in AC transmission. Explain why AC transmission requires 3 lines.

(2 marks)

AC is transmitted as 3 phase power. **1 mark**

Each phase is on a separate line. **1 mark**

End of Section 3