Y12 PHYSICS ATAR

Semester 1 Examination, 2017

Question/Answer Booklet

ALL SAINTS' COLLEGE

Student Number: In figures

In words ______________________________

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Time allowed for this paper

Reading time before commencing work: ten minutes
Working time for paper: three hours

Materials required/recommended for this paper

To be provided by the supervisor
This Question/Answer Booklet
Formulae and Constants Sheet

To be provided by the candidate

Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters, mathaid

Special items: non-programmable calculators satisfying the conditions set by the School Curriculum Standards Authority for this course

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. Suggested working time for this section is 50 minutes.

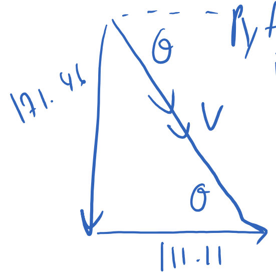
Question 1

A plane is being flown at a horizontal speed of 400 km h^{-1} at an altitude of 1500 m. A piece of the plane becomes dislodged and drops off it whilst it is in motion. If air resistance can be ignored, calculate the velocity of this piece of the plane when it lands on the ground (in m s^{-1}).

(4 marks)

$u_h = \frac{400}{3.6} = 111.11$ m/s ✓ $\quad u_v = 0 \quad a_v = -9.8$ m/s^2 $\quad S_v = -1500$ m

vertical
$v^2 = u^2 + 2as$
$v^2 = 2 \times -9.8 \times -1500$
$v = -171.46$ m/s ✓



Pythagoras
$\vec{v} = \sqrt{171.46^2 + 111.11^2}$
$\vec{v} = 204$ m/s ✓

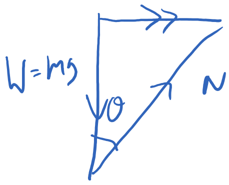
$\theta = \tan^{-1} = \frac{171.46}{111.11}$
$\theta = 57.1°$ ✓

$v = 204$ m/s at $57.1°$ below horizon

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 follow a horizontal circular path with a radius of 250 m at 110 kmh^{-1}. You do not need to allow for friction.

(3 marks)



$\Sigma F = \frac{mv^2}{r}$ $\quad v = \frac{110}{3.6} = 30.556$ m/s

$\tan\theta = \frac{mv^2}{r} \div mg = \frac{v^2}{g.r}$ ✓

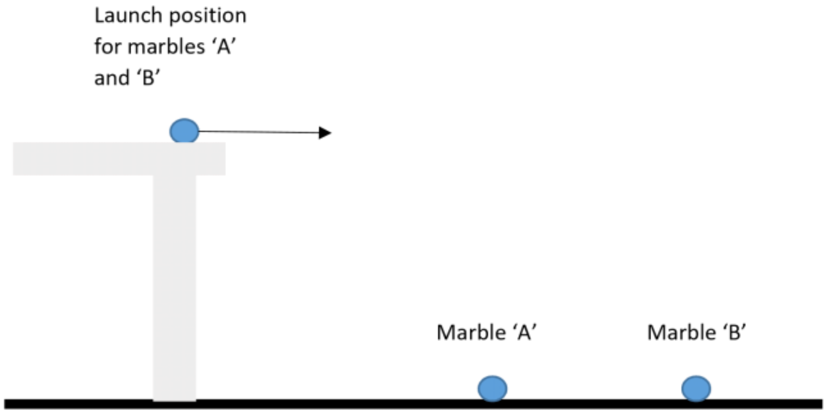
$\tan\theta = \frac{30.556^2}{9.8 \times 250} = 0.38107$ ✓

$\theta = \tan^{-1}(0.38107) = 20.9°$ ✓

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'? Circle a response and 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.

EXPLANATION:

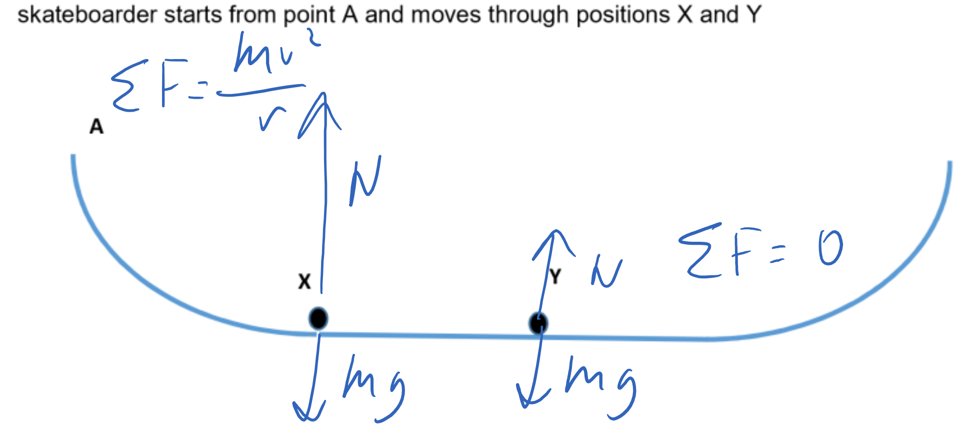
initial $u_{vertical}$ = zero for both ✓

s_{horiz} for B is greater ✓

$\therefore$ u_{horiz} for B is greater ✓

Question 4

The diagram below shows the cross-sectional structure of a skateboard halfpipe. Two positions 'X' and 'Y' are marked on the halfpipe ('X' is at the bottom of the curved section, 'Y' is on the flat section). A skateboarder starts from point A and moves through positions X and Y



Compare the normal reaction forces experienced by the 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)

Reaction force X > Reaction at Y ✓

At X in circular motion

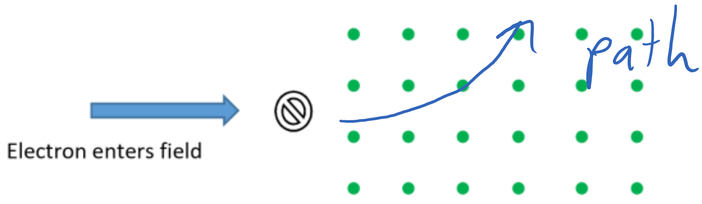
$\Sigma F = \frac{mv^2}{r} = N - mg$ ✓ $\therefore N = \frac{mv^2}{r} + mg$ ✓

At Y ΣF vertical $= 0$

$\therefore N = mg$ ✓

Question 5

An electron emitted from the beta decay of a radioactive isotope enters a magnetic field at a speed of 90% the speed of light. It experiences a force of 1.94 x 10^{-12} N.



a) On the diagram sketch the approximate path the electron will follow.

(1 mark)

b) Calculate the magnetic flux density of the field.

(3 marks)

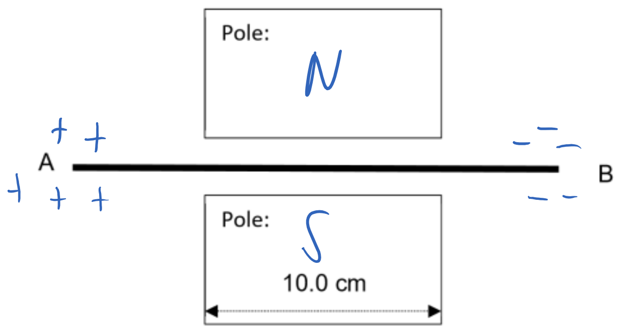
$q = -1.60 \times 10^{-19}$ C $\quad V = 0.9 \times 3 \times 10^8 \quad F = 1.94 \times 10^{-12}$

$F = q.v.B$

$$B = \frac{F}{q.v} = \frac{1.94 \times 10^{-12}}{1.60 \times 10^{-19} \times 0.9 \times 3 \times 10^8} = 4.49 \times 10^{-2}\ T$$

Question 6

A length of copper wire is pulled into the page between the poles of 2 bar magnets (as shown below). It moves with a velocity of 2.00 cm s^{-1} and the length of the wire exposed to magnetic flux 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) Mark each of the poles above as North or South. as above

(1 mark)

b) Calculate the magnetic flux density at the location of the wire.

(2 marks)

$l = 0.10$ m $\quad emf = 2.74 \times 10^{-3} \quad V = 0.02$ m/s

$$emf = l.v.B \qquad B = \frac{emf}{l.v} = \frac{2.74 \times 10^{-3}}{0.1 \times 0.02} = 1.37\ T$$

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)

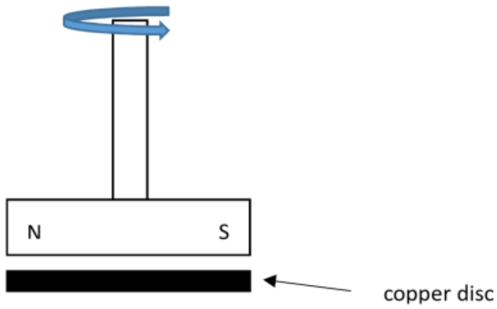
$F = IlB\sin\theta$ At $\theta = 90°$ F = maximum (100%)

If F = 75% of maximum, then $\sin\theta = 0.75$

$\theta = \sin^{-1}(0.75) = 48.6°$

Question 8

A simple analogue car speedometer utilises magnetic properties in its operation. Its main components consist of a rotating bar magnet placed above a circular copper disc (see the diagram below).



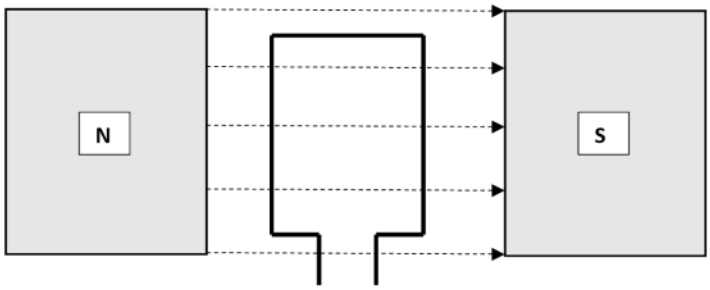
As the bar magnet rotates in the manner shown, the copper disc follows it by rotating in the same direction. Explain why.

(4 marks)

- rotating magnet causes a change in flux through the copper disc
- emf generated according to Faraday's Law
  $emf = \frac{\Delta \Phi}{\Delta t}$ ∴ Eddy currents established
- Eddy currents establish magnetic field to oppose original flux
- Repulsion / Attraction effects cause disc to spin

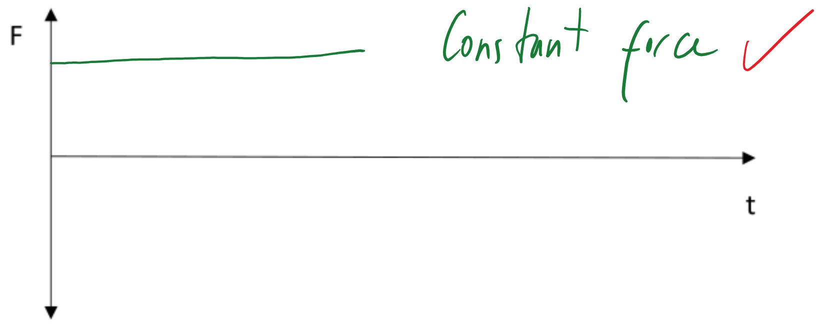
Question 9

The diagram below shows the structure of a simple DC motor (ie – a coil and a uniform magnetic field). The coil can be assumed to have a constant current flowing in it; and the magnetic field can be assumed to be uniform through the coil as it rotates. The coil is connected to a DC battery by a commutator (not shown).



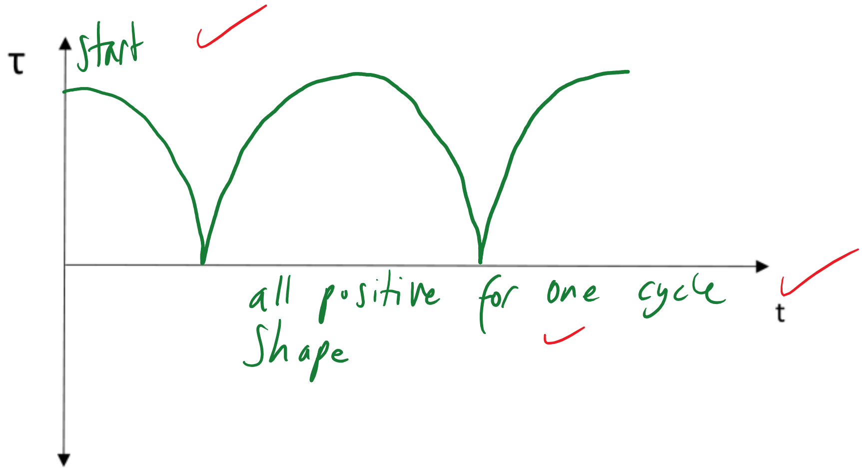
a) On the set of axes below, show how the magnitude of the magnetic force acting on one side of the coil varies over a quarter of a rotation from the position shown at a constant rate of rotation.

(1 mark)



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

(3 marks)



Question 10

A coil of area 25.0 cm^2 is made with 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)

$$\Phi = B.A = 175 \times 10^{-6} \times 25 \times 10^{-4}$$

$$\Phi = 4.38 \times 10^{-7}\ Wb$$

b) The field collapses to zero in a time of 25 ms, calculate the average emf generated in the coil.

(2 marks)

$$emf = -N\frac{\Phi_2 - \Phi_1}{t} = -200\left(\frac{0 - 4.375 \times 10^{-7}}{25 \times 10^{-3}}\right)$$

$$emf = 3.50 \times 10^{-3}\ V$$

Question 11

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)

$$B = \frac{\mu_0}{2\pi} \times \frac{I}{r} = \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{550 \times 10^{-3}}{0.20}$$

$$B = 5.50 \times 10^{-7}\ T$$

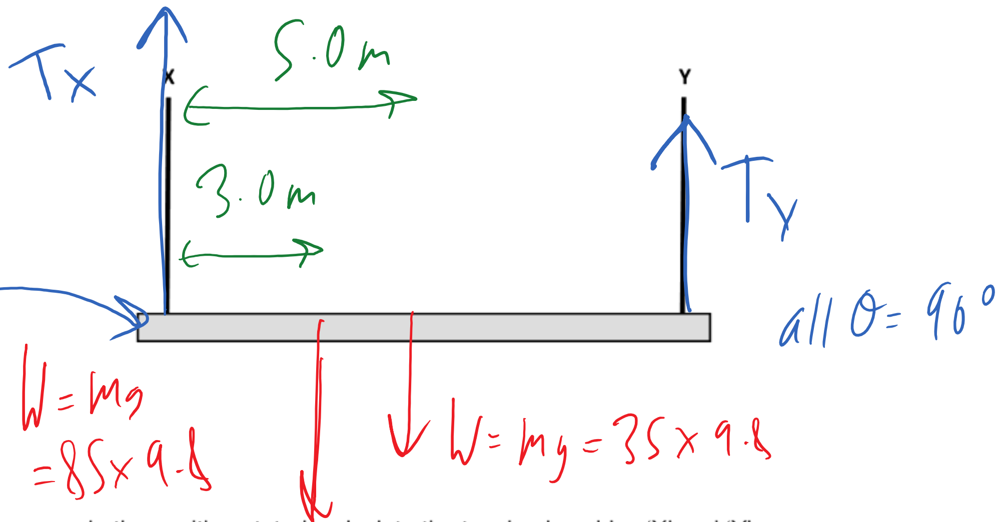
b) The Magnetic Constant, μ_0, is also known as "the magnetic permeability of free space" and applies to air. The magnetic permeability of high pressure argon is slightly lower than the value for air. If the experiment was conducted in high pressure argon, explain how that would change the result.

(2 marks)

In the equation $B = \frac{\mu_0 I}{2\pi r}$ as μ_0 decreases then so does the value of B

Question 12

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)

Taking moments from X $\tau = r.F.\sin\theta$

Σ acwm = Σ cwm

$10 \times T_y = 3 \times (85 \times 9.8) + 5 \times (35 \times 9.8)$

$T_y = 421.4 = 421\ N$ (up)

$\Sigma F_{vertical} = 0$ $\Sigma F_{up} = \Sigma F_{down}$

$T_x + T_y = W_1 + W_2$

$T_x + 421.4 = (35 + 85) \times 9.8$

$T_x = 754.6\ N$

$T_x = 755\ N$ up

Question 13

Khai has a study lamp that uses a 35 W globe that operates at 24 V_{RMS}. The lamp plugs into the house 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)

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \qquad \frac{240}{24} = \frac{N_p}{30}$$

$$\therefore N_p = 300 \text{ turns}$$

b) Calculate the RMS current flowing in the primary coil of the lamp when it is operating if the transformer is 84% efficient at transferring energy from the primary coil to the secondary coil.

(3 marks)

$$P_{out} = 84\% \times P_{IN}$$

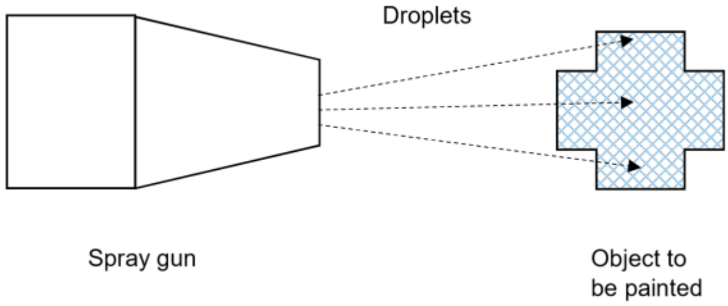
$$P_{IN} = \frac{P_{out}}{0.84} = \frac{35}{0.84} = 41.67 \text{ W}$$

$$P_{IN} = V_{in} \times I_{IN} = \quad 41.67 = 240 \times I_{IN}$$

$$I_{IN} = \frac{41.67}{240} = 0.174 \text{ A}$$

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 charge on each spherical droplet is +2.00 x 10^{-10} C and they have a diameter of 150 μm.

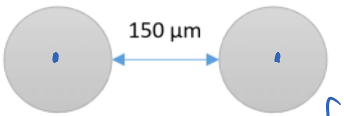
a) State whether electrons were added to or removed from the droplets of paint by the spray gun.

(1 mark)

Removed

b) Calculate the electrostatic force acting between 2 adjacent droplets when they have a surface to surface separation of 150 μm as shown below,

(3 marks)



$r = 300 \times 10^{-6}$ m

Separation $= 300 \times 10^{-6}$ m

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

$$F = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{(2 \times 10^{-10})^2}{(300 \times 10^{-6})^2}$$

$$F = 4.00 \times 10^{-3} \text{ N}$$

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. Suggested working time for this section is 90 minutes.

Question 15 (18 marks)

Some Year 12 Physics students conducted an experiment investigating the link between electromagnetic induction and gravity in the following situation.

The students placed a conducting rod on an inclined plane. The rod started from rest and was allowed to slide freely down the slope on parallel conducting rails (friction can be ignored in this activity).

A magnetic field was acting at right angles to the slope; hence, an emf was induced in the rod as it moved down the slope. A voltmeter was connected to the rails at a distance of 1.00 m down the slope and the emf (V_{MAX}) was measured at this point. A resistor was connected between the rails at the bottom of the slope

The diagrams below illustrate how the equipment was set up in this experiment.

Diagram 1: Side view of equipment

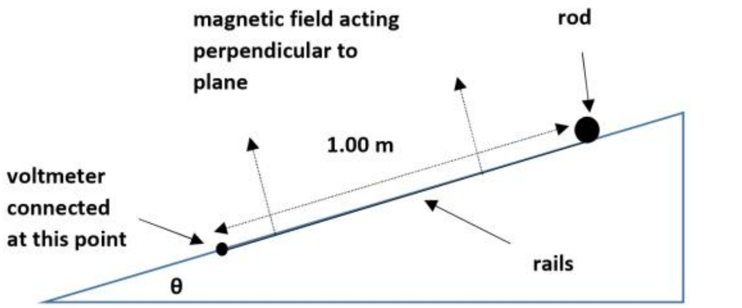
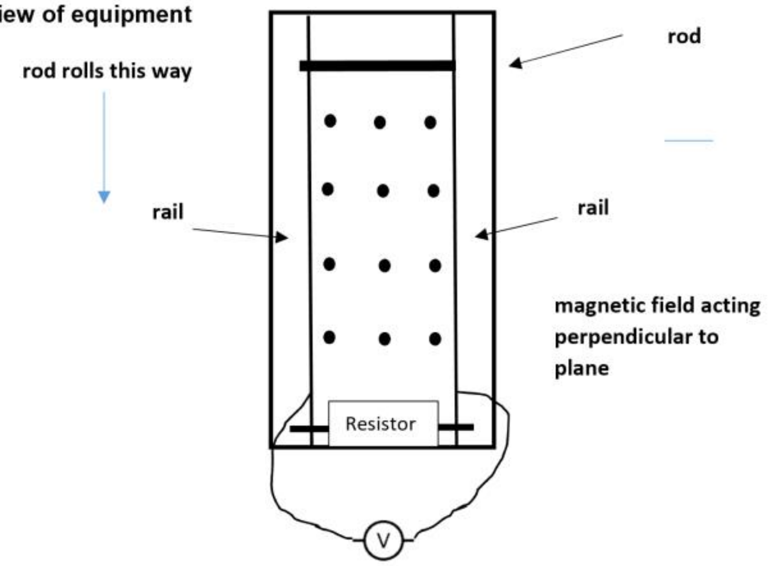


Diagram 2: Top view of equipment



The following parameters were measured by the students:

Initial velocity of rod, u = 0 m s^{-1}

Distance travelled down the inclined plane, s = 1.00 m

Mass of rod, m = 45.0 g

Magnetic flux density, B = 0.50 T

Distance between rails (ie – length of conducting rod), l = 10.0 cm

During the course of their investigation, the students discovered that they could calculate an experimental value for 'g' (acceleration due to Earth's gravitational field) by investigating the relationship between 'θ' (the angle between the inclined plane and the horizontal) and 'V_{MAX}' (the maximum EMF induced in the rod at a distance of 1.00 m down the plane).

It is known that the acceleration of an object down an inclined plane (a_s) is given by:

$$a_s = g \sin\theta$$

It is also known that the instantaneous velocity of the rod at any distance 's' down the slope is given by:

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

Hence, by combining these two relationships, the following expression can be derived to determine the final velocity 'v' of the rod after it has rolled 1.00 m down the inclined plane:

$$v = \sqrt{2\,s\,g\sin\theta} \quad \text{— (1)}$$

a) The emf induced in the rod at any point on the slope is given by the formula:

$$emf = lvB$$

Combine this formula with the expression derived for 'v' shown earlier to show that the induced EMF (V_{MAX}) in this rod after it has moved 1.00 m down the slope is given by the expression:

$$V_{MAX}{}^2 = 0.005\,g\sin\theta$$

$l = 0.1$ $B = 0.5$ $s = 1.0$

(3 marks)

$V_{max} = emf = l.v.B$ ✓

substitute — (1) and values

$V_{max} = 0.1 \times \sqrt{2 \times 1.00 \times g \sin\theta} \times 0.5$ ✓

$V_{max} = 0.05 \times \sqrt{2 g \sin\theta}$

$V_{max}{}^2 = 2.5 \times 10^{-3} \times 2 g \sin\theta = 0.005 g \sin\theta$ ✓

The students collected data to investigate the relationship between 'θ' and 'V_{MAX}'. They gradually increased the angle (θ) the plane made with the horizontal and recorded the value of the emf induced (V_{MAX}) measured by the voltmeter after rolling 1.00 m down the slope. Their measured values are shown in the table below.

θ	sin θ	V_{MAX} (x 10^{-2} V)	$(V_{MAX})^2$ (x 10^{-3} V^2)
10°	0.17	7.80	6.08
20°	0.34	11.0	12.0
30°	0.50	13.2	17.4
40°	0.64	15.0	22.5
50°	0.77	16.4	26.8
60°	0.87	17.4	30.3

✓ ✓

b) Complete the table by filling in the missing values for sin θ and $(V_{MAX})^2$.

(2 marks)

c) Plot a graph of '$(V_{MAX})^2$' versus 'sin θ' so that the gradient you obtain can be used to determine 'g'. You must **break your axes** to get your data on as much of the graph paper as possible with standard axes steps. Draw a line of best fit through the data.

(5 marks)

d) (i) Determine the slope of your line of best fit. Show on the graph how you obtained your values.

(3 marks)

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{24 \times 10^{-3}}{0.68}$$ graph ✓ graph ✓

$$\text{gradient} = 0.0353 \pm$$

(ii) Use your value of the gradient to calculate an experimental value of 'g'. (Show working).

(2 marks)

$$\text{gradient} = 0.005 \times g$$ ✓

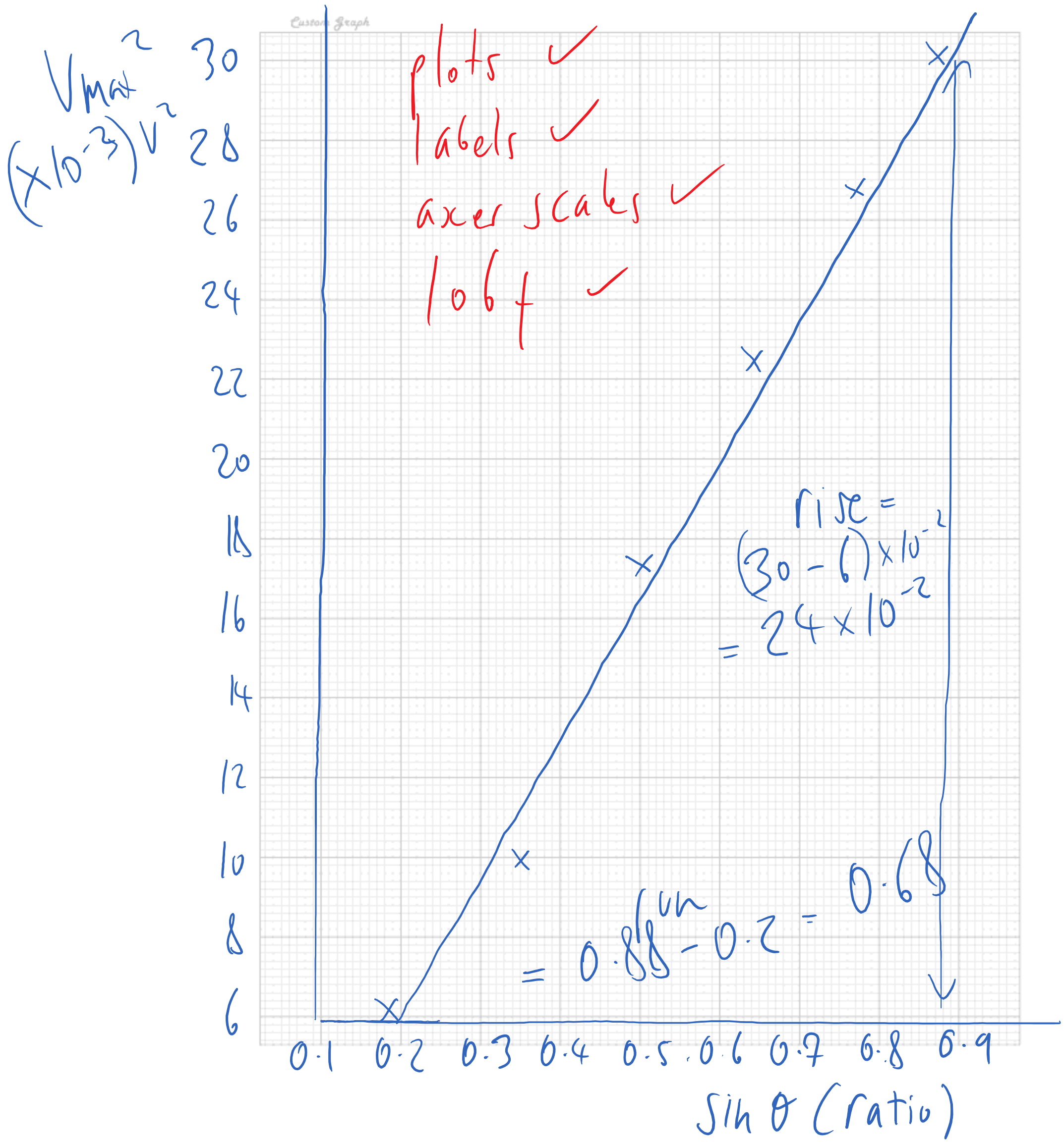
$$0.0353 = 0.005 \times g$$

$$g = 7.06 \pm \text{m/s}^2$$ ✓

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 in this experiment.

(3 marks)

Current established as rod slides down
Force on current carrying rod given ✓
by F = IlB ✓ ✓
Direction opposes motion by RH palm rule

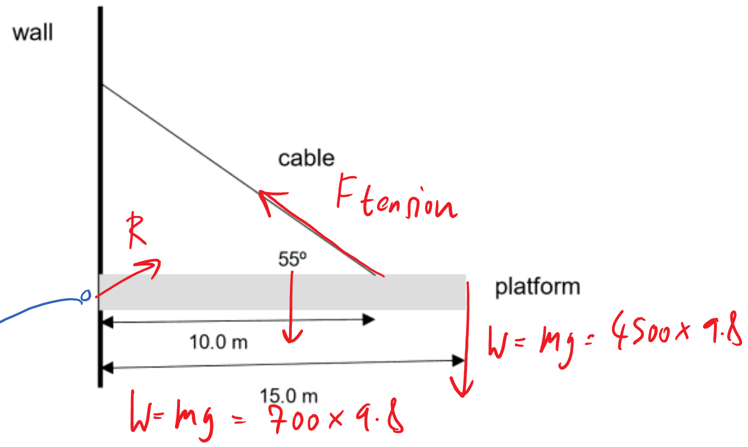


Vmax²
(×10⁻³) V²
30
28
26
24
22
20
18
16
14
12
10
8
6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
sin θ (ratio)
plots ✓
labels ✓
axes scales ✓
lobf ✓
rise =
(30 − 6) × 10⁻²
= 24 × 10⁻²
run
= 0.88 − 0.2 = 0.68

Additional graph paper if required.

Question 16 **(16 marks)**

A platform has been constructed so people can walk out over a gorge and view it. The platform structure is shown in the diagram below.



The platform is designed to support a load of 4.5 tonnes and is 15 m long. A single steel cable supports the platform and is attached 10.0 m from the end at 55° as shown in the figure. The platform has a mass of 0.7 tonnes that is uniformly distributed. The platform is pivoted to the wall at the left hand edge.

The 4.5 tonne design load is acting at the right-hand edge of the platform.

The steel cable shown has a maximum tensile strength of 1.50×10^5 N.

a) Draw a free-body diagram showing all the forces acting on the platform. Label the forces appropriately on the diagram above.

all correct forces ✓ correct location ✓ labelled ✓

(3 marks)

b) Show that with the design load acting at the right of the platform, the cable will be able to support the platform. Support your answer with calculations to determine the tension in the cable.

(4 marks)

pivot $\tau = r . F . \sin\theta$ $\Sigma M = 0$ ✓

$\Sigma \text{acwm} = \Sigma \text{cwm}$

$10 \times F_t \times \sin 55° = 7.5 \times 700 \times 9.8 \times \sin 90° + 15 \times 4500 \times 9.8 \times \sin 90°$ ✓ ✓

$F_t = 8.70 \times 10^4$ N ✓

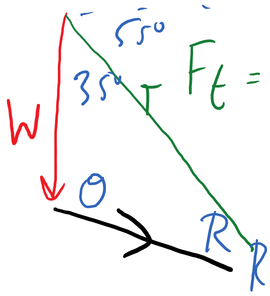
this is less than 1.50×10^5 N maximum

c) Calculate the magnitude of the force that the wall exerts on the platform. [If you could not calculate an answer for the previous question, use a value of 8.70 x 10^4 N for the tension in the cable]

(4 marks)

$\Sigma F = 0$ $\quad W = (4500 + 700) \times 9.8$

$W = 50960$ N



$F_t = 87000$ N $\quad$ By Cosine rule

$R^2 = W^2 + F_t^2 - 2W.F_t \cos 35°$

$R^2 = 50960^2 + 87000^2 - 2 \times 50960 \times 87000 \times \cos 35°$

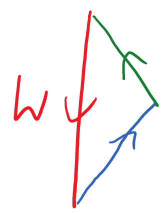
$R = 53874.55 = 5.39 \times 10^4$ N

d) If the design load of 4.5 tonnes is moved towards the middle of the platform, describe what happens the magnitude and direction of the reaction force you calculated in part c).

(2 marks)

Magnitude: decreases

Direction: more upright



F_t decreases

e) If the design load is exceeded, calculate how much mass the platform can support at the right-hand edge before the cable snaps

(3 marks)

let $F_t = 1.50 \times 10^5$

$10 \times 1.50 \times 10^5 \times \sin 55° = 7.5 \times 700 \times 9.8 + 15 \times m \times 9.8$

$1177278.066 = 15 \times m \times 9.8$

$m = 8008.69 = 8.01 \times 10^3$ kg

Question 17 **(14 marks)**

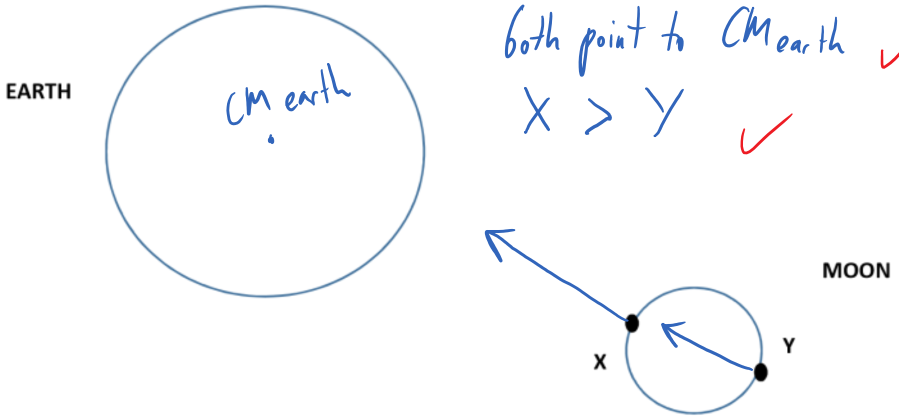
In astrophysics, the 'Roche Limit' or 'Roche Radius' is the distance within which a natural satellite (eg – the Moon) will disintegrate due to its host celestial body (eg – the Earth) exerting a 'tidal force' on it. Disintegration occurs because the tidal forces from the host exceed the gravitational force holding the natural satellite together.

Inside the Roche Limit or Roche Radius, satellites break up into particles and dust and typically form rings (eg – like those around Saturn); outside of it, satellites tend to form almost perfect spherical shapes.

a) The diagram below shows the Moon in orbit around the Earth (Not to scale). Consider the two points shown: 'X' and 'Y'. On the diagram, draw vectors with arrows to show the relative magnitude and direction of the Earth's gravitational field acting at these points. (2 marks)

both point to CM earth ✓

X > Y ✓



b) The 'Roche Radius' for the Moon orbiting around the Earth is 9492 km. With reference to the Formulae and Data Sheet and information in this question, clearly explain why the Moon has not disintegrated. No calculations are required but you must make 2 separate points to justify your response. (2 marks)

9492 km is less than 3.84×10^8 m
∴ Moon is outside Roche limit ✓
So tidal forces do not exceed gravitational forces holding moon together. ✓

c) The Roche Limit is different if the natural satellite is composed of gas or liquid. Explain whether the value would be higher or lower than for a natural satellite composed of rock. (2 marks)

The value would be higher as fluids not held together as strongly ✓ as solid rock, so disintegration can occur at a greater separation. ✓

d) Use the data supplied in your Formulae and Data Sheet to calculate the Earth's gravitational field strength at position 'X' (g_x) on the Moon's surface.

(3 marks)

$$r_x = r_{moon-earth} - r_{moon}$$

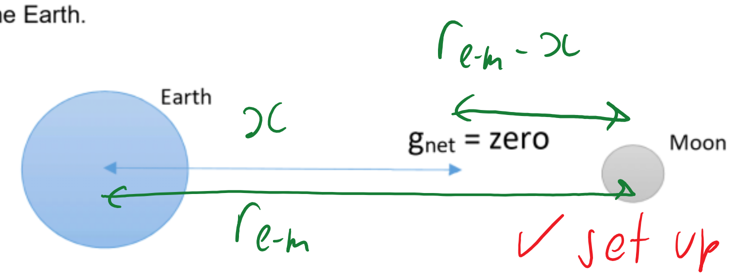
$$r_x = 3.84 \times 10^8 - 1.74 \times 10^6 = 382260000 \text{ m} \quad ✓$$

$$g_x = G\frac{M_{earth}}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(382260000)^2} \quad ✓$$

$$g_x = 2.7251 \times 10^{-3} = 2.73 \times 10^{-3} \text{ N kg}^{-1} \quad ✓$$

e) There is point between the Earth and the Moon where the net gravitational field strength due to the Earth and the Moon is zero. Calculate how far this point is from the centre of the Earth.

(5 marks)



$$g_{earth} = g_{moon}$$

$$\frac{G \times M_{earth}}{x^2} = \frac{G \times M_{moon}}{(r_{em} - x)^2} \quad ✓$$

$$\frac{M_{earth}}{M_{moon}} = \frac{x^2}{(r_{em} - x)^2} \quad ✓$$

$$\sqrt{\frac{M_{earth}}{M_{moon}}} = \frac{x}{r_{em} - x} \rightarrow \sqrt{\frac{5.97 \times 10^{24}}{7.35 \times 10^{22}}} = \frac{x}{r_{em} - x}$$

$$9.012463 = \frac{x}{r_{em} - x} \qquad 9.012463 \times r_{em} - 9.012463x = x \quad ✓$$

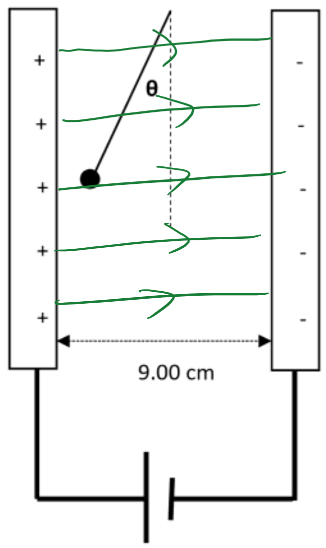
$$9.012463 \times r_{em} = 10.012463\, x \quad ✓$$

$$x = \frac{9.012463 \times 3.84 \times 10^8}{10.012463} = 3.46 \times 10^8 \text{ m}$$

SEE NEXT PAGE

Question 18 **(14 marks)**

A small charged object of mass 0.500 mg is suspended from an 8.00 cm long piece of string made of insulating material. The charge on the object is 25.0 nC. The object is placed between 2 parallel plates that are connected to a 500 V voltage source which gives them an electric charge as shown. The plate separation is 9.00 cm.



a) On the diagram above, draw the electric field between the charged plates with 5 field lines. (2 marks)

5 lines ✓ direction ✓

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

negative ✓

attracted to positive plate ✓

c) Calculate the electric field strength between the two charged plates. (2 marks)

$$E = \frac{F_E}{q} = \frac{V}{d} = \frac{500}{0.09}$$ ✓

$$E = 5.56 \times 10^{3}\ V\,m^{-1}$$ ✓

d) Calculate the electrostatic force acting on the charged object (if you could not calculate an answer to part c), use E = 5550 V m^{-1}).

(2 marks)

$F_E = E \times q$

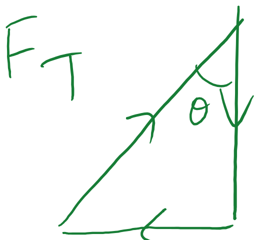
$= 5555 \times 25 \times 10^{-9}$

$F_E = 1.39 \times 10^{-4}$ N (left)

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)

$\Sigma F = 0$



$W = mg = 0.5 \times 10^{-6} \times 9.8$

$=$

$F_E = 1.38 \times 10^{-4}$

$\theta = \tan^{-1}\left(\frac{1.38 \times 10^{-4}}{0.5 \times 10^{-6} \times 9.8}\right)$

$\theta = 88^\circ$ (± rounding)

f) An electron initially at rest on the negative plate travels through the electric field to the positive plate. Calculate the maximum speed that the electron can attain in this electric field.

(3 marks)

$W = Vq = \Delta KE$ $\quad u = 0 \quad v = ?$

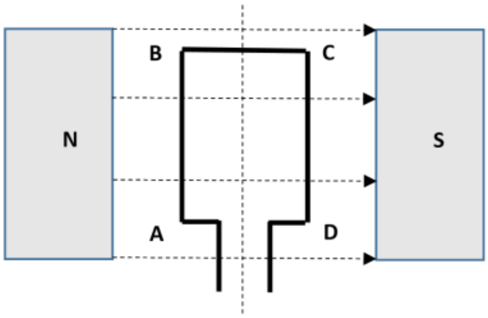
$V.q = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

$500 \times 1.60 \times 10^{-19} = \frac{1}{2} \times 9.11 \times 10^{-31} \times v^2$

$v = 1.33 \times 10^{7}$ m s^{-1}

Question 19 **(13 marks)**

The diagram below shows the structure of a simple AC generator. Slip rings are not shown.



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**.

a) As the coil rotates from this position, an emf is induced. In which direction is this induced emf – ABCD or DCBA? You must justify your response to earn both marks.

(2 marks)

Answer: ABCD ✓

Justification: charge moves out of page, field right ✓
force up by RH palm rule
OR - Current flows to establish a field to block increase
LENZ's law

b) As the coil rotates from this position is the instantaneous value of emf increasing or decreasing? You must justify your response to earn both marks.

(2 marks)

Answer: decreasing ✓

Justification: max rate of change, charge moving perpendicular to field lines, (max emf at zero flux)
OR similar ✓

The AC generator rotates at rate of 600 revolutions per minute.

c) Calculate the maximum emf generated. ✓

(3 marks)

$f = \frac{600}{60} = 10\ Hz$

$V_{max} = 2\pi NBAf = 2\pi \times 30 \times 0.4 \times (0.2 \times 0.1) \times 10$ ✓

$V_{max} = 15.1\ V$ ✓

When the generator is turned at a slower speed the RMS voltage (V_{RMS}) is measured as 4.00 V

d) . Determine the maximum emf in this case.

(2 marks)

$$V_{RMS} = \frac{V_{max}}{\sqrt{2}}$$

$$V_{max} = V_{RMS} \times \sqrt{2} = 4.00 \times \sqrt{2}$$

$$V_{max} = 5.66\ V$$

e) When the generator is connected to an external resistive circuit the torque required to turn the generator at the same rate of rotation increases. Explain why.

(2 marks)

Once current is flowing in coil the lengths next to magnet poles experience a force ($F = BI\ell$) given by RH palm. Opposes the driving torque. (NOT Back EMF)

f) Slip rings in an AC generator are less prone to electrical damage compared to the commutator arrangement in a DC generator. Explain why this is the case.

(2 marks)

Commutator is making / breaking contact twice per revolution. Sparking occurs as charge jumps the gap. Leads to erosion of contact material

Slip rings in constant contact

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 circular with a radius of 2.50 x 10^{20} m (about 26000 light years); its average orbital speed is 2.20 x 10^5 m s^{-1}.

a) Demonstrate by calculation that the orbital period of the Sun around the galactic centre of the Milky Way is 2.26 x 10^8 years. (3 marks)

$$V = \frac{2\pi r}{T} \qquad T = \frac{2\pi r}{V} = \frac{2\pi\ 2.50 \times 10^{20}}{2.20 \times 10^5}$$

$$T = 7.14 \times 10^{15}\ s$$

$$T = \frac{7.14 \times 10^{15}}{365 \times 24 \times 60 \times 60} = 2.26 \times 10^8\ yrs$$

b) The circular orbit of the Sun around the galactic centre of the Milky Way is due to the gravitational force of attraction between the Sun's mass and centre of mass of the Milky Way. Calculate the mass of the Milky Way based on this information. (4 marks)

$$T^2 = \frac{4\pi^2}{GM} r^3 \qquad T = 7.14 \times 10^{15}\ s \qquad r = 2.50 \times 10^{20}\ m$$

$$M = \frac{4\pi^2 r^3}{G \cdot T^2}$$

$$M = \frac{4 \times \pi^2 \times (2.50 \times 10^{20})^3}{6.67 \times 10^{-11} \times (7.14 \times 10^{15})^2}$$

$$M = 1.81 \times 10^{41}\ Kg$$

The planet Mercury is a natural satellite of the Sun. Mercury has a mass of 3.29 x 10^{23} kg and a radius of 2 440 km. Mercury is travelling around the Sun at an orbital radius of 57 909 050 km

c) Calculation that the centripetal acceleration of Mercury around the Sun. (3 marks)

$$a = \frac{v^2}{r} = g = \frac{GM}{r^2} \quad (\text{for satellite})$$

$$a = \frac{GM}{r^2} = \frac{6.67\times10^{-11} \times 1.99\times10^{30}}{(57\,909\,050\,000)^2}$$

$$a = 0.0396 \text{ m s}^{-2}$$

d) Calculate the orbital speed of Mercury around the Sun. (3 marks)

$$\frac{v^2}{r} = \frac{GM}{r^2} \qquad v = \sqrt{\frac{GM}{r}}$$

$$v = \sqrt{\frac{6.67\times10^{-11} \times 1.99\times10^{30}}{57\,909\,050\,000}}$$

$$v = 4.79 \times 10^4 \text{ m s}^{-1}$$

e) Over billions of years the mass of the Sun will decrease. What effect this will have on the orbit of Mercury? You must refer to the orbital radius and the orbital period in your response. (2 marks)

less tightly bound by gravity

∴ radius will increase

orbital period will increase

(If gravity = zero → straight line motion

T → infinity r → infinity)

End of Section 2

Section Three: Comprehension 20% (36 Marks)

This section contains **two (2)** questions. You must answer both questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

Question 21 **(18 marks)**

"How do gravitational slingshots work?"

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

Have you ever heard that spacecraft can speed themselves up by performing gravitational slingshot maneuvers? What's involved to get yourself going faster across the Solar System.

So, before we go any further a "gravitational slingshot" is a gravity assist that will speed up a 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.

This process nets out to zero, with no overall increase in velocity as your spacecraft falls into and out of the gravity well. So how do they do it? Here's the trick. Each planet has an orbital speed travelling around the Sun.

As the spacecraft approaches the planet, its gravity pulls the much lighter spacecraft so that it catches up with the planet in orbit. It's the orbital momentum from the planet which gives the spacecraft a tremendous speed boost. The closer it can fly, the more momentum it receives, and the faster it flies away from the encounter.

To kick the velocity even higher, the spacecraft can fire its rockets during the closest approach, and the high speed encounter will multiply the effect of the rockets. This speed boost comes with a cost. It's still a transfer of momentum. The planet loses a tiny bit of orbital velocity.

If you did enough gravitational slingshots, such as several zillion zillion slingshots, you'd eventually cause the planet to crash into the Sun. You can use gravitational slingshots to decelerate by doing the whole thing backwards. You approach the planet in the opposite direction that it's orbiting the Sun. The transfer of momentum will slow down the spacecraft a significant amount, and speed up the planet an infinitesimal amount.

NASA's MESSENGER spacecraft made 2 Earth flybys, 2 Venus flybys and 3 Mercury flybys before it was going slowly enough to make an orbital insertion around Mercury.

Ulysses, the solar probe launched in 1990, used gravity assists to totally change its trajectory into a polar orbit above and below the Sun.

Cassini used flybys of Venus, Earth and Jupiter to reach Saturn with an efficient flight path.

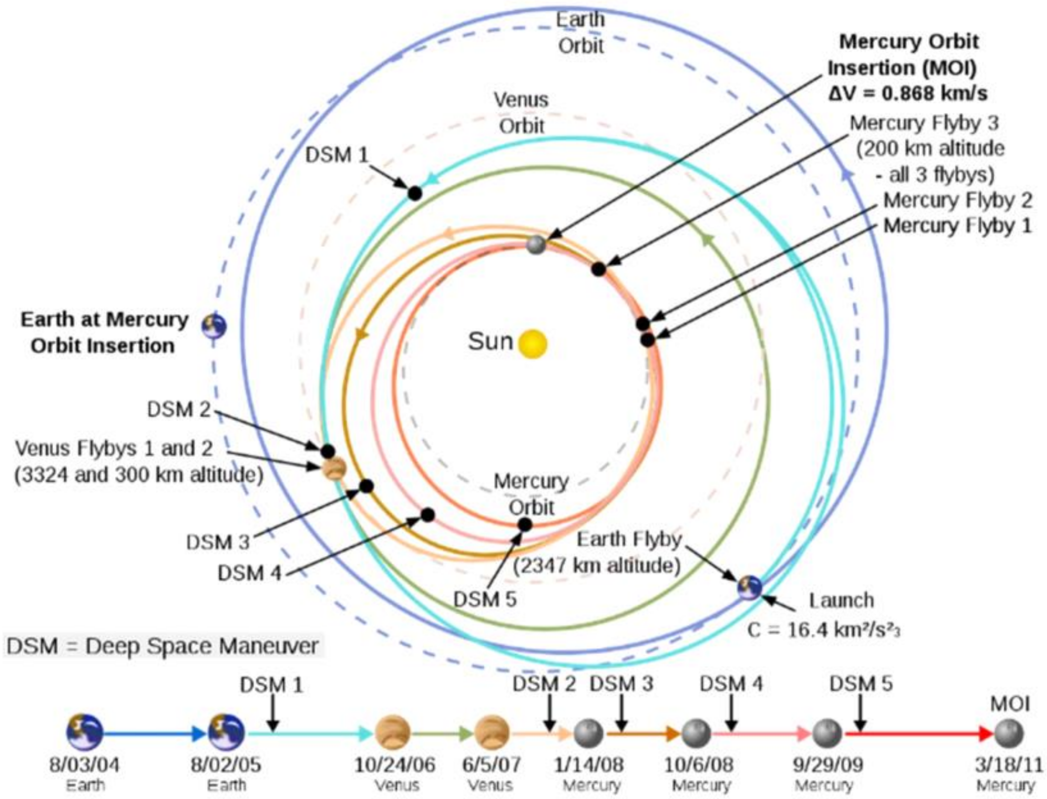


Diagram detailing the Messenger orbital maneuvers.

Nature sure is trying to make it easy for us. Gravitational slingshots are an elegant way to slow down spacecraft, tweak their orbits into directions you could never reach any other way, or accelerate to incredible speeds.

It's a brilliant dance using orbital mechanics to aid in our exploration of the cosmos. It's a shining example of the genius and the ingenuity of the minds who are helping to push humanity further out into the stars.

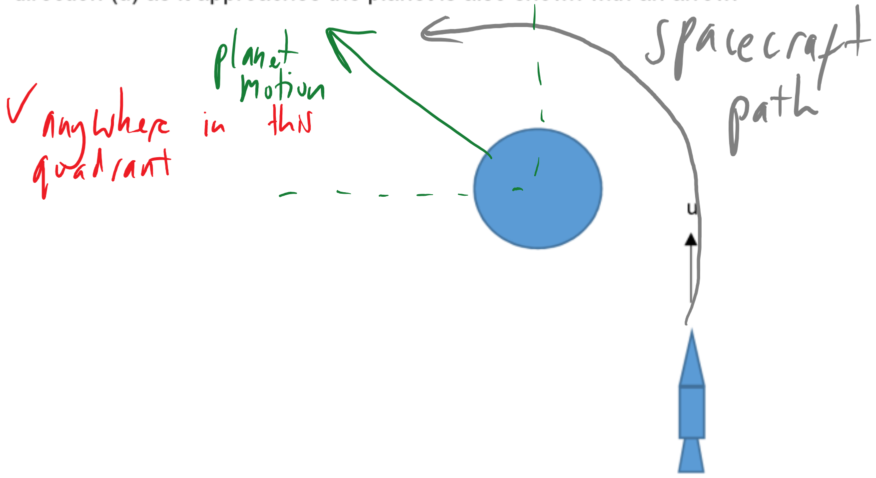
a) "Voyager is a spacecraft that was sent out beyond the Solar System, it used gravitational slingshots past Jupiter and Saturn to increase its velocity enough to escape the Sun's gravity."

Voyager needed a minimum speed to escape the Sun's gravity. Explain why this speed is needed and how it gets to this speed.

(4 marks)

If speed not enough gravitational attraction of Sun pulls voyager ✓ back from a straight line ✓ or puts into elliptical orbit
By slingshot that catches ✓ up to planet
Transfers momentum from planet ✓ to Voyager
any 4 good points

b) The diagram below is incomplete. It shows a spacecraft approaching a planet which it is planning to use for a gravitational slingshot to increase its velocity. Its initial velocity direction (u) as it approaches the planet is also shown with an arrow.



i) On the diagram, indicate with an arrow the direction of the planet's motion around the sun. Label it 'planet motion' and briefly explain your choice.

(2 marks)

must approach a planet that is moving away from craft for an ✓ increase in speed to occur.

ii) On the same diagram draw the path of the spacecraft as it passes by the planet. Briefly explain your response. (not orbit)

(3 marks)

Must go around planet
planets Centre of mass must be
within the curve
any 2 good points

c) The gravitational slingshot maneuver involves flying a spacecraft dangerously close to a massive planet. In August 2011, NASA's Juno mission to Jupiter was launched. Juno used the Earth to complete a gravitational slingshot. Juno came to within 560 km of the Earth's surface. If Juno has a mass of 1593 kg, calculate the gravitational force acting on Juno at this point.

(4 marks)

$r = r_e + \text{altitude} = 6.37 \times 10^6 + 560{,}000 = 6.93 \times 10^7$

$F = G\frac{m_1 m_2}{r^2} = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1593}{(6.37 \times 10^7)^2}$

$F = 13208.38 = 1.32 \times 10^4 \text{ N}$

d) It's possible that if a spacecraft like Juno 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 with reference to Physics concepts in the passage and from the Physics ATAR course.

(3 marks)

Slingshot transfers momentum from planet to Juno
Reduction in momentum = reduction obital speed
Projectile falls out of circular path if speed
is reduced. This can result in spiralling
towards host planet. any 3 valid points

e) Consider a spacecraft which is about to complete a slingshot maneuver. Is the total mechanical energy of the spacecraft the same before and after the slingshot? Explain.

(2 marks)

No, total mechanical energy has been
increased by an external force doing
work on the spacecraft.

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

https://www.extremetech.com/extreme/142741-tesla-turns-in-his-grave-is-it-finally-time-to-switch-from-ac-to-dc

Paragraph 1

AC power transmission losses are greater than DC losses. That is hardly an industry secret. In fact the reason you can wirelessly charge a cell phone is because any changing current will radiate away some energy. You just need to coil the wire up to gather some of that energy in a convenient place. 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

Depending on the voltage, wire characteristics, and environment, other parasitic losses in AC transmission can become insidious, much more so than the relatively small radiative loss. 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 more 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.

Tesla v Edison

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 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 **Voltage is King**

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. To transmit the same power as DC, an AC system will need to operate with a higher peak voltage, since most of the time the level is below that of an equivalent DC system. During the portion of the cycle when the AC is at lower voltages, efficiency is lost because, as above, voltage is king.

Paragraph 6

Some new projects, such as the Three Gorges Dam in China (pictured), and 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.

Paragraph 7

If widespread change does happen, hopefully it will be gradual enough to permit proper precautions to be put in place. Standard wisdom for handling AC electrical power will have to be re-written for DC by experience. Cartoonists, in particular, will be severely affected as they have by tradition used DC exclusively in their work. When Jerry hands Tom a DC live wire, Tom is unable to let go — to ensuing dramatic effect. With the rapid reversal of current in AC, the muscles relax long enough for you to release and pull away. Undoubtedly, there would be some safety issues like this to be ironed out, but it looks like high voltage DC transmission will be here to stay, at least for some applications.

a) "AC power transmission losses are greater than DC losses. This is hardly an industry secret." (Paragraph 1). Two of the reasons for this statement are outlined in the article – the "skin effect" (Paragraph 2); and in Paragraph 5 ("Voltage is king"). Using physics concepts, explain these losses and why they make AC power transmission less efficient than DC power.

(4 marks)

Skin effect. Current not travelling along entire cross section (Area ↓) ✓
→ Resistance of wire increased ✓
$P_{loss} = I^2 R$ – increased

AC vs DC for most of AC cycle voltage is below equivalent DC at these portion of the cycle ✓ efficiency is reduced ✓

Any valid pair of points

b) State two (2) reasons that AC power transmission is still mostly used instead of DC power transmission.

(2 marks)

Reason 1: 3 phase AC generators and transformers established in network ✓. Expensive to change.

Reason 2: 3 phase AC Induction motor is still widely used (needs AC) ✓

At the Muja power station in WA, power can be generated at 200 MW and 16000 V RMS. For transmission, a step-up transformer increases the voltage to 330 Kv and can be assumed to be 100% efficient. The total resistance of the transmission lines to the next substation are 50 Ω

c) calculate the voltage drop in those lines

(3 marks)

$$\Delta V = IR \qquad P_{out} = I_{out} V_{out}$$

$$I_{out} = \frac{P_{out}}{V_{out}}$$

$$\Delta V = \frac{P_{out}}{V_{out}} \times R = \frac{200 \times 10^6}{330{,}000} \times 50$$

$$\Delta V = 3.03 \times 10^4 \text{ V}$$

d) 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)

The transfer of current from external supply voltage to a rotating coil in DC motor

Require direction of current to be switch every 1/2 a turn in coil

Graphite brush = fixed conducting contact that links to commutator that rotates beneath it.

e) Explain why AC power is less dangerous than DC power in terms of electrocution.

(2 marks)

For large portions of AC cycle instantaneous current is low.

Allows muscles to relax and release grip and pull away.

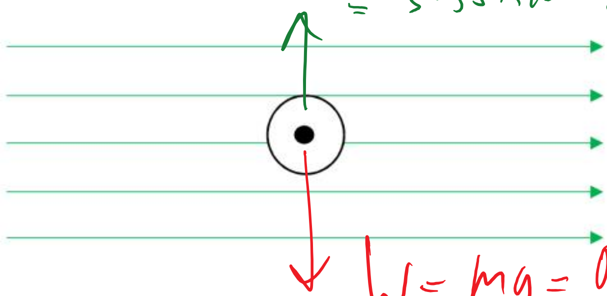
f) Consider a DC power line carrying a current of 150 A horizontally above the ground (indicated out of the page). A section of the power line has a mass of 25.4 g and a length of 10.0 m. The Earth's magnetic field has a direction right as indicated on the diagram and has a flux density of 5.55×10^{-5} T. Consider the **weight** of the power line and the **force due to current** to determine the net force on the power line.

(4 marks)

$F_e = B \cdot I \cdot l$

$= 5.55\times10^{-5} \times 150 \times 10$

$F_{ele} = 0.08325$ N



$W = mg = 0.0254 \times 9.8$

$= 0.24892$ N

$F_{net} = W - F_e$

$= 0.24892 - 0.08325$

$= 0.166$ N down

End of Section 3

Additional working space

Additional working space

Additional working space