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 its maximum 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.

If air resistance can be ignored, calculate the velocity of this piece of the plane when it lands on the ground (in ms^{-1}).

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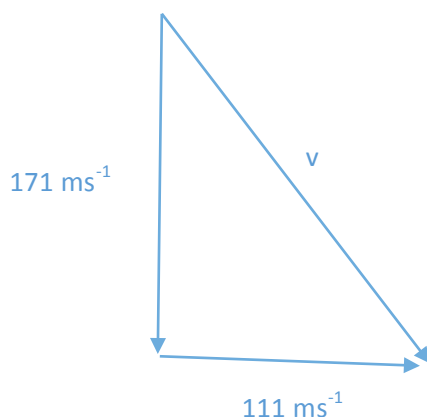
$v^2 = u^2 + 2as; u = 0\ ms^{-1}, a = 9.80\ ms^{-2}, s = 1500m$

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

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

$\tan \theta = \frac{171}{111}; \theta = 57.0^o$ **1 mark**

SEE NEXT PAGE

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}.
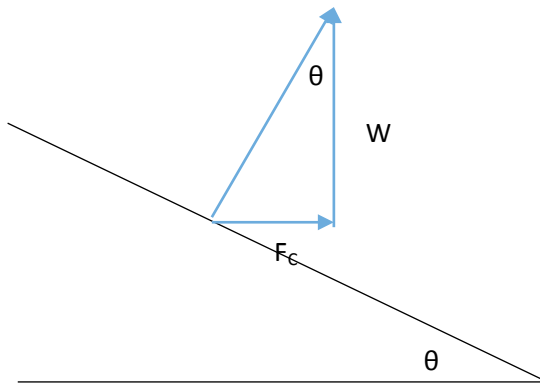
(3 marks)

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

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

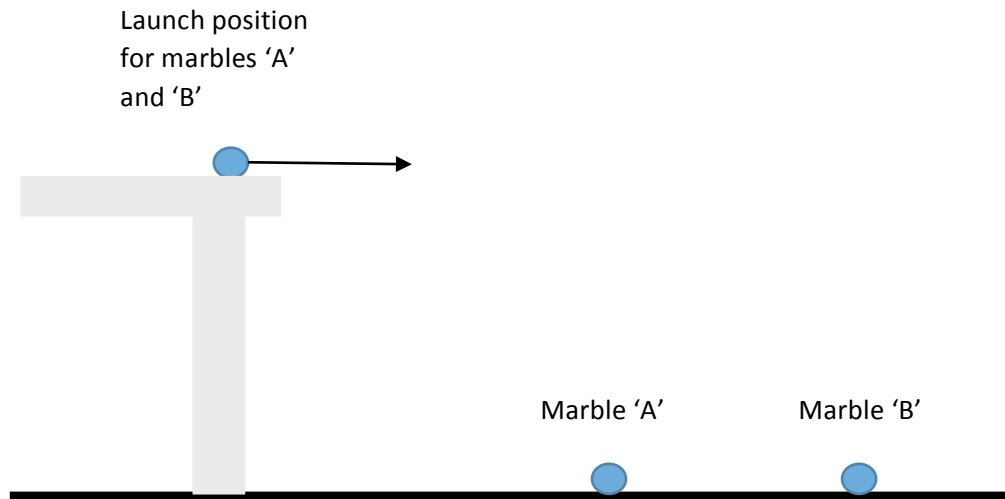$$\therefore \ \tan \theta = \frac{30.6^2}{(9.8 \ x \ 250)} \qquad \textbf{1 mark}$$

$$\theta = 20.9^o \qquad \textbf{1 mark}$$

SEE NEXT PAGE

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:

- **Both marbles have an initial vertical velocity of 0 ms^{-1}.**   **1 mark**

- **Horizontal displacement for marble B is greater than horizontal displacement for marble A.**   **1 mark**
- **∴ marble B's initial horizontal velocity is greater than marble A; hence, marble B's launch velocity is greater than marble A.**   **1 mark**

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 he needs to do this.
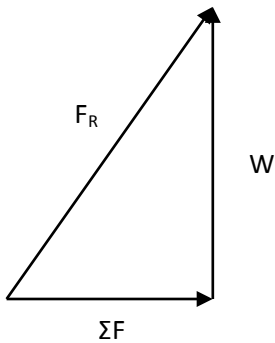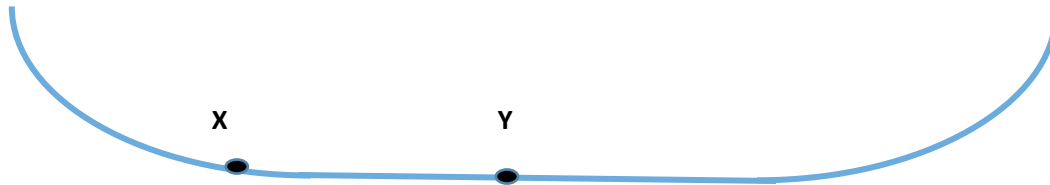
(4 marks)

Diagram – 1 mark

- **Without leaning over, the player is unable to generate enough friction to create the centripetal force required.** **1 mark**
- **By leaning over, they are able to create a net horizontal force via friction towards the centre of their circular path.**
1 mark
- **This larger frictional force is able to supply the large centripetal force required.**
1 mark

SEE NEXT PAGE

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).

X   Y

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**   **1 mark**
- **At X, the reaction force must 'overcome' weight, and**

  also supply the centripetal force ie $R = F_X = \dfrac{mv^2}{r} + mg$ 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.

A _____ B

2.00 cm s^{-1}

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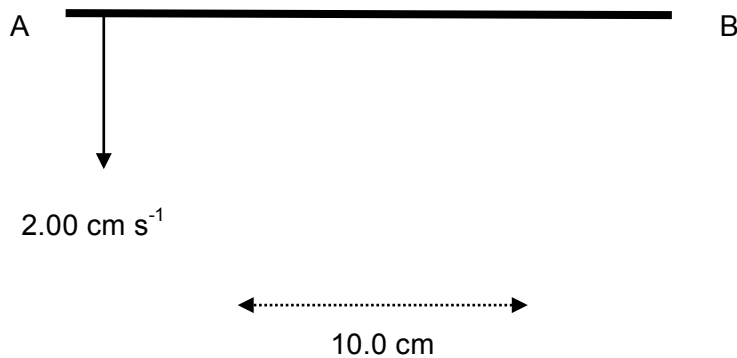
The end of the copper wire marked 'B' gains a net negative charge and the wire generates a small emf with an average value of 2.74 mV.

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) Estimate the strength of the bar magnet's magnetic field near its face.

(2 marks)

$emf = lvB, let\ l = 0.100\ m$

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

$B = 1.37\ V = 1.4\ T\ (2sf)$ **1 mark**

Question 7

A current-carrying straight conductor is placed in a magnetic field and experiences a magnetic force less than the maximum value this force could be in this field. If the conductor carries a current at 30^0 to the direction of the magnetic field, then what fraction of this maximum force will the conductor experience? Show working.   (3 marks)
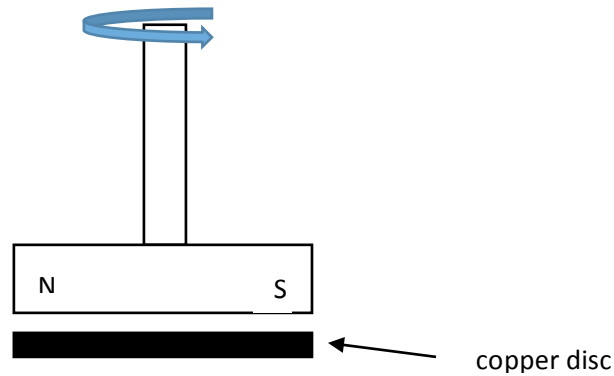
I

B (direction of magnetic field)

30°

F = ILBsinθ
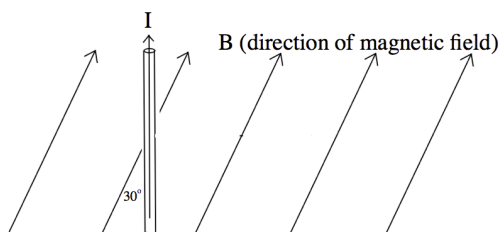
F = ILBsin30

F = ILB0.5

Therefore fraction is ½ of maximum

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).


copper disc

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 ΔΦ across the surface of the copper disc.**
  1 mark

- **∴ 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).   1 mark**

- **Hence, the copper disc rotates with the bar magnet to oppose the ΔΦ it experiences.**
  1 mark

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 large enough to completely surround the coil as it rotates.
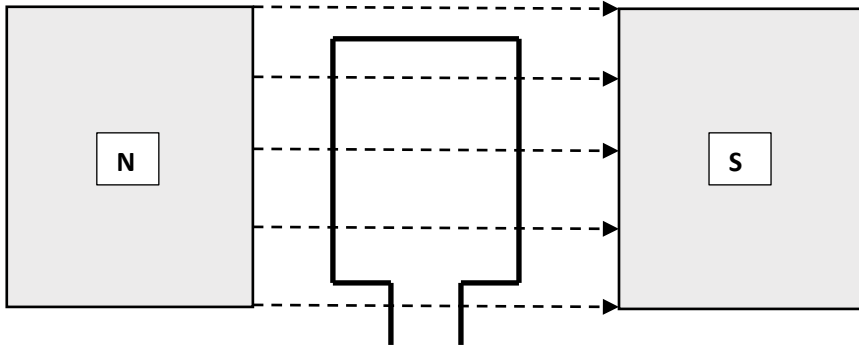
a) On the set of axes below, show how the magnitude of the magnetic force acting on one side of the coil varies over ONE compete rotation.

(1 mark)

Constant value
1 mark
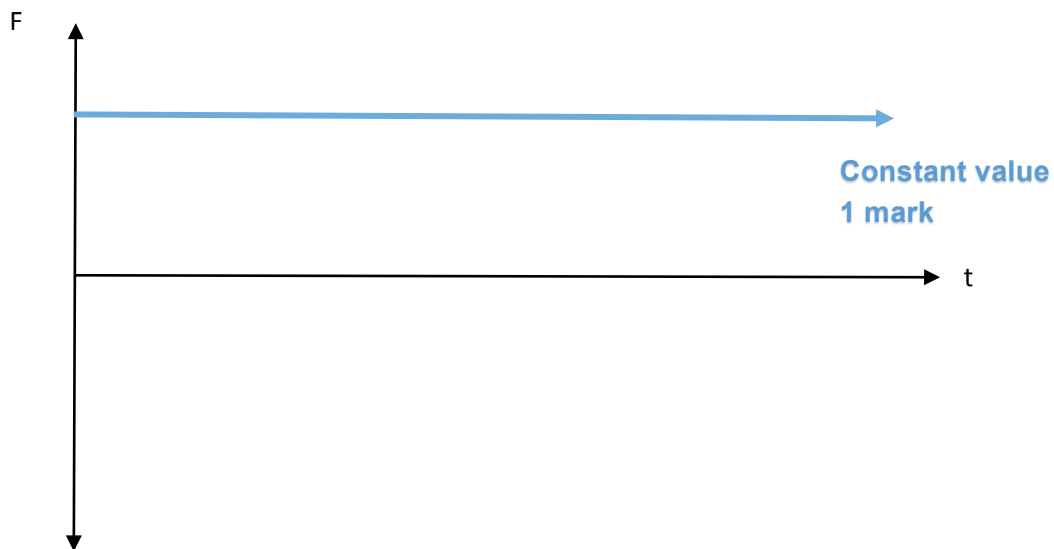
Question 9 continued on next page

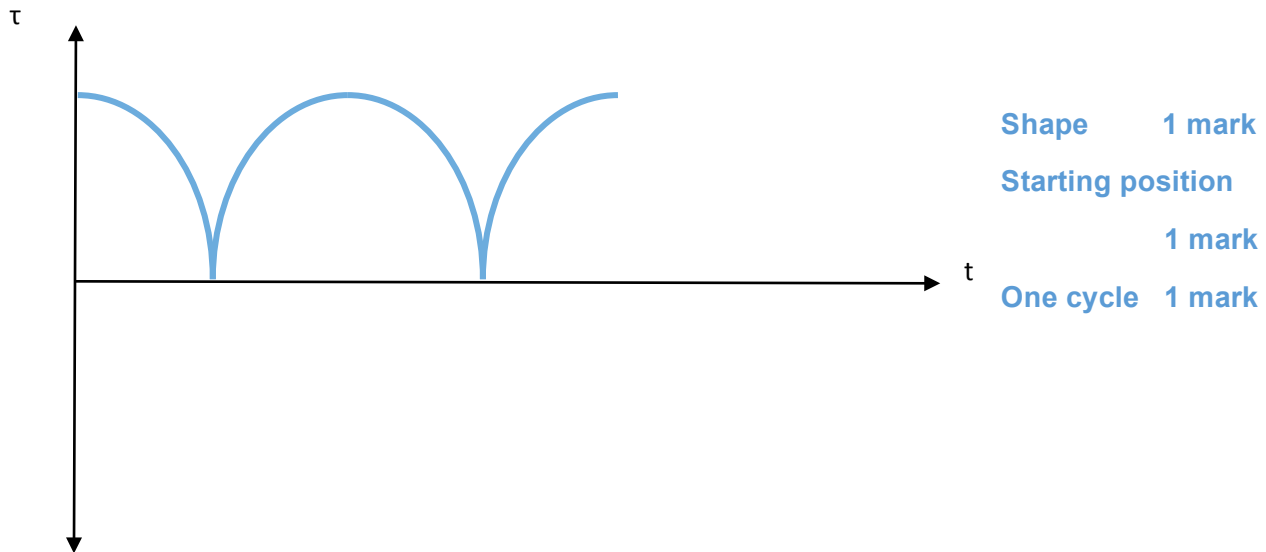b) On the set of axes below, show how the torque (τ) acting on the coil varies over ONE compete rotation. Assume the coil starts in the position shown.

(3 marks)

Shape   1 mark

Starting position

1 mark

One cycle   1 mark

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)

$$\emptyset = BA = 175 \times 10^{-6} \times 25.0 \times 10^{-4}$$ **1 mark x 200**

$$= 4.38 \times 10^{-7} \ Wb$$ **1 mark 8.75 x 10^{-5} Wb**

b) If the field collapses to zero in 25 ms, calculate the average emf generated in the coil in this time.

(2 marks)

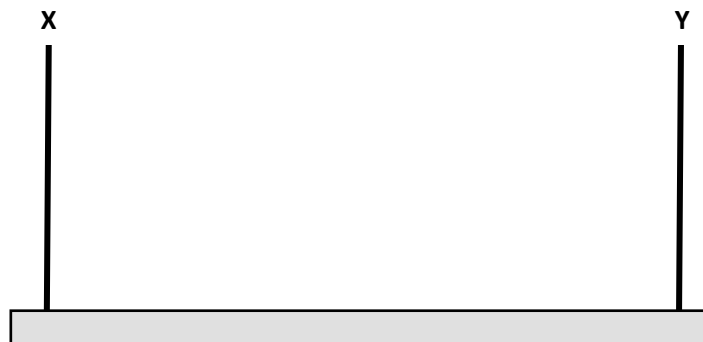$$average \ emf = \frac{-N\Delta\emptyset}{t} = \frac{-200 \ x - 4.38 \ x \ 10^{-7}}{25 \ x \ 10^{-3}}$$ **1 mark**

$$= 3.50 \times 10^{-3} \ V$$ **1 mark**

SEE NEXT PAGE

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**

$(85\ x\ 9.8\ x\ 3) + (35\ x\ 9.8\ x\ 5) = F_Y\ x\ 10$　　　**1 mark**

$\therefore\ F_Y = 421\ N\ up$　　　**1 mark**

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

$B = \dfrac{\mu_0}{2\pi}\dfrac{I}{r} = \dfrac{4\pi\ x\ 10^{-7}}{2\pi}\ x\ \dfrac{550\ x\ 10^{-3}}{0.20}$　　　**1 mark**

$\therefore B = 5.5\ x\ 10^{-7}\ T$　　　**1 mark**

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

Cody 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**

$$\therefore N_P = 300 \; turns$$ **1 mark**

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

(3 marks)

$$Ideal \; transformer: P_P = P_{S;} V_P I_P = 35$$ **1 mark**

$$240 \; x \; I_P = 35$$ **1 mark**

$$\therefore I_P = \frac{35}{240} = 0.145 \; A$$ **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.

Droplets

Spray gun   Object to
be painted
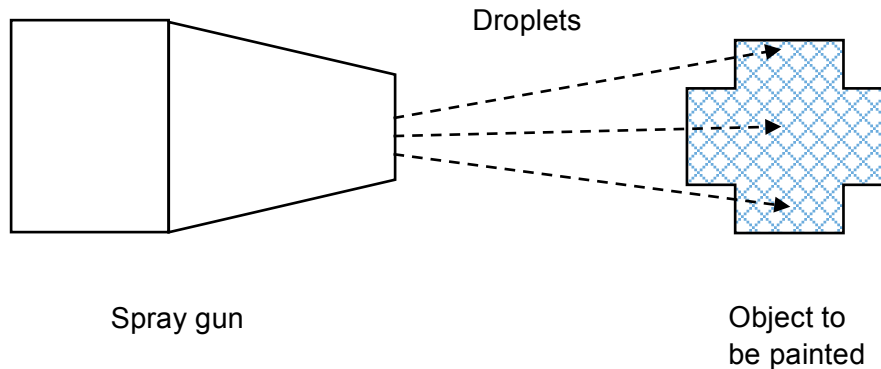
The magnitude of the charge on each droplet is 2.0×10^{-10} C and, on average, they have a diameter of about 150 μm.

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)

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

$$= \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{2 \times 10^{-10} \times 2 \times 10^{-10}}{(150 \times 10^{-6})^2}$$ **1 mark**

$$= 1.60 \times 10^{-2} \, N \, repulsion$$ **1 mark**

End of Section One

SEE NEXT PAGE

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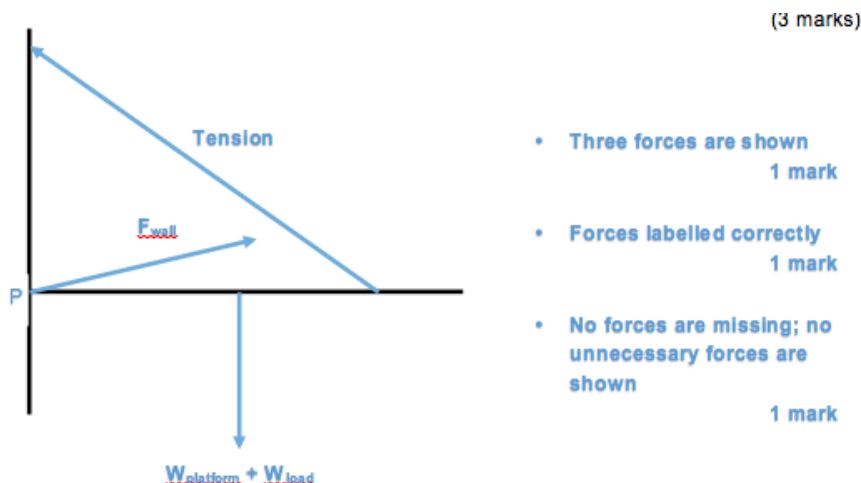
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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- 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 90 minutes.

Question 15   **(16 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.

(3 marks)

- **Three forces are shown**
  1 mark

- **Forces labelled correctly**
  1 mark

- **No forces are missing; no unnecessary forces are shown**
  1 mark

The platform is designed to support a load of 8.5 tonnes and is 15 m long. A single steel cable supports the platform, attached 10.0 m from the end at 55° as shown in the figure. The platform has a mass of 0.7 tonnes.

The platform is uniform and it can be assumed that – when it is acting - the 8.5 tonne maximum load acts half-way along its length.

The steel cable shown has a maximum tensile strength of 1.5×10^5 N.

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

(3 marks)

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.

(4 marks)

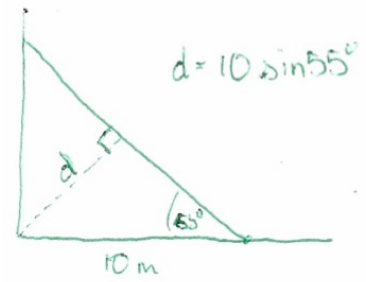$Take\ moments\ about\ P;\ \Sigma M = 0;\ \Sigma M_c = \Sigma M_A$ **1 mark**

$(8500 + 700)x\ 9.8\ x\ 7.5 = (T\ \sin 55^o)\ x\ 10.0$
        (ie 6.76x10⁵Nm)   **1 mark**

$\therefore T = 8.25\ x\ 10^4\ N$
                                1 mark

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

$d = 10 \sin 55^\circ$

c) Hence, calculate the magnitude of the force that the wall exerts on the platform. [Hint – if you could not calculate an answer for part b), use a value of 9.0 x 10⁴ N for the tension in the cable]

(4 marks)

$\Sigma F = 0;\ \Sigma F_{UP} = \Sigma F_{DOWN};$
$F_P = (8500 + 700)x\ 9.8$
        $- 8.25\ x\ 10^4\ \sin 55^o = 2.25\ x\ 10^4\ N\ up$
                                1 mark

$\Sigma F_{LEFT} = \Sigma F_{RIGHT}; \therefore F_P =$
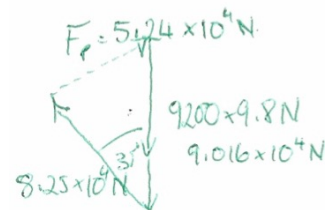$8.24\ x\ 10^{-4}\ \cos 55^o = 4.73\ x\ 10^4\ N\ right$ **1 mark**

$F_P^{\ 2} = (2.25\ x\ 10^4)^2 + (4.73\ x\ 10^4)^2;\ F_P = 5.24\ x\ 10^4\ N$
                                2 marks
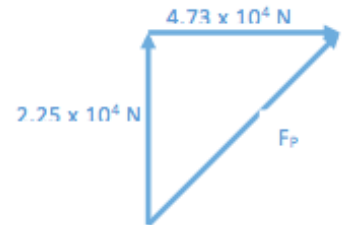
OR by triangle of forces ie
Using cosine rule

d) If the maximum load of 8.5 tonnes is gradually moved towards the end of the platform, describe what happens the magnitude and direction 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 towards the edge of the platform the load can move until the load limit on the wire is exceeded.

(3 marks)

$(700\ x\ 9.8\ x\ 7.5) + (8500\ x\ 9.8\ x\ r) = 1.5\ x\ 10^5\ x\ \sin 55^o\ x\ 10.0$ **1 mark**

$r = 14.1\ m$ (13.6 if centre of mass doesn't remain at 7.5m)   **1 mark**

$r < 15\ m, \therefore\ cable\ WILL\ snap$ **1 mark**

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Question 16   **(17 marks)**

In astrophysics, the 'Roche Limit' or 'Roche Radius' is the distance within which a celestial body (eg – the Moon) - which is held together by its own gravity - will disintegrate due to a second celestial body (eg – the Earth) exerting a 'tidal force' on the first that exceeds the gravitational force holding it together.

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

a) The diagram below shows the Moon in orbit around 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 field acting on these points on the Moon.

(4 marks)
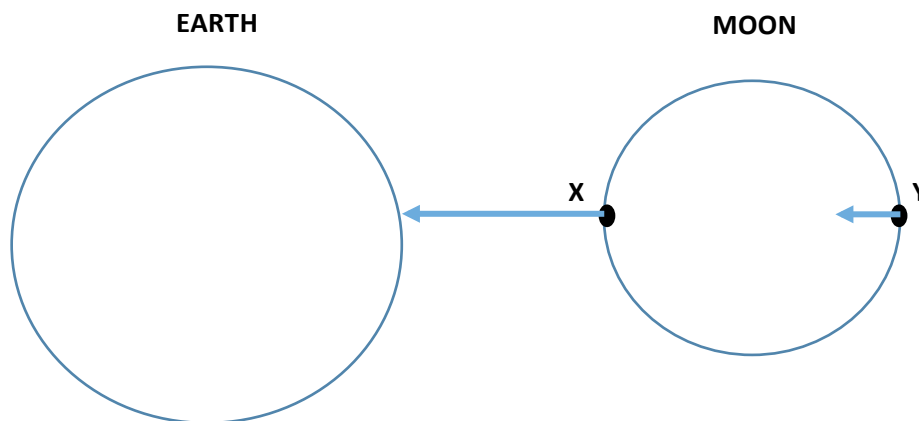
Size of the earth is bigger than the moon   **1 mark**

Two arrows pointing towards the Earth's centre of mass   **1 mark**

Direction of both arrows is the same   **1 mark**

$F_X > F_Y$ **1 mark**

b) The 'Roche Radius' for the Moon orbiting around the Earth is 9492 km. The Moon's orbital radius around the Earth is 384 399 km. Hence, the Moon does not disintegrate at this distance – the tidal forces are not large enough. In terms of the gravitational forces due to the Earth acting on different sides of the Moon, explain why it doesn't disintegrate at this distance. Diagrams may help your explanation.

(4 marks)

- **Outside Roche Limit, the difference between the forces on either side of the Moon (ie – at X and Y) is insignificant.**

  1 mark

- **Hence, the nett tidal force acting on the Moon is virtually zero.**   **1 mark**

- **Therefore, the gravitational attraction of the Moon's matter towards its centre of mass far exceeds the tidal forces acting on the Moon.**   **2 marks**

SEE NEXT PAGE

c) Use the data supplied in your Formulae and Data Sheet to calculate the Earth's
gravitational field strength at position 'X' (g_x) and position 'Y' (g_y).

(5 marks)

$$g_x = \frac{Gm}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(94292 \times 10^3 - 1.74 \times 10^6)^2}$$ **2 marks**	$$g_x = \frac{Gm}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(3.84 \times 10^8 - 1.74 \times 10^6)^2}$$ **2 marks**
$$= 6.64 \, ms^{-2}$$ **1 mark**	$$= 0.00273 \, ms^{-2}$$ **1 mark**
$$g_y = \frac{Gm}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(94292 \times 10^3 + 1.74 \times 10^6)^2}$$ **1 mark**	$$g_y = \frac{Gm}{r^2} = \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{(3.84 \times 10^8 + 1.74 \times 10^6)^2}$$ **1 mark**
$$= 3.16 \, ms^{-2}$$ **1 mark**	$$= 0.00268 \, ms^{-2}$$ **1 mark**

d) For a variety of reasons, astrophysicists have calculated two Roche Limit values for the
Moon with the Earth as its second celestial object – the value in part c), which assumes the
Moon is a rigid, solid body; and another value assuming that it has the density of a liquid.
This value is much larger – 34 638 km. Explain why the 'liquid' value is much larger than
the 'rigid body' value.

(4 marks)

- **The forces of attraction between the particles in a liquid are far less than in a solid.** **1 mark**
- **Hence, the net tidal force required to disintegrate a Moon made of liquid would be much less than for a solid Moon.** **1 mark**
- **Gravitational field strength is inversely proportional to the square of the distance between two bodies.** **1 mark**
- **∴The minimum force required for disintegration can be achieved at a much greater distance from the Moon.** **1 mark**

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Question 17   **(11 marks)**

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

10.0 cm

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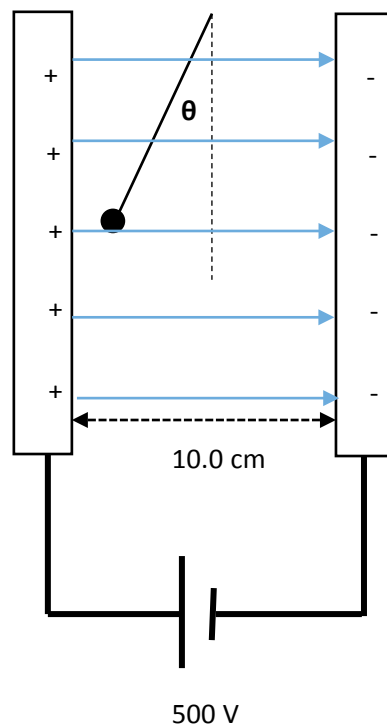
a) On the diagram above, draw the electric field between the charged plates.

(2 marks)

- **Direction of field**   **1 mark**
- **Uniform shape**   **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**

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

(2 marks)

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

$$\therefore F = 1.25 \; x \; 10^{-4} \; N \qquad\qquad\qquad \textbf{1 mark}$$

e) Calculate the size of the angle 'θ'. Show all working. [If you could not calculate an answer for part (d), use F_E = 1.4 x 10^{-4} N].
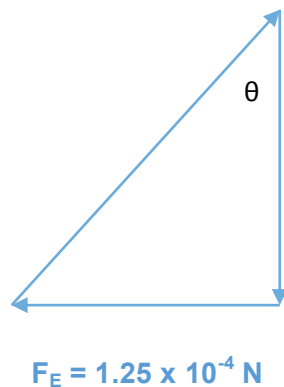
(3 marks)

W = mg

= 0.5 x 10^{-6} x 9.8   • **Weight calculation**

= 4.9 x 10^{-6} N   **1 mark**

(= 0.5 x 10^{-3} x 9.8

= 4.9 x 10^{-3} N)

F_E = 1.25 x 10^{-4} N

$$\tan \theta = \frac{1.25 \; x \; 10^{-3}}{4.9 \; x \; 10^{-6}} \qquad \textbf{1 mark}$$

$$\theta = 90^{o} \; or \; 1.46^{o} \qquad\qquad \textbf{1 mark}$$

Question 18   **(13 marks)**

The diagram below shows the structure of a simple AC generator.
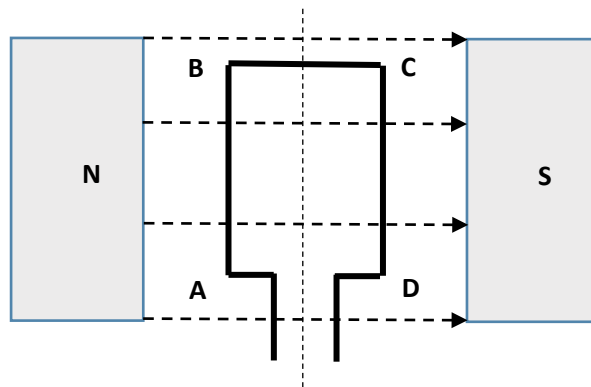
The coil ABCD consists of 30 turns, is pivoted around its central axis, and has dimensions AB = CD = 20.0 cm and AD = BC = 10.0 cm. It lies in a uniform magnetic field of strength 0.400 T. At the moment in time shown, side AB is rotating in an **upwards direction**.

a) As the coil rotates from this position, an emf is induced. In which direction is this induced emf – ABCD or DCBA?

(1 mark)

ANSWER: **ABCD**   **1 mark**

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

b) (i) 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.

c)   (5 marks)

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

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

$= -15.1\ V$ **1 mark**

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

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

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

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

SEE NEXT PAGE

c)   The generator needs to work harder when it is connected to a circuit – explain why.

(2 marks)

- **As the coil rotates, the induced emf and current will oppose the rotation of the coil (Lenz's Law).   1 mark**

- **Therefore, the rate of change of flux and through the coil and, hence, the size of the induced emf is reduced.   1 mark**

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

d)   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.

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

SEE NEXT PAGE

Question 19   **(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 a radius of about 2.5×10^{20} m (about 26000 light years); its average orbital speed is about 2.2×10^5 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**

$$T = \frac{2\pi \times 2.5 \times 10^{20}}{2.2 \times 10^5}$$ **1 mark**

$$\therefore T = 7.14 \times 10^{15} \, s$$ **1 mark**

$$= 2.26 \times 10^8 \, years$$ **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**

$$\therefore g = \frac{(2.2 \times 10^5)^2}{2.5 \times 10^{20}}$$ **1 mark**

$$= 1.94 \times 10^{-10} \, Nkg^{-1}$$ **1 mark**

c) 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 and Milky Way's centres of mass. Use the data provided and answers calculated thus far to show that the mass of our galaxy inside our Sun's orbit must be about 1.8×10^{41} kg. [If you could not calculate an answer to part a), use 7×10^{15} s; if you could not calculate an answer to part b), use 1.9×10^{-10} Nkg^{-1}]

(3 marks)

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

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

$$\therefore m = 1.81 \times 10^{41} \, kg$$ **1 mark**

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

(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**

e) The mass of the Milky Way inside our Sun's orbit is about $1.8\ x\ 10^{41}$ kg – which is about 10^{11} times the mass of our Sun. However, when scientists estimate the mass of the **visible matter** inside the Sun's orbit it only comes to about 10^{10} times the mass of our Sun.

i)   What does this imply about the types of matter in our Galaxy?   (2 marks)

- **Implies that a significant amount of matter in the Milky Way galaxy is NOT visible.**

  1 mark

- **Even though it is invisible, this matter still exerts gravitational force on other matter in the universe.**   **1 mark**

ii)   If the mass of our galaxy was only 10^{10} times the mass of our Sun, describe one (1) effect this would have on our Sun's motion.

(1 mark)

- **If mass was only 10^{10} times the mass of our Sun, then the following changes would occur to the Sun's orbit:**

  Decrease in orbital velocity; increase in orbital period.   **1 mark**

SEE NEXT PAGE

**Question 20**   **(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 roll freely down the slope on some conducting rails (friction was assumed to be insignificant in this activity).

A magnetic field was acting at right angles to the slope; hence, an emf was induced in the rod as it rolled 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.

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
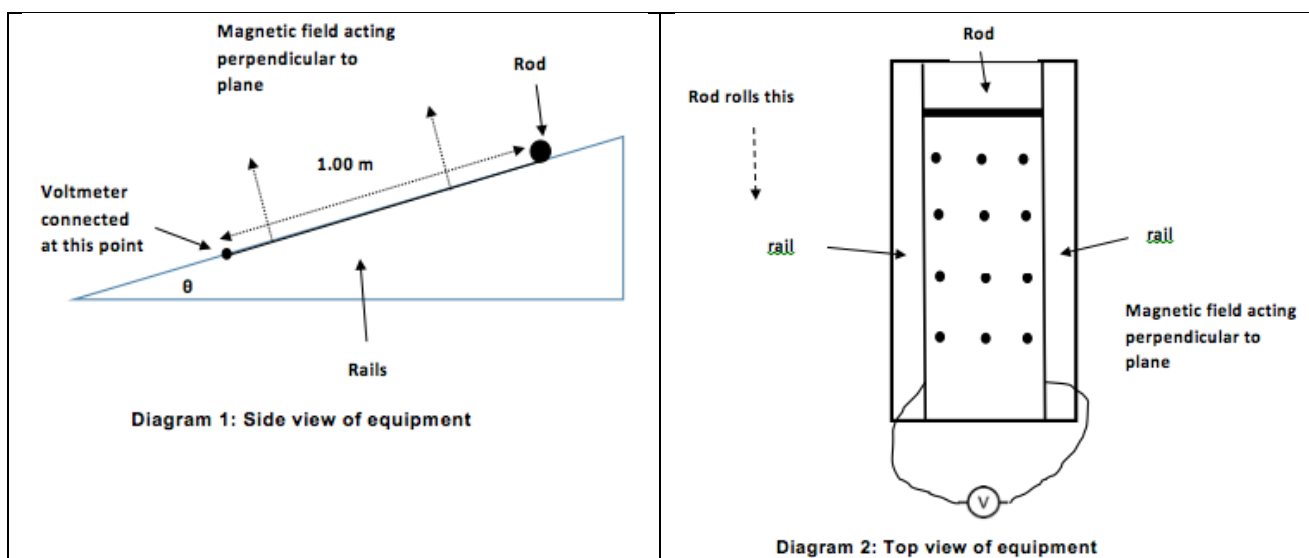
The following parameters were measured by the students:

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

Distance rolled down the inclined plane, s = 1.00 m

Mass of rod, m = 45.0 g

Magnetic field strength, 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:

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

SEE NEXT PAGE

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:

$$v = \sqrt{2\,s\,g\sin\theta}$$

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 rolled 1.00 m down the slope is given by the expression (remember that l = 10.0 cm; and B = 0.500 T):

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

(3 marks)

$emf = lvB;\ V_{MAX} = 0.1\,x\,\left(\sqrt{2\,x\,1.00\,x\,g\,\sin\theta}\right)x\,0.5$

$V_{MAX} = 0.05\sqrt{2\,x\,g\,\sin\theta}$ **1 mark**

$(V_{MAX})^2 = 2.5\,x\,10^{-3}\,x\,2g\,\sin\theta$ **1 mark**

$(V_{MAX})^2 = 0.005\,g\,\sin\theta$ **1 mark**

The students collect some 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	$(V_{MAX})^2$ (x 10^{-3} V^2)	V_{MAX} (x 10^{-2} V)
10º	0.17	6.08	7.80
20º	0.34	12.0	11.0
30º	**0.50**	17.5	**13.2**
40º	0.64	22.5	15.0
50º	0.77	26.8	16.4
60º	**0.87**	**30.3**	17.4
70º	0.94	32.9	18.1

$\sin 30^o\ and\ \sin 60^o$ $1\ mark;$ $13.2\,x\,10^{-2}\,(V_{MAX})$ $1\ mark;$ $30.3\,x\,10^{-3}$ $1\ mark$

(3 marks)

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

c) On the grid provided on the next page, draw a graph of 'sin θ' v '(V_MAX)^2'. Place 'sin θ' on the horizontal axis. Draw a line of best fit through the data.

(4 marks)

Axes labelled correctly   **1 mark**
Correct units for (V_MAX)^2   **1 mark**
Points plotted correctly   **1 mark**
Line of best fit   **1 mark**

d) (i) Find the slope of your line of best fit. Include units.

(3 marks)

$$Slope = \frac{(30 \times 10^{-3} - 4 \times 10^{-3})}{(0.88 - 0.11)}$$ **uses points from graph**   **1 mark**

$$= 0.0334 \ V^2$$ **answer**   **1 mark**

   Correct units   **1 mark**

(ii) Use your value from d) (i) to calculate an experimental value for the value of 'g'. Show working.

(2 marks)

$(V_{MAX})^2 = 0.005 \ g \ \sin\theta; \ \therefore (V_{MAX})^2 / \sin\theta = 0.005 \ g = 0.0344$ **1 mark**

$\therefore g = \frac{0.0344}{0.005} = 6.75 \ ms^{-2}$ **1 mark**

e) Compare this experimental value for 'g' to the accepted value of 9.80 ms^{-2}. 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 accelerates down the slope, the induced emf and current creates a magnetic force on the rod.**

   1 mark

- **According to Lenz's Law, this force opposes the motion of the rod.**

   1 mark

- **Hence a_SLOPE < g.**

   1 mark

- **NOTE – if an answer does not explain the above successfully BUT discusses friction or any other reasonable answer for the reduced value (eg – shape of the rod) award 1 mark ONLY.**
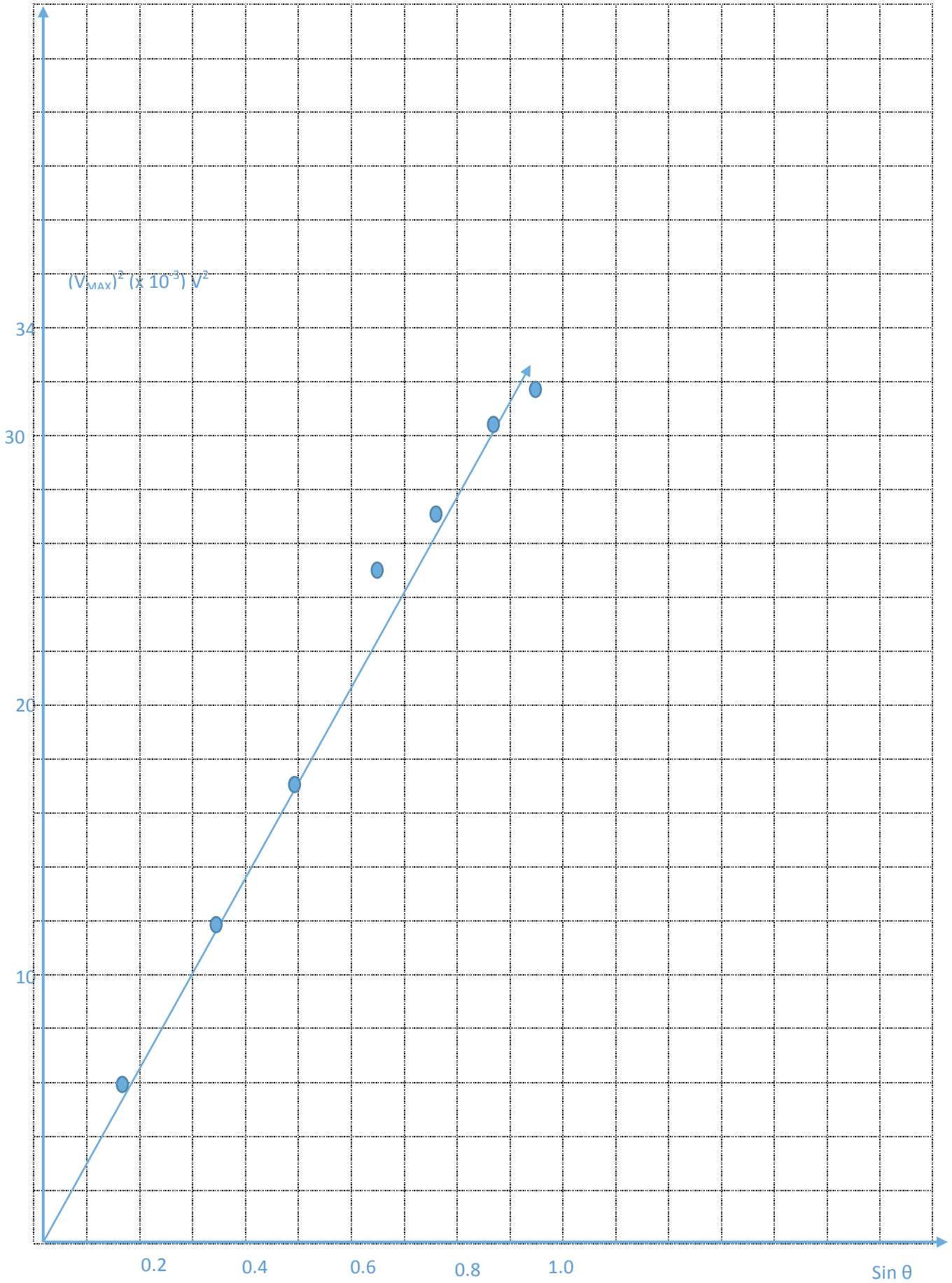
Section Three: Comprehension and Data Analysis   **20% (36 Marks)**

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?"

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.

Let's say you want to go back in time and prevent Kirk from dying on the Enterprise B.

You could use a slingshot maneuver. You'd want to be careful that you don't accidentally create an alternate reality future where the Earth has been assimilated by the Borg, because Kirk wasn't in the Nexus to meet up with Professor Picard and Sir Iandalf Magnetopants, while they having the best time ever gallivanting around New York City.

sigh Ah, man. I really love those guys. What was I saying? Oh right. One of the best ways to increase the speed of a spacecraft is with a gravitational slingshot, also known as a gravity assist.

There are times that fantasy has bled out too far into the hive mind, and people confuse a made up thing with an actual thing because of quirky similarities, nomenclature and possibly just a lack of understanding.

So, before we go any further a "gravitational slingshot" is a gravity assist that will speed up an actual spacecraft, "slingshot maneuver" is made up bananas nonsense. 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.

SEE NEXT PAGE

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. And Cassini used flybys of Venus, Earth and Jupiter to reach Saturn with an efficient flight path.
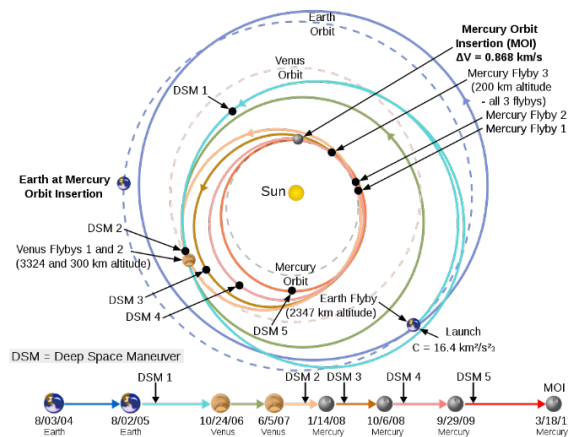
Nature sure is trying to make it easy for us. Gravitational slingshots are an elegant way to slow down spacecraft, tweak their orbits into directions you could never reach any other way, or accelerate to incredible speeds.

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 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."

Voyager (which is not under any external sources of power from engines, thrusters, etc.) needed a minimum speed to escape the Sun's gravity. In terms of the Sun's gravitational force, explain.   (4 marks)

- **Any object trying to 'escape' the Sun will have to overcome its gravitational attraction.**   **1 mark**

- **Due to this gravitational attraction, objects trying to travel away from the Sun will decelerate (ie – speed will decrease).**   **1 mark**

- **If the object's speed reduces to zero, the object will fall back towards the Sun.**

  1 mark

- **If the object's initial speed is large enough, gravity will not be able to reduce it to zero – object will escape.**   **1 mark**

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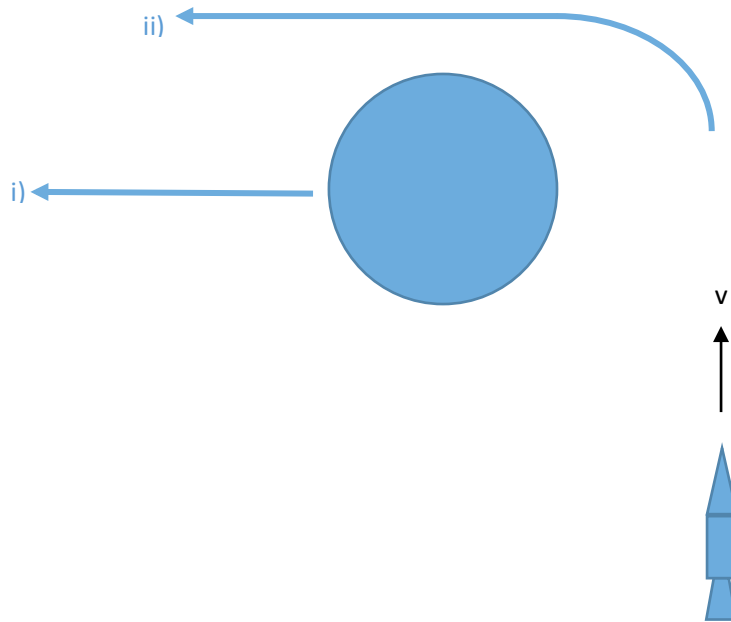

i) On the diagram, indicate with an arrow the direction of the planet's motion around the sun.

(1 mark)

*   **See diagram – arrow points left   1 mark**

ii) On the same diagram you used in part i), draw the path that the spacecraft would take as it passed by the planet. Again, provide a brief explanation for your choice. A vector diagram may aid your explanation.

(5 marks)

*   **See diagram – arrow anticlockwise   1 mark**
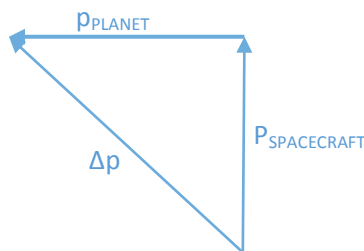
*   **Vector for 'p' of spacecraft 1 mark**
*   **Vector for 'p' of planet 1 mark**
*   **Vector for resultant 'p' 1 mark**

*   **Some momentum from the planet is transferred to the spacecraft, speeding it up.**

1 mark

SEE NEXT PAGE

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 (it is now in orbit around Jupiter). As part of this mission, Juno used the Earth to complete a gravitational slingshot. In completing this maneuver, Juno came to within 560 km of the Earth's surface. If Juno has a mass of 1593 kg, calculate the gravitational force of attraction acting on Juno at this point.

(4 marks)

$$F_g = \frac{Gm_1m_2}{r^2}$$ **1 mark**

$$= \frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24} \times 1593}{(560 \times 10^3 + 6.37 \times 10^6)^2}$$ **2 marks**

$$= 13230 \; N$$ **1 mark**

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 using any Physics concepts you have learned.

(4 marks)

- **A slingshot maneuver involves a transfer of momentum from the planet to the spacecraft.**   **1 mark**

- **The spacecraft gains momentum from the planet.**   **1 mark**

- **As the spacecraft gains momentum, its speed increases; as the planet loses momentum, it loses speed.**   **1 mark**

- **As the planet loses speed, its orbital radius decreases.**   **1 mark**

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.

SEE NEXT PAGE

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.

Voltage is King

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. 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

There is a limit though, to how high of a voltage your system would still see benefit. Above 100 kilovolts or so, corona loss, due to the high voltage ionizing air molecules begins to occur. These days, high DC voltage levels can be attained more easily with new technology employing small, high-frequency switching converters. A traditional bugbear for early DC transmission efforts included lightning strikes and other insults which would wreak havoc if not quickly isolated. New switches to handle these situations have recently been developed.

Paragraph 7

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

SEE NEXT PAGE

Paragraph 8

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)

- **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

- **With AC power, the transmission voltage is lower than an equivalent DC voltage for large portions of each cycle.**

  1 mark

- **Hence, for large portions of each cycle, the transmission current and accompanying power losses are higher for AC power than DC power.**

  1 mark

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

(2 marks)

- **Traditional power generation is also AC.**   **1 mark**

- **The most common form of commercial motor is the AC induction motor.**

  1 mark

- **NOTE – need some flexibility here; there are many other reasons for using AC power; anything reasonable needs to be considered on its merits.**

"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)

$$I = \frac{P}{V} = \frac{200 \times 10^6}{330\,000} = 606\ A \qquad \textbf{1 mark}$$

(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 c) (i), use value of 600 A]

(4 marks)

$$P_{loss} = I^2 R = 606^2 \times 10 \qquad \textbf{1 mark}$$

$$= 3.67 \times 10^6\ W \qquad \textbf{1 mark}$$

$$V_{drop} = IR = 606 \times 10 \qquad \textbf{1 mark}$$

$$= 6060\ V \qquad \textbf{1 mark}$$

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

(2 marks)

$$P_d = 200 \times 10^6 - 3.67 \times 10^6 = 1.96 \times 10^8\ W \qquad \textbf{1 mark}$$

$$\%\ efficiency = \frac{1.96 \times 10^8}{200 \times 10^6} \times 100\% = 98.2\% \qquad \textbf{1 mark}$$

c) 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**

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

(2 marks)

- **For large portions of the AC cycle, the current flowing is well below that in an equivalent DC power supply. Hence, during an electric shock, the muscles relax long enough for you to release and pull away,**

1 mark

- **In DC power, a high current remains at that high, constant value.**

1 mark

End of Section 3

Additional working space

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End of Section 3

SEE NEXT PAGE

Additional working space

Additional working space

Additional working space

Additional graph if required.

End of examination