PHYSICS

YEAR 12

UNIT 3

Insert School Logo

SOLUTIONS

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	11	11	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 2019.* 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 **eleven (11)** 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 ammeter was used to measure the current flowing in a DC motor. When the motor is operating normally with the rotor coil rotating freely, the current measured is 2.50 A. However, when the rotor coil is prevented from rotating, this measured current increases sharply to 4.05 A. Explain this observation (no calculations are necessary).

(4 marks)

When the motor is operating normally with the rotor coil rotating freely, a back EMF (V_{BACK}) is induced in the coil.	1 mark
Hence the voltage around coil (V_{COIL}) would be equal to: $V_{COIL} = EMF - V_{BACK} (EMF = external\ power\ source)$ $\therefore V_{COIL} < EMF$	1 mark
When the coil stops rotating, the back EMF (V_{BACK}) reduces to zero; hence, $V_{COIL} = EMF$.	1 mark
The increase in the coil voltage (V_{COIL}) will be associated with a corresponding increase in the coil's current.	1 mark

Question 2

The diagram below shows two planets 'X' and 'Y' which have masses of 'm' and '5m' respectively.

[The measurements described in this question for Planet 'X' and Planet 'Y' are made independently of each other]

Planet 'X'
with a
mass of 'm'   d

Planet 'Y'
with a
mass of
'5m'   d
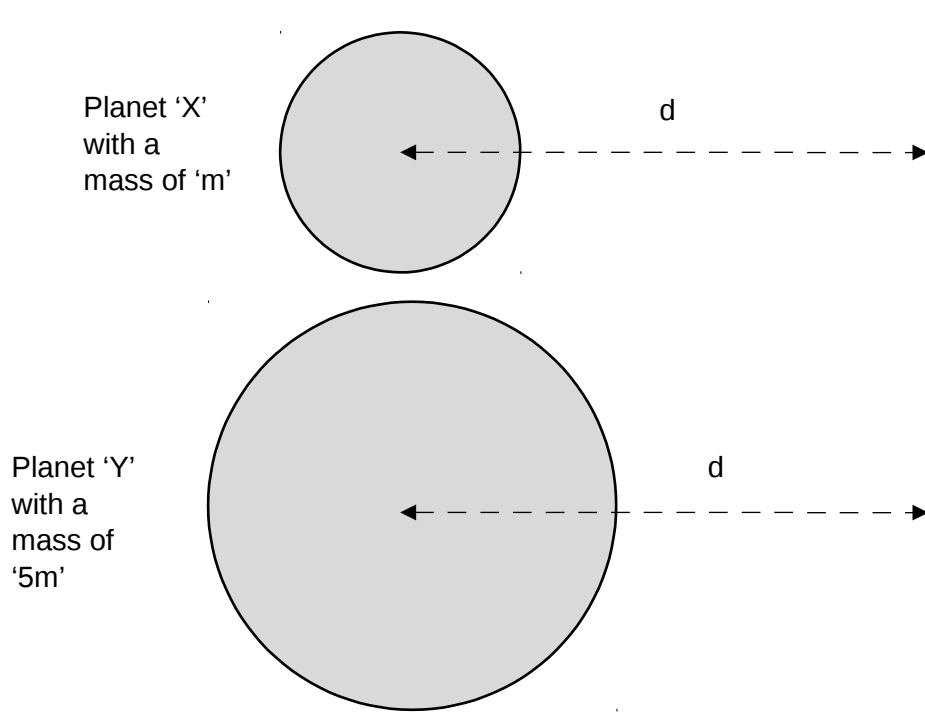
The gravitational field strength is measured at a distance 'd' from each planet's centre of mass (as shown). The gravitational field strength due to Planet X at distance 'd' is measured to be 2.5 ms⁻². Calculate the gravitational field strength at distance 'd' from Planet Y.
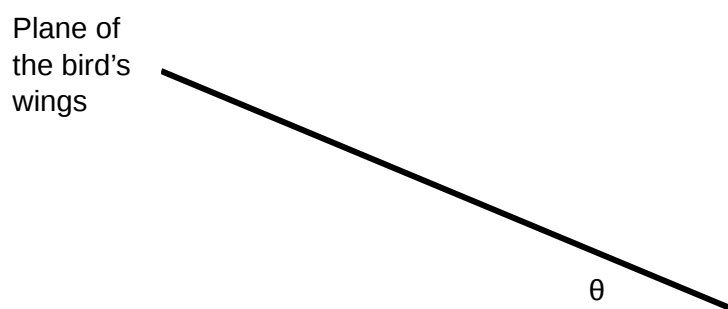
(4 marks)

$Planet\ 'X':g=\dfrac{Gm_X}{r^2}; 2.5=\dfrac{Gm}{d^2}; Planet\ 'Y':g=\dfrac{Gm_Y}{r^2}; g_Y=\dfrac{G\times 5m}{d^2}$	1 mark
$\therefore \dfrac{2.5}{g_Y}=\dfrac{\dfrac{Gm}{d^2}}{\dfrac{G\times 5m}{d^2}};$	1 mark
$\dfrac{2.5}{g_Y}=\dfrac{m}{5m}=0.2$	1 mark
$\therefore g_Y=12.5\,ms^{-2}$	1 mark

Question 3

A bird is able turn in a circular path of radius 'r' at a particular speed 'v' by banking its wings at an angle (θ) to the horizontal towards the centre of this path. See below.

Plane of
the bird's
wings

θ

Explain why the angle of banking 'θ' of the bird needs to increase if the radius of its circular path decreases while maintaining the same air speed (v). Include an appropriate mathematical expression and a vector diagram to aid your answer. You can assume that any lift forces are perpendicular to the plane of the bird's wings.
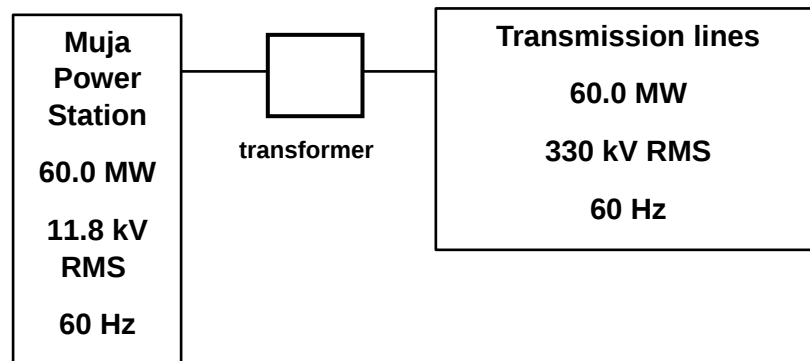
(4 marks)

θ N W = mg $F_c = mv^2/r$	1 mark
$\tan\theta = \dfrac{F_c}{W}$	1 mark
$\therefore \tan\theta = \dfrac{\dfrac{mv^2}{r}}{mg} = \dfrac{v^2}{gr}$	1 mark
Hence, if 'v' is constant and 'r' is decreased, 'tan θ' and 'θ' must be increased.	1 mark

Question 4

The generator at the Muja Power Station generates electric power at 60 MW, 11.8 kV RMS. This power is then stepped up by a transformer to a transmission voltage of 330 kV RMS.

Muja Power Station 60.0 MW 11.8 kV RMS 60 Hz	transformer	Transmission lines 60.0 MW 330 kV RMS 60 Hz

a) Calculate the turns ratio for the step-up transformer described above.

(2 marks)

Ideal transformer turns ratio: $\dfrac{V_P}{V_S} = \dfrac{11800}{330000}$	1 mark
= 0.0358	1 mark

b) In the scenario described above, the data indicates an 'ideal' transformer. In reality, no transformer is 'ideal'. Explain. In your answer, describe one (1) factor that prevents the existence of 'ideal' transformers.

(4 marks)

Ideal transformer, assumes no power losses in the transformer: ie, $P_{PRIMARY} = P_{SECONDARY} = 60.0$ MW.	1 mark
In reality, there are power losses in transformers.	1 mark
Describes one type of power loss – eg, heat loss in coils due to resistance; back emf in coils; eddy currents in iron cores of transformer; etc.	1 mark
$\therefore$ in reality, $P_{PRIMARY} > P_{SECONDARY}$ due to these heat losses.	1 mark

Question 5

Estimate the minimum horizontal force required to tip over a fully-filled 1 litre Coke bottle with a base width of about 7 cm and a height of about 30 cm. Clearly state any assumptions you make while answering this question. Draw any appropriate forces and distances on the diagram.
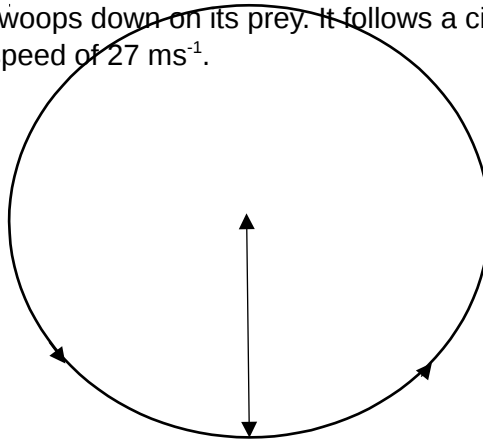
(4 marks)

Assume height of bottle is 30cm; width of bottle is 7 cm; and the bottle and its contents are uniform with a mass of 1 kg (accept between 750g and 1.1 kg).	1 mark
Take moments about 'P'; bottle begins to tip over when $\Sigma M_C = \Sigma M_A$.	1 mark
$\therefore F_H \times 0.30 = 1 \times 9.8 \times 0.035$	1 mark
$accept\, 0.8$ $F_H = 1.1\, N\, (1.3\, N\, ; must\, be\, ¿\, 1 \vee 2\, significant\, figures)$	1 mark

Question 6

An eagle of mass 55 kg swoops down on its prey. It follows a circular arc of radius 87 m and is travelling at a top speed of 27 ms^{-1}.

a)   Ignoring air resistance, calculate the maximum force experienced by the eagle's wings as it catches its prey.   r = 87 m

(3 marks)

$At\ lowest\ point\ of\ arc\ ,F_{WINGS}=\dfrac{mv^2}{r}+mg$	1 mark
$F_{WINGS}=\dfrac{55\times 27^2}{87}+55\times 9.80$	1 mark
$¿\ 1.00\times 10^3\ N$	1 mark

b)   Clearly state the point at which this maximum force occurs.

(1 mark)

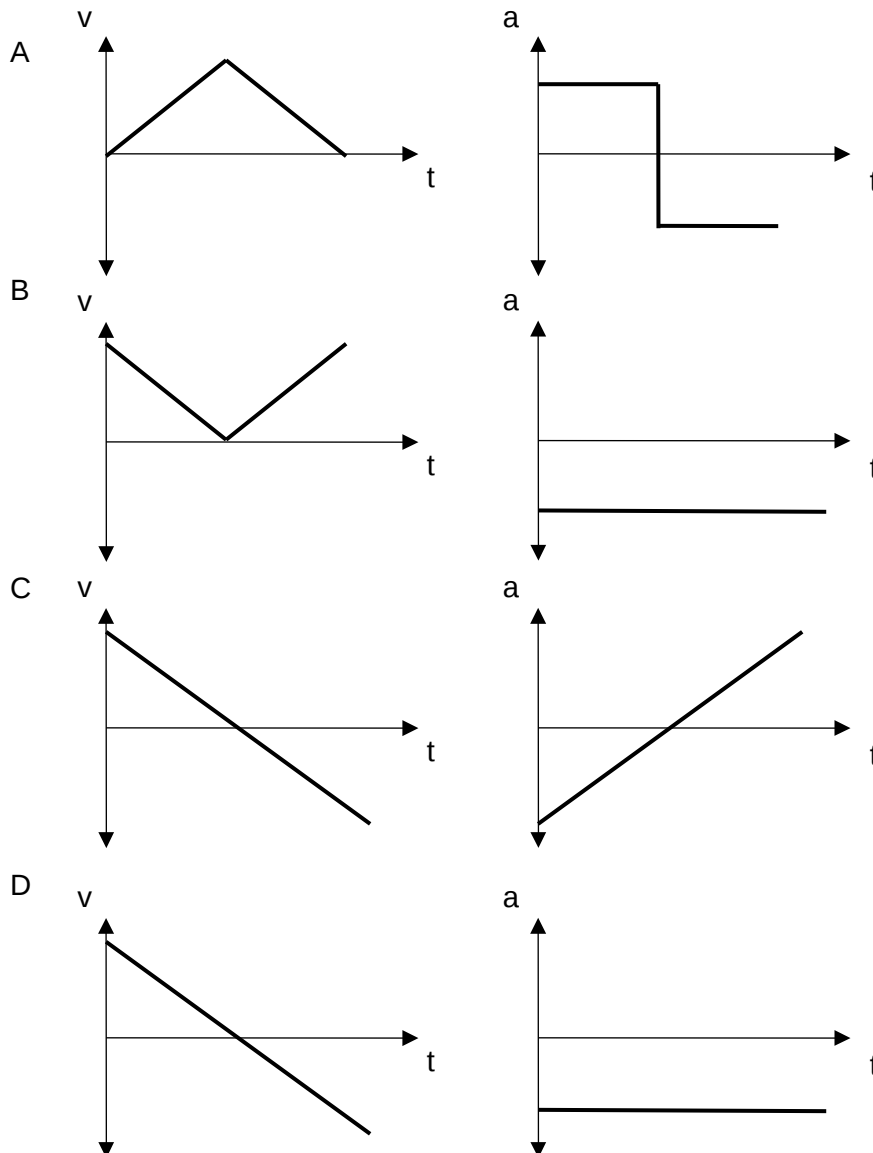|	
Maximum force occurs at the lowest point of the arc.	1 mark

Question 7

A projectile is fired upwards at an angle to the horizontal and lands at the same height from which it is launched.

a)   Which pair of graphs best describes:

        (i)   the vertical component of the projectile's velocity (v); and
        (ii)   the projectile's acceleration (a)
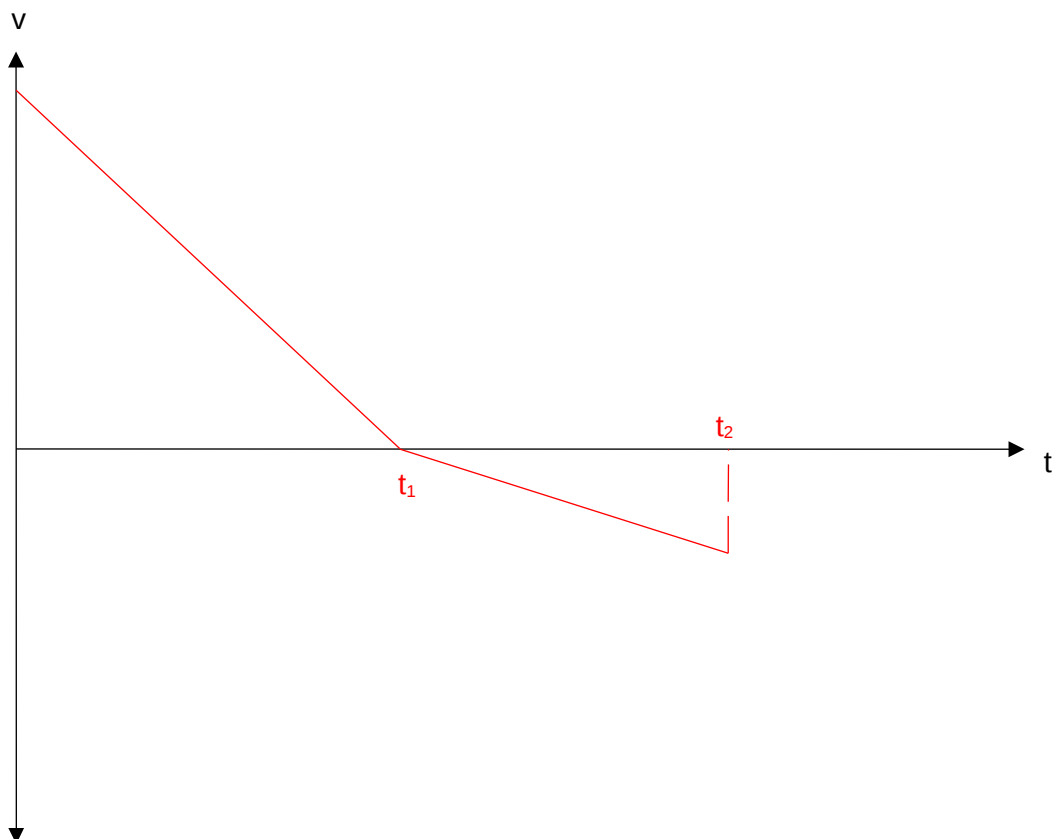
        as a function of its flight time (t).

(2 marks)

ANSWER: _____

D	2 marks

b)   On the axes below, **sketch** a graph for the vertical component of the projectile's velocity (v) as a function of its flight time (t) **when air resistance is taken into account.** No values need to be written – but relative sizes of quantities must be shown.

(3 marks)

General shape of graph shown – upward part of flight is positive 'v'; downward part of flight is negative 'v' (or vice versa). Curve is acceptable. Final speed at $t = t_2$ is less than initial speed at $t = 0$.	1 mark
Slope of line for upward part of flight ($t = 0$ to t_1) is steeper than the slope of line for downward part of flight ($t = t_1$ to t_2). Curves are acceptable.	1 mark
Time for upward path ($t = 0$ to t_1) for time for downward path ($t = t_1$ to t_2).	1 mark

SEE NEXT PAGE

Question 8

A pair of parallel metal plates, placed in a vacuum, are separated by a distance 4.00 mm and have a potential difference of 1200 V applied between them.

a)   Calculate the magnitude of the electric field between the two plates.

(2 marks)

$E=\dfrac{V}{d}; \quad \therefore E=\dfrac{1200}{4.00\times 10^{-3}}$	1 mark
$\therefore E=3.00\times 10^{5}V\,m^{-1}$	1 mark

b)   Calculate the magnitude of the electrostatic force acting on an electron placed between the plates.

(2 marks)

$E=\dfrac{F}{q}; \therefore F=Eq=3.00\times 10^{5}\times 1.60\times 10^{-19}$	1 mark
$.80\times 10^{-14}N$	1 mark

A beam of electrons is fired between the plates at a speed of 4.50×10^{6} ms^{-1} in the direction shown.

electron
beam

1200 V
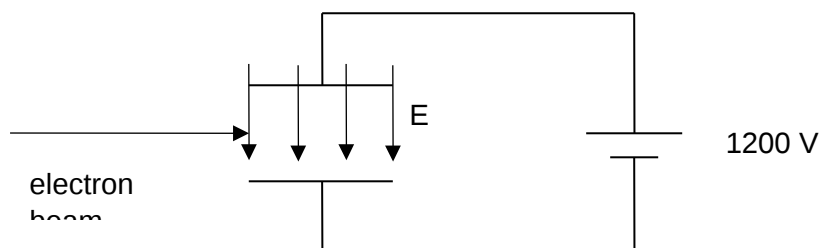
A magnetic field is applied to the electron beam sufficient to allow the electron beam to pass between the plates without deviating.

c)   On the diagram, indicate the direction of this magnetic field.

(1 mark)

'B' is into the page.	1 mark

SEE NEXT PAGE

d)   Hence, calculate the magnitude of the magnetic field required.

(2 marks)

$F=Bvq \; ; \therefore B=\dfrac{F}{vq} \; ; \therefore B=\dfrac{4.80 \times 10^{-14}}{4.50 \times 10^{6} \times 1.60 \times 10^{-19}}$	1 mark
$¿ 6.67 \times 10^{-2} T$	1 mark

Question 9

A motorbike and rider have a combined mass 325 kg. They are travelling on a road banked at an angle of 32.0° to the horizontal. A force equal to 3000 N up the plane is applied by the engine to the motorbike. Calculate the magnitude of the net acceleration experienced by the motorbike.
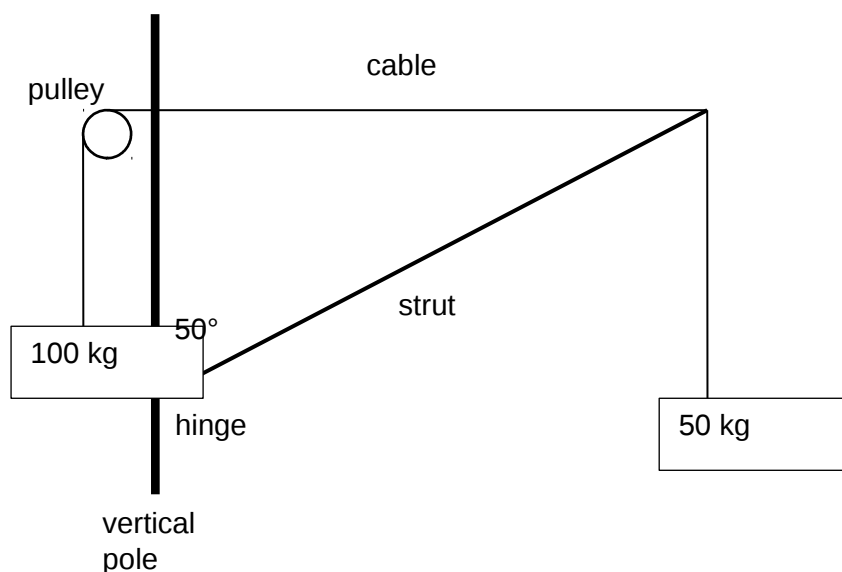
(4 marks)

$Force\,down\,the\,slope \left(F_s \right):$ $F_S=mg\sin\theta=325 \times 9.80 \times \sin 32.0^{\circ}$	1 mark
$\therefore F_S=1.69 \times 10^{3} N$	1 mark
$Force\,up\,slope \left(F_{UP} \right)=3000\,N$ $\therefore \Sigma F=3000-1.69 \times 10^{3}=1.31 \times 10^{3} N$	1 mark
$\Sigma F=ma \; ; \therefore a=\dfrac{\Sigma F}{m}=\dfrac{1.31 \times 10^{3}}{325}=4.04\,ms^{-2}$	1 mark

Question 10

The diagram below shows a pulley system designed to raise a mass. At the instant shown, the system can be considered to be in equilibrium.

cable

pulley

strut

50°

100 kg

hinge

50 kg

vertical
pole

The strut is uniform and is 2.00m in length; it is attached to a vertical pole by a hinge; and it forms an angle of 50° with the vertical pole as shown. A 50.0kg mass is suspended from the end of the strut as shown. The strut is held in place by a cable attached to its end; the cable runs over the pulley and has a 100kg mass attached to it as shown in the diagram. The length of cable between the pulley and the end of the strut is horizontal.

a)　　Calculate the mass of the strut.

(3 marks)

|	
Take moments out about $_\square P' : \Sigma M = 0$ $100 \times 9.8 \times 2.00 \times \sin 40° = m \times 9.80 \times 1.00 \times \sin 50° + 50 \times 9.80 \times 2.00 \times \sin 5($	1 mark
$1260 - 751 = 7.51 \times m$	1 mark
$\therefore m = 67.8\,kg$	1　mar k

b)   The strut is hinged at its contact with the vertical pole. Hence, it can rotate and
        change the size of the angle of 50°. The 100 kg mass is increased in size. In words,
        explain what happens to the magnitude of angle between the strut and the vertical
        pole.

(3 marks)

Increasing the mass to 150kg increases the size of the anticlockwise moments around the hinge.	1 mark
Hence, the clockwise moments around the hinge must increase proportionally.	1 mark
Given that other dimensions will not change, this can only be achieved by the prescribed angle decreasing below 50° and the complementary angle increasing above 40°.	1 mark

Question 11

An unusual electrical generator consists of a 1.10 m long conducting rod moved with a
constant velocity through a magnetic field of strength 1.30 T. The force required to move the
conductor in this way is equal to 8.90 N. The ends of the conducting rod are connected to a
1.20 Ω resistor. This arrangement is shown below.
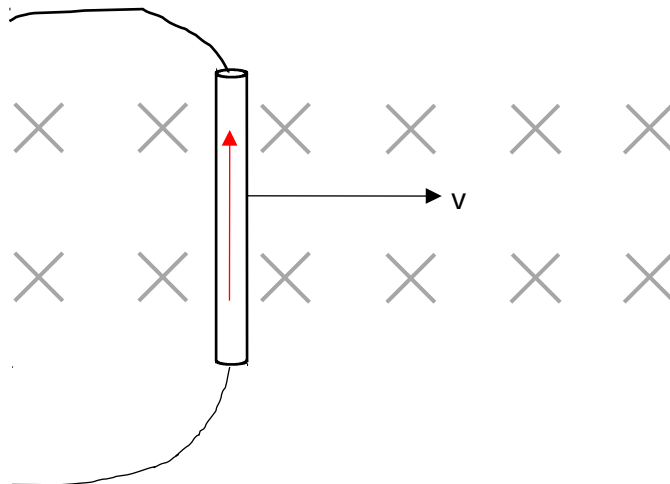
a)   On the diagram, indicate the direction of conventional current in the conducting rod.

(1)

Arrow pointing upwards on conducting rod.	1 mark

b)   Calculate the constant velocity 'v' of the conducting rod.

(5)

$\Sigma F = 0 ; \therefore F_{PULL} = 8.90 = F_B = IBl$;	1 mark
$I = \dfrac{F_B}{Bl} = \dfrac{8.90}{1.30 \times 1.10} = 6.22 \, A$	1 mark
$EMF = IR = 6.22 \times 1.20 = 7.47 \, V$	1 mark
$EMF = lvB ; \therefore v = \dfrac{EMF}{Bl} = \dfrac{7.47}{1.30 \times 1.10}$	1 mark
$¿ 5.22 \, ms^{-1}$	1 mark

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.

- 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 90 minutes.

Question 12   **(14 marks)**

Electric motors are used to do a variety of tasks. One common use is to lift weights (eg – in a crane or a lift). The input into the motor is electrical energy and the output is the work done in lifting the mass (ie – a gain in gravitational potential energy (ΔE_P). A diagram outlining this system is shown below.
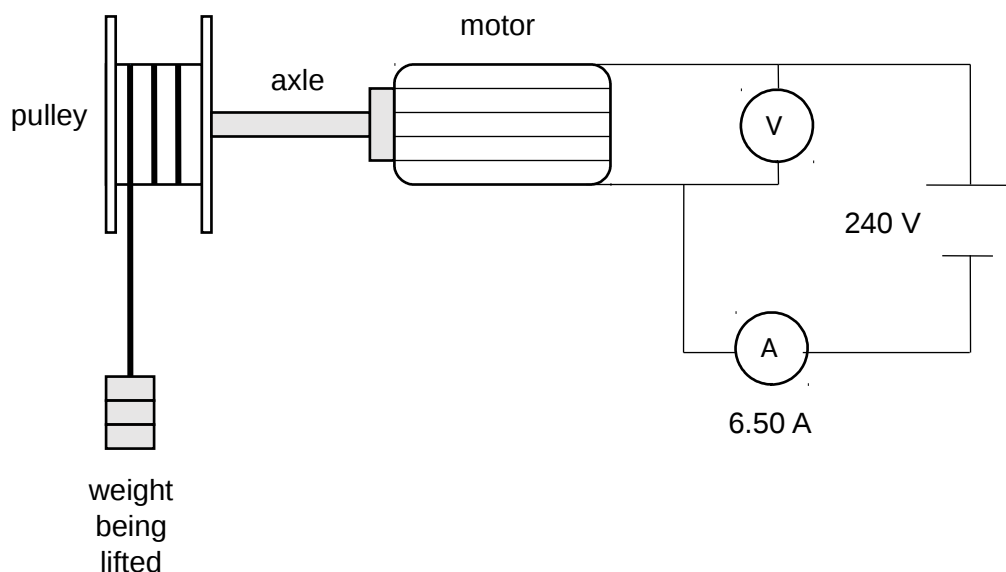
The DC motor operates at a voltage of 240 V and draws a current of 6.50 A. It is able to lift a mass of 30.0 kg through a vertical height of 3.50 m in 1.05 s.

a)　　　Calculate the gain in gravitational potential energy (ΔE_P) experienced by the mass and hence, the rate at which the DC motor does work on the mass

(3)

$\Delta E_P = mg\Delta h = 30.0 \times 9.80 \times 3.50; \therefore \Delta E_P = 1.03 \times 10^3 J$	1 mark
$P = \dfrac{\Delta E_P}{t} = \dfrac{1.03 \times 10^3}{1.05}$	1 mark
$\therefore P = 9.80 \times 10^2 W$	1　mark

b)　　　Calculate the electric power generated by the DC motor and, hence, the percentage efficiency of the electric motor.

[If you were unable to calculate an answer for the rate at which the motor does work on the mass in part (a); use 1.00 x 10³ W]

(3)

$P = VI = 240 \times 6.50$	1 mark
$\therefore P = 1560 W$	1 mark
$\therefore \% efficiency = \dfrac{980}{1560} \times 100 = 62.8\%$	1 mark

SEE NEXT PAGE

The pulley has a diameter of 65.0 cm. The DC motor consists of a rectangular 200 turn coil (ABCD) that has the dimensions shown in the diagram below. The coil lies in a magnetic field of strength 'B' Tesla (see diagram).
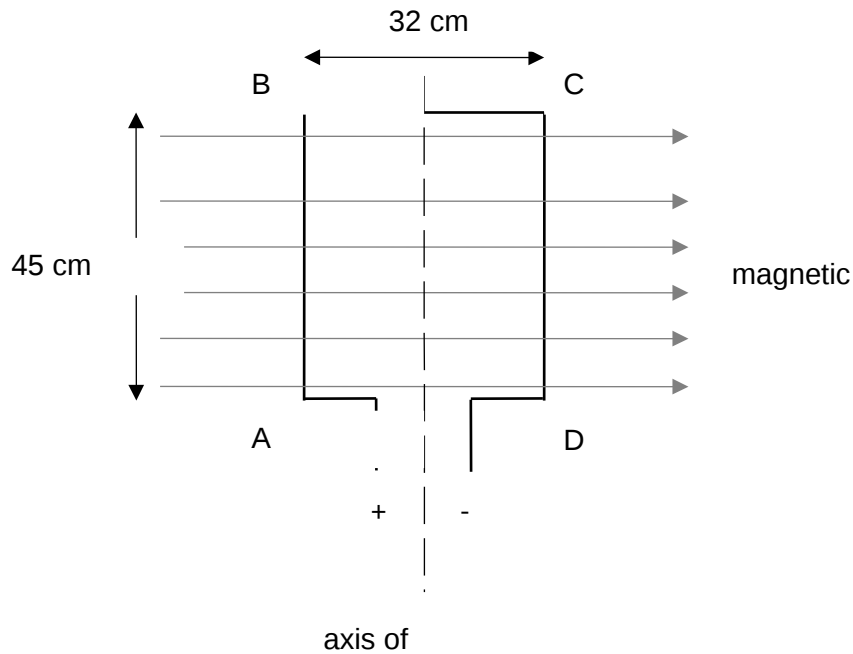
c)   Given the polarity of the current flowing in the coil, state the direction of the magnetic force experienced by:

(2)

(i)   side AB.

Into the page	1 mark

(ii)   Side BC.

| No force exerted | 1 mark |

d)   The DC motor raises the 30.0 kg mass at a constant velocity. Given its dimensions, calculate the maximum torque produced by the DC motor.

(3)

$F=mg=30.0 \times 9.80$	1 mark
$¿294\,N$	1 mark
$\therefore \tau_{max}=294 \times \dfrac{0.65}{2}=95.6\,Nm$	1 mark

e)   Hence, calculate the size of the magnetic field 'B'. [Hint if you were unable to calculate an answer for part (d), use 96.0 Nm]

(3)

$\tau_{max}=IBnA\,;\therefore B=\dfrac{\tau_{max}}{InA}$	1 mark
$¿\dfrac{95.6}{6.50 \times 200 \times 0.32 \times 0.45}$	1 mark
$¿0.510\,T$ (0.577 T)	1 mark

Question 13   **(13 marks)**

A soccer player is shooting at a goal from directly in front of it. The player is 15.0 m from the goal line and kicks the ball with a launch angle of 30.0° to make sure the ball gets over a 'wall' set up by the opposition. The diagram below illustrates this situation. The height of the goal (ie – the crossbar above the ground) is 2.44 m.
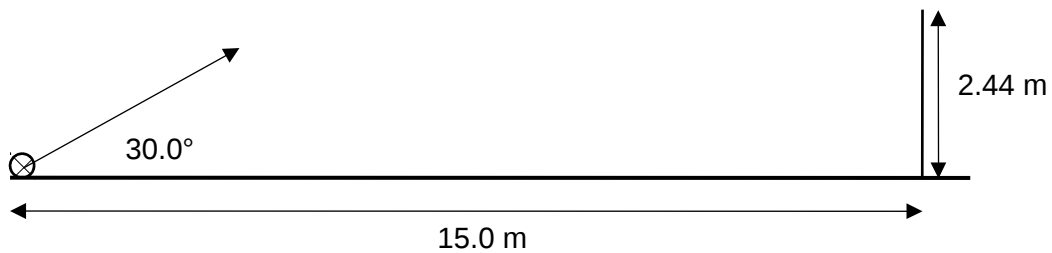
The player is trying to launch the ball with a velocity 'v' that allows it pass under the crossbar. For parts (a), (b) and (c), IGNORE the effects of air resistance.

a)   Write down expressions for the horizontal (u_h) and vertical (u_v) components of the launch velocity in terms of 'u' and 'θ'. Show clearly how you obtained these with a vector diagram.

[4]
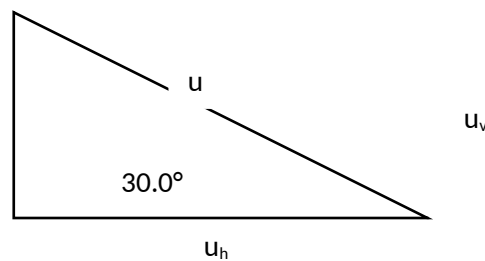
Vector diagram drawn correctly (see above).	1 mark
$\dfrac{u_v}{u}=\sin 30.0°$	1 mark
$\therefore u_v=u\sin 30.0°$	1 mark
$30.0°; \therefore u_h=¿ u\cos 30.0°$ $\dfrac{u_h}{u}=\sin ¿$	1 mark

b)   Using horizontal components, show that the mathematical expression for the time taken for the ball to reach the goal line is:

$$t = \frac{17.3}{u}$$

(3)

$v = \frac{s}{t}$; $\therefore t = \frac{s}{v}$	1 mark
$t = \dfrac{15.0}{u\cos 30.0°}$	1 mark
$\therefore t = \dfrac{17.3}{u}$	1 mark

c)   Using the expression derived in part (b), data from the vertical plane, and an appropriate motion formula, calculate the maximum launch velocity 'v' that allows the ball to pass under the crossbar.

(4)

$u_v = u\sin 30.0°$; $a = -9.80\, ms^{-2}$; $t = \dfrac{17.3}{v}$; $s_v = 2.44\, m$	1 mark
$s = ut + \frac{1}{2}at^2$; $2.44 = (u\sin 30.0°)\left(\dfrac{17.3}{u}\right) + (0.5)(-9.80)\left(\dfrac{17.3}{u}\right)^2$	1 mark
$2.44 = 8.65 - \dfrac{1467}{u^2}$	1 mark
$\therefore u = \sqrt{\dfrac{-1467}{(2.44-8.65)}} = 15.4\, ms^{-1}$	1 mark

d)   If air resistance is taken into account, state how the following would have to change for a successful shot:

(2)

(i)   Launch velocity 'u' if launch angle 'θ' remains at 30°.

'u' must increase.	1 mark

     (ii)   Launch angle 'θ' if the launch velocity 'u' remains at the answer calculated in part (c).

'θ' must increase.	1 mark

Question 14 (15 marks)

The diagram below shows the side-on view of a single drawer in a chest of drawers. The drawer is in an extended, open position and a book has been placed inside it as shown. The drawer is held in place by two identical pieces of wood acting as brackets above and below it. The drawer slides in and out between these two brackets when it is pushed and pulled by its handle. Two points, 'X' and 'Y', are labelled on each bracket as shown.
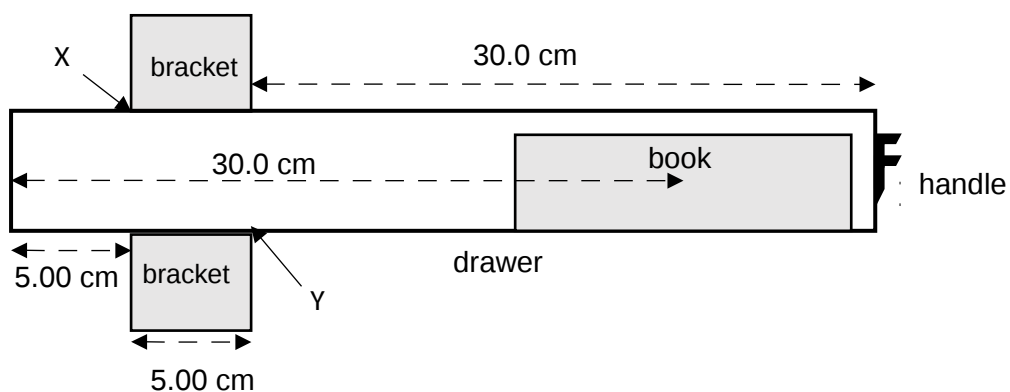
Both the drawer and the book can be considered to be uniform and have masses of 1.20 kg and 0.850 kg respectively. The distance from the left hand edge of the drawer to the centre of mass of the book is measured to be 30.0 cm (as shown). The mass of the handle is insignificant and can be ignored.
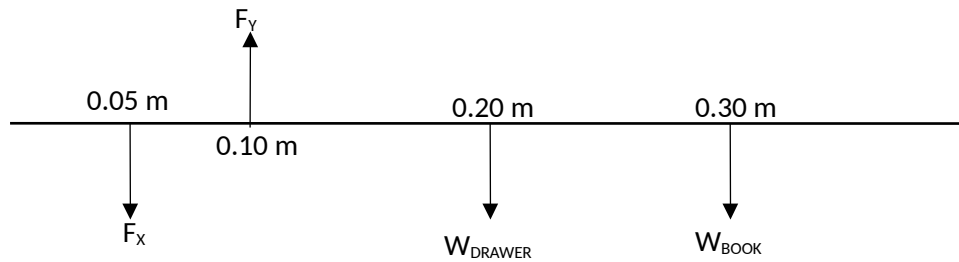
The other significant dimensions in this situation are shown.

In this extended position, the drawer is in equilibrium and stationary. It can also be considered to be horizontal.

a)   In the space below, draw a labelled free body diagram showing all the forces acting on the drawer. Make sure you include 'F$_X$' and 'F$_Y$' – the forces acting at points 'X' and 'Y'.

(4)

F$_x$ shown – correctly labelled.	1 mark
F$_Y$ shown - correctly labelled.	1 mark
W$_{DRAWER}$ shown - correctly labelled.	1 mark
W$_{BOOK}$ shown - correctly labelled.	1 mark

b)   Given that the drawer is in a state of mechanical equilibrium, calculate:

(i)   the magnitude of the force acting at 'X' (ie – F$_X$).

(3)

Take moments about $_\square Y'$; $\Sigma M = 0.$	1 mark
$F_x \times 0.050 = 11.8 \times 0.10 + 8.33 \times 0.20$	2 marks
$\therefore F_X = 56.8\, N$	1 mark

(ii)   the magnitude of the force acting at 'Y' (ie – F$_Y$).

[If you were unable to calculate an answer for part (b) (i), use a value of 58.0 N].

(3)

$\Sigma F = 0$; $\Sigma F_{UP} = \Sigma F_{DOWN}$	1 mark
$56.9 + 11.8 + 8.3 = F_Y$	1 mark
$F_Y = 76.9\, N \left(\unicode{191} 78.1\, N \right)$	1 mark

SEE NEXT PAGE

c)   The drawer is slowly pushed back into its unextended position within the chest of
        drawers by being pushed towards the left by the handle. Describe how the magnitude
        of forces at 'X' and 'Y' (ie - 'F_X' and 'F_Y') will change as this drawer is pushed back to
        its unextended position. Explain your answer.

(5)

|	
F_X decreases.	1 mark
ΣCWM due to weight of book and drawer decreases; distance of F_X to 'Y' (pivot) does not change.	1 mark
Distance of F_X to 'Y' (pivot) does not change.	1 mark
F_Y decreases.	1 mark
As F_X decreases, $\Sigma F_{DOWNWARDS}$ decreases; hence, $\Sigma F_{UPWARDS}$ (ie – F_Y) decreases.	1 mark

Question 15   **(18 marks)**

A single coil is placed at a distance 'd' from a current-carrying conductor as shown below. Conventional current (I) is flowing in the straight conductor as indicated in the diagram.

The coil is small enough to assume that the magnetic flux density due to the conductor contained within its area is CONSTANT.
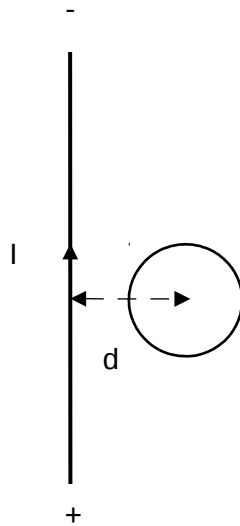
The coil has a radius of 1.00 cm and its centre is positioned at a distance (d) of 5.00 cm from the conductor. The conductor initially carries a current (I) of 0.450 A.

a)   Calculate the magnetic field strength at the centre of the coil.

(3)

$B = \dfrac{\mu_o\, I}{2\pi\, r}$	1 mark
$\therefore B = \dfrac{2 \times 10^{-7} \times 0.450}{0.050}$	1 mark
$\therefore B = 1.80 \times 10^{-6}\, T$	1 mark

b)   Given the assumption described above regarding the magnetic field strength within the area of the coil, calculate the total magnetic flux contained within the coil.

(3)

$\varnothing = BA \; ; \therefore \varnothing = 1.80 \times 10^{-6} \times \pi \times 0.010^2$	2 marks
$\therefore \varnothing = 5.65 \times 10^{-10} \, Wb \, (if \, B = 1.90 \times 10^{-6} \, T , \varnothing = 5.97 \times 10^{-10} \, Wb)$	1 mar k

c)   The current (I) in the conductor is now increased to 0.650 A in a time of 0.750 s. The coil remains in the same position (ie – its centre remains 5.00 cm from the conductor). Calculate the average EMF generated in the coil during this time. [If you were unable to calculate an answer for part (b), use an answer of 6.00 x 10⁻¹⁰ Wb]

(5)

$When \, I = 0.450 \, A , \varnothing_1 = 5.65 \times 10^{-10} \, Wb \, (6.00 \times 10^{-10} \, Wb)$ $When \, I = 0.650 \, A , B = \dfrac{2.00 \times 10^{-7} \times 0.650}{0.050} = 2.60 \times 10^{-6} \, T$	1 mark
$\therefore \varnothing_2 = BA = 2.60 \times \pi \times 0.010^2 = 8.17 \times 10^{-10} \, Wb$	1 mark
$\therefore \Delta\varnothing = \varnothing_2 - \varnothing_1 = 8.17 \times 10^{-10} - 5.65 \times 10^{-10} = 2.52 \times 10^{-10} \, Wb \, (2.$	1 mark
$\therefore AVERAGE \, EMF = \dfrac{-N \, \Delta\varnothing}{t} = \dfrac{-1 \times 2.52 \times 10^{-10}}{0.750}$	1 mark
$¿ -3.36 \times 10^{-10} \, V \, (-2.89 \times 10^{-10} \, V)$	1 mark

SEE NEXT PAGE

d)   On the diagram on the previous page indicate: (i) the direction of the magnetic field
        due to the current-carrying conductor INSIDE the coil; and (ii) state the direction (ie –
        clockwise or anticlockwise) of the induced current in the coil.

                                                                                                (2)

(i) Into the page.	1 mark
(ii) Anticlockwise.	1 mark

e)   As the current in the conductor is increased, it is possible to move the coil in a way
        where NO (zero) EMF is induced. Explain how the coil must be moved so that no
        EMF is induced.

                                                                                                (5)

| For NO EMF to be induced, $\Delta\Phi = 0$.	1 mark
As 'I' increases, 'B' at every point around the conductor increases proportionally.	1 mark
As 'r' increases, 'B' at every point decreases proportionally.	1 mark
Hence, over the 0.750 s that 'I' increases, the coil can be moved away at such a rate that 'B' remains constant within the coil at every point. OR Coil can be rotated in a way that its area perpendicular to field is reduced; $\Delta\phi \propto A$.	1 mark
Hence, $\Delta\Phi$ remains at zero.	1 mark

Question 16 **(14 marks)**

NASA astronauts need to train to operate in the weightless conditions they experience when they are in orbit around the Earth. A specially designed aeroplane called G-FORCE-ONE (known as a ZERO-G plane) is employed to do this training.

a)   Explain why astronauts in orbit experience weightlessness. As part of your response, answer this question: are the astronauts actually weightless?

(3)

The astronauts are not actually weightless; they are in orbit due to the gravitational field of the earth.	1 mark
Both the astronauts and the satellite they occupy are in free fall around the earth.	1 mark
Hence, the net force between the satellite and the astronaut is zero.	1 mark

In order for the passengers on G-FORCE-ONE to feel weightless, the aircraft must climb at a steep angle (45° nose high), level off, and then dive, creating a **parabolic path**. In the diagram below, the arrow represents the direction of flight of the ZERO-G plane.
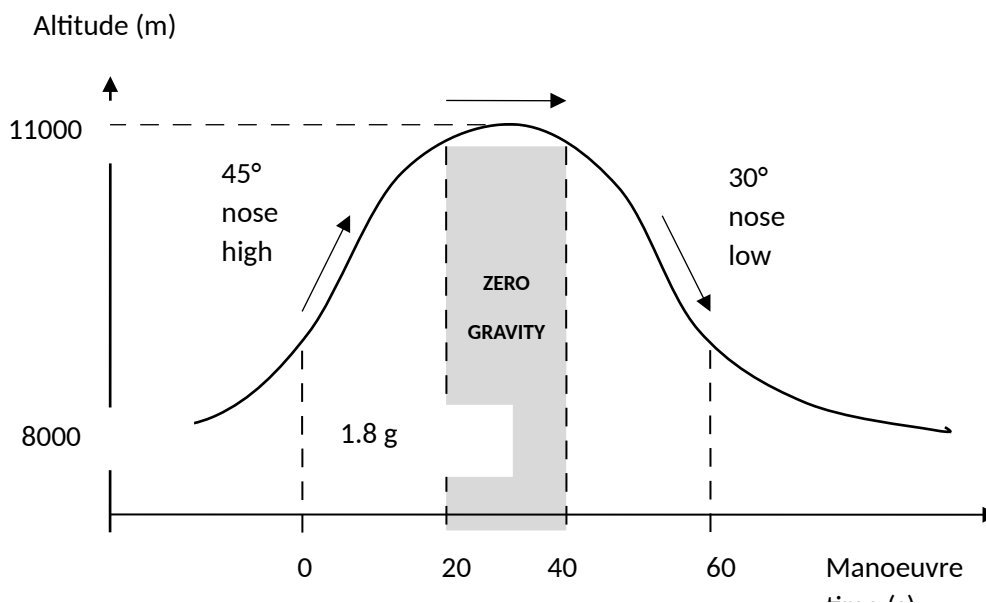
As the ZERO-G plane climbs to the peak of its arc, the pilot orients it at a 45-degree angle upwards (as shown).

b)   During the climb, the plane and its passengers experience a net acceleration equal to
       1.8 times the strength of gravity alone; ie – the passengers' apparent weight
       becomes nearly twice as much as their true weight. Explain. As part of your answer,
       calculate the plane's acceleration vertically upwards that creates the 1.8 g force on
       the passengers.

(4)

The net acceleration (Σa) experienced by the astronauts will be: $\Sigma a = g + a_{up}$	1 mark
The net acceleration experienced by the astronaut is greater than acceleration due to gravity.	1 mark
$\Sigma a = 1.8 \times 9.80 = 17.6 \, ms^{-2} \, ; \Sigma a = g + a_{up} \, ; 17.6 = 9.80 + a_{up}$	1 mark
$\therefore a_{up} = 17.6 - 9.80 = 7.80 \, ms^{-2}$	1 mark

c)   Explain how weightlessness ('zero gravity') is achieved at the top of the parabolic
       arc.

(3)

At the top of the arc, the centripetal force required can be entirely supplied by gravity.	1 mark
In this case, the normal force experienced by the astronaut will be zero.	1 mark
Hence, the astronaut will be weightless.	1 mark

d)   If the radius of the arc at the top of the parabolic path is equal to 500 metres,
       calculate the speed that the plane must be travelling at to achieve 'weightlessness'.
       Assume that the plane's motion is circular at this point.

(4)

$At \; the \; top \; of \; the \; arc : N = \dfrac{mv^2}{r} - mg$	1 mark
$If \; weightless , N = 0 \; ; \therefore \dfrac{mv^2}{r} = mg \; ; v = \sqrt{gr}$	1 mark
$v = \sqrt{9.80 \times 500}$	1 mark
$v = 70.0 \, ms^{-1}$	1 mark

SEE NEXT PAGE

**Question 17**   **(16 marks)**

The moons of Saturn are numerous and diverse – ranging from tiny 'moonlets' one kilometre across to the enormous Titan, which is larger than the planet Mercury. Saturn has 62 moons with confirmed orbits – 53 of which are named and only 13 have diameters larger than 50 kilometres. Data for two of the moons are provided below:

NAME	DIAMETER (km)	MASS (kg)	ORBITAL RADIUS (km)	ORBITAL PERIOD (Earth days)
Mimas	396	4.00×10^{19}	1.86×10^5	0.90
Dione	1123	1.10×10^{21}	$3.77 \quad 10^5$	

a)   The diagram below shows Saturn; approximate representations of the orbits of its two moons, Mimas and Dione; and the moons' positions at a particular point in time. On the diagram below, draw two vectors (arrows) that indicate (i) the direction and (ii) strength of the gravitational field due to Saturn's mass at the points indicated. Ignore any gravitational effects the moons' masses may have on the other.

(2)
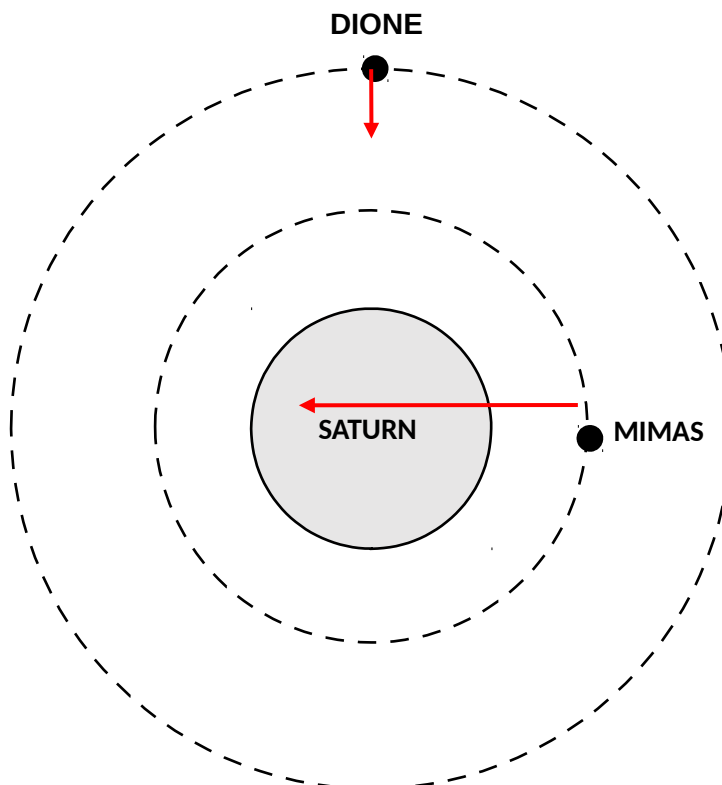
Two arrows drawn, both arrows point towards the centre of Saturn.	1 mark
Arrow for MIMAS is about four times the length of the arrow for DIONE.	1 mark

b)   Using the data provided for Mimas and Dione in the table above – as well as Kepler's 3rd Law - calculate the orbital period for Dione in Earth days.

(4)

Kepler's 3rd Law states: $\dfrac{r^3}{T^2} = \dfrac{Gm}{4\pi^2} = constant\;; \therefore \left(\dfrac{r_1}{r_2}\right)^3 = \left(\dfrac{T_2}{T_1}\right)^2$	1 mark
From data table: MIMAS, r_1 = 1.86 x 10^5 km, T_1 = 0.90 days DIONE, r_2 = 3.77 x 10^5 km, T_2 = ? days	1 mark
$\left(\dfrac{3.77 \times 10^5}{1.86 \times 10^5}\right)^3 = \left(\dfrac{T_2}{0.90}\right)^2$	1 mark
$\therefore T_2 = \sqrt{0.120 \times 0.81} = 2.60\,days$	1 mark

c)   Use the data provided for Mimas to calculate the mass of Saturn.

(4)

$\dfrac{r^3}{T^2} = \dfrac{Gm}{4\pi^2} = constant\;; \therefore m = \dfrac{4\pi^2 r^3}{GT^2}$	1 mark
$m = \dfrac{4\pi^2 \times \left(1.86 \times 10^5 \times 10^3\right)^3}{6.67 \times 10^{-11} \times \left(0.90 \times 24 \times 3600\right)^2}$	2 marks
$¿6.30 \times 10^{26}\,kg$	1 mark

d)   Which moon has the higher orbital speed - Mimas or Dione? Explain without calculating any values.

(3)

$If\ F_g = F_c, then\ \dfrac{Gm_1 m_2}{r^2} = \dfrac{mv^2}{r}\,, v = \sqrt{\dfrac{Gm}{r}}$	1 mark
$\therefore v \propto \dfrac{1}{\sqrt{r}}$	1 mark
Hence, $v_{MIMAS} > v_{DIONE}$	1 mark

e)   NASA intends to insert a probe into an orbit around Saturn for scientific observations of its weather. Two students are discussing this probe; one student states: "All of the objects in this probe will appear weightless because there are no forces acting on an object when it is in orbit." Is this student correct? Explain your answer.

(3)

Student is correct.	1 mark
Even though the probe and all objects in it still experience a force due to gravity from Saturn to create the orbital path …	1 mark
…the 'apparent weight' of the object will be zero given that its net force with the probe will be zero.	1 mark

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 18   **(18 marks)**

EVIDENCE FOR DARK MATTER

By examining the light from stars, astronomers are able to measure the rotational (orbital) speeds of stars in our own Milky Way. The distance of each star to the galactic centre around which all the rotations occur (ie – their orbital radii) can also be determined by various means.

If the mass of the Milky Way galaxy was equal to the 'normal' visible matter in the stars seen by astronomers, then the rotational speeds of the stars should vary as predicted by 'Keplerian Motion'. Newton's Laws can be used to predict the stars' speeds from their orbital radius.

However, when the orbital speeds of stars in the Milky Way galaxy are measured we find that no matter the orbital radius, these are virtually constant - they do not decrease as the distance from the galactic centre increases.

One explanation for this phenomenon is that there are huge amounts of unseen 'dark' matter in outer parts of the galaxy causing the stars to orbit more quickly.

The table below contains data for six (6) stars in the Milky Way Galaxy – including our own Sun. The data shows orbital radius (r); predicted orbital speed (v_p); the square of the predicted orbital speed (v_p^2); and the inverse of the orbital radius ($^1/_r$). Some values are missing in the last two (2) columns.

Star	Orbital Radius (r) (x 10^{20} m)	Predicted Orbital Speed (v_p) (x 10^4 ms^{-1})	Square of Predicted Orbital Speed (v_p^2) (x 10^9 m^{2}s^{-2})	Inverse of Orbital Radius ($^1/_r$) (x 10^{-21} m^{-1})
1	0.473	25.5	65.0	21.1
2	1.42	14.7	21.6	7.04
SUN	2.65	10.8	11.7	3.77
3	4.54	8.23	6.77	2.20
4	6.34	6.97	4.86	1.58
5	8.57	6.01	3.61	1.17

a)   Complete the table by calculating the missing values in the last two columns.

(2)

v_p = 10.8 x 10^4 ms^{-1}; $(v_p)^2$ = 11.7 x 10^9 m^{2}s^{-2}	1 mark
r = 4.54 x 1020 m; $^1/_r$ = 2.20 x 10^{-21} m^{-1}	1 mark

b)   By combining concepts of gravitational force and centripetal force, an expression for orbital speed can be derived. This expression is:

$$v^2 = \frac{Gm}{r}$$

In the space below, show how the expression above is derived.

(2)

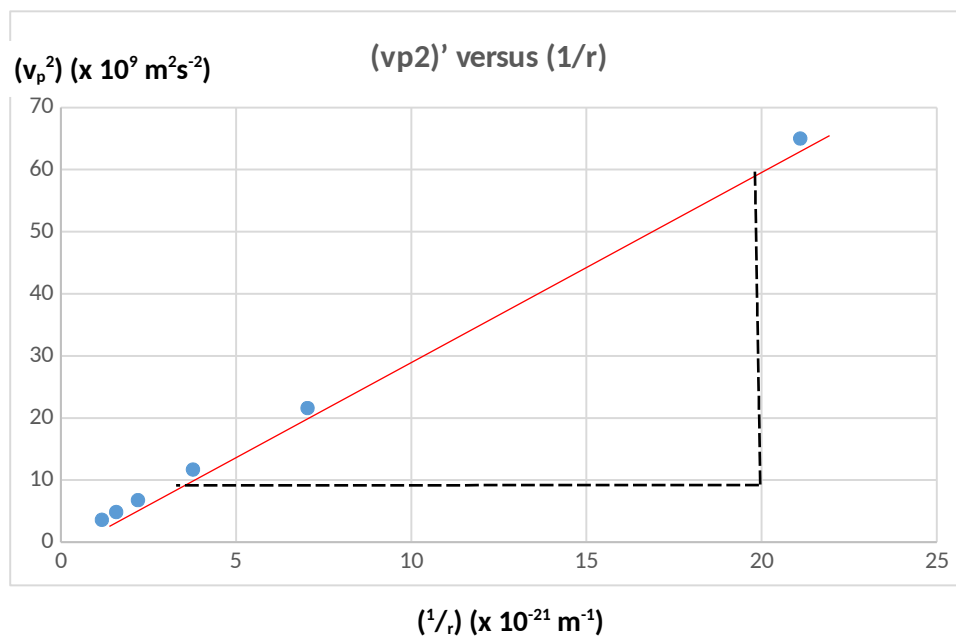|	
$F_g = F_c; \dfrac{GM_E m_S}{r^2} = \dfrac{m_S v^2}{r}$	1 mark
$\therefore v^2 = \dfrac{GM_E}{r}$	1 mark

SEE NEXT PAGE

c)　　　On the grid on the next page, plot a graph of **'Square of Predicted Orbital Speed (v_p^2)'** versus **'Inverse of Orbital Radius ($^1/_r$)'**. Place 'Inverse of Orbital Radius ($^1/_r$)' on the horizontal axis. Draw a line of best fit for your data.

(4)

Appropriate scales provided ($^1/r$ placed on x-axis).	1 mark
Correct units provided.	1 mark
Points plotted correctly.	1 mark
Line of best fit drawn appropriately.	1 mark

d)   Calculate the slope of your line of best fit. Include units.

(3)

Uses points from graph not table	1 mark
$Slope = \dfrac{(62-10) \times 10^9}{(20-3) \times 10^{-21}} = 3.06 \times 10^{30} (range = 3.00 - 4.00 \times 10^{30})$	1 mark
$m^3 s^{-2}$	1 mark

e)   Use the expression derived in part (b) and the slope from part (d) to calculate a
        predicted value for the mass of the galaxy.

(3)

$v^2 = \dfrac{Gm}{r} \; ; \therefore v^2 r = slope = Gm$	1 mark
$3.06 \times 10^{30} = 6.67 \times 10^{-11} \times m$ $\therefore m = \dfrac{3.06 \times 10^{30}}{6.67 \times 10^{-11}}$	1 mark
$¿ 4.59 \times 10^{40} kg \left(4.50 - 6.00 \times 10^{40} kg \right)$	1 mark
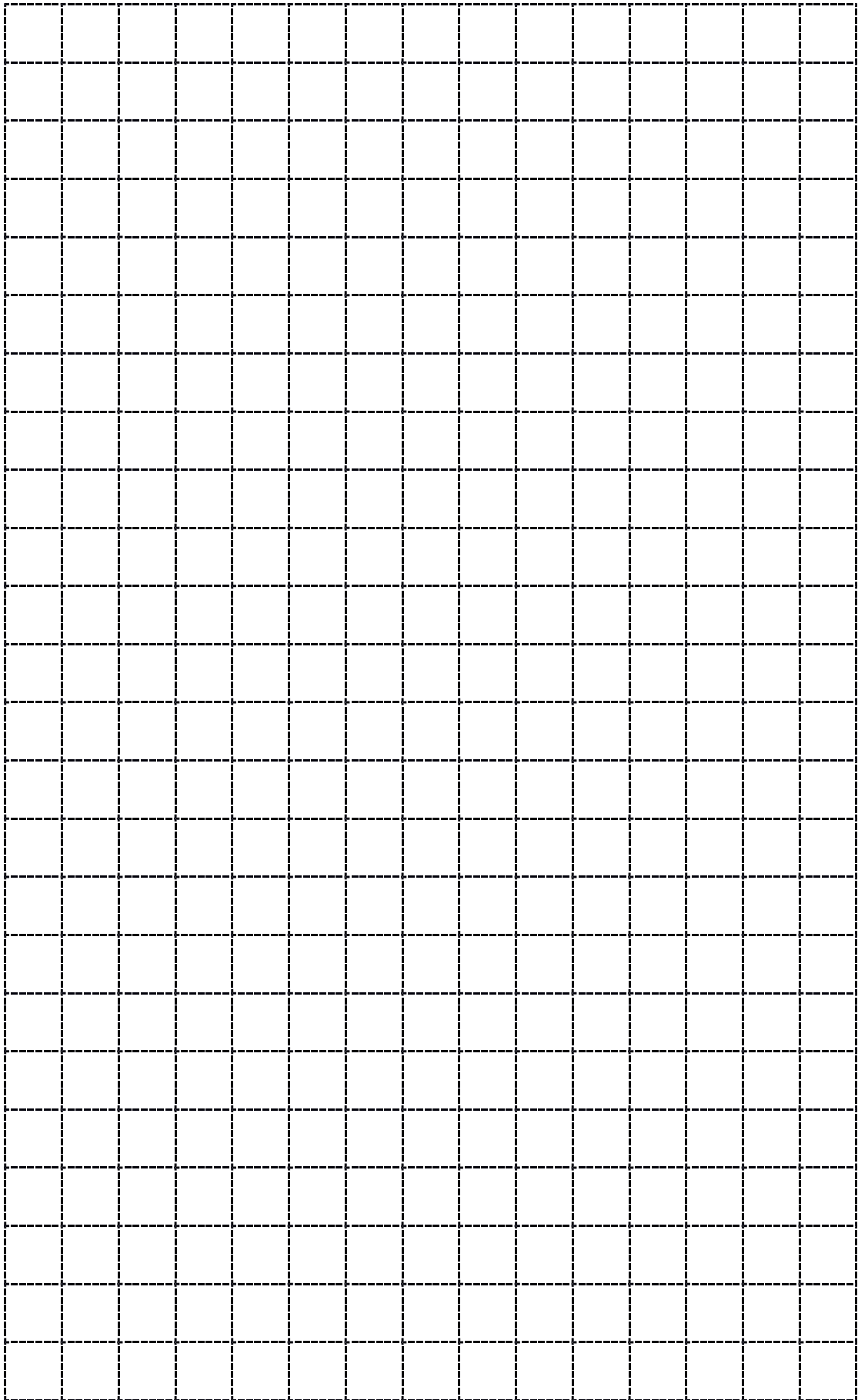
As stated in the article, when the **actual** orbital speeds of stars in the Milky Way galaxy are measured, we find that no matter the orbital radius, these are virtually **constant** - they **do not** decrease as the distance from the galactic centre increases.

f) This suggests when the '**Square of the Actual Orbital Speeds 'v$_A$²''** is plotted against the **'Inverse of Orbital Radius ($^1/_r$)'** a **'flat' rotation curve** should result. Explain.

(2)

'v$_A$' is constant as 'r' increases.	1 mark
Hence, 'v$_A$²' will remain constant as '$^1/r$' decreases.	1 mark

g) The 'flat' rotation curve in part (f) suggests that the stars in the Milky Way (as well as all other galaxies) are embedded in a large halo of 'dark matter'. When the amount of visible matter in the Milky Way galaxy (ie – stars, gas, dust, etc.) is measured it turns out to be much less than that measured by Newton's Laws. As much as 90% of the mass in a galaxy may be of this unseen type of matter.

Explain why the flat curve from part (f) provides evidence for 'dark matter'.

(2)

The ACTUAL data suggests that the orbital velocities of stars in our galaxy do not fall as quickly as predicted by the amount of visible matter in the galaxy (ie: $v=\sqrt{\dfrac{GM}{r}}\ ; as\ r\uparrow, v\downarrow$).	1 mark
One possible reason for this would be the presence of vast amounts of invisible or dark matter which increases the gravitational force available (ie – if 'M' is much larger than the visible matter suggests, 'v' will remain much higher than expected).	1 mark

Question 19   **(18 marks)**

THE LARGE HADRON COLLIDER

In September, 2008, the CERN particle accelerator complex started up its latest and most powerful addition – the Large Hadron Collider (LHC). This particle accelerator was the most powerful and large if its type – a 27 kilometre ring that accelerates charged particles (normally protons) to speeds approaching the speed of light.

Super conducting magnets (cooled to -271.3 °C, so that they can conduct electricity without resistance) bend two beams of protons into near-circular paths travelling in opposite directions before they are caused to collide in detectors.

The proton beams consist of 2808 'bunches' of 1.2×10^{11} protons (at the start of their acceleration n the LHC) and undergo 1 billion collisions per second. The total energy of each proton collision is up to a maximum of 14 TeV (normally about 13 TeV). At these energies, the protons are travelling so quickly that they circumnavigate the 27 km long LHC 11000 times per second.

The fragments and information gained from these collisions provide critical information about the origins of our universe and the nature of matter itself.

ACCELERATING THE PARTICLES

The protons' journey begins in the 'source chamber' – essentially a cylinder of hydrogen gas releases its H-atoms into a strong electric field where protons are separated from their electrons.

The protons are accelerated to high speeds by very strong electric fields. Initially, this acceleration is achieved in two (2) linear accelerators (LINAC 1 and LINAC 2). By the time the protons leave LINAC 2 and enter the next phase of acceleration (in the PS Booster), they have an energy of 50 MeV.

Subsequent particle acceleration and protons beam energies increase as follows:

- PS Booster accelerates the proton beam to an energy of 1.4 GeV.
- Proton Synchrotron (PS) accelerates the proton beam to an energy of 25 GeV.
- Super Proton Synchrotron (SPS) accelerates the proton beam to an energy of 450 GeV.
- In the Large Hadron Collider (LHC), the proton beam is accelerated for 20 minutes to a maximum energy of 6.5 TeV. The beams are circulated in this ring for several hours under normal operating conditions.
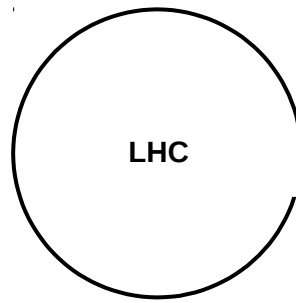
GUIDING THE BEAM IN THE LARGE HADRON COLLIDER (LHC)

The beam is guided in to a near-circular path in the 27 kilometre circumference LHC in high-vacuum tubes by extremely powerful electromagnetic devices (magnets).

LHC

**Circumfer
ence = 27**

There are 9593 magnets in the LHC – varying from single dipoles, quadrupoles, sextupoles, octupoles, decapoles, etc. The strongest magnets consist of 1232 dipoles.

The diploes are essentially used to guide the trajectory of the beams around the accelerators. The 'insertion' quadrupoles are special magnets used to 'squeeze' the proton beams and focus them to a size that is so small that the probability of proton collisions are enhanced greatly.

The peak dipole magnetic field strength reaches 7.74 T in the LHC. At a temperature of 1.9 K, the super conducting magnets can carry a current of 11850 A which allows a maximum magnetic field strength of 8.33 T. This temperature is critical to guide the proton beam around the 27 km circumference LHC at an energy of 6.5 TeV without colliding with the sides of the vacuum tubes. At 4.5 K, the magnets could only carry a current of 8500 A and produce a magnetic field strength in the order of 6 T.

### HOW DO WE 'SEE' THE PARTICLES PRODUCED BY THE PROTON COLLISIONS?

For each proton collision, the particle physicist's goal is to count, track and characterise all the other different particles produced in order to reconstruct the collisions process as fully as possible. If the track of a particle can be traced, much valuable information can be discerned about that particle – particularly if the collision takes place in a magnetic field. Characteristics such as charge and momentum can be calculated. Very high momentum particles travel in almost straight lines; very low momentum particles make tighter spirals.

a)   Explain why the H-atoms need to be ionised (ie – protons created) for the operation of the LHC.

(2)

Electric fields and magnetic fields are used to accelerate the particles.	1 mark
These fields can only exert forces on charged particles.	1 mark

The diagram below shows the structure of the particle accelerators in LINAC 1 and LINAC 2. It consists of 'drift tubes' (where the protons maintain a constant velocity) and 'gaps' between the tubes where the proton acceleration takes place. The proton acceleration occurs due to an alternating electric potential difference between each drift tube.
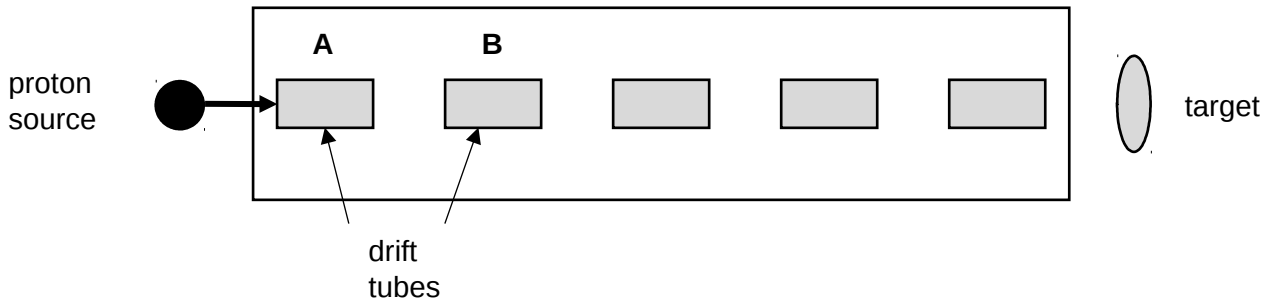
b)   On the two drift tubes that are indicated with arrows ('A' and 'B'), draw two symbols ('+' and '-') to represent the electric potential required to accelerate the proton in the gap between them.

(1)

Tube A: +; Tube B: -	1 mark

c)   "At these energies, the protons are travelling so quickly that they circumnavigate the 27 km long LHC 11000 times per second."

Use this information to calculate the speed of the protons as they travel around the LHC.

(3)

|	
$T = \dfrac{1}{f} = \dfrac{1}{11000} = 9.09 \times 10^{-5} s$	1 mark
$v = \dfrac{2 \pi r}{T} = \dfrac{27000}{9.09 \times 10^{-5}}$	1 mark
$¿ 2.97 \times 10^{8} ms^{-1}$	1 mark

d) When the protons leave the two (2) linear accelerators (LINAC 1 and LINAC 2), they have achieved an energy of 50 MeV. Use this information to calculate the speed of the protons as they leave LINAC 2, given that relativistic effects can be ignored.

(3)

$E = 50 \times 10^6 \times 1.6 \times 10^{-19} = 8.00 \times 10^{-12} J$	1 mark
$8.00 \times 10^{-12} = 0.5 \times 1.67 \times 10^{-27} \times v^2$ $\therefore v = \sqrt{\dfrac{2 \times 8.00 \times 10^{-12}}{1.67 \times 10^{-27}}}$	1 mark
$¿ 9.79 \times 10^7 \, ms^{-1}$	1 mark

e) Explain why changing the temperature of the super conductors (eg – increasing to 4.5 K) will cause protons to collide with the vacuum tubes in the LHC. Include any mathematical expressions that will assist your answer.

(4)

The resistance (R) of the superconductors increases as temperature (T) increases.	1 mark
Since V= IR (and V is constant), an increase in the resistance (R) of the superconductors will cause a decrease in the current (I) in the LHC.	1 mark
The magnetic field strength 'B' of the superconductors is given by: $B = \dfrac{\mu_o}{2\pi} \dfrac{I}{r} ; \therefore \downarrow I \, means \downarrow B$	1 mark
The radius of the path required for the protons is given by: $r = \dfrac{mv}{qB} ; \therefore \downarrow B \, means \uparrow r$ Hence, radius of path will not match the radius of the LHC.	1 mark

The diagram below shows the tracks of two particles (A and B) in a detector.
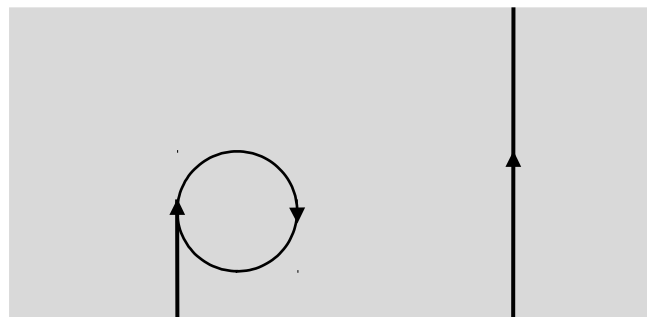
Particle A   **Particle B**

Both particles have the same sized positive charge.

f)   Use information in the article to describe each particle as either "very high momentum" or "very low momentum". In the space below the table, explain why the path of Particle 'B' is virtually straight despite its positive charge.

(4)

Particle 'A'	Low momentum
Particle 'B'	High momentum

Particle 'A': Low momentum; **Particle 'B':** High momentum	1 mark
Momentum is calculated by p = mv; higher 'p', higher 'v'.	1 mark
Radius of curved path created by magnetic field: $r = \dfrac{mv}{Bq}$	1 mark
∴ Increase 'v', increase 'r' – straighter path results.	1 mark

g)   On the diagram above, indicate the direction of the magnetic field that would cause the path of Particle 'A' to curve in the manner shown.

(1)

'B' out of the page.	1 mark

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SEE NEXT PAGE