



## ROSSMOYNE SENIOR HIGH SCHOOL SCIENCE

### Semester 1, Examination 2019

# ATAR Physics Unit 3 Question/Answer Booklet **SOLUTIONS**

**Student Number:** In figures

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In words

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### Time allowed for this paper

Reading time before commencing work: ten minutes

Working time for paper: three hours

### Materials required/recommended for this paper

#### ***To be provided by the supervisor***

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

#### ***To be provided by the candidate***

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

Special items: Calculators satisfying the conditions set by 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 material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

**Circle your Teacher's name:** Mr Holyoake, Mr Patterson, Mrs Shashikumar

## 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
			<b>Total</b>	180	100

### Instructions to candidates

- 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.
- Write answers in this Question/Answer Booklet.
- 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.
- You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.
- 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.

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- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
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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 ( $V_{\text{BACK}}$ ) is induced in the coil.	1 mark
Hence the voltage around coil ( $V_{\text{COIL}}$ ) would be equal to: $V_{\text{COIL}} = EMF - V_{\text{BACK}}$ ( $EMF = \text{external power source}$ ) $\therefore V_{\text{COIL}} < EMF$	1 mark
When the coil stops rotating, the back EMF ( $V_{\text{BACK}}$ ) reduces to zero; hence, $V_{\text{COIL}} = EMF$ .	1 mark
The increase in the coil voltage ( $V_{\text{COIL}}$ ) will be associated with a corresponding increase in the coil's current.	1 mark

Look for the quality of understanding and appropriate use of induction and back Emf to explain observation 0-4

**Question 2**

At some distance from the centre of a planet, the gravitational field strength is  $2.00 \text{ m s}^{-2}$ . Calculate the gravitational field strength at a distance twice as far from the centre of the planet.

(4 marks)

$g = \frac{GM}{r^2}$ selects equation	1 mark
$g' = \frac{GM}{(2r)^2}$ uses $2r$	1 mark
$g' = \frac{1}{4} \frac{GM}{r^2}$	1 mark
$\therefore g' = 0.500 \text{ m s}^{-2}$ answer is evaluated	1 mark

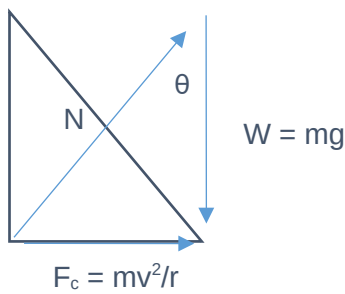
No carry through marks

**Question 3**

A car is able to turn in a circular path of radius ' $r$ ' at a particular speed ' $v$ ' by using a banked road at an angle ( $\theta$ ) to the horizontal. See below.

Explain why the angle of banking ' $\theta$ ' of the road needs to increase if the radius of its circular path decreases while maintaining the same speed ( $v$ ). Include an appropriate mathematical expression and a vector diagram to aid your answer.

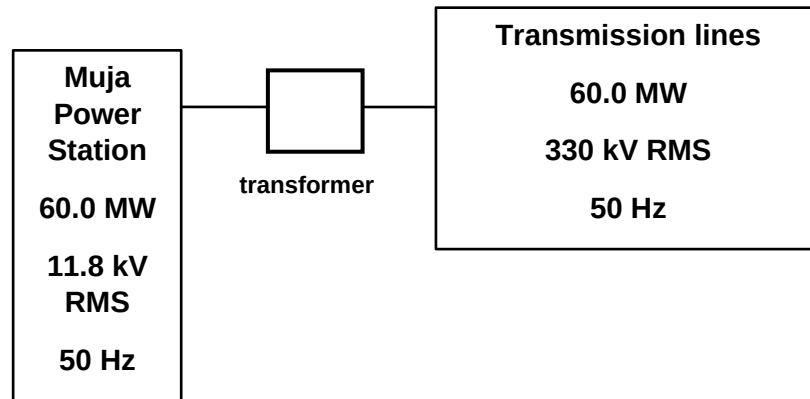
(4 marks)

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

Allow a max of 2 for sin0

#### Question 4

The generator at the Kwinana Power Station generates electric power at 70.0 MW, 11.8 kV RMS. This power is then stepped up by a transformer to a transmission voltage of 330 kV RMS.



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

(2 marks)

Ideal transformer turns ratio: $\frac{V_p}{V_s} = \frac{5800}{330000} = 0.0176$	1-2
(or 1:56.9)	

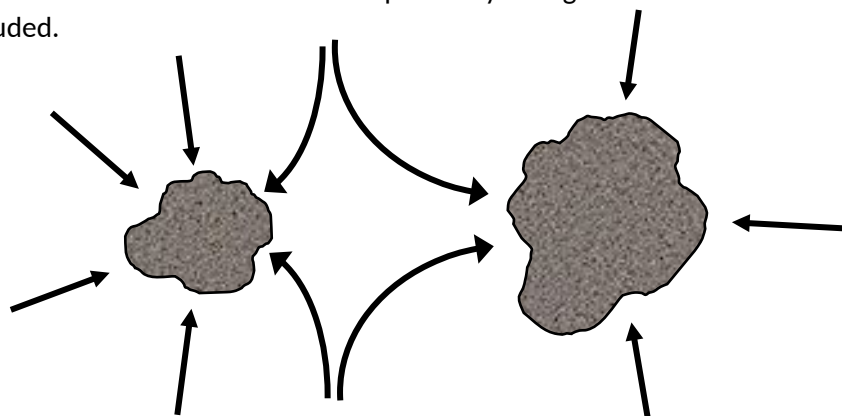
- b) In the scenario described above, the data indicates an 'ideal' transformer. In reality, no transformer is 'ideal'. Explain what is assumed for an 'ideal transformer', and why no transformer is ideal.

(4 marks)

Ideal transformer, assumes no power losses in the transformer: ie, $P_{\text{PRIMARY}} = P_{\text{SECONDARY}} = 70.0 \text{ MW}$ .	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, $P_{\text{PRIMARY}} > P_{\text{SECONDARY}}$ due to these heat losses.	1 mark

### Question 5

The diagram below is of two asteroids in close proximity. The gravitational field in this region has also been included.



Which asteroid (left or right) has the larger mass? Explain your choice.

(3 marks)

Description	Marks
Left	1
Describes how field shape shows evidence of answer	1
"The field lines on the left are closer together/denser/has more field lines/the vertical asymptote favours the left"	
Explains relationship between field and mass	1
"This is caused by the larger mass which produces a larger gravitational field strength"/"Denser field lines is an indication of larger mass"	
<b>Total</b>	<b>3</b>

### Question 6

A plane of mass 870 kg pulls up from a nosedive. It follows a circular arc of radius 220 m and is travelling at a top speed of  $36 \text{ ms}^{-1}$ .

- a) Ignoring air resistance, calculate the maximum force experienced by the underside of the plane's wings.

(3 marks)

At lowest point of arc, $F_{\text{WINGS}} = \frac{mv^2}{r} + mg$	1 mark
$F_{\text{WINGS}} = \frac{870 \times 36^2}{220} + 870 \times 9.80$	1 mark
$1.37 \times 10^4 \text{ N}$	1 mark

No carry through

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

(1 mark)

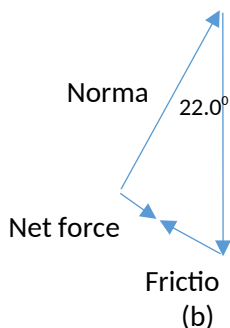
Maximum force occurs at the lowest point of the arc.

1 mark

### Question 7

A 600 g block on a ramp inclined at  $22.0^\circ$  is accelerating down the ramp at  $2.16 \text{ m s}^{-2}$ .

- (a) Draw a labelled vector diagram showing the relationship between the physical forces and the net force acting on the block. Include the angle in the diagram. (3 marks)



Description	Marks
All vectors labelled showing forces in correct positions	1
Arrow heads show correct relationship/directions	1
Places angle in correct corner	1
<b>Total</b>	<b>3</b>

- (b) Calculate the frictional force acting on the block. (3 marks)

Description	Marks
Finds net force $\sum F = ma = 0.600 \times 2.16 = 1.296 \text{ N}$	1
Uses vector relationship to find friction $\sum F = F_{\text{down}} - F_{\text{friction}}$ $F_{\text{friction}} = F_{\text{down}} - \sum F$ $F_{\text{friction}} = mg \sin \theta - \sum F$ $F_{\text{friction}} = 0.600 \times 9.8 \times \sin(22.0) - 1.296 = 0.907 \text{ N}$	1-2
<b>Total</b>	<b>3</b>

### 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)

$E = \frac{V}{d}; \therefore E = \frac{1200}{4.00 \times 10^{-3}}$	-1 if wrong units 1 mark
$\therefore E = 3.00 \times 10^5 \text{ V m}^{-1}$	1 mark

- b) Calculate the magnitude of the electrostatic force acting on an electron placed between the plates. (2 marks)

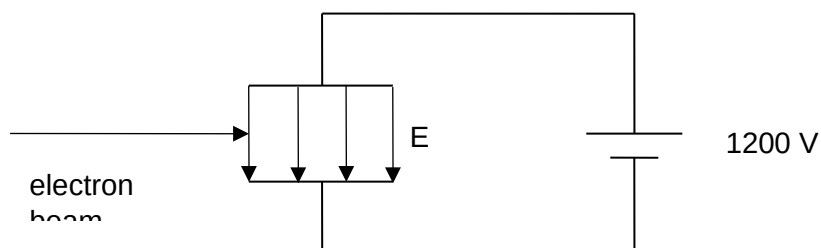
$E = \frac{F}{q}; \therefore F = Eq = 3.00 \times 10^5 \times 1.60 \times 10^{-19}$	1 mark
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$$30 \times 10^{-14} \text{ N}$$

1 mark

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



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 out of the page

1 mark

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

(2 marks)

$$F = Bvq; \therefore B = \frac{F}{vq}; \therefore B = \frac{4.80 \times 10^{-14}}{4.50 \times 10^6 \times 1.60 \times 10^{-19}}$$

1 mark

$$6.67 \times 10^{-2} \text{ T}$$

1 mark

### Question 9

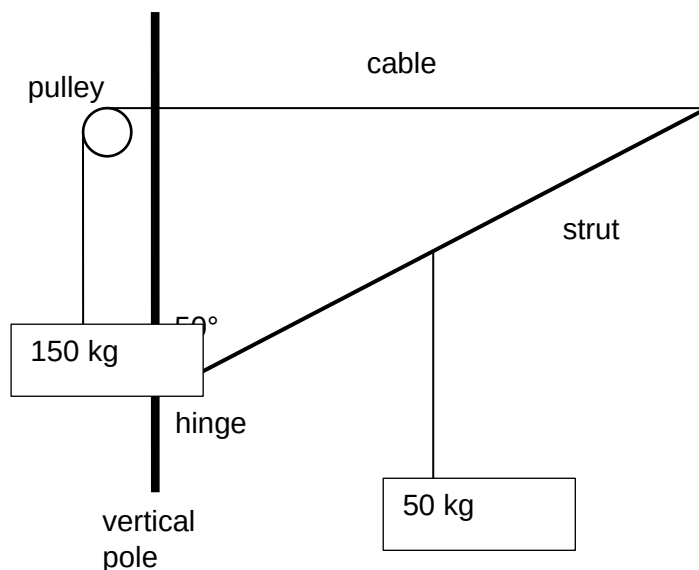
Two spheres with equal but opposite electric charge are placed 7.55 cm apart and experience  $5.11 \times 10^{-4} \text{ N}$  of attractive force. Calculate the magnitude of the electric charge on each sphere.

(3 marks)

Description	Marks
$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$ where $q_1 = q_2$	1
$q = \sqrt{4F\pi\epsilon_0 r^2}$	1-2
$q = \sqrt{4 \times 5.11 \times 10^{-4} \times 3.14 \times 8.85 \times 10^{-12} \times 0.0755^2} = 1.80 \times 10^{-8} \text{ C}$	
<b>Total</b>	<b>3</b>

**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.



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  $50^\circ$  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 $P$ : $\Sigma M = 0$ $150 \times 9.8 \times 2.00 \times \sin 40^\circ = m \times 9.80 \times 1.00 \times \sin 50^\circ + 50 \times 9.80 \times 1.00 \times \sin 50^\circ$	1-2 mark
$\therefore m = 202 \text{ kg}$ 3 sig figs or -1	1 mark

- b) The strut is hinged at its contact with the vertical pole. Hence, it can rotate and change the size of the angle of  $50^\circ$ . 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.

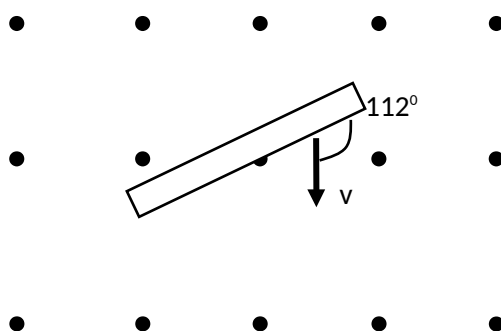
(3 marks)

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 $50^\circ$ and the complementary angle increasing above $40^\circ$ .	1 mark

There were two possible interpretations of this question – does the boom rise or is the angle changed to re establish equilibrium pay 0-3 depending on answer quality

### Question 11

An 0.800 m metal rod is moving down through a magnetic field (out of the page) at  $12.0 \text{ m s}^{-1}$  as shown in the diagram below. The magnetic flux density is  $29.0 \text{ mT}$ .



- (a) On the diagram, indicate which region of the rod would accumulate positive charge.

(1 mark)

Description	Marks
Shows positive charge on far left side of rod (see above)	1
<b>Total</b>	<b>1</b>

- (b) Calculate the magnitude of the emf across the rod.

(4 marks)

Description	Marks
$\epsilon = vBl$	1
$12.0 \times 29.0 \times 10^{-3} \times 0.800 \times \sin(112) = 0.258 \text{ V}$	1-3
<b>Total</b>	<b>4</b>
Max 2 if sin112 omitted Also check Sig figs here	

**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.

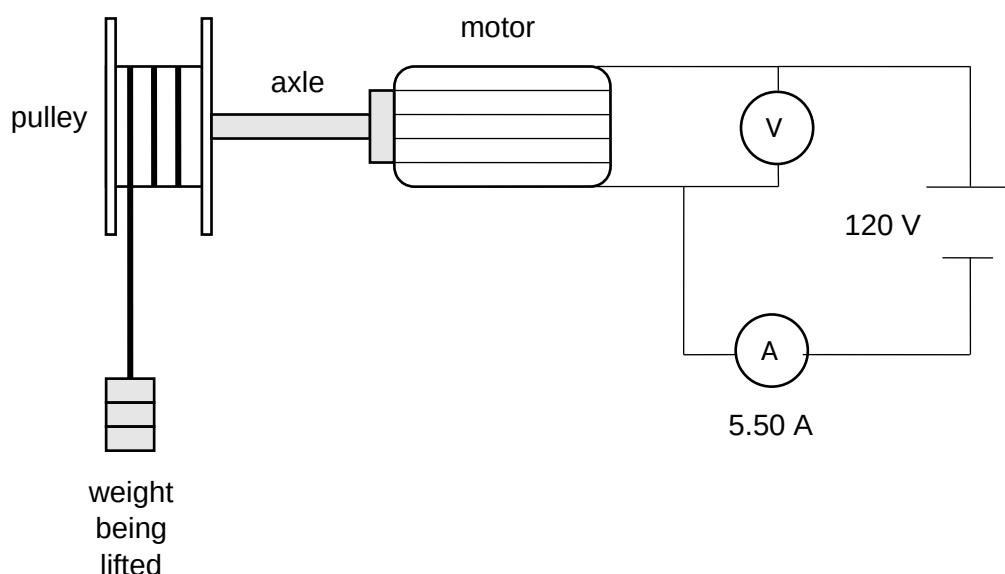
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Suggested working time for this section is 90 minutes.

**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 ( $\Delta E_P$ )). A diagram outlining this system is shown below.



The DC motor operates at a voltage of 120 V and draws a current of 5.50 A. It is able to lift a mass of 15.0 kg through a vertical height of 3.50 m in 1.05 s.

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

(3)

$\Delta E_p = mg \Delta h = 15.0 \times 9.80 \times 3.50 ; \therefore \Delta E_p = 5.145 \times 10^2 J$	1 mark
$P = \frac{\Delta E_p}{t} = \frac{5.145 \times 10^2}{1.05} = 4.90 \times 10^2 W$	1-2 mark

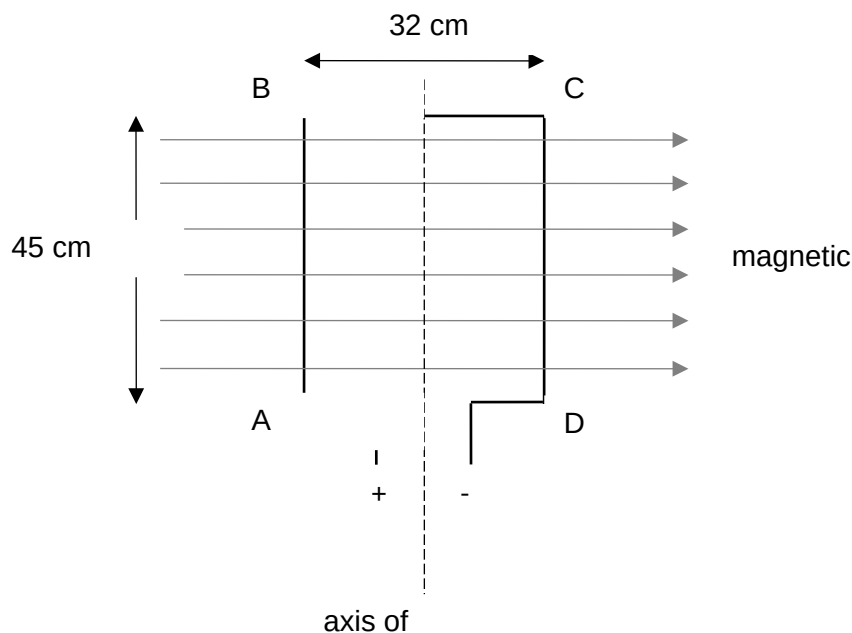
- b) Calculate the electric power consumed by the DC motor and, hence, the percentage efficiency of the electric motor.

[If you were unable to calculate an answer for the rate at which the motor does work on the mass in part (a); use  $4.50 \times 10^2 W$ ]

(3)

$P = VI = 120 \times 5.50 = 660 W$	1-2 mark
$\therefore \% \text{efficiency} = \frac{490}{660} \times 100 = 74.2 \%$	1 mark

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 Accepted 'Down' if ALSO gave "into the page" as an alternative/synonym – NOT if 'Down' was the only answer as this was interpreted as 'down the page'.	1 mark
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(ii) Side BC.

No force exerted	1 mark
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- 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 when the coil is parallel to the field.

(3)

$F = mg = 30.0 \times 9.80 = 294$	1 mark
$\therefore \tau_{max} = 294 \times \frac{0.65}{2} = 95.6 \text{ Nm}$	1-2 mark
If used the coil radius (not pulley radius) AND multiplied by '2 sides', no marks for torque calc.	

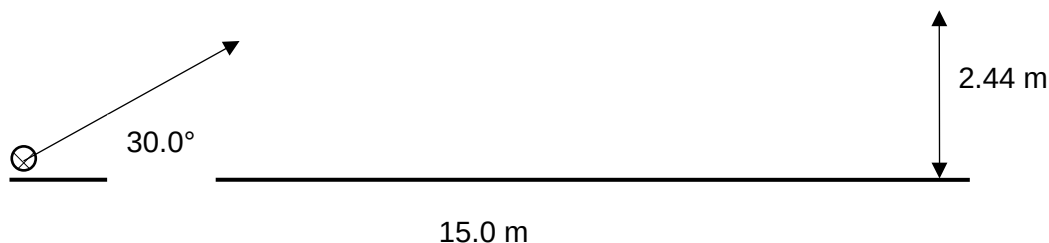
- e) Hence, calculate the size of the magnetic field 'B'. [Hint if you were unable to calculate an answer for part (d), use 96.0 Nm]

(3)

$\tau_{max} = IBnA ; \therefore B = \frac{\tau_{max}}{InA}$	1 mark
$\therefore \frac{95.6}{5.50 \times 240 \times 0.32 \times 0.45} = 0.503 \text{ T}$	1-2 mark

**Question 13****(13 marks)**

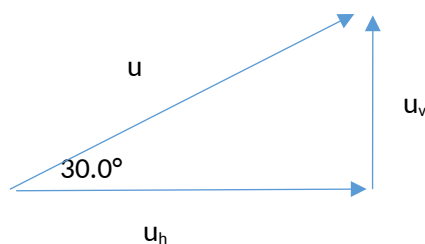
A soccer player is shooting at a goal from directly in front of it. The player is 15.0 m from the goal line and kicks the ball with a launch angle of  $30.0^\circ$ . The diagram below illustrates this situation. The height of the goal (ie – the crossbar above the ground) is 2.44 m.



The player is trying to launch the ball with a velocity 'u' that allows it to hit 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 ' $\theta$ '. Show clearly how you obtained these with a vector diagram.

[4]



Vector diagram drawn with arrows and labels (see above).	1-2 mark
$\frac{u_v}{u} = \sin 30.0^\circ$ and $\frac{u_h}{u} = \cos 30.0^\circ$	1 mark
$u_v = u \sin 30.0^\circ$ $u_h = u \cos 30.0^\circ$	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
$t = \frac{15.0}{u \cos 30.0^\circ} = \frac{17.3}{u}$	1-2 mark



Logical reasoning/working out must be shown for marks	
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- 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 hit the crossbar.

(4)

$s = ut + \frac{1}{2}at^2;$	1 mark
$2.44 = (u \sin 30.0^\circ) \left( \frac{17.3}{u} \right) + (0.5)(-9.80) \left( \frac{17.3}{u} \right)^2$	1-2 mark
$\therefore u = 15.4 \text{ ms}^{-1}$	1 mark
<p>If used method above but confused about u and <math>u_v</math>, 3 marks max IF also converted using <math>u = u_v \sin \theta</math></p> <p>If incorrectly used <math>v^2 = u^2 + 2as</math>, may have 1 mark max IF also converted to final speed using <math>u = u_v \sin \theta</math></p>	

- 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°.

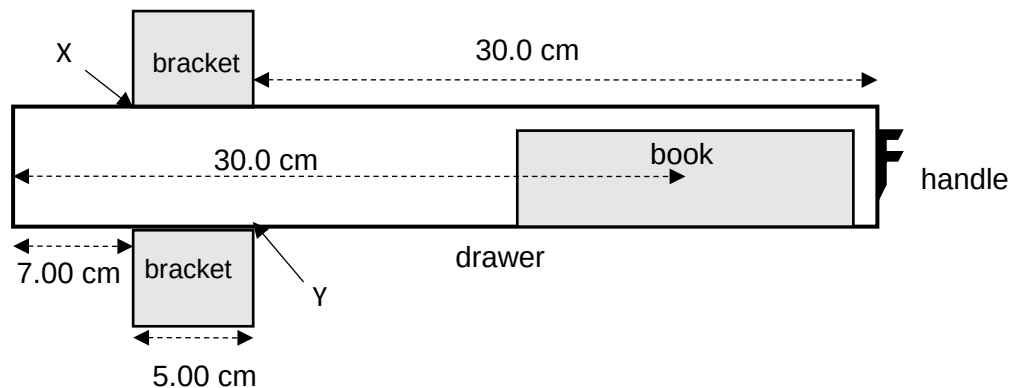
'u' must increase.	1 mark
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- (ii) Launch angle 'θ' if the launch velocity 'u' remains at the answer calculated in part (c).

'θ' must increase.	1 mark
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**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.



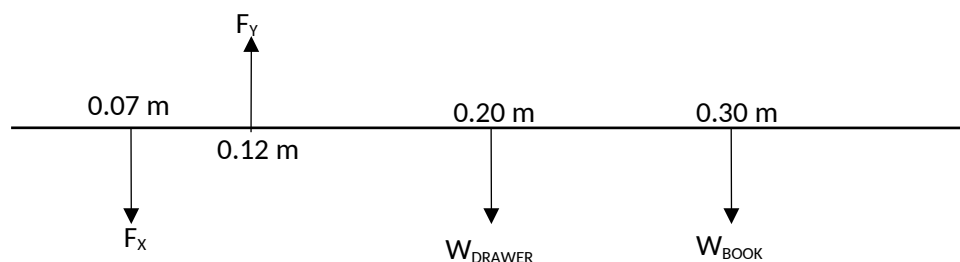
Both the drawer and the book can be considered to be uniform and have masses of 1.20 kg and 0.850 kg respectively. The distance from the left hand edge of the drawer to the centre of mass of the book is measured to be 30.0 cm (as shown). The mass of the handle is insignificant and can be ignored.

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
$W_{\text{DRAWER}}$ shown - correctly labelled.	1 mark

$W_{\text{BOOK}}$  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 'Y'; $\Sigma M = 0$ , showing three torques involved	1 mark
$F_x r_x = F_B r_B + F_D r_D$ $F_x \times 0.050 = 1.2 \times 9.8 \times 0.09 + 0.85 \times 9.8 \times 0.18$ $F_x = 51.2 \text{ N m}$	1-2 marks

(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)

$\Sigma F = 0; \Sigma F_{\text{UP}} = \Sigma F_{\text{DOWN}}$	1 mark
$41.6 + 11.8 + 8.3 = F_y$ $F_y = 71.3 \text{ N}$	1-2 mark
May also solve using torques if taking pp at location other than Y.	

- 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.

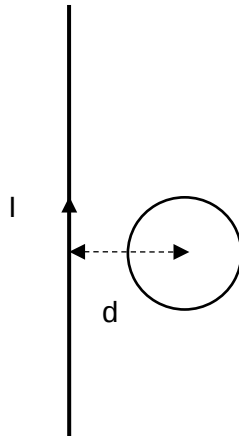
(5)

$F_X$ decreases.	1 mark
Distance from pp to book/drawer weight force decreases, $\Sigma CWM$ due to weight of book and drawer decreases	1 mark
$F_X$ decreases to reduce the anticlockwise torque	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****(14 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 of 2.10 A.

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

**(3)**

$B = \frac{\mu_0 I}{2\pi r}$	1 mark
$\therefore B = \frac{2 \times 10^{-7} \times 2.10}{0.050} = 8.40 \times 10^{-6} T$	1-2 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)

$\Phi = BA; \therefore$	1
$\Phi = 8.40 \times 10^{-6} \times \pi \times 0.010^2$ $\Phi = 2.64 \times 10^{-9} \text{ Wb}$	1-2 marks

- c) The current (I) in the conductor is now increased which increases the flux within the coil to a value of  $8.17 \times 10^{-9} \text{ Wb}$  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  $6.00 \times 10^{-10} \text{ Wb}$ ] (3)

$\therefore \Delta \Phi = \Phi_2 - \Phi_1 = 8.17 \times 10^{-9} - 2.64 \times 10^{-9} = 5.53 \times 10^{-9} \text{ Wb}$	1 mark
$\therefore \text{AVERAGE EMF} = \frac{\Delta \Phi}{t} = \frac{5.53 \times 10^{-9}}{0.750} = 7.37 \times 10^{-9} \text{ V}$	1-2 mark
(2.89 $\times 10^{-9} \text{ V}$ if used assumed value)	

- 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

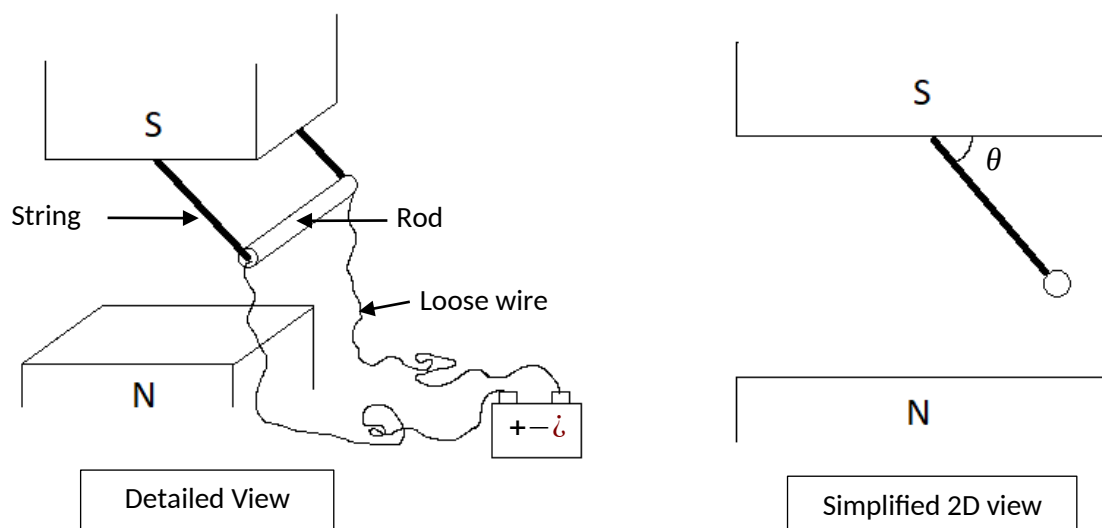
- e) It is possible to shift the coil while the current in the conductor is being increased such that no EMF is induced in the coil. Explain.

(3)

For NO EMF to be induced, $\Delta\Phi = 0$ .	1 mark
As 'I' increases, 'B' at every point around the conductor increases proportionally, increasing the flux.	1 mark
By increasing 'r', 'B' at every point decreases proportionally, keeping flux a constant	1 mark
If used rotation instead of shifting, 2 marks max if referring to changes in flux and faraday's law.	

**Question 16****(15 marks)**

A 20.0 cm long conducting rod forms a circuit with a 3.00 V battery, connected via some loose wires which dangle freely from either end of the rod. The rod is also tethered to a magnet via a pair of strings and can swing freely. Another magnet sits below the rod to create a uniform 0.500 T field. The rod's uniform distributed mass is 0.0900 kg and has a 2.00  $\Omega$  resistance. You may assume the mass of the string and loose wires are negligible and the resistance of the loose wires is negligible.



When everything is connected, the rod swings to one side and remains in the position shown in the simplified 2D view.

- (a) By drawing a positive and negative sign, label the polarity of the battery in the diagram above. (1 mark)

Description	Marks
See above (one mark for positive and negative labelled correctly)	1
<b>Total</b>	<b>1</b>

- (b) Calculate the current through the rod. (1 mark)

Description	Marks
$I = \frac{V}{R} = \frac{3.00}{2.00} = 1.50 \text{ A}$	1
<b>Total</b>	<b>1</b>



- (c) Calculate the magnetic force acting on the rod. (2 marks)

Description	Marks
$F = IBl = 1.50 \times 0.500 \times 0.200 = 0.150 \text{ N}$	1-2
<b>Total</b>	<b>2</b>

- (d) Calculate the tension in one of the pieces of string. (4 marks)

Description	Marks
Finds weight force $F_g = mg = 0.0900 \times 9.8 = 0.882 \text{ N}$	1
Sums weight and magnetic forces, equating to tension $T = \sqrt{F_g^2 + F_B^2}$ $T = \sqrt{0.882^2 + 0.150^2} = 0.8947 \text{ N}$	1-2
Halves tension between two strings $T = \frac{0.8947}{2} = 0.447 \text{ N}$	1
<b>Total</b>	<b>4</b>

- (e) Calculate the angle the string makes with the magnet face ( $\theta$  in diagram). (2 marks)

Description	Marks
$\theta = \tan^{-1} \frac{F_g}{F_B} = \tan^{-1} \frac{0.882}{0.150} = 80.3^\circ$	1-2
<b>Total</b>	<b>2</b>

- (f) The battery is removed and the loose wires left dangling, disconnected. The rod swings like a pendulum and comes to a complete stop in 5.60 s. The rod is returned to its starting position, prior to when the battery was removed. The loose wires that were connected to the battery are connected together. The rod is let go, swings like a pendulum but this time comes to a complete stop in 2.90 s. Explain the difference in time. (5 marks)

Description	Marks
States an induced emf forms when cutting flux lines "As the rod swings, it cuts through flux lines which will induce an emf according to Faraday's law"	1
Compares the open circuit vs closed circuit scenario "When the wires are connected, a current can flow around the circuit made by the rod and wires. When the wires are disconnected no current can flow"	1-2
States a retardation force slows the rod in the closed circuit scenario, in response to a new magnetic field being produced – reducing the time until stopping "When a current flows, it will produce a magnetic field that opposes the change in field caused by the movement of the rod – these fields interact to create a force that opposes the motion of the rod. This makes the coil slow down faster"	1-2
<b>Total</b>	<b>5</b>

No sustained current

- $F = ILB$ ,  $I = \frac{vB}{R}$
- Interaction between the Created Magnetic field & the external magnetic field create a force
- Retarding force slows down the motion

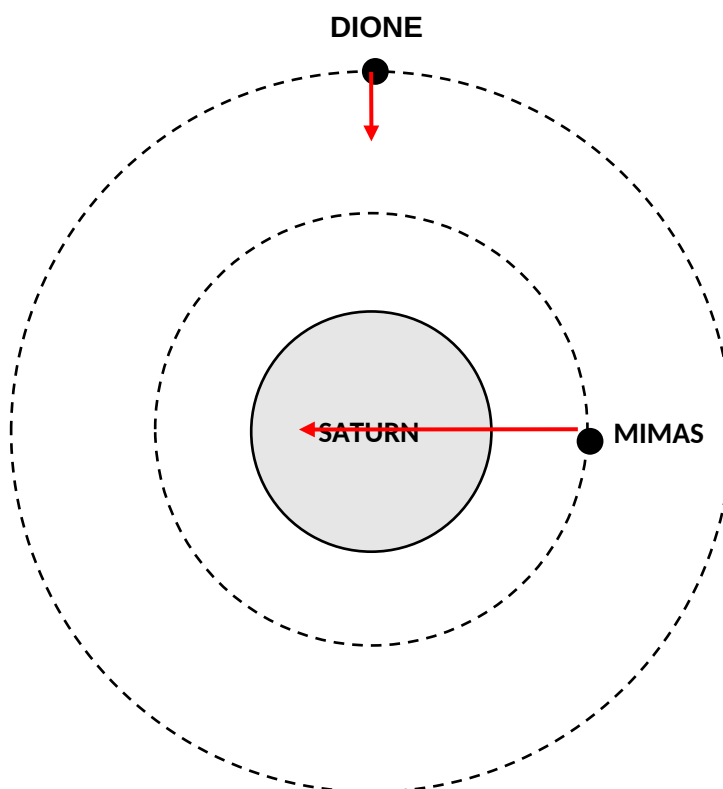
**Question 17****(16 marks)**

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	$4.00 \times 10^{19}$	$1.86 \times 10^5$	0.90
Dione	1123	$1.10 \times 10^{21}$	$3.77 \times 10^5$	

- 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 3<sup>rd</sup> Law - calculate the orbital period for Dione in Earth days.

(4)

Kepler's 3<sup>rd</sup> Law states:  $\frac{r^3}{T^2} = \frac{Gm}{4\pi^2} = \text{constant}$ ;  $\therefore \left(\frac{r_1}{r_2}\right)^3 = \left(\frac{T_2}{T_1}\right)^2$

1 mark

From data table: MIMAS,  $r_1 = 1.86 \times 10^5$  km,  $T_1 = 0.90$  days  
DIONE,  $r_2 = 3.77 \times 10^5$  km,  $T_2 = ?$  days

1 mark

$$\left(\frac{3.77 \times 10^5}{1.86 \times 10^5}\right)^3 = \left(\frac{T_2}{0.90}\right)^2$$

1 mark

$$\therefore T_2 = \sqrt{0.120 \times 0.81} = 2.60 \text{ days}$$

1 mark

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

(4)

$$\frac{r^3}{T^2} = \frac{Gm}{4\pi^2} = \text{constant}; \therefore m = \frac{4\pi^2 r^3}{G T^2}$$

1 mark

$$m = \frac{4\pi^2 \times (1.86 \times 10^5 \times 10^3)^3}{6.67 \times 10^{-11} \times (0.90 \times 24 \times 3600)^2}$$

2 marks

$$\therefore 6.30 \times 10^{26} \text{ kg}$$

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 $\frac{G m_1 m_2}{r^2} = \frac{mv^2}{r}$ , $v = \sqrt{\frac{Gm}{r}}$	1 mark
$\therefore v \propto \frac{1}{\sqrt{r}}$	1 mark
Hence, $v_{\text{MIMAS}} > v_{\text{DIONE}}$	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 <b>incorrect</b> or student is correct suitable explanation required	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 ... $F_c$	2 mark
or...the 'apparent weight' of the object will be zero given that its net force with the probe will be zero, <b>no reaction force</b> .	1 mark

If **Incorrect** option chosen 1 + 2 = 3 marks awarded

If **Correct** option chosen 1 + 1 = 2 marks awarded

•

**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.

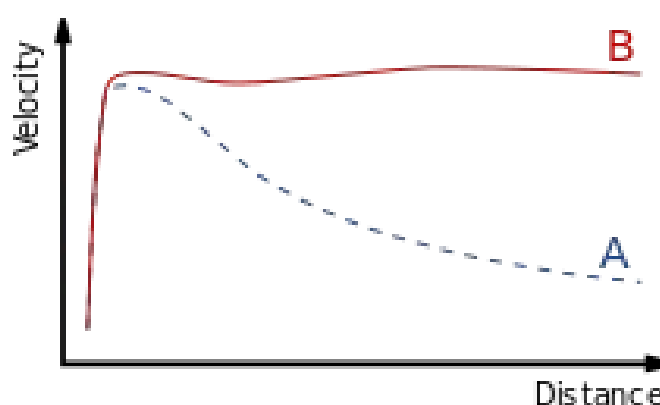
Suggested working time for this section is 40 minutes.

**Question 18****(18 marks)****EVIDENCE FOR DARK MATTER**

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

If the mass of the Milky Way galaxy was dominated by the stars and gas seen by astronomers, then the revolution speeds of the stars should vary as predicted by Newton's Laws. One expectation is that the velocity of the star should decrease the further it is from the galactic centre.

However, when the orbital speeds of stars in the Milky Way galaxy are measured we find that no matter the orbital radius, the speed of each star remains a constant  $210 \text{ km s}^{-1}$ .



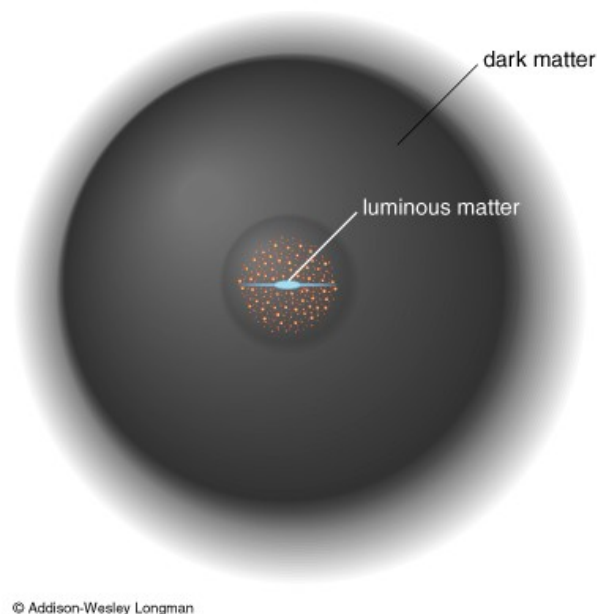
A – Predicted trend of orbital velocity against distance

B – Actual trend of orbital velocity against distance

The preferred theory to explain this result is the presence of 'dark matter'. The Milky Way (and all the universe) is believed to contain much more matter than what we have observed. In addition to stars, gas and planets, there is up to 90% more matter that cannot be seen, does not interact with matter, but does have a gravitational influence. This extra matter is

**SEE NEXT PAGE**

referred to as dark matter and its existence would explain why stars in our galaxy all have the same orbital speed. The dark matter seems to spread with a fairly uniform density much further from the galactic centre than 'standard' matter does.



The simple approach to predicting a star's orbital velocity is to approximate that the galaxy's mass is located in the centre – this is fine when looking at a star near the far edge of the galaxy. However, with 90% of a galaxy's matter being spread out much further than most stars, such an estimation no longer is appropriate.

- a) 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)

$F_g = F_c; \frac{G M_E m_s}{r^2} = \frac{m_s v^2}{r}$	1 mark
$\therefore v^2 = \frac{G M_E}{r}$	1 mark

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 ( $1/r$ ).

Star	Orbital Radius ( $r$ ) ( $\times 10^{20}$ m)	Predicted Orbital Speed ( $v_p$ ) ( $\times 10^4$ ms $^{-1}$ )	Square of Predicted Orbital Speed ( $v_p^2$ ) ( $\times 10^9$ m $^2$ s $^{-2}$ )	Inverse of Orbital Radius ( $1/r$ ) ( $\times 10^{-21}$ 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

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

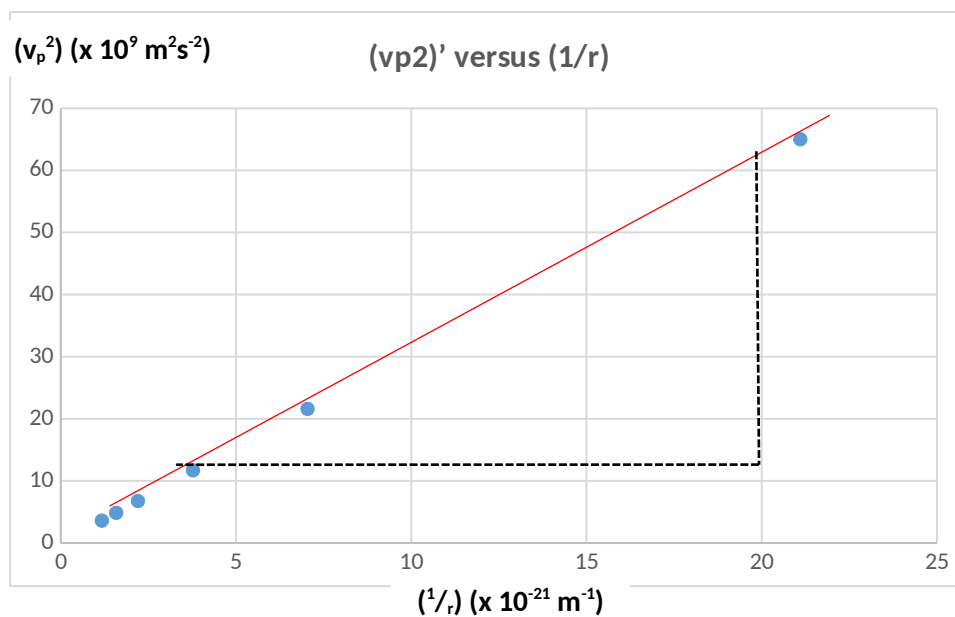
(2)

$v_p = 10.8 \times 10^4$ ms $^{-1}$ ; $(v_p)^2 = 11.7 \times 10^9$ m $^2$ s $^{-2}$	1 mark
$r = 4.54 \times 10^{20}$ m; $1/r = 2.20 \times 10^{-21}$ m $^{-1}$	1 mark

- 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.

(5)





Title relating variables	1 mark
Appropriate scales provided with labelled axes	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
$\text{Slope} = \frac{(62-10) \times 10^9}{(20-3) \times 10^{-21}} = 3.06 \times 10^{30} \text{ (range} = 3.00 - 4.00 \times 10^{30})$	1 mark
$\text{m}^3 \text{ s}^{-2}$	1 mark

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

(3)

$v^2 = \frac{Gm}{r}; \therefore v^2 r = \text{slope} = Gm$	1 mark
$3.06 \times 10^{30} = 6.67 \times 10^{-11} \times m$ $\therefore m = \frac{3.06 \times 10^{30}}{6.67 \times 10^{-11}}$ $\hookrightarrow 4.59 \times 10^{40} \text{ kg} (4.50 - 6.00 \times 10^{40} \text{ kg})$	1-2 mark

- f) By referring to gravitational forces acting on a star, explain why the presence of dark matter could manipulate the orbital speed of all stars in a galaxy to be fairly constant.

(3 marks)

States the issue with centre of mass modelling as described in article "The galaxy cannot be modelled/estimated to be a point mass when analysing the orbit of stars as they are deep within the mass of the galaxy"	1 mark
States that gravitational force of dark matter on outer edges works against "centre of mass" gravitational force "There is a significant gravitational force pulling a star 'out' of the galaxy, due to the outer edge dark matter"	1 mark
Refers back to explain how this affects orbital velocity "The distribution of dark matter results in a net gravitational force of each star in the galaxy that keeps their orbital velocity similar."	1 mark

**Question 19****(18 marks)****Metal detectors: a powerful tool to detect hidden metals**

Metal detectors are used in civil engineering, archaeology, security, mining and by hobby “detectorists”. The design is simple, and credit is given to Gustave Trouve, from France, as the inventor who used a metal detector to locate bullet fragments in patients.

Metal detectors work by transmitting a signal in the form of a magnetic field from a search coil, powered by an electrical supply. Historically, the search coil was round and operated by an AC supply as high as 20 kHz. This is true even if the metal detector was powered by a convenient portable battery- the DC of the battery must be converted into AC. The most powerful detectors produce fields as high as 0.800 T.

The magnetic field induces eddy currents in target metals, which in turn produce their own magnetic fields – this is the return signal. The return signals are detected by another coil in the metal detector which acts as a magnetometer (device for measuring magnetic fields).

Various coil shapes are used for metal detectors, each with distinct advantages. A pair of ‘D’ shaped coils arranged back to back to form a circle help minimise the effects of mineralisation in soil. Mineralisation is the tendency for some particles in the soil to mimic metals, which will alter the magnetic field signal of the metal detector. The soil in rural northern Australia, with its high iron content has a large mineralisation effect.

A key innovation of metal detector design was the introduction of pulse induction (PI). Rather than using a standard oscillating electric supply, PI detectors produce a relatively large magnetic field but over a much smaller time scale by driving large currents through the search coil. When no target metal is within proximity, the magnetic field in the magnetometer reduces at a uniform rate, producing predictable currents. In the presence of a target metal however, the magnetic field declines at a reduced rate. The time differences are small, but modern electronics allows the difference to be measured to give accurate results. The benefits of a PI mode of detection is that it penetrates deeper into the ground and is also better at ignoring mineralisation in the soil.

If you have ever been on a plane, chances are you walked through a metal detector. These use PI technology. While exact numbers are manufacturer specific, a walk-through PI detector typically sends out 100 pulses a second – each pulse lasting a few microseconds. The magnetic fields are safe to biological matter, even through repeat exposure. This makes metal detectors ideal for the detection of concealed weaponry with no adverse health effects.

(a) Describe why there are two distinct coils of wire in a metal detector.(2 marks)

Description	Marks
States use of search coil “One coil produces a magnetic field from an electrical supply”	1
States use of magnetometer coil “Another coil detects the return magnetic field to detect the presence of a target metal”	1
<b>Total</b>	<b>2</b>

- (b) State **one** advantage and **one** disadvantage described by the article when a battery is used to power a metal detector. (2 marks)

Description	Marks
States advantage of being portable "The use of a battery means the metal detector is portable and can be used away from electrical mains"	1
States disadvantage that the DC must be converted to AC "The battery supplies DC while the metal detector needs AC"	1
<b>Total</b>	<b>2</b>

- (c) Explain why a metal detector must use an AC supply. (3 marks)

Description	Marks
States difference in magnetic fields produced between AC and DC "An AC supply creates a <b>changing</b> magnetic field, DC does not."	1
States that change in magnetic field induces a current in target metal "The changing magnetic field in the presence of a conductor will induce eddy currents in the conductor"	1
States induced current produces another magnetic field which can be detected "Eddy currents in turn produce their own magnetic field. This field can be detected by the magnetometer in the metal detector"	1
<b>Total</b>	<b>3</b>

- (d) State the benefit of a pair of 'D' shaped coils and where this type of detector may be used. (2 marks)

Description	Marks
States benefit "A pair of D shaped coils minimising the effect of mineralisation"	1
States location from article "This is useful in rural northern Australia where mineralisation is high"	1
<b>Total</b>	<b>2</b>

## Question 20 (continued)

- (e) An Australian one dollar coin has a 2.50 cm diameter. A powerful metal detector operating at 20.0 kHz passes over a one dollar coin, buried just under the surface.
- (i) Calculate the maximum possible change in flux passing through the face of the coin as the metal detector field changes from 0.00 T to its peak field density in the presence of the coin. (2 marks)

Description	Marks
$\Delta \Phi = \Delta BA = B \times \pi r^2$ $\Delta \Phi = 0.800 \times \pi \times \left(\frac{0.025}{2}\right)^2 = 3.926 \times 10^{-4} = 3.93 \times 10^{-4} \text{ Wb}$	1-2
<b>Total</b>	<b>2</b>

- (ii) Using your answer from part (i), calculate the average induced emf in the coin. You may assume the coin behaves like a single coil of wire with an identical cross sectional area as the coin and that the flux changes linearly with time. (If you could not obtain an answer to part (i), you may use a value of  $4.00 \times 10^{-4} \text{ Wb}$ ) (3 marks)

Description	Marks
$t = \frac{1}{f} = \frac{1}{20.0 \times 10^3} = 5.00 \times 10^{-5} \text{ s}$ Time for go from 0 Wb to max Wb: $t = \frac{1}{4} \times 5.00 \times 10^{-5} = 1.25 \times 10^{-5} \text{ s}$	1-2
$\varepsilon = \frac{\Delta \Phi}{\Delta t} = \frac{3.93 \times 10^{-4}}{1.25 \times 10^{-5}} = 31.4 \text{ V}$	1
Solving for MAX emf is 1 mark. Solving for rms is 2 marks.	
<b>Total</b>	<b>3</b>

- (iii) State **two** reasons why your answers to part (i) and (ii) could be smaller in practice than these theoretical answers. (2 marks)

Description	Marks
One mark for each acceptable reason	
Mineralisation of the soil	1
Coin facing not perpendicular to magnetic field, increased distance from coil	1
<b>Total</b>	<b>2</b>
Other acceptable reasons but NOT effects that change current (not emf). E.g. resistance	

of coil affects current, not change in flux and emf.
--

- (f) Describe why, in the presence of a target metal, the PI magnetic field decreases at a reduced rate. (2 marks)

Description	Marks
Refers to induced field <b>opposing changes</b> (not just opposing field) "When the magnetic field is in the presence of a target metal, it will induce eddy currents that produce their own field which oppose the change in flux."	1
Relates opposition to a decreased rate of field reduction "This opposition to the change in flux causes a longer decay time of the original field."	1
<b>Total</b>	<b>2</b>