HOLY CROSS COLLEGE

SEMESTER 1, 2018

Question/Answer Booklet

12 PHYSICS

Please place your student identification label in this box

SOLUTIONS

Student Name ______________________________

Student's Teacher ______________________________

Time allowed for this paper

Reading time before commencing work: 10 minutes
Working time for paper: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor
This Question/Answer Booklet
Multiple-choice Answer Sheet
Data Sheet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid, ruler, highlighters

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

Important note to candidates

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

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Answers	11	11	50	54	30
Section Two: Problem-solving	6	6	90	90	50
Section Three: Comprehension	2	2	40	36	20
				180	100

Instructions to candidates

1. The rules for the conduct of examinations at Holy Cross College are detailed in the College Examination Policy. Sitting this examination implies that you agree to abide by these rules.

2. Write your answers in this Question/Answer Booklet.

3. Working or reasoning should be clearly shown when calculating or estimating answers.

4. You must be careful to confine your responses to the specific questions asked and to 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 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(s) that you are continuing to answer at the top of the page.

6. Answers to questions involving calculations should be ***evaluated and given in decimal form.*** It is suggested that you quote all answers to ***three significant figures***, with the exception of questions for which estimates are required. Despite an incorrect final result, credit may be obtained for method and working, providing these are ***clearly and legibly set out***.

7. Questions containing the instruction *"**estimate**"* may give insufficient numerical data for their solution. Students should provide appropriate figures to enable an approximate solution to be obtained. Give final answers to a maximum of ***two significant figures*** and include appropriate units where applicable.

8. Note that when an answer is a vector quantity, it must be given with magnitude and direction.

9. In all calculations, units must be consistent throughout your working.

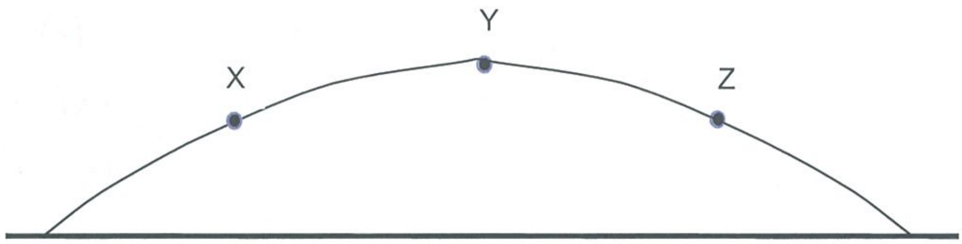
Section One: Short response **30% (54 Marks)**

This section has **11** questions. Answer **all** questions.

Suggested working time: 50 minutes.

Question 1 **(4 marks)**

The diagram below shows the trajectory of a projectile as it travels from left to right (i.e. from X to Y to Z).



	At 'X'	At 'Y'	At 'Z'
A	↙	←	↖
B	↓	↓	↓
C	↗	→	↘
D	↓	↑	↓
E	↓	0	↑
F	↑	0	↓

(a) Which set of vectors (A – F) best illustrates the acceleration experienced by the ball in flight (ignore air resistance)? (1 mark)

B

(b) Which set of vectors (A – F) best illustrates the instantaneous velocity of the ball in flight (ignore air resistance)? (1 mark)

C

(c) Which set of vectors best illustrates the vertical component of the ball's velocity in flight (ignore air resistance)? (1 mark)

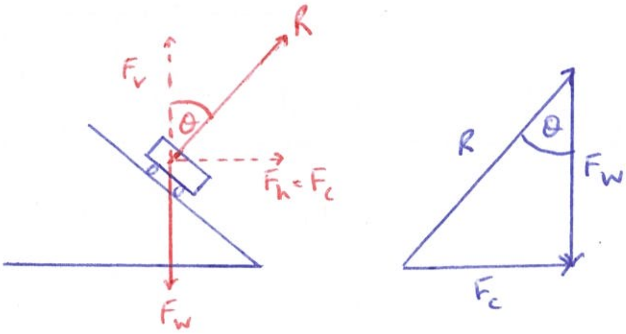
F

(d) If air resistance is taken into account, which set of vectors best illustrates the force due to this air resistance experienced by the ball in flight? (1 mark)

A [1 mark each]

Question 2 **(5 marks)**

The banking of roads can help cars navigate high speed bends safely. Derive an equation to calculate the angle to the horizontal that a road should be inclined for a 1.50×10^3 kg car to negotiate a horizontal circular path with a radius of 2.50×10^2 m at 1.10×10^2 kmh^{-1}. (Ignore the frictional effects of the road on the car.)



$$\tan\theta = \frac{F_c}{F_w}$$

$$= \frac{mv^2}{r} \times \frac{1}{mg} \quad (1)$$

$$\Rightarrow \tan\theta = \frac{v^2}{rg} \quad (1)$$

$$= \frac{(30.6)^2}{(9.80)(2.50 \times 10^2)} \quad (1)$$

Conversion (1)

$$= 0.3822$$

$$\Rightarrow \theta = 20.9^\circ \quad (1)$$

Question 3 **(5 marks)**

The table below shows some data for two planets orbiting a distant star in another galaxy. Kepler's Third Law relates the radius and period of orbit for planets orbiting a star.

Planets	**Mass (kg)**	**Orbital radius (m)**	**Radius of planet (m)**	**Length of one day (s)**	**Orbital period (s)**
Alpha	1.15×10^{25}	4.50×10^{11}	7.90×10^6	9.60×10^4	8.50×10^7
Beta	1.60×10^{24}	9.00×10^{11}	3.80×10^6	4.80×10^4	-

Use this information and appropriate data from the table to calculate the value for the orbital period of Beta.

$$r^3 = \frac{G M_{star} T^2}{4\pi^2}$$

$$\Rightarrow \frac{r^3}{T^2} = \frac{G M_{star}}{4\pi^2} = \text{constant} \quad (1)$$

[Chooses r and T data - 1 mark]

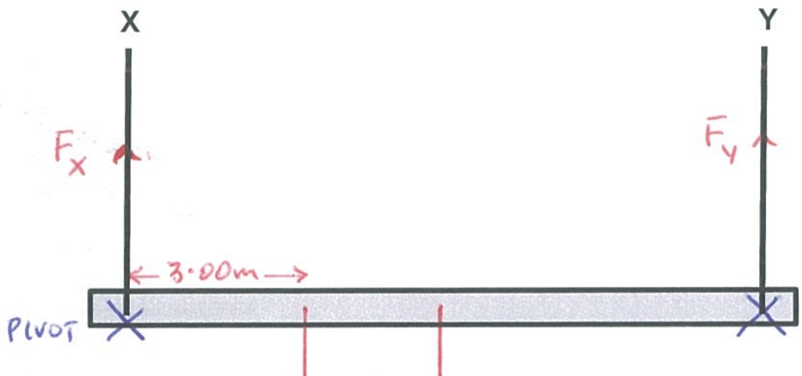
$$\therefore \frac{r_{Alpha}^3}{T_{Alpha}^2} = \frac{r_{Beta}^3}{T_{Beta}^2} \quad (1)$$

$$\Rightarrow \frac{(4.50 \times 10^{11})^3}{(8.50 \times 10^7)^2} = \frac{(9.00 \times 10^{11})^3}{T_{Beta}^2} \quad (1)$$

$$\Rightarrow T_{Beta} = 2.40 \times 10^8 \text{ s} \quad (1)$$

Question 4 **(5 marks)**

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



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

833N 343N [Calculation of weights - 1 mark]

Take X as pivot

$\Sigma CM = \Sigma ACM$

$\Rightarrow (833)(3.00) + (343)(5.00) = F_y(10.0)$ (1)

$\Rightarrow \underline{F_y = 421\text{ N}}$ (1)

$\Sigma F_v = 0$

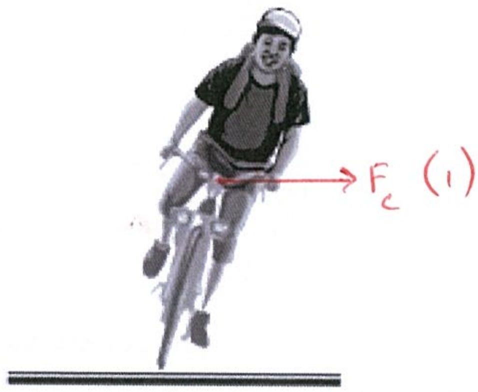
$\Rightarrow F_x + 421 = 833 + 343$ (1)

$\Rightarrow \underline{F_x = 755\text{ N}}$ (1)

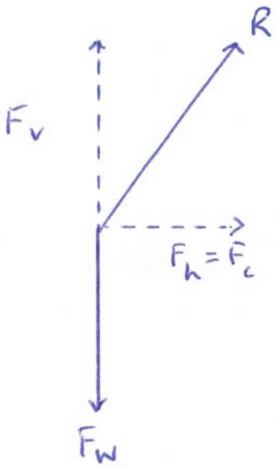
Question 5 **(4 marks)**

The diagram shows a cyclist rounding a circular bend on his bicycle.

(a) Show with an arrow the nett force on him as he rounds the bend. (1 mark)



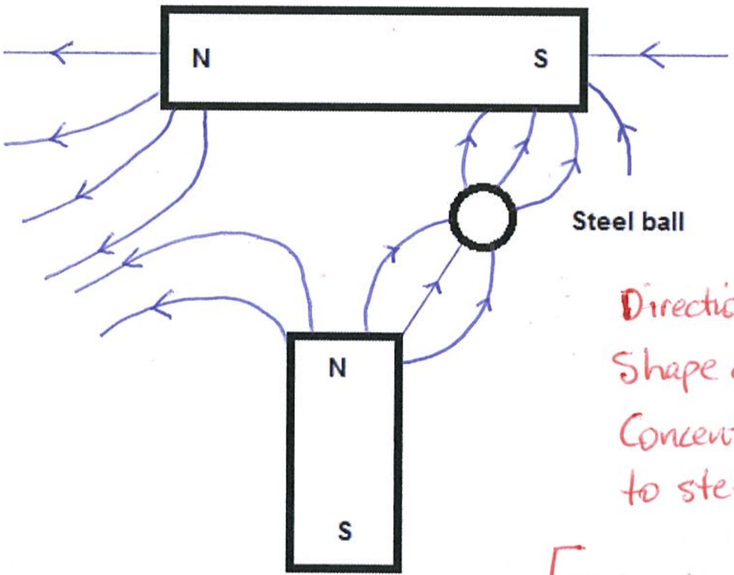
(b) Explain why the rider must lean his bicycle as he takes the corner. (3 marks)



- If the rider doesn't lean, the tyres won't generate enough sideways friction to make it around the corner. (1)
- By leaning, the reaction force has a horizontal component. (1)
- This provides the centripetal force required to safely make it around the corner. (1)

Question 6 **(5 marks)**

(a) On the following diagram, draw the magnetic fields between the magnets and the steel ball. (3 marks)

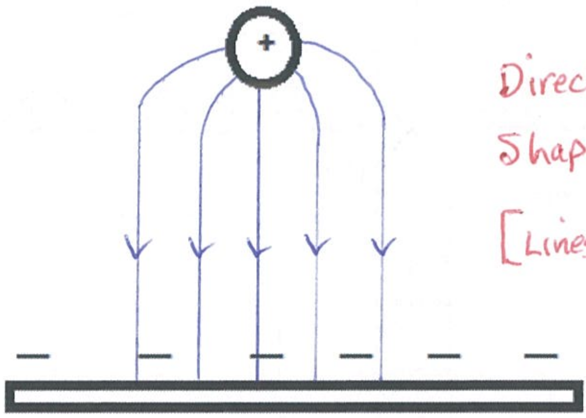


Direction of field (1)
Shape of fields (1)
Concentration of field to steel ball (1)

[Lines touch - 1 mark off]

See next page

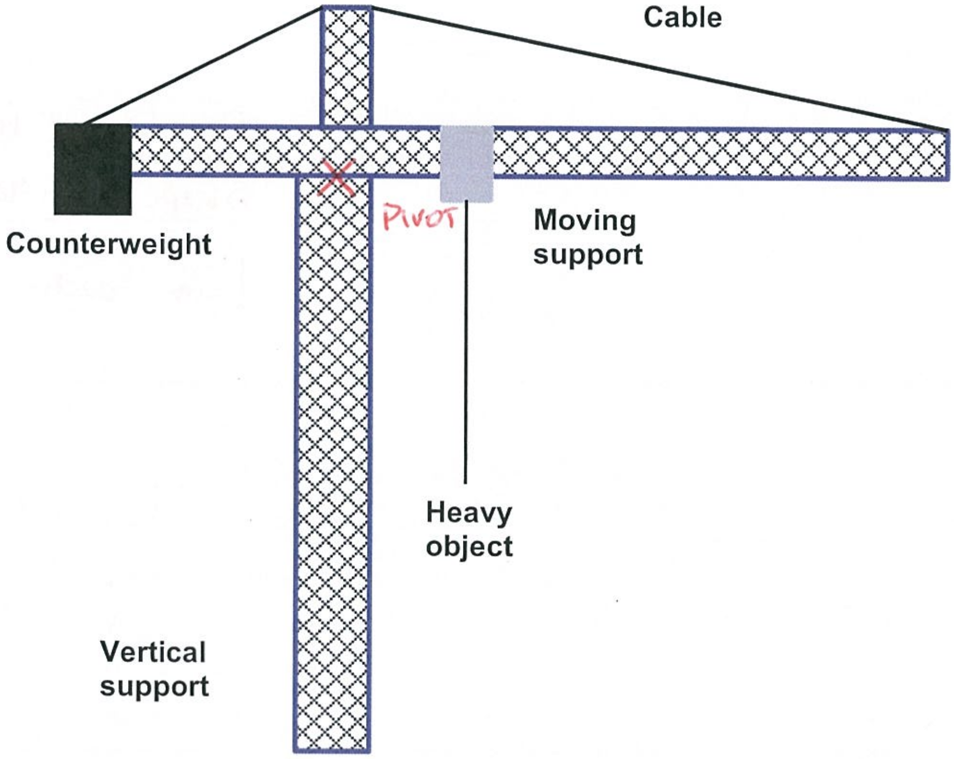
(b) Draw the electric field between the negative plate and the charged sphere in the following diagram. (2 marks)



Direction of field (1)
Shape of field (1)
[Lines touch - 1 mark off]

Question 7 **(4 marks)**

The diagram below shows a crane supporting a "heavy object" as shown. The "moving support" can be moved towards the "vertical support" or away from it.



(a) Explain the role of the "counterweight" and "cable" in this structure. (2 marks)

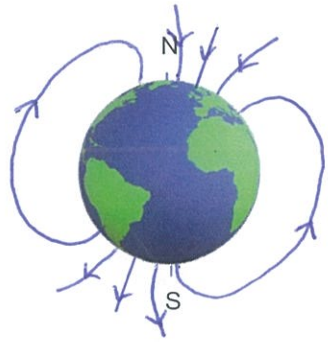
- The heavy object and the arm of the crane provide clockwise moments around the pivot on the vertical support. (1)
- The counterweight and the tension in the cable provide anticlockwise moments about the pivot and keep the crane in mechanical equilibrium. (1)

(b) Explain how the tension in the cable changes if the 'heavy object" is moved to the right by the "moving support". (2 marks)

- Moving the heavy object to the right increases the clockwise moments. (1)
- The tension in the cable must increase to increase the anticlockwise moments to maintain equilibrium. (1)

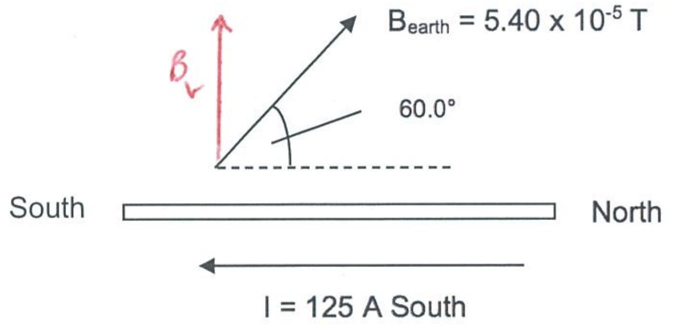
Question 8 **(7 marks)**

(a) On the diagram, show the magnetic field of the Earth. (3 marks)



(b) An alternating current of 125 A flows a 50.0 m span of transmission cable that is orientated in a north-south direction. The transmission cable is located at a point in Western Australia where the Earth's magnetic field intensity is 5.40×10^{-5} T at 60.0 ° angle of dip. Assume the cable is horizontal along its length.

At the instant that the current is flowing towards South, what would be the force acting on the length of the wire? (4 marks)



Looking west

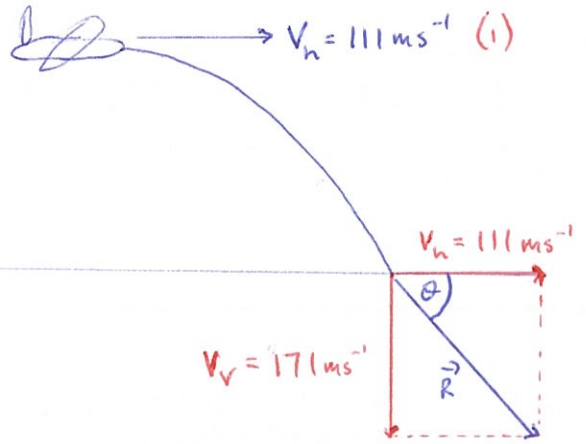
$F = I l B_v$ Correct component (1)

$= (125)(50.0)(5.40 \times 10^{-5} \cos 30.0°)$ (1)

$= \underline{0.292 \text{ N} \quad \text{West}}$
(1) (1)

Question 9 **(5 marks)**

An aeroplane is being flown with its maximum horizontal speed of 4.00×10^2 kmh^{-1} at an altitude of 1.50×10^3 m. A piece of the plane becomes dislodged and drops off it whilst it is in motion.
If air resistance can be ignored, calculate the velocity of this piece of the plane when it lands on the ground (in ms^{-1}).



+VE

<u>VERTICALLY</u>

$v = ?$
$u = 0\ ms^{-1}$
$a = 9.80\ ms^{-2}$
$t = ?$
$s = 1.50 \times 10^{3}\ m$

$v^2 = u^2 + 2as$
$= 0 + 2(9.80)(1.50 \times 10^3)$ (1)
$\Rightarrow v = 171\ ms^{-1}$ down (1)

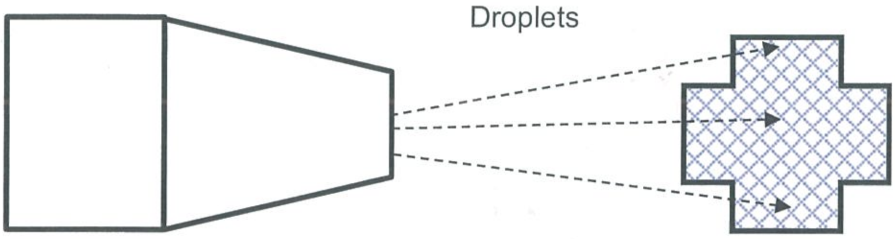
$\vec{R} = \sqrt{(111)^2 + (171)^2}$
$= 204\ ms^{-1}$ (1)

$\tan\theta = \frac{171}{111}$
$\Rightarrow \theta = 57.0^\circ$ (1)

$\therefore$ V_{impact} = <u>$204\ ms^{-1}$ at 57.0° to the horizontal</u>

Question 11 **(5 marks)**

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



The magnitude of the charge on each droplet is 2.00×10^{-10} C and, on average, they have a diameter of about 1.50×10^{2} μm.

(a) State whether electrons were added to or removed from the droplets of paint by the spray gun. (1 mark)

• Removed (1)

(b) Calculate the electrostatic force acting between adjacent droplets if their surfaces are virtually touching. (Assume the distance apart is the average diameter of a drop.) (4 marks)

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

$$= \frac{1}{4\pi(8.85\times10^{-12})} \cdot \frac{(2.00\times10^{-10})^2}{(1.50\times10^{-4})^2} \quad (1)$$

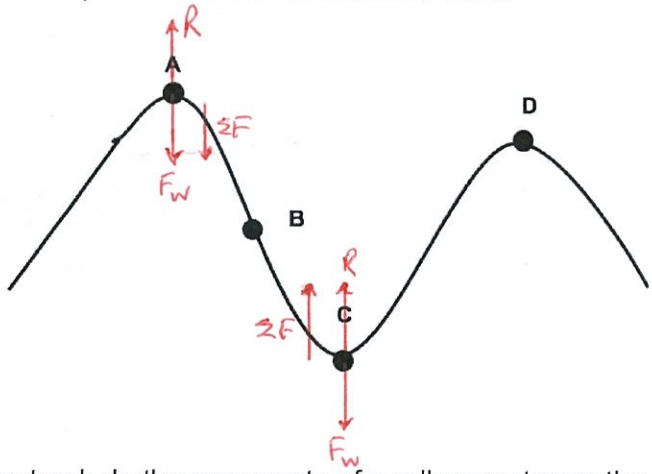
Conversion (1)

$$= \underline{1.60\times10^{-2}\ \text{N}}\ \underline{\text{repulsion}}$$

(1) (1)

Question 10 **(6 marks)**

The diagram below shows four positions on a rollercoaster track.



(a) At which point on the track do the occupants of a rollercoaster on the track experience MAXIMUM normal force? Justify your answer. (3 marks)

• Point C (1)

$$\Sigma F = F_c = R - F_W$$

$$\Rightarrow R = F_c + F_W \quad (1)$$

∴ Apparent weight R is greater than the real weight F_W by an amount F_c (due to the circular motion). (1)

(b) The occupants of the rollercoaster feel 'weightless' at A. Derive an expression relating the instantaneous speed *v* of the rollercoaster and the radius of the track *r* at A to cause this sensation. (3 marks)

$$\Sigma F = F_c = F_W - R$$

$$\text{If } R = 0 \Rightarrow F_c = F_W \quad (1)$$

$$\Rightarrow \frac{\cancel{m}v^2}{r} = \cancel{m}g \quad (1)$$

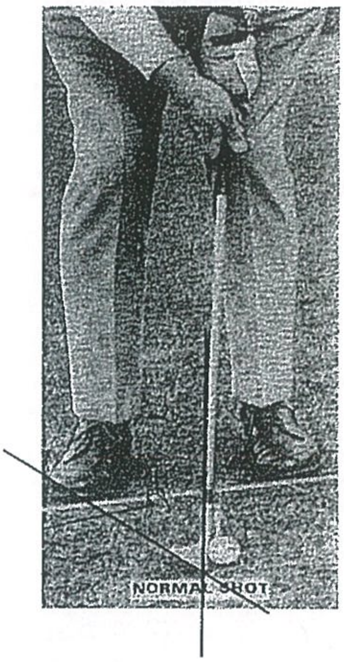
$$\Rightarrow v = \sqrt{gr} \quad (1)$$

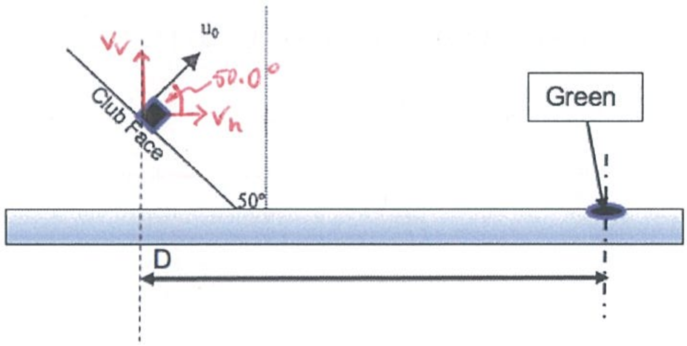
Section Two: Problem-solving **50% (90 Marks)**

This section has **six (6)** questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 90 minutes.

Question 12 **(15 marks)**





A wedge is a golf club designed to hit the ball over short distances. When correctly hit, the ball does not roll when it arrives at its destination, the green. The green, or putting green, is the culmination of a golf hole, where the flagstick and hole are located. Getting the golf ball into the hole on the putting green is the object of the game of golf.

To do this, the club face is lofted. This means that the club face is inclined at 50.0° to the vertical as shown in the diagram above **(not drawn to scale).**

Assume that when hit, the ball leaves the club face **at right angles** to the face. The **horizontal distance of ball from launch point to putting green** is shown as **D**.

(a) Write expressions giving the horizontal and vertical components of the ball's initial velocity $\boldsymbol{u_0}$. (2 marks)

$V_v = u_0 \cos 40.0^\circ$ (1)

$V_h = u_0 \cos 50.0^\circ$. (1)

(b) In terms of $\boldsymbol{u_0}$, $\boldsymbol{t}$ or $\boldsymbol{D}$, write appropriate equations to calculate each of the following:

(i) the horizontal distance travelled by the ball after a time $\boldsymbol{t}$. (2 marks)

$s_h = v_h t$ (1)

$= \underline{u_0 \cos 50.0^\circ t}$ (1)

(ii) the height of the ball at any time t. (2 marks)

$v = ?$
$u = -u_0 \cos 40.0^\circ \, ms^{-1}$ (1)
$a = 9.80 \, ms^{-2}$
$t = t$
$s = ?$

$\downarrow +ve$

$$s = ut + \frac{1}{2}at^2$$
$$= -u_0 \cos 40.0^\circ t + \frac{1}{2}(9.80)t^2$$
$$\Rightarrow \underline{s_v = -u_0 \cos 40.0^\circ t + 4.90t^2} \quad (1)$$

(iii) the horizontal distance from the ball to the green at any time t. (2 marks)

$x = D - u_0 \cos 50.0^\circ t$ where x = distance from ball to green.

Tiger Smith, a champion golfer, 1.00×10^2 m from the hole, aims and hits his ball. Remarkably, it lands nicely in the hole, which is in the centre of the green. His wedge has a loft of 50.0° to the vertical.

(c) With equations derived in (b) or otherwise, find:

(i) the velocity with which the ball must leave the club. (2 marks)

<u>HORIZONTALLY</u>

$$s_h = u_0 \cos 50.0^\circ t$$
$$\Rightarrow t = \frac{1.00 \times 10^2}{u_0 \cos 50.0^\circ}$$

<u>VERTICALLY</u>

$$s_v = -u_0 \cos 40.0^\circ t + 4.90t^2$$

Sub. for t: $\Rightarrow 0 = -u_0 \cos 40.0^\circ \left(\frac{1.00 \times 10^2}{u_0 \cos 50.0^\circ}\right) + \frac{4.90(1.00 \times 10^2)^2}{u_0^2 \cos^2 50.0^\circ}$ (1)

$$\Rightarrow 1.192 \times 10^2 = \frac{1.186 \times 10^5}{u_0^2}$$

$$\Rightarrow \underline{u_0 = 31.5 \, ms^{-1} \text{ at right angles to the face}} \quad (1)$$

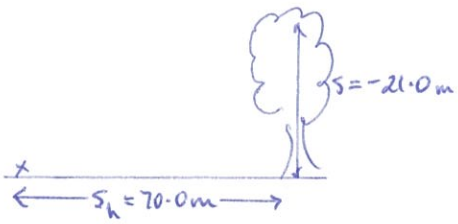
(ii) the time the ball is in the air. (2 marks)

$$t = \frac{1.00 \times 10^2}{u_0 \cos 50.0^\circ}$$

$$= \frac{1.00 \times 10^2}{31.5 \cos 50.0^\circ} \quad (1)$$

$$= \underline{4.94\,s} \quad (1)$$

(d) There is a large tree, 21.0 m tall, between Tiger and the green. If the tree is 70.0 m from Tiger, determine with calculations if the ball will clear the tree. (3 marks)



HORIZONTALLY $s_h = u_0 \cos 50.0^\circ\, t$

$$\Rightarrow t = \frac{70.0}{31.5 \cos 50.0^\circ}$$

$$= \underline{3.46\,s} \quad (1)$$

VERTICALLY $s_v = -u_0 \cos 40.0^\circ\, t + 4.90t^2$

$$= -(31.5 \cos 40.0^\circ)(3.46) + 4.90(3.46)^2 \quad (1)$$

$$= -24.8\,m$$

∴ Ball clears the tree by 3.8 m (1)

Question 13 **(15 marks)**

The Kepler NASA mission aims to search for planets orbiting stars in other solar systems. The star named Kepler-20 has been observed to have several planets orbiting it. Kepler-20 is 950 light-years from Earth.

Information about Kepler-20 and some of the planets orbiting it is summarised in the table below.

Astronomical object	Radius	Mass	Orbital period around Kepler 20
Star – Kepler 20	$0.944 \times \text{radius}_{SUN}$	$0.912 \times \text{mass}_{SUN}$	
Planet – Kepler 20b	$2.40 \times \text{radius}_{EARTH}$		290 days
Planet – Kepler 20e	$0.87 \times \text{radius}_{EARTH}$		6.1 days
Planet – Kepler 20f	$1.03 \times \text{radius}_{EARTH}$		19.6 days

(a) A light-year is an astronomical unit of distance. It is defined as the distance travelled by light in one year. Calculate the distance from Kepler-20 to Earth in kilometres. (2 marks)

$s = vt$

$= (950)(3.00\times10^{8})(365.25)(24.0)(3.60\times10^{3})$ (1)

$= \underline{8.99\times10^{15} \text{ km}}$ (1)

(b) Astronomers express the mass of Kepler-20 as $(0.912 \pm 0.035) \times \text{mass}_{SUN}$. Calculate the maximum value astronomers expect for the mass of Kepler-20. (2 marks)

$m = (0.912 + 0.035)(1.99\times10^{30})$ (1)

$= \underline{1.88\times10^{30} \text{ kg}}$ (1)

(c) Calculate the orbital radius of Kepler-20e around Kepler-20. You should use the mass for Kepler-20 quoted in the table and assume the orbit is circular. (4 marks)

$r^3 = \dfrac{GMT^2}{4\pi^2}$

(1) (1)

$\Rightarrow r = \sqrt[3]{\dfrac{(6.67\times10^{-11})(0.912\times1.99\times10^{30})(6.1\times24.0\times3.60\times10^{3})^2}{4\pi^2}}$ (1)

$= \underline{9.48\times10^{9} \text{ m}}$ (1)

(d) The mass of Kepler-20b is unknown but it has been speculated that it may have a density similar to that of Earth, 5520 kgm^{-3}. Calculate the surface gravity of Kepler-20b if its density is 5520 kgm^{-3}. (4 marks)

Reminder: $density = \frac{mass}{volume}$

$volume\ of\ a\ sphere = \frac{4}{3}\pi r^3$

$$D = \frac{m}{V}$$

$$\Rightarrow m = (5520)\frac{4}{3}\pi(2.40 \times 6.37 \times 10^6)^3 \quad (1)$$

$$= 8.262 \times 10^{25}\ kg. \quad (1)$$

$$g = \frac{GM}{r^2}$$

$$= \frac{(6.67 \times 10^{-11})(8.262 \times 10^{25})}{(2.40 \times 6.37 \times 10^6)^2} \quad (1)$$

$$= \underline{23.6\ ms^{-2}} \quad (1)$$

The Kepler mission is particularly concerned with finding planets that lie within the habitable zones of stars. A planet in a star's habitable zone receives the right amount of energy from the star to maintain liquid water on its surface, provided it also has an appropriate atmosphere.

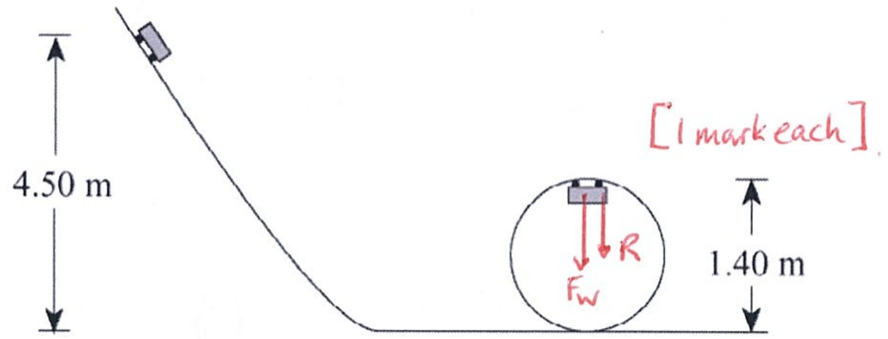
(e) By comparing the Kepler-20 system and our own solar system, suggest which planet in the Kepler-20 system is most likely to lie in the habitable zone. Explain your answer. (3 marks)

- Kepler-20b (1)
- Small orbital periods ⇒ planet too close to the star (too hot). (1)
- Kepler-20b has a similar orbital period to Earth - more likely to be far enough away to have liquid water. (1)

Question 14 **(15 marks)**

An astronaut on a distant planet performs a "loop-the-loop" experiment. She releases a 1.30 kg cart from a height of 4.50 m. Assume any friction between cart and track is negligible. The gravitational field strength of the distant planet is g_{planet}. The speed of the cart at the top of the circular loop is v_{top}. It is observed that the track exerts a normal reaction force of 21.0 N on the cart at the top of the loop.

(a) Draw and label clearly the forces acting on the cart at the top of loop. (2 marks)



(b) The astronaut derived the equation $(v_{top})^2 = 5.30\ g_{planet}$. Using Physics principles and calculations, justify clearly if you agree with the astronaut. (5 marks)

$E_T(top) = E_T(loop)$

$\Rightarrow E_p = E_p + E_k$ (1)

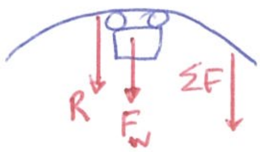
$\Rightarrow \cancel{m}gh = \cancel{m}gh' + \frac{1}{2}\cancel{m}v^2$ (1)

$\Rightarrow 4.50g = 1.40g + \frac{1}{2}v^2$ (1)

$\Rightarrow v^2 = 6.20g$ (1)

$\therefore$ Disagree (1)

(c) Calculate the gravitational field strength on the distant planet using your Physics understanding of vertical circular motion. (4 marks)



$$\Sigma F = F_c = F_w + R$$

$$\Rightarrow \frac{mv^2}{r} = mg + R$$

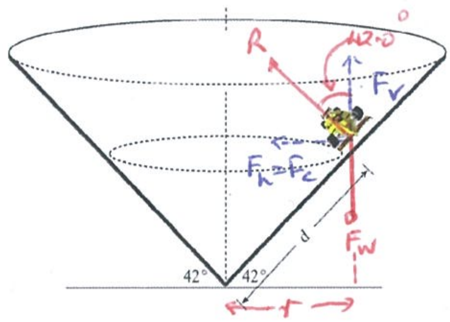
$$\Rightarrow \frac{(1.30)(6.20g)}{(0.70)} = 1.30g + 21.0$$

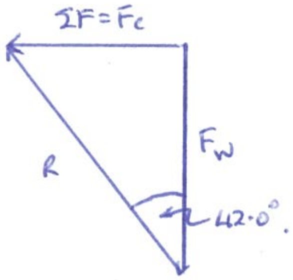
$$\Rightarrow 10.2g = 21.0$$

$$\Rightarrow g = 2.06 \text{ ms}^{-2}$$

(d) The astronaut has returned to Earth and is designing a racetrack. The racetrack surface has the shape of an inverted cone on which cars race in a horizontal circle as shown.

For a steady speed of 29.0 ms^{-1}, calculate the distance ***d*** a driver should drive her car if she wishes to stay on a circular path without friction? (4 marks)



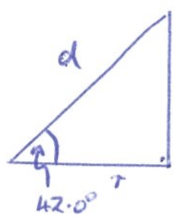


$$\tan 42.0° = \frac{F_c}{F_W} = \frac{mv^2}{r} \times \frac{1}{mg}$$

$$\Rightarrow r = \frac{v^2}{g \tan 42.0°} \quad (1)$$

$$= \frac{(29.0)^2}{(9.80)(\tan 42.0°)} \quad (1)$$

$$= 95.31 \text{ m} \quad (1)$$



$$\cos 42.0° = \frac{r}{d}$$

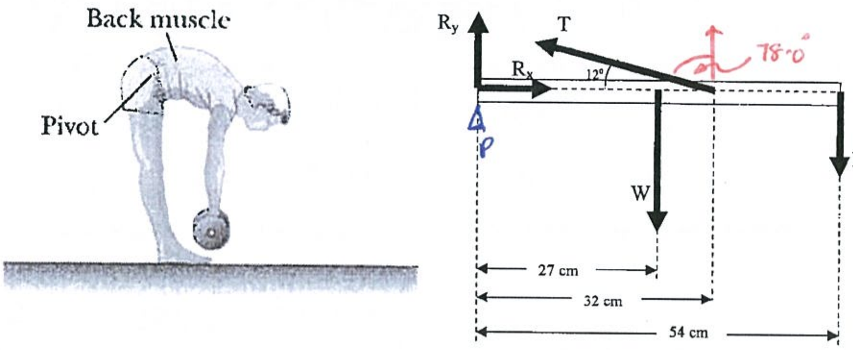
$$\Rightarrow d = \frac{(95.31)}{\cos 42.0°}$$

$$= \underline{128 \text{ m}} \quad (1)$$

Question 15 **(15 marks)**

A person bending forward to lift a load with his "back" rather than with his "knees" can be injured by the large forces acting on the back muscles and vertebrae.

To consider the magnitude of the forces involved in such poor lifting practices, consider the simplified diagram for a person lifting a 25.0 kg load (***L***) below.



The spine and upper body are represented as a uniform horizontal rod of 41.5 kg (***W***) pivoted at the base of the spine (***P***). The erector spinalis muscle acts at an angle to horizontal of 12.0° to maintain the position of the back. The components of the reaction force ($\boldsymbol{R_x}$ and $\boldsymbol{R_y}$) are also shown on diagram.

(a) Determine the tension (***T***) in the erector spinalis muscle while in this position. (4 marks)

Take moments about P

$\Sigma CM = \Sigma ACM$ (1)

$\Rightarrow (407)(0{\cdot}270) + (245)(0{\cdot}540) = (T\cos 78{\cdot}0)(0{\cdot}320)$ (2)

$\Rightarrow \underline{T = 3{\cdot}64 \times 10^3\ N}$ (1)

(b) Determine the horizontal component of the reaction force on the spine ($\boldsymbol{R_x}$) while in this position. (2 marks)

$\Sigma F_h = 0$

$\Rightarrow R_x = 3{\cdot}64 \times 10^3 \cos 12{\cdot}0°$ (1)

$= \underline{3{\cdot}56 \times 10^3\ N \text{ right}}.$ (1)

(c) Determine the vertical component of the reaction force on the spine ($\boldsymbol{R}_Y$) while in this position. (3 marks)

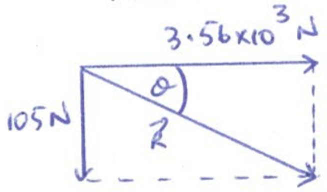
$$\Sigma F_V = 0$$

$$\Rightarrow R_Y + 3.64\times10^3 \cos 78.0^\circ = 407 + 245 \quad (1)$$

$$\Rightarrow R_Y = -105\text{ N} \quad (1)$$

$$\therefore \underline{R_Y = 105\text{ N down}}. \quad (1)$$

(d) Determine the reaction force on the spine ($\boldsymbol{R}$) (which is not shown on the diagram) while in this position. (3 marks)



$$\vec{R} = \sqrt{(3.56\times10^3)^2 + (105)^2}$$

$$= 3.56\times10^3\text{ N} \quad (1)$$

$$\tan\theta = \frac{105}{3.56\times10^3}$$

$$\Rightarrow \theta = 1.69^\circ \quad (1)$$

$$\therefore \underline{\vec{R} = 3.56\times10^3\text{ N at } 1.69^\circ \text{ below the horizontal}}. \quad (1)$$

(e) Describe and justify ***three*** strategies using physics principles for a person to lift heavy objects. (3 marks)

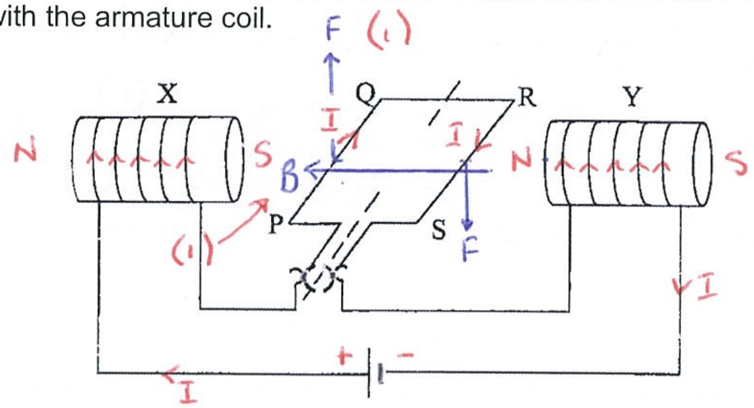
- Keep the load close to the feet – reduces the turning effect so back muscles exert less force. (1)
- Keep back straight – more upright so load is closer to the feet. (1)
- Bend knees – become more upright and the load is closer to the feet. (1)

$\tau_2 < \tau_1$

[Could use suitable diagrams]

Question 16 **(15 marks)**

The schematic diagram below shows an electric motor that produces a magnetic field from field coils on either side of the armature coil. It is called a series-wound motor because the field coils X and Y are wired in series with the armature coil.



- The armature coil of the motor has 150 turns.
- Side PQ is 5.00 cm long and side QR is 4.00 cm long.
- A 12.0 V supply provides a current of 0.750 A and generates a 0.0950 T magnetic field across the armature coil.

(a) (i) Draw and label the direction of the magnetic field ***B***. (1 mark)

(ii) Draw and label the direction of the force ***F*** on side PQ. (1 mark)

(b) Calculate the force on the side RS of the armature. (3 marks)

$F = N \times I \ell B$ (1)

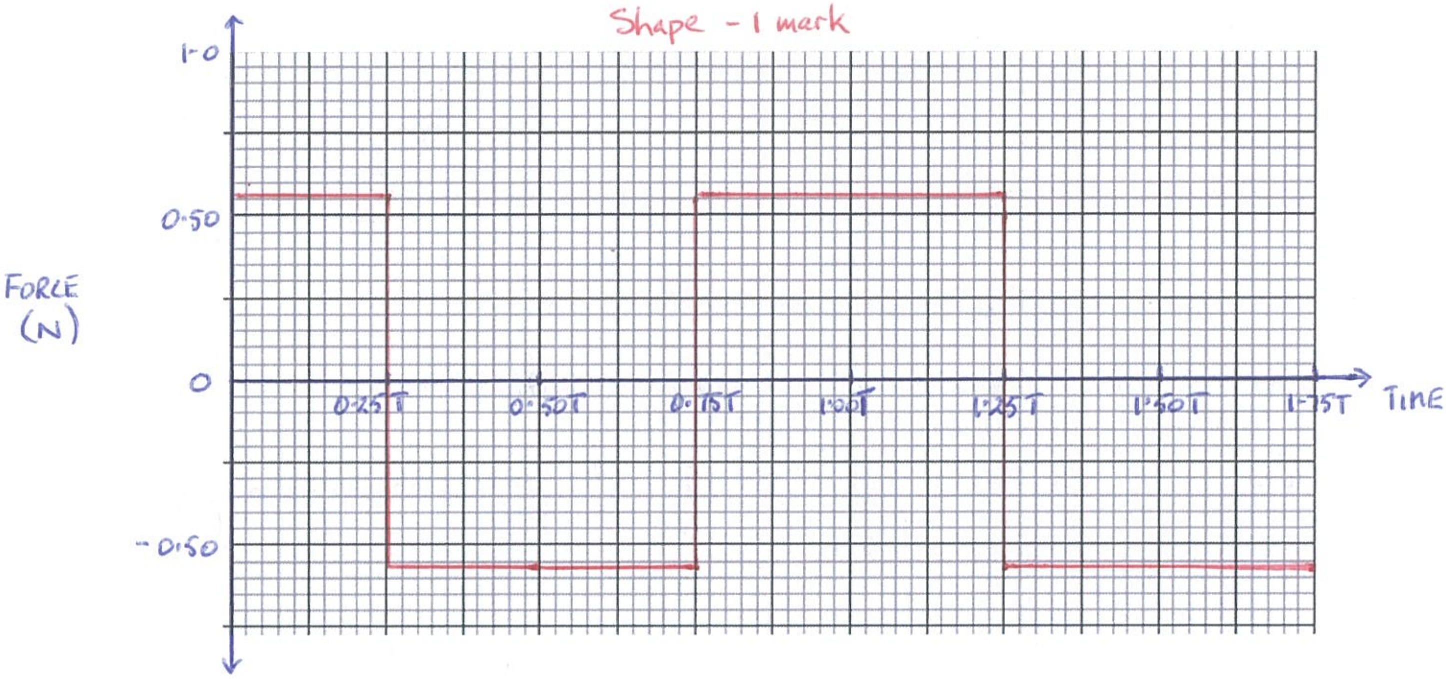
$= (150)(0.750)(0.0500)(0.0950)$ (1)

$= \underline{0.534 \text{ N downwards}}$ (1)

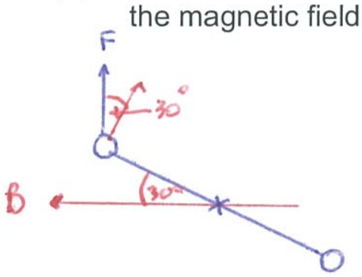
(c) Sketch below the graph of the force on the side PQ (vertical axis) versus time ***t*** (horizontal axis) for this simple motor.

For the time axis, show time from time t = 0 to 1.75 ***T***, where ***T*** is the motor's period. (2 marks)

Labelled axes - 1 mark
Shape - 1 mark



(d) Determine the torque produced when the plane of the armature coil is at an angle of 30.0° to the magnetic field. (3 marks)



$M = 2 \times F\cos 30.0° \, r$ (1)

$= 2(0.534 \cos 30.0°)(0.0200)$ (1)

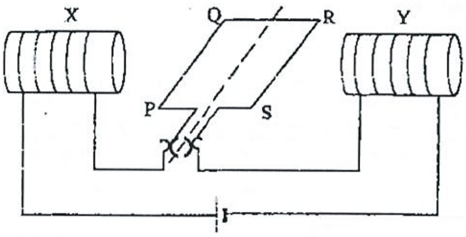
$= \underline{1.85 \times 10^{-2} \text{ Nm clockwise}}$ (1)

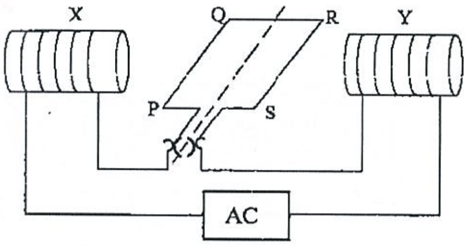
(e) Describe and explain two practical ways in which the motor can be modified to produce a greater torque. (2 marks)

- Increase number of coils.
- Increase current.
- Use curved poles - radial field.
- Add iron core to concentrate the magnetic field.

[Any 2 - 2 marks]

(f) One advantage of this type of motor is that it works on either AC or DC electrical supplies. Using either or both diagrams below as part of your answer, explain why and how this motor will turn with respect of the type of electrical supply provided. (3 marks)

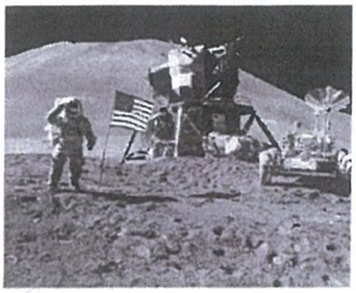




- Field coils are in series with one another. (1)
- When the current reverses in one, it does in the other. (1)
- Thus, when the direction of B changes, the force on each side remains in the same direction. (1)

Question 17 **(15 marks)**

The Earth's moon has always been of primary interest to astronomers and this led to one of the most significant achievements of the twentieth century – humankind landing on the Moon.



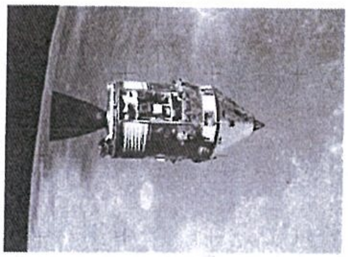

(a) Calculate the period for the Moon in orbit around the Earth. (5 marks)

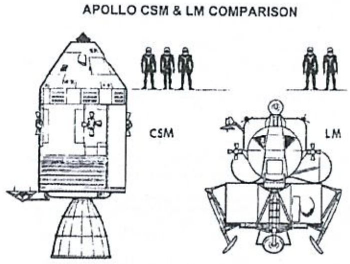
$$T^2 = \frac{4\pi^2 r^3}{GM_E} \quad (1)$$

$$\Rightarrow T = \sqrt{\frac{4\pi^2 (3.84\times10^8)^3}{(6.67\times10^{-11})(5.97\times10^{24})}} \quad (3)$$

$$= \underline{2.37\times10^6 \text{ s}} \quad (1)$$

(b) An important aspect of the Apollo lunar landing missions was the return of the Lunar Landing Module (LM) to the orbiting Command Service Module (CSM) before returning the astronauts to Earth.





Determine the height above the Moon's surface for which an orbit will effectively allow a Command Service Module to remain "fixed" above the Landing Module situated on the Moon's surface. (Assume the period of rotation of the Moon is 27.3 days.) (6 marks)

$$r^3 = \frac{G M_m T^2}{4\pi^2} \quad (1)$$

$$\Rightarrow \quad r = \sqrt[3]{\frac{(6.67\times10^{-11})(7.35\times10^{22})(27.3\times24.0\times3.60\times10^3)^2}{4\pi^2}} \quad (2)$$

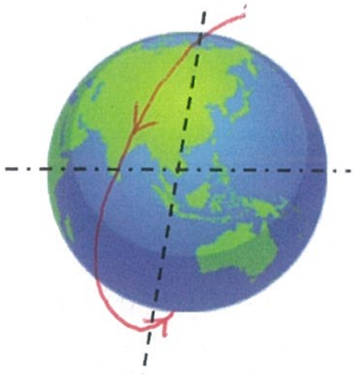
$$= 8.84\times10^7 \text{ m} \quad (1)$$

$$h = r - r_{moon}$$

$$= 8.84\times10^7 - 1.74\times10^6 \quad (1)$$

$$= \underline{8.67\times10^7 \text{ m}} \quad (1)$$

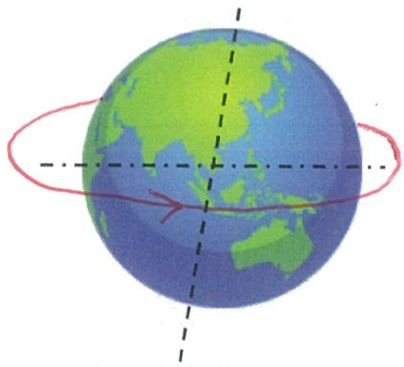
(c) On the diagrams below, carefully illustrate and indicate direction of a polar orbit and a geostationary orbit. (4 marks)



Polar Orbit

Circular orbit - 1 mark

Around Earth's centre - 1 mark



Geostationary Orbit

West to east - 1 mark

Above the equator - 1 mark

Section Three: Comprehension **20% (36 Marks)**

This section has two (2) questions. Write your answers in the spaces 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.

Suggested working time: 40 minutes.

Question 18 **(18 marks)**

The Mass of an Electron

A tuning eye tube, also known as a magic eye tube, is a vacuum tube where electrons are released from a hot cathode at the centre. The electrons are then accelerated towards two anodes. The anodes form a semi-circular funnel shape around the cathode. These electrons are accelerated towards the anode by an accelerating voltage (V_a). Refer to Figure 1 for more details on the structure of this tube.

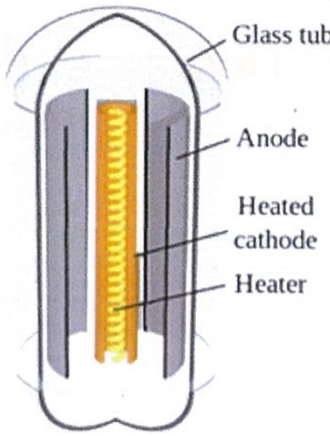


Figure 1: Tuning eye tube

When the accelerated electrons hit the anode, fluorescence occurs, releasing a pale green light. The pattern that the fluorescent light forms is that of two fan-shaped beams of light with straight edges, as shown in Figure 2a and 2b below.

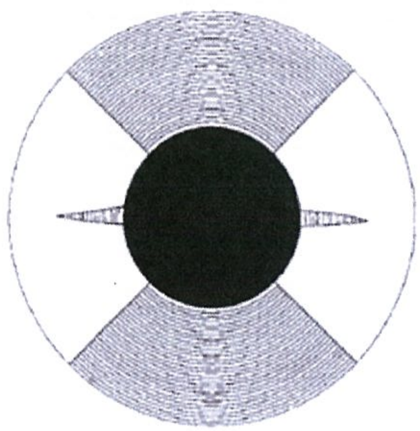


Figure 2a: Top view of the fluorescent pattern when the tuning eye tube is not exposed to a magnetic field.

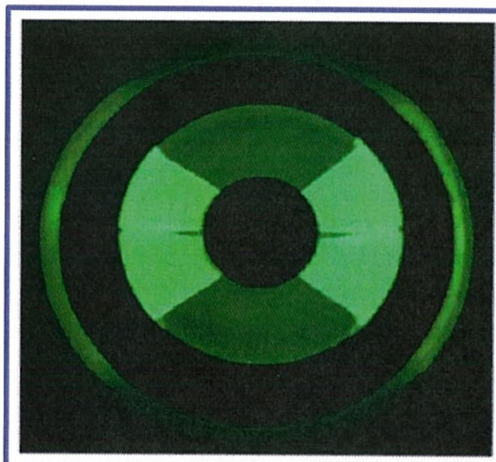


Figure 2b: Actual image of the fluorescent pattern without exposure to a magnetic field.

The tuning eye tube is then placed inside a solenoid as shown in Figure 3 below.

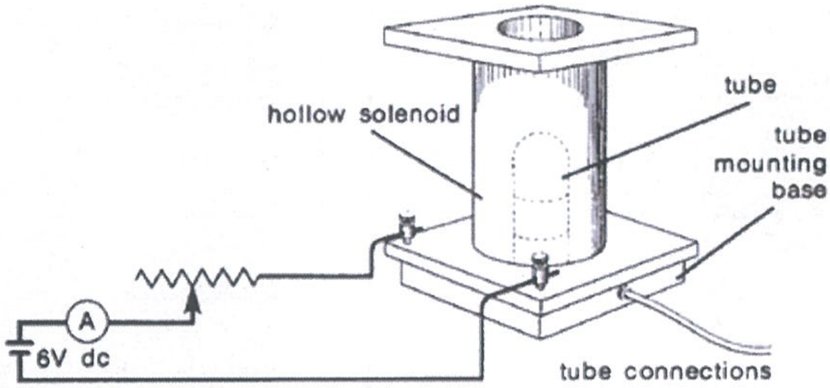


Figure 3: Tuning eye tube placed inside a solenoid that is connected to a variable resistor, which allows current to the solenoid to be adjusted.

When a particular current is passed through the wire coils of a solenoid, a uniform magnetic field is generated inside the solenoid. Thus, the electrons in the tube experience a uniform magnetic field, shown in Figure 4.

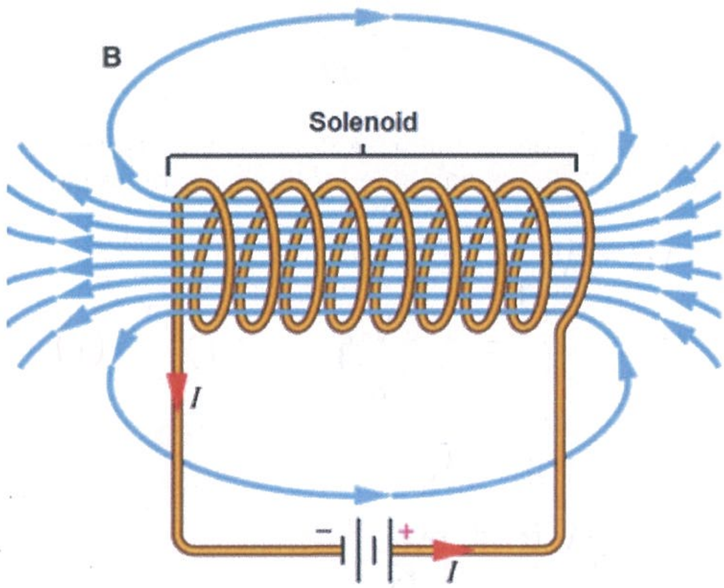


Figure 4: Uniform magnetic field inside a current conducting solenoid.

The magnetic force is supplying all the centripetal force, since the tuning eye tube is a vacuum tube. When the tube is exposed to a uniform magnetic field, the electrons are deflected by this magnetic force into a circular arch that has a measurable radius of curvature ***R*** as shown in Figure 5a and 5b. The radius of curvature, the strength of the magnetic field inside the solenoid and the accelerating voltage are all used to determine the mass of the electron.

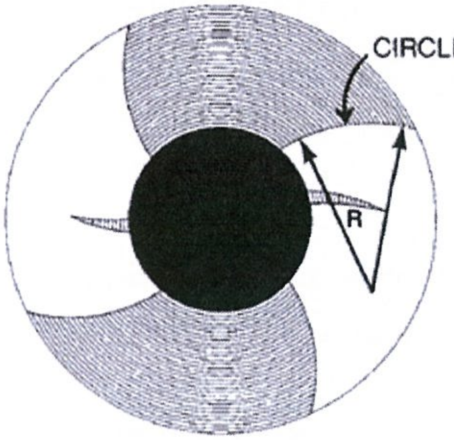


Figure 5a: The electrons are deflected by the magnetic field to create an arch that has a measurable radius of curvature ***R***.

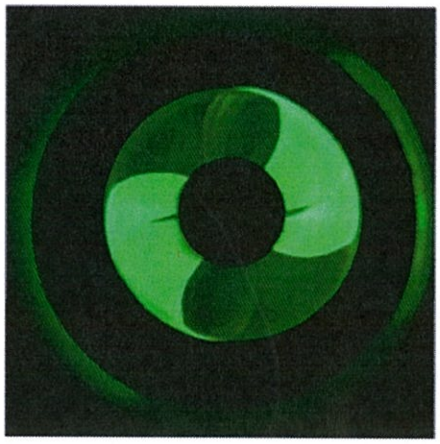


Figure 5b: Actual image of tube exposed to a magnetic field.

(a) The equation for the mass of an electron is:

$$m = \frac{R^2 q B^2}{2V_a}$$

(i) Starting with the equation for the work done on the electron, then using force equations, derive the above equation for the mass of an electron. (3 marks)

$$W = V_a q = \frac{1}{2}mv^2$$

$$\Rightarrow \quad v^2 = \frac{2V_a q}{m} \quad - (1) \qquad (1)$$

$$F_B = F_c$$

$$\Rightarrow \quad qvB = \frac{mv^2}{R}$$

$$\Rightarrow \quad R = \frac{mv}{qB}$$

$$\Rightarrow \quad R^2 = \frac{m^2 v^2}{qB} \qquad (1)$$

Sub (1) $\Rightarrow \quad R^2 = \frac{m^{\cancel{2}}\, 2V_a \cancel{q}}{q^{\cancel{2}} B^2 \cancel{m}}$

$$\Rightarrow \quad m = \frac{R^2 q B^2}{2V_a} \qquad (1)$$

(ii) If the edge of the fanned-out beam is arched to have a radius of curvature of 1.16 cm in a magnetic field of 4.50 mT and the tube has a voltage of 2.40 x 10² V, determine the mass of an electron according to this study? (2 marks)

$$m = \frac{R^2 q B^2}{2V_a}$$

$$= \frac{(1.16\times10^{-2})^2(1.60\times10^{-19})(4.50\times10^{-3})^2}{2(2.40\times10^2)} \quad (1)$$

$$= \underline{9.08\times10^{-31}\ kg} \quad (1)$$

(b) (i) Using 9.11 x 10⁻³¹ kg as the mass of an electron, given that the voltage difference across the anode and cathode is 2.40 x 10² V and assuming the electrons released from the cathode have no initial velocity, determine the acceleration of the electrons towards the anode. (2 marks)

$$F = Eq = \frac{Vq}{d} = ma$$

$$\Rightarrow a = \frac{Vq}{md} \quad (1)$$

$$= \frac{(2.40\times10^2)(1.60\times10^{-19})}{(9.11\times10^{-31})(1.00\times10^{-2})}$$

$$= \underline{4.21\times10^{15}\ ms^{-2}} \quad (1)$$

(ii) If protons were used instead of electrons, state by how many times the voltage would need to increase to get the protons to achieve the same acceleration as the electrons. Show your calculations. (2 marks)

$$a_{electron} = a_{proton}$$

$$\Rightarrow \frac{V_e \cancel{q}}{m_e \cancel{d}} = \frac{V_p \cancel{q}}{m_p \cancel{d}}$$

$$\Rightarrow V_p = \frac{m_p V_e}{m_e} \quad (1)$$

$$= \frac{(1.67\times10^{-27})V_e}{(9.11\times10^{-31})}$$

$$= \underline{1.83\times10^3\ V_e} \quad (1)$$

(c) Given that the mass of an electron is 9.11×10^{-31} kg and that the initial velocity of the electron leaving the cathode is zero, use the ***average velocity*** of the electron as it travels towards the anode, perpendicular to the magnetic field, to estimate the magnitude of the deflection due to a magnetic field strength of 2.50×10^{2} μT. The distance between the anode and cathode is 1.00 cm.

Note: The accelerating voltage supplied to the tube is still 2.40×10^{2} V. If you were unable to solve for the acceleration in part (b) (i), then use a value of 4.40×10^{13} ms^{-2}.

(8 marks)

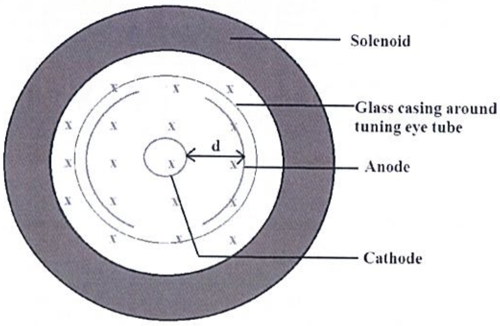
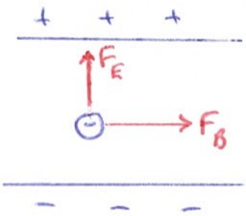


Figure 6: Tuning eye tube inside a solenoid that is producing a magnetic field



Effect of electric field:

$v = ?$
$u = 0\ ms^{-1}$
$a = 4.21 \times 10^{-15}\ ms^{-2}$
$t = ?$
$s = 1.00 \times 10^{-2}\ m$

$v^2 = u^2 + 2as$
$= 0 + 2(4.21 \times 10^{-15})(1.00 \times 10^{-2})$
$\Rightarrow v = 9.18 \times 10^{6}\ ms^{-1}$ (1)

$v = u + at$
$\Rightarrow t = \dfrac{9.18 \times 10^{6} - 0}{4.21 \times 10^{-15}}$
$= 2.18 \times 10^{-9}\ s$ (1)

$V_{ave} = \dfrac{s}{t}$
$= \dfrac{1.00 \times 10^{-2}}{2.18 \times 10^{-9}}$
$= 4.59 \times 10^{6}\ ms^{-1}$ (1)

Effect of magnetic field:

$F = qvB = ma_{\perp}$
$\Rightarrow a_{\perp} = \dfrac{qvB}{m}$ (1)
$= \dfrac{(1.60 \times 10^{-19})(4.59 \times 10^{6})(2.50 \times 10^{-4})}{(9.11 \times 10^{-31})}$ (1)
$= 2.01 \times 10^{14}\ ms^{-2}$ perpendicular to movement. (1)

$v = ?$
$u = 0\ ms^{-1}$
$a = 2.01 \times 10^{14}\ ms^{-2}$
$t = 2.18 \times 10^{-9}\ s$
$s = ?$

$s = ut + \frac{1}{2}at^2$
$= 0 + \frac{1}{2}(2.01 \times 10^{14})(2.18 \times 10^{-9})^2$ (1)
$= \underline{4.78 \times 10^{-4}\ m}$ (1)

(d) Using the information show in figure 6 in part (c), determine if the electrons are deflected in a clockwise or anticlockwise direction. (1 mark)

clockwise (1)

Question 19 **(18 marks)**

Coulomb's Law

The electrical force that electrically charged particles can exert on each other is much stronger than the gravitational force. The strength of the electrical force can be expected to depend on the magnitude of the charges and on the distance between them. The formula governing the exact nature of the relationship of very small charged particles has become known as Coulomb's Law (after Charles-Augustin Coulomb, 1736-1806). The methods used to study Coulomb's Law all involve balancing the electrical force with other forces that are easier to measure.

In the PSSC-type Coulomb's Law Apparatus shown in Figure 7, a pith ball (a Styrofoam low-mass ball) is suspended on a light weight string in such a way that its movement is confined to one plane. A grid is placed under the pith balls, with a ruler placed behind the grid allowing easy measurement of distances.

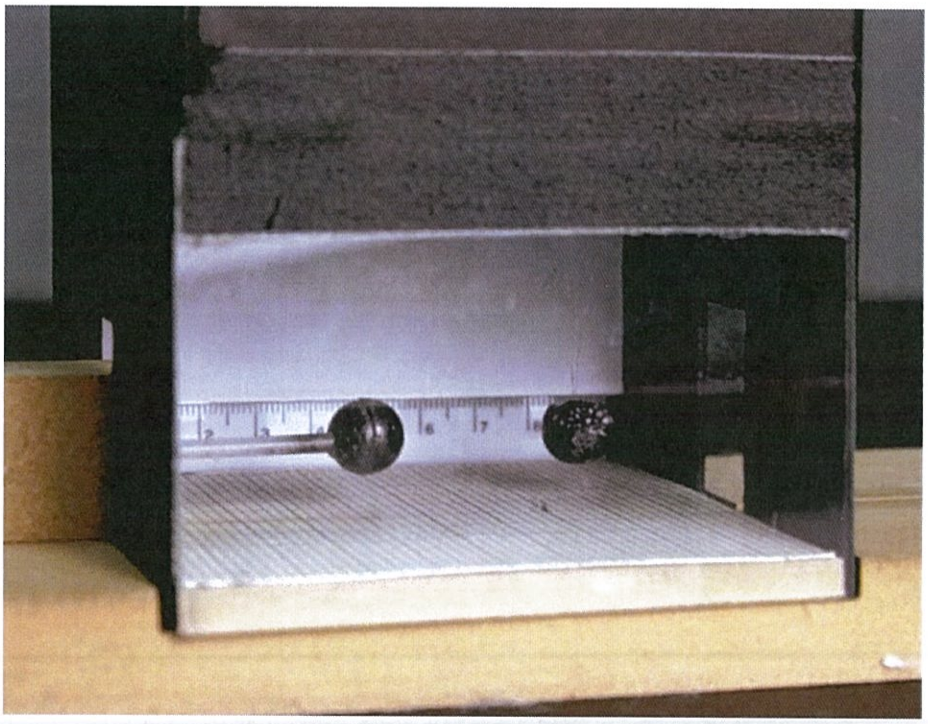


Figure 7: PSSC-type Coulomb's Law Apparatus

The pith ball is then electrically charged by transferring electrons onto it using a charged acetate strip. An identical pith ball is given an exactly equal charge using the same acetate strip. This second pith ball is then placed a distance ***R*** from the first pith ball. This causes the suspended pith ball to deflect a linear distance ***d***, as shown in Figure 8 on the next page.

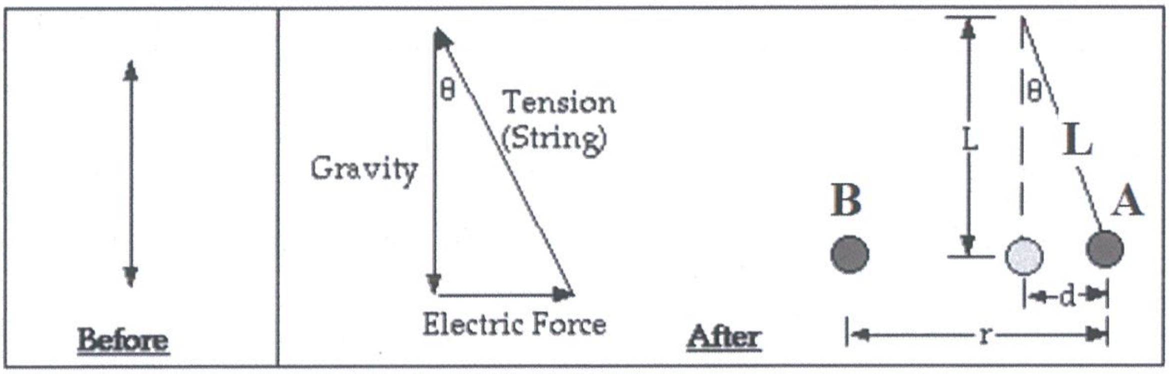


Figure 8: Deflection of the suspended pith ball, labelled A by an equally charged pith ball labelled B.

From Figure 8: $\frac{d}{L} = \sin\theta$ and the force in the x-direction pushing on the pith ball is $F = mg\sin\theta$.

(a) Use the above information to derive a formula that shows that the electrostatic force is directly related to the distance ***d*** that the pith ball is deflected. (1 mark)

$$F_E = mg\sin\theta$$
$$= \frac{mgd}{L} \quad (1)$$

ie. $F_E \propto d$

(b) Use your equation from (a) and Coulomb's Law to show that the square of the distance between two pith balls (***R***^{2}) is inversely proportional to distance the pith ball is deflected ***d***. Isolate for ***R***^{2} and rearrange the equation to determine the gradient of the line if you plotted ***R***^{2} on the y-axis and ***1/d*** (or d^{-1}) on the x-axis. (3 marks)

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

$$\Rightarrow \frac{mgd}{L} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q^2}{R^2} \quad (1)$$

$$\Rightarrow R^2 = \frac{q^2 L}{4\pi\varepsilon_0 mgd} \quad (1)$$

$$\therefore R^2 = \frac{k}{d} \quad \text{where } k = \frac{q^2 L}{4\pi\varepsilon_0 mg} \quad (1)$$

(c) Fill in the missing values in the table below. (2 marks)

Ruler position of the suspended pith ball prior to being charged (cm)	Ruler position of stationary charged pith ball (cm)	Ruler position of the suspended, deflected pith ball (cm)	R (m)	R^2 (x 10^{-3} m^2)	d (m)	1/d (m^{-1})
7.00	1.50	7.90	0.064	4.10	0.009	111
7.00	2.00	8.01	0.060	3.61	0.010	99.0
7.00	2.80	8.30	0.055	3.02	($\frac{1}{2}$) 0.0130	76.9
7.00	3.20	8.40	0.052	2.70	0.014	71.4
7.00	3.80	8.60 ($\frac{1}{2}$)	0.0480	2.30	0.016	62.5
7.00	5.35	9.36	0.040	1.60	0.024	42.4
7.00	6.06	9.76	0.037	1.37	0.028	36.2
				($\frac{1}{2}$)		($\frac{1}{2}$)

(d) Graph R^2 on the y-axis and $1/d$ on the x-axis on the graph paper on the next page. Additional graph paper is supplied at the end of this question if required. (4 marks)

(e) Draw the line of best fit and determine the charge on the pith balls, given that the pith ball has a mass of 2.00 g and the length of the string is 50.0 cm. (3 marks)

$$\text{gradient} = \frac{R^2}{\frac{1}{d}} = \frac{(4.50 - 0.00)\times 10^{-3}}{(120 - 0.0)}$$

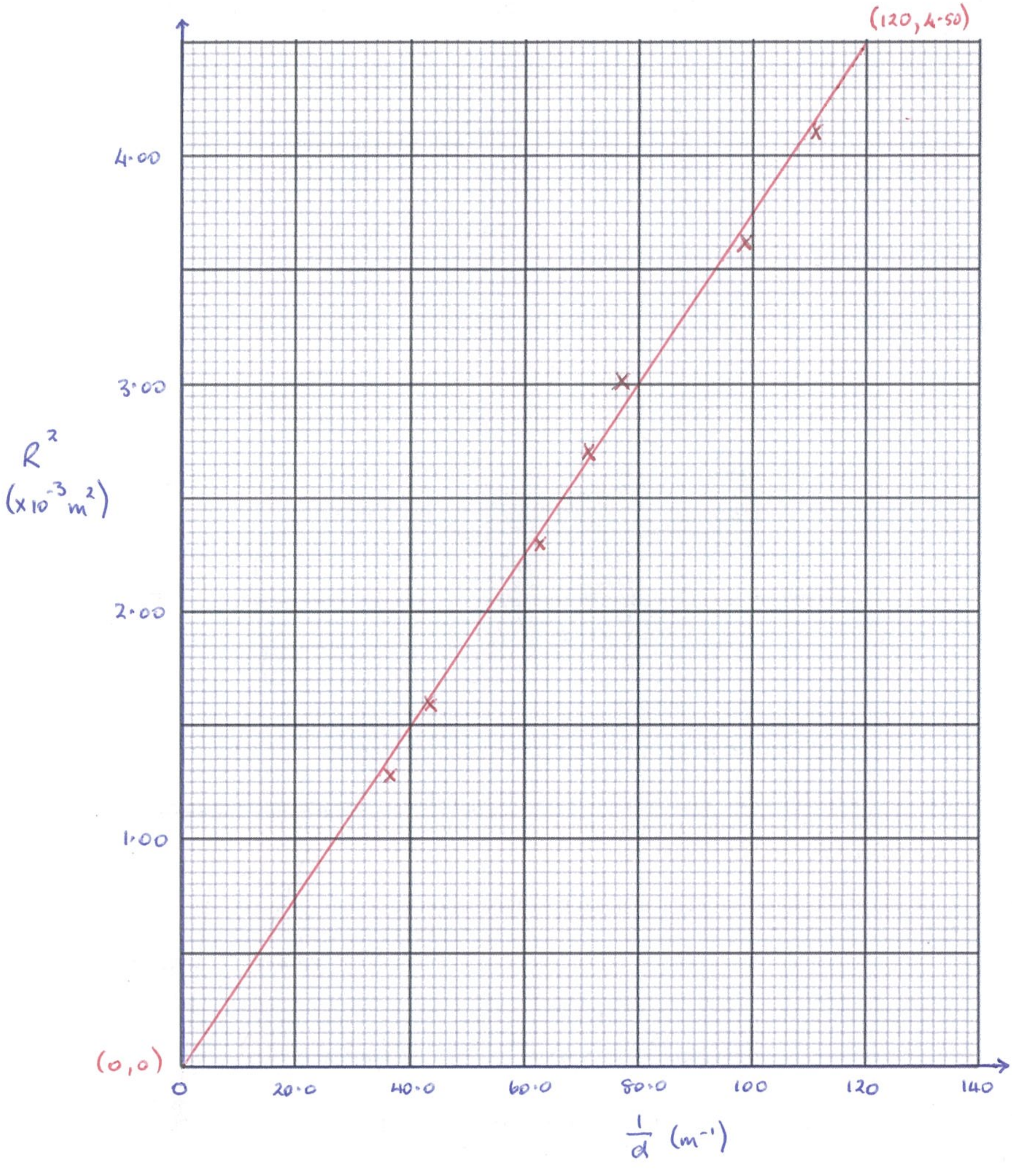
$$= 3.75 \times 10^{-5}\ m^3 \quad (1)$$

$$= k.$$

$$\Rightarrow \frac{q^2 L}{4\pi\varepsilon_0 mg} = 3.75 \times 10^{-5}$$

$$\Rightarrow q = \sqrt{\frac{(3.75\times10^{-5})\,4\pi(8.85\times10^{-12})(2.00\times10^{-3})(9.80)}{(0.500)}} \quad (1)$$

$$= \underline{1.28 \times 10^{-8}\ C} \quad (\pm 0.10\times10^{-8}\ C) \quad (1)$$



Labels + units (1)
Scales (1)
Plotting (1)
Line of best fit (1)

In another version of the PSSC-type apparatus, the pith ball is suspended by two strings. Refer to Figure 9 below.

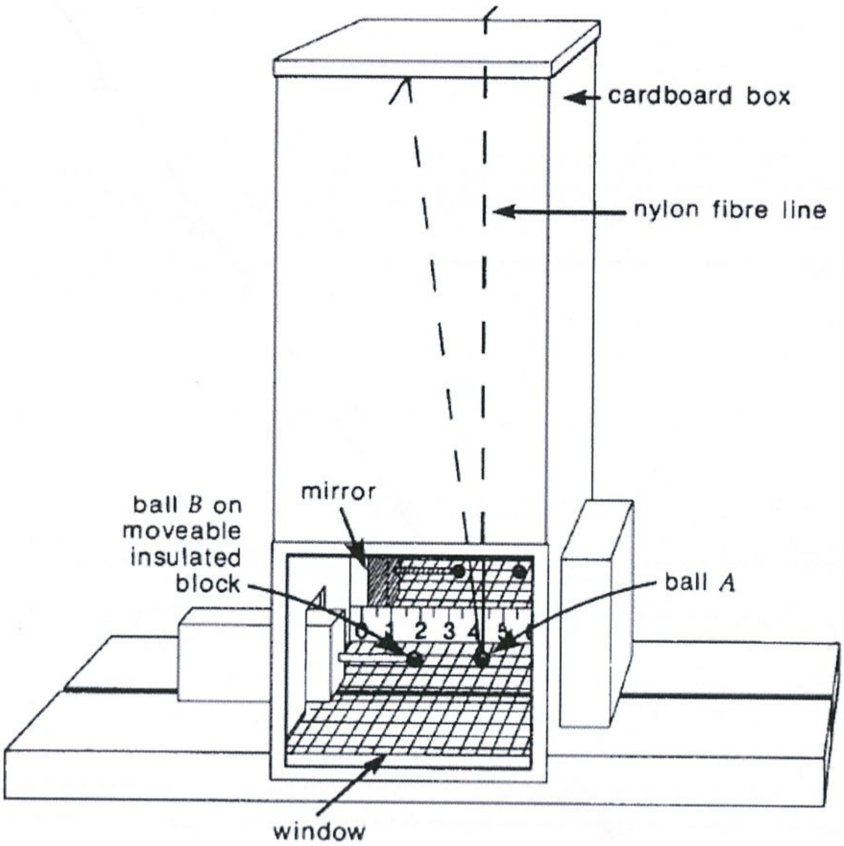
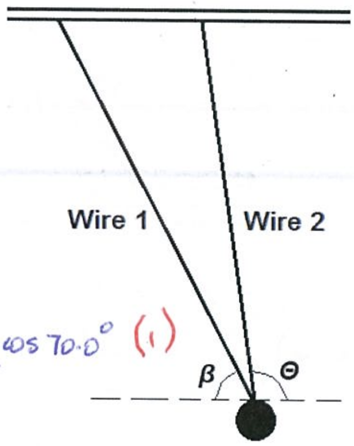
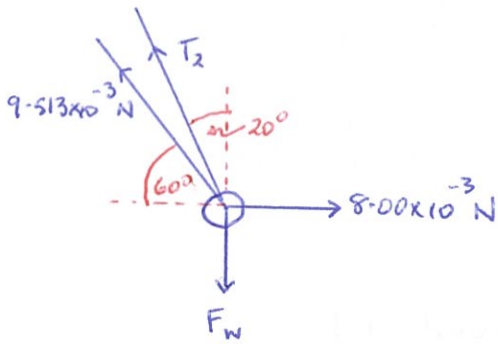


Figure 9: PSSC-type Coulomb's Law Apparatus

(f) When a 8.00 mN electrostatic force acts horizontally on a pith ball, the following equilibrium occurs, with the following angles being created, $\boldsymbol{\beta}$ = 60° and $\boldsymbol{\Theta}$ = 110 °.



(i) If the tension in wire 1 is 9.513 mN, what is the tension in wire 2? (2 marks)



$\Sigma F_h = 0$

$\Rightarrow 8.00\times10^{-3} = 9.513\times10^{-3}\cos 60.0^\circ + T_2\cos 70.0^\circ$ (1)

$\Rightarrow \underline{T_2 = 9.48\times10^{-3}\text{ N}}$ (1)

(ii) What is the mass of the pith ball in ***grams***? (3 marks)

$\Sigma F_v = 0$

$\Rightarrow m(9.80) = 9.513 \times 10^{-3} \cos 30.0° + 9.48 \times 10^{-3} \cos 20.0°$ (1)

$\Rightarrow m = 1.75 \times 10^{-3}$ kg (1)

$= \underline{1.75}$ g (1)

END OF EXAMINATION

ADDITIONAL WORKING SPACE

ADDITIONAL WORKING SPACE

ADDITIONAL WORKING SPACE