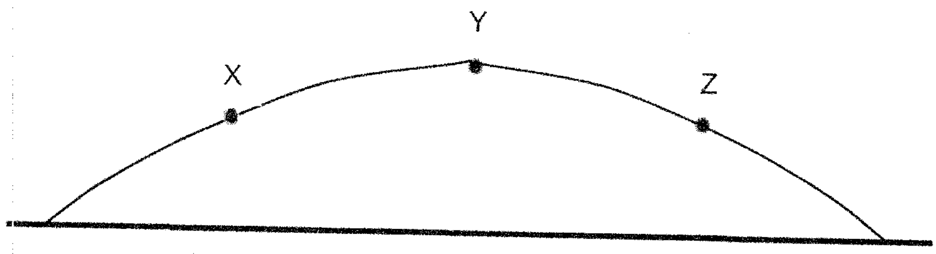
Section One: Short response **30% (60 Marks)**

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

Suggested working time: 55 minutes.

Question 1 **(3 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

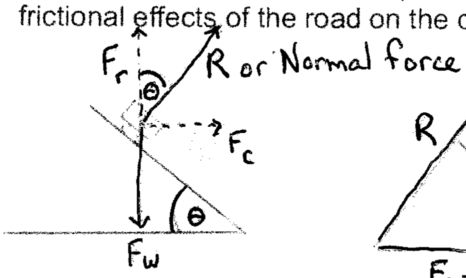
(c) If air resistance is taken into account, which set of vectors best illustrates the force due to this air resistance experienced by the ball in flight? (1 mark)

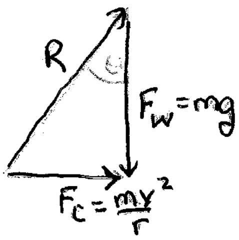
A

[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.)





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

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

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

$$\frac{(30.6)^2}{(9.80)(2.50\times10^2)} \quad (1)$$

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.

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

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

$$\frac{r^3_{Alpha}}{T^2_{Alpha}} = \frac{r^3_{Beta}}{T^2_{Beta}} \quad (1)$$

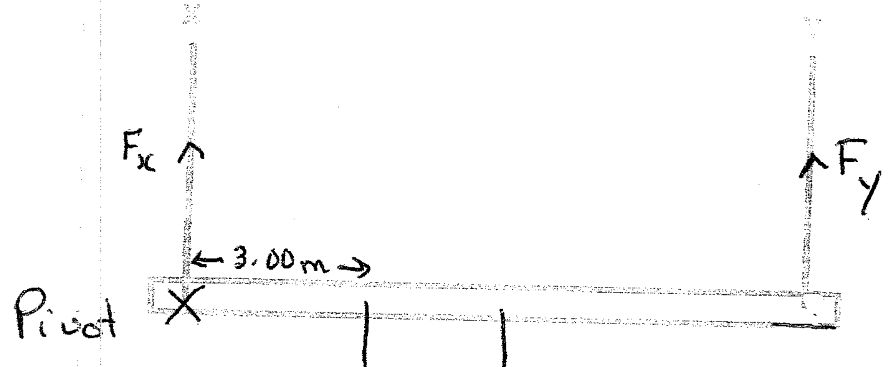
$$\Rightarrow \frac{(4.50\times10^{11})^3}{(8.50\times10^7)^2} = \frac{(9.00\times10^{11})^3}{T^2_{Beta}} \quad (1)$$

$$\Rightarrow T_{Beta} = 2.40\times10^8\ s \quad (1)$$

[Chooses r and T data = 1 mark]

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'.

833 N 343 N [Calculation of weights (1) mark]

Take X as pivot

$\Sigma CM = \Sigma ACM$

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

$F_y = 421\ N$ (1)

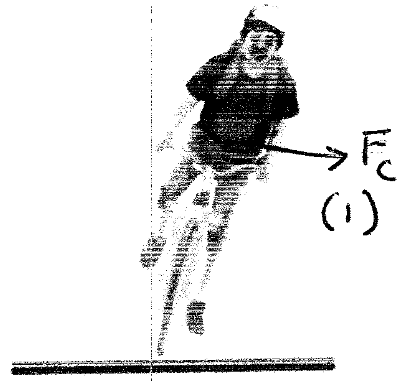
$\Sigma F = 0$

$F_x + 421 = 533 + 343$ (1)

$F_x = 755\ N$ (1)

Question 5 **(4 marks)**

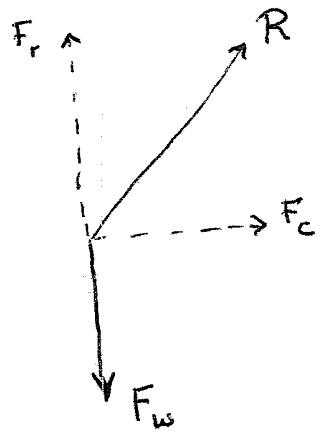
The diagram shows a cyclist rounding a circular bend on his bicycle.



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

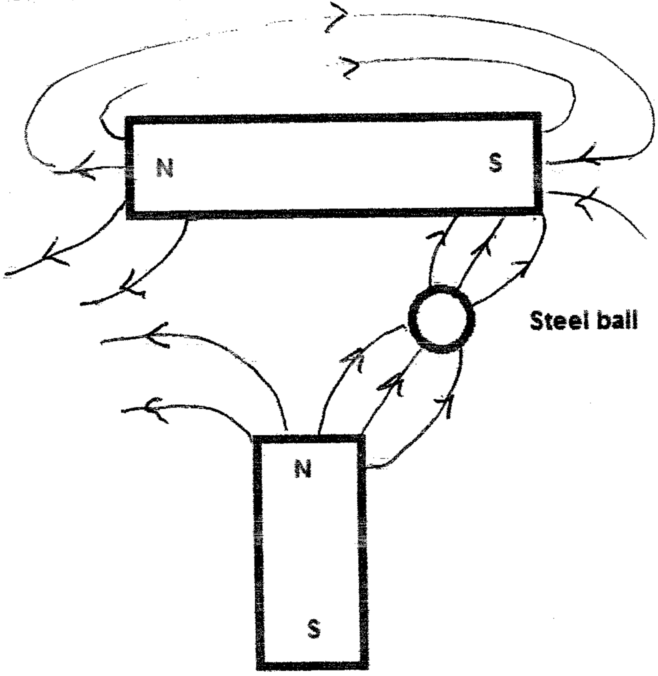
(b) Explain why the rider must lean his bicycle as he takes the corner. (3 marks)

- If the rider does not 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 horizontal force 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)



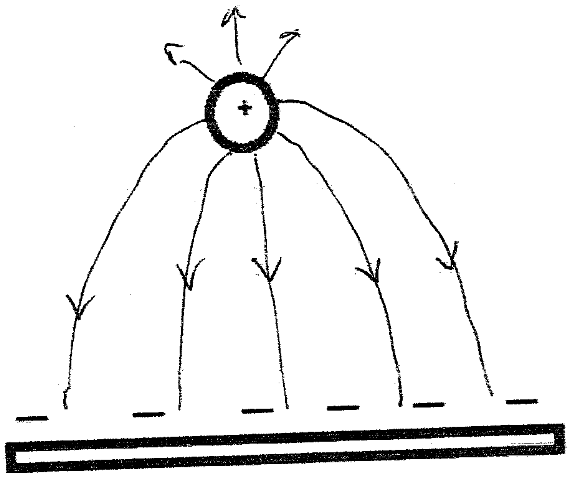
(1) Direction of field

(1) Shape of fields

(1) Concentration of field to steel ball

(-1) If lines touch

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



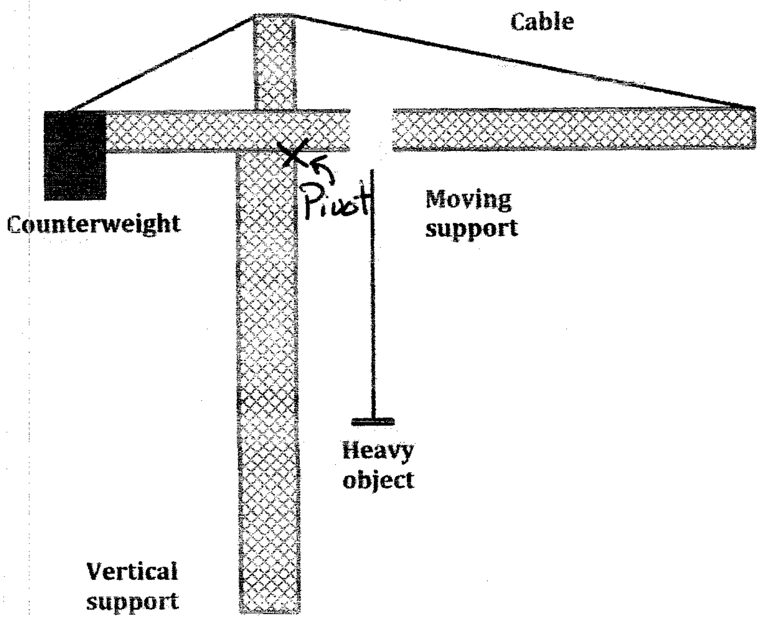
(1) Direction of field

(1) Shape of field

(-1) If lines touch

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)

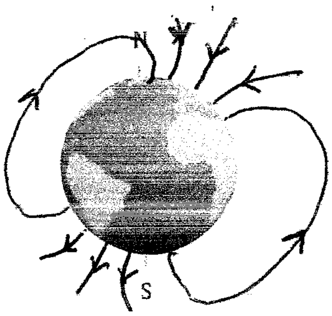
- The heavy object and the arm of the crane provide clockwise torque (moment) around the pivot point on the vertical support. (1)
- The counterweight and tension in the cable provide anticlockwise moments about the pivot helping to provide mechanical equilibrium. (1)

(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 clockwise moment (1)
- The tension in the cable must increase to increase the anticlockwise moments to maintain equilibrium. (1)

Question 8 **(7 marks)**

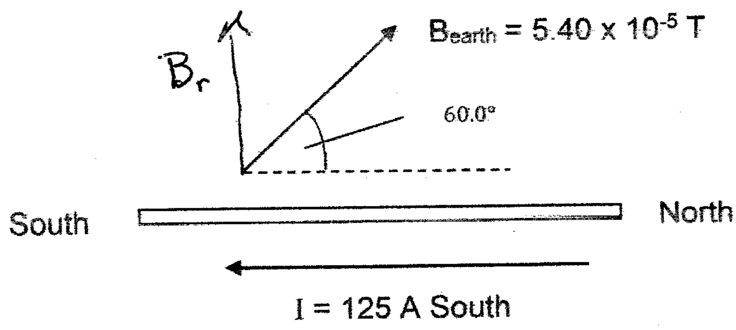
(a) On the diagram, show the magnetic field of the Earth. (3 marks)



(1) Direction of field
(1) Shape of field
(1) Field at angle to rotational axis.

(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

$F = I\ell B_r$ correct component (1)

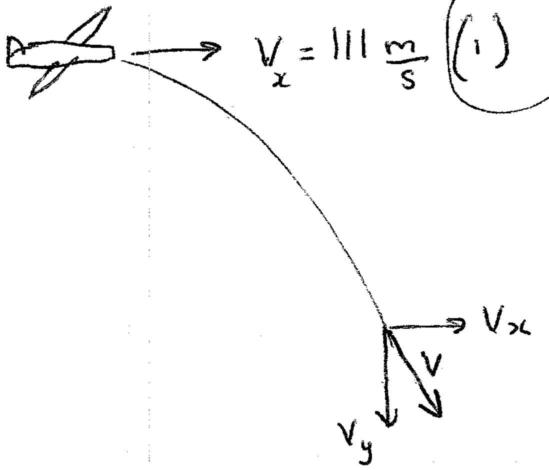
$= (125)(50.0)(5.40 \times 10^{-5} \cos 30.0°)$ (1)

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

Question 9 **(5 marks)**

An aeroplane is being flown with its maximum horizontal speed of 4.00 x 10^2 kmh^{-1} at an altitude of 1.50 x 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}).

$V_x = 111 \frac{m}{s}$ (1)



Vertically $\downarrow$ +ve

$V_y = ?$
$u_y = 0$
$a_y = 9.8 ms^{-2}$
$t = ?$
$s = 1.5 \times 10^3 m$

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

$v^2 = 0 + 2(9.80)(1.50 \times 10^3)$ (1)

$v_y = 171 \ ms^{-1}$ down (1)

$V = \sqrt{V_x^2 + V_y^2}$

$V = \sqrt{111^2 + 171^2}$

$V = 204 ms^{-1}$ (1)

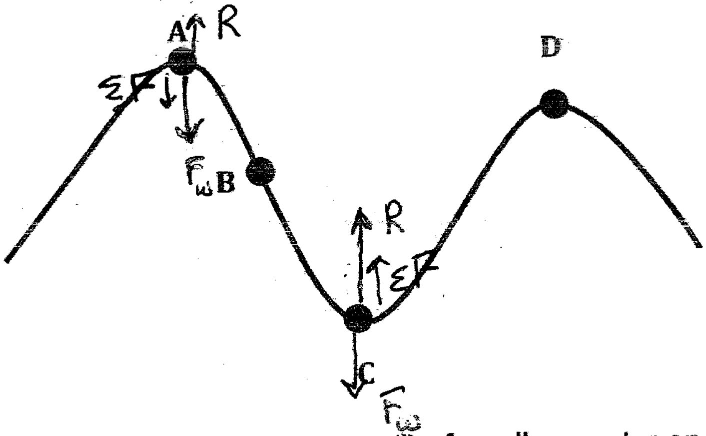
$\tan\theta = \frac{171}{111}$

$\theta = 57.0°$ (1)

$V_{impact} = 204 ms^{-1}$ at $57.0°$ to horizontal

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)
- $\Sigma F = F_c = R - F_w$

  $R = F_c + F_w$ (1)

$\therefore$ Apparent weight R is greater than the real weight F_w by an amount F_c (due to 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)

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

If $R = 0 \Rightarrow F_c = F_w$ (1)

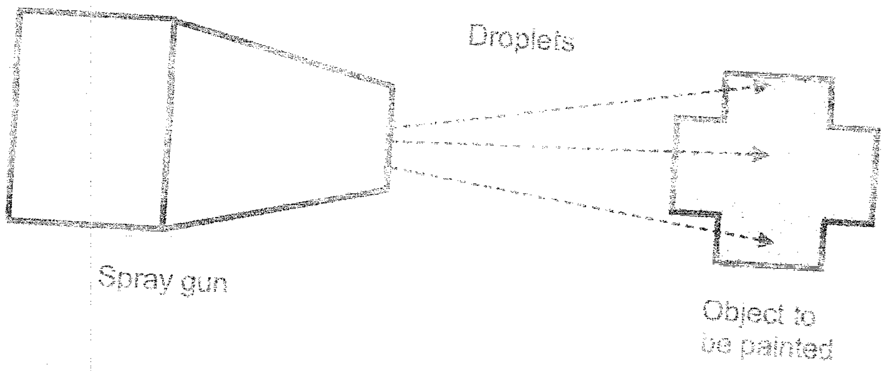
$$\frac{\cancel{m}v^2}{r} = \cancel{m}g \quad (1)$$

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

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.

(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)

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

(1) (1)

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

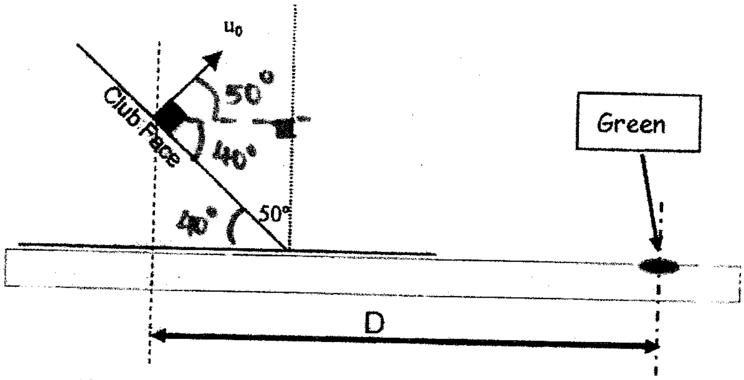
This section has (6) questions. Answer **all** questions. Write your answers in the spaces provided. When calculating numerical answers, show your working or reasoning clearly. Give final answers to **three** significant figures and include appropriate units where applicable.

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.

Supplementary pages for the use of planning/continuing your answer to a question have been provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

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 u_0. (2 marks)

$u_H = u_0 \cos 50^0$ ✓

$u_V = u_0 \sin 50^0$ ✓

b) In terms of u_0, t or D calculate each of the following, using appropriate equations:

(i) the horizontal distance travelled by the ball after a time t. (2 marks)

$$S_H = \underbrace{u_0 \cos 50}_{✓} \times \underbrace{t}_{✓}$$

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

$a_V = -9.8$ $\updownarrow^{+}_{-}$

$S_V = u_V t + \frac{1}{2} a_V t^2$ ✓

$= (u_0 \sin 50)t - 4.9t^2$ ✓

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

$X = D - S_V$

$= D - \{(u_0 \sin 50)t - 4.9t^2\}$ ✓✓

Tiger Smith, a champion golfer, is 100 m from the hole which is in the centre of the green. His wedge has a loft of 50^0 with the vertical, and the ball he hits lands on the hole.

With equations derived in (b) or otherwise, find

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

$S_H = 100$, $t = \frac{100}{u_0 \cos 50^\circ}$

VM $S_V = (u_0 \sin 50)t - 4.9t^2$ ✓

on impact $S_V = 0 = u_0 \sin 50 \left(\frac{100}{u_0 \cos 50}\right) - 4.9\left(\frac{100}{u_0 \cos 50}\right)^2$

$0 = \frac{100}{u_0 \cos 50^\circ}\left[u_0 \sin 50^\circ - \frac{490}{u_0 \cos 50^\circ}\right]$

$u_0^2 = \frac{490}{\sin 50 (\cos 50^\circ)}$ | $u_0 = \sqrt{995} = 31.5 \text{ ms}^{-1}$ ✓

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

$t = \frac{100}{31.5 \cos 50^\circ} = 5.02 \text{ s}$ ✓

✓

d) There is a large tree, 21 m tall, between Tiger and the green. If the green is 70 m from Tiger, determine with calculations if the ball will clear the tree. (3 marks)

$S_H = 70 \text{ m}$

$t = \frac{70}{31.5 \cos 50^\circ} = 3.46 \text{ s}$ ✓

$S_V = u_V t + \frac{1}{2} a_V t^2$

$= (31.5 \sin 50^\circ)3.46 - 4.9(3.46)^2$

$= 24.8$ m high where the tree is ✓

∴ so ball will clear the tree ✓

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)

$s = vt$

$= 950 \times 3\times10^8 \times 365.25 \times 24 \times 60\times60/1000$ ✓

$= 8.99 \times 10^{15}$ km ✓

(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)

Mass of Kepler 20

$= (0.912 + 0.035) \times \text{Mass}_{SUN}$

$= 0.947 \times 1.99 \times 10^{30}$ ✓

$= 1.88 \times 10^{30}$ kg ✓

(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)

$$\frac{mv^2}{r} = \frac{GmM_{star}}{r^2}$$

sub $v = \frac{2\pi r}{T}$ ✓

$$\therefore r^3 = \frac{GM_{star}t^2}{4\pi^2} = \frac{6.67\times10^{-11}\times0.912\times1.99\times10^{30}\times(6.1\times24\times60\times60)^2}{4\pi^2}$$ ✓

$$= 8.52\times10^{29}\ m^3$$ ✓

$$r = \sqrt[3]{8.52\times10^{29}} = 9.48\times10^{9}\ m$$ ✓

(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 kg m^{-3}. Calculate the surface gravity of Kepler 20b if its density is 5520 kg m^{-3}.

(4 marks)

Reminder:

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

$$volume\ of\ a\ sphere = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(2.4\times6.38\times10^6)^3$$

$$= 1.50\times10^{22}\ m^3$$ ✓

Mas = density × vol

$= 5520\times1.50\times10^{22}$

$= 8.28\times10^{25}$ kg ✓

$$g = \frac{GM}{r^2} = \frac{6.67\times10^{-11}\times8.28\times10^{25}}{(2.4\times6.38\times10^6)^2} = 23.6\ N\,kg^{-1}$$ ✓ ✓

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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 20 b ✓

Given star is approximately same size as our own planet, small orbital periods will place ~~planets~~ planets too close for liquid water. ✓

20 b has orbital period most similar to Earth's so most likely to be habitable. ✓

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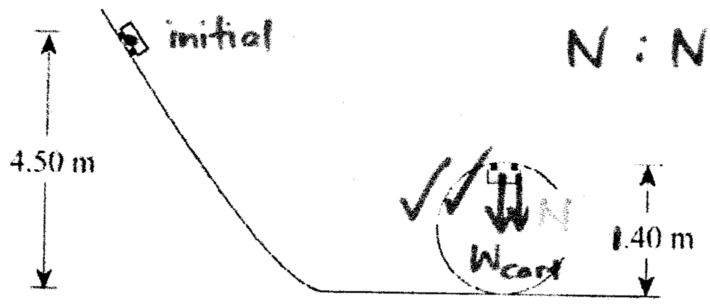
Question 14 **(15 marks)**

An astronaut on a distant planet performs a "loop-the-loop" experiment. She releases a 1.3 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 N on the cart at the top of the loop.

Wcart : Weight (cart)
N : Normal Force



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

b) The astronaut derived the equation $(v_{top})^2 = 5.3\ g_{planet}$
Using physics principles and calculations, justify clearly if you agree with the astronaut.
(5 marks)

Use conservation of energy ✓

$$TE_{initial} = TE_{top}$$

$$PE_{ini} + KE_{ini} = PE_{top} + KE_{top}$$ ✓

$$1.3g_{planet}(4.5) + 0 = 1.3g(1.4) + KE_{top}$$

$$1.3g_{planet}(4.5-1.4) = \frac{1}{2}(1.3)v_{top}^2$$

$$4.03g_{planet} = 0.65\ v_{top}^2$$ ✓

$$v_{top}^2 = 6.2g_{planet}$$ ✓

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disagree ; $v_{top}^2 = 6.2g_{planet} \neq 5.3g_{planet}$ ✓

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

At top of cart

$$F_c = W_{cart} + N \quad \checkmark$$

↓ centre (+)

$$\frac{mv_{top}^2}{r} = mg_{planet} + 21 \quad \checkmark$$

$$\frac{1.3 \times 6.2 g_{planet}}{0.7} = 1.3 g_{planet} + 21$$

$$11.51 g_{planet} = 1.3 g_{planet} + 21 \quad \checkmark$$

$$10.21 g_{planet} = 21$$

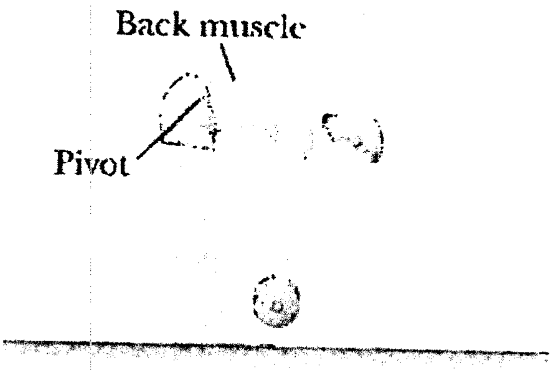
$$g_{planet} = 2.06 \text{ N kg}^{-1}$$

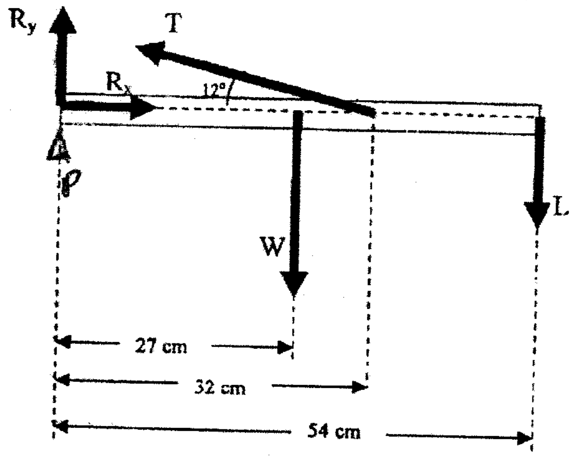
towards centre of circle ✓

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 acted 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 (Rx) and (RY) are also shown on diagram.

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

Take torque about P:

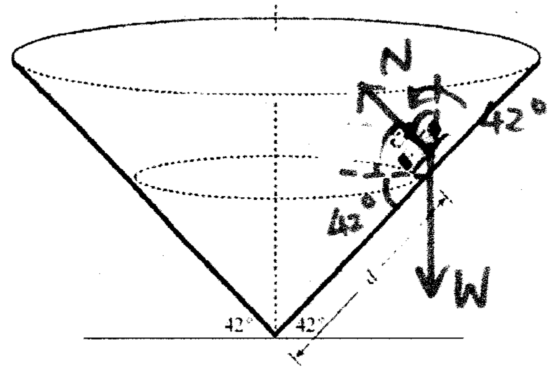
$$\left.\begin{array}{c}\Sigma \tau_{CW} = \Sigma \tau_{ACW}\end{array}\right\} ✓$$

$$(L \times r_L) + (W \times r_W) = T(r_T \sin 12°) \quad ✓$$

$$T = \frac{(25 \times 9.8 \times 0.54) + (41.5 \times 9.8 \times 0.27)}{0.32 \sin 12°} \quad ✓$$

$$= 3.64 \times 10^3 \text{ N} \quad ✓$$

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 horizontal circle shown below.



For a steady speed of 29 m s^{-1}, calculate the distance **d,** a driver should drive her car if she wishes to stay on a circular path without friction? (4 marks)

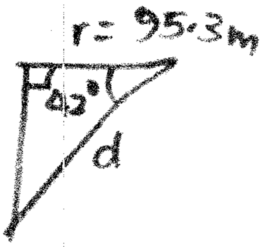
$$\tan 42° = \frac{F_c}{W}$$

$$F_c = W \tan 42° \quad ✓$$

$$\frac{mv^2}{r} = mg \tan 42°$$

$$r = \frac{v^2}{g \tan 42°} = \frac{29^2}{9.8 \tan 42°} \quad ✓$$

$$= 95.3 \text{m}$$



$$\therefore \quad d = \frac{r}{\cos 42°} = \frac{95.3}{\cos 42°} \quad ✓$$

$$= 1.28 \times 10^2 \text{ m} \quad ✓$$

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b) Determine the **horizontal component of the reaction force on the spine (R_X)** while in this position.

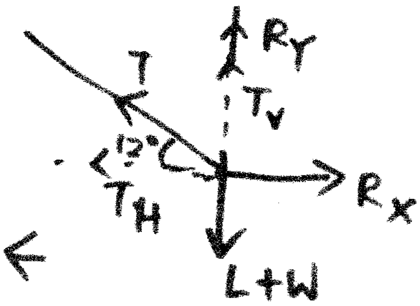
(2 marks)

Horizontal: $F_{\rightarrow} = F_{\leftarrow}$ ✓

$R_X = T_H$

$= 3.64\times10^3 \cos 12°$

$= 3.56\times10^3\ N \leftarrow$ ✓



c) Determine the **vertical component of the reaction force on the spine (R_Y)** while in this position.

(3 marks)

Vertically: $F_{\uparrow} = F_{\downarrow}$ ✓

$R_Y + T_V = L + W$

$R_Y = -T_V + L + W$ ✓

$= -(3.64\times10^3)\sin 12° + (25\times9.8) + (41.5\times9.8)$

$= -105\ N$

$\therefore R_Y = 105\ N \downarrow$ ✓

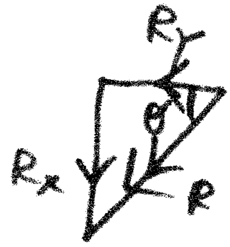
d) Determine **the reaction force on the spine (R) (which is not shown on the diagram)** while in this position.

(3 marks)

$R = \sqrt{R_X^2 + R_Y}$

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

$= 3.561\times10^3\ N$ ✓



at angle $\theta = \tan^{-1}\left(\frac{R_X}{R_Y}\right)$

$= \tan^{-1}\left(\frac{3.56\times10^3}{105}\right) = 88°$ ✓

SEE NEXT PAGE

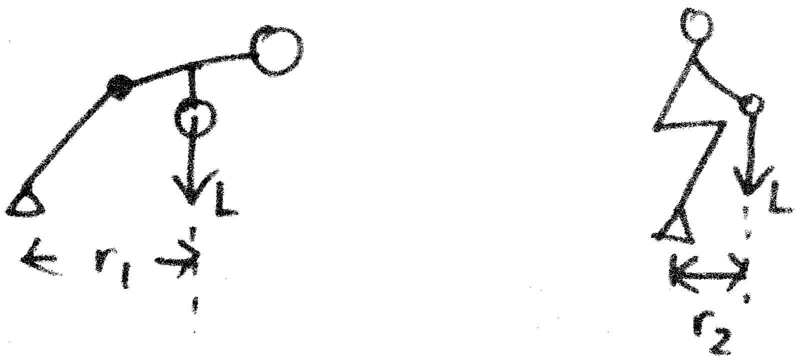
$R = 3.561\times10^3\ N$ at $51.69°W$ ✓

with aid of diagrams

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

1 & 2) try to maintain a straight back / bend knees load produces minimal torque since distance to pivot is minimal

3) Keep load as close as possible the reduced torque less counter balance / restoring torque from back muscles & less ~~tension~~/strain and less risk to surrounding tissues



(✓. Each strategy & correct justification) or diagram

✓×3

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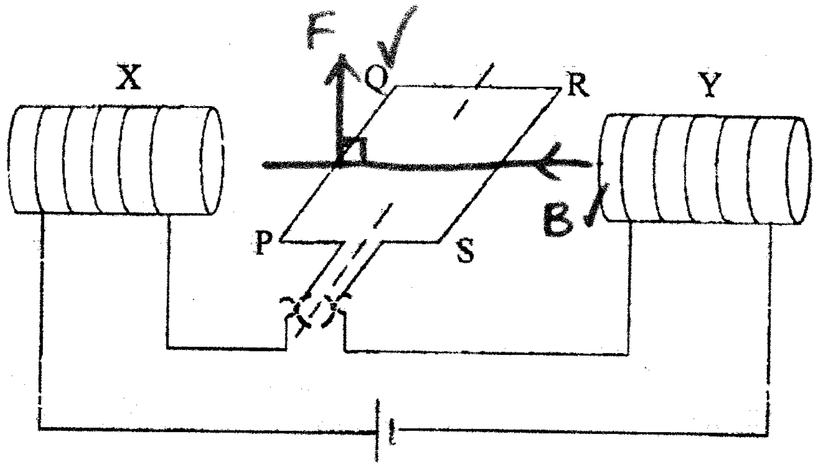
Question 16 **(15 marks)**

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 5.0 cm long and side QR is 4.0 cm long.
- A 12 V supply provides a current of 0.75 A and generates a 0.095 T magnetic field across the armature coil.

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

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

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

$F_{RS} = BILN \sin\theta$ ✓

$= 150 \times 0.095 \times 0.75 \times 5.0 \times 10^{-2}$ ✓

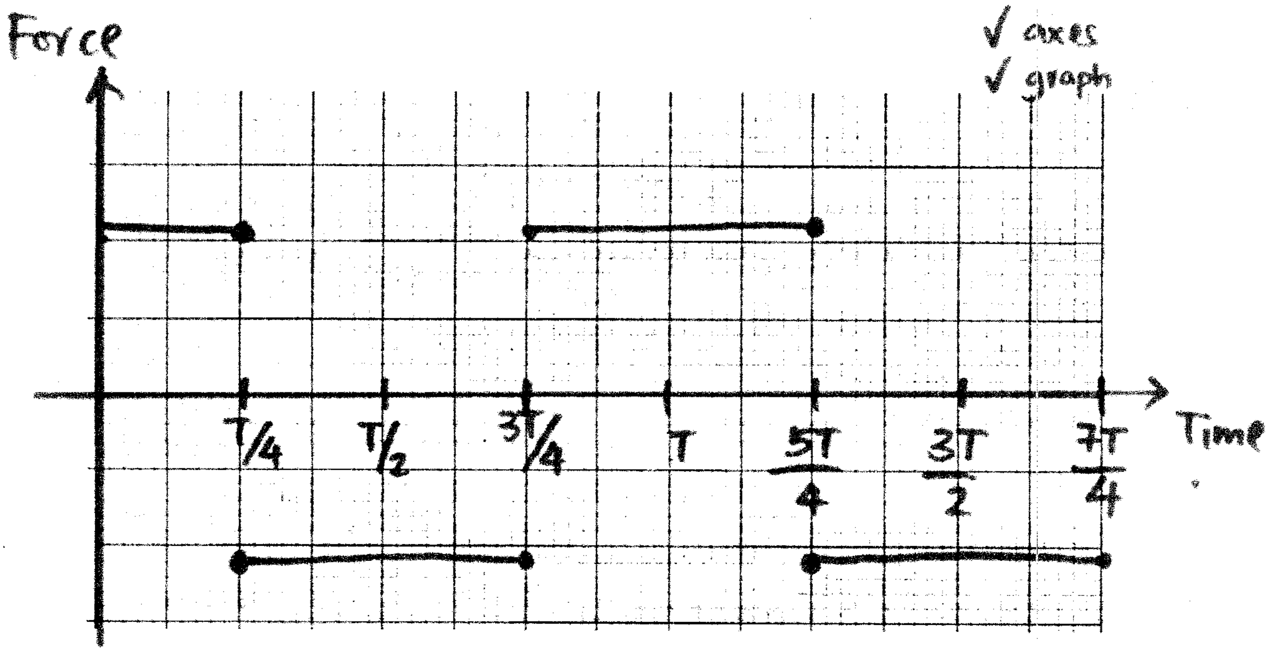
$= 0.53$ N ↓ ✓

SEE NEXT PAGE

c) Sketch the graph below 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)

✓ axes
✓ graph



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)

$\tau = NBIA\cos\theta$ ✓ or $\tau = 2 \times Fr$

$= 150 \times 0.095 \times 0.75 \times 5\times10^{-2} \times 4\times10^{-2} \times \cos 30^\circ$ ✓

$= 0.0185$ Nm CW ✓

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

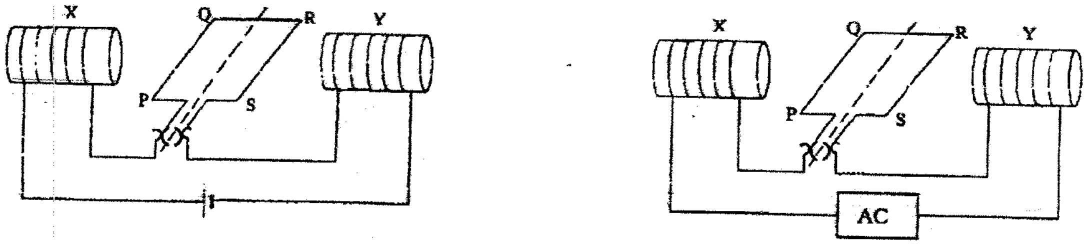
from $\tau = NBIA\cos\theta$

↑ N, B, I, A
(any 2)

more field coils,
inc area of armature
↑ turns
add iron core
use curved poles

SEE NEXT PAGE

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 armature coils so that when current reverses in one, it reverses in the other

then when direction of B changes, direction of force on each side of coil stays the same

∴ coils will always rotate in the same direction

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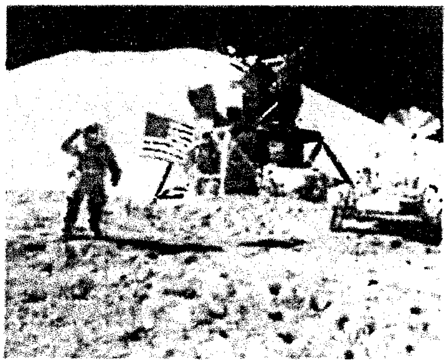
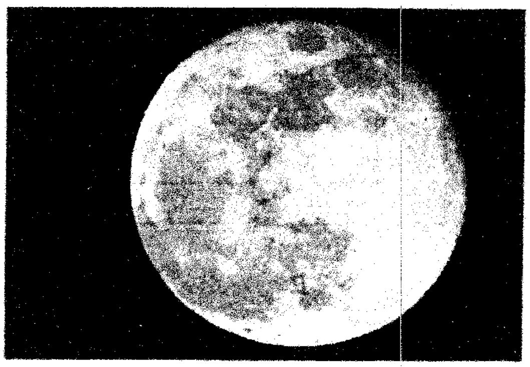
Question 17 **(15 marks)**

The Earth's moon has always been of primary interest to astronomers and this lead to one of the most significant achievements of the 20th century – Man landing on the Moon.





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

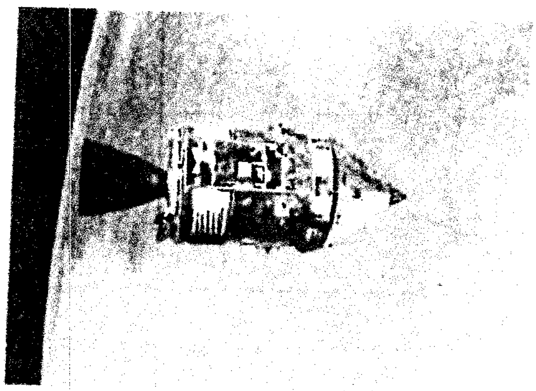
$$F_c = \frac{mv^2}{r} \quad \checkmark, \quad v = \frac{2\pi r}{T} \quad \checkmark, \quad F_c = \frac{GmM_E}{r^2} \quad \checkmark$$

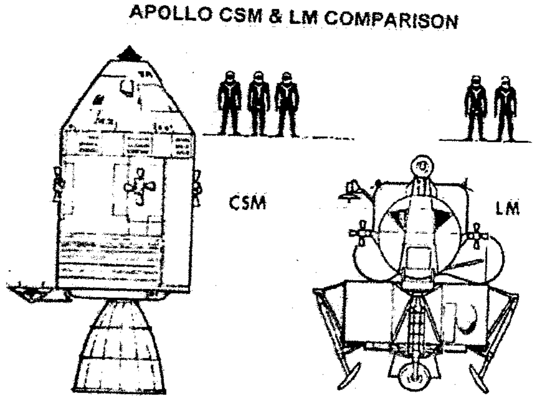
$$T^2 = \frac{4\pi^2 r^3}{GM_E} \quad \checkmark$$

$$= \frac{4\pi^2(3.84\times10^8)^3}{6.67\times10^{-11}\times5.98\times10^{24}} \quad \checkmark \checkmark$$

$$\left.\begin{aligned} T &= 2.37\times10^6 \text{ s} \\ &= 27.4 \text{ days} \end{aligned}\right\} \checkmark$$

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 to 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. (6 marks)

Assume the period of rotation of the Moon is 27.3 days.

A lunar stationary orbit

$$F_C = F_G \quad ✓$$

$$\frac{m_c v^2}{r} = \frac{G m m_c}{r_c^2} \quad ✓$$

$$r_c^3 = \frac{G m T^2}{4\pi^2} \quad ✓ \quad ✓$$

$$= \frac{6.67\times10^{-11} \times 7.35\times10^{22} \times (27.3 \times 24 \times 60 \times 60)^2}{4\pi^2}$$

$$= 8.84\times10^7 \text{ m}$$

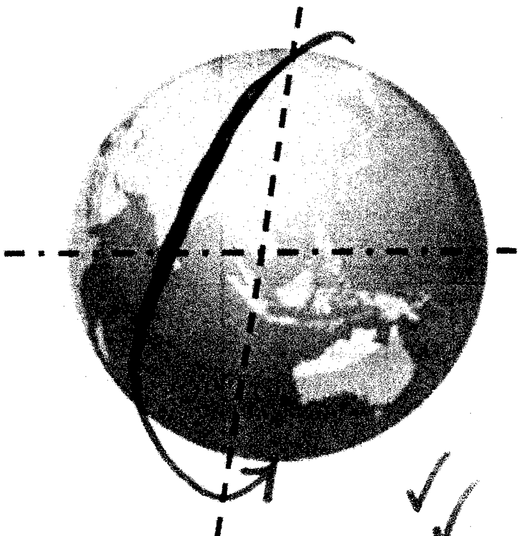
$$h = r_c - r_m \quad ✓$$

$$= (8.84\times10^7) - (1.74\times10^6) = 8.67\times10^7 \text{ m}$$

$h = 8.67\times10^4$ km above moon's surface ✓

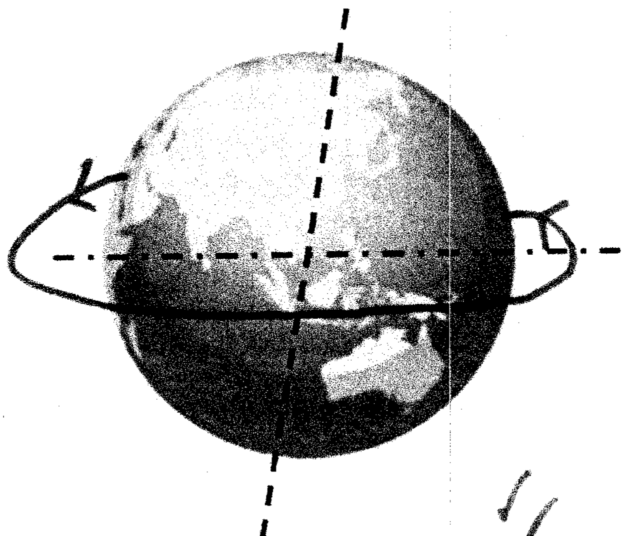
EXT PAGE

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



Polar orbit

circular orbit about Earth's COG



Geostationary orbit

over Equator West to East

END OF SECTION TWO

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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.

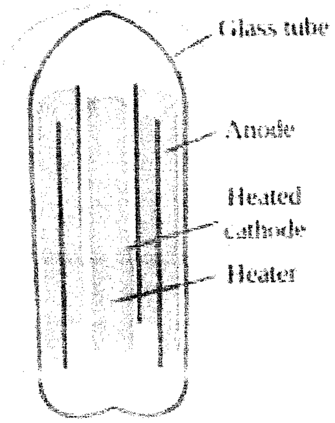


Figure 1: Tuning eye tube

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.

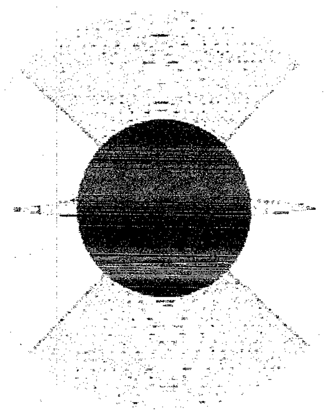


Figure 2a: Top view of the fluorescent pattern when the tuning eye tube is not exposed to a magnetic field.

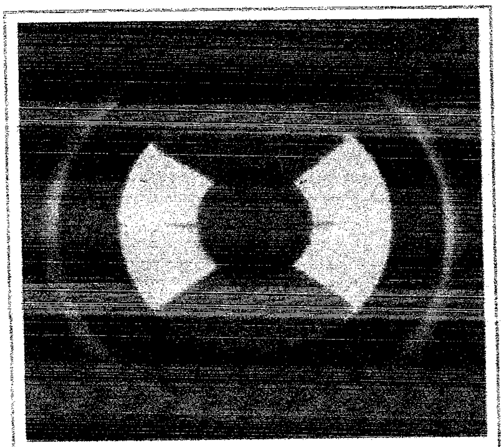


Figure 2b: Actual image of the fluorescent pattern without exposure to a magnetic field.

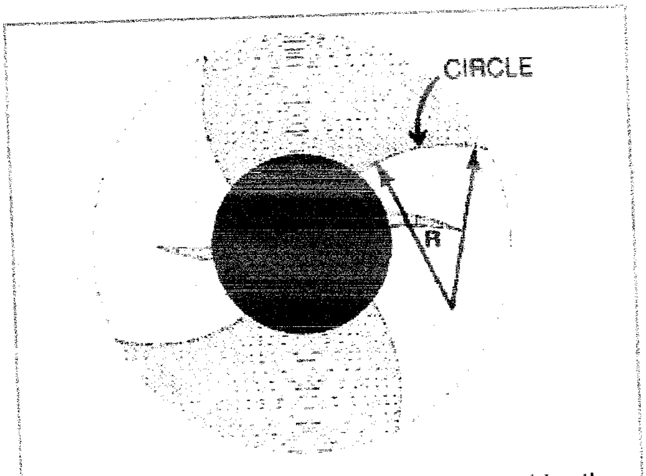


Figure 5a: The electrons are deflected by the magnetic field to create an arch that has a measurable radius of curvature, R.

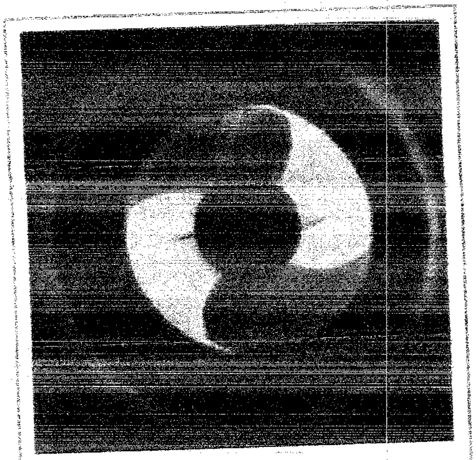


Figure 5b: Actual image of tube exposed to a magnetic field.

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

$$m = \frac{R^2qB^2}{2V_a}$$

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)

$$qV_a = \frac{1}{2}mv^2$$

$$\boxed{\frac{2qV_a}{m} = v^2} \quad \text{OR} \quad \boxed{v = \sqrt{\frac{2qV_A}{m}}} \quad 1$$

$$F_M = F_c$$

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

$$\frac{qvBR}{v^2} = m = \frac{qBR}{v} = \frac{qBR}{\sqrt{\frac{2qV_a}{m}}} \quad 1$$

Subbed in velocity

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

$$m^{\cancel{2}} = \frac{qB^2R^2}{2V_A}\cancel{m} \quad 1$$

squared both sides then cancelled mass

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 4.5 mT and the tube has a voltage of 240 V then what is the mass of an electron according to this study? (2 marks)

$$m = \frac{(0.0116)^2(1.6\times10^{-19})(0.0045)^2}{2(240)} \quad 1$$

$$m = 9.08\times10^{-31}\ \text{kg} \quad 1$$

(b) i. Using 9.11 x 10^{-31} kg as the mass of an electron and given that the voltage difference across the anode and cathode is 240V and assuming the electrons released from the cathode have no initial velocity, determine the acceleration of the electrons towards the anode. (2 marks)

$$F = ma$$

$$\frac{qV}{m} = a = \frac{1.6\times10^{-19}(240)}{9.11\times10^{-31}} \quad 1$$

$$a = 4.22\times10^{13}\ ms^{-2} \quad 1$$

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)

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

$$\frac{qV_e}{m_e} = \frac{qV_p}{m_p}$$

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

$$\frac{1.67\times10^{-27}}{9.11\times10^{-31}} = 1833\times \quad 1$$

$\boxed{1.83\times10^3 \text{ times}}$

Alternatively if they calculated

$$V_p = \frac{ma}{q}$$

and ratioed it to $V_{electron}$

$$\frac{V_p}{V_e} = \frac{439940}{240} \quad 1$$

(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 250 μT. The distance between the anode and cathode is 1.00 cm. Note: The accelerating voltage supplied to the tube is still 240V. 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)

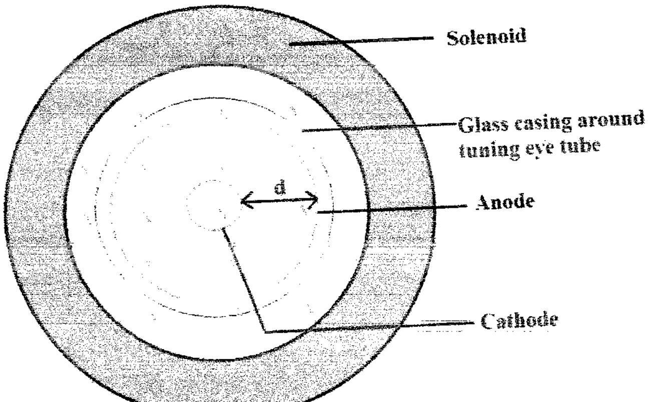


Figure 6: Tuning eye tube inside a solenoid that is producing a magnetic field

$a_x = 4.22 \times 10^{13}\ ms^{-2}$ from (b)i

$S_x = u_x t + \frac{1}{2}at^2$

$\sqrt{\frac{2S_x}{a}} = t = \sqrt{\frac{2(0.01)}{4.22 \times 10^{13}}}$ 1

$t = 2.177 \times 10^{-8}\ s$ 1

$a = \frac{v_f - \cancel{v_i}^{0}}{t}$ ∴ $v_f = at$

$v_{fx} = 4.22 \times 10^{13}(2.177 \times 10^{-8})$ 1

$v_{fx} = 918694\ \frac{m}{s}$

$V_{Avg} = \frac{V_f + V_i}{2} = \frac{918694 + 0}{2} = 459347\ \frac{m}{s}$ 1

$F_M = ma_y$

$\frac{qvB}{m} = a_y = \frac{(1.6 \times 10^{-19})(459347)(250 \times 10^{-6})}{9.11 \times 10^{-31}}$ 1

$a_y = 2.017 \times 10^{13}\ ms^{-2}$ 1

$S_y = \cancel{ut}^{0} + \frac{1}{2}at^2$

$S_y = \frac{1}{2}(2.017 \times 10^{13})(2.177 \times 10^{-8})^2$ 1

$S_y = 0.478\ cm$ 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)

anticlockwise 1

(18 marks)

Question 19

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 or 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.

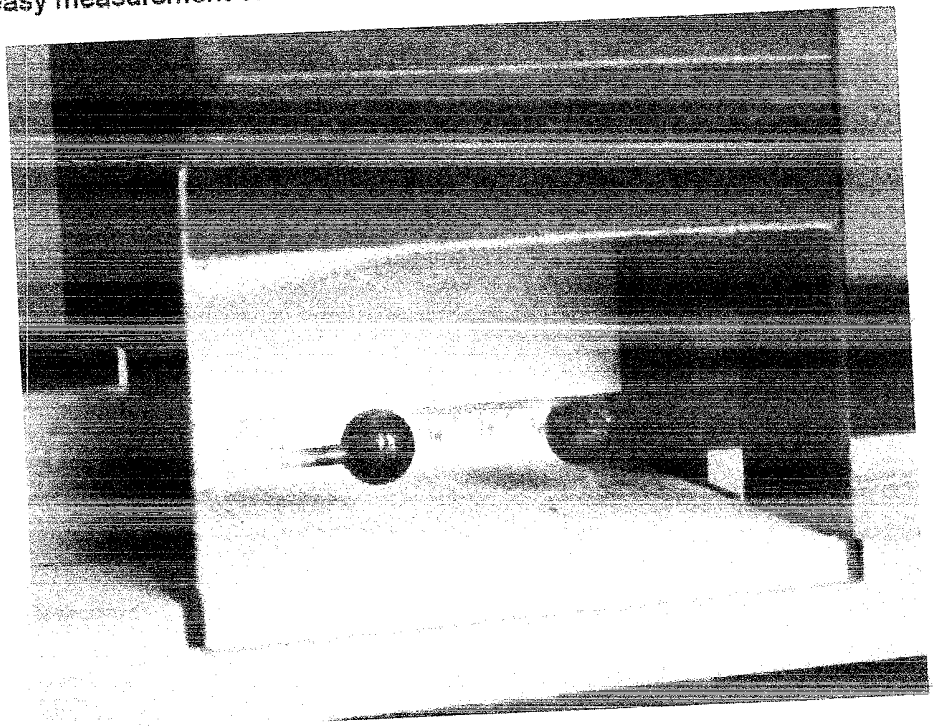


Figure 7: PSSC-type Coulomb's Law Apparatus

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.

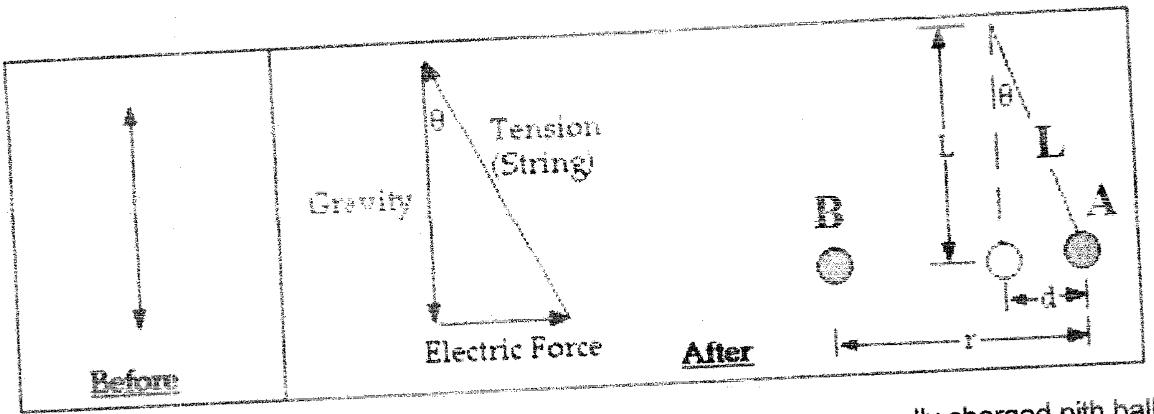


Figure 8: Deflection of the suspended pith ball, labelled A by an equally charged pith ball labelled B.

From Figure 7 $d/L = \sin\Theta$ 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 marks)

$$\sin\Theta = \sin\Theta$$

$$\frac{d}{L} = \frac{F}{mg} \quad \text{given } \Theta \text{ is small.}$$

$$\boxed{\frac{dmg}{L} = F_E} \quad 1$$

(b) Next use your equation from (a) 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)

$$F_E = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

$$\therefore \frac{dmg}{L} = \frac{q^2}{4\pi\epsilon_0 R^2} \quad 1 \quad \text{where } q_1 = q_2$$

$$R^2 = \frac{q^2 L}{4\pi\epsilon_0 mg\, d} \quad 1$$

$$R^2 = \boxed{\frac{q^2 L}{4\pi\epsilon_0 mg}} \frac{1}{d}$$

1 constant gradient of graph

(c) Fill in the data 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 (m^2) x 10^{-3} ½	d (m)	1/d (m^{-1}) ½
7.00	1.50	7.90	0.064	4.09	0.009	111
7.00	2.00	8.01	0.060	3.60	0.010	100
7.00	2.80	8.30	0.055	3.03	0.013 ½	76.9
7.00	3.20	8.40	0.052	2.70	0.014	71.4
7.00	3.80	8.60 ½	0.048	2.12	0.016	62.5
7.00	5.35	9.36	0.040	1.60	0.024	41.7
7.00	6.06	9.76	0.037	1.37	0.028	35.7

(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 2.00g and the length of the string is 50 cm. (3 marks)

$$\text{gradient} = \frac{3.0 \times 10^{-3} - 0}{80 - 0}$$

$$\text{gradient} = 3.75 \times 10^{-5} \quad 1$$

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

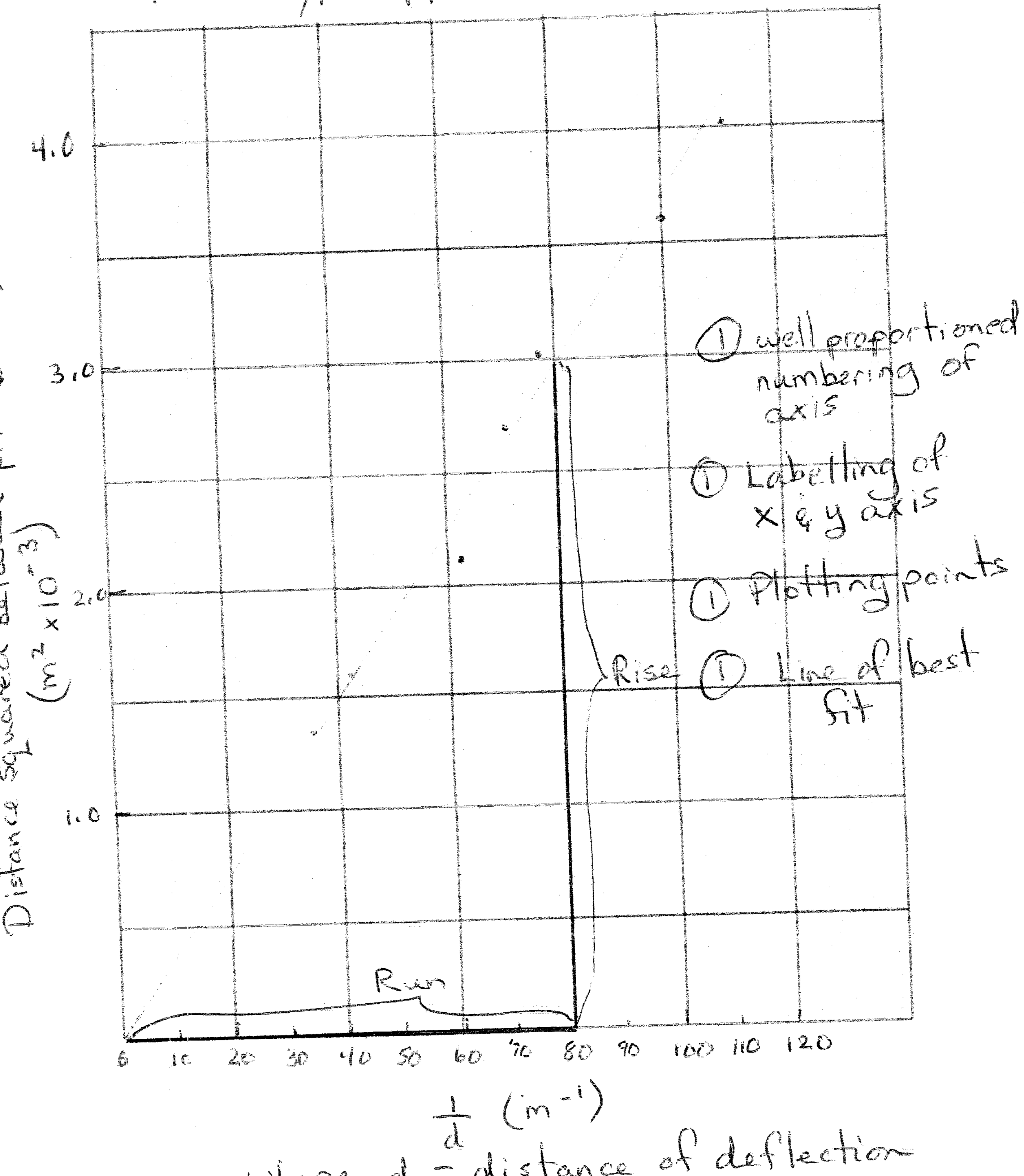
$$q^2 = \frac{3.75 \times 10^{-5}(4\pi)(8.85 \times 10^{-12})(0.002)(9.8)}{(0.5)} \quad 1$$

$$q^2 = 1.6348 \times 10^{-16}$$

$$q = \sqrt{1.6348 \times 10^{-16}}$$

$$q = 1.3 \times 10^{-8}\,C \pm 0.1 \times 10^{-8}\,C \quad 1$$

PSSC-type apparatus results



where d = distance of deflection

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

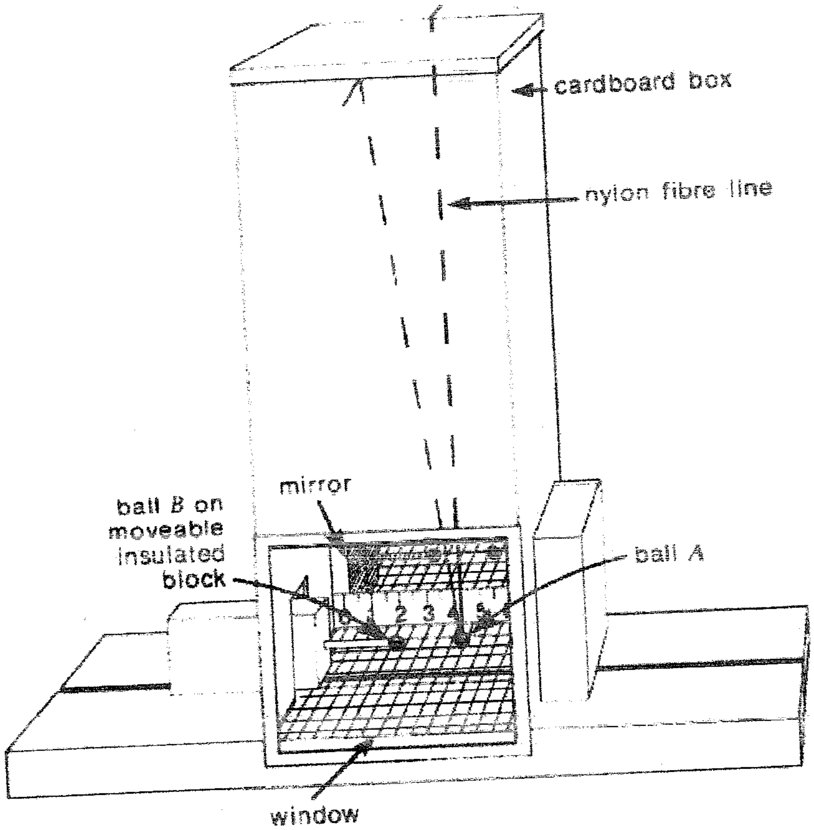
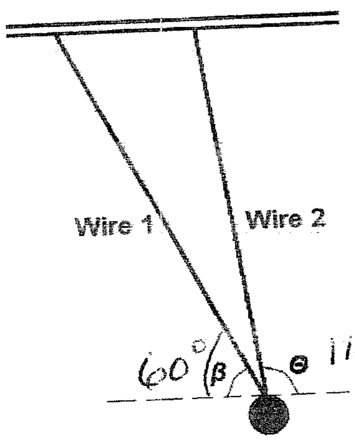


Figure 9: PSSC-type Coulomb's Law Apparatus

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



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

$$\Sigma F_x = 0 = +F_M - T_{1x} - T_{2x}$$

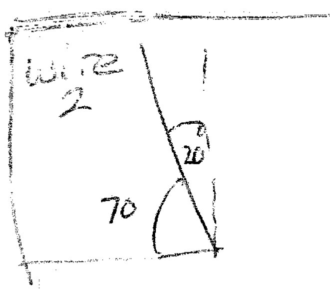
$$F_M = T_1 \cos 60° + T_2 \cos 70°$$

OR

$$F_M = T_1 \sin 30° + T_2 \sin 20°$$

(1) $0.008 = 9.513 \times 10^{-3} \sin 30 + T_2 \sin 20°$

(1) $\boxed{9.48 \times 10^{-3} = T_2}$



ii. What is the mass of the pith ball? (3 marks)

$$\Sigma F_y = 0 = -mg + T_1 \sin 60^\circ + T_2 \sin 70^\circ$$

$$mg = T_1 \sin 60^\circ + T_2 \sin 70^\circ \quad 1$$

OR $$mg = T_1 \cos 30^\circ + T_2 \cos 20^\circ$$

$$mg = 9.513 \times 10^{-3} (\cos 30^\circ) + 9.48 \times 10^{-3} (\cos 20^\circ) \; 1$$

$$m = \frac{0.017147}{9.8} = 0.001749 \text{ kg}$$

$$\boxed{m = 1.75 \text{ g}} \quad 1$$