ALL SAINTS' COLLEGE

WACE PHYSICS Stage 3

Semester 1 Examination, 2014

Question/Answer Booklet

Student Number: In figures

In words ____

____

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
Formulae and Constants Sheet

To be provided by the candidate

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

Special items: non-programmable calculators satisfying the conditions set by the SCSA 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 response	15	15	50	54	30
Section Two: Problem-solving	9	9	90	90	50
Section Three: Comprehension	1	1	40	36	20
				180	100

Raw exam score: ____________

_________%

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2010.* Sitting this examination implies that you agree to abide by these rules.

2. Write answers in this Question/Answer Booklet.

3. You must be careful to confine your responses to the specific questions asked and follow any instructions that are specific to a particular question.

4. Working or reasoning should be clearly shown when calculating or estimating answers. It is suggested that answers to calculations are given to 3 significant figures.

   When you are required to estimate show your working or reasoning clearly. Give final answers to a maximum of 2 significant figures and include appropriate units.

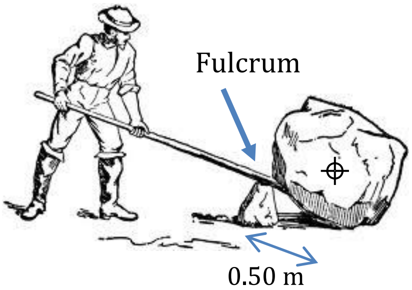
5. A spare page is included at the end of the booklet. It can be used for planning your responses and/or as additional space if required to continue an answer.
   - Planning: If you use the spare pages for planning, indicate this clearly.
   - Continuing an answer: If you need to use the space to continue 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)

Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 50 minutes.

Question 1 (4 marks)

A rigid lever is placed under a 300 kg rock. A fulcrum is placed at 0.50 m from the end of the lever (and centre of mass of the rock), placing the lever at 30.0° above the horizontal.



Estimate the minimum magnitude of force that must be applied to the end of the lever to lift the rock vertically upward? (Assume the force is exerted at one point).

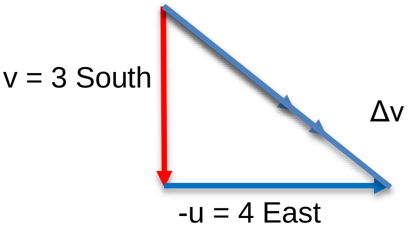
Let length of lever = 2.00 m ✓ reasonable estimate (1 to 3)

Take moments about fulcrum, angle at left must be 90° angle at right must be 60°

$M = r.F.\sin\theta$
$\Sigma acwm = \Sigma cwm$
$1.5 \times F \times \sin 90$ ✓ $= 0.5 \times 300 \times 9.8 \times \sin 60$ ✓
$F = 848.7$ N
$F = 8.5 \times 10^2$ N = 2 sig figs ✓

Question 2 (4 marks)

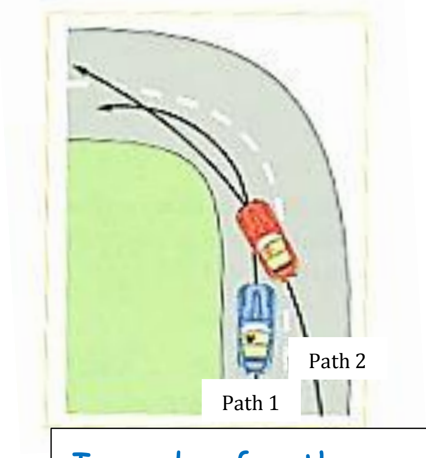
A golf ball rolls along the ground at 4.00 m s^{-1} West. It then strikes a pole and rebounds at 3.00 m s^{-1} South. Calculate the change in velocity of the golf ball with reference to a vector diagram.



$\Delta v = v + (-u)$ (shown on vector diagram) ✓
$\Delta v = (4^2 + 3^2)^{0.5}$ ✓ $= 5.00$ m s^{-1}
Direction from diagram $\theta = \tan^{-1}(4/3) = 53.1°$ ✓
$\Delta v = 5.00$ m s^{-1} S 53.1° E ✓ (E 36.9° S)

Question 3 **(3 marks)**

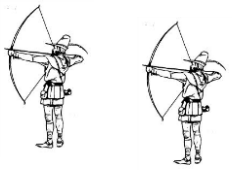
Racing car drivers routinely cut corners, as shown by the racing line (Path 2) in the diagram below. Explain how taking Path 2 allows the curve to be taken at greater speed than Path 1.



In order for the car to be in circular motion a net centripetal force must be applied towards centre of curve. (via Friction from ground) ✓
$F = mv^2 / r$ so if the radius is bigger the amount of friction required can be reduced. ✓
This means that the speed can be larger for a given threshold of friction available. ✓ Or similar.

Question 4 **(3 marks)**

Two archers fire identically shaped arrows towards a target. The initial launch speed and angles are equal but one arrow is twice as massive as the other. They are discussing which arrow will have better range. Explain the physics principles for range in terms of 'no air resistance' and 'air resistance'.



No air resistance – mass does not affect acceleration ✓ so the range is the same regardless of the different mass ✓
Air resistance - a larger mass in the same shape has greater inertia and is less affected by force of air resistance opposing motion ✓, so it has a greater range. ✓
Or similar.

Question 5 **(5 marks)**

A farmer needs to supply an AC electric pump with high voltage but only has a 240 V domestic supply available. He uses a transformer with 400 turns of wire on the primary stage to step up the voltage to 3.30 kV. Assume that the transformer is 100 % efficient in terms of magnetic flux linkage between the coils but only 89.0 % efficient in terms of power transfer. The transformer has an electrical power output of 4.85 kW.

a) Calculate the number of turns required on the secondary winding. (2)

$N_s / N_p = V_s / V_p$

$N_s / 400 = 3300 / 240$ ✓

$N_s = 5500$ turns ✓

b) Calculate the current draw on the primary stage of the transformer. (3)

P (primary) = P (secondary) / 0.89

P (primary) = 4850 / 0.89 ✓ = 5449.438 W

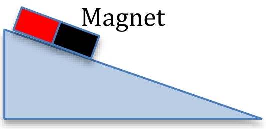
P = VI

5449.438 = 240 x I ✓

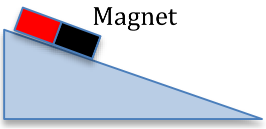
I = 22.7 A ✓

Question 6 **(3 marks)**

Two identical bar magnets are placed on frictionless inclined planes that have the same dimensions. One inclined plane is made of plastic, the other is aluminium. The bar magnets are released together and slide down. Explain which magnet will reach the bottom first referring to physics principles.



Plastic inclined plane



Aluminium inclined plane

Magnet on plastic plane arrives first ✓

Eddy currents are formed on the aluminium plane ✓

The Eddy Currents form their own magnetic field that oppose the sliding magnet's field.✓

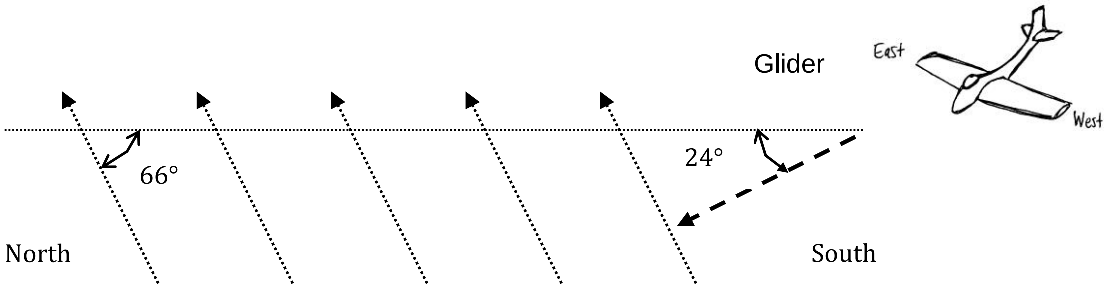
Question 7 **(3 marks)**

Explain, making reference to the domain theory of magnetism, why a permanent magnet can pick up a steel paper-clip, even though the paper-clip is not a permanent magnet.

Without the presence of a permanent magnet the ferromagnetic domains in the paper clip are randomly arranged ✓
As a magnet approaches the paper clip the domains are induced to align with the magnets field lines ✓
Now the paper clip is a temporary magnet that is attracted to the permanent magnet.✓

Question 8 **(4 marks)**

An aluminium glider with a wingspan of 22.0 m is flying due North over Perth where the Earth's magnetic field has a flux density of 5.50×10^{-5} T at an angle of dip 66° to the horizontal. The pilot starts her descent with a velocity of 56.0 m s^{-1} at an angle of 24° to the horizontal.



a) Calculate the potential difference between the tips of each wing of the glider. (2)

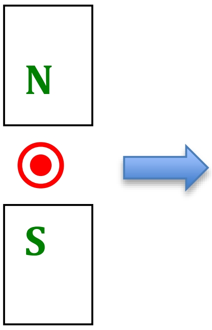
Emf = vBl (wings and field lines are perpendicular)
Emf = 56 x 5.50 x 10^{-5} x 22✓
.Emf = 0.0678 V ✓

b) On which wing tip (East or West) would there be a build-up of electrons? Explain briefly. (2)

By application of left hand slap rule for electrons in motion with the direction of flight✓
West wing tip ✓

Question 9 **(3 marks)**

The diagram below shows a piece of wire that is carrying a current passing through a magnetic field. The current in the wire is 2.00 A, the flux density of the magnet is 10.0 μT and the length of the wire in the field is 7.00 cm. Calculate the force exerted on the wire and show its direction on the diagram.



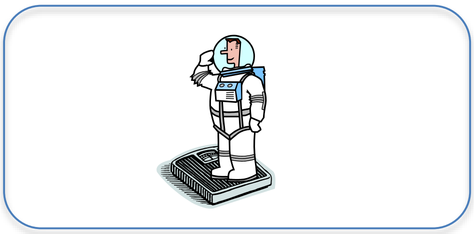
F = BIl

F= $10 \times 10^{-6} \times 2 \times 0.07$ ✓ = 1.40×10^{-6} N ✓

Shows right.✓

Question 10 **(3 marks)**

To simulate the apparent weightlessness of space orbit, astronauts are trained in the hold of a cargo aircraft that is accelerating downward at 'g'. Why will the astronauts appear to be weightless, as measured standing on a bathroom scale, in this accelerated frame of reference?



In the frame of reference of the ground all objects are accelerated down at 9.80 m s^{-2} ✓

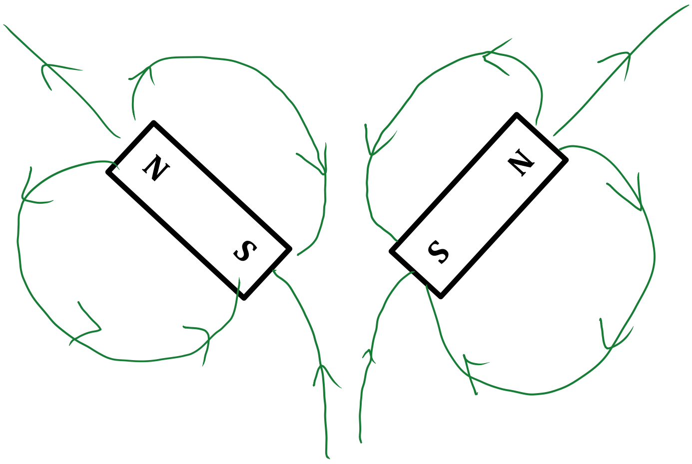
This means there is no action force of astronaut to scale and no normal reaction force from scales to astronaut ✓

Apparent weight is sensation form normal reaction which equals zero.✓

Or 3 similar good points

Question 11 **(3 marks)**

Sketch the magnetic field lines that would be established in the bar magnet configuration below and state whether the magnets are likely to attract, repel or remain stationery if set on a low friction surface.



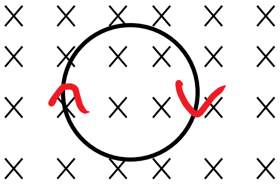
General field line shape✓

Vector addition between and below magnets shows field lines approximately upright. ✓

Repulsion ✓

Question 12 **(4 marks)**

A circular coil consists of 200 turns of copper wire. It has a radius of 5.00 cm and a uniform magnetic field of flux density 120 mT is threaded through the coil. The magnetic field reduces by 75% in a time of 15.0 ms. Calculate the emf generated in the coil and show the direction of induced current on the diagram.



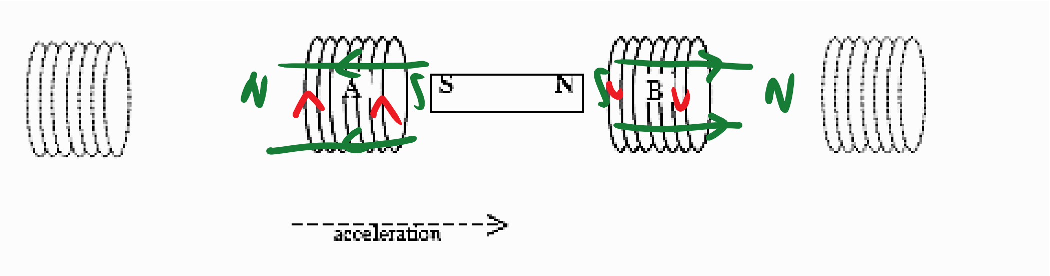
$\Phi_2 - \Phi_1$ = 0.75 B.A = 0.75 x 0.120 x π x 0.05^2 ✓ = 7.06858 x 10^{-4} Wb

Emf = -N ($\Phi_2 - \Phi_1$) / t = (-200 x 7.06858 x 10^{-4}) / 0.015 ✓

Emf = 9.42 V ✓

Clockwise current ✓

Question 13 **(4 marks)**



A coil gun (above) accelerates a magnetic probe through a series of current carrying coils. The direction of the current through each coil is able to reversed as the magnet travels through it. For the instant shown, current is flowing through coils marked A and B.

(a) On the diagram above, draw (for the instant shown), the field lines through the centre of coils A and B which would result in an acceleration of the magnet to the right.

(2)

(b) State the direction of the current flowing in each coil if viewed through the coils from the right hand side of the page.

(2)

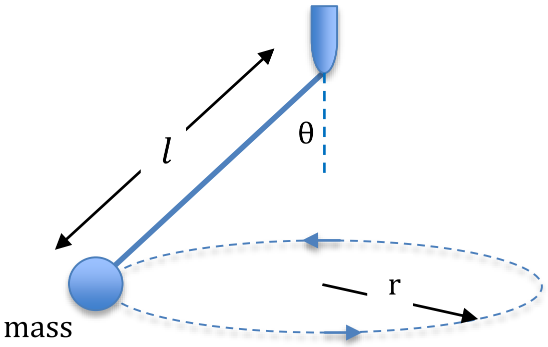
Coil A- clockwise ✓

Coil - B Anticlockwise ✓

Question 14 **(4 marks)**

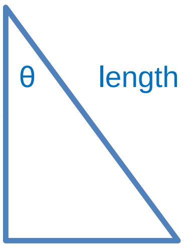
Consider a mass moving in uniform horizontal circular motion at the end of a string. It is straightforward to measure the length of the string (l) and the period of rotation (T). Show by algebraic derivation that the horizontal radius (r) is related to the period and the length by the following expression:

$$r = \sqrt{l^2 - \frac{g^2T^4}{16.\pi^4}}$$

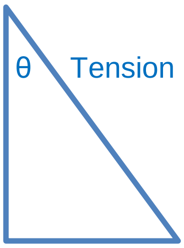


By consideration of similar triangles

By Pythagoras $= \sqrt{l^2 - r^2}$



W= mg



ΣF = $\frac{mv^2}{r}$

$$\tan\theta = \frac{r}{\sqrt{l^2-r^2}}$$

$$\tan\theta = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{gr} = \quad ✓$$

by substitution of $v = \frac{2\pi r}{T}$

$$\tan\theta = \frac{4\pi^2 r}{gT^2}$$

Equate the two expressions for Tan θ

$$\frac{r}{\sqrt{l^2-r^2}} = \frac{4\pi^2 r}{gT^2} \quad ✓$$

Square both sides

$$\frac{r^2}{l^2-r^2} = \frac{16\pi^4 r^2}{g^2T^4}$$

Divide by r²

$$\frac{1}{l^2-r^2} = \frac{16\pi^4}{g^2T^4}$$

Invert

$$\frac{l^2-r^2}{1} = \frac{g^2T^4}{16\pi^4}$$

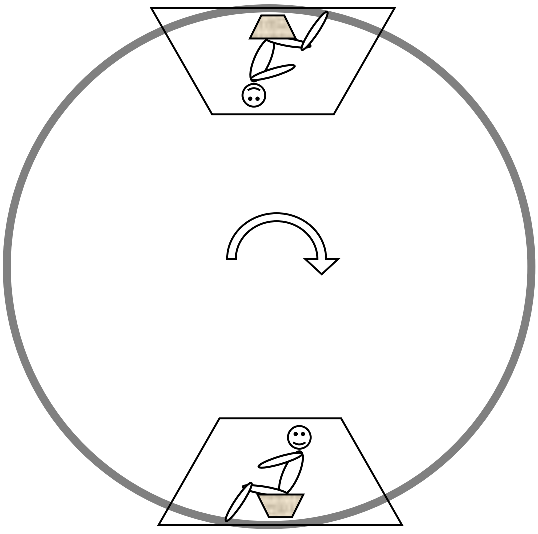
Rearrange

$$r^2 = l^2 - \frac{g^2T^4}{16\pi^4} \quad ✓$$

Square root

$$r = \sqrt{l^2 - \frac{g^2T^4}{16.\pi^4}} \quad ✓$$

Question 15 **(4 marks)**

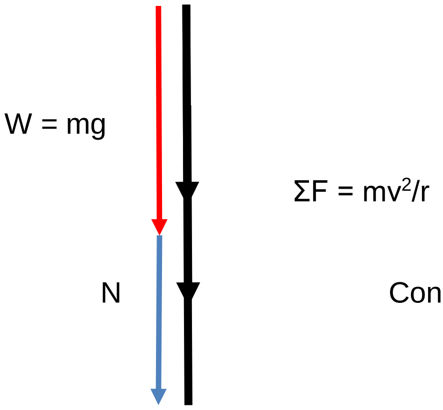


Pilots are trained to withstand high accelerations by riding in a capsule that can move in vertical circles at a constant speed.

A pilot of mass of 85 kg travels in a vertical circle of diameter 28.0 m

It takes 4.75 s to complete one revolution in a circle.

Calculate the sensation of apparent weight that a pilot experiences at the top of the circle and express this as a percentage of his normal weight on Earth.



Consider forces acting towards centre of circle

$v = 2\pi r$ / T = (2 x π x 14) / 4.75 =18.51886 m s^{-1} ✓

From analysis of vector diagram $\Sigma F = W + N$

N (down) = $mv^2/ r - mg$ (Concept)

N = (85 x 18.51886^2 / 14) – (85 x 9.8) ✓

N = 1249.2 N (down) ✓

W = mg = 85 x 9.8 N:W = 1249.2 / (85 x 9.8) = 150% ✓

End of Section One

Section Two: Problem Solving **50% (90 Marks)**

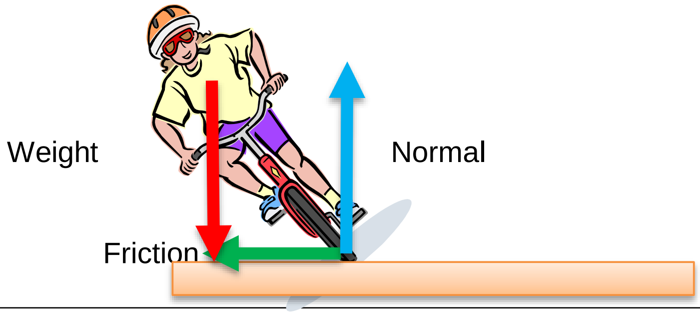
Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 90 minutes.

Question 1 **(16 marks)**

When riding around a corner (on flat ground), a cyclist will naturally 'lean into' the corner.

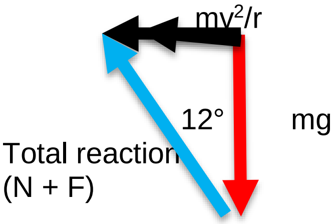
(a) Explain with the aid of a vector diagram why this is so.

(3)



A cyclist must lean into a corner to generate a friction force at the outer edge of a tyre acting towards the centre of the circle ✓
This unbalanced force is the centripetal force✓
Diagram indicates F ✓ (The Weight and Normal are balanced)

(b) A cyclist leans in towards the centre of a 150 m radius bend, so that there is an angle of 12.0° between her body and the vertical. Calculate her speed with reference to a vector diagram.



(4)

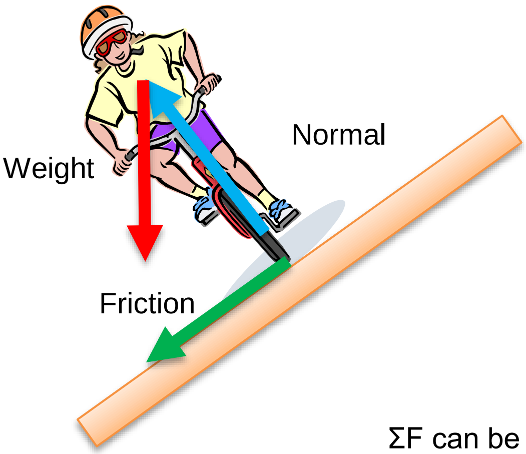
Labelled vector diagram ✓
Tan θ = $(mv^2/r) / mg = v^2 / gr$ ✓ (derives)
Tan 12° = $v^2 / (9.8 \times 150)$ ✓
V = 17.7 m s^{-1} ✓

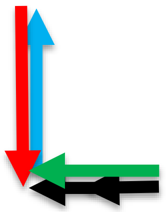
Track cycling takes place in an arena called a velodrome, as shown in the picture below. Velodromes have steeply banked curves. Banking in the curves, called superelevation, allows riders to keep their bikes relatively perpendicular to the surface while riding at speed. When travelling through the turns, riders' speeds may exceed 85.0 km h^{-1}.

(c) Explain, with the aid of a diagram, how a banked curve allows track cyclists to travel at higher speeds than they would be able to on a flat track.

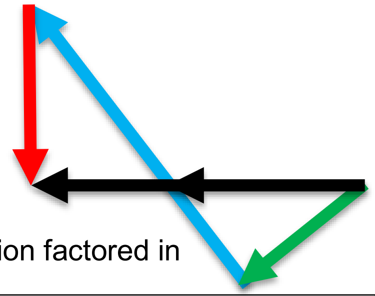
(4)

Forces available on banked track





ΣF = Friction on a flat track



ΣF can be greater with friction factored in on a banked track

vector diagram ✓
By driving into the curve the curve exerts a normal reaction force back onto the bike. The faster the bike drives into the curve the greater the normal reaction force. ✓
The speed can be set so the normal reaction and weight combine to give a resultant force acting to the centre of the horizontal circle. ✓
This motion can be achieved without friction, so if friction is also factored in then the speed can be higher on the banked track compared to the speed on flat ground. (This can be seen by comparing vector diagrams that use the maximum friction available from a surface) ✓

(d) A velodrome track has a radius of 20.0 m and a cyclist is travelling at 61.2 km h^{-1} on the track. Calculate the angle the track would need to be banked at if centripetal force is derived only from the normal reaction force.

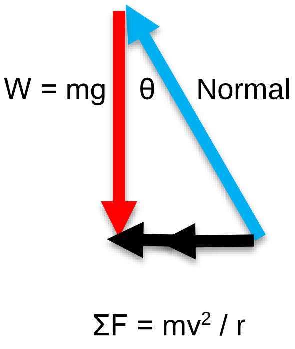
(3)

$r = 20.0$ m $\quad v = 61.2/3.6 = 17.0$ m s^{-1} ✓

$\tan\theta = (mv^2 / r) / mg. = v^2 / g.r$

$\tan\theta = 17^2 / (9.80 \times 20)$ ✓

$\theta = 55.8°$ ✓

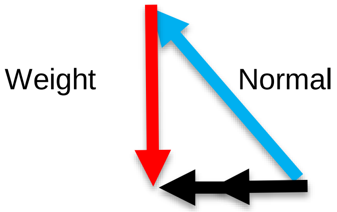


(e) Explain, by comparing two vector diagrams, why the actual velodrome track would not need to be banked as sharply as calculated in part (d).

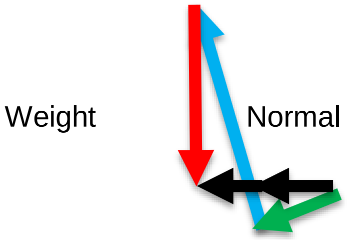
(2)

By comparing vector diagrams to achieve the same value of ΣF it can be shown that the angle of the normal is less steep if friction acts ✓

Vector diagrams drawn correctly. ✓



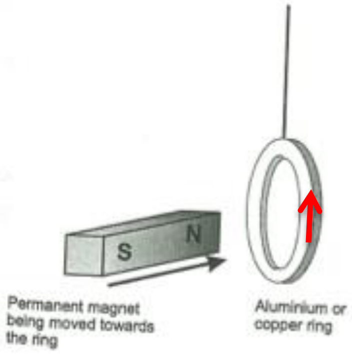
ΣF acts towards centre (no reliance on friction)



Equal ΣF with friction allows for less banking angle

Question 2 **(7 marks)**

The north pole of a magnet is brought towards a circular metal ring that hangs freely from a vertical string, as shown in the diagram below.



Current ✓

(a) Show the direction of induced current in the ring by drawing an arrow on the diagram and labelling it current.

(1)

(b) What type of magnetic pole (north or south) would be set up on the side of the ring closest to the magnet?

(1)

North ✓

(c) Explain why current is produced in the ring.

(3)

As the magnet approaches the ring, the magnetic flux within the ring is changing. ✓
According to Faraday's Law of induction, an emf is established within a conducting loop as the flux with in that loop is changing. ✓
The emf drives current around the ring according to Ohm's Law (I = V/R) ✓

(d) Describe and explain any motion of the ring as the magnet approaches.

(2)

The ring will swing backwards (like a pendulum) ✓

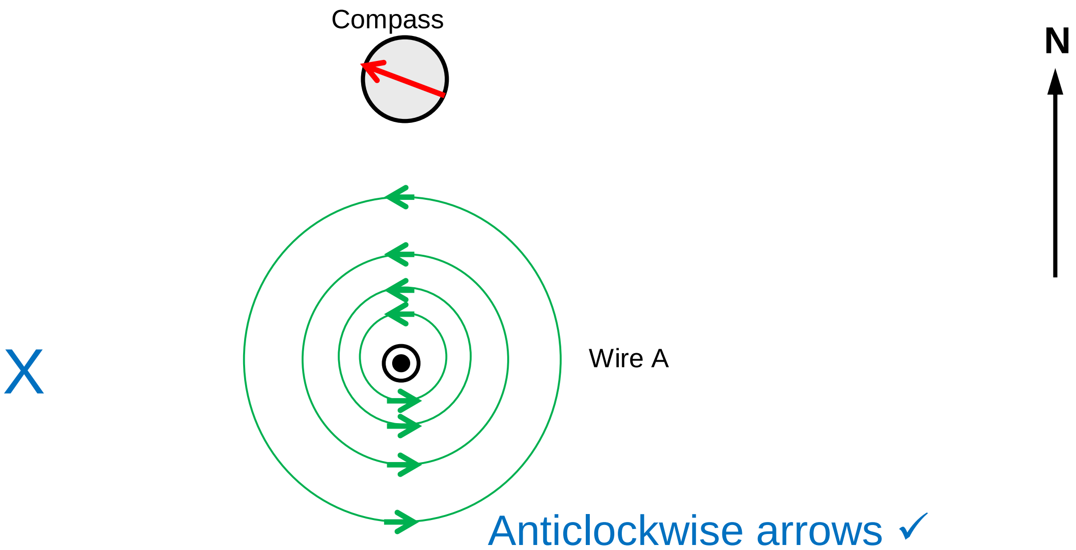
According to Lenz's Law the direction of emf (and current) is such that a magnetic field is formed the induced current to oppose the field causing the change. This leads to repulsion between the ring and the magnet. ✓

Question 3 **(5 marks)**

The diagram below represents the current in a wire ‘A’ looking down from above the wire. This experiment is conducted near the equator where the flux density is 55.5 µT. The Geographic North Pole of the Earth is towards the top of the page and is aligned with the magnetic pole. A small compass is placed to the North of the wire, as shown.

a. Draw in four field lines around the wire, to indicate the magnetic flux formed by the current in the wire.

(2)



Anticlockwise arrows ✓

Concentric circles with higher density closer ✓

b. Inside the compass, draw an arrow to show the direction of the resultant field. At this location the strength of the field from the wire is double that of the field from the Earth.

(1)

Arrow as above (approx. 26° angle of elevation above East-West) ✓

c. Put the letter ‘X’ on the diagram to show a location where the resultant flux density is equal to zero.

(1)

Shows X West of wire at a distance a little over the wire-compass distance ✓

d. State the direction of force acting on the wire by circling a response below.

(1)

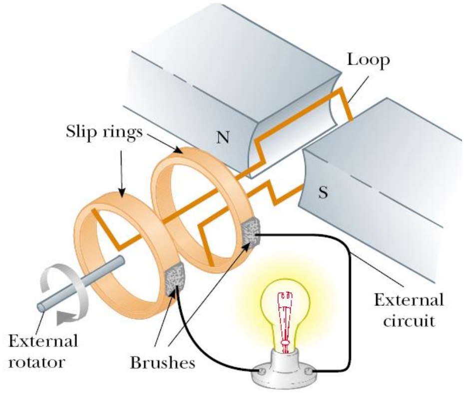
North South East [✓ West] Into page Out of page

Question 4

(5 marks)

An AC generator is shown in the diagram.

- The loop is a rectangle 15.0 cm long by 8.00 cm wide.
- The loop has 120 turns of copper wire.
- The loop is rotating at a constant rate of 5400 rpm
- The uniform magnetic flux density between the magnetic poles is 834 mT



i. Calculate the approximate average emf output from this generator by considering a rotation of the coil through ¼ of a turn from maximum flux contained in the coil to zero flux contained in the coil.

(3)

Φ_1 = BA = 0.834 x 0.15 x 0.08 Φ_2 = 0

N = 120   f = 5400 / 60 = 90   T = 0.0111 $T_{\frac{1}{4}}$= 0.002777 ✓

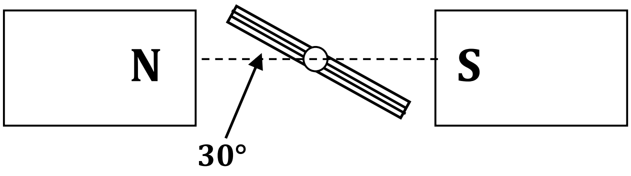
emf = -N (Φ_2 - Φ_1) / t

emf = NBA / $T_{\frac{1}{4}}$

emf = 120 x 0.834 x 0.15 x 0.08 / 0.002777 ✓

emf = 432 V ✓

At one instant during rotation the plane of coil makes an angle of 30° with the magnetic field lines as shown in the diagram below:



ii. Determine the value of the *instantaneous emf* in this position as a percentage (%) of the *maximum emf* for this generator.

(2)

emf instantaneous = emf max x cos 30 ✓

emf instantaneous = 86.6 % of emf max ✓

Question 5 **(9 marks)**

Mars has two moons, Phobos and Deimos which move around it in orbits very close to the planet's surface. These satellites of Mars are so tiny that they were not discovered until 1877.

The orbit of Phobos can be assumed to be circular and has a semimajor axis (radius) of 9378 km and a period of 7 hours and 39 minutes. This information can be used to calculate the mass of Mars.

(a) Calculate the circumference of the orbit of Phobos.

(2)

$c = 2\pi r = 2 \times \pi \times 9\ 378\ 000$ ✓
$c = 5.89 \times 10^7$ m ✓

(b) Calculate the speed of Phobos.

(3)

$T = (7 \times 60 \times 60) + (39 \times 60) = 27540$ s ✓

$v = 2\pi r\ /\ T = 2 \times \pi \times 9\ 378\ 000\ /\ 27540$ ✓
$v = 2139.568$ m s^{-1} $= 2.14 \times 10^3$ m s^{-1} ✓

(c) Calculate the mass of Mars from the information provided in the question.

(4)

r = 9 378 000 m ✓

v = 2139.568 m s^{-1} = 2.14 x 10^3 m s^{-1} ✓

$\frac{v^2}{r} = G\frac{M}{r^2}$ concept ✓

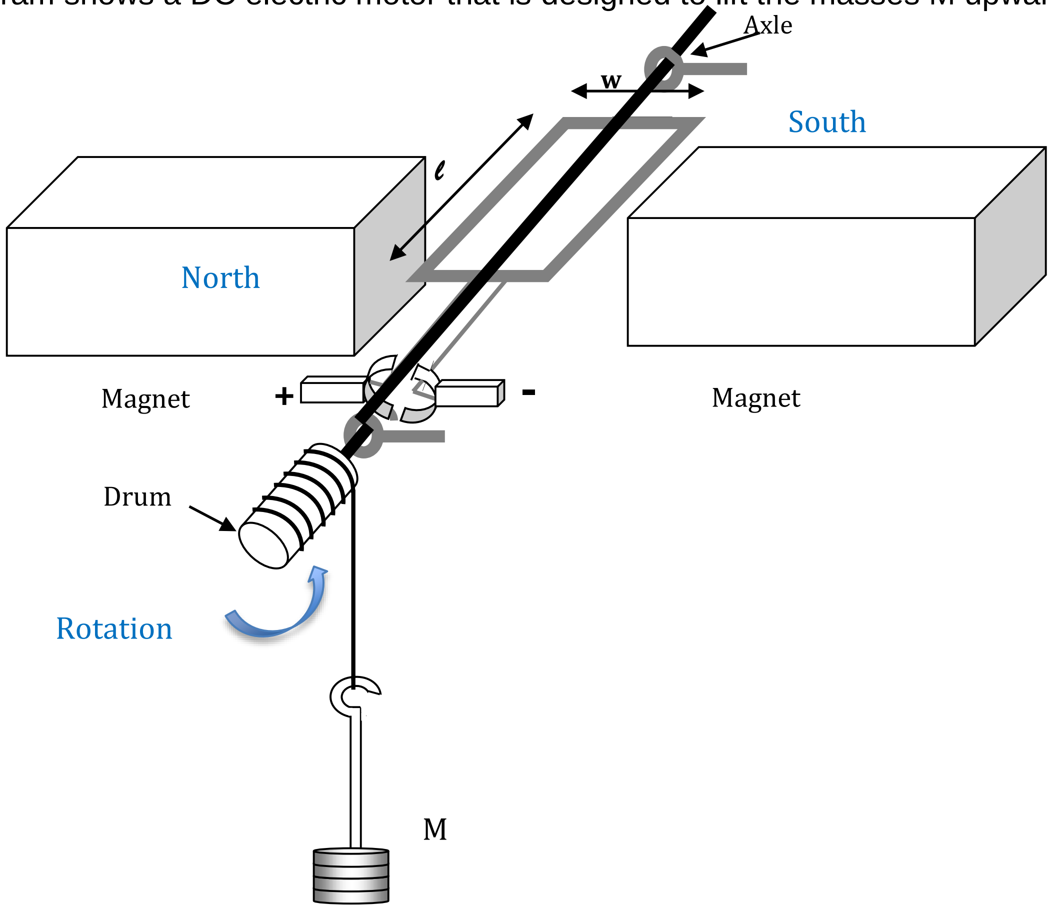
$\frac{2139.568^2}{9\,378\,000} = 6.67 \times 10^{-11}\frac{M}{9\,378\,000^2}$ ✓

M = 6.44 x 10^{23} kg ✓

Alternative methods such as Kepler 2 also acceptable.

Question 6 **(12 marks)**

The diagram shows a DC electric motor that is designed to lift the masses M upwards.



a. Draw in the North and South magnet pole arrangement on the diagram to ensure that the motor turns in the correct direction.

(1)

b. Motor specification:

Length of coil (*l*) = 12.0 cm
Width of coil (w) = 5.60 cm
Number of turns = 150
Coil resistance = 1.85 Ω

Voltage of battery connected = 12.0 V
Flux density of magnets = 1.25×10^{-2} T
Drum diameter = 4.20 cm

Use these values to calculate the maximum torque available from this motor.

(4)

I = V / R = 12 / 1.85 = 6.486486486 A ✓

A = w x l = 0.12 x 0.056 = 0.00672 m^2 ✓

Torque max = 2 x BIlN x w/2 = BANI

Torque max = $1.25 \times 10^{-2} \times 0.00672 \times 150 \times 6.486486486$ ✓

Torque max = 8.17×10^{-2} N m anti-clockwise ✓

c. The torque available from this simple motor varies over one complete rotation. Explain why.

(2)

The angle between the force (constant direction) ✓ and the lever arm (w/2) varies as the coil rotates ✓

Or similar

d. For this question assume that the motor can deliver a constant torque of 8.0 x 10^{-2} N m. Calculate the maximum mass that it would be capable of lifting.

(3)

lever arm on the drum = 0.021 m ✓
T = r F
0.08 = 0.021 x mg

m = 0.08 / (0.021 x 9.8) ✓
m = 0.389 kg ✓

e. An ammeter is connected to the motor to measure the current in the circuit. It is noticed that without the load attached the current in the circuit is much less than when the motor is used to lift the load. Explain why the current increases when the load is attached.

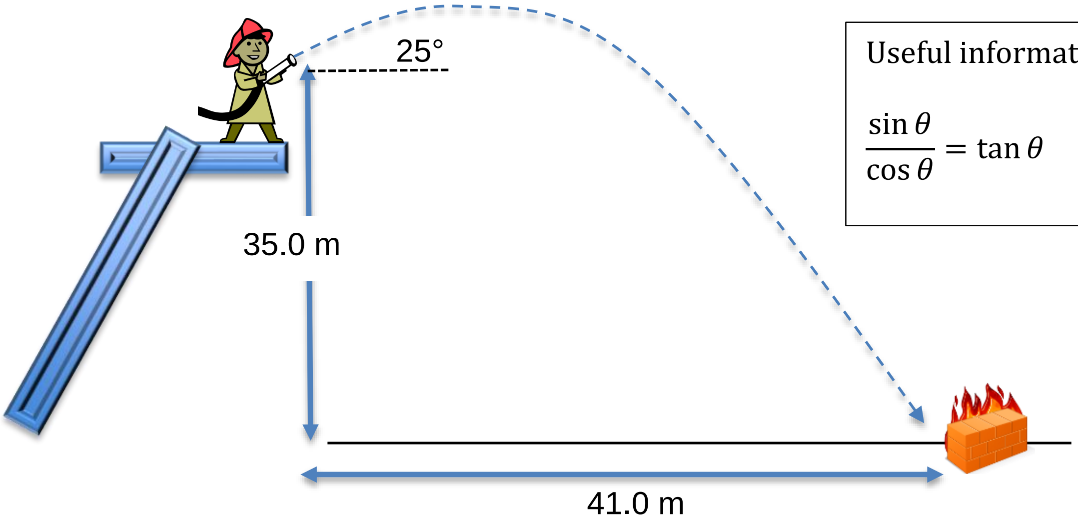
(2)

According to Faradays Law the rotating coil in the motor experiences a change in flux so also behaves as a generator – to establish a back emf which opposes the battery emf. ✓

With the load attached the rate of change of flux is reduced so back emf is reduced and current increases. ✓

Question 7 **(13 marks)**

The diagram shows a fireperson who directs a hose at a fire from a height of 35.0 m to achieve a range of 41.0 m.



Useful information:

$$\frac{\sin\theta}{\cos\theta} = \tan\theta$$

(a) The fireperson sets the hose at an angle of 25.0° above the horizontal. Calculate the initial speed of the water required to reach the target.

(5)

In the vertical

$a = -9.80$ s (vertical) $= -35.0$ m u (vertical) $= u \sin 25°$

In the horizontal

s (horiz) $= 41.0$ m u (horizontal) $= u \cos 25° = s / t_f$

so $t_f = 41 / u \cos 25$

In the vertical

$s = ut + \frac{1}{2} at^2$

$-35 = u \sin 25 \times (41/u \cos 25) - 4.9\ (41^2 / u^2 \times \cos^2 25)$

$-35 = (41 \times \tan 25) - 10027.9548633/u^2$

$54.11 = 10027.9548633/u^2$

$u^2 = 10027.9548633 / 54.11$

$u = 13.6$ m s^{-1} at 25° elevation

(b) Calculate the time taken for the water to be at a height of 35.0 m again after leaving the hose. If you could not solve for the initial velocity use a value of 13.6 m s^{-1} at 25.0° above the horizontal.

(3)

In the vertical (reference start height)

a = -9.80   s (vertical) = 0 m   u (vertical) = 13.6 sin 25°= 5.75 m/s

v = -13.6 x sin 25° (same magnitude opposite direction) ✓

t = v – u / a = (-13.6 x sin 25° - 13.6 sin 25°) / -9.8 ✓

t = 1.17 s ✓

(c) Calculate the **velocity** of the water just before it strikes the ground. You must make reference to a vector diagram. (If you could not solve for the initial velocity use a value of 13.6 m s^{-1} at 25.0° above the horizontal).

(5)

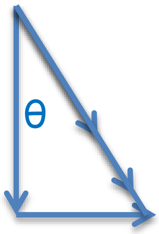
In the vertical (reference start height)

a = -9.80   s (vertical) = -35 m   u (vertical) = 13.6 sin 25°

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

$v^2 = (13.6 \sin 25°)^2 - (19.6 \times -35)$ ✓

v = -26.8 m s^{-1} (down) ✓



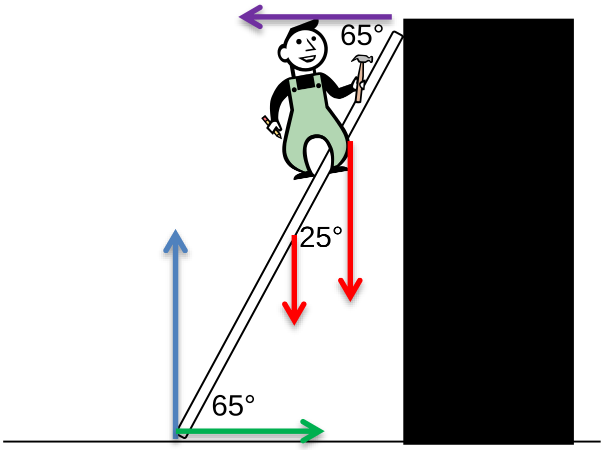
Constant speed in horizontal = 13.6 cos 25 = 12.3 m s^{-1} right ✓

final velocity = $\sqrt{26.8^2 + 12.3^2} = 29.5\, m\, s^{-1}$ ✓

θ = $\tan^{-1}$ (12.3 / 26.8) = 24.7° to the vertical ▯ (65° below horiz)

Question 8 **(14 marks)**

A 70.0 kg builder climbs a uniform ladder which is 5.10 m long and has a weight of 200 N. The ladder leans against a vertical wall and the builder is two-thirds (2/3) of the way up the ladder. The bottom of the ladder rests on rough horizontal ground. The top of the ladder rests on a frictionless wall so a normal reaction force is applied from the wall to the ladder. The ladder makes an angle of 65.0° with the horizontal.



(a) Calculate the normal force of the wall acting on the ladder. You must clearly explain the physics principles used in your response.

(5)

If the ladder is in static equilibrium

ΣMOMENTS = 0 M = r.F.sinθ concept understood ✓

Σacwm = Σcwm (take moments about base)

5.1 x N x sin 65 ✓ = 2.55 x 200 x sin 25° + 3.4 x 70 x 9.8 x sin 25° ✓

5.1 x N x sin 65 = 1201.25

N = 259.88888 N = 260 N ✓

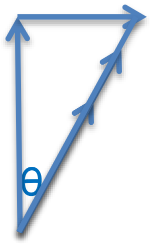
Direction = Left ✓

(b) Calculate the total force acting on the bottom of the ladder. You must clearly explain the physics principles used in your response.

(5)

By $\Sigma F = 0$, so $\Sigma F\ (\text{right}) = \Sigma F\ (\text{left})$

Friction (right) = Top Normal (left) = 260 N right ✓



$\Sigma F\ (\text{up}) = \Sigma F\ (\text{down})$

Base Normal = ΣWeight = $(70 \times 9.8) + 200 = 886$ N up ✓

By Pythagoras Total Force = $(260^2 + 886^2)^{0.5}$ ✓

Total Force on bottom = 923 N ✓

Angle $\theta = \tan^{-1}(260/886) = 16.4°$ from vertical ✓

(c) Circle the correct response to complete the sentence.

"As the builder climbs higher up the ladder, the ladder is ___________ likely to slip?

less [✓ more] equally is not

(1)

Explain your reasoning with reference to appropriate equations.

(3)

The lever arm to the builder increases so he generates a greater clockwise moment, $M = r.F.\sin\theta$ ✓

For the ladder to remain in static equilibrium $\Sigma \text{MOMENTS} = 0$ so the anticlockwise moment must increase. ✓

For this to happen the Normal reaction from the wall must increase and because $\Sigma F = 0$, $\Sigma F\ (\text{right}) = \Sigma F\ (\text{left})$ the friction supplied by the rough ground must be larger and it is more likely to exceed the threshold available. ✓

Question 9 **(9 marks)**

a. Explain, with reference to an appropriate formula, why high voltage power lines are used when electrical power is transported over large distances.

(3)

Electrical Power = V_{emf} x I

So a given power can be achieved with high voltage and low current ✓

The electrical cables that transport electricity have a given resistance, where power lost to heat is given by $P_{loss} = I^2R$. ✓

So if current is minimised then Power loss is minimised. ✓

b. When electricity is supplied to households it must typically be stepped down from 66,000 V to 240 V. Explain why transformer will only work with AC and not DC current.

(3)

According to Faraday's Law induced emf on the secondary is given by the rate of change in flux within the secondary winding. ✓

DC current in the primary will establish a magnetic field in the both the primary and secondary but there will be no change so no induced emf. ✓

In an AC supply the voltage/current varies in a sinusoidal fashion ensuring a constantly changing flux and hence constantly changing emf and current. ✓

c. Describe two sources of inefficiency for the energy transformations within a transformer.

(2)

Formation of Eddy Currents in the core leads to unwanted heating effects. ✓

Heating effects from current in the wires given by $P_{loss} = I^2R$. ✓

(Sound from 50 Hz vibrations)

d. Describe a suitable material for the core of a transformer. Explain briefly.

(1)

e.g. Soft Iron. Any ferromagnetic material that concentrates field lines and optimises flux linkage between primary and secondary coils. ✓

End of Section Two

Spare page for additional working

Section Three: Comprehension 20% (36 Marks)

Answer **all** questions. Write your answers in the space provided. Suggested working time for this section is 40 minutes.

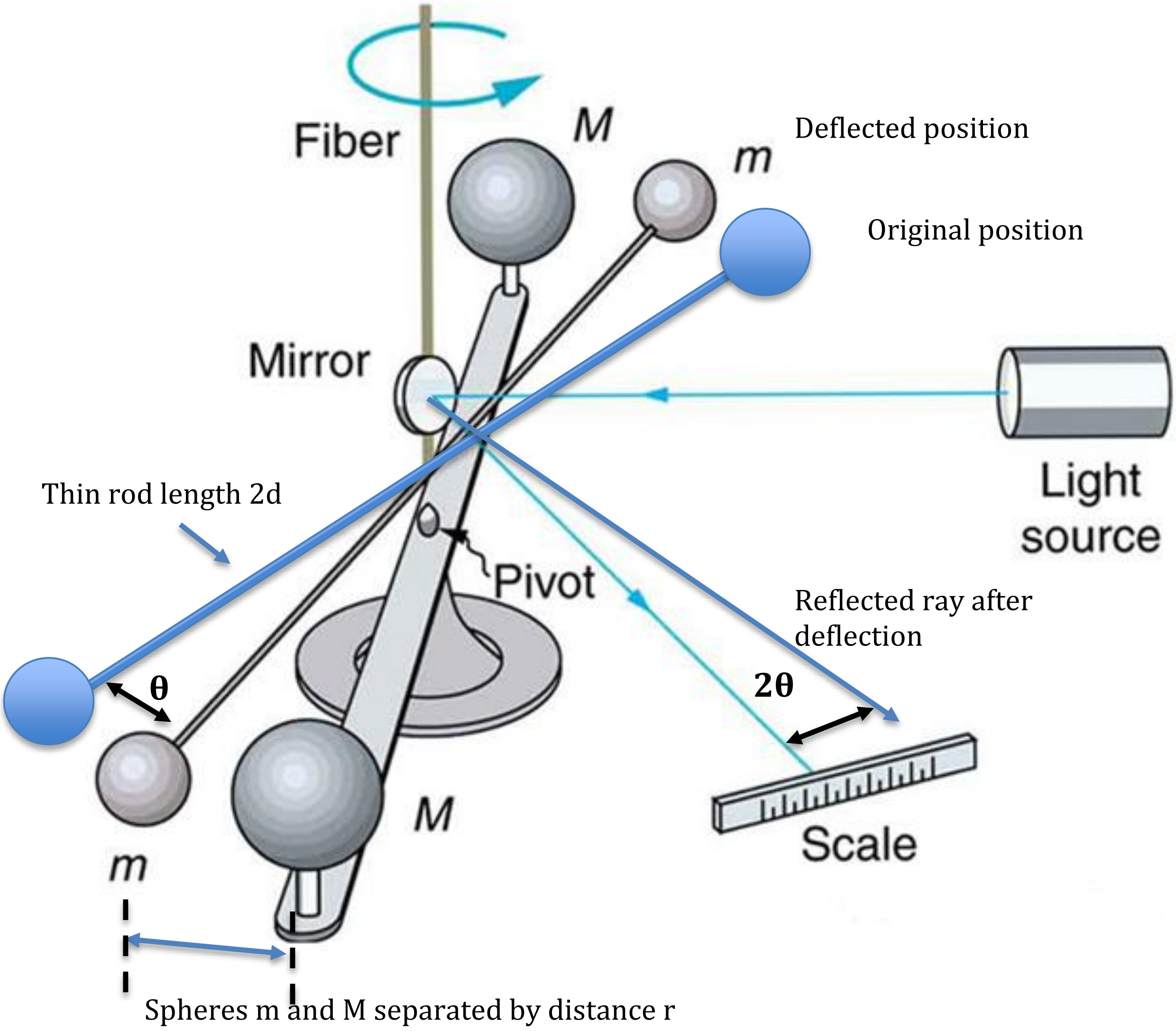
Question 1 (36 marks)

The Cavendish Apparatus

Sir Isaac Newton studied the motion of heavenly bodies such as the planets and the moon. Through his examination of the orbits of the planets about the Sun and the Moon about the Earth, he developed a law of universal gravitation. In this he proposed a universal constant G (the universal gravitational constant), which would have the same numerical value for all objects.

Henry Cavendish (1731-1810) was the first to measure the universal gravitational constant G experimentally, over 100 years later, in 1798. The Cavendish apparatus consists of two small spheres, each of mass m, fixed to the ends of a light horizontal rod suspended by a thin metal wire (known as the torsion fiber). When the rod turns, the wire (which is fixed in place at the top) becomes twisted - this twisting is known as torsion. The twisted wire exerts a force to try and restore the rod back to its original position. This force is proportional to the angle of rotation of the rod. The greater the twist in the rod, the greater the torsional force exerted will be to return the rod back to its original position. The Cavendish apparatus was calibrated to determine the relationship between the angle of rotation and the amount of torsional force.

Figure 1 – The Cavendish Apparatus



To measure the angle of rotation a light beam and mirror are used. The angle of rotation of the rod is determined by measuring the deflection of the beam of light. Although the rod is only rotated through an angle θ, the beam of light is deflected through 2θ - thus magnifying the effect.

When two large spheres, each of mass *M*, are placed near the smaller ones, the attractive force between the smaller and larger spheres causes the rod to rotate and the thin metal wire twists until the system is in rotational equilibrium (i.e the torque due to the twisting equals the torque due to gravitational force).

A group of students used a similar setup to Cavendish's experiment to determine the universal gravitational constant using the relationship;

$$F = G\frac{Mm}{r^2}$$

They hung a thin rod (of length 2d) with small lead spheres (of equal mass) at each end from a fine wire. Two large spheres were placed near the small spheres on the rod. The gravitational force between the large and small spheres twisted the rod. When the rod reached equilibrium, the torque from the wire balanced the torque from the gravitational force.

(a) Show, including appropriate comments/captions, that the total torque on the rod is

(2)

By consideration of T = r.F.sinθ, (note r = lever arm in equation)
The lever arm = d in this experiment (= 0.45 m)

The force between 1 pair of spheres is given by:

$F = G\,\frac{mM}{r^2}$ ✓ Where r – separation between spheres

The total torque from both pairs of spheres is then:

$T = 2 \times d \times G\,\frac{mM}{r^2}$ which by re-arrangement = $2G\,\frac{mM}{r^2}d$ ✓

(b) In one trial, the beam of light was shone onto the mirror and reflected onto the scale, where the beam's deflection from its starting position could be measured. Initially the beam and the screen were perpendicular to each other. The screen was 5.50 m from the mirror. After rotation the light beam was deflected through 3.45 mm on the scale. Calculate the angle of rotation of the rod.

(3)

Referring to the diagram Tan 2θ = opp/adj = 0.00345/5.50 ✓

2θ = tan^{-1}(0.00345/5.50) = 0.0359° ✓

θ = 0.0178°✓

The students' results are given below.

M = 1.50 kg m = 15.0 g Length of rod = 90.0 cm

r (m)	τ (x 10^{-10} N m)	$\frac{1}{r^2}$ (m^{-2})
0.050 ± 0.001	5.26	400 ± 16
0.070 ± 0.001	2.69	204 ± 6
0.090 ± 0.001	1.63	123 ± 3
0.110 ± 0.001	1.09	82.6 ± 1.5
0.130 ± 0.001	0.779	59.2 ± 0.9
0.150 ± 0.001	0.350	44.4 ± 0.6

The values of 'r' were measured with a ruler with 1 mm intervals. The students were confident that there measurements had an uncertainty range of +/- 1 mm. The uncertainty range for the first column is shown.

(c) Process the students' data with appropriate uncertainty ranges for $\frac{1}{r^2}$ so that you are able to plot a graph of Torque (vertical axis) versus $\frac{1}{r^2}$ (horizontal axis). Two values have been done for you.

(3)

$1/r^2$ values ✓ appropriate sig figs ✓ uncertainty values ✓

(d) Place the units for $\frac{1}{r^2}$ in the appropriate position in the table above.

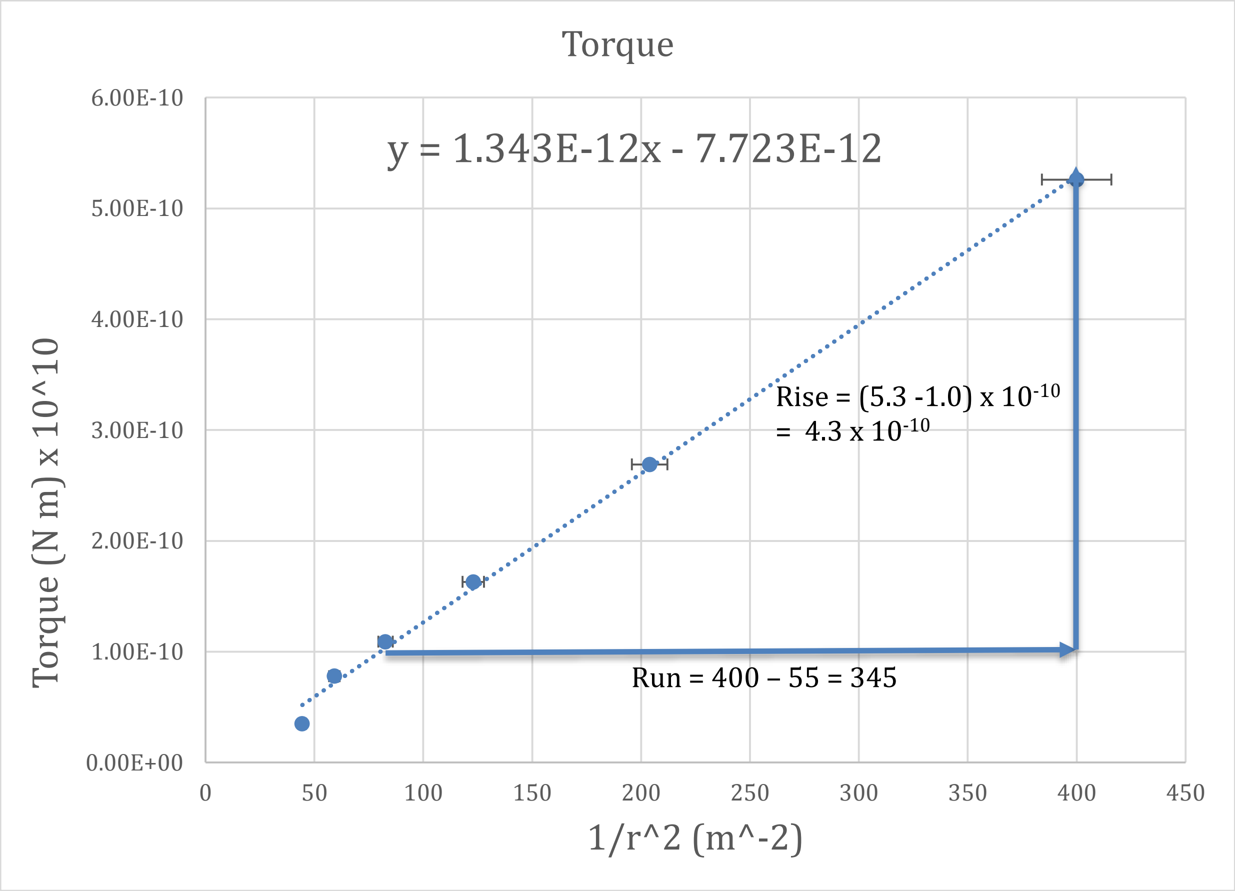
(1)

(m^{-2})

(e) Plot a fully labelled graph of Torque versus $\frac{1}{r^2}$. You must include error bars and a line of best fit.

(4)

Plots, axes labels, units, error bars, lobf (-1 any incorrect)



(f) Determine the gradient of your line of best fit.

(3)

Refers to rise and run from lobf. ✓

Gradient = rise / run = 4.3×10^{-10} / 345 ✓

Gradient = 1.25×10^{-12} ✓ ($N\ m^3$) allow range

(g) Use the gradient from your graph to determine the value of the universal gravitational constant, *G*.

(3)

Gradient = 1.25×10^{-12} = 2 G M m d ✓ concept

G = 1.25×10^{-12} / (2 M m d)

G = 1.25×10^{-12} / (2 x 1.50 x 0.015 x 0.45) ✓

G = 6.17×10^{-11} ✓

(h) Determine the percentage difference in your result from the accepted value.

(2)

% diff = (experimental value – accepted value) / accepted value (%)

% diff = (6.17×10^{-11} – 6.67×10^{-11}) / 6.67×10^{-11} ✓

% diff = 7.50 % ✓

(i) If a second trial was conducted and the mass of the larger spheres was increased to 2.00 kg

i. The gradient of the line of best fit would be: (circle a response)

(1)

[✓ greater] the same less impossible to determine

ii. How would this affect the value of *G* determined? Explain your reasoning.

(2)

No effect ✓

The torque values will be greater but the steeper gradient is compensated by a higher value of (2GmMd) ✓ G is a constant

(j) Referring to the table of results. Consider the value of $\frac{1}{r^2}$ when the torque = 5.26×10^{-10} N m

State the absolute uncertainty of this value: $\pm$ 16 m^{-2} (1)

State the relative uncertainty of this value: $\pm$ 4 % (1)

The derivations in this experiment assume that only the large sphere closest to each small sphere contributes to the gravitational force on the small sphere.

(j) Is this a reasonable assumption? Explain your reasoning.

To justify your response:

- Compare the gravitational forces on the small sphere due to each of the two large (1.50 kg) spheres in the scenario that is likely to cause the most error.
- Explain what effect the furthest large sphere will have on the torque values measured.

(6)

Most error when small sphere has greatest separation from its large sphere partner.

This occurs at r = 0.15 m ✓

Force between 2 spheres at 0.15 m separation:

$F = G\frac{mM}{r^2}$ $F = 6.67 \times 10^{-11}\frac{0.015\times1.5}{0.15^2} = 6.67 \times 10^{-11}N$ ✓

The opposite large sphere has a separation given by

R = $\sqrt{0.15^2 + 0.9^2}$ = 0.912 m (approximately) ✓ (ok to use 0.90 m)

Force between small sphere and opposite large sphere

$F = G\frac{mM}{r^2}$ $F = 6.67 \times 10^{-11}\frac{0.015\times1.5}{0.9^2} = 1.85 \times 10^{-12}N$ ✓

This is approximately (0.185 / 6.67)% = 2.8% of the force used in the torque calculation, so in itself it has quite a small effect. ✓

By consideration of T = r.F.sinθ, Its effect on torque is further diminished as the angle it makes to the lever is only a few degrees compared to nearly 90° for the 2 spheres close to each other. ✓

(k) Describe two other possible sources of experimental error and explain how their effects could be minimized by careful experimental design.

(4)

Source of experimental error 1:	Air movement from draughts could disrupt the readings✓
Effect minimised by:	A sealed room where air movement is restricted.✓
Source of experimental error 2:	Temperature changes leading to thermal expansion of equipment. ✓
Effect minimised by:	Temperature controlled room ✓

Any valid points that acknowledge the sensitive nature of this experiment.

Spare pages for additional working

Spare pages for additional working