PHYSICS

Stage 3

MLC Semester 1 Physics
Examination, 2011

Question/Answer Booklet

Please place your student name in this box

Time allowed for this paper

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

Special items: non-programmable calculators satisfying the conditions set by the Curriculum Council 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 PAPER

Section	No. of questions	No. of questions to be attempted	No. of marks out of 180	Proportion of examination total
A: Short Answers	13	ALL	54	30%
B: Problem Solving	6	ALL	90	50%
C: Comprehension and Interpretation	2	ALL	36	20%

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 to follow any instructions that are specific to a particular question.

4. Working or reasoning must be clearly shown when calculating or estimating answers.

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.

SECTION ONE: Short Answer

54 marks FONT ?

This section has **thirteen (13)** questions. Answer in the spaces provided.

Suggested working time: 50 minutes.

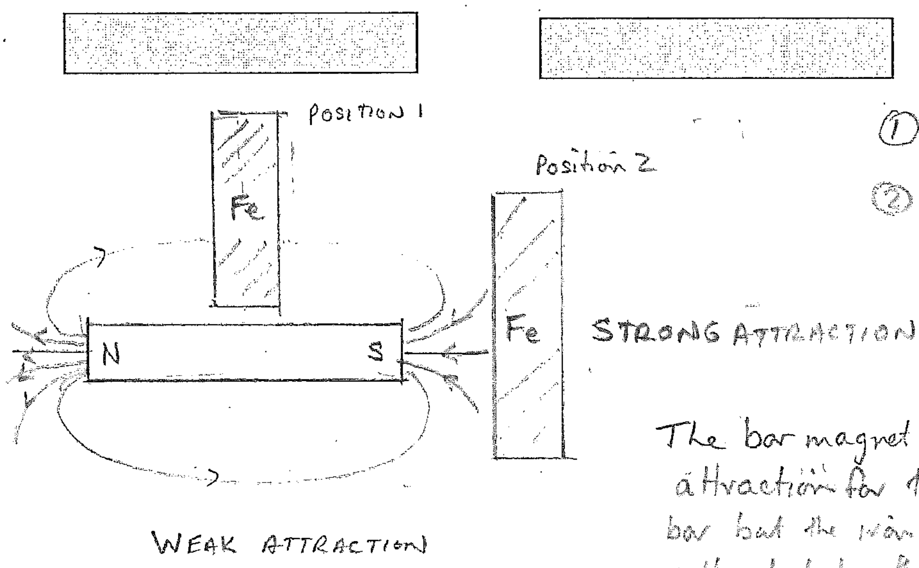
Question 1

Suppose you have two iron bars that look identical. One is a magnet and the other is an ordinary iron bar. By not using anything else besides these two bars, what could you do to tell which was the magnet? **Note: You are only permitted to observe interactions between the two bars.**

Hint: Draw the magnetic field around the bar magnet.

[3 marks]

Hard question.



① field lines drawn

② good explanation

The bar magnet will have a strong attraction for the middle of the iron bar but the iron bar will only be weakly attracted to the middle of the magnet as the field there is weak.

Question 2

A man fires a bullet horizontally from a pistol held in his left hand, while simultaneously releasing another bullet held in his right hand at the same height. Which bullet hits the ground first? Explain your answer (ignore air resistance).

[4 marks]

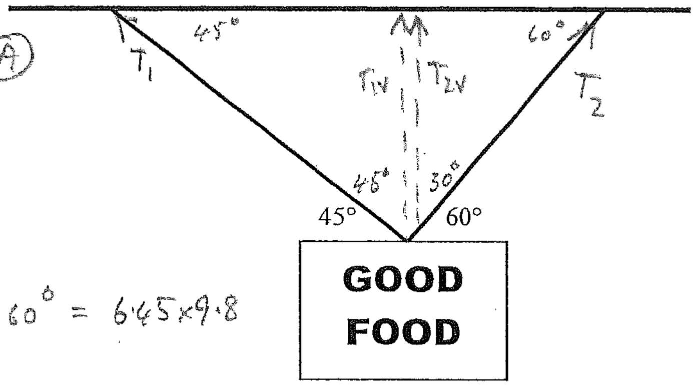
Both bullets hit the ground at the same time. ②

The vertical component of the velocity of both bullets is ① zero and hence the time taken to reach the ground will be the same as it is only dependent on gravity and vertical speed if the height is the ① same. ($s_v = u_v t + \frac{1}{2} a_v t^2$)

Question 3

An advertising sign outside a shop is suspended by two wires from an awning as shown in the diagram below. Given that the sign has a mass of 6.45 kg, calculate the magnitude of the tension in each wire.

[4 marks]



$\Sigma F_V = 0$

(1) $\therefore T_1 \sin 45° + T_2 \sin 60° = mg$ (A)

$\Sigma F_H = 0$

(1) $\therefore T_1 \cos 45° = T_2 \cos 60°$ (B)

sub (B) int (A)

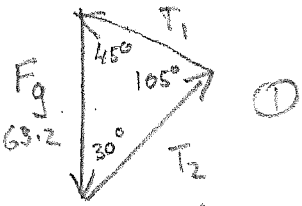
$\therefore T_1 \sin 45° + T_1 \dfrac{\cos 45°}{\cos 60°} \times \sin 60° = 6.45 \times 9.8$

(1) $\therefore T_1 = \dfrac{63.2}{(\sin 45° + \cos 45° \tan 60°)}$

$= 32.7$ N

(1) $T_2 = T_1 \dfrac{\cos 45°}{\cos 60°} = 46.3$ N

or



(1)

(1) sin rule $\dfrac{a}{\sin A} = \dfrac{b}{\sin B} = \dfrac{c}{\sin C}$

$\therefore \dfrac{F_g}{\sin 105°} = \dfrac{T_1}{\sin 30°}$

$\therefore T_1 = \dfrac{63.2}{\sin 105°} \times \sin 30°$

$= 32.7$ (1)

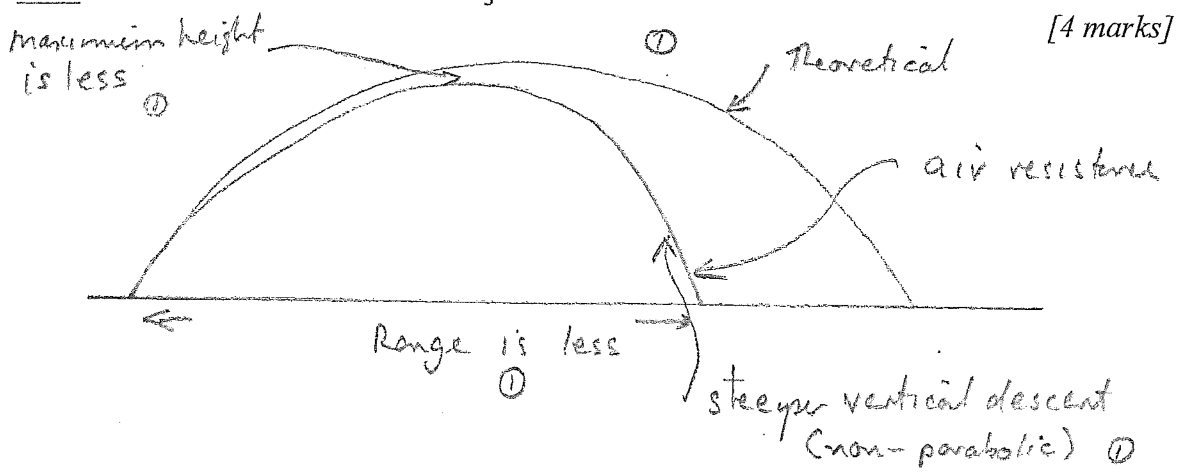
$\therefore T_2 = \dfrac{63.2}{\sin 105} \times \sin 45°$

$= 46.3$ N (1)

Question 4

Draw a diagram below showing the theoretical trajectory of a projectile through the air, contrasted with the actual trajectory you would expect if air resistance is taken into account. On your diagram, highlight <u>three</u> differences between the two trajectories.

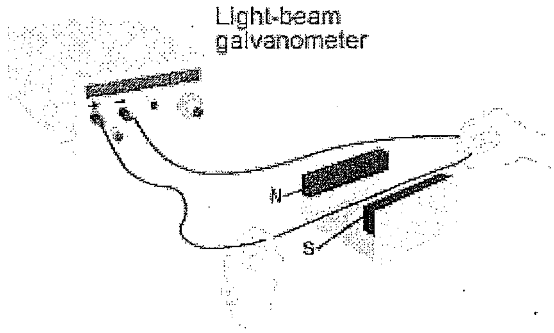
[4 marks]



Question 5

As part of an investigation into electromagnetic induction, a student used a length of wire to cut perpendicularly through a magnetic field, moving the wire at a steady speed of 40 cm/sec. He noted that the galvanometer attached to the ends of the wire showed a current of 2.3 mA. The total resistance of the circuit was 850 mΩ. From the diagram below, estimate the effective length of wire that cut through the field, and hence calculate a value for the strength of the magnetic field in the region between the magnetic poles.

[4 marks]



$\ell \simeq 0.1\,m$
$R = 0.85\,\Omega$
$I = 2.3\times10^{-3}\,A$ ①
$v = 40\,cm\,s^{-1} = 0.4\,m\,s^{-1}$

$\mathcal{E} = B\ell v$ ① and $V = IR$ ①

$\therefore IR = B\ell v$

$\therefore B = \dfrac{IR}{\ell v}$

$= \dfrac{2.3\times10^{-3}\times 0.85}{0.1\times 0.4}$

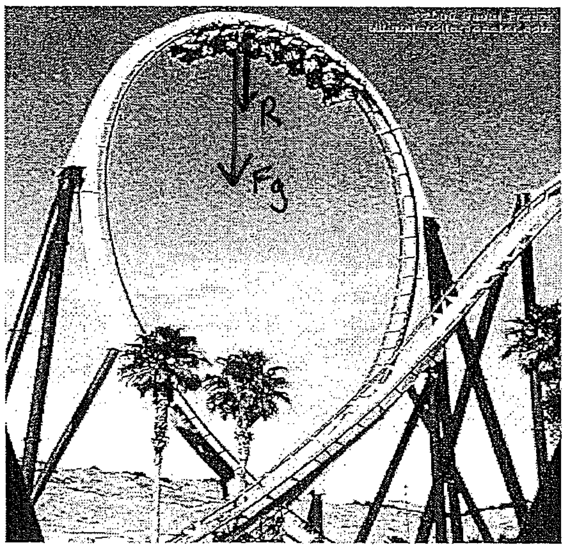
$= 49\,mT$ ①

Question 6

The picture below shows a roller coaster passing upside down through a vertical loop of **diameter 18 m**.

(a) Sketch and label the two forces acting on one of the passengers in the roller coaster as it passes through the top of the loop in the picture.

① each *[2 marks]*



(b) As the roller coaster passes upside down through the top of the loop, the passenger experiences a reaction force that is equal to half of his normal weight. Determine the speed of the roller coaster as it passes through the top of the loop.

[3 marks]

$F_c = R + F_g$ ①

$\therefore \dfrac{mv^2}{r} = \tfrac{1}{2}mg + mg$

$\therefore v^2 = \tfrac{3}{2}gr$ ①

$v = \sqrt{\tfrac{3}{2}\times9.8\times\tfrac{18}{2}}$

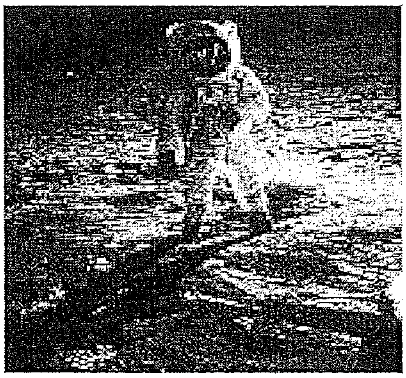
$= 11.5$

$\therefore v \simeq 12\,m\,s^{-1}$ ①
or $41\,km\,h^{-1}$

Question 7

The acceleration due to gravity on the surface of the Moon is 1.60 m/s^2. Using this value for acceleration due to gravity and the value for the radius of the Moon given in the formula sheet, determine the mass of the Moon.

[3 marks]



$$g = \frac{GM}{r^2} \quad (1)$$

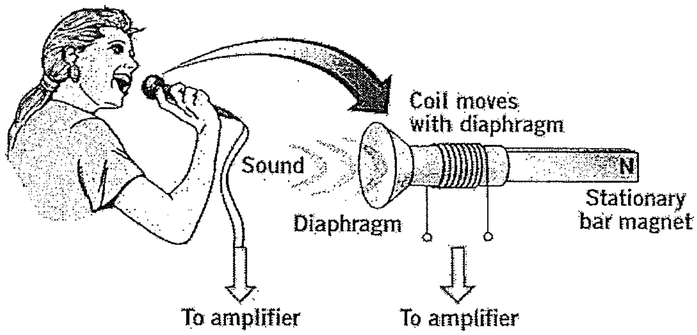
$$\therefore 1.60 = \frac{6.67 \times 10^{-11} \times M_{moon}}{(1.74 \times 10^6)^2} \quad (1)$$

$$\therefore M_{moon} = 7.3 \times 10^{22}\ \text{kg} \quad (1)$$

Question 8

The diagram shows the inner working of a simple microphone. Briefly explain how such a device can convert "sound" energy to "electrical" energy.

[4 marks]



As the coil moves with the diaphram it moves towards and away from (1) the magnet. Since magnetic field lines are being (1) cut an emf (1) will be generated in the coil given by $\mathcal{E} = -\frac{N\Delta\phi}{\Delta t}$ (Faradays Law)

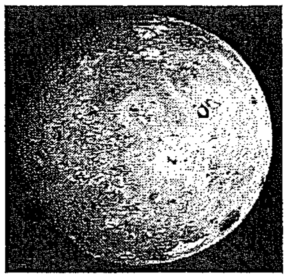
This emf will generate a current which will be amplified and produce sound in the speakers. (1)

(Since the emf responds to the rate of change of these the variations in emf will match the incoming sound wave frequencies.)

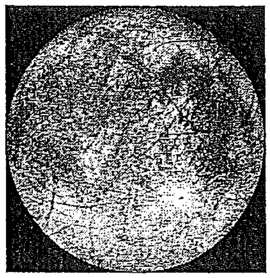
Question 9

Jupiter has four large moons, which are also known as the Galilean moons after their discoverer. The closest two to Jupiter of these moons are Io, which orbits with a radius of 422 000 km, and Europa, which has an orbital radius of 671 000 km. If Io takes 1.77 days to complete an orbit around Jupiter, calculate the orbital period of Europa.

[4 marks]



IO



EUROPA

$F_c = F_g$

$\therefore \frac{\cancel{m}v^2}{\cancel{R}} = \frac{GM_J\cancel{m}}{R^2}$ (1)

$\therefore \frac{\frac{4\pi^2R^2}{T^2}}{R} = \frac{GM_J}{R^2}$

$\therefore \frac{R^3}{T^2} = \frac{GM_J}{4\pi^2}$ (1) (Kepler's 3rd Law)

$T_{IO} = 1.77$ days

$R_{IO} = 422\,000$ km

$R_{Europa} = 671,000$ km

$\therefore \frac{R_{IO}^3}{T_{IO}^2} = \frac{R_{Europa}^3}{T_{Europa}^2}$ (1)

$\therefore T_{Europa}^2 = \frac{R_{EUROPA}^3}{R_{IO}^3} \times T_{IO}^2$

$= \frac{(671\,000 \text{ km})^3}{(422\,000 \text{ km})^3} \times (1.77d)^2$

$\therefore T_{EUROPA} = 3.55$ days (1)

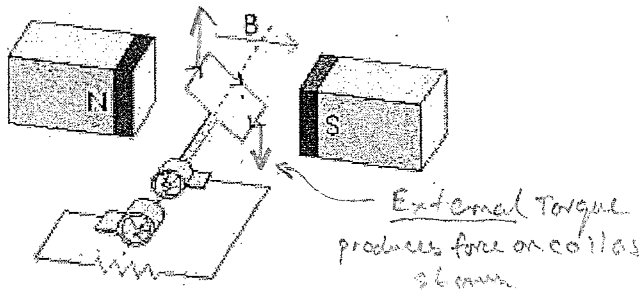
$= 3.07 \times 10^5$ s

Question 10

The diagram shows a simple electric generator.

(a) Show, or state, the direction of rotation necessary for the induced current to be in the direction shown. *[1 mark]*

Clockwise as viewed from commutator. (1)



(b) Such a generator has an armature (rotating coil) that is square with sides of length 3.0 cm, consists of 200 turns, rotates at 20 revolutions per second and produces an average emf of 2.4 V. Find the magnetic field intensity present between the poles of the magnets.

[3 marks]

If use $\frac{1}{4}$ turn average.

$\therefore \mathcal{E}_{avg} = 4BANf$

$\therefore 2.4 = 4B(3\times10^{-2})^2 \times 200 \times 20$

$\therefore B = \frac{2.4}{4\times(3\times10^{-2})^2 \times 200 \times 20}$

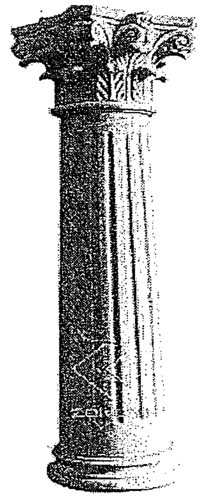
$= 0.17$ T

If use rms.

$\mathcal{E}_{rms} = \frac{2\pi}{\sqrt{2}} BANf$

$= 0.15$ T

Question 11



A cylindrical stone column is free standing in an upright position as shown in the picture at right. The column is 2.8 m tall, of average diameter 70 cm and has a mass of 4.5 tonnes.

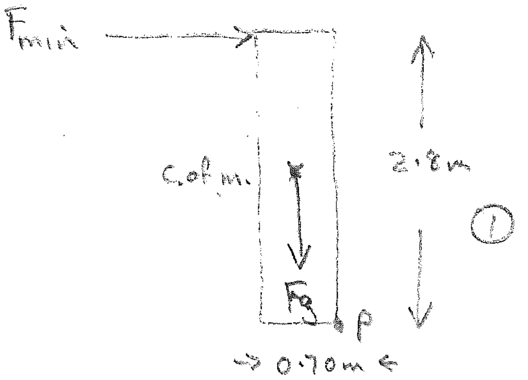
(a) Is the column in stable equilibrium? Discuss.

[2 marks]

It is a stable equilibrium ① as a small disturbance will result in it returning to its upright position ①

(b) ~~Determine~~ Estimate the minimum force needed to push over the column.

[3 marks]



Assume c. of m. in middle of column.

Take moments about P.

$\Sigma \tau_{cw} = \Sigma \tau_{acw}$ ①

$\therefore F_{min} \times 2.8 = F_g \times \left(\frac{0.70}{2}\right)$

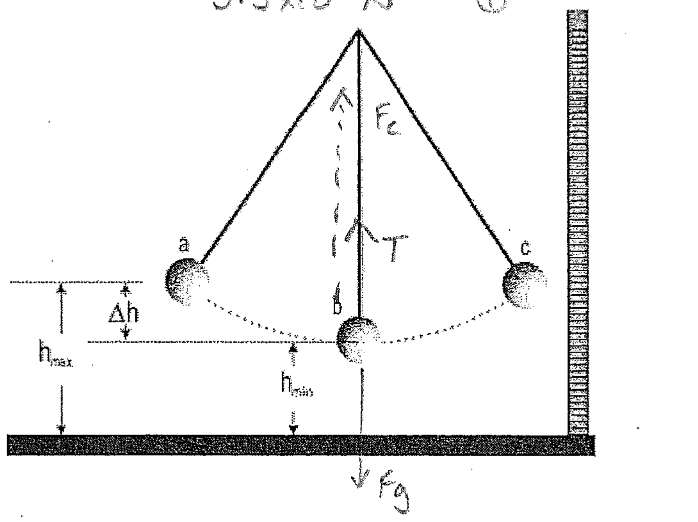
$\therefore F_{min} = \frac{4.5 \times 10^3 \times 9.8 \times 0.35}{2.8}$

$= 5.5 \times 10^3$ N ①

Question 12

A simple pendulum consists of a ball of mass 85 g attached to a 60 cm long string. The ball is released from rest at position **a**, as shown in the diagram at right. Given that the value of Δh is 14 cm, calculate the tension in the string as the ball swings through position **b** (lowest point).

[4 marks]



$\Sigma E_{gp} = \Sigma E_k$

$\therefore mg\Delta h = \frac{1}{2}mv^2$

$\therefore v^2 = 2g\Delta h$ ① $(v = 1.66\ ms^{-1})$

At b : $F_c = T - F_g$ ①

$\therefore T = F_c + F_g$

$= \frac{mv^2}{r} + mg$ ①

$\therefore T = \frac{0.085 \times (2 \times 9.8 \times 0.14)}{0.60} + 0.085 \times 9.8$

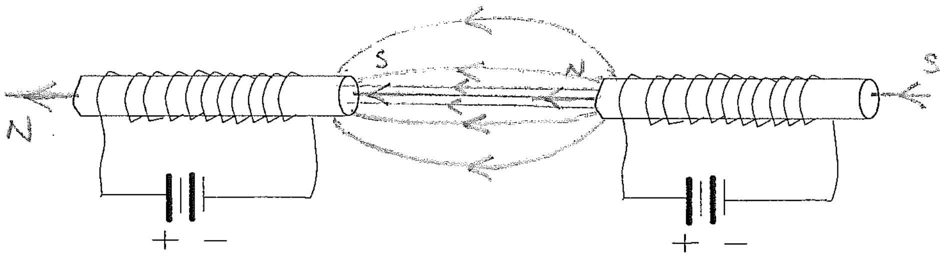
$= 0.389\ N + 0.833$

$= 1.2$ N ①

Question 13

(a) Two solenoids (coils) are placed a short distance apart as shown in the figure below. Sketch the magnetic field in the region between the two solenoids.

[2 marks]

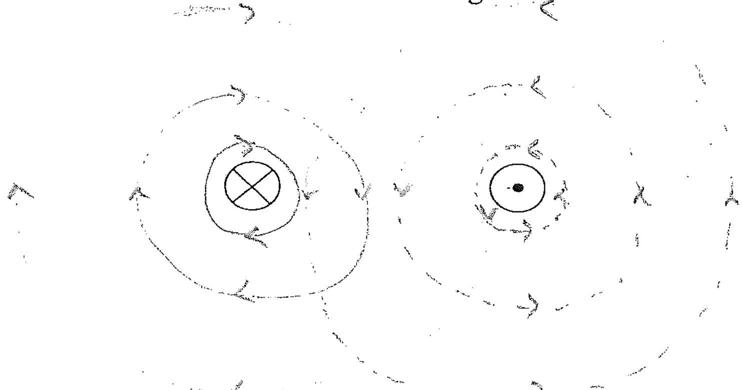


2

(b) The figure below shows two current carrying wires, one carrying current into the page and one carrying current out of the page. Show the magnetic fields surrounding each of the wires. You do NOT need to show how the magnetic fields of the two wires would interact.

[2 marks]

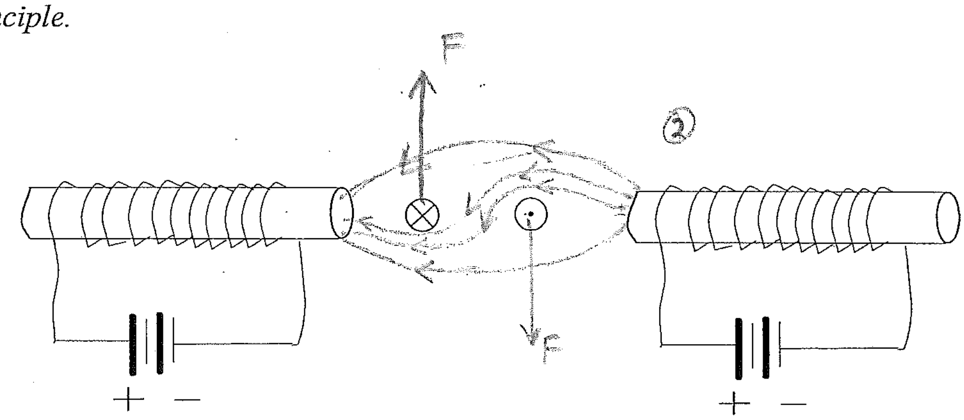
individual fields.



2

(c) Now sketch the **resultant** magnetic field, when the wires from part (b) are placed between the coils of part (a), in the figure below. Use your sketch to briefly explain the *electric motor principle.*

[3 marks]



The field lines are concentrated above the wire with current coming out of the page and below the wire with current going into the page. This results in a force on each wire as shown causing rotation clockwise. 1

(It is the interaction of both fields which results in a force, catapult effect)

SECTION TWO: Problem Solving 90 marks

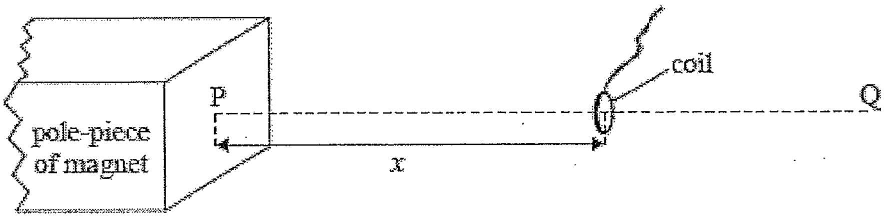
This section has **six (6)** questions. Answer in the spaces provided.

Suggested working time: 90 minutes.

Question 14 [14 marks]

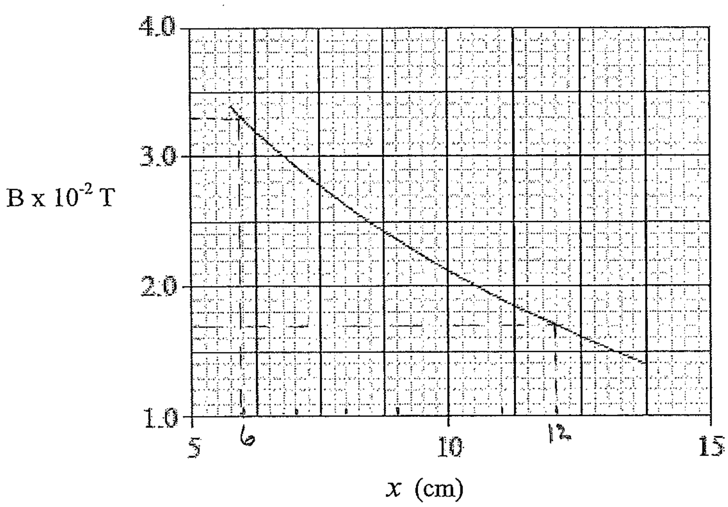
cross-sectional area

A small circular coil of area of cross-section 1.7×10^{-4} m^2 contains 250 turns of wire. The coil is connected to a resistor (not shown in diagram). The plane of the coil is placed parallel to, and a distance x from, the pole of a magnet, as shown below.



PQ is a line that is normal to the pole. The variation with distance *x* along line PQ of the mean magnetic field strength *B* in the coil is shown below.

Difficult scale



(a) When the coil is situated a distance 6.0 cm from the pole-piece of the magnet,

(i) state the average magnetic field strength in the coil. *[1 mark]*

3.3×10^{-2} T

(ii) calculate the magnetic flux linkage through the coil. *[2 marks]*

$\phi = BA = 3.3 \times 10^{-2} \times 1.7 \times 10^{-4}$ ①

$= 5.6 \times 10^{-6}$ Wb ①

(b) The coil is moved along PQ so that the distance x changes from 6.0 cm to 12.0 cm in a time of 0.35 s.

(i) Show that the **change** in magnetic flux through the coil is approximately 3 x10^{-6} Wb *[2 marks]*

$\phi_2 = BA = 1.7\times10^{-2} \times 1.7\times10^{-4} = 2.89\times10^{-6}$ Wb ①

$\therefore \Delta\phi = \phi_2 - \phi_1 = 2.89\times10^{-6} - 5.61\times10^{-6}$
$= -2.7 \times10^{-6}$ Wb ①
$\simeq -3\times10^{-6}$ Wb as suggested.

(-ve sign indicated direction of change)

(ii) Calculate the average emf induced in the coil during this time. *[2 marks]*

$\mathcal{E} = -\dfrac{N\Delta\phi}{\Delta t}$ ①

$= -250 \dfrac{(-2.7\times10^{-6})}{0.35}$

$= 1.93$ mV
$\simeq 1.9$ mV ①

(iii) Explain why work has to be done to move the coil along the line PQ. *[3 marks]*

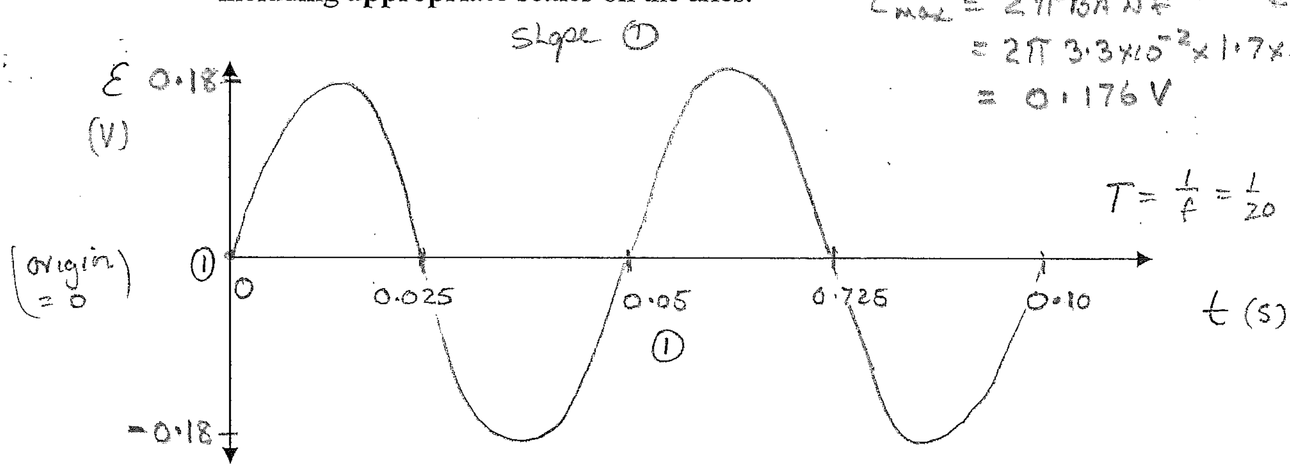
The coil will produce an emf which will create (Faraday's Law) a current ① that has a magnetic field which will oppose the change in flux. ① (Lenz's Law). The induced current creates a force on the coil which opposes the motion. ①
The work done is the product of this force and the distance moved, (W = F.s)

(iv) The coil is again placed at the 6 cm mark and rotated about a vertical axis (perpendicular to PQ) at 1200 rpm. Sketch a graph of induced emf against time, including **appropriate scales** on the axes.

$f = 1200$ rpm $= \frac{1200}{60} = 20$ Hz

$\mathcal{E}_{max} = 2\pi BANf$
$= 2\pi\, 3.3\times10^{-2} \times 1.7\times10^{-4} \times 250 \times 2[illegible]$
$= 0.176$ V

$T = \frac{1}{f} = \frac{1}{20} = 0.05$ s

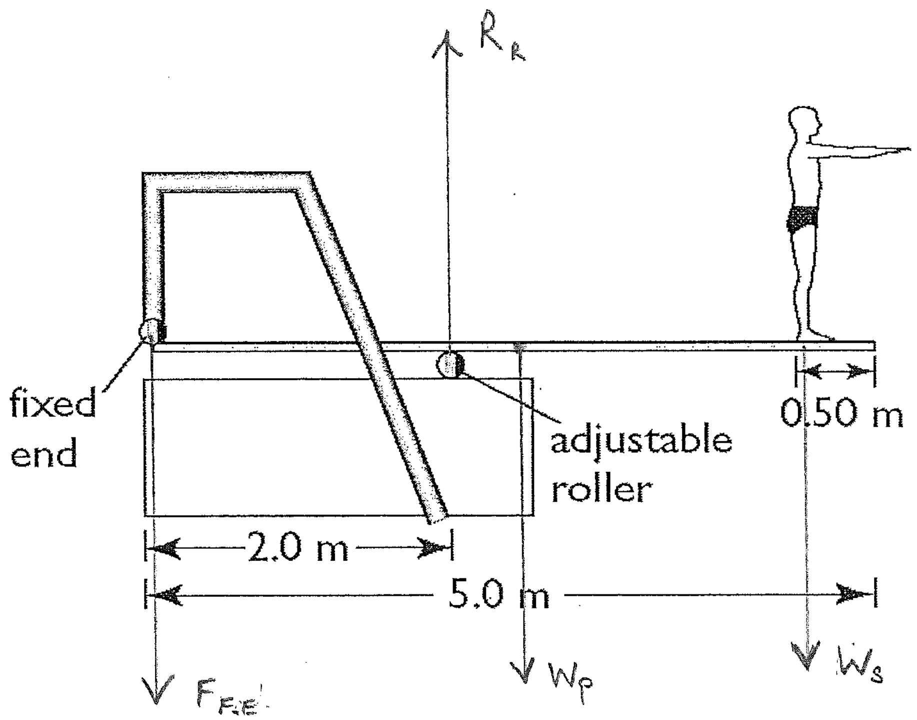


[4 marks]

Question 15 [15 marks]

uniform

A diving board consists of a 5.00 m long plank that is fixed at one end and supported by an adjustable roller. The plank has a mass of 40.0 kg. Steve of mass 88.0 kg stands 0.500 m from the free end of the plank. The roller makes contact with the plank at a distance of 2.00m from the fixed end as shown in the diagram below.



(a) On the diagram, mark in the direction and position of the forces acting on the plank. *[4 marks]*

① each

(b) What is the magnitude of the force that the roller exerts on the plank? *[4 marks]*

Take moments about fixed end. ①

$$\sum \tau_{acw} = \sum \tau_{cw} \quad ①$$

$$\therefore \quad R_R \times 2 = W_P \times 2.5 + W_S \times 4.5 \quad ①$$

$$\therefore \quad R_R = \frac{(40 \times 2.5 + 88 \times 4.5) \times 9.8}{2}$$

$$= 2.43 \times 10^3 \text{ N up} \quad ①$$

(c) What is the magnitude and direction of the force acting on the fixed end of the plank?

[3 marks]

$\Sigma F_{up} = \Sigma F_{down}$

$\therefore F_{F.E} + W_p + W_s = R_R$ ①

$\therefore F_{F.E} = R_R - (W_p + W_s)$

$= 2.43 \times 10^3 - (40 + 88) \times 9.8$

$= 1.18 \times 10^3$ N down ①

①

(d) Write an expression for the force of the roller versus distance from the fixed end and use this to sketch a graph of force of the roller versus distance from the fixed end, putting in appropriate values calculated above.

[4 marks]

$R_R \times x = W_p \times 2.5 + W_s \times 4.5$ ①

$\therefore R_R = \frac{40 \times 9.8 \times 2.5 + 88 \times 9.8 \times 4.5}{x}$

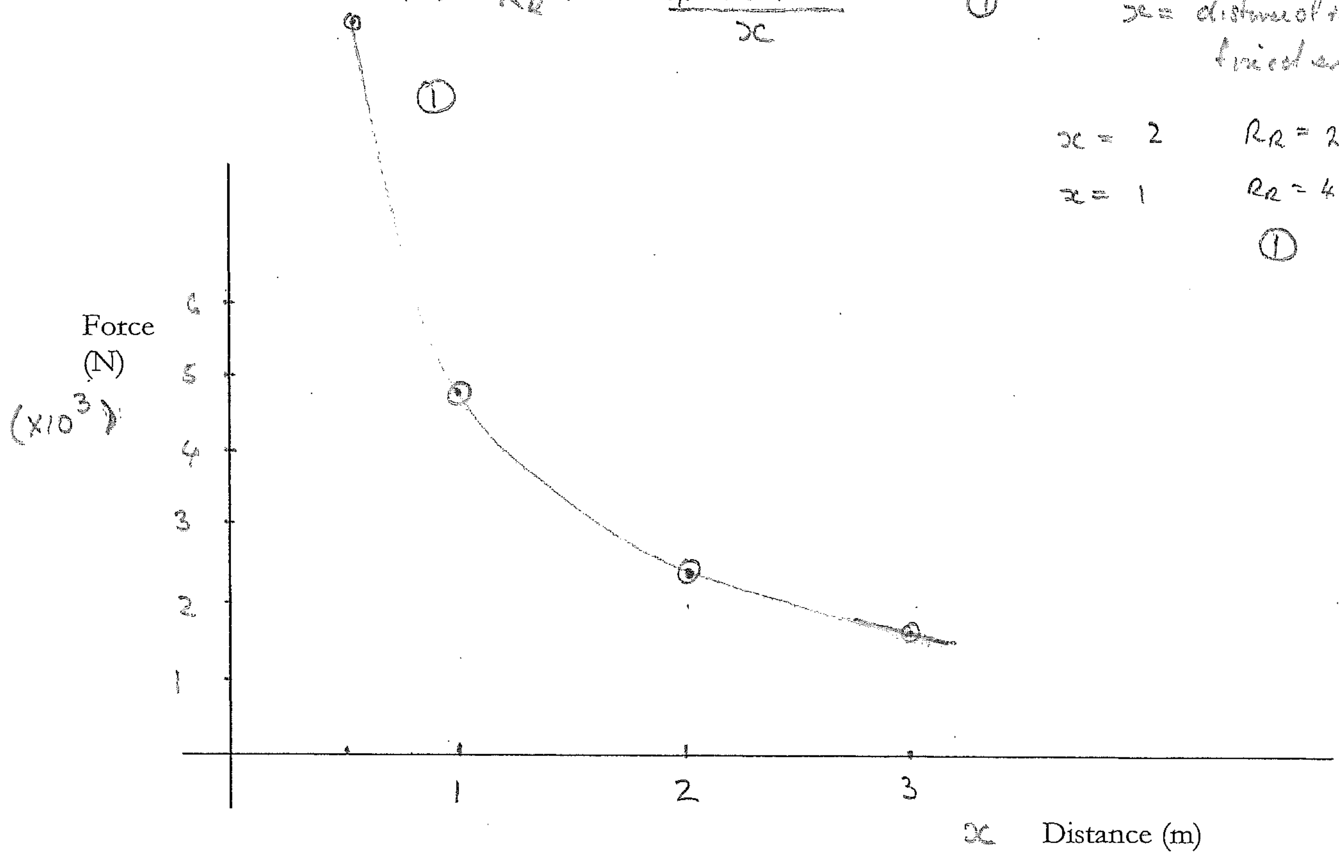
$\therefore R_R = \frac{4.86 \times 10^3}{x}$ ①

x = distance of roller from fixed end.

$x = 2$ $R_R = 2.43 \times 10^3$

$x = 1$ $R_R = 4.86 \times 10^3$

①



Question 16 [16 marks]

In a shotput event an athlete hurls a 4.5 kg shot, releasing the shot from a height of 2.2 m above the ground at an angle of 35° above the horizontal. The shot reaches a maximum height above the ground of 3.8 m during its trajectory.

(a) Use the information about the maximum height reached by the shot to calculate the vertical component of its initial velocity.

[3 marks]

$v^2 = u^2 + 2as$ ①

$\therefore 0 = u_v^2 + 2(-9.8)\,1.6$ ①

$\therefore u_v^2 = 31.4$

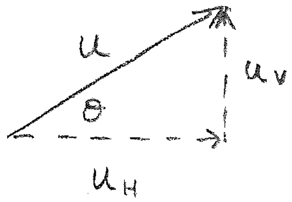
$\therefore u_v = 5.6\ \mathrm{ms^{-1}}$ ①

$\Delta S = 3.8 - 2.2 = 1.6\ \mathrm{m}$

(If use $S = 3.8$ then $u_v = 8.6\ \mathrm{ms^{-1}}$)

(b) Find the initial speed of the shot and the horizontal component of its initial velocity. (if you have no answer from part a, use $u_v = 6.4$ m/s)

[2 marks]



$\sin\theta = \dfrac{u_v}{u}$

$\therefore \sin 35° = \dfrac{5.6}{u}$

$\therefore u = \dfrac{5.6}{\sin 35°}$

$u = 9.8$ m/s ①

$u_H = u\cos\theta$

$= 9.76 \cos 35°$

$= 8.0\ \mathrm{ms^{-1}}$ ①

(for $u_v = 6.4$ $u = 11.2$ m/s & $u_H = 9.1$ m/s)

($u = 15$ m/s for $s = 3.8$
$u_H = 12.3$ m/s)

(c) Calculate the time of flight of the shot through the air.

[4 marks]

$s = ut + \frac{1}{2}at^2$ ①

$\therefore -2.2 = 5.6t - 4.9t^2$

$\therefore 4.9t^2 - 5.6t - 2.2 = 0$

$\therefore t = \dfrac{5.6}{9.8} \pm \dfrac{\sqrt{5.6^2 - 4 \times 4.9 \times (-2.2)}}{9.8}$

$= 0.571 \pm 0.881$

$= 1.45$ s

($t = 1.98$ s)
$u_v = 8.6$ m/s

($u_v = 6.4$ m/s $\Rightarrow t = 1.59$ s)

(d) How far does the shot put land from the release point?

[2 marks]

$$R = u_H t \quad ①$$
$$= 8.0 \times 1.45$$
$$= 11.6\,m \quad ①$$

(for $u_V = 6.4$ & $u_H = 9.1$ $\Rightarrow R = 14.5\,m$)

($R = 29.4\,m$, $u_V = 8.6$)

(e) Explain why releasing the shot at an angle of 35° above the horizontal gives a better range than releasing at an angle of 45°.

[2 marks]

A release angle of 45° is only optimum when the vertical displacement is zero. As the vertical displacement is below the release point it will have a greater time of flight so some of the vertical speed can be offset by giving the shot more horizontal speed, thus reducing the launch angle. Since $R = u_H t$ if u_H is increased then range will increase provided t is not reduced by as much of a factor.

(f) Use energy considerations to calculate the speed of the shot when it hits the ground.

[3 marks]

$\Delta E_{gp} = \Delta E_k$ ① provided air resistance losses ignored.

$$\therefore mg\Delta h = \tfrac{1}{2}mv^2 - \tfrac{1}{2}mu^2 \quad ①$$
$$\therefore v^2 = u^2 + 2g\Delta h$$
$$= 9.8^2 + 2\times(-9.8)\times(-2.2)$$
$$= 139$$
$$\therefore v = 11.8\,ms^{-1} \quad ①$$

(for $u = 11.2\,m/s$ $v = 13.0$)

Question 17 [14 marks]

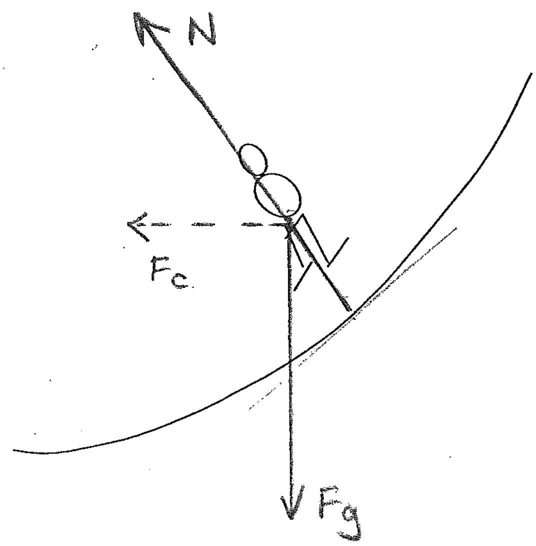
A cyclist is riding around a velodrome on the banked curve section. The banking changes from an angle of $0.0°$ at the bottom to a maximum of $48.0°$ at the top.

(a) On the diagram at right draw in the forces acting on the cyclist as they are moving in a horizontal circle with the bicycle normal to the track and no sideways friction acting (ignore any friction force of propulsion forwards).

Also show the resultant force with a dashed line. Label all forces

[3 marks]

① each



(b) Using a force diagram similar to that above derive the expression below for the situation where no sideways friction is necessary:

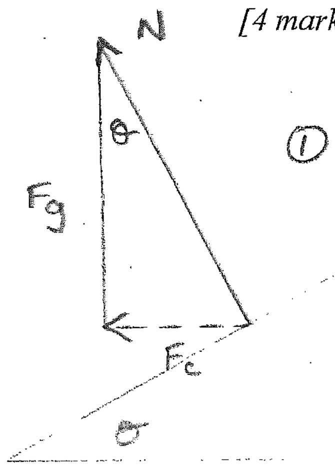
$$\tan(\theta) = v^2/rg$$

[4 marks]

$\tan\theta = \frac{F_c}{F_g}$ ①

$\therefore \tan\theta = \frac{mv^2/r}{mg}$ ① ①

$\therefore \tan\theta = \frac{v^2}{rg}$



(c) If the radius of curvature is 20.0 m at the position shown and the cyclist of mass 75.0 kg is moving in a horizontal circle where the angle is 24.0°, then at what speed, in km/h, must ~~he~~ the cyclist travel for there to be no sideways friction necessary?

[2 marks]

$$\tan\theta = \frac{v^2}{rg}$$

$$\therefore \tan 24^\circ = \frac{v^2}{20 \times 9.8}$$

$$\therefore v = \sqrt{(20 \times 9.8 \times \tan 24^\circ)}$$

$$= 9.34 \text{ ms}^{-1} \quad ①$$

$$= 33.6 \text{ km h}^{-1}$$

(d) How long will it take the cyclist to travel around the semicircular end of the track at this speed? (if no value for speed from above use 50.0km/h)

[2 marks]

$$l = \pi r$$

$$= 20\pi \text{ m}$$

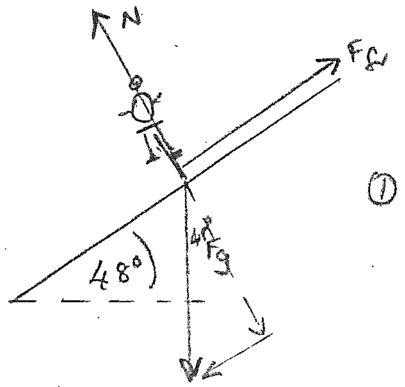
$$V_{avg} = \frac{s}{t}$$

$$\therefore 9.34 = \frac{20\pi}{t}$$

$$\therefore t = \frac{20\pi}{9.34} = 6.73 \text{ s}$$

(e) If the cyclist decides to tactically stop near the top of the curve where the slope is 48° then what friction force is required to stop ~~him~~ the cyclist sliding down the slope?

[3 marks]



$$F_{fr} = F_{g\parallel} \quad ①$$

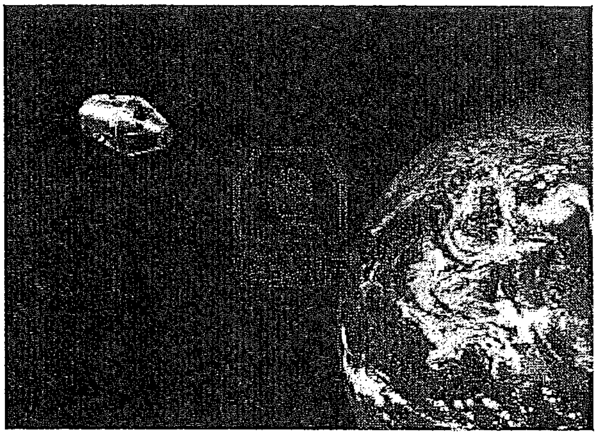
$$= mg\sin\theta$$

$$= 75 \times 9.8 \times \sin 48^\circ$$

$$= 546 \text{ N} \quad ①$$

Question 18 [15 marks]

A manned spacecraft is in a circular orbit around the Earth, at an altitude where the gravitational attraction of the Earth is only 10% of the value it has at the surface of the Earth.



(a) Calculate the altitude (height above the surface) of the spacecraft.

[4 marks]

$$g = \frac{G M_E}{r^2} \quad ①$$

$$\therefore g \propto \frac{1}{r^2}$$

Hence $$\frac{g_1}{g_2} = \frac{r_2^2}{r_1^2}$$

$$\therefore \frac{g}{0.1g} = \frac{r_2^2}{r_E^2} \quad ①$$

$$\therefore r_2^2 = 10 r_E^2 = 10 \times (6.38 \times 10^6)^2 = 4.07 \times 10^{14}\ m^2$$

$$\therefore r_2 = 2.02 \times 10^7\ m$$

$$r_2 = 2.018 \times 10^7\ m \quad ①$$

$$\therefore \text{Altitude} = 2.018 \times 10^7 - 6.38 \times 10^6$$
$$= 1.38 \times 10^7\ m \quad ①$$

(b) The centripetal force required by the spacecraft to stay in orbit is provided by the gravitational attraction of the Earth. Derive the formula

$$\mathbf{v} = \sqrt{(\mathbf{GM/r})}$$

where **v** = orbital speed, **G** = universal gravitational constant, **M** = mass of the Earth and **r** = orbital radius.

[3 marks]

$$F_c = F_g \quad ①$$

$$\therefore \frac{\cancel{m} v^2}{r} = \frac{G M \cancel{m}}{r^2} \quad ①$$

$$\therefore v^2 = \frac{G M}{r^2} \times r$$

$$\therefore v = \sqrt{\left(\frac{GM}{r}\right)} \quad ①$$

(c) Calculate the speed of the spacecraft in this orbit.

[2 marks]

$$\therefore v = \sqrt{\left(\frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{2.018 \times 10^7}\right)}$$

$$= 4.45 \times 10^3\ ms^{-1} \text{ or } 16,000\ kmh^{-1}$$

(d) Determine the orbital period of the spacecraft.

[2 marks]

$$V = \frac{2\pi r}{T}$$ ①

$$\therefore T = \frac{2\pi r}{V}$$

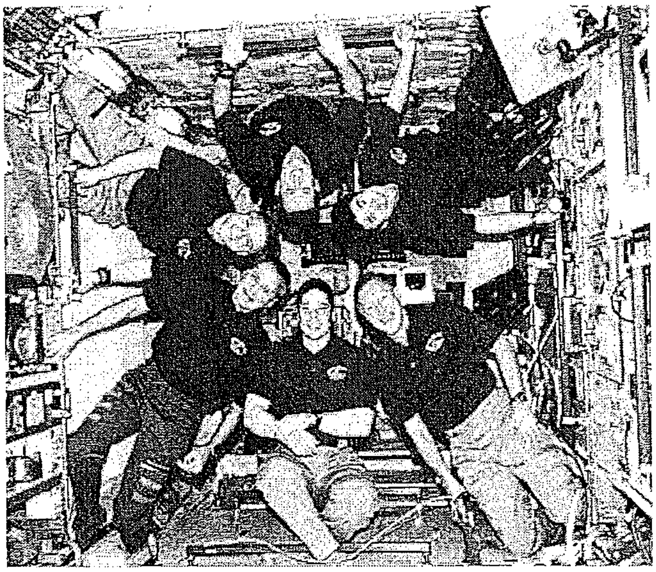
$$= \frac{2\pi \times 2.018\times10^7}{4.45\times10^3}$$

$$= 2.85\times10^4 \text{ s}$$ ①

$$= 7.92 \text{ hours}$$ or 7 hours 55 mins

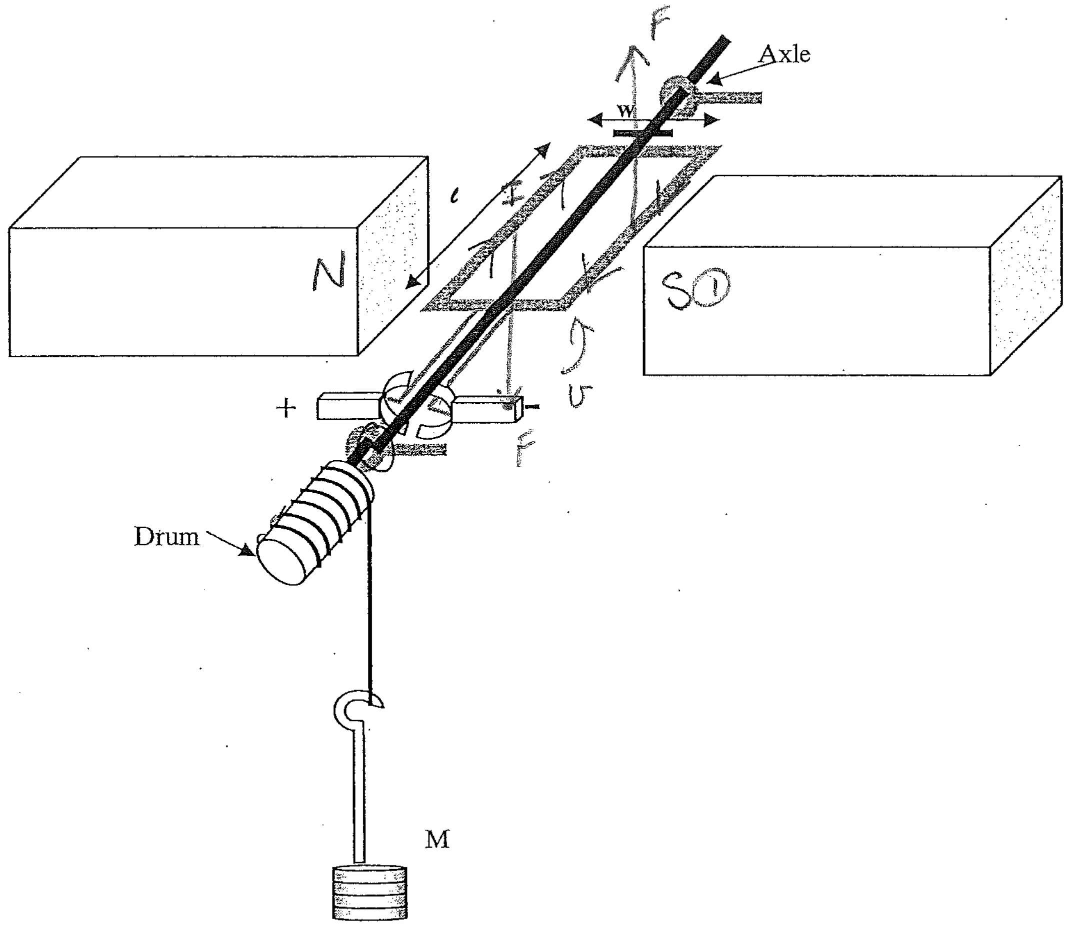
(e) Astronauts aboard the spacecraft drift around freely through the interior of the craft. Are they weightless? Discuss.

[4 marks]



The astronauts are not truly weightless as they are in free fall ① around the Earth. They experience apparent weightlessness ① as the spacecraft and astronauts are all accelerating ① at the same rate hence there is no ① net force between spacecraft and astronauts.

Question 19 [16 marks]



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

(a) Draw in the north and south poles of the magnets so that the motor turns in the correct direction.

[1 mark]

(b) The important data related to the motor are shown below:

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 magnet = 1.25 x 10^{-2} T
Drum diameter = 4.20 cm

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

[4 marks]

$\tau_{max} = NIAB$ ①
$= 150 \times 6.49 \times 6.72 \times 10^{-3} \times 0.0125$
$= 0.0817$ Nm anticlockwise ①

$V = IR$ ①
$\therefore I = \frac{12}{1.85} = 6.49$ A

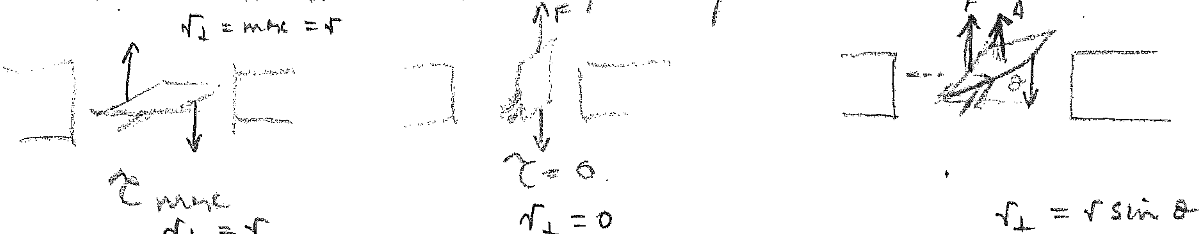
$A = 0.12 \times 0.056$ ①
$= 6.72 \times 10^{-3}$ m^2

~~Question 19 continued~~

(c) The torque available from a simple motor like this varies over one complete rotation of the motor. Explain why this is so and indicate in which positions a maximum and minimum occur.

[3 marks]

Since the torque, $\tau = r_\perp F$ then as the perpendicular distance changes the torque will change. As the magnetic field is horizontal the force perpendicular to the wire is always up on one side and down on the other. $r_\perp$ is a maximum when the plane of the coil is parallel to the field and so the torque is a maximum. The torque is a minimum when the plane of the coil is $\perp$ to the field.



(d) Assuming that the effective torque available from the motor is 70% of the maximum. Calculate the maximum mass that it would be capable of lifting (if you were not able to calculate the motor torque from the previous question take the value as 8.0 x 10^{-2} Nm).

[3 marks]

$$\tau_{eff} = 0.7 \times 0.818 \text{ Nm}$$
$$= 0.0573 \text{ Nm} \quad (1)$$

$$\tau = r_\perp \times F$$

$$r_{Drum} = 2.1 \text{ cm} = 2.1 \times 10^{-2} \text{ m}$$

$$\therefore F_{max} = \frac{\tau}{r_\perp} = \frac{0.0573}{2.1 \times 10^{-2}} = 2.73 \text{ N} \quad (1)$$

$$F = mg$$

$$\therefore m = \frac{F}{g} = \frac{2.73}{9.8} = 0.278 \text{ kg} \quad (1)$$
$$= 278 \text{ g}$$

Question 19 continued

(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 marks]

When the load is attached the motor turns more slowly. (1) This reduces the back emf (1) so the current will increase as the effective p.d. across the motor increases

(f) Even when there is no load attached the motor will increase its rotational speed up to a maximum value ~~which is well below that due to frictional forces of air and moving parts~~. Explain why the motor will have a maximum speed even if there is no friction.

[3marks]

As the motor spins the back emf increases as the motor is acting as a generator. (1) Since $\mathcal{E}_{max} = 2\pi BANf$ the maximum back emf is proportional to frequency. (1) Thus the motor will continue to increase in speed only up to a maximum frequency which generates an emf equal to the applied emf. (1) Thus the torque on the motor decreases as I decreases until it just overcomes the load plus frictional and resistance losses.

SECTION THREE: Comprehension **36 marks**

This section has **two (2)** questions. Answer in the spaces provided.

Suggested working time: 40 minutes.

Question 20 (18 marks)

LAUNCHING A NEW ERA IN ROLLER COASTERS

Paragraph 1

The evolution of roller coaster materials and technology can be witnessed at Cedar Point, in Sandusky, Ohio. Its offerings include wooden coasters, such as the Blue Streak, dating back to 1964, and steel giants such as the Millennium Force, which opened in 2000 at 94 metres high with a maximum speed of 150 km/h. The Millennium Force, built for $25 million, was the 2001 Amusement Today winner in the Best Steel Coaster category (Figure 1).

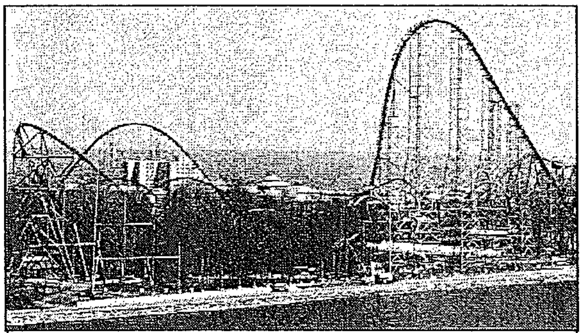


Figure 1: Millennium Force Roller Coaster

Paragraph 2

Monty Jasper, with a master's degree in mechanical engineering, said he has watched the amusement industry evolve dramatically since he began work in this business as a ride operator in 1973. "From a materials standpoint, there are lighter, less expensive, stronger steels today than there were years ago," Jasper said. Some of the newest magnetic braking systems on roller coasters are equipped with aluminium alloy brake fins.

Paragraph 3

The braking systems themselves offer a safer, smoother ride experience. As recently as the 1970s, all roller coasters were built with mechanical brakes that needed to be manually adjusted and that could malfunction in bad weather. "If it rained that day they wouldn't run a ride," Jasper said.

Paragraph 4

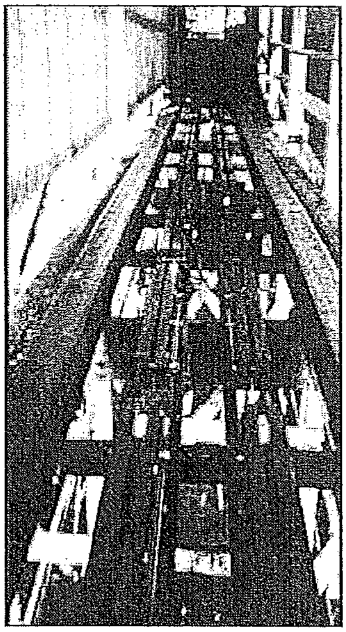
The newest magnetic braking systems offer numerous benefits over the old, mechanical brakes: They have no moving parts, require no control system, have no contact surfaces, and thus, no wear and tear resulting from friction, according to Magnetar Technologies Corporation, which markets Soft Stop Brakes to roller coaster manufacturers. The brakes operate with a copper alloy fin (chosen for its strength over aluminium alloys) mounted on the roller coaster. The fin travels between two parallel rows of high-strength magnets. As the train rolls through the magnets, they bring it to a smooth, gradual stop. The magnetic brakes can be placed at points along a roller coaster track to slow the train down as needed. The result, said Ed Pribonic, president of the company, is a passive system that can operate in any weather, even if ice or grease is on the track or fin. Magnetar has just installed the brakes on two roller coasters in Kennywood Park in Pittsburgh, Pennsylvania. One set went onto the Phantom's Revenge, a steel coaster that opened in 2001, and the other onto the Jack Rabbit, a wooden coaster dating back to 1922 (Figures 2a and 2b). Until now, the Jack Rabbit operated with its original skid brakes, Pribonic said. Skid brakes involve two long blocks of wood built into the floor of the station. When the ride operator pulls a lever, the blocks are raised, sliding over plates of steel along the bottom of the car and dragging it to a stop.

Paragraph 5
Magnets are also being used on new thrill rides as a launch system. Using a linear induction motor, Cedar Point's new Wicked Twister will accelerate riders through the coaster's station to a maximum speed of 116 km/h in 2.5 seconds (Figure 3). The launch system, which is growing more popular in thrill rides and roller coasters, replaces the traditional lift chain that pulls roller coaster cars up a hill and releases them, allowing gravity to provide the energy necessary for the coaster to complete the track circuit. The Wicked Twister, which opens this month, will send its passengers up a 66 meter tall twisting steel tower.

Paragraph 6
The ride is propelled as a copper alloy fin passes through coils on the track. "When we get ready to fire, we press a button and an electronic current energises the coils, projects a magnetic field between them and the copper alloy fin is in between," Jasper said. The fin is pushed forward to the next set of coils, and so on, picking up momentum along the way. The system, which also involves magnetic brakes, is energy intensive, Jasper said.

Paragraph 7
"Let me put it this way: We're using such a massive jolt of electricity to operate Wicked Twister that it would be enough to power 550 average sized houses," he said. Other launch systems are achieving similar results, such as linear synchronous motors or compressed air systems, reportedly taking passengers from 0 to 129 km/h in 1.5 seconds.

Paragraph 8
Without a doubt, materials-driven technologies such as magnetic brakes and high-powered launch systems have taken the roller coaster competition to new heights. Pribonic, who has worked in this business for more than 20 years, believes materials are going to have to improve to keep up with the increasing demands of high-intensity rides. "Materials, by and large, haven't changed," he said. Although rides are towering higher and moving faster than ever, old, familiar, and somewhat mild steel, grade A-36 or higher, remains the preferred material for roller coaster structures. Better options would be high-strength steel alloys, titanium, or even advanced fibres, to fill the need for high-strength materials for roller coaster structures.



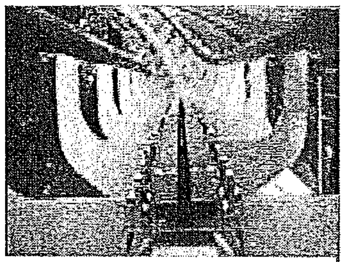


Figure 2. (a-top) Magnetic brakes installed in 2002 on the Jack Rabbit. (b-bottom) Magnetic brakes also were installed in Kennywood's newest coaster.

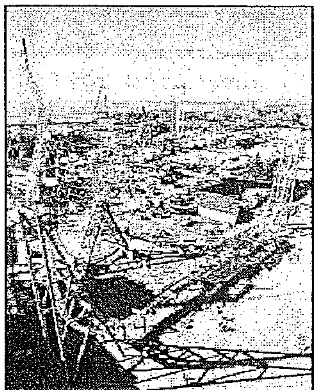


Figure 3: Wicked Twister under construction.

(a) What are two disadvantages of traditional m*echanical brakes* on roller coasters? (paragraphs 2 and 3).

[2 marks]

Mechanical brakes need to be mechanically adjusted. ①
" " could malfunction in bad weather, causing the ride to be shut down. ①

(b) Explain the operation of "Soft Stop Brakes" (paragraph 4). Be sure to refer to Physics that you have learnt this year to explain their operation.

[3 marks]

The copper alloy fins pass through a magnetic field. ①
By Faradays Law, the rate at which flux is cut will generate an emf, the faster the roller coaster the the greater the rate of flux change and hence emf. ①
This emf will generate a current (eddy current) within the fins which will create a magnetic field that opposes ① the change and hence motion of the roller coaster (Lenz's Law)
Thus the greatest braking occurs at the highest speeds.

(c) What happens to the kinetic energy of the roller coaster as it is stopped by the magnetic brakes?

[2 marks]

The kinetic energy is converted to electrical energy and then heat within the fins. ②

(d) The brakes operate with a copper alloy (paragraph 4), because of its strength, compared to aluminium. Why do you think the manufacturers don't use an even stronger alloy such as titanium steel?

[2 marks]

The alloy must also be a good conductor (low resistance) so that large currents can flow within the alloy. Titanium steel is not a good enough conductor. 2

(e) The new magnetic launch system is discussed in paragraphs 5-7. Explain why the copper alloy fin is pushed forward to the next set of coils.

[2 marks]

As the field is changing in the coil it generates and induced current and field in the copper fins. This opposes the change and causes repulsion propelling the coaster forward.

(f) The *Wicked Twister*, when full of passengers, has a mass of 5,550 kg. Using this fact and the data in paragraph 5, find the force applied by the magnetic launch system while the coaster is accelerated through the station.

[3 marks]

$V_{max} = 116 \text{ km h}^{-1} = 32.2 \text{ m s}^{-1}$

$t = 2.5 \text{ s}$

$F = ma$ 1

$= m \frac{\Delta v}{t}$

$= 5550 \times \frac{(32.2 - 0)}{2.5}$ 1

$= 71500 \text{ N}$ 1

$\simeq 72000 \text{ N}$

(g) If the magnetic launching system operates on a voltage of 3 200 V, find the size of the current drawn by the magnetic launch system while the coaster is accelerated through the station. State any assumptions that you need to make.

[4 marks]

Assume Force is constant.

Assume no friction forces or resistance losses.

$$P = VI = \frac{W}{t} = \frac{\Delta E_K}{t} \quad ①$$

①

$$\therefore VI = \frac{\Delta E_K}{t}$$

$$\therefore 3200 \times I = \frac{\frac{1}{2} m v^2}{t}$$

$$= \frac{\frac{1}{2} \times 5550 \times 32.2^2}{2.5} \quad ①$$

$$3200 \times I = 1150000$$

$$\therefore I = \frac{1150000}{3200}$$

$$= 360\ A \quad ①$$

OR $W = F \times s = 7200 \times (V_{avg} \times t)$

$$= 7200 \times \frac{32.2}{2} \times 2.5$$

$$= 290000\ J$$

$W = VIt$

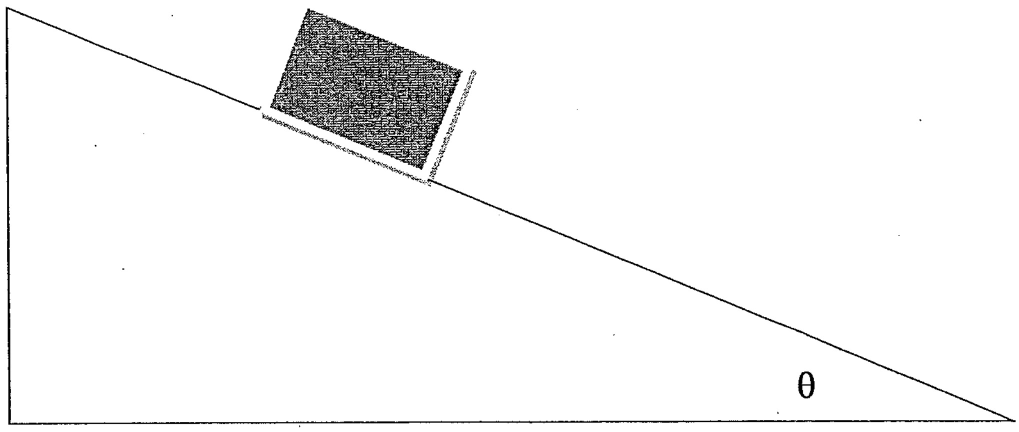
$$\therefore 290000 = 3200 \times I \times 2.5$$

$$\therefore I = \frac{290000}{3200 \times 2.5}$$

$$= 360\ A$$

Question 21 (18 marks)

A student decides to investigate the relationship between the velocity of an object down a slope and the distance that it has slid. The student knows that friction is important and that there are two coefficients of friction; static, μ_s (when the object is stationary) and kinetic, μ_k, (when the object is moving). The force of friction, F_{fr}, is given by: $F_{fr} = \mu N$, where μ is the coefficient of friction (static or kinetic depending on whether it is stationary or moving) and N is the normal force. The value for μ_s is found from the minimum force required to just get the object moving.
The student uses a sensor to record the velocity down a 30.0°slope at various distances once the object is sliding. These are recorded in the table below.



Velocity v (m/s)	0.65	0.80	0.90	1.10	1.35	1.48	1.80
Displacement s (m)	0.050	0.100	0.150	0.250	0.400	0.500	0.750
v^2 $(m/s)^2$	0·42	0·64	0·81	1·21	1·82	2·19	3·24

It is expected that the relationship down the slope should follow the equation of motion:

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

where **u** is the initial velocity and **a** is the acceleration down the slope.

The student decides to plot v^2 against s to verify that the object obeys this relationship.

(a) Record values of v^2 in the table above.

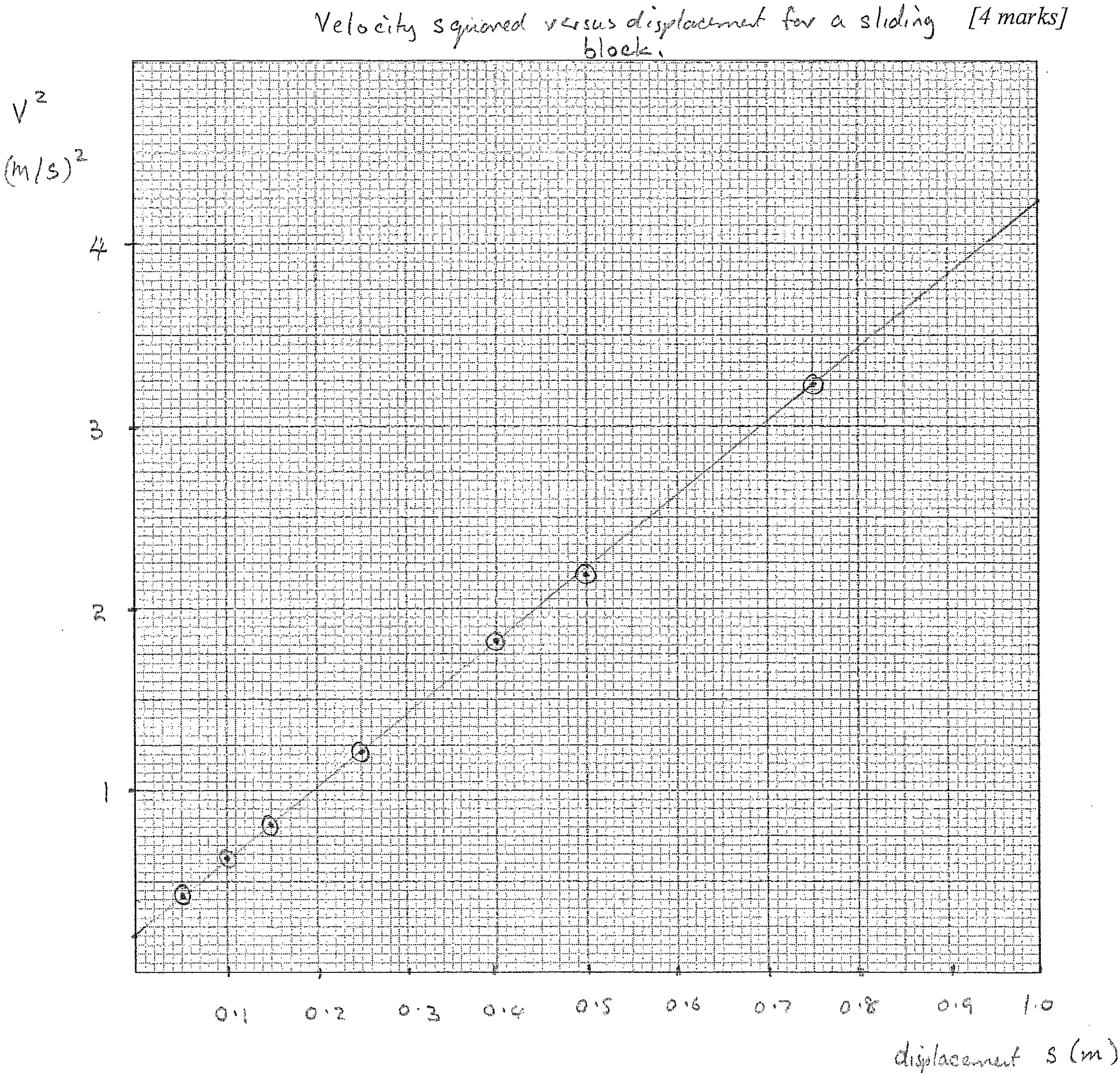
[2 marks] 2

(b) Explain why v^2 is plotted against s.

[2 marks] 2

If v^2 is plotted against s a straight line graph will result as $v^2 \propto s$ from above equation. This allows values such as u^2 to be found from the intercept and a from the gradient. ($2a$ = grad.)

(c) Plot $\mathbf{v}^2$ against $\mathbf{s}$ on the graph paper below. *[4 marks]*



(d) Calculate the gradient of the graph with appropriate units. *[3 marks]*

$$\text{gradient} = \frac{\Delta v^2}{\Delta s} = \frac{4.24 - 0.2}{1.0 - 0.0} = 4.04 \ m/s^2$$

① ① ①

WORKING must be shown.

(e) Use the graph and gradient to determine the acceleration down the slope and the initial velocity at zero displacement.

[3 marks]

gradient = 2a ①

$\therefore a = \frac{grad}{2} = \frac{4.04}{2} = 2.02\ m/s^2$ ①

$u^2 = 0.2$

$\therefore u = \sqrt{0.2} = 0.45\ m/s$ ①

By considering energy changes the student derives a formula that takes into account friction, which is given below:

$$v^2 = u^2 + 2gs(\sin(\theta)-\mu_k\cos(\theta))$$

where g is the acceleration due to gravity (9.80 m/s^2) and θ is the angle of the slope.

(f) Use the gradient value obtained earlier (if no value from earlier use 2.2) to determine μ_k for the slope at 30.0°.

[2 marks]

$\therefore$ gradient $= 2g(\sin\theta - \mu_k\cos\theta)$

$\therefore 4.04 = 2\times 9.8(\sin 30 - \mu_k \cos 30)$

$\frac{4.04}{19.6} = (0.5 - 0.866\mu_k)$

$\therefore 0.206 - 0.5 = -0.866\mu_k$

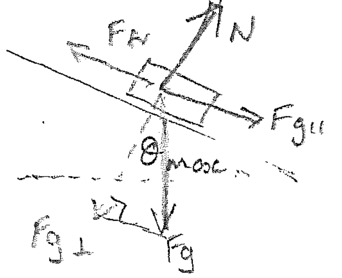
$\therefore \mu_k = \frac{0.294}{0.866}$

$= 0.339$

(g) Explain how the equipment could be used to determine the maximum coefficient of static friction.

[2 marks]

Place block on slope and raise the slope slowly until it just starts to slide. Repeat and record readings of θ_{max}. ②



$\tan\theta = \frac{F_{g\parallel}}{F_{g\perp}} = \frac{F_{fr}}{F_{g\perp}}$

$= \frac{\mu_s N}{F_{g\perp}}$ $\quad N = F_{g\perp}$

$\therefore \boxed{\mu_s = \tan\theta}$

END OF PAPER

only requires description