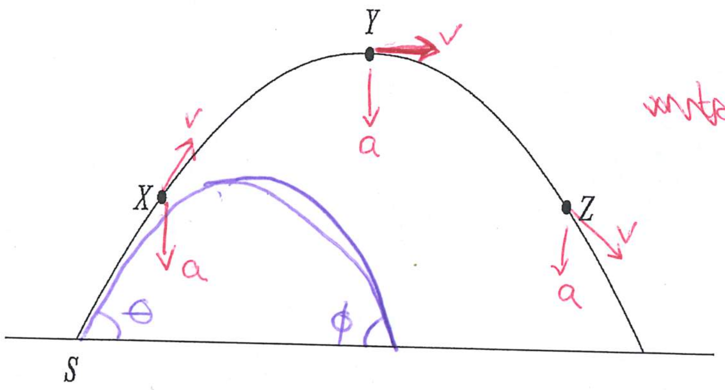
Section One: Short response **30% (58 Marks)**

This section has **16** questions. Answer **all** questions.

Suggested working time: 55 minutes.

Question 1 **(5 marks)**

A ball is thrown from *S* at an angle to the horizontal as shown in the diagram below. *X*, *Y*, and *Z* are different positions along the ball's trajectory.



(a) On the diagram above, label each position (X, Y and Z) with an arrow that best represents the velocity and the acceleration of the ball, at that time.

½ each (3 marks)

(b) The trajectory shown above assumes that the ball is not affected by air resistance. Draw the trajectory of the ball if air resistance is present.

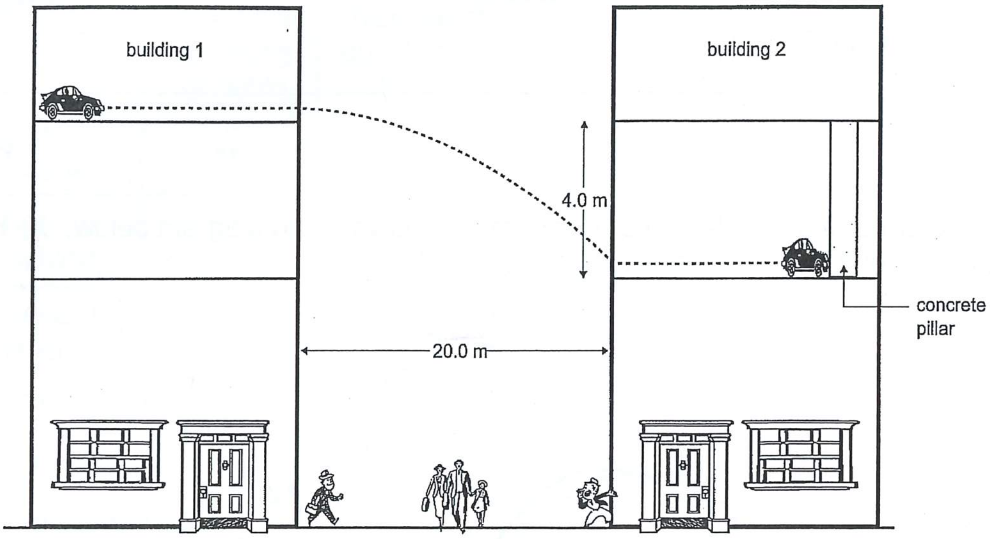
(2 marks)

These properties drawn on the diagram

½ for each

(1) not symmetrical
(1) S_H smaller
(1) S_V smaller
(1) angle of ascent < angle of descent $\phi > \theta$

Question 2 **(4 marks)**



In a movie, the stunt men drove their car across a horizontal car park in building 1 and landed it in the car park of building 2, one floor lower. Building 2 is 20.0 m from building 1, as shown in the figure above. The floor where the car lands in building 2 is 4.00 m below the floor from which it started in building 1.

Calculate the minimum speed at which the car should leave building 1 in order to land in the car park of building 2, if the effect of air resistance is ignored.

1 $u_v = 0$

$s_v = u_v t + \frac{1}{2} a_v t^2$

$s_v = 4 m$

$4 = 0 + 4.9 t^2 \Rightarrow t = 0.90 s$ 1

$s_h = 20 m$

$s_h = u_h t + \frac{1}{2} a_h t^2$

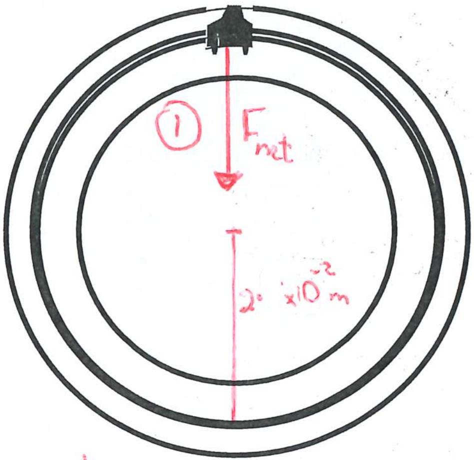
$20 = u_h (0.9) + 0 \Rightarrow u_h = 22.13 m s^{-1}$ 1

$u_t = u_h = 22.13$

$u_v = 0 \Rightarrow$ no effect on u_{total}

Question 3 **(4 marks)**

A toy slot car set has a horizontal circular track as shown in the diagram opposite.



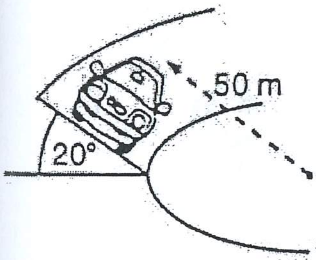
(a) On the diagram, show the direction of the nett (unbalanced) force acting on the slot car.

(b) The diagram is drawn one-tenth full size. The mass of the slot car is 0.250 kg and the nett force is 3.25 N, ***estimate*** the speed of the car.

Diameter 5.2×10^{-2} m
Radius 2.6×10^{-2} m } show on diagram
(Accept $2.5 \rightarrow 2.8\times10^{-2}$) $\Rightarrow r = 2.6\times10^{-1}$ m 1

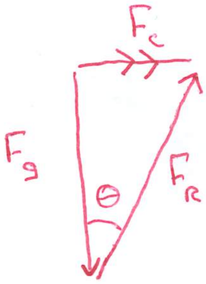
$F = \frac{mv^2}{r} \Rightarrow \underbrace{v = \sqrt{\frac{(3.25)(2.6\times10^{-1})}{0.25}}}_{1} = \underbrace{1.8 \text{ m s}^{-1}}_{1}$ - no more than 2 sig fig

Question 4 **(4 marks)**



A new car is being test driven to determine how it performs when driven on slippery, banked surfaces. The car has a mass of 1.20 tonne and is driven around a 20.0° banked curve, which has a radius of 50.0 m.

(a) ***Derive the formula*** that indicates the maximum speed the car can drive around the curve without slipping. (2 marks)



1 $\tan\theta = \frac{F_c}{F_g} = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg}$

1 $v = \sqrt{rg\tan\theta}$

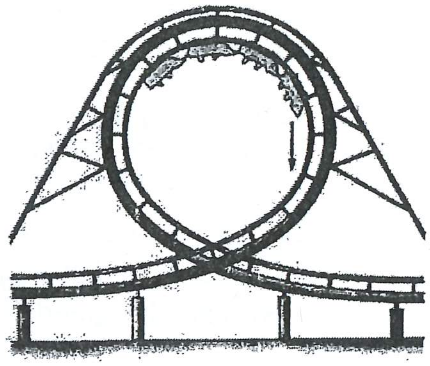
(b) Use this formula to ***calculate the maximum speed*** of the car without slipping as it drives around the curve. (2 marks)

$v = \sqrt{rg\tan\theta} = (50.0)(9.8)(\tan 20°)$ 1

$= 13.4 \text{ m s}^{-1}$ 1

Question 5 **(4 marks)**

A thrill seeker is persuaded to go on a "loop the loop" amusement ride similar to the one in the picture opposite. The circular loop has a diameter of 18.0 m and it takes 4.70 s to complete one loop.



(a) Calculate the centripetal acceleration of a 40.0 kg rider. (3 marks)

$a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2(9)}{(4.7)^2}$ 1

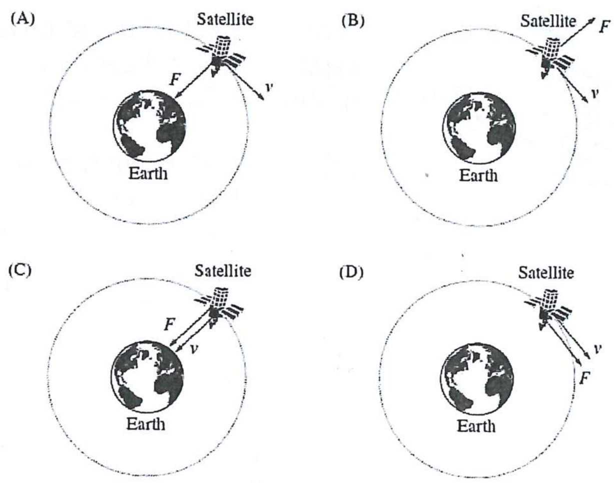
$= 16\ m\,s^{-2}$ 1 towards the centre 1

(b) Is the centripetal acceleration for a 50.0 kg rider the same, increased or decreased? (1 mark)

Answer: Same 1

Question 6 **(4 marks)**

The diagrams show a communications satellite in orbit about the Earth.



(a) Which diagram correctly represents the ***nett force F*** acting on the satellite and the ***velocity v*** of the satellite?

Answer: A 1

(b) Explain why domestic satellite dishes for pay-TV do not 'track' across the sky (i.e. they don't move), although the satellites that they receive their signals from are in constant motion.

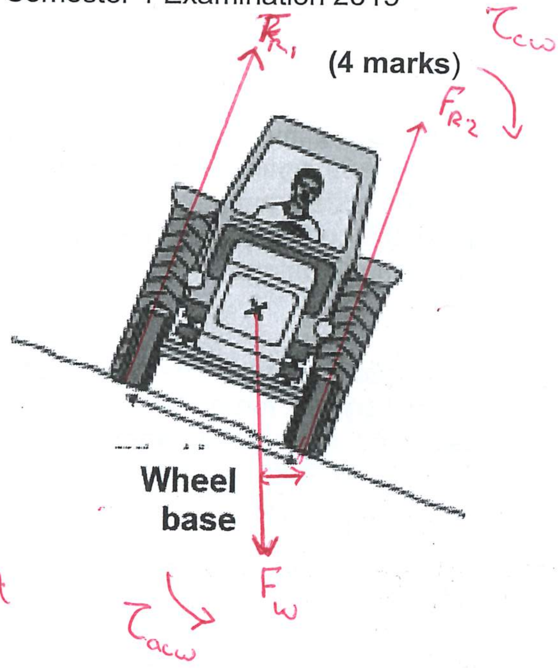
The satellites are in a geosynchronous orbit 1

meaning They have a period of 24 hours 1

Therefore they remain over the same geographical location on Earth 1

Question 7 **(4 marks)**

Tractors are often used on sloping fields so stability is important in their design. On the diagram, ***X*** marks the centre of mass of the tractor.



(a) Using force and torque diagrams, clearly explain why the tractor has not toppled over. (2 marks)

(1) Centre of mass (F_w) lies within the wheel base

(1) F_w provides an ACW moment which is greater than the CW moment due to F_{R1}

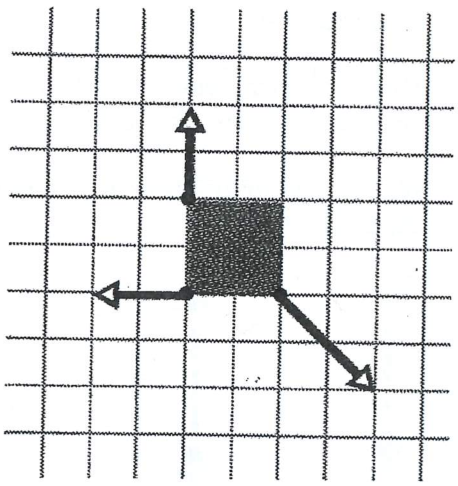
(b) State how the design of the tractor could be modified to increase the tractor's stability. (2 marks)

(1) Lower centre of mass

(1) Increase width of base

Question 8 **(3 marks)**

The figure shows an overhead view (birds-eye view) of a metal square lying flat on a frictionless floor. Three forces, which are drawn to scale, act at the corners of the square. **Circle** the correct answer.



(a) Is the square in translational equilibrium?

YES NO

(b) Is the square in rotational equilibrium?

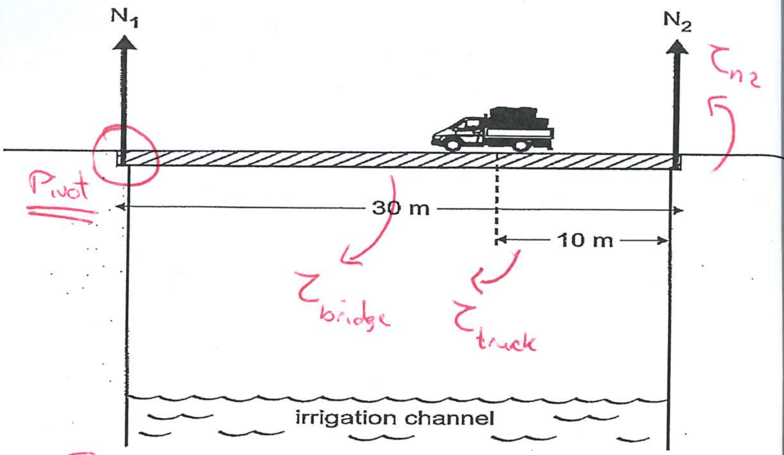
YES NO

(c) Is it possible for a fourth force to act on the fourth corner of the square such that the square is in static equilibrium?

YES NO

Question 9 **(4 marks)**

The bridge in the diagram can be considered as a uniform concrete beam of length 30.0 m and mass 20.0 tonnes. A heavily loaded small truck of mass 6.00 tonnes is pictured crossing the bridge.



Calculate the magnitude of each of the normal contact forces N_1 (F_{n1}) and N_2 (F_{n2}) at each end of the bridge when the centre of mass of the truck is 10.0 m from one end.

1 $\Sigma \tau = 0$ OR $\Sigma \tau_{cwm} = \Sigma \tau_{acwm}$

↑ −ve
↓ +ve

$\tau_{truck} + \tau_{bridge} = \tau_{N2}$

1 $20 \times 9.8 \times 6 \times 10^3 + (20 \times 10^3)(9.8)(15) = (F_{N2})(30)$

$F_{N2} = 1.37 \times 10^5$ N up

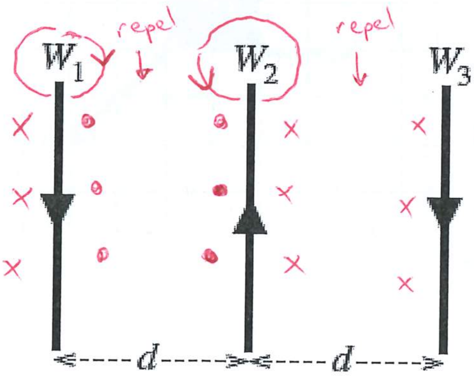
1 $\Sigma F = 0 \Rightarrow F_{w\ truck} + F_{w\ bridge} + F_{N1} + F_{N2} = 0$
down down up up

1 $F_{N1} = (20 \times 10^3 \times 9.8) + (6 \times 10^3 \times 9.8) - 1.37 \times 10^5 = 1.18 \times 10^5$ N

Question 10 **(1 mark)**

Three identical wires W_1, W_2 and W_3 are positions as shown. Each carries a current of the same magnitude in the direction indicted.

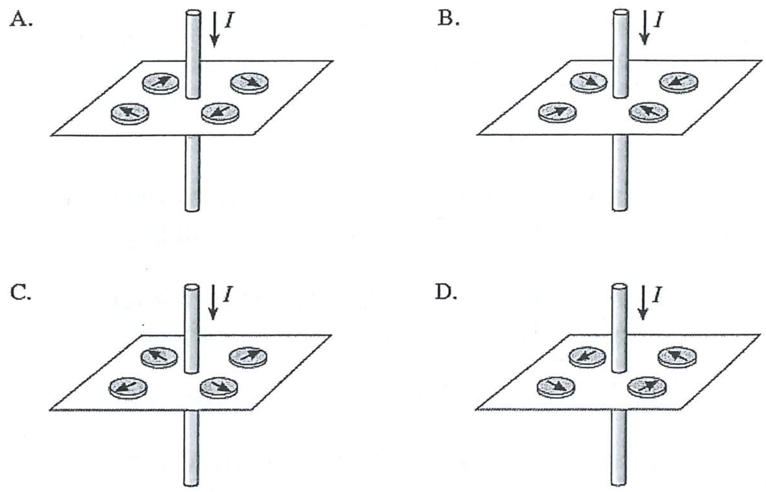
What is the magnitude and direction of the resultant force on W_2? ***Circle*** the correct answer (A, B, C, D).



	Magnitude	*Direction*
(A)	Zero	None
(B)	Non zero	To the left
(C)	Non zero	To the right
(D)	Non zero	Out of the page

Question 11 **(1 mark)**

Which of the following diagrams best shows the orientation for a set of four compasses placed around a current-carrying wire?

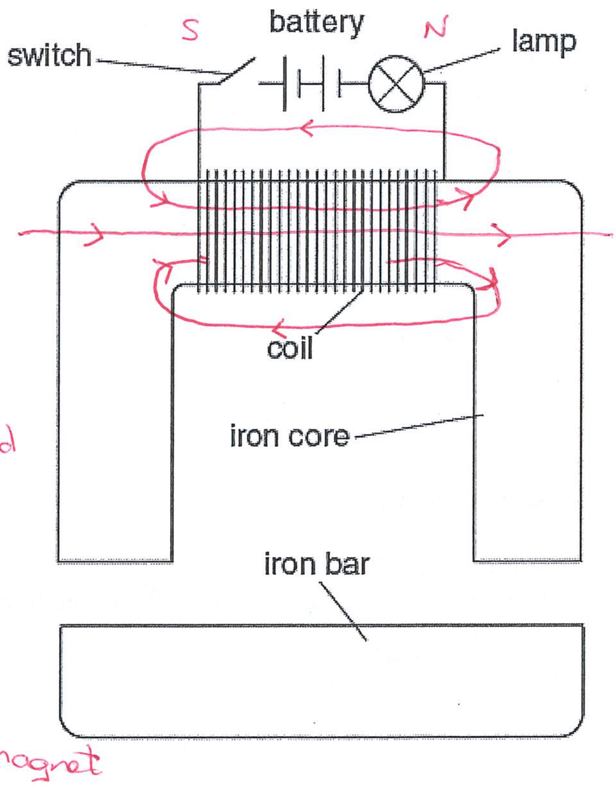


Answer: A

Question 12 **(4 marks)**

This question is about using an electromagnet to lift a heavy load.

The figure shows a coil of insulated wire wrapped around the centre of an iron core. An iron bar is pulled up to the core when the switch is closed. The lamp glows when there is current in the coil.



(a) On the diagram, sketch ***two complete loops*** of flux produced by the coil when the switch is closed. (1) correct dirn (2 marks)

(1) goes through centre of solenoid

(b) Use ideas of magnetic flux to explain why the iron bar is pulled up to the iron core when the switch is closed. (2 marks)

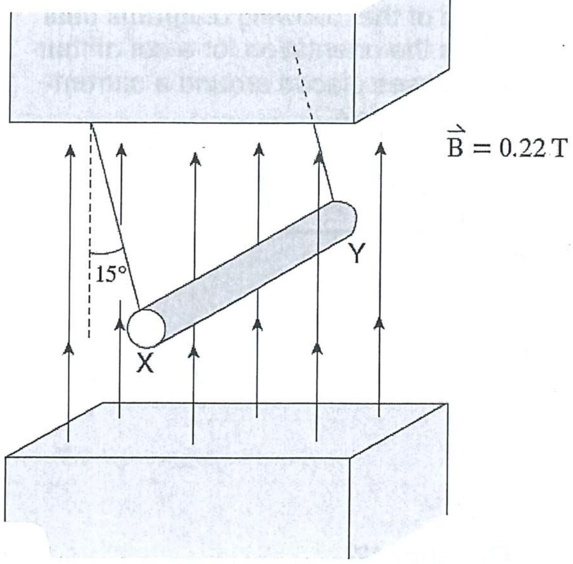
(1) The coil creates a magnetic field / it is a solenoid / electromagnet

(1) This induces magnetism in the iron core which attracts the iron bar upwards

Question 13 **(4 marks)**

An 18.0 cm long metal rod of mass 35.0 g is suspended from the ceiling with a light wire of negligible mass. A uniform 0.220 T magnetic field is directed vertically upward.

When there is a current in the rod, it swings outward 15.0° to the vertical as shown in the figure opposite.

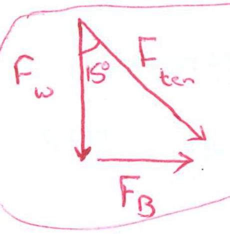


(a) What is the direction of the current in the rod? ***Circle*** the correct response. (1 mark)

X to Y   Y to X   No current

(b) Calculate the magnitude of the current in the rod. (3 marks)

1



$\tan 15° = \frac{F_B}{mg} = \frac{I.L.B}{mg}$

diagram not necessary

$\Rightarrow I = \frac{(\tan 15°)(m)(g)}{L.B} = \frac{(\tan 15)(35 \times 10^{-3})(9.8)}{(18 \times 10^{-2})(0.220)}$ 1

$= 2.32$ A 1

Answer 2.32A into page / X to Y

Question 14 **(3 marks)**

A beta particle travels at a speed of 3.90 x10^3 km h^{-1} while following a circular path of radius 0.0200 m perpendicular to a magnetic field. Calculate the strength of the magnetic field. Show all working.

1
$v = \frac{3.90 \times 10^3}{3.6} = 1.083 \times 10^3 \text{ m s}^{-1}$

$q = 1.6 \times 10^{-19}$ C

$m = 9.11 \times 10^{-31}$ kg

$r = \frac{mv}{qB} \Rightarrow B = \frac{m.v}{q.r}$

$= \frac{(9.11 \times 10^{-31})(1.083 \times 10^3)}{(1.6 \times 10^{-19})(0.0200)}$ 1

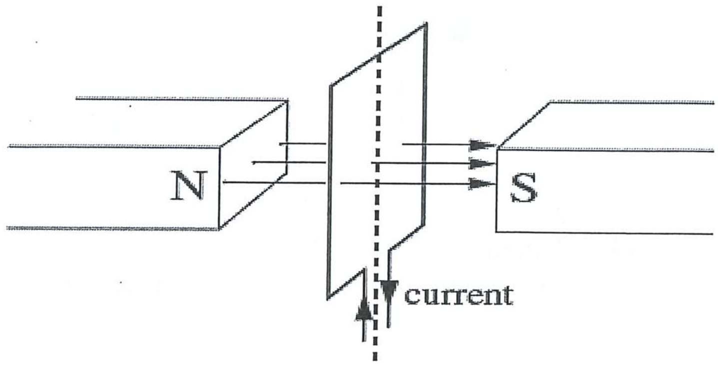
$= 3.08 \times 10^{-7}$ T

Answer: 3.08×10^{-7} T

1

Question 15 **(3 marks)**

An electric motor is set up as shown in the diagram below. When the current is supplied, the coil does not turn. Which of the following is required for the coil to start turning?



(a) The magnetic field must be increased.

(b) The direction of the current must be reversed.

(c) The magnitude of the current must be increased.

1 (d) The starting position of the coil must be changed.

Answer: _______

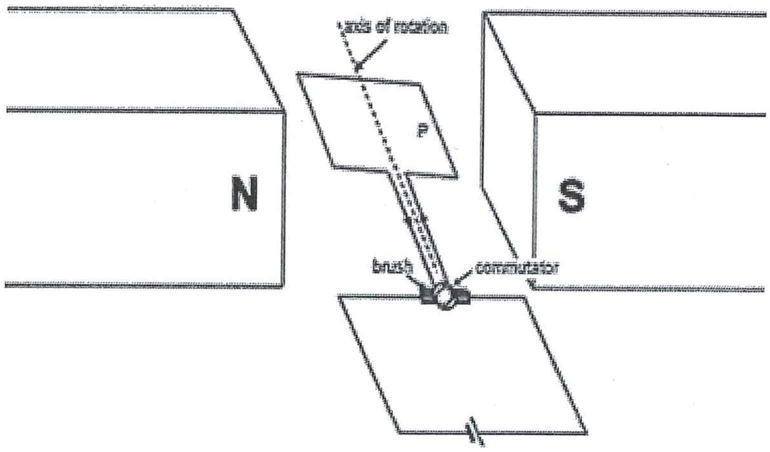
Briefly explain what needs to change to allow the coil to start turning.

1 • Orientate the coil horizontally instead of vertically

• If orientated horizontally the coil ~~it~~ experiences a downward force
1 and therefore a CW torque OR in the current position the coil experiences a force (into the page) but no torque

Question 16 **(6 marks)**

The circuit of a simple DC motor is shown in the figure opposite. It consists of a current-carrying coil of 50 turns as the armature. The coil is square with sides of 5.00 cm. The coil is in a uniform magnetic field of strength 5.00 mT. A current of 3.00 A flows through the coil in the direction shown in the diagram.



(a) Calculate the magnitude of the force on side P of the coil. (2 marks)

$F = N\,I\,l\,B$

$= (50)(3.00)(5.0\times10^{-2})(5.00\times10^{-3})$ 1

$= \underbrace{0.0375\,N = 3.75\times10^{-2}\,N}$ 1

(b) When the coil is in the position shown in the diagram, which of the directions (A, B, C or D) best indicates the direction of the force exerted on side P? Circle the correct answer

(1 mark)

(c) The ends of the coil are connected to a split-ring commutator, so that the coil is free to rotate. Explain why the split-ring commutator is fundamental to the operation of the DC electric motor.

(3 marks)

1 A split ring commutator allows the direction of the current to reverse every 180°

1 This allows the ~~force~~ to ~~change~~ coil to keep turning in the same direction

1 as the torque remains clockwise or anticlockwise

(Diagram explaining torque/force also OK)

Section Three: Comprehension **23% (40 Marks)**

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

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

Suggested working time: 40 minutes.

Question 23 **(20 marks)**

Neutron star collisions create huge magnetic spikes

The strongest magnetic fields known in the universe are produced when a pair of extremely dense and compact stars merge. The first computational model has been devised of such an event that takes magnetism into account. The model begins with two cold neutron stars in a circular orbit around each other, both with masses 1.4 times that of the Sun. Comparative masses can be seen in Table 1.

When their orbits decay and the two stars collide, they merge to form a single object incredibly quickly - within about 2 milliseconds. Spiral arms then form off the central object and, at the point of intersection, instability causes the two stars' magnetic fields to curl into vortex rolls.

Previous work had suggested that merged neutron star remnants might collapse under their own weight to produce black holes before being able to produce a big magnetic spike. But the collapse is estimated to take at least 100 milliseconds, and the new data suggests an extremely short timescale for the amplification of the merged object's magnetic field, showing the spike should occur in reality.

Table 1: Comparative masses of known entities in the Universe.

Object	Mass	Radius
the sun	1.99×10^{30} kg	696,000 km
white dwarf star	0.5 to 1.4 solar masses	5000 km
neutron star	1.4 to 3 solar masses	10 km
stellar black hole	more than 3 solar masses	$2Gm/c^2$ (event horizon)
super massive black hole	$> 10^6$ solar masses	$2Gm/c^2$
the known universe	10^{53} kg	13.7×10^9 light years

(Table adapted from http://hypertextbook.com/physics/matter/density/)

(a) Neutron stars are the remnants of huge stars that have exploded as supernovae. The neutron star mentioned in Paragraph 1 has a radius that is only of the order of 10 km. Such a dense object has very high gravitational field strength at its surface.

The density of an object is given by its mass divided by its volume:

$$\textbf{Density } (\rho) = \frac{m}{V}$$

(i) For a spherical star of average density ρ, the magnitude of g at its surface is given by:

$$g = \frac{4}{3}G\pi r\rho$$

where G is the universal gravitational constant.

Use these expressions to show that the units of g are Nkg^{-1} (3 marks)

Units for $G = N m^2 kg^{-2}$

Units for $\rho = \frac{mass}{volume} = kg\ m^{-3}$ (1)

(1)

Units for $g = \underbrace{N \cancel{m^2} kg^{-2}}_{G} \underbrace{\cancel{m}}_{r} \underbrace{kg\ \cancel{m^{-3}}}_{\rho} = N\ kg^{-1}$ (1)

(ii) The volume of a sphere is given by the expression: $V = \frac{4}{3}\pi r^3$.

(1) for volume calc

Use this expression, the formula in part (i) and information in Table 1, to ***ESTIMATE*** the gravitational field strength at the surface of the neutron star. (5 marks)

OR use $\left(\frac{1.4+3}{2}\right) = 2.2$

$\rho_{largest} = \frac{mass}{volume} = \frac{(1.99\times10^{30})(3)}{4/3\,\pi\,(10\times10^3)^3}$ (1) $= 1.425\times10^{18}\ kg\ m^{-3}$ (1)

$\rho_{smallest} = \frac{mass}{volume} = \frac{(1.99\times10^{30})(1.4)}{4/3\,\pi\,(10\times10^3)^3} = 6.65\times10^{17}\ kg\ m^{-3}$

(1)

$g_{biggest} = \frac{4}{3}G\pi r\rho = (\frac{4}{3})(6.67\times10^{-11})(10\times10^3)(1.425\times10^{18}) = 3.98\times10^{12}\ N\ kg^{-1}$

$g_{smallest} = \frac{4}{3}G\pi r\rho = (\frac{4}{3})(6.67\times10^{-11})(10\times10^3)(6.67\times10^{17}) = 1.86\times10^{12}\ N\ kg^{-1}$

Estimate somewhere in between $= 2.9\times10^{12}\ N\ kg^{-1}$ (1)

(b) A remarkable property of neutron stars is that they spin about their axes at a very great rate. The radiation from these stars is observed as regular pulses. This gives rise to the name 'pulsars'. This particular neutron star of radius 10.0 km rotates 50.0 times every second.

(i) Show that the speed of a point on the equator of the star is approximately one percent (1%) of the speed of light. (3 marks)

$v = \frac{2\pi r}{T} = 2\pi r f = 2\pi(10 \times 10^3)(50)$

$\doteq 3.14 \times 10^6 \ m s^{-1}$ (1)

$c = 3.00 \times 10^8 \ m s^{-1} \Rightarrow 1\% = 3.00 \times 10^6 \ m s^{-1}$ (1)

$3.00 \times 10^6 \simeq 3.14 \times 10^6 \ m s^{-1}$ (1)

(ii) Calculate the centripetal acceleration at a point on the equator of the star. (3 marks)

$a = \frac{v^2}{r} = \frac{(3.14 \times 10^6)^2}{10 \times 10^3} = 9.86 \times 10^8 \ m s^{-2}$ towards centre

(1) (1) (1)

Below is astronomical data that you may find useful when answering the following question.

mass of Cassini = 2.20×10^3 kg	diameter of Saturn = 1.21×10^8 m
mass of Jupiter = 1.90×10^{27} kg	Saturn day = 10.7 Earth hours
mass of Saturn = 5.70×10^{26} kg	

(c) Calculate the magnitude of the total gravitational field strength experienced by Cassini when it is 3.90×10^{11} m from Saturn. (2 marks)

$$g = \frac{Gm}{r^2} = \frac{(6.67\times10^{-11})(5.70\times10^{26})}{\left[3.90\times10^{11} + \left(\frac{1.21\times10^8}{2}\right)\right]^2}$$

$$= 2.5\times10^{-7}\ \text{N kg}^{-1}$$

1 radius

1 rest of calculation / answer

(d) The Earth has multiple satellites orbiting it at any point in time. The centripetal force required to keep the satellites in orbit is provided by the Earth's gravitational field. Use this fact to derive an expression for the orbital radius ***r*** for the satellite, let:

G = the gravitational force constant
r = the radius of orbit of the satellite
v = the speed of the satellite in its orbit
M_E = the mass of the Earth
M_S = the mass of the satellite

(2 marks)

$$F_c = F_G \quad 1$$

$$\left.\begin{aligned} \frac{m_s v^2}{r} &= \frac{G m_s m_E}{r^2} \\ r &= \frac{G m_E}{v^2} \end{aligned}\right\} 1$$

(e) A telecommunications satellite needs to be placed at a certain height above the surface of the Earth at the equator so that it remains in geosynchronous orbit. Calculate the orbital radius `of the satellite.

(2 marks)

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

1

$$r = \sqrt[3]{\frac{(6.67\times10^{-11})(5.98\times10^{24})(24\times60\times60)^2}{4\pi^2}}$$

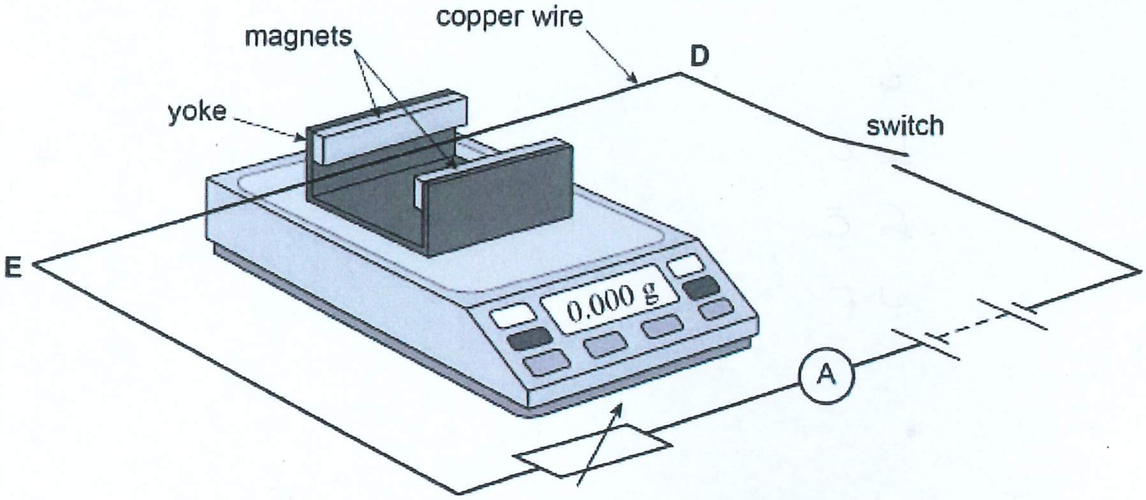
$$= 4.23\times10^{7}\,m \quad 1$$

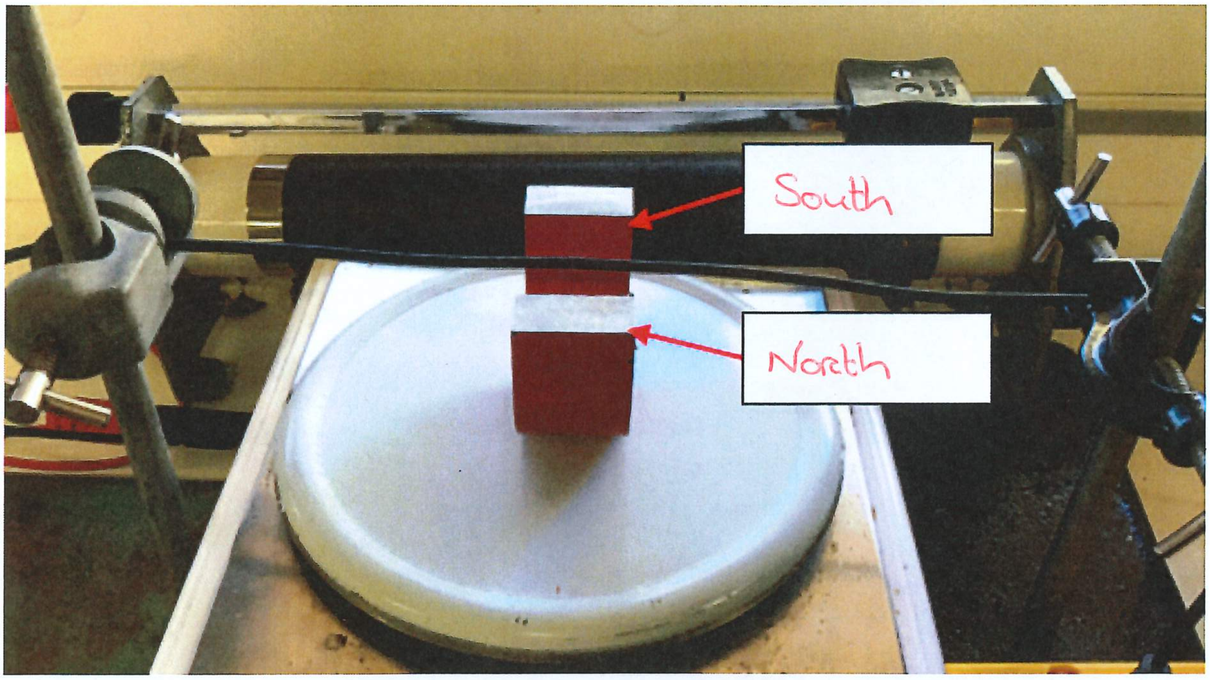
1 for $24\times60\times60$

1 for rest of calculation and answer

Question 24 **(20 marks)**

Determining the Magnetic Field Strength (B) of a Horse-shoe Magnet





Students performed an experiment to calculate the magnetic field strength (***B***) of a horse-shoe magnet.

The equipment was set up as shown in the photograph. The diagram above shows the configuration of the circuit. The horse-shoe magnet was placed on the mass balance and it was tared (set to read 0.00 g). The current-carrying conductor was stretched tightly and clamped in place such that it was unable to move.

The current through the conductor was varied and the reading on the mass balance noted. The results are displayed in the table below.

Current (A)	Change in Mass (Δm) (g)	$\times 10^{-3}$ Force (N) $= mg$
0.0	0.00	0
1.0	0.18	1.8
2.0	0.33	3.2
3.0	0.53	5.2
4.0	0.76	7.4
5.0	0.97	9.5

(a) The direction of conventional current in the photograph above is left to right. Annotate the north and south pole of the magnet on the photograph above. (1 mark)

(b) Explain, using relevant mathematical relationships or formulae, how this experimental setup can be used to calculate the magnitude of magnetic field strength of the horse-shoe magnet. (2 marks)

The current carrying conductor experiences a force when placed in the magnetic field

Magnitude of force $F = I.l.B$

(I and F vary, l constant measured, B calculated)

(c) Complete the table above by filling in the values for force. (2 marks)

1 correct values

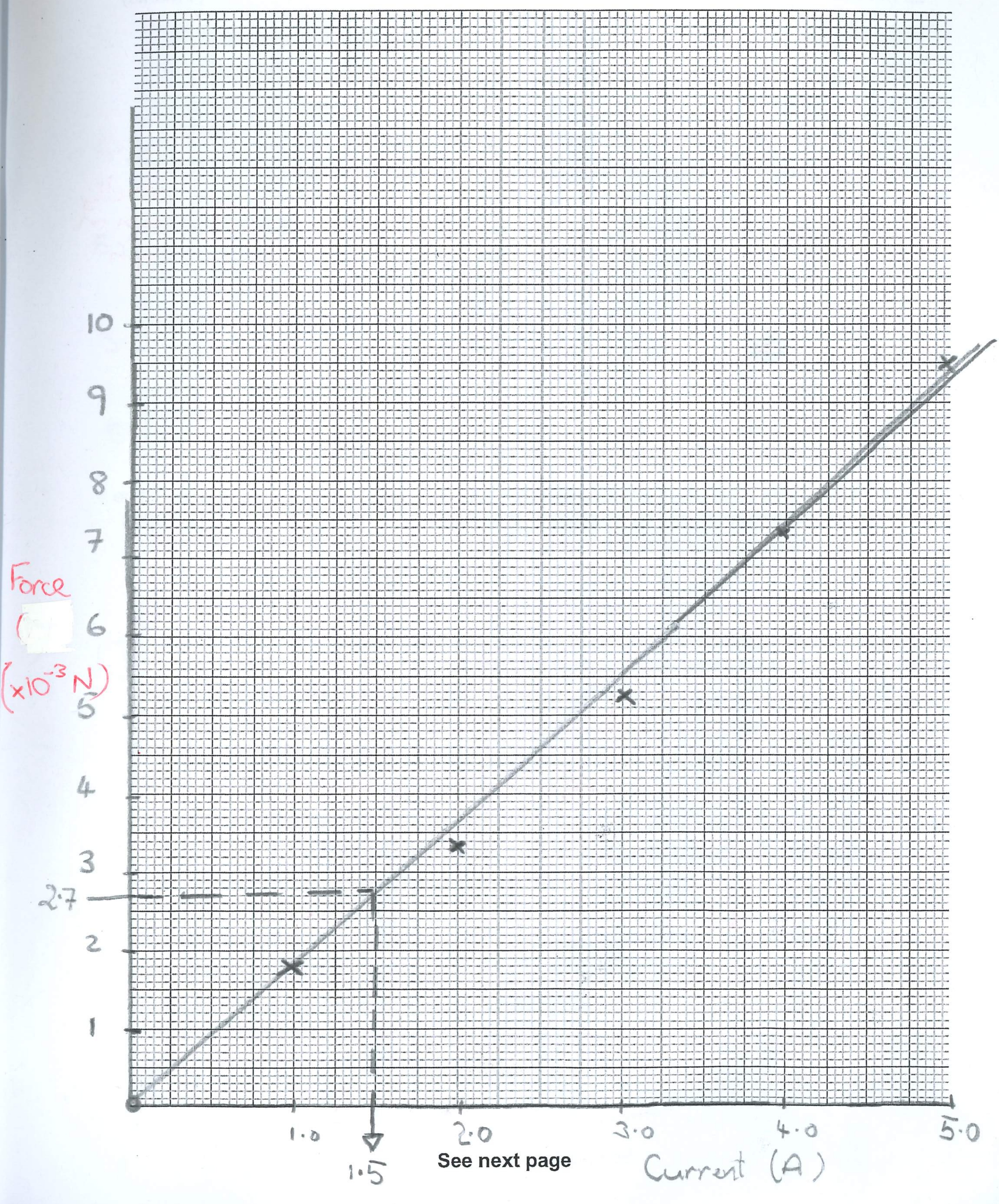
1 2 sig fig

(d) The photograph is 50.0 % the size of the real equipment. Use the photograph, and this information, to measure the length of the conductor in the magnetic field. (1 mark)

magnetic field extends beyond the poles

Measured length = 1.5×10^{-2} m ⇒

Length of conductor in magnetic field = 3×10^{-2} m accept 2.8 → 3.4



(e) Use the mathematical relationship you have described in part (b), and the information you calculated in (c), to draw a graph that will allow you to calculate the magnetic field strength of the horse-shoe magnet. Do not include error-bars. (4 marks)

(f) Use the graph to calculate the magnetic field strength of the horse shoe magnet. Clearly show all working. (4 marks)

$$\underset{y}{F} = \underset{x}{I}\ \underbrace{l\ B}_{m}$$ ① (or equivalent

gradient $= \dfrac{y_2 - y_1}{x_2 - x} = \dfrac{\quad}{1.5 - 0}$ NA^{-1} ① correctly shown on graph

① units

$m = 1.8 \quad l.B$

$B = \dfrac{1.8}{3\times10^{-2}} = 60$

(g) For the fourth data point only (balance reading = 0.53 g; current = 3.0 A), calculate the value for magnetic field strength and its associated uncertainty. (4 marks)

$B = \dfrac{F}{I.l} \Rightarrow$ optional

uncertainty $= \%\Delta m + \%I\ (+\%l)$

$\%\Delta m$: $0.53 \pm 0.005 = 0.53 \pm$ 0.94%

$\%I$: $3.0 \pm 0.05 = 3.0 \pm$ 1.67%

($\%l$: $1.5\times10^{-2} \pm 0.05\times10^{-2}$ $1.5\times10^{-2} \pm 3.3\%$)

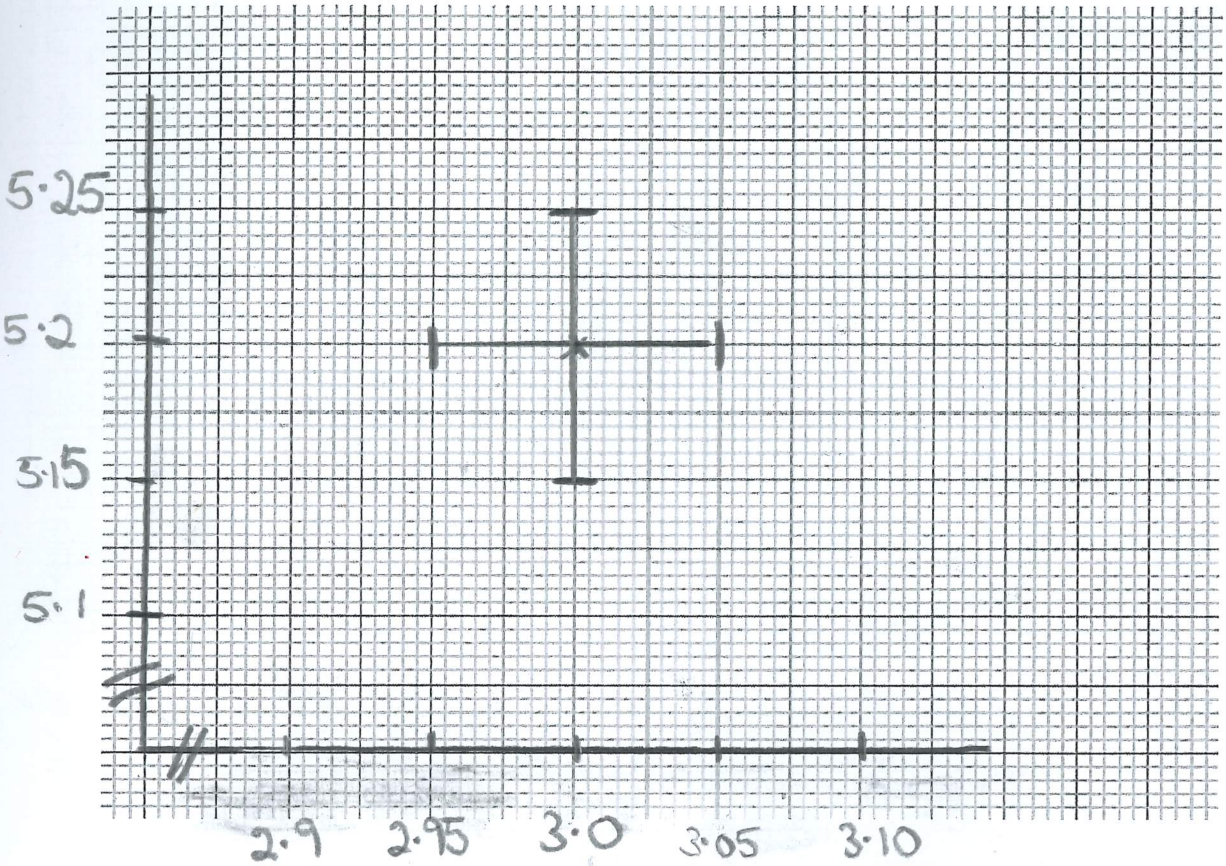
% Uncertainty $= 0.94 + 1.67\ (+3.3) = 2.61\%$ (or 5.91%)

$B = \dfrac{(0.53\times10^{-3})(9.81)}{(3.0)(3.0\times10^{-2})} = 5.88\times10^{-2}\,T \pm 2.61\%$

$= 5.88\times10^{-2} \pm 1.53\times10^{-3}\,T$

(h) Error bars should be included for all points on your graph; however, as they are very small, they are difficult to display accurately at graph scale.

For the fourth data point only (balance reading = 0.53 g; current = 3.0 A), display the error bar associated with this point only by drawing a ***magnified version of this point*** on the graph paper below. (2 marks)



(1) both error bars included

(1) size of error bar

OK if force or mass plotted on y axis

END OF EXAM

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