CHRIST CHURCH GRAMMAR SCHOOL

YEAR 12

PHYSICS STAGE 3

MID YEAR EXAMINATION 2012

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1		
2		
3		
Total		/ 180 = %

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
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 un-authorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Short Answers	14	14	50	54	30%
Section Two: Problem-Solving	7	7	90	90	50%
Section Three: Comprehension	1	1	40	36	20%
				Total	100

Instructions to candidates

1. Write your answers in this Question/Answer Booklet

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

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.

YEAR 12
PHYSICS STAGE 3
MID YEAR EXAMINATION 2012

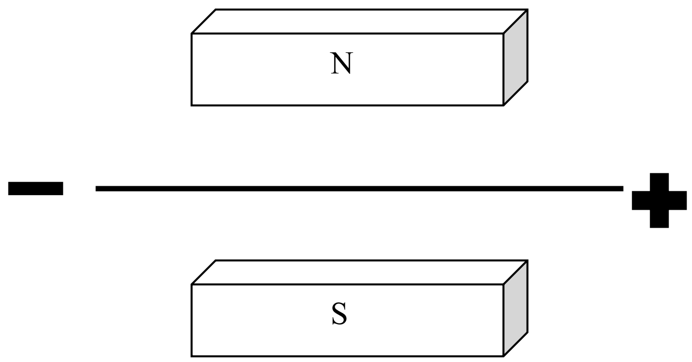
Section One: Short Response

This section has **fourteen (14)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **50 minutes**.

Question 1 **(2 marks)**

The diagram below shows the view a student has of a physics demonstration, in which a length of wire is connected in a DC circuit (not shown). When a switch is closed, the circuit is complete.



(a) Which way will the wire move relative to the student?

(1 mark)

- Out of the page

(b) How could the student make the wire move in the opposite direction?

(1 mark)

- Reverse the polarity of the wire or
- Reverse the polarity of the magnets

Question 2 **(3 marks)**

The maximum acceleration a pilot can withstand without blacking out is a = 6g. How tight a turn can a fighter pilot make if he is travelling at Mach 3 (1020 ms^{-1})?

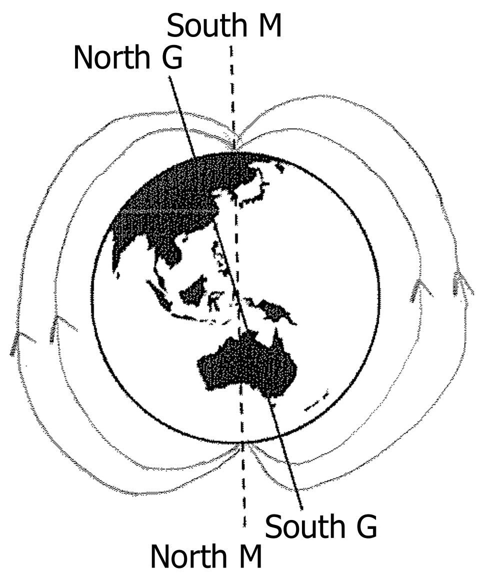
$$a_c = \frac{v^2}{r} \quad 1$$

$$(6)(9.8) = \frac{1020^2}{r} \quad 1$$

$$r = 17.7 \times 10^3\, m \quad 1$$

Question 3 **(4 marks)**

On this diagram of the Earth below, sketch the Earth's magnetic field, indicating the location of the magnetic and geographic poles and their polarity.



Question 4 **(5 marks)**

A boy is spinning a yoyo above his head so that it flies in a horizontal path, at a constant speed. The yoyo has a mass of 125 g, and the length of string it is attached to is 52.0 cm long. It completes one revolution in 1.25×10^{-1} s.

(a) Is the yoyo's velocity constant? Explain your answer.

(2 marks)

- No – velocity has both magnitude and direction.
- The direction of the yoyo is constantly changing as it moves around the circular path.

(b) Calculate the magnitude of the centripetal force acting on the yoyo.

(3 marks)

$$F_c = \frac{mv^2}{r} \quad 1$$

$$= \frac{(0.125)\left(\frac{2\pi 0.52}{0.125}\right)^2}{0.52} \quad 1$$

$$F_c = 164\,N \quad 1$$

Question 5 **(3 marks)**

A ball is swung in a vertical circle on the end of a piece of string. When is the string most likely to break. Explain your reasoning.

- At the bottom of the circle.
- At the bottom of the circle the centripetal force is provided solely by the tension, at the top of the circle the weight force also contributes to the centripetal force.
- At the bottom of the circle, the tension in the string must also supply sufficient force to overcome the weight of the ball – therefore at the bottom the tension in the string will be the greatest and is most likely to break.

Question 6 **(4 marks)**

Estimate the **minimum** magnitude of the force of wind required to blow the truck over. Assume the truck has a mass of 2.00 tonne.

1

Wind 2, trucks 0

Two trucks lie on their side on a bridge at Toyama city, western Japan, on April 3, 2012, after a typhoon-like spring storm brought strong gusts and heavy rains to Japan, causing traffic chaos. Meteorologists urged the public to stay indoors if possible. (AFP: Jiji Press)

- Width of wheel base 1.8 – 2.5 m
- Height 3.0 – 4.0 m

1

$$\Sigma\tau_{cw} = \Sigma\tau_{ccw}$$ 0.5

$$\tau = rF\sin\theta$$ 0.5

Take lower right hand wheel as pivot

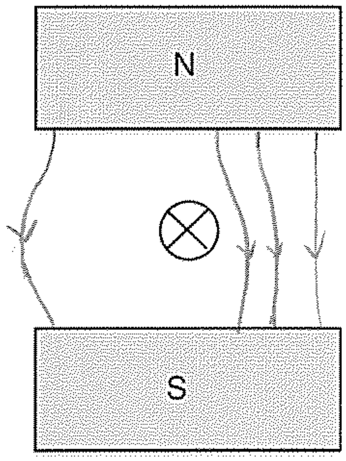
$$\Sigma\tau_{cw} = (4)(F)(\sin 90)$$ 0.5

$$\Sigma\tau_{ccw} = (1.3)(2000 \times 9.8)(\sin 90)$$ 0.5

$$F = 6.4 \times 10^{3}\ N$$ 1

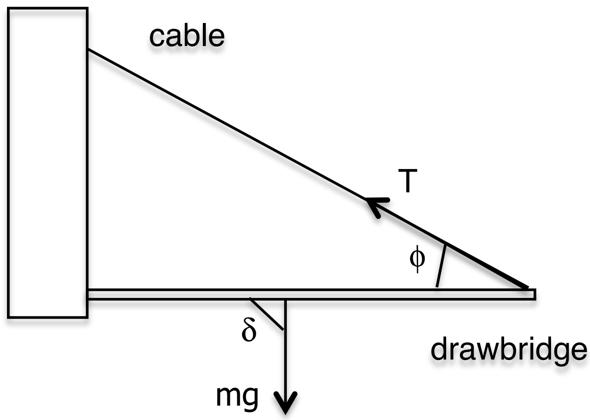
Question 7 **(2 marks)**

Sketch the resultant magnetic field for the diagram below;



Question 8 **(3 marks)**

Otto has been tasked with pulling up the drawbridge to close the castle. As he pulls on the cable, see diagram below, he finds that his task becomes easier and easier. Provide an explanation for Otto's observation.



Although there are no marks allocated, students should have annotated their diagrams.

- As the cable is raised, the angle (δ) between the weight of the drawbridge and the radius to the pivot decreases (approaches 0°) and the angle (ϕ) between the cable (tension force) and the radius increases (approaches 90°).
- As the drawbridge is in static equilibrium, the sum of the clockwise torque must equal the sum of the counterclockwise torque.
- $\tau = rF\sin\theta$, so as the angle δ decreases, the clockwise torque will decrease, as the angle ϕ is increasing F must decrease to maintain equilibrium as the values of r do not change.

Question 9 **(4 marks)**

A 4.50 kg mass is given an initial velocity of 14.0 ms^{-1} up an incline that makes an angle of 37.0° with the horizontal. When its displacement is 8.00 m, its upwards velocity has diminished to 5.20 ms^{-1}. What is the frictional force between the mass and the plane?

$v^2 = u^2 + 2as$ 0.5

$5.2^2 = 14^2 + (2)(a)(8)$ 0.5

$a = 10.6\,ms^{-2}\ down\ the\ plane$

1

$\Sigma F = ma$ 0.5

$mg\sin\theta + F_f = ma$

$(4.50)(9.8)(\sin 37) + F_f = (4.50)(10.6)$ 0.5

$F_f = 21.2\,N\ (down\ the\ plane)$

1

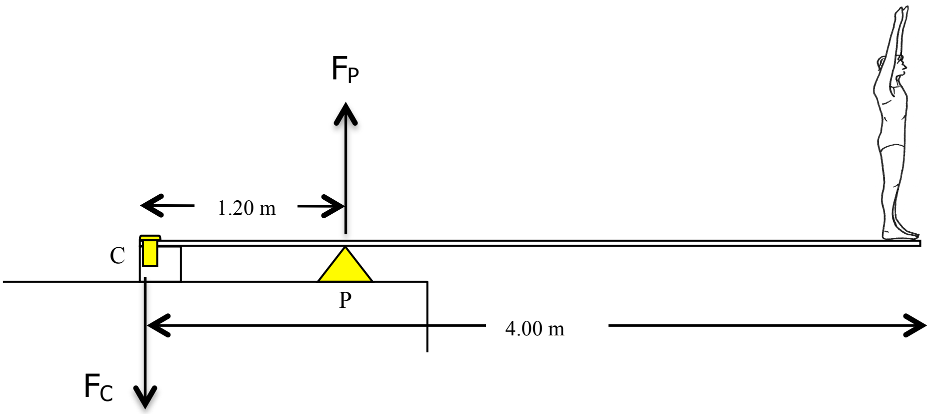
Question 10 **(4 marks)**

Explain why it is not possible for the iron in the centre of the Earth to be the cause of its magnetic field. Make reference to the domain theory of magnetism in your answer.

- All atoms have an individual magnetic moment due to the motion of their (unpaired) electrons.
- Domains are regions in a ferromagnetic material where all the individual atomic magnetic moments are aligned.
- Due to the very high temperatures in the centre of the Earth, the particles have high kinetic energy.
- This thermal agitation of the particles knocks the magnetic moments out of alignment preventing the iron from forming a permanent magnet (it is above the curie temperature of the iron).

Question 11 **(7 marks)**

A springboard diver with a mass of 62.5 kg is standing on the end of a diving board as shown below. The springboard has a mass of 120 kg. A clamp at C holds the end of the board in place.



Assume that the springboard is uniform and rigid (does not bend).

(a) On the diagram, use arrows to show the direction of the forces on the board due to the pivot point (P) and the clamp (C).

(2 marks)

(b) Calculate the magnitudes of the forces acting on the clamp (C) and the pivot point (P) when the diver is standing on the end of the board.

(5 marks)

$$\Sigma\tau_{cw} = \Sigma\tau_{ccw} \quad 0.5$$

$$\tau = rF\sin\theta \quad 0.5$$

$$Take\text{'}P\text{'}\,as\ pivot$$

$$\Sigma\tau_{cw} = (2.8)(62.5\times9.8)(\sin 90) + (0.8)(120\times9.8)(\sin 90) \quad 0.5$$

$$\Sigma\tau_{ccw} = (1.2)(C)(\sin 90) \quad 0.5$$

$$C = 2.21\times10^{3}\,N \quad 1$$

$$\Sigma F_y = 0 \quad 0.5$$

$$P - 2.21\times10^{3} - (62.5\times9.8) - (120\times9.8) = 0 \quad 0.5$$

$$P = 4.00\times10^{3}\,N \quad 1$$

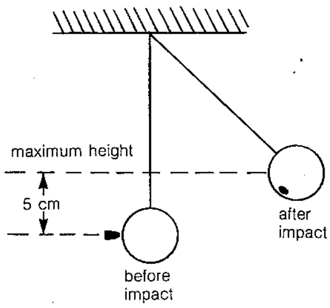
Question 12 **(4 marks)**

A current of 30.0 A flows up a 5.00 m vertical power pole. The power pole is located in Perth where the magnetic field is 5.50 x 10^{-5} T at 66.0° to the horizontal. Determine the force acting on the power line due to the Earth's magnetic field.

$$F = I\ell B \quad 1$$
$$= (30)(5)(5.50\times10^{-5}\cos 66) \quad 1$$
$$= 3.36\times10^{-3} N \quad West$$
1 1

Question 13 **(4 marks)**

The velocity of a bullet is to be determined using a ballistic pendulum. A bullet of mass 20.0 g is fired horizontally towards the centre of the bob of a stationary pendulum of 9.98 kg. If the centre of the bob moves through a vertical height of 5.00 cm before it comes to rest, calculate the speed of the bullet before impact.

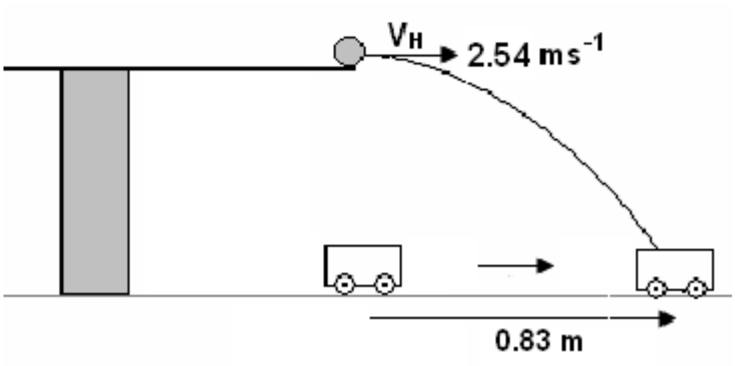


$$\Sigma E_i = \Sigma E_f \quad 1$$
$$E_{Ki} + E_{Pi} = E_{Kf} + E_{Pf}$$
$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv^2 + mgh \quad 1$$
$$\frac{1}{2}(0.02)(v^2) + (9.98)(9.8)(0) = \frac{1}{2}(9.98+0.02)(0) + (9.98+0.02)(9.8)(0.05) \quad 1$$
$$v = 22.1\, ms^{-1} \quad 1$$

Question 14 **(5 marks)**

Young Johnny and his brother Sam are playing a new game. Johnny rolls a large ball bearing along the top of a table with a constant speed of 2.54 ms^{-1} while his brother pushes a small trolley along the ground below. The idea of the game is to get the ball bearing to land in the trolley after leaving the table. This occurs when the trolley and the ball are in the position shown and the trolley is released 0.83 m away from where it will catch the ball bearing. Calculate the height of the table.

(5 marks)



$s = tv$ 1

$0.83 = (t)(2.54)$ 0.5

$t = 3.06\ s$ 1

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

$s = (0)(0.327) + \frac{1}{2}(-9.8)(0.327^2)$ 0.5

$= 0.524\ m$ 1

End of Section One

YEAR 12
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Section Two: Problem-Solving

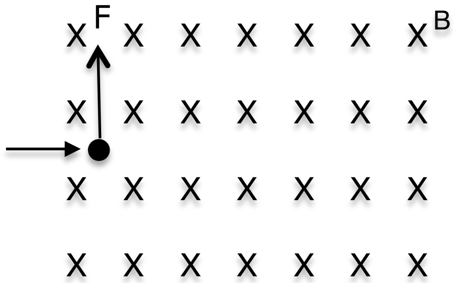
This section has **seven (7)** questions. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **90 minutes**.

NAME:_______________________________________

Question 1 **(11 marks)**

A particle of charge -12.0 x 10^{-18} C enters a uniform magnetic field of magnitude 1.60 mT with a velocity of 5.00 x 10^{6} ms^{-1} as shown in the figure below. The charged particle has a mass of 6.83 x 10^{-28} kg.



(a) Calculate the magnitude of the force on the charge.

(3 marks)

$$F = qvB \quad 1$$
$$= (12\times10^{-18})(5\times10^{6})(1.60\times10^{-3}) \quad 1$$
$$= 9.60\times10^{-14}\,N \quad 1$$

(b) Annotate the diagram above to show the direction of the force on the charge.

(1 mark)

(c) Determine the radius of the path of the particle.

(4 marks)

$$F_c = \frac{mv^2}{r} \qquad F_B = qvB \quad 1$$
$$\frac{mv^2}{r} = qvB \quad 1$$
$$\frac{(6.83\times10^{-28})(5\times10^{6})}{r} = (12\times10^{-18})(1.60\times10^{-3}) \quad 1$$
$$r = 0.178\,m \quad 1$$

(d) Explain why the particle will move in a circular path.

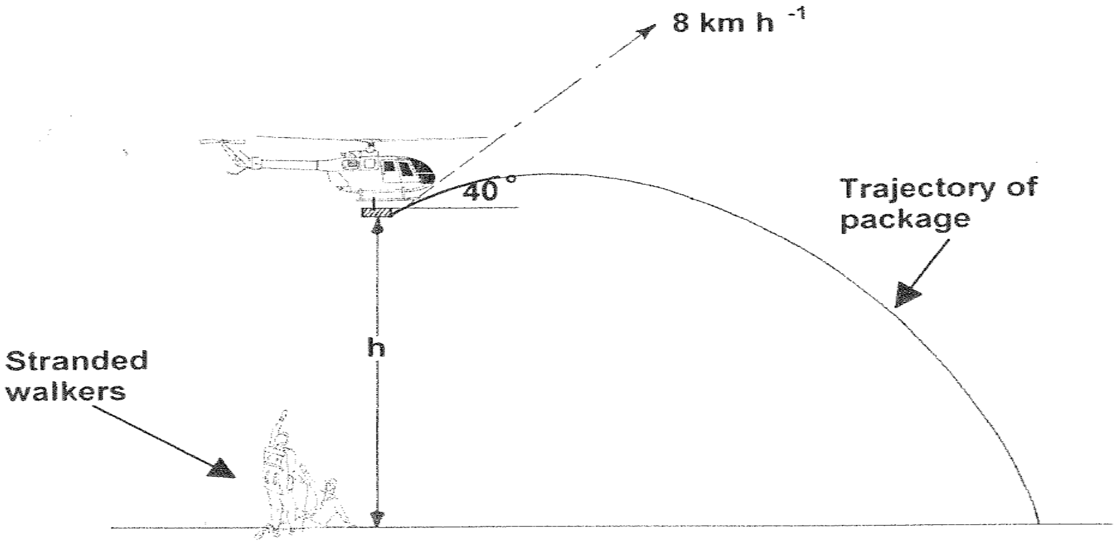
(3 marks)

(1.5 marks each)

- The direction of the magnetic force on the charged particle is always perpendicular to the direction of the velocity of the charged particle (and the magnetic field).
- This means that the charged particle will be continually pulled out of its straight line path into a circular path.

Question 2 **(15 marks)**

A helicopter is required to drop emergency equipment to a group of walkers stranded in rugged bushland. A package is released from the helicopter at an altitude (h) directly above the group. The helicopter is moving with a velocity of 8.00 kmh^{-1} at an angle of 40.0° above the horizontal when the package is released. The package lands on the ground 2.50 s after being released.



(a) Calculate the value of h.

(5 marks)

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

$$= (2.22\sin 40)(2.50) + \frac{1}{2}(-9.8)(2.50^2) \quad 2$$

$$= -27.1\,m$$

$$h = 27.1\,m \quad 1$$

(b) If the helicopter continues to fly with its initial velocity, calculate the distance between the helicopter and the package at the instant the package hits the ground.

(3 marks)

$s = tv$ 0.5

$= (2.50)(2.22\sin 40)$ 1

$= 3.93 + 27.1$ 0.5

$= 31.0\,m$ 1

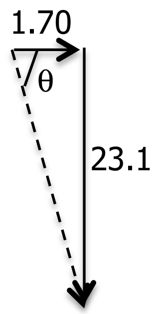
(c) Determine the speed of the package at the instant the package hits the ground.

(4 marks)

$v = u + at$ 1

$= (2.22\sin 40) + (-9.8)(2.5)$ 0.5

$= -23.1\,ms^{-1}$ 0.5



$v = \sqrt{(23.1^2 + 1.7^2)}$ 0.5

$= 23.2\ ms^{-1}$

$\tan\theta = \dfrac{23.1}{1.7}$ 0.5

$\theta = 85.8^\circ$

$v = 23.2\,ms^{-1}\ 85.8^\circ\, below\, the\, horizontal$ 1

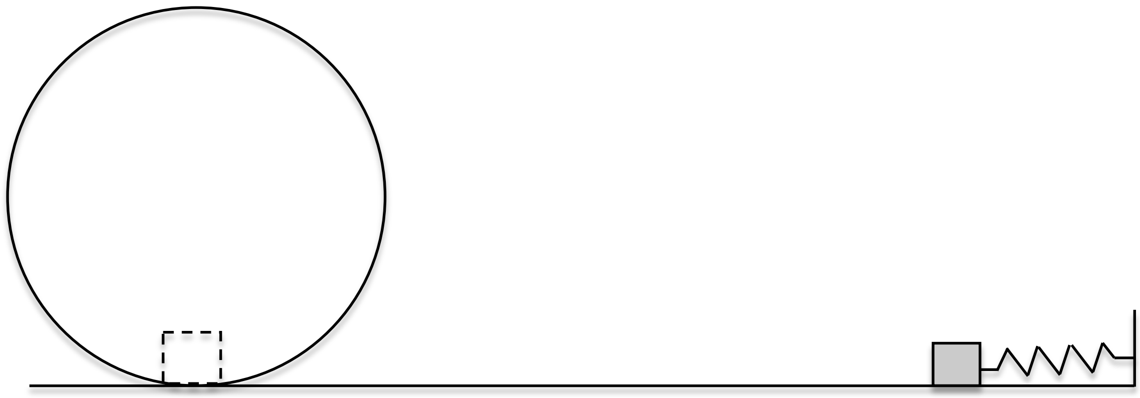
(d) If the helicopter was travelling horizontally at the same speed ($8.00kmh^{-1}$) and height (h) when it released the package, would you expect the package to land closer or further away from the group? Explain your answer.

(3 marks)

- Further from the group.
- The horizontal component of the velocity will be greater (as there is no vertical component).
- It will travel a greater distance in the horizontal direction (even though the time in the air has decreased due to no initial vertical motion upwards – it still will travel a greater distance 5.22 m cf 4.25 m).
- Could also verify by calculation.

Question 3 **(10 marks)**

A block of mass 0.500 kg is pushed against a horizontal spring. The energy stored in the spring is equal to 36.0 J. When released, the block travels along a frictionless, horizontal surface to point B, the bottom of a vertical circular track of diameter 3.00 m, as shown below.



(a) What is the initial speed of the block?

(3 marks)

$$\Sigma E_i = \Sigma E_f$$

$$E_{stored} = E_{kf}$$

$$E_{stored} = \frac{1}{2}mv^2 \quad 1$$

$$36 = \frac{1}{2}(0.5)(v^2) \quad 1$$

$$v = 12.0\ ms^{-1} \quad 1$$

(b) What is the speed of the block at the top of the circular track?

(3 marks)

$$\Sigma E_i = \Sigma E_f \quad 0.5$$

$$E_{ki} + E_{pi} = E_{kf} + E_{pf}$$

$$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv^2 + mgh \quad 0.5$$

$$\frac{1}{2}(0.5)(12^2) + (0.5)(9.8)(0) = \frac{1}{2}(0.5)(v^2) + (0.5)(9.8)(3.00) \quad 1$$

$$v = 9.23\ ms^{-1} \quad 1$$

(c) Will the block reach the top of the circular track? Justify your answer by making reference to appropriate calculation/s.

(4 marks)

$$\Sigma F = ma$$

$$-F_N - mg = -\frac{mv^2}{r} \quad 0.5$$

$$\min imum\, speed\, to\, make\, loop\; F_N = 0 \quad 0.5$$

$$v^2 = rg \quad 0.5$$

$$v^2 = (1.5)(9.8) \quad 0.5$$

$$v = 3.83\, ms^{-1} \quad 1$$

- Yes – block has sufficient speed to remain in contact with the track –so F_N will provide the remaining centripetal force (in addition to mg) to keep the block on the track. 1

Question 4 **(11 marks)**

A rocket booster enabled satellite of mass 1250 kg, including fuel, is in Earth orbit at an altitude of 6.30 x 10^2 km.

(a) Calculate the speed of the satellite.

(4 marks)

0.5 $F_c = \frac{m_s v^2}{r}$ $F_g = G\frac{m_s m_E}{r^2}$ 0.5

$$\frac{m_s v^2}{r} = G\frac{m_s m_E}{r^2}$$

$$v = \sqrt{\frac{Gm_E}{r}} \quad 1$$

$$= \sqrt{\frac{(6.67\times10^{-11})(5.97\times10^{24})}{(6.38\times10^6 + 6.3\times10^5)}} \quad 1 \quad 1$$

$$v = 7.54\times10^3\ ms^{-1} \quad 1$$

(b) What is the orbital period of the satellite?

(3 marks)

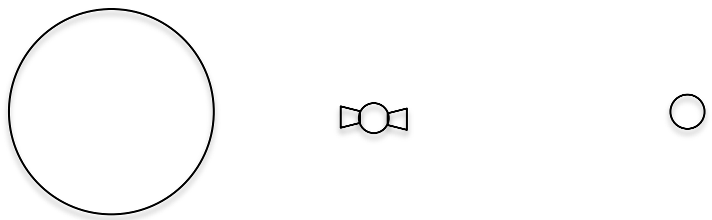
$$v = \frac{2\pi r}{T} \quad 1$$

$$T = \frac{2\pi(6.38\times10^6 + 6.3\times10^5)}{7.54\times10^3} \quad 1$$

$$= 5.84\times10^3\ s \quad 1$$

(c) At a certain point in its orbit, the satellite is directly between the moon and the Earth, as shown in the diagram below (diagram is **not** to scale). Determine the net force on the satellite at this point.

(4 marks)



$$F_1 = G\frac{m_s m_E}{r^2}$$ 0.5

$$F_1 = 6.67\times10^{-11}\frac{(1250)(5.97\times10^{24})}{(6.38\times10^{6}+6.3\times10^{5})^2}$$ 0.5

$$F_1 = 10.1\times10^{3}N$$ 0.5

$$F_2 = G\frac{m_s m_m}{r^2}$$

$$F_2 = 6.67\times10^{-11}\frac{(1250)(7.35\times10^{22})}{(3.94\times10^{8}-6.38\times10^{6}-6.3\times10^{5})^2}$$ 0.5

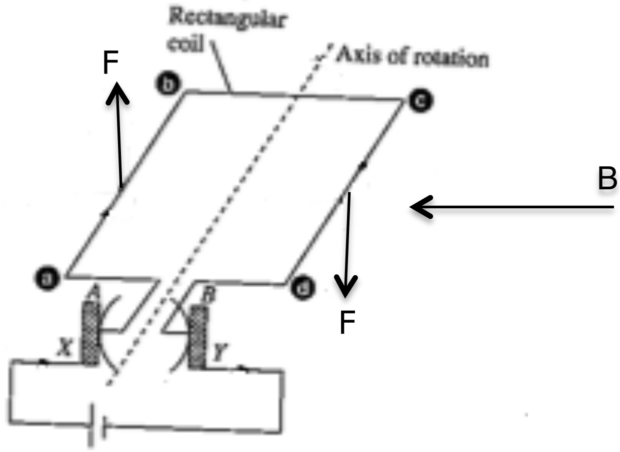
$$F_2 = 40.9\times10^{-3}N$$ 0.5

$$F_1 - F_2 = 10.1\times10^{3} - 40.9\times10^{-3}$$ 0.5

$$= 10.1\times10^{3}\,N\ towards\ the\ Earth$$ 1

Question 5 **(15 marks)**

A DC commutator motor consists of a rectangular coil of 225 turns and area 0.45 m^2 in a uniform magnetic field of 0.21 T. A current of 376 μA flows through the coil.



(a) Draw arrows on the diagram above to show the forces on the sides of the motor.

(1 mark)

(b) What is the magnitude of the force on the side 'cd'?

(3 marks)

$$F = I\ell B \quad 1$$
$$= (225)(376\times10^{-6})(0.671)(0.21) \quad 1$$
$$= 1.19\times10^{-2}\,N \quad 1$$

(c) What is the maximum torque on the coil?

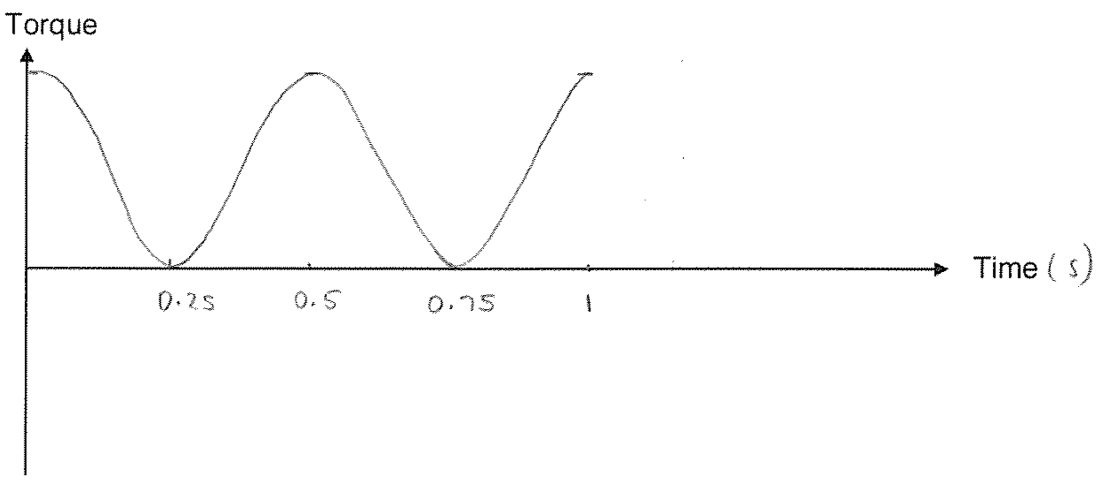
(4 marks)

$$\tau = NAIB \quad 1$$
$$= (225)(0.45)(376\times10^{-6})(0.21) \quad 1$$
$$= 7.99\times10^{-3}\ Nm \quad clockwise$$

1 1

(d) On the axes below, sketch the torque as the coil is rotated through one complete revolution (from the starting point shown above). Assume that clockwise torque is positive and that one revolution takes 1.00 s.

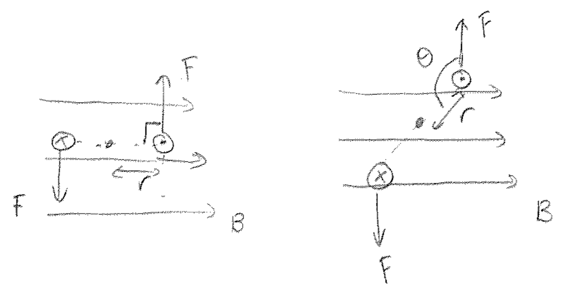
(2 marks)



(e) Explain, with the aid of a suitable diagram, why the torque varies.

(3 marks)

- The angle between the magnetic field and the force exerted on the rotor is always 90°.
- Thus as the rotor turns, the angle between the force and the radius to the pivot increases above 90°. As $\tau = rF\sin\theta$, as θ increases above 90°, so does τ as r and F are constant.



(f) Explain why a split-ring commutator is necessary in a DC motor.

(2 marks)

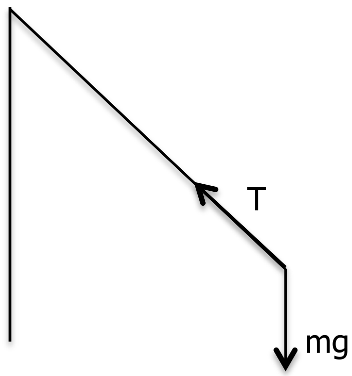
- A split-ring commutator changes the direction of the current every half a cycle.
- This ensures the current always flows in the same direction through each side of the motor meaning the direction of torque will always be the same.

Question 6 **(13 marks)**

Totem tennis was a fun family activity, popular in the 1970s and 1980s. It involved hitting a tennis ball which was tethered to a pole (the totem), as shown in the diagram below.

Assume the tennis ball has a mass of 250 g and is attached to the totem by a 1.20 m long cord which makes an angle of 40° with the vertical.

(a) Draw a freebody diagram showing all the forces acting on the tennis ball (2 marks)



(b) Determine the tension in the cord. (3 marks)

$$\Sigma F_V = T\cos 40 - mg = 0 \quad 1$$

$$T = \frac{mg}{\cos 40}$$

$$= \frac{(0.25)(9.8)}{\cos 40} \quad 1$$

$$= 3.20\,N \quad 1$$

(c) Determine the speed of the ball

(4 marks)

$$\Sigma F_H = T\sin 40 = \frac{mv^2}{r} \quad 1$$

$$(3.20)(\sin 40) = \frac{(0.25)(v^2)}{1.20(\sin 40)} \quad 2$$

$$v = 2.52\,ms^{-1} \quad 1$$

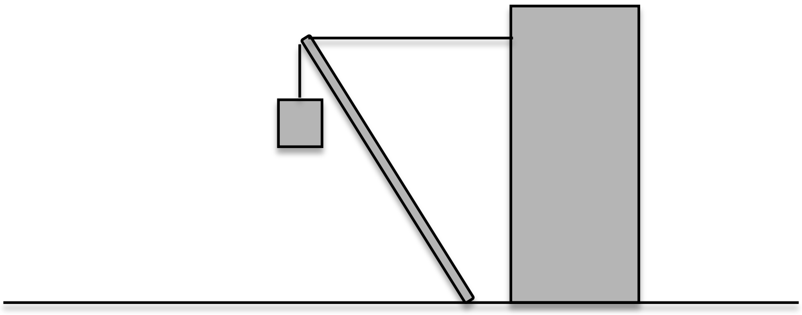
(d) An expert totem tennis player will be able to hit the ball with a larger speed. What would happen to the radius of the tennis ball and the tension in the cord? Explain your reasoning.

(4 marks)

- As the ball moves faster, a greater centripetal force will be required to maintain the circular path. As Tsinθ = mv^2/r, either T must increase or r must increase to balance the increase in speed.
- As Tcosθ must always be equal mg, therefore if the tension in the cord were to increase, the angle θ must increase.
- If the angle θ increase, the radius of the path must also increase.
- Therefore the tension will stay the same.

Question 7 **(15 marks)**

A uniform beam, of mass 40.0 kg and length 2.50 m, is inclined at an angle of 35.0° to the horizontal with its upper end supported by a horizontal rope tied to a wall and its lower end resting on a rough floor, as shown in the diagram below. A box hangs from the end of the beam.



(a) On the diagram above draw in **all** the forces acting **on the beam**.
[Hint, if the beam were to slip, it would slip to the right]

(3 marks)

(b) Use Newton's 2nd Law to write formulae for the horizontal and vertical forces acting on the system.

(4 marks)

$$\Sigma F_V = 0$$
$$\Sigma F_V = -m_{beam}g - m_{box}g + F_N = 0 \quad 2$$

$$\Sigma F_H = 0$$
$$\Sigma F_H = T - F_f = 0 \quad 2$$

(c) If the maximum friction that can be supplied between the beam and the floor is 420 N determine the maximum weight of box that can be suspended before the beam slips.

(4 marks)

$$\Sigma\tau_{cw} = \Sigma\tau_{ccw} \quad 0.5$$
$$\tau = rF\sin\theta \quad 0.5$$
$$Take\ base\ as\ pivot$$
$$\Sigma\tau_{cw} = (2.5)(420)(\sin 35) \quad 1$$
$$\Sigma\tau_{ccw} = (2.5)(m_{box}9.8)(\sin 55) + (1.25)(40 \times 9.8)(\sin 55) \quad 1$$
$$W_{box} = 98.1N \quad 1$$

(d) Determine the reaction force between the floor and the beam

(4 marks)

$$F_f = 420\,N \quad 0.5$$
$$F_N = m_{beam}g + m_{box}g$$
$$= (40)(9.8) + (10)(9.8) \quad 0.5$$
$$= 490\,N \quad 1$$

$$F_R = \sqrt{420^2 + 490^2} \quad 0.5$$
$$= 645\,N$$

$$\tan\theta = \frac{490}{420} \quad 0.5$$
$$\theta = 49.4^\circ$$

F_R = 645 N, 49.4° above the horizontal. 1

End of Section Two

YEAR 12
PHYSICS STAGE 3
MID YEAR EXAMINATION 2012

Section Three: Comprehension

This section has **one (1)** question. Answer **all** questions. Write your answers in the space provided.

Suggested working time for this section is **40 minutes**.

NAME:_______________________________________

Question 1 **(36 marks)**

The Discovery of the Electron

In 1897 Joseph John (J. J) Thomson discovered the first 'elementary particle' – the electron.

A favourite pastime among physicists at the end of the 19th century was to amuse themselves with 'Crookes Tubes' (named after their inventor, Sir William Crookes). Crookes tubes were sealed glass tubes from which most of the air had been evacuated and into which electrodes (flat pieces of metal) had been inserted at each end. When a high voltage was placed between the cathode (negative electrode) and the anode (positive electrode), the tube would light up. If a metal object were inserted between the electrodes, its shadow would be cast against the anode end of the tube by the 'cathode rays' that were emitted by the cathode, see Figure 1. The Crookes Tube or cathode ray tube as they came to be known became the main component of the television set.

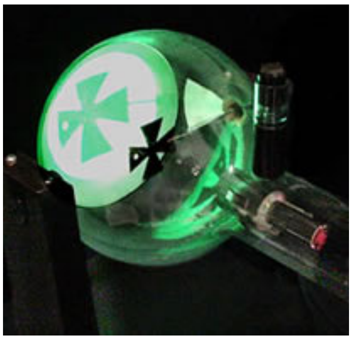


Figure 1 – An illuminated Crookes Tube. The metal 'Maltese Cross' in the centre of the tube is casting a shadow on the anode at the rear of the tube. (http://www-outreach.phy.cam.ac.uk/camphy/electron/electron1_1.htm)

J.J Thomson noticed that these cathode rays could be deflected by both electric and magnetic fields. That meant the rays consisted of charged particles. Thomson determined that they were 'negative corpuscles', i.e. negatively charged particles.

In an ingenious experiment he measured the charge to mass ratio of this corpuscle. Because the value was not zero or infinity it meant that the particle had a definite charge and definite mass (although Thomson's experiment could not give them individually).

Thomson found that he could deflect the cathode rays in an electric field produced by a pair of metal plates. One of the plates was negatively charged and repelled the cathode rays, while the other was positively charged and attracted them. Thomson's experimental setup is shown in Figure 2.

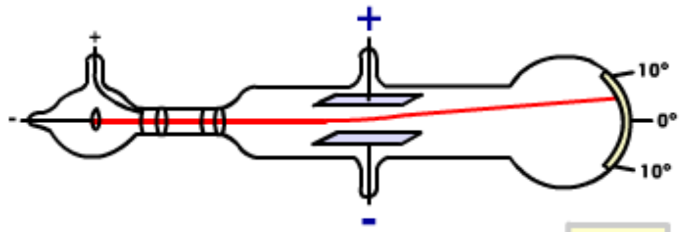


Figure 2. A beam of electrons travelling horizontally is passed through an electric field. The electrons are attracted towards the positively charged plate and repelled by the negatively charged plate.
(http://www-outreach.phy.cam.ac.uk/camphy/electron/electron1_1.htm)

Thomson was able to measure the amount of vertical deflection after the electron had passed through the plates, but he did not know what the initial speed of the electrons was.

A current in a coil of wire produces a magnetic field. Two coils arranged as a Helmholtz pair, see Figure 3, will produce a uniform magnetic field.

Figure 3 – Helmholtz coils surrounding a cathode ray tube.
(thesciencesource.com)

A beam of charged particles passing through the magnetic field will be bent at right angles to the field in a circular arc or a complete circle. In his tube, Thomson positioned the coils so that the deflection was in the opposite direction to the deflection produced by the electric field. By adjusting the strengths of the electric and magnetic fields the rays could be deflected, in one direction by the electric field and back in an equal amount by the magnetic field. The forces were balanced – this enabled Thomson to determine their initial velocity (i.e their velocity as they entered the plate region).

(a) Show that the velocity of an electron entering the plate region is given by $v = \frac{E}{B}$. (2 marks)

$F_B = qvB$ 0.5 $F_E = qE$ 0.5

$$F_B = F_E$$
$$qvB = qE \quad 0.5$$
$$v = \frac{E}{B} \quad 0.5$$

(b) Why do the magnetic field and electric fields need to be at right angles to each other?

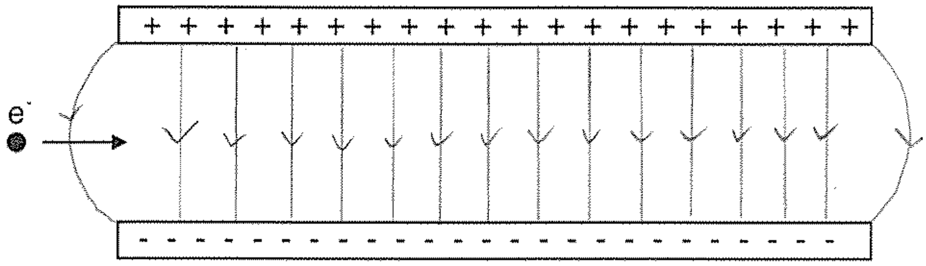
(3 marks)

- The force due to the electric field on the electron will act in the same direction as the electric field. It will either push the electron down or up.
- The force due to the magnetic field on the electron will be perpendicular to both the direction of the magnetic field and the direction of the electron's velocity.
- If the magnetic and electric fields were in the same direction, the electron would be deflected into or out of the page and it would not balance the forces. By having them perpendicular to each other the magnetic field will deflect in the opposite direction to the electric field.

By turning off the magnetic field, Thomson could measure the angle of deflection of the cathode rays in the electric field alone.

(c) Draw in the electric field on the diagram below and indicate the direction of the force on the electron.

(2 marks)



(d) If the plates are 8.00 mm apart and a potential difference of 2.00 kV is applied between the plates, determine the magnitude of the electric field between the plate and the magnitude of the force on the electron.

(5 marks)

$$E = \frac{V}{d} \quad 1$$
$$= \frac{2\times10^{3}}{8\times10^{-3}} \quad 0.5$$
$$= 250\ kV \quad 1$$

$$F = qE \quad 1$$
$$= (1.6\times10^{-19})(250\times10^{3}) \quad 0.5$$
$$= 4.00\times10^{-14}\ N \quad 1$$

(e) Show that acceleration experienced by a charged particle in the field is given by $a = \frac{qE}{m}$.

(2 marks)

$$F = ma \quad 0.5 \quad F = qE \quad 0.5$$
$$ma = qE \quad 0.5$$
$$a = \frac{qE}{m} \quad 0.5$$

If the length of the plates is denoted 'd', and the initial (horizontal) velocity of the electrons 'v_h' the time taken for an electron to pass through the plates will be given by, $t = \frac{d}{v_H}$.

(f) What is the vertical component of the electron's velocity as it leaves the plate area?

(2 marks)

$$v = u + at \quad 0.5$$

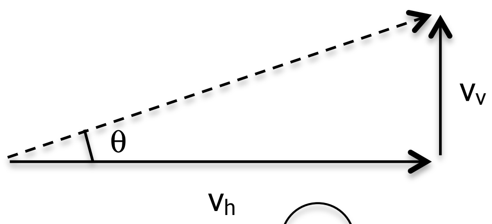
$$v = 0 + \frac{qE}{m}t \quad 0.5$$

$$v = 0 + \left(\frac{qE}{m}\right)\left(\frac{d}{v_H}\right) \quad 0.5$$

$$v_V = \frac{qEd}{mv_H} \quad 0.5$$

(h) Draw a vector diagram showing the horizontal and vertical components of the electron's velocity and use it to show that: $\tan\theta = \frac{qEd}{mv_h^2}$, where θ is the angle the electron is deflected through.

(3 marks)



1

$$\tan\theta = \frac{opp}{adj} = \frac{v_v}{v_h}$$

$$\tan\theta = \frac{\frac{qEd}{mv_h}}{v_h} \quad 1$$

$$\tan\theta = \frac{qEd}{mv_h^2} \quad 1$$

Some typical results for Thomson's experiment are given below:

d = 0.05 m

E (Vm^{-1})	B (μT)	θ°	$\tan\theta$	E/v^2 ($Vm^{-3}s^2$ or $JC^{-1}m^{-2}s^2$) x 10^{-12}
2880	120	1.6	0.028	5.00
5400	180	3.0	0.052	6.00
10080	312	5.6	0.098	9.66
16920	576	9.4	0.17	19.6
20880	696	11.6	0.21	23.2

(i) Process the data in the table above so that you are able to plot a graph of

$$\tan\theta \ vs \ \frac{E}{v_h^2}$$

You will also need to complete the units for one column.

(2 marks)

(j) Plot a graph of $\tan\theta \ vs \ \frac{E}{v_h^2}$ on the graph paper on page 35.

(5 marks)

(k) Determine the gradient of your graph.

(3 marks)

$$gradient = \frac{rise}{run}$$

1 - triangle

$$= \frac{0.188 - 0.04}{(20-5)\times 10^{-12}} \quad 1$$

$$= 9.87\times 10^{9}\, V^{-1}m^{3}s^{-2} \ or \ J^{-1}Cm^{2}s^{-2} \quad 1$$

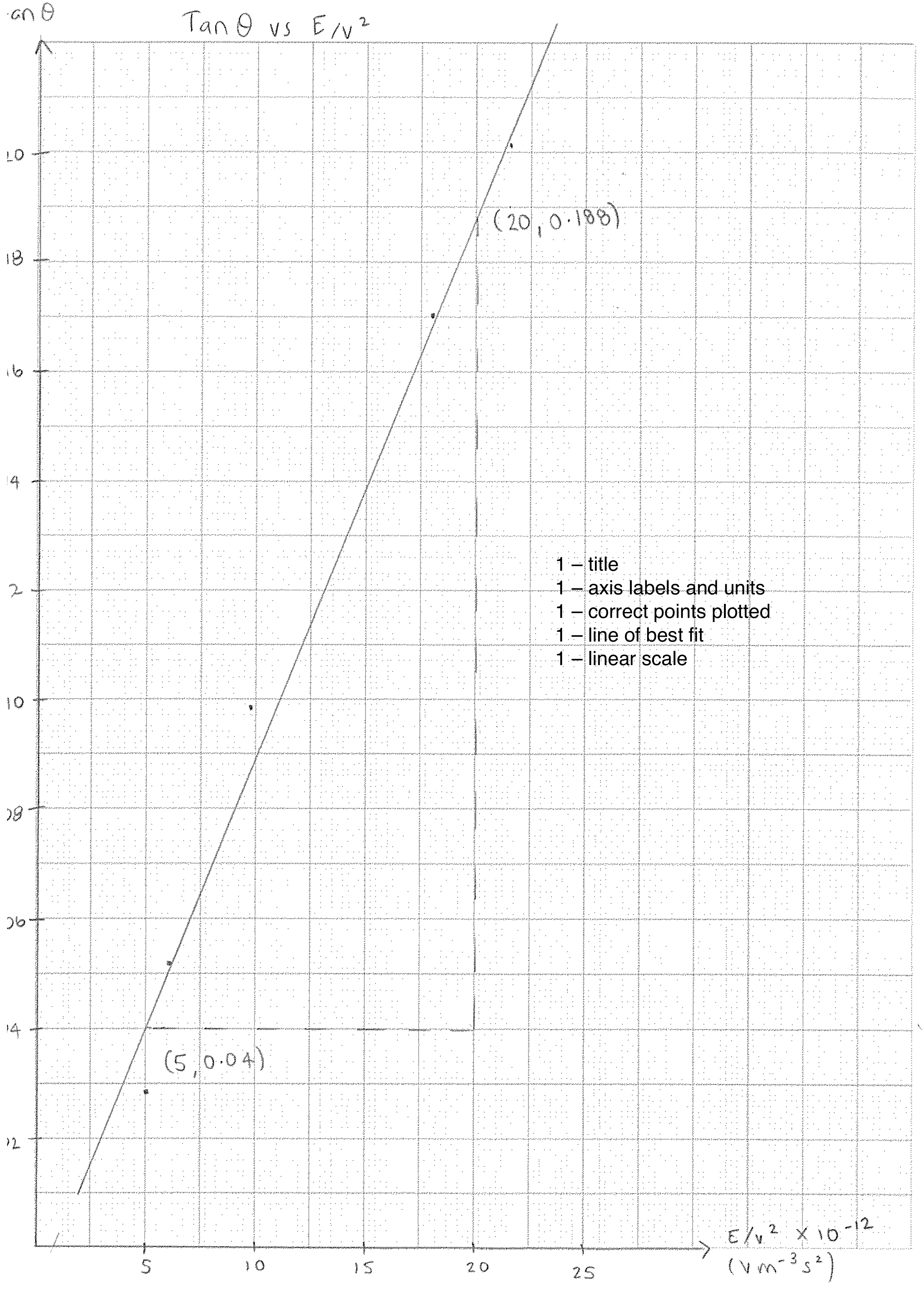
(l) Use the gradient of your graph to determine a value for the charge to mass ratio for an electron.

(3 marks)

$$gradient = \frac{qd}{m} \quad 1$$

$$9.87\times 10^{9} = \left(\frac{q}{m}\right)0.05 \quad 1$$

$$\frac{q}{m} = 1.97\times 10^{11}\, Ckg^{-1} \quad 1$$



1 – title
1 – axis labels and units
1 – correct points plotted
1 – line of best fit
1 – linear scale

(m) Use the values on your data sheet to determine the currently accepted charge to mass ratio for an electron.

(2 marks)

$$\frac{q}{m} = \frac{1.6 \times 10^{-19}}{9.11 \times 10^{-31}} = 1.76 \times 10^{11}\ Ckg^{-1}$$

1 1

Thomson also measured the charge to mass ratio for hydrogen ions. Hydrogen ions were particles that had all the same properties as hydrogen atoms except that, while an electric field did not deflect the atoms, it deflected the ions in an opposite direction to the 'negative corpuscles'. This meant the hydrogen ions were positively charged. Also the q/m ratio of the negative particles seemed to be about 1000 times larger than the q/m ratio of the hydrogen ion. Assuming the charges were the same, the new particle must be 1000 times lighter than hydrogen. The conclusion was that the atom was no longer the smallest entity. Thomson had discovered the first sub-atomic particle, which soon became known as the electron.

(n) Discuss the change in gradient for a hydrogen ion if the initial velocity and length of the plates is the same.

(2 marks)

- The q/m ration for the hydrogen ion is 1000 smaller than that of an electron.
- Therefore the gradient will be less steep.

End of Section Three