CORPUS CHRISTI COLLEGE
SEQUERE DOMINUM

YEAR 12 ATAR PHYSICS
UNIT 3 and 4
SEMESTER ONE
EXAMINATION 2017

Teacher: W O'CALLAGHAN / K ROURKE
(Circle)

Student Number: In figures

In words Solns

Time allowed for this paper Reading time before commencing work: 10 minutes
Working Time: 3 hours

Materials required/recommended for this paper

To be provided by the supervisor This Question/Answer Booklet
Formulae and Constants Booklet

To be provided by the candidate
Standard items: pens, pencils, eraser, correction fluid/tape, ruler, highlighters
Special items: non-programmable calculators approved for use in the WACE examinations, drawing templates, drawing compass and a protractor

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.

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

This section has **12** questions. Answer **all** questions.

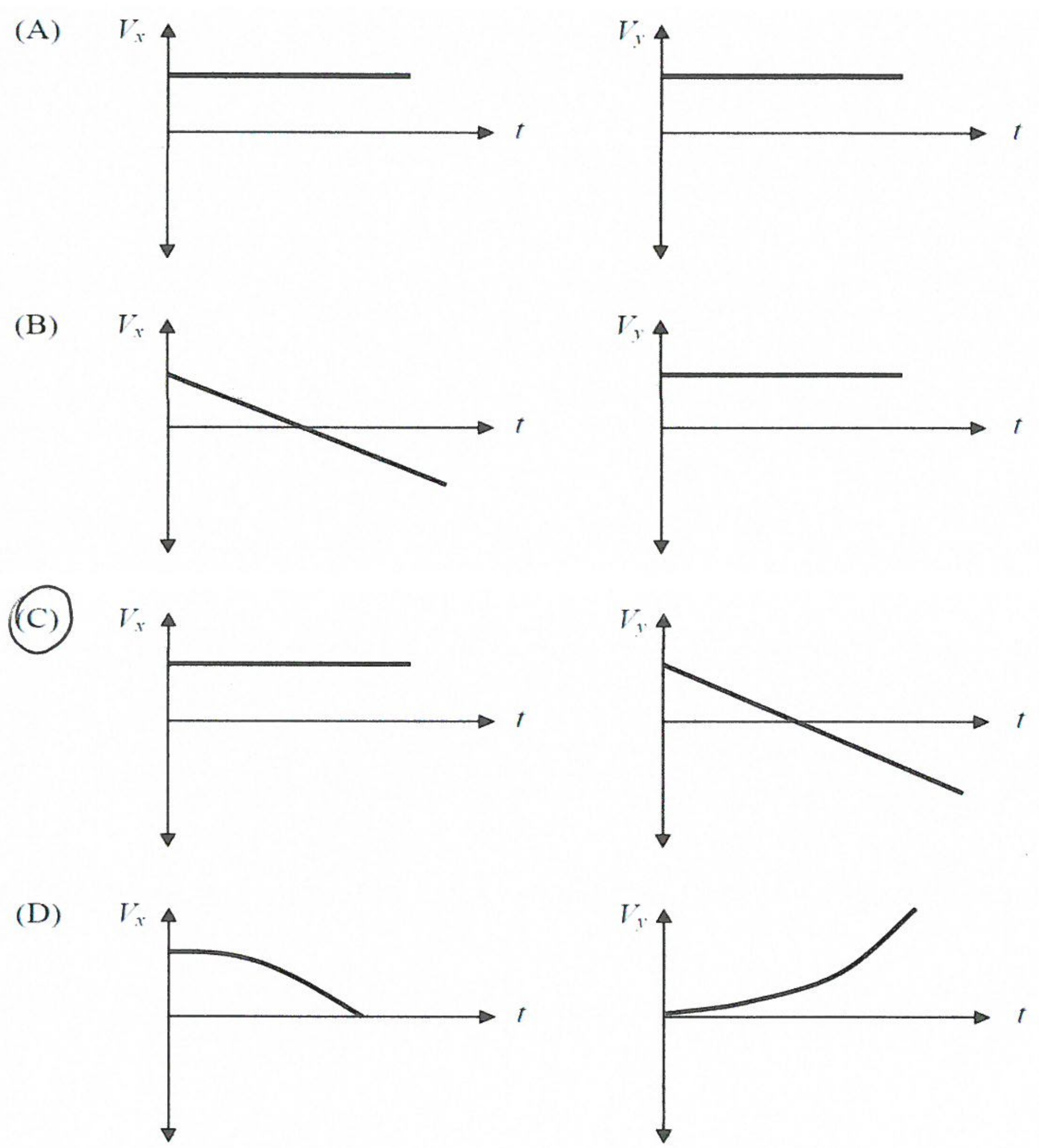
Suggested working time: 55 minutes.

Question 1 **(6 marks)**

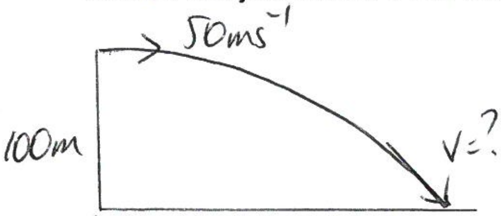
(a) Multiple choice:

A projectile is thrown with an initial velocity V at an angle of θ.

Which pair of graphs best represents the motion of a projectile? Circle the correct answer. Note that V_x is the horizontal component and V_y is the vertical component of initial velocity V respectively. Assume negligible air resistance. (1 mark)



(b) A cannon fires a cannon ball horizontally at speed of 50.0 m s^{-1} from the top of a bridge that is 100 m above the surface of a lake below. Ignoring air resistance, calculate the ***velocity*** of the cannon ball just before it hits the water. (5 marks)



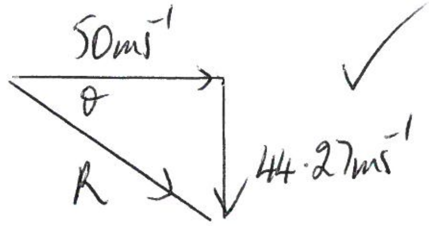
$V_{horiz} = 50ms^{-1}$

vert : $V^2 = u^2 + 2as$

$= 0 + 2(9.8)(100)$

$V = \sqrt{1960}$

$= 44.27ms^{-1}$ ✓



✓

$R^2 = 50^2 + 44.27^2$

$\therefore R = \sqrt{4460}$

$= 66.78ms^{-1}$ ✓

$\tan\theta = \frac{44.27}{50}$ ✓

$\therefore \theta = 41.52^\circ$ ∴ $\underline{vel = 66.8ms^{-1}}$, $\underline{41.5^\circ}$ $\underline{\text{below horiz}}$ ✓

Question 2 **(5 marks)**

(a) A 1400 kg car rounds a flat circular corner of diameter 195 m. If the friction between the tires and the road is 7546 N, what is the maximum speed that the car can travel? (3 marks)

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

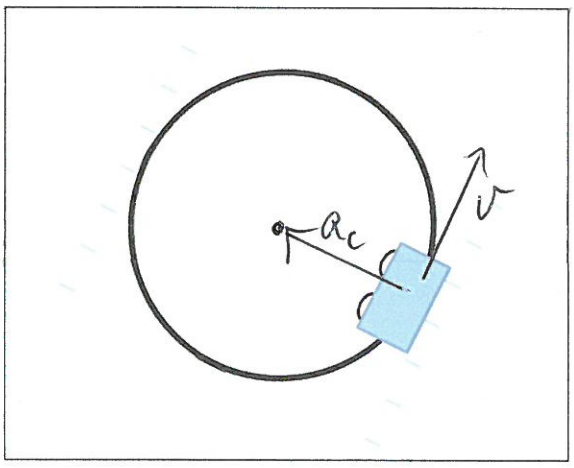
$7546 = \frac{1400\,v^2}{(195/2)}$ ✓

$v^2 = 525.53$ ✓

$\therefore V = \sqrt{525.53} = \underline{22.9ms^{-1}}$ ✓

(b) This is a top view of the car in the previous question which is traveling in a **counter clockwise** (anti-clockwise)circle.

Draw and label clearly the direction of the velocity and acceleration of the car at this point. (2 marks)



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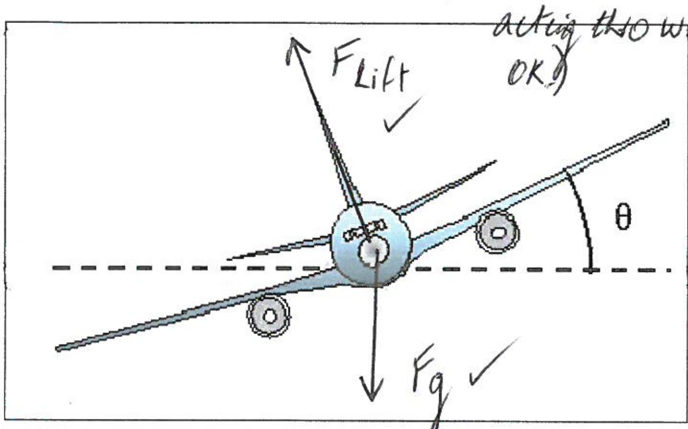
Question 3 **(6 marks)**

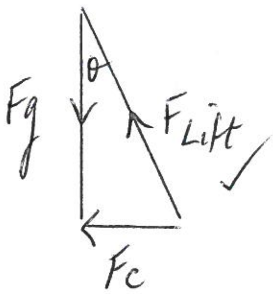
For a passenger jet the maximum legal banking angle is 27.5°.

(2x F_{Lift} acting thro wings OK)

(a) Draw and label clearly the direction of the forces acting on the figure of the passenger jet.
(2 marks)



(b) Calculate the minimum radius of a turn for a passenger jet travelling at a speed of 900 kmh^{-1}. Include a vector diagram, together with the relevant formulae from the data Sheet, in your answer.
(4 marks)



$\tan\theta = \dfrac{F_c}{F_g}$

$= \dfrac{mv^2}{r} \times \dfrac{1}{mg}$ ✓ ($\frac{1}{2}$ each formula)

$= \dfrac{v^2}{rg}$

$V = 900/3.6 = 250 ms^{-1}$ ✓

$\tan 27.5^\circ = \dfrac{250^2}{r(9.8)}$ $\therefore r = 12251 m = \underline{12.3 km}$ ✓

Question 4 **(3 marks)**

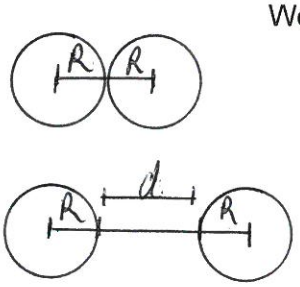
Two identical uniform spheres each of radius R are placed in contact. The gravitational force between them is *F*.

The spheres are now separated until the force of attraction is $\frac{F.}{9}$

What is the distance between the ***surfaces*** of the spheres after they have been separated? Show your working in space provided.

✓
A. 2R
B. 4R
C. 8R
D. 12R

Working



$F = 9\times10^9 \dfrac{m_1 m_2}{(2R)^2}$

$F/9 \Rightarrow$ distance is $3 \times (2R)$ ✓✓
$\therefore 6R$
So dist $= 6R - 2R = \underline{\underline{4R}}$

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Question 5 **(5 marks)**

Figure 5 below shows a gripper which is used for hand strengthening exercises.

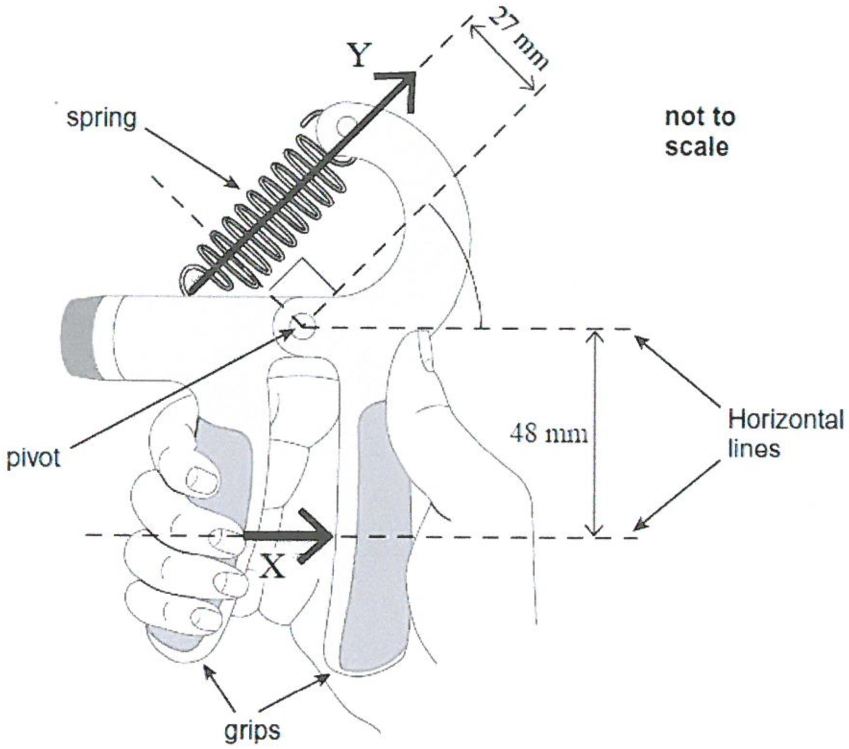


Figure 5

Figure 5 shows the gripper being squeezed. In this situation, the gripper is in equilibrium. The force produced by the fingers is equivalent to the single force **X** of magnitude 250 N acting in the direction shown in Figure 5. A force, **Y**, is exerted by the spring.

(a Calculate the moment of force **X** about the pivot. State an appropriate unit. (3 marks)

$\tau = Fr$

$= 250 \times 0.048$

$= 12.0$ Nm (3sf) anticlockwise

(b) Calculate force **Y**. (2 marks)

τ of X provides the τ acting on spring.

$\tau = Fr$

$12 = F \times 0.027$

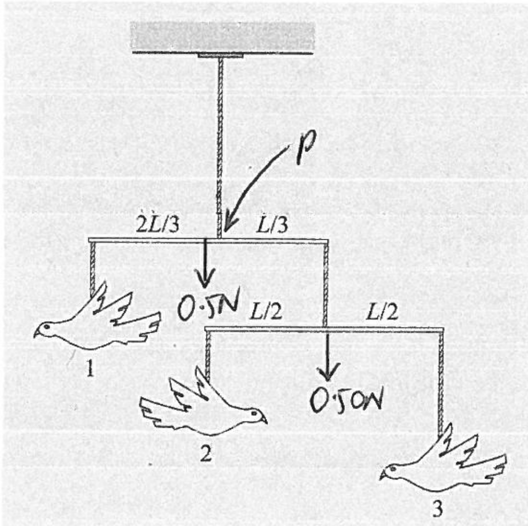
$\therefore F = 444.44 = 444$ N (3sf)

5

Question 6 **(5 marks)**

The mobile depicted below hangs in equilibrium. It consists of objects held by vertical strings of negligible mass.

Bird-3 weighs 1.40 N, while ***each*** of the identical uniform horizontal bars weighs 0.50 N.



Find

(a) the weights of birds-1 and -2, and

(b) the tension in the upper string.

a) Bird 2 has a weight of 1.40N. ✓

At equil^m: $\Sigma CM = \Sigma ACM$

$$(1.4 + 1.4 + 0.5) \times \frac{L}{3} = B_1 \times \frac{2L}{3} + 0.5 \times \left(\frac{2L}{3} - \frac{1L}{2}\right)$$

L is common factor (cancels)

$$\frac{3.30}{3} = \frac{2}{3}B_1 + 0.5\left(\frac{2}{3} - \frac{1}{2}\right)$$

$$1.10 = 0.667 B_1 + 0.0835$$

$$B_1 = \frac{1.10 - 0.0835}{0.667}$$ ✓✓✓

$$= 1.524\ N \quad \therefore \text{Wt of } B_1 = 1.52N \ (3sf)$$

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

$$T = 1.524 + 3.30 + 0.5 = 5.324N = 5.32N \ (3sf)$$ ✓

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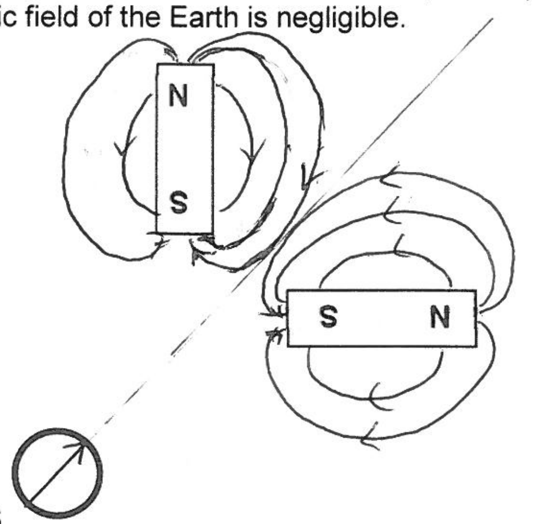
Question 7 **(7 marks)**

(a) Two identical magnets are fixed in a position on a flat bench. A compass is placed near the magnets. Assume that the magnetic field of the Earth is negligible.



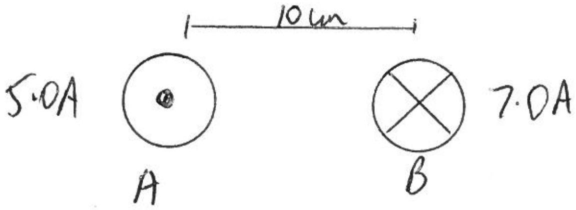
COMPASS

(i) Sketch the magnetic field in the region around the magnets. (1 mark)

(ii) Indicate the direction that the compass will point by placing an arrow in the circle. (1 mark)

(b) Two parallel straight wires **A** and **B** are 10.0 cm apart carry currents in opposite directions. Current in wire **A** is 5.0 A out of the page and current in wire **B** is 7.0 A into the page.

(i) Draw a diagram below to represent the situation. (1 mark)



symbols only

(ii) Determine the magnitude and direction of the resultant magnetic field halfway between the wires. (4 marks)

A: $B = \frac{\mu_0}{2\pi}\frac{I}{d}$ $\mu_0 = 4\pi \times 10^{-7}$

$= 2\times10^{-7} \frac{5}{0.05} = 2\times10^{-5}$ T ✓ to top of pg

B: $B = 2\times10^{-7}\frac{7}{0.05} = 2.8\times10^{-5}$ T ✓ to top of pg

$\therefore$ Total $B = \underline{4.80\times10^{-5}\text{ T}}$ ✓ $\underline{\text{to top of pg}}$ ✓

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Question 8 **(5 marks)**

Electromagnets are widely used in electrical devices. One of the simplest and, most common applications is in a relay. When the switch S is closed in a relay circuit, Figure 8, current flows in the coil, causing a strong magnetic field around the coil.

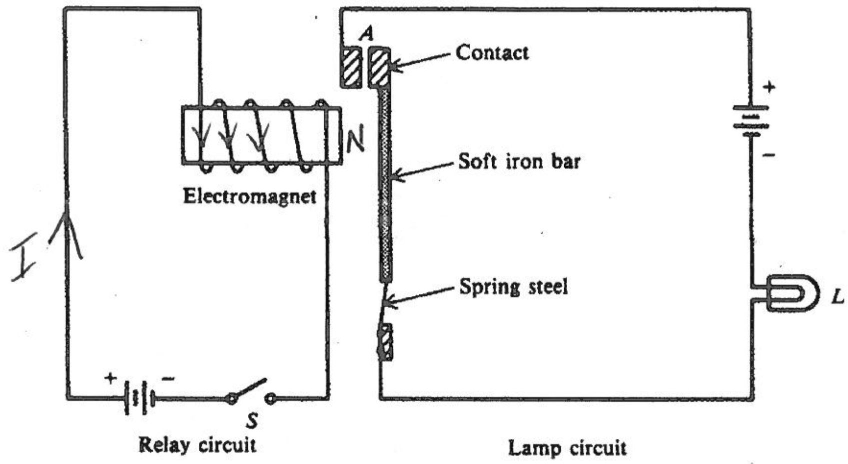

Figure 8

(a) Indicate ***clearly*** on Figure 8 the North pole of the electromagnet when the switch S is closed in the relay circuit. (1 mark)

(b) Explain 2 reasons why a *soft iron bar* is used. (2 marks)

1. Iron is ferromagnetic $\left(\frac{1}{2}\right)$ It will be strongly $\left(\frac{1}{2}\right)$ attracted to the electromagnet. ✓
2. Soft iron loses its magnetism quickly. ✓

(c) Briefly explain how the relay circuit controls the lamp circuit. (2 marks) ($\frac{1}{2}$ each)

1. The switch in the relay circuit causes the electromagnet to become magnetic.
2. This attracts the soft iron bar due to induction.
3. This causes the contacts to touch completing the circuit.
4. The current then flows in the lamp circuit.

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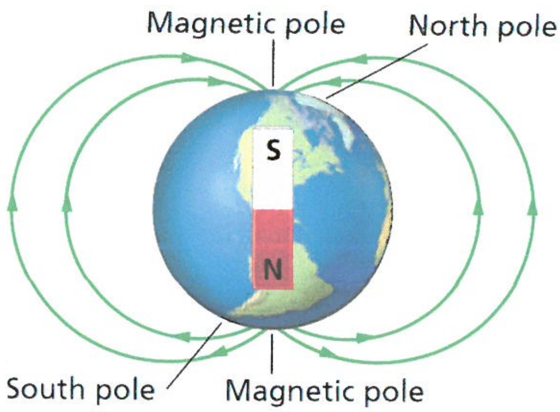
Question 9 **(6 marks)**

The Earth's magnetic field lines are shown below.



(a) At what location, poles or equator is the magnetic field strength the greatest? Justify your answer. (2 marks)

Earth's magnetic field strength is greatest at the poles. The field lines are closer together at the poles.

A power line carries a 225 A current from East to West, parallel to the surface of Earth.

(b) Calculate the magnetic force resulting from the Earth's magnetic field of 50 μT acting on each metre of the wire? (3 marks)

$$F = ILB$$

$$\frac{F}{L} = IB = (225\ \text{A})(5.0\times10^{-5}\ \text{T})$$

$$= 0.011\ \text{N/m}$$

The force would be downward.

direction ✓

(c) In your judgement, would this force be important in designing towers to hold this power line? Explain. (1 mark)]

No; the force is much smaller than the weight of the wires.

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Question 10 **(4 marks)**

Figure 10 shows a coil located between the poles of 2 magnets. The shaped pole pieces shown in Figure 10 result in a uniform radial field of B = 0.10 T over a limited range of deflection. Assume that the entire coil length is in the field.

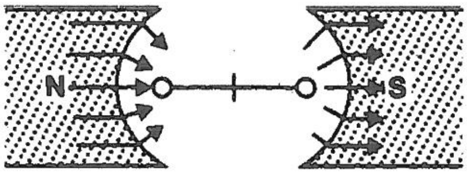

Figure 10

The coil contains 35 turns and measures 23 mm by 17 mm.

(a) What is the magnitude of the torque that results from a coil current of 15 mA? (3 marks)

$\tau = Fr$

$F = BIl \times n$

$= 0.10 \times (15 \times 10^{-3})(23 \times 10^{-3}) \times 35$

$= 1.21 \times 10^{-3}$ N

$= 2 \times 1.21 \times 10^{-3} \times \frac{(1.7 \times 10^{-3})}{2}$

$= 2.053 \times 10^{-6}$ Nm

$= \underline{2.05 \times 10^{-6} \text{ Nm}}$ (3sf)

(b) The above coil and radial field provide a D'Arsonval meter movement. It has a restoring spring with a torque given by the expression $5.87 \times 10^{-5}\ \theta$ (N m), where the angle of rotation, θ, is in radians. What angle of rotation results from a coil current of 15 mA? (1 mark)

$\tau = 5.87 \times 10^{-5}\ \theta = 2.05 \times 10^{-6}$

$\theta = \frac{2.05 \times 10^{-6}}{5.87 \times 10^{-5}} = \underline{28.6^{o}}$

Question 11 **(4 marks)**

Two electrons, X and Y, travel at right angles to a uniform magnetic field.

X experiences a magnetic force, F_X, and Y experiences a magnetic force, F_Y.

What is the ratio $\frac{F_X}{F_Y}$ if the kinetic energy of X is half that of Y?

Told:
E_K of $X = \frac{1}{2} E_K$ of Y

Want $\frac{F_X}{F_Y}$

$F = Bqv$ and $E_K = \frac{1}{2}mv^2$

$\therefore v = \sqrt{E_K / \tfrac{1}{2}m}$

So $\frac{F_X}{F_Y} = \frac{\cancel{B_X}\cancel{q_X} v_X}{\cancel{B_Y}\cancel{q_Y} v_Y} = \sqrt{\frac{E_X}{\frac{1}{2}m}} \times \sqrt{\frac{\frac{1}{2}m}{E_K}}$

$= \sqrt{\frac{E_X}{E_Y}} = \sqrt{\frac{\frac{1}{2}E_Y}{E_Y}} = \sqrt{\frac{1}{2}}$

$= \underline{0.707 \quad \therefore F_X = 0.707 F_Y}$

(8)

Question 12 **(4 marks)**

A proton travels east through a downward (into the page) magnetic field of 0.024 T at a speed of 1.8 x 10^6 m s^{-1}.

(a) What is the magnitude and direction of the force acting on the proton? (2 marks)

$F = Bqv$

$= 0.024 \times 1.6 \times 10^{-19} \times 1.8 \times 10^{6}$

$= 6.912 \times 10^{-15}$ ✓

$= \underline{6.91 \times 10^{-15}\ N}$ (3sf) $\underline{\text{North}}$. ✓

(b) What is the centripetal acceleration of the proton? (2 marks)

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

$F_c = F_B$

$\frac{mv^2}{r} = Bqv$

$r = \frac{mv}{Bq}$

$\therefore a_c = \frac{v^{\cancel{2}}}{1} \times \frac{Bq}{m\cancel{v}}$

$= \frac{1.8 \times 10^{6} \times 0.024 \times 1.6 \times 10^{-19}}{1.67 \times 10^{-27}}$

$= \underline{4.14 \times 10^{12}\ ms^{-2}}$ Towards centre of O

* OR

$F_c = F_B$

$m a_c = Bqv = 6.91 \times 10^{-15}$

$\therefore a_c = \frac{6.91 \times 10^{-15}}{1.67 \times 10^{-27}}$ ✓ $= \underline{4.14 \times 10^{12}\ ms^{-2}}$ $\underline{\text{Towards Centre of O}}$ ✓

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Section Two: Problem-solving **50% (89 Marks)**

This section has **six (6)** questions. Answer **all** questions. Write your answers in the spaces provided.

Suggested working time: 90 minutes.

Question 13 **(10 marks)**

(a) (i) If in Figure 13A the friction between the block and the incline is negligible, how much must the object on the right weigh if the 200 N block is to remain at rest?

(3 marks)

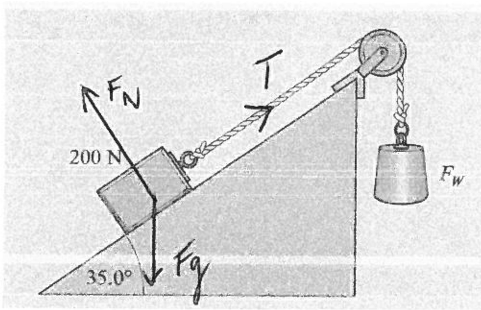
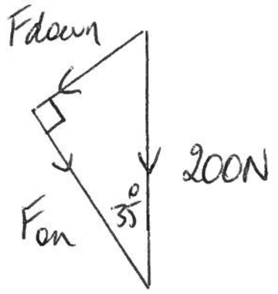


Figure 13A



$\sin 35^{\circ} = \frac{F_{down}}{200}$

$\therefore F_{down} = 200 \sin 35^{\circ}$

$\therefore F_{up} = 114.7 N$

$\therefore \underline{F_W = 115 N}$ (3sf)

(ii) The system in Figure 13A remains at rest when F_w = 220 N. What is the magnitude and the direction of the friction force on the 200 N block? (2 marks)

$F_{friction} = 220 - 114.7$

$= 105.3 N$

$\therefore \underline{F_{friction} = 105 N}$, $\underline{\text{down the slope}}$ (opposes motion)

5

(b) In Figure 13B, the pulleys are frictionless and weightless and the system hangs in equilibrium. If the tension in the right-hand string is 200.0 N, what are the values of the tension ***T*** and mass of the load? (5 marks)

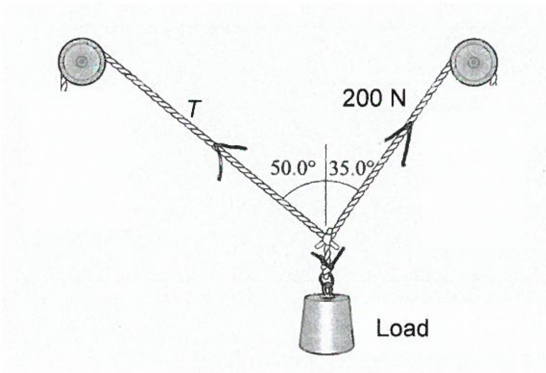
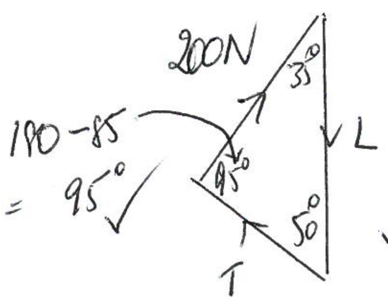


Figure 13B



$$\frac{L}{\sin 95^\circ} = \frac{200}{\sin 50^\circ} \quad \therefore L = 260.1\,N$$

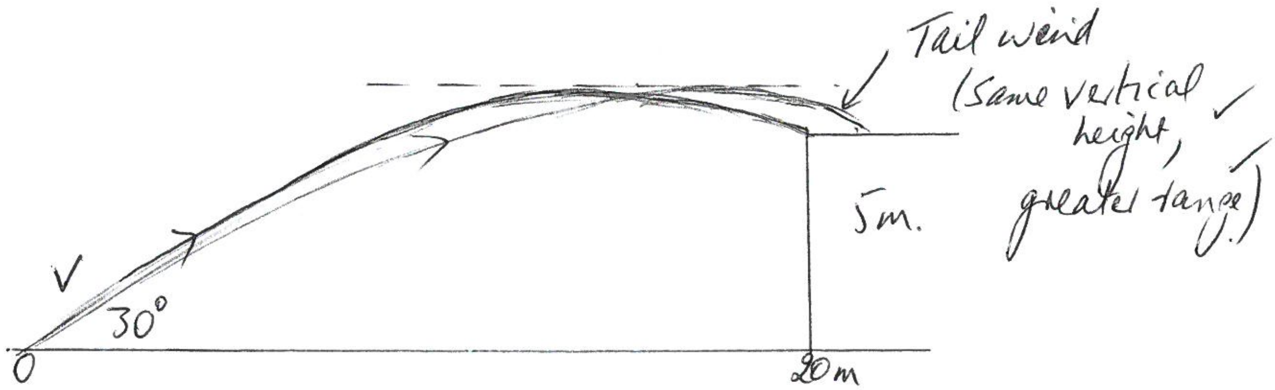
$$F_g = mg$$

$$\therefore m = \frac{260.1}{9.8} = 26.5\,kg$$

$$\left[\ \frac{T}{\sin 35^\circ} = \frac{200}{\sin 50^\circ} \quad T = 146\,N\ \right]$$

Question 14 **(10 marks)**

A ball is thrown upward at an angle of 30° to the horizontal and, on its way down, lands on the top edge of a building that is 20 m away. The top edge is 5.0 m above the throwing point.



(a) In the space above draw a diagram to illustrate the information given. (2 marks)

(b) On the same diagram show the path taken by the ball if a horizontal tail wind were present. (2 marks)

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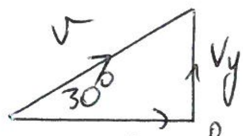
(c) How fast was the ball thrown? Show your working clearly. (6 marks)



Horiz $s = vt$

$$20 = V\cos 30 \times t \quad \ldots (1)$$

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

$$5 = V\sin 30° \times t + \tfrac{1}{2}(-9.8)t^2$$

$$5 = V\sin 30° \times t - 4.9t^2 \quad \ldots (2)$$

From (1) $t = \dfrac{20}{V\cos 30°}$ Subst into (2)

$$5 = \cancel{V}\sin 30° \times \frac{20}{\cancel{V}\cos 30°} - 4.9\left(\frac{20}{V\cos 30°}\right)$$

$$5 = 11.547 - 4.9\left(\frac{400}{V^2\cos^2 30°}\right)$$

$$5 - 11.547 = -\frac{2613}{V^2}$$

$$V = \sqrt{\frac{2613}{6.547}} = \sqrt{399} = 20.0\ ms^{-1}\ (3sf)$$

Question 15 **(18 marks)**

One of the vertical circular rides in Fisics Fantasy Land has a radius of 35.0 m. A passenger is sitting in a car that is just cresting the top of the ride.

(a) On Figure 15A draw and label clearly the direction of the forces acting on the figure of the passenger in the car.
(2 marks)

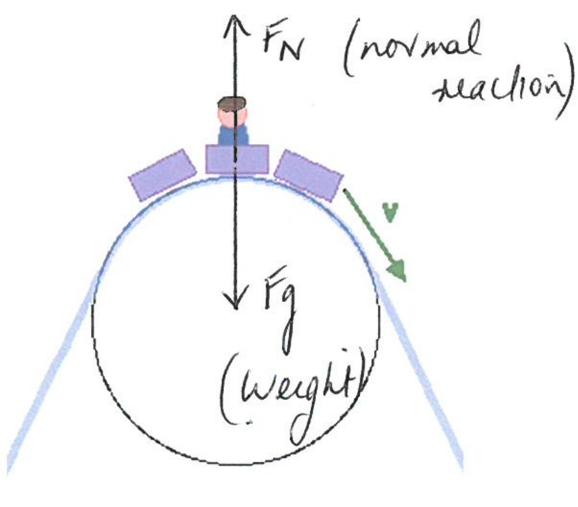


Figure 15A

(b) How fast must the car be moving in order that the passenger momentarily lifts off the seat and feels weightless? (4 marks)

At top of ⊙ $F_N = F_c - F_g$ ✓

If apparently weightless $F_N = 0$ ✓

∴ All F_c provided by gravity

∴ $F_c = F_g$

$\frac{mv^2}{r} = mg$ ✓

$V = \sqrt{rg} = \sqrt{35 \times 9.8}$

$= 18.5 ms^{-1}$ ✓

(c) Explain what would happen to the passenger if the speed were greater that that calculated in (b) and no seat belts were worn. (4 marks)

In order to travel in a circle there must be a F_c present. ✓

Also, the greater the speed the greater the F_c needed; $F_c = \frac{mv^2}{r}$ ✓

The only force providing the F_c is the force of gravity ✓

If this is not sufficient the passenger would continue to travel in a straight ✓(½) line, out of the car, according to Newton's First Law.

✓(½)

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(d) The ride continues and the car and passenger enters a loop of radius 50 m, as shown in Figure 15B. The car and passenger have a mass of 300 kg. The speed at the top of the larger loop is **twice** that calculated in (b) above.

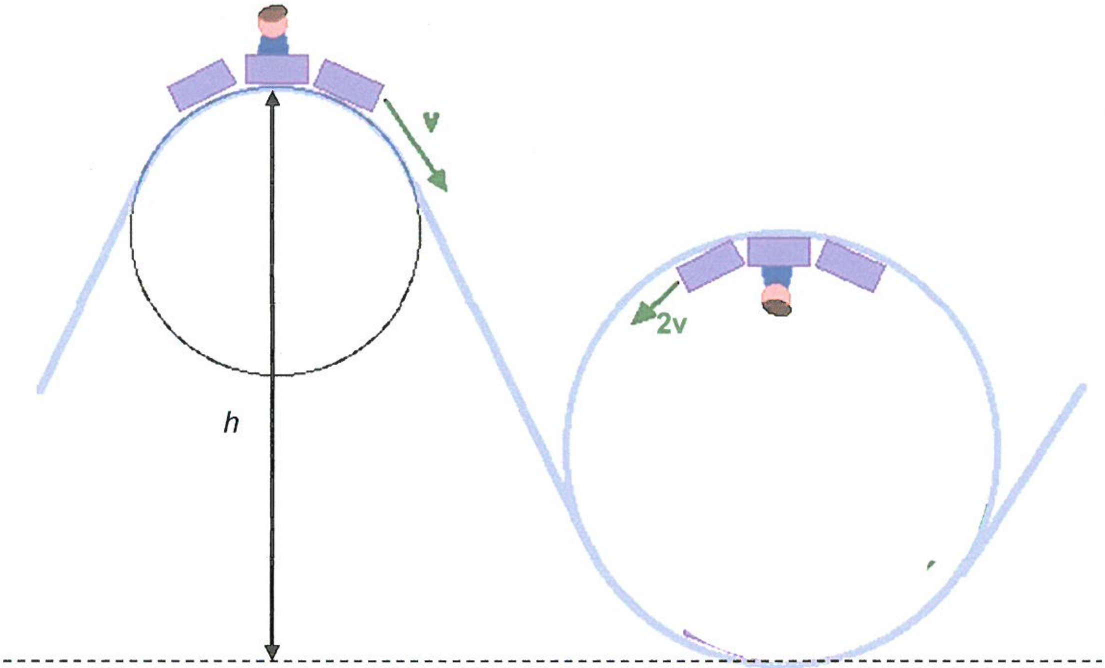

Figure 15B

(i) How large a force must the rail exert when the car and passenger are at the top of the larger loop? [If you were not able to calculate the speed in (b) use 16.0 m s^{-1}.]
(4 marks)

$V = 2 \times 18.5$
$= 37 ms^{-1}$ ✓

$F_N = F_C - F_g$
$= \frac{mv^2}{r} - mg = m\left(\frac{v^2}{r} - 9.8\right)$ ✓
$= 300\left(\frac{37^2}{50} - 9.8\right)$
$= 5274 N$ ✓
$= \underline{5270 N}$ $\underline{\text{down.}}$ ✓ (3sf)

(ii) Calculate the height h required to provide this speed at the top of the larger loop.
(4 marks)

E conserved.

$\frac{1}{2}mv^2 + mgh = \frac{1}{2}mv^2 + mgh$ ✓
$\frac{1}{2}(18.5)^2 + 9.8h = \frac{1}{2}(37)^2 + 9.8 \times (2 \times 50)$ ✓
$9.8h = 1493$ ✓
$\therefore h = \frac{1493}{9.8} = \underline{152.4 m = 152 m}$ ✓ (3sf)

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Question 16 **(12 marks)**

Consider Figure 16. The 2.20 m boom is pivoted at C, is uniform and has a mass of 80.0 kg. The boom is attached to the wall at A with a rope exerting a force of 3.11 kN, as shown.

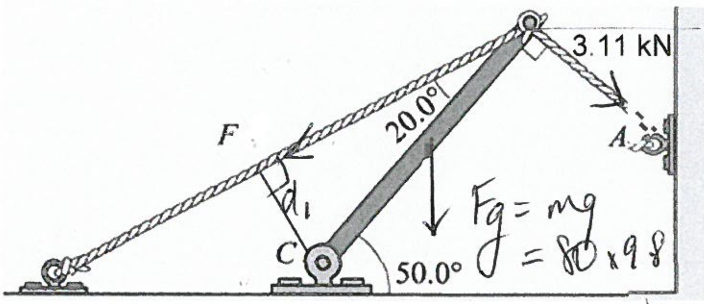


Figure 16. $= 784N$

(a) Determine the tension F. (6 marks)

At equul^m $\Sigma CM = \Sigma ACM$

$F \times d_1 = 784 \times d_2 ✓ + 3110 \times 2.20 ✓$

20°, 2.20m, d_1

$\sin 20° = \frac{d_1}{2.20}$

✓ $d_1 = 0.7524m$

$\therefore F \times 0.7524 = 784 \times 0.7071 + 3110 \times 2.20$

$F = \frac{7396}{0.7524}$ ✓✓

$F = 9830N$

1.1m, 50°, d_2

$d_2 = 1.1 \cos 50°$

✓ $= 0.7071m$

(b) ***Using components***, determine the magnitude and direction of the reaction to the boom at C , (6 marks)

x, $-x$, y, $-y$

x, 40°, y, 3110N

9830, 30°, y, x

x	y	
0	−784	✓
2382	−1999	✓
−8513	−4915	✓
−6131N	−7698N	✓

Vertical Reaction is 7698 ✓

$= 7.70 \times 10^2$ N up ✓

/12

Question 17 **(18 marks)**

(a) What is the current delivered to an electric motor if it has 80 turns of wire wrapped on a rectangular coil, of dimensions 2.5 m by 4.0 m? Assume that the motor provides a maximum torque 6400 Nm when a uniform 0.80 T magnetic field exists within the motor. (4 marks)

$\tau = Fr$

$6400 = BIl \times r$ ✓

$6400 = 0.80 \times I \times (2.5 \times 80) \times \frac{4.0}{2} \times 2$ ✓

$\therefore I = \frac{6400}{640} = \underline{10.0 A\ (3sf)}$ ✓ ✓

(b) Consider Figure 17A which shows the diagram of a simple motor.

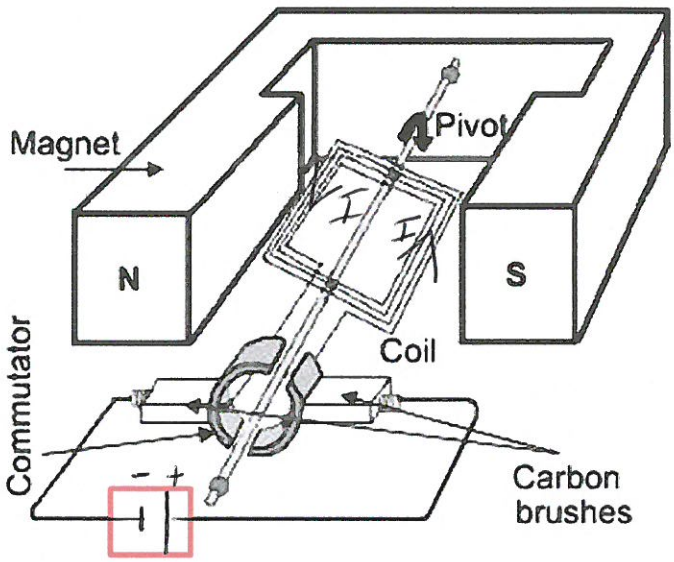


Figure 17A

The coil is rotating clockwise, as viewed from the commutator. On the diagram show the direction of the current flowing in the coil and in the box ▭ show the polarity of the power supply. (2 marks)

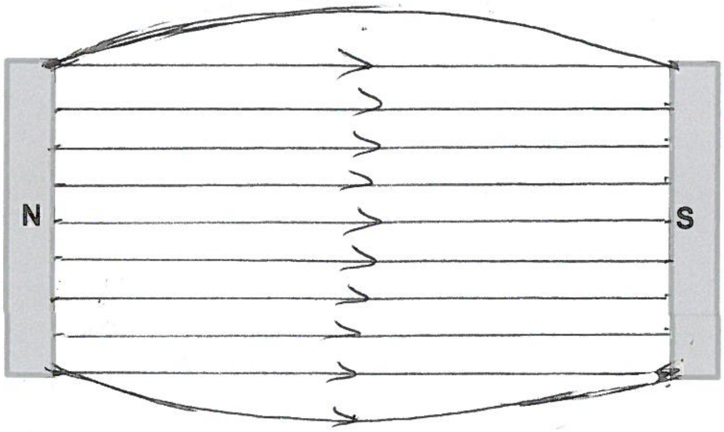
(c) State the function of the split ring commutator of a simple motor. (2 marks)

The function is to reverse the current direction in the coil after it turns 180° so as to maintain the same direction of rotation of coil.

8

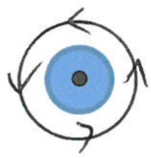
(d) The torque on a motor coil in a magnetic field is due to the nature of simple magnetic field diagrams that give rise to this effect.

(i) Draw the magnet field between two magnets. (2 marks)

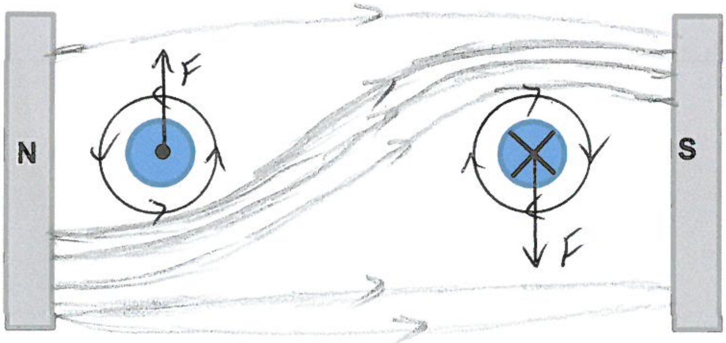


direction ✓
even spacing $(\frac{1}{2})$
end effects $(\frac{1}{2})$

(ii) Draw the field due to a current in the following straight wire. (1 mark)



(iii) Draw the resulting field if they are put together. Show at least 6 lines of magnetic flux. This last field is known as the "catapult" field. Using arrows show direction of the force on each wire due to the magnetic fields. (3 marks)



B fields close to wires ✓$(\frac{1}{2})$
B field between wires ✓✓
Force arrows $(\frac{1}{2})$

6

(e) Consider the following Figure 17B diagram. The coil rotates clockwise in the plane of the page through an angle θ.

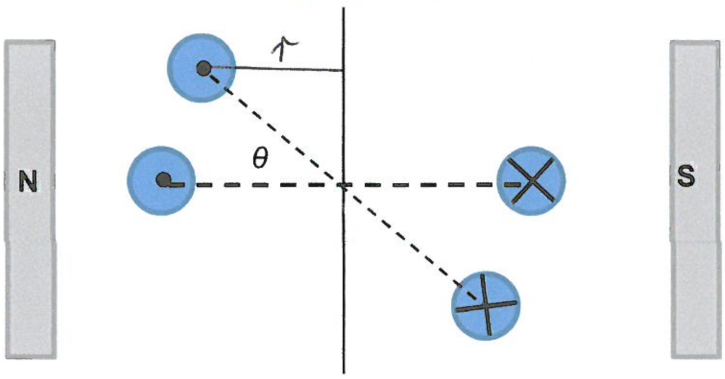
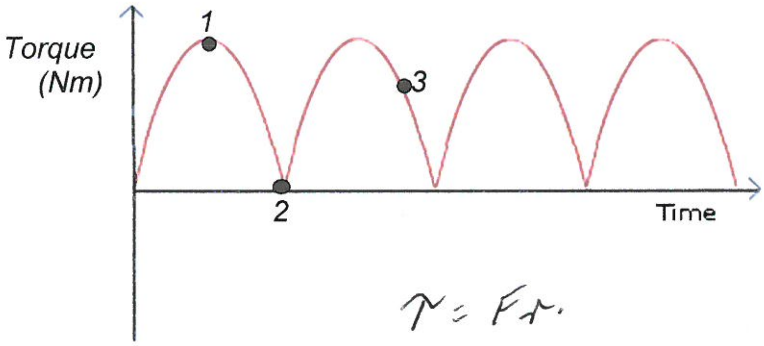


Figure 17B

Use Figure 17B to explain the following graph of the torque for a simple motor, referring in particular to points 1, 2 and 3 on the graph. (4 marks)



$\tau = Fr$.

Point 1. Max torque occurs when $\theta = 90°$.
This gives max $\tau = Fr$ since ✓
F is perpendicular to B and r is maximum
Point 2. Min torque occurs when $\theta = 0°$.
At this time $r = 0$ and $I = 0$ ✓✓
since the position of the coil co-incides
with the split in the commutator.

Point 3. Reduced torque occurs for $0° < \theta < 90°$ ✓
since r is less than maximum.

/4

Question 18 **(22 marks)**

A student is investigating a circuit containing two horizontal conducting parallel plates separated by an insulator or dielectric. The circuit is set up as shown in Figure 18.1.

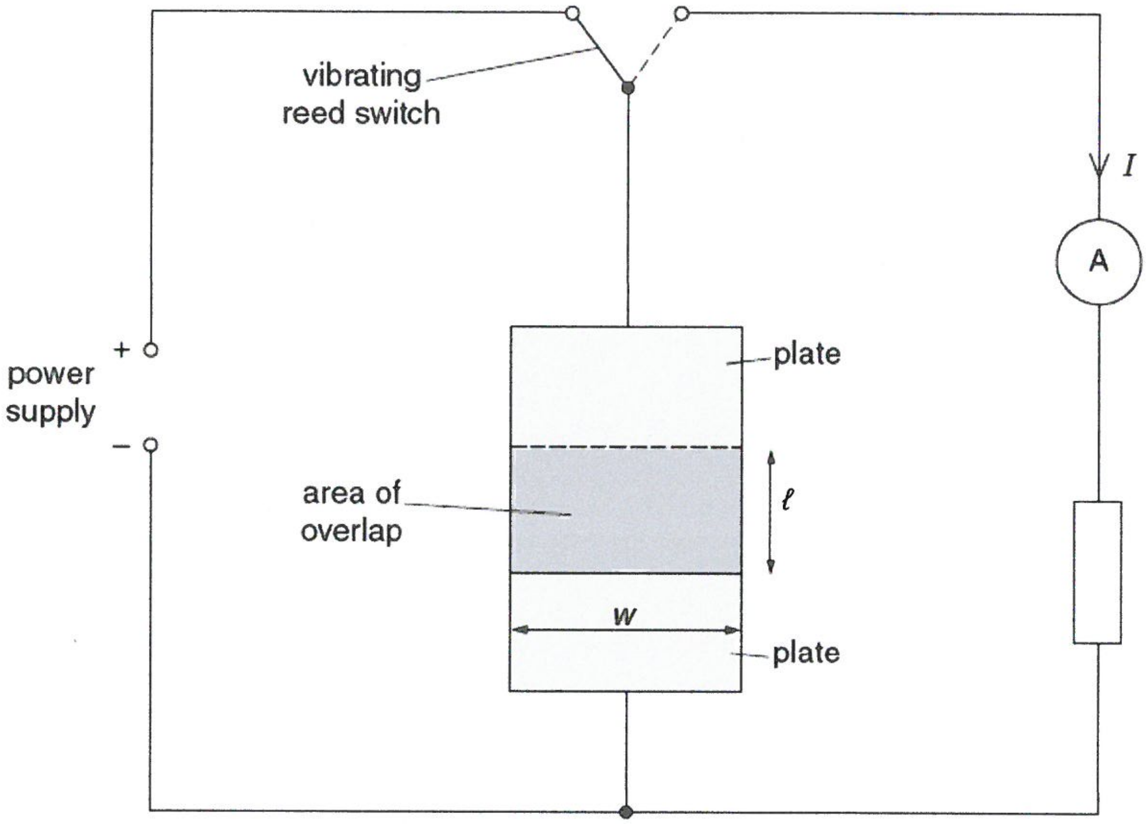


Figure 18.1.

Figure 18.2 shows the construction of the parallel plate assembly.

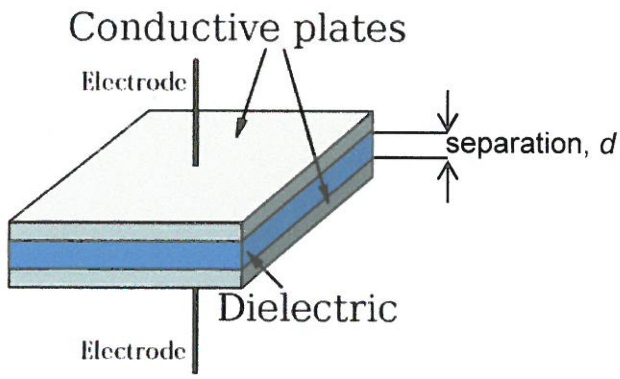


Figure 18.2

An experiment is carried out to investigate how the current I varies with the area X of overlap of the parallel plates. The student measures the length ℓ of overlap. To determine the area X of overlap, the student uses the relationship

$$X = w\ell$$

where w is the width of the plates.

It is suggested that I and X are related by the equation

$$\frac{I}{fX} = \frac{\varepsilon V}{d}$$

where V is the voltage of the power supply, f is the frequency of the vibrating reed switch, d is the separation of the two parallel plates and ε is a constant.

(a) A graph is to be plotted with I on the y-axis against X on the x-axis.

(i) Write the equation with I as the subject of the equation and in the form $y = m\,x$. (1 mark)

$$I = \frac{\varepsilon V f X}{d}$$ ✓

$$I = \frac{\varepsilon V f}{d} X$$ ✓

(ii) Determine an expression for the gradient. (1 mark)

$$\text{gradient} = \frac{\varepsilon V f}{d}$$

(b) **The width w of the plates has a value of 0.300 ± 0.005 m.**

(i) When the length ℓ of the overlap is 0.160 ± 0.005 m calculate the area X of the overlap, including the uncertainty. Express your answer in standard form to the correct significant figures. Show your working clearly. (4 marks)

$$A = l \times w$$
$$= 0.160 \times 0.300$$
$$= 0.048\ m^2$$ ✓

% error: w: $\frac{0.005}{0.300} \times 100 = 1.6\dot{7}\%$

l: $= \frac{0.005}{0.160} \times 100 = 3.1\dot{3}\%$

4.80% ✓

$\therefore A = 0.048 \pm 4.80\%$

$= 0.048 \pm 0.0023$ ✓

$= 0.048 \pm 0.002$ (match dec places)

$\therefore A = (4.80 \pm 0.2) \times 10^{-2}\ m^2$ ✓ ($\frac{1}{2}$)

($\frac{1}{2}$) ↑ 3sf ↑ OK if 2sf used.

6

(ii) More values of ℓ and I are given in Table 18.

ℓ (m)	I (10^{-6} A)	X (10^{-2} m^2)
0.160 ± 0.005	4.6	4.80 ± 0.2 (0.23)
0.180 ± 0.005	5.3	5.40 ± 0.2 (0.24)
0.210 ± 0.005	6.2	6.30 ± 0.3 (0.255)
0.240 ± 0.005	7.1	7.20 ± 0.3 (0.27)
0.270 ± 0.005	8.0	8.10 ± 0.3 (0.285)
0.300 ± 0.005	8.8	9.00 ± 0.3 (0.300)

Calculate and record values of X in Table 18. Include the uncertainties in X.

(2 marks)

(c) (i) Plot a graph of I (10^{-6} A) against X (10^{-2} m^2). Include error bars for X. (3 marks)

(ii) Draw the straight line of best fit on your graph. (2 marks)

(iii) Determine the gradient of the line of best fit. Show your working clearly. (5 marks)

2 points on the line (8.10, 8.0) (6.00, 5.85) ✓

$$\text{grad} = \frac{\text{rise}}{\text{run}} = \frac{(8 - 5.85) \times 10^{-6}}{(8.10 - 6.00) \times 10^{-2}}$$

$$= 1.02 \times 10^{-4}$$ ✓ ✓ ✓ ✓

$$= 1.0 \times 10^{-4}\ \text{A m}^{-2}\ (2\text{sf})$$

(d) (i) ***Using your answers to (a) and (c)(iii),*** determine the value of ε. Include an appropriate unit.

Data: V = 12.0 ± 0.2 V, f = 400 ± 10 Hz and d = 0.0030 ± 0.0002 m.

(4 marks)]

$$\text{grad} = \frac{\varepsilon V f}{d} \qquad \text{A m}^{-2} = \frac{\varepsilon\,(\text{V})(\text{Hz})}{\text{m}}$$

$$1 \times 10^{-4} = \frac{\varepsilon\,(12)(400)}{0.003}$$ ✓

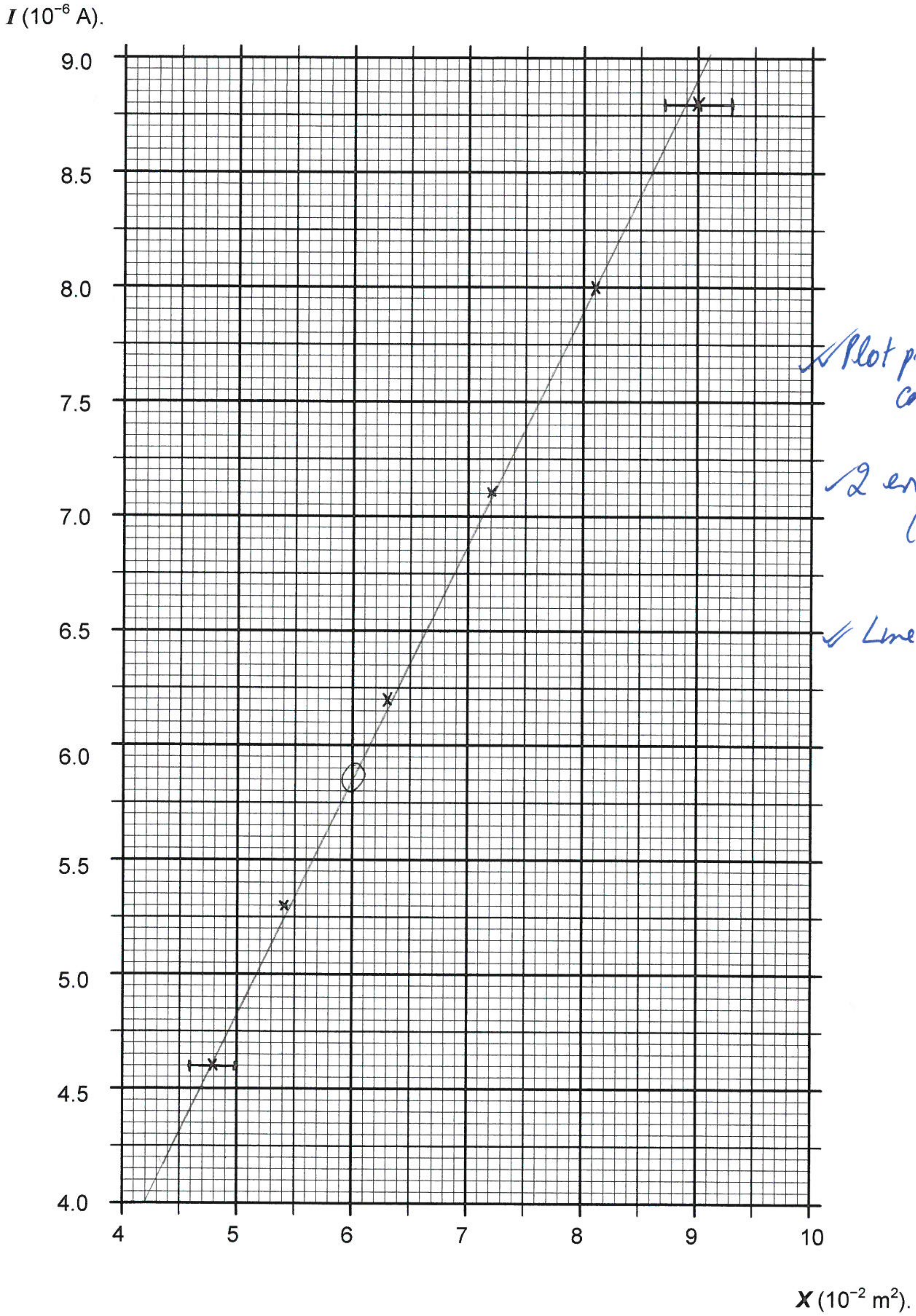
$$\varepsilon = 6.375 \times 10^{-11}\ (2\text{sf})$$ ✓

$$= 6.4 \times 10^{-11}\ \text{A m}^{-1}\ \text{V}^{-1}\ \text{Hz}^{-1}$$ ✓ ✓

(ii) Determine the percentage uncertainty in your value of ε

Cancelled.

16



✓ Plot points carefully

✓ 2 error bars ($\frac{1}{2}$ each)

✓ Line of best fit

SOLUTIONS

SECTION C: Comprehension and Interpretation

Marks Allotted: 20 marks out of 200 marks total.

Read the passage carefully and answer all of the questions at the end. Candidates are reminded of the need for correct English and clear and concise presentation of answers. Diagrams (sketches), equations and/or numerical results should be included where appropriate.

1.

IN SEARCH OF PLANET X

Pluto has lost its status as a planet, after a much-anticipated debate over the inclusion of other possible objects as planets in our solar system. The article below describes the search for these objects.

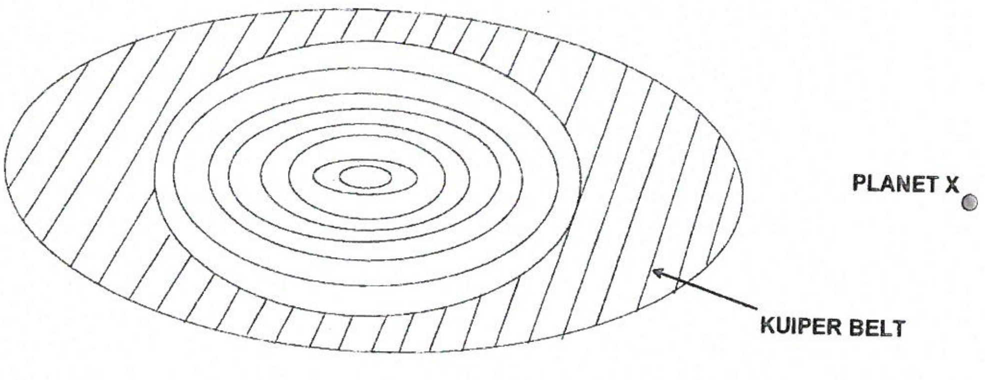
Marc Buie, eminent astronomer, has been studying the solar system beyond Pluto, among the swarm of small worlds called the Kuiper Belt. He has been looking at the very edge, about 50 times further out from the Sun than the Earth's orbit. Here, at the "Kuiper Cliff", the number of astronomical objects drops off dramatically. He speaks of the possibility that some "massive object" has swept the zone clean of debris. (para. 1)

Other astronomers agree that there could be another large planet out there. Just how large has become clearer when computer models of the orbits of nearby objects predicted the kind of celestial object that could carve out the Kuiper Cliff and concluded that a planet about the mass of Mars or Earth would provide "a remarkable match" with the observations. (para. 2)

The last time the idea of a tenth planet created a stir was in 1983, when planetary scientists began to realise that some comets were coming from a region not far beyond Neptune and Pluto. Since 2001, astronomers have discovered four KBOs (Kuiper Belt Objects) bigger than 1 000 kilometres across. Caltech astronomers announced the latest one, fully half the size of Pluto, in October 2001. They have provisionally called it Quaoar, after a native god of the indigenous dwellers of the Los Angeles region. Quaoar is over 1 200 kilometres across and orbits the Sun every 288 years. (para. 3)

As well as containing the key to the origin of life, the Kuiper Belt, and Pluto in particular, may hold the key to how planets form. Studying the craters on both Pluto and its moon Charon, for example, will reveal how KBOs have collided over billions of years and provide clues to the way all the planets formed from smaller objects. (para. 4)

Pluto is only 2320 kilometres across, one-fifth the size of Earth. And the 1978 discovery that it is circled by a moon Charon, whose diameter is 1270 kilometres, makes it even more distinct from the other planets we know about. Pluto and Charon make up a 'twin planet' - the only example in the solar system. (para. 5)



In 2000, NASA scrapped its own Pluto-Kuiper Express mission on the grounds of expense. Under intense public pressure, it held a competition for universities and industry to design a cheaper, better mission. From this was born the New Horizons space probe, due for launch in December 2006. The mission's lead scientist calculates that New Horizons will return 10 times more data than the cancelled Pluto-Kuiper Express, and at little more than half the cost. (para. 6)

Just over a year after the New Horizons' launch, it will swing past Jupiter and pick up enough velocity to reach Pluto, possibly as early as July 2015. Indeed, by the time New Horizons reaches the Kuiper Belt, we may have confirmed that a new planet exists. Because of its vast distance from Earth, the only way we'll find out for sure is to visit this new frontier of the solar system and get a closer look. (para. 7)

QUESTIONS:

1. How is it possible that some "massive object" can sweep the zone clean of debris? (3 marks)

$$F = \frac{GM_p m}{r^2}$$

- If the mass of the planet is large, the force of gravity is large. (1)

∴ It attracts the smaller objects to itself, clearing the area. (1)

- As the mass of the planet increases, so does the force of gravity and the effect increases. (1)

2. Calculate the radius of the orbit of Quaoar about the Sun. (4 marks)

$$r^3 = \frac{GM_s T^2}{4\pi^2} \quad (1)$$

$$= \frac{(6.67\times10^{-11})(1.99\times10^{30})(288\times365\times24\times3.60\times10^{3})^2}{4\pi^2} \quad (2)$$

$$\Rightarrow \underline{r = 6.52\times10^{12}\text{ m}} \quad (1)$$

[Note: Some students may use 1 year = 365.25 days]

3. If it is assumed that Quaoar is rocky and has the same density as the Earth, compare the mass of Quaoar with that of the Earth.

[density = mass / volume and $V_{sphere} = 4/3\ \pi\ r^3$] (4 marks)

$$D_Q = D_E$$

$$\Rightarrow \frac{m_Q}{V_Q} = \frac{m_E}{V_E} \quad (1)$$

$$\therefore \frac{m_Q}{m_E} = \frac{\frac{4}{3}\pi r_Q^3}{\frac{4}{3}\pi r_E^3} \quad (1)$$

$$= \frac{(6.00 \times 10^5)^3}{(6.37 \times 10^6)^3} \quad (1)$$

$$= \underline{8.36 \times 10^{-4}} \quad (1)$$

4. If the distance between the centres of Pluto and Charon is about 21 000 km and the mass of Charon is about one-sixth that of Pluto, determine the position of the centre of mass of the Pluto – Charon system, about which they both rotate. (2 marks)

$m_{Pluto} : m_{Charon}$

$\Rightarrow\ 6 : 1$

. Centre of mass is $\frac{6}{7}$ × distance from Charon. (1)

ie. $\frac{6}{7} \times \frac{21000}{1}$

= <u>18,000 km from Charon</u> (1)

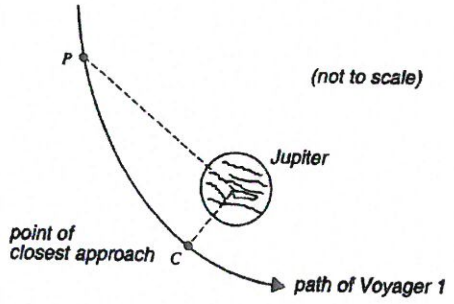
(3,000 km from Pluto)

5. (a) What property of Jupiter makes it ideal to use in the 'sling-shot' effect? (2 marks)

• Has a very large mass. (1)

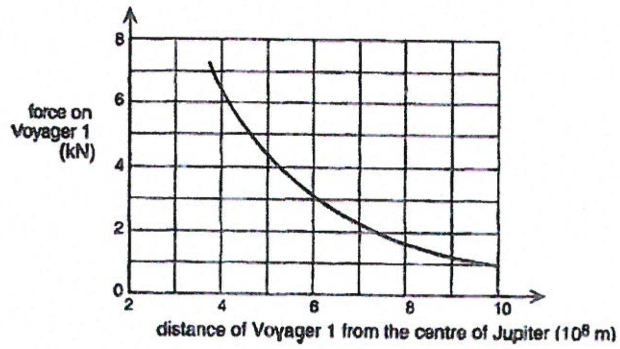
∴ Very large gravitational attraction. (1)

(b) The Voyager 1 spacecraft, which also used the 'sling-shot' effect in 1979 when it travelled past Jupiter with its engines off, is shown in the following diagram.



As Voyager 1 moved from point P to point C, the kinetic energy changed by 4.0×10^{11} J. At point C, the point of closest approach, the force attracting the spacecraft to Jupiter was 6.4×10^3 N.

The graph following shows how the force that attracted Voyager 1 depended on the distance from the centre of Jupiter.



(i) Explain ***how*** you would use the information above to determine the distance of point P from the centre of Jupiter. (A numerical answer is ***not*** required.)

(3 marks)

- Use the area under the graph. (1)
- Start at $F = 6{\cdot}4 \times 10^3$ N (y-axis) (1)
- Calculate the distance required to give an area $= 4{\cdot}0 \times 10^{11}$ J (1)

(ii) Briefly explain why the answer to (i) above cannot be obtained using the standard formulae to calculate work.

(2 marks)

- $W = Fs$ requires F to be constant. (1)
- The graph shows that F changes. (1)

2.

The Cyclotron

A cyclotron is a device for accelerating charged particles to high energies, generally for the purpose of allowing them to collide with atomic nuclei in a target to cause a nuclear reaction. Many present day cyclotrons are located in hospitals, where the nuclear reactions produce short-lived radioactive pharmaceuticals for use in medical diagnosis or treatment. (para. 1)

This article describes some of the Physics behind the operation of a cyclotron.

To understand how a cyclotron works, first you have to understand two basic points about electric and magnetic fields and their effects on charged particles.

1. When a charged particle is in an electric field it feels a force that accelerates it in the direction of the field (or in the direction opposite to that direction if it is a negatively charged particle). If this force is in the direction that the particle is already traveling then clearly this acceleration speeds up its motion and thus adds energy (and this is what we want our accelerator to do).

2. When a charged particle is moving through a magnetic field region it feels a force that is perpendicular to its direction of motion (and also perpendicular to the magnetic field). Such a force makes the particle change direction but does not change its speed. This means that in a large enough region of magnetic field the particle will travel in a circle. The size of the circle depends on the speed of the particle and the strength of the magnetic field. (para. 2)

Now how can we use these two facts to design an accelerator - a cyclotron is one example. We make the region of magnetic field by having a pair of large flat magnets, one above the other, with opposite poles facing, so there is magnetic field pointing down from the lower magnet towards the upper one. We arrange two such regions, each one D-shaped (when looked at from above) with the straight sides of the two D's facing one another (i.e. one D is backwards). Now we have a place where a moving electric charge (or rather a bunch of such charges) goes around half a circle in one D, then goes straight ahead till it reaches the other D, and makes another semicircle in that one, and so on. (para. 3)

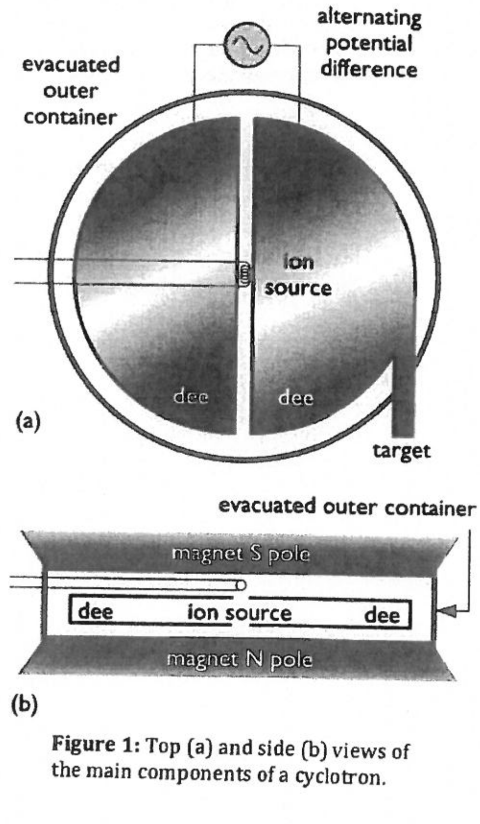


Figure 1: Top (a) and side (b) views of the main components of a cyclotron.

So now what we have to do is arrange to have an electric field turn on in the right direction (and at the right time) to give the charges a bit of a push each time they cross the gap between the two D's. You can see that the electric field has to reverse its direction while the charge is going around the semicircle inside the D, so that when the charges cross the gap again in the opposite direction they are again accelerated a little. (para. 4)

You also need to build a chamber that you can evacuate to very low air pressure in the entire region where your charged particles are traveling -- between the two pairs of D-shaped magnets and in the gap between them. This is because you will keep losing your accelerated particles if they collide with air molecules, so you want as little air (or anything else) as possible inside your accelerator. (para. 5)

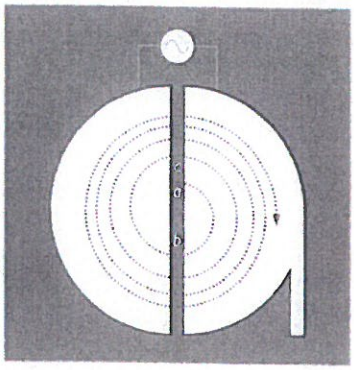


Figure 2: A uniform magnetic field causes the ions in a cyclotron to move in semicircular paths within each dee. The radius increases at each gap due to the increase in speed of the ions.

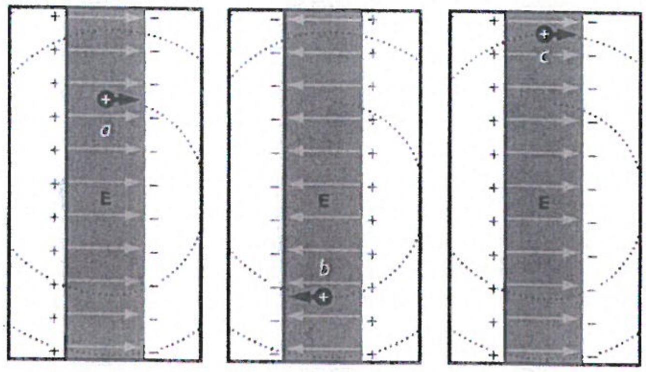


Figure 3: The alternating potential difference between the dees produces an electric field **E** that continually reverses direction. If the ions always arrive at the gap when the field is in the correct direction, they are accelerated each time they cross the gap.

Because the particle is speeding up each time it crosses from one D to the other it travels in a spiral path with increasing radius. So the limit on what energy you can get with such a machine is given by the size of the D-shaped magnets, and the vacuum-chamber between them. This limitation makes it very expensive to build a high energy cyclotron and so modern high energy circular accelerators are built using a different design, known as a synchrotron.

(para. 6)

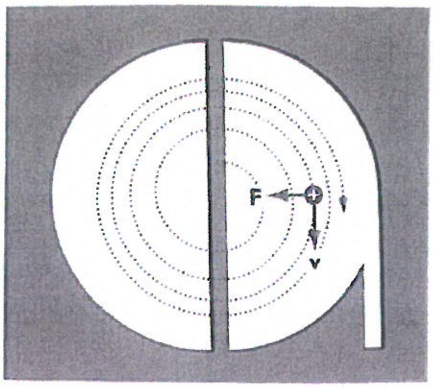


Figure 4: A positive ion moving in a circular arc as shown experiences a net force toward the centre of its path. This force is provided by a uniform magnetic field.

The basic physics principle is the same, you use magnets to make the particle go in a circle, and regions with electric field in them (usually radio frequency or microwave cavities) to accelerate the particles. You make the vacuum chamber a tube that goes in a circle. Then you must adjust the magnet strength (these are electromagnets) as the particles speed up to keep the same radius for their circular path. There is a limited range of energy over which this can be achieved, so if you look for example at the Fermilab accelerator, you can see they have a series of rings of increasing radius and then feed the particles from a smaller ring to a larger one once they reach the highest energy that can be made to circulate in the small ring. (para. 7)

Questions

1. Figure 1 shows that an AC current is used to provide the potential difference between the dees of the cyclotron. Why can't a DC current be used?

(2 marks)

- Current must reverse direction so that the particle is accelerated as it passes between the dees.
- If DC is used, the particle would accelerate in one direction and decelerate in the other.

2. Why does the radius of curvature of the charged particle in a cyclotron keep increasing? (paragraph 6)

$r = \frac{mv}{qB}$

(2 marks)

- $r \propto v$ (1)
- As v increases, r will increase. (1)

3. Explain how a synchrotron differs from a cyclotron? (paragraphs 6 and 7)

(2 marks)

SYNCHROTRON - magnetic field strength increases so the centripetal force applied keeps the particles in a constant radius. (1)

CYCLOTRON - the radius of curvature increases until the particle exits. (1)

4. Figure 4 shows a positive ion moving in a circular arc. In which direction is the magnetic field? Circle the correct word(s).

(2 marks)

To the left	**To the right**	**Up**
Down	**Into the page**	**Out of the page** (2)

5. A deuteron is an isotope of hydrogen with symbol $^{2}_{1}H$ and a single ion has a mass of 3.34×10^{-27} kg and is singly charged. In one cyclotron experiment, a magnetic field of 1.50 T is used and deuterons were extracted at a radius of 25.0 cm. What was the speed of the deuterons when they were extracted?

(3 marks)

$$r = \frac{mv}{qB}$$

$$\Rightarrow \quad v = \frac{rqB}{m} \quad (1)$$

$$= \frac{(0.250)(1.60 \times 10^{-19})(1.50)}{(3.34 \times 10^{-27})} \quad (1)$$

$$= \underline{1.80 \times 10^{7}\ ms^{-1}} \quad (1)$$

6. An early cyclotron had a dee diameter of 24.0 cm and the oscillating electric field had a frequency of 10.6 MHz .

(a) If the frequency of the circular motion of the ions is the same as the electric field, determine the period of the ion's circular motion.

(2 marks)

$$T = \frac{1}{f}$$

$$= \frac{1}{10.6 \times 10^{6}} \quad (1)$$

$$= \underline{9.43 \times 10^{-8}\ s} \quad (1)$$

(b) What magnetic field would be required to achieve this period for a proton? (Hint: a proton is singly charged and its mass is given in the data sheet.)

(5 marks)

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

$$= \frac{2\pi(0.240)}{9.43 \times 10^{-8}} \quad (1)$$

$$= 1.60 \times 10^{7}\ ms^{-1} \quad (1)$$

$$r = \frac{mv}{qB}$$

$$\Rightarrow \quad B = \frac{mv}{qr} \quad (1)$$

$$= \frac{(1.67 \times 10^{-27})(1.60 \times 10^{7})}{(1.60 \times 10^{-19})(0.240)} \quad (1)$$

$$= 0.696\ T \quad (1)$$

(c) How would your answer to (b) have differed for a larger cyclotron?

(2 marks)

- From $B = \frac{mv}{qr}$, $B \propto \frac{1}{r}$ (1)
- As r would be larger, B must be smaller. (1)

END OF EXAMINATION