## Section A

Answer **all** the questions in this section.

**1** An object is launched at a speed of 30 m s$^{-1}$ with an angle of 60° from the ground as shown in Fig. 1.1. Ignore air resistance.

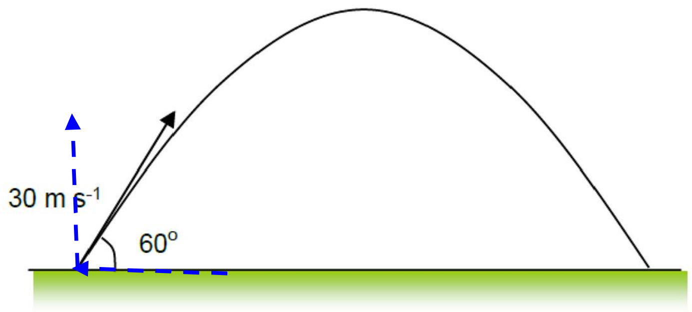



**Fig 1.1**

**(a)** Show the time taken for the object to reach its maximum height is 2.65 s. [1]

Consider vertical motion:

$u_y = 30 \, sin \, sin \, 60$ (upwards), $a = 9.81$ (downwards), $v_y = 0$ at maximum height

Using $v_y = u_y + at$, taking upwards positive:

$$0 = 30 \, sin \, sin \, 60 + (-9.81)t$$

$t = \frac{30 sinsin \, 60}{9.81} = 2.648 \approx 2.65$ s (shown)

**(b)** Calculate the time taken for the object to hit the ground.

Time taken = 2 × 2.65 = 5.30 s

time = ………………… s [1]

**(c)** Hence or otherwise, calculate the horizontal distance travelled by the object from the point of launch to the point it first hits the ground.

Consider horizontal motion:

$s_x = (u \, cos \, cos \, \theta) \times t = (30 \, cos \, cos \, 60) \times 5.30 = 79.5$ or 80 m

horizontal distance = ………………… m [2]

**[Turn over**

| | | |
|---|---|---|
| | **(d)** | On Fig. 1.2 below, sketch the variation with time *t* of the vertical component of the velocity $v_y$ from the time it leaves the ground to the time it hits the ground. [2] |

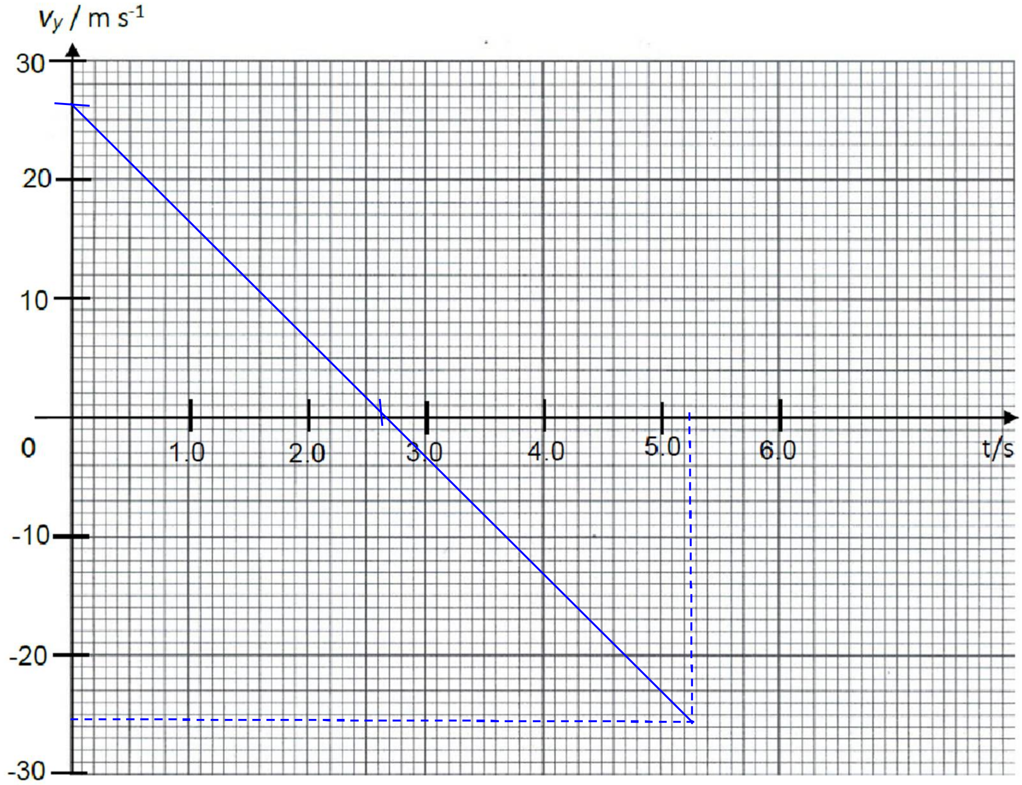



**Fig. 1.2**

Straight line negative gradient (1 mark)

Start at (0, 26) and end at (5.3, -26) (1 mark)

| | | | |
|---|---|---|---|
| | **(e)** | On Fig. 1.3, sketch | |
| | | **(i)** | the variation of the horizontal component of the velocity with time of the object for the duration of time in flight. Label this line **A**. [1]<br>Horizontal speed $(u_x) = 30 \cos\cos 60 = 15$ m s$^{-1}$ is constant. |
| | | **(ii)** | the variation of the horizontal component of the velocity with time of the object for the duration of time in flight if air resistance is not negligible. Label this line **B**. [1]<br>Horizontal speed decreases from 15 m s$^{-1}$ to zero in a time of less than 5.3 s. |

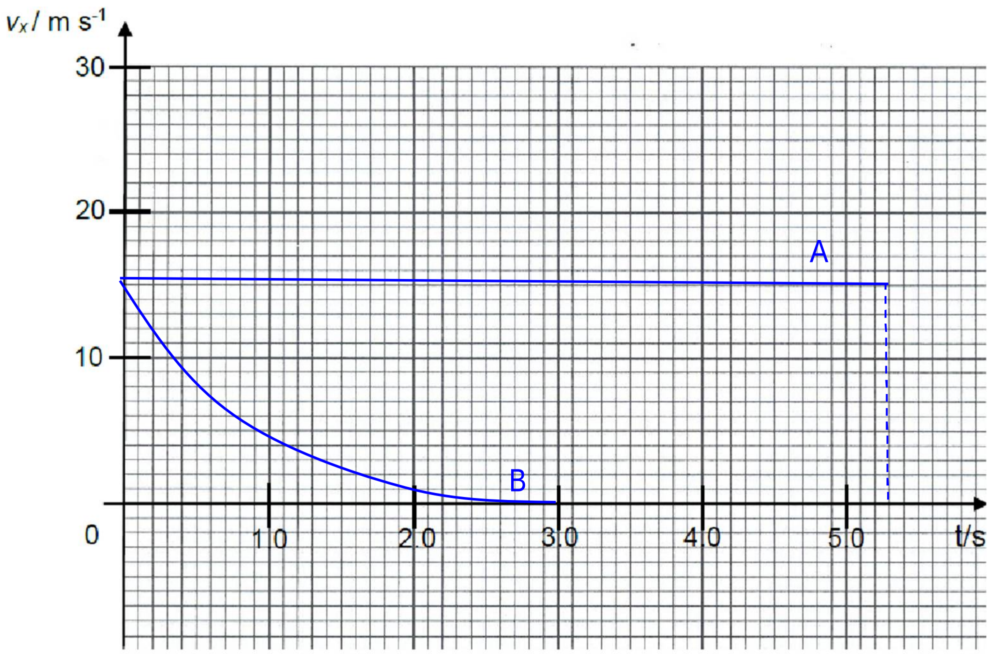



**Fig. 1.3**

In the presence of air resistance, horizontally net force = $-kv$ where $k$ is a constant

$ma = -kv$ ® $a = -\left(\frac{k}{m}\right)v$ ® gradient of curve B = acceleration □ proportional to $-v$

[Total: 8]

**2** An aeroplane of mass 1.5 x $10^5$ kg moves horizontally with constant velocity. The forces exerted on the aeroplane are as shown in the **Fig. 2.1** below.

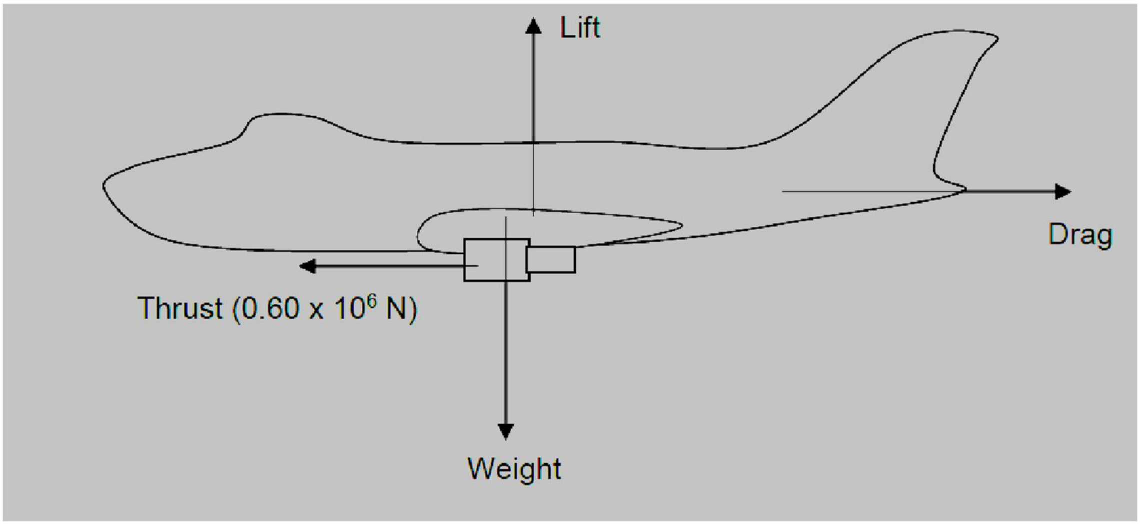



**Fig. 2.1**

**(a)** Calculate the values of the lift and the drag.

Moves horizontally ® vertical forces are balanced, hence
Lift = weight = 1.5 x $10^5$ x 9.81 = 1.47 x $10^6$ N

Moves horizontally with constant velocity ® horizontal forces are also balance, hence
Drag = Thrust = 0.60 x $10^6$ N

Lift = ……….…………. N [1]

Drag = ……….…………. N [1]

**(b)** **(i)** Define *torque of a couple*.

The product of one force in the couple and the perpendicular distance between the two forces in the couple.

[1]

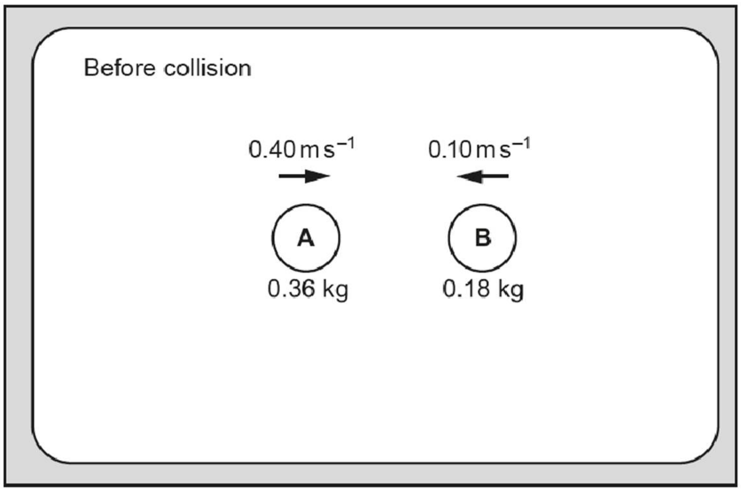
**(iv)** The horizontal separation of the lines of action of lift and weight is 0.80 m. Using your answer to **(ii)** and **(iii)**, determine the vertical separation of the lines of action of the thrust and drag.

Refer to Fig. 2.1. The lift and weight are equal in magnitude, opposite in direction and acting at two different points so these two forces formed a couple. The torque is anti-clockwise.

Torque due to lift and weight = 1.47 x $10^6$ x 0.80

Since the aeroplane is not rotating, the torque due to thrust and drag must be clockwise and same magnitude as the torque due to lift and weight.

| | | | |
|---|---|---|---|
| | | | $(0.60 \times 10^6)(y) = 1.47 \times 10^6 \times 0.80$ ® $y = \frac{1.47}{0.60} \times 0.80 = 1.96$ H 2.0 m |

| | | | |
|---|---|---|---|
| **3** | **(a)** | State the principle of conservation of linear momentum.<br>In the absence of a resultant external force acting on a system of interacting objects, the total momentum of the system is constant. | |
| | **(b)** | Fig. 3.1 shows two discs, **A** and **B**, on a frictionless table collide head-on. Disc **A** has a mass of 0.36 kg and disc **B** has a mass of 0.18 kg. Before colliding, disc **A** has a velocity of 0.40 m s$^{1}$ and disc **B** a velocity of 0.10 m s$^{-1}$ in the opposite direction. On colliding they stick together.<br><br><br>**Fig. 3.1**<br>Calculate | |
| | | **(i)** | the velocity of the discs after the collision.<br>From momentum conservation and taking velocity to the right as positive:<br>(0.36)(0.40) + (0.18)(□0.10) = (0.36 + 0.18)(v)<br>v = 0.233 m s$^{-1}$<br>velocity = ……0.233…… m s$^{-1}$ [2]<br>direction = ……rightwards…… [1] |
| | | **(ii)** | the kinetic energy lost during the collision expressed as a percentage of the initial kinetic energy of the two discs.<br>Total kinetic energy before collision = $\frac{1}{2}(0.36)(0.40)^2 + \frac{1}{2}(0.18)(0.10)^2 = 0.029\ 7$<br>Total kinetic energy after collision = $\frac{1}{2}(0.36 + 0.18)(0.233)^2 = 0.014\ 658$ |

| | | | |
|---|---|---|---|
| | | | Percentage lost = $\frac{(0.0297-0.014658)}{0.0297}$ × 100% = 51% <br> [3] <br> [Total: 8] |
| **4** | A company rents out tower cranes of many different sizes. <br><br> A tower crane is illustrated in Fig. 4.1. This type of tower crane is called a flat-top tower crane because the jib and counter jib are horizontal. <br><br> A crane can be constructed to different arrangements of height, jib and counter-jib length, and balancing load. <br><br> The size of the base can be varied to cope with different maximum loads lifted by the crane. <br><br> Note: The masses of the loads in Fig. 4.1 and in Table 4.1 are given in tonnes (t). One tonne is 1000 kg. | | |

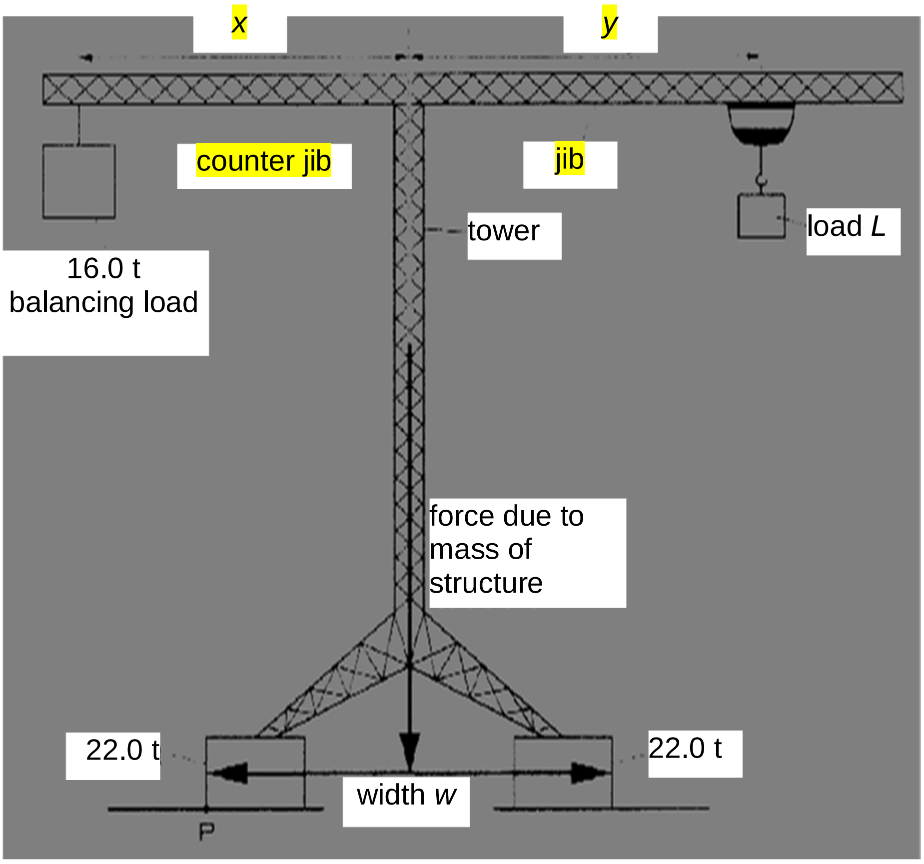



**Fig. 4.1**

Distance *x* is the fixed distance. This is a different distance for each different crane arrangement.

Distance *y* is variable and changes as the load *L* is moved in and out from the tower, along the jib.

Table 4.1 lists information for four different crane arrangements.

The maximum load $L$ in tonnes that can be lifted for different distances $y$ from the centre of the tower for each arrangement is also shown.

**Table 4.1**

| crane arrangement | total length of jib and counter jib / m | distance $x$ to 16.0 t balancing load / m | Maximum load $L$ at different distances $y$ / t | | |
|---|---|---|---|---|---|
| | | | y = 30 m | y = 52 m | y = 75 m |
| A | 95.0 | 17.3 | 8.48 | 4.31 | 2.60 |
| B | 75.0 | 19.4 | 9.79 | 5.15 | – |
| C | 75.0 | 21.1 | 10.81 | 5.77 | – |
| D | 55.0 | 22.3 | 11.53 | – | – |

**(a)** **(i)** Calculate the weight of the 16.0 t balancing load.

Weight = 16.0 x 1000 x 9.81 = 1.57 x $10^5$ N

weight = ……………………… unit ……….. [2]

**(ii)** Using the data in Table 4.1, explain why there is no detail provided for crane D when $y$ = 52 m.

Referring to Fig 4.1 and the data for crane D in table 4.1,
Maximum value of y H 55.0 □ 22.3 = 32.7 m. Hence, no data for y = 52 m [1]

**(b)** **(i)** Show, for crane A, that the load and the balancing load given in the table can never put the crane into equilibrium.

Taking moments about the mid-point of the tower:

Anti-clockwise moment due to 16.0 t balancing load = 1.57 x $10^5$ x 17.3 = 2.72 x $10^6$ Nm

When y = 30 m, clockwise moment due to load = (8.48)(1000)(9.81)(30) = 2.50 x $10^6$ Nm

When y = 52 m, clockwise moment due to load = (4.31)(1000)(9.81)(52) = 2.20 x $10^6$ Nm

When y = 75 m, clockwise moment due to load = (2.60)(1000)(9.81)(75) = 1.91 x $10^6$ Nm

Clockwise moment due to the load is always less than anticlockwise moment due to the balancing load, hence the two loads cannot put the crane into equilibrium.

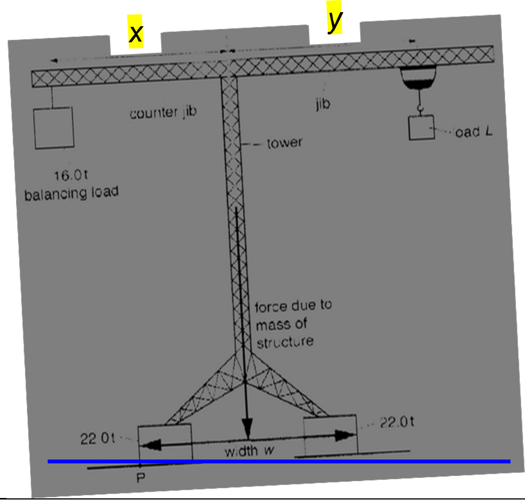
[3]

| | | | |
|---|---|---|---|
| | | | |

**(ii)** When in use, crane A is in equilibrium. Suggest how this is achieved.

The weight of the crane structure and the weight of the 22.0 t base will provide the necessary moment to keep the crane in equilibrium.

[2]



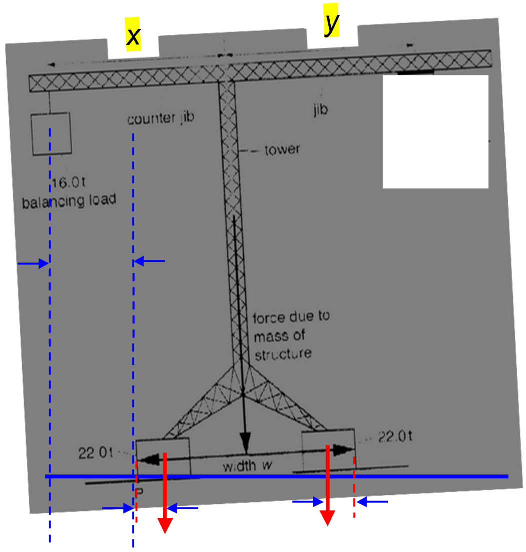

**(c)** The width *w* of the base of a crane is important in providing stability.

For crane C, the foundations of the base are two identical large cubic concrete masses, each of mass 22.0 t. These masses are firmly attached to the crane.

The total mass of the crane structure is 17.0 t and the force due to the mass of the crane acts through the centre of the legs.

The balancing load is 16.0 t and is 21.1 m from the centre of the tower.

By taking moments about point P in Fig. 4.1, determine, for zero load, the minimum possible value of *w* before the right hand concrete mass lifts from the ground.




Let the width of the concrete mass be $d$

Taking moments about P:

$$(16.0)(\cancel{1000})(\cancel{9.81})\left(21.1-\frac{w}{2}\right) = (22.0)(\cancel{1000})(\cancel{9.81})\left(\frac{d}{2}\right) + (17.0)(\cancel{1000})(\cancel{9.81})\left(\frac{w}{2}\right)$$

$$\cancel{+}\ \cancel{(22.0)}(1000)(9.81)\left(w-\frac{d}{2}\right)$$

| | | | |
|---|---|---|---|
| | | $(16.0)(21.1) - (16.0)\left(\frac{w}{2}\right) =$ ~~$(22.0)\left(\frac{x}{2}\right)$~~ $+ (17.0)\left(\frac{w}{2}\right) + (22.0)(w) -$ ~~$(22.0)\left(\frac{x}{2}\right)$~~<br><br>$(16.0)(21.1) = (17.0)\left(\frac{w}{2}\right) + (22.0)(w) + (16.0)\left(\frac{w}{2}\right) = w\left(\frac{17}{2} + 22 + \frac{16}{2}\right)$<br><br>$w = 8.77$ m<br><br>minimum value of *w* = ………………….. m [3] | |
| **(d)** | **(i)** | A motor on the crane lifts a load from the ground into position.<br><br>The motor needs to lift a load of 12000 kg a distance of 80 m.<br><br>Suggest a suitable time period for the duration of the lift and hence make a calculation to estimate the output power of the motor.<br><br>Suggested time = ……500…………….. s Lifting speed H 10 to 100 cm $s^{-1}$<br><br>Output power = $\frac{Gain\ in\ gpe}{time} = \frac{mgh}{t} = \frac{12{,}000 \times 9.81 \times 80}{500}$ = 20,000 W (1 sig. fig.)<br><br>output power = ………………………….. W [3] | |
| | **(ii)** | The efficiency of the motor is 65%. Calculate the electrical power input required for your answer to **(d)(i)**.<br><br>Output power = 0.65 x Input power<br><br>Input power = $\frac{20{,}000}{0.65}$ = 31,000 W<br><br>Power input = ……………………….. W [2]<br><br>[Total: 16] | |

**5** **(a)** Fig. 5.1 shows a drum of a top-loading washing machine that spins around a vertical axis.

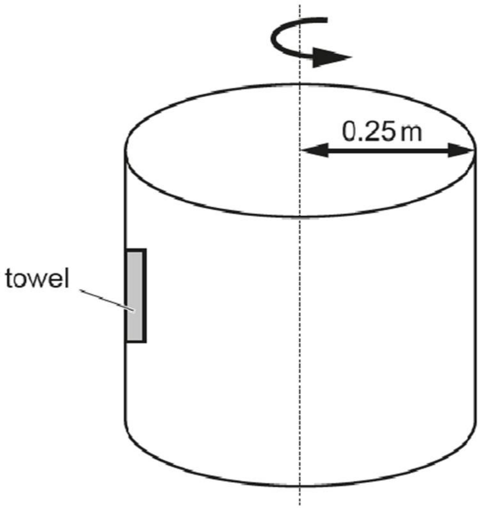



**Fig. 5.1**

The drum has a radius of 0.25 m and spins at a rate of 1200 revolutions per minute.

Determine the centripetal force on a damp towel, of mass 0.80 kg, on the inner wall of the drum.

One revolution = 2□ radians ® 1200 revolutions per min = $\frac{1200\times 2\pi}{60}$ rad $s^{-1}$

Centripetal force = mass x centripetal acceleration = $mr\omega^2$ = 0.80 × 0.25 × $\left(\frac{1200\times 2\pi}{60}\right)^2$

= 3158 H 3200 N

centripetal force = …………….. N [2]

**(b)** Fig. 5.2 shows the drum of a front-loading washing machine, which also has a radius of 0.25 m and spins about a horizontal axis at the same rate of 1200 revolutions per minute.

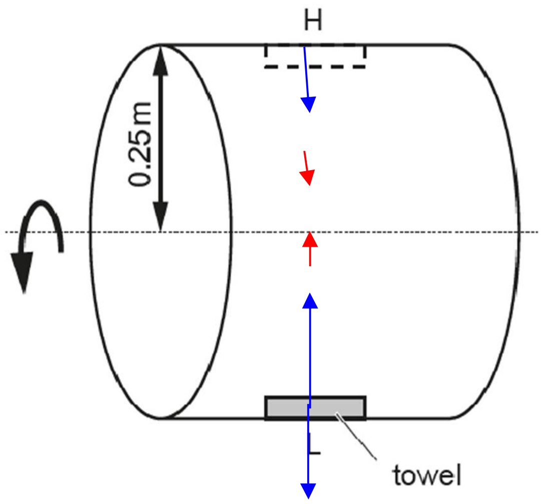



**Fig. 5.2**

By considering the forces on the towel, determine the normal contact force exerted by the wall of the drum on the towel, of mass 0.80 kg, when the towel is at its:

**(i)** lowest point in the rotation (L);

From Newton's 2nd Law: Resultant force = ma

$N - mg = ma$

$N = ma + mg$ = 3158 + (0.80)(9.81) = 3166 H

3200 N

Normal contact force = ……………. N [2]

**(ii)** Highest point in the rotation (H).

From Newton's 2nd Law: Resultant force = ma

$N + mg = ma$

$N = ma - mg$ = 3158 – (0.80)(9.81) = 3150 H

3200 N

Normal contact force = ……………. N [2]

[Total: 6]

**6** **(a)** Fig. 6.1 shows a circuit with a network of resistors.

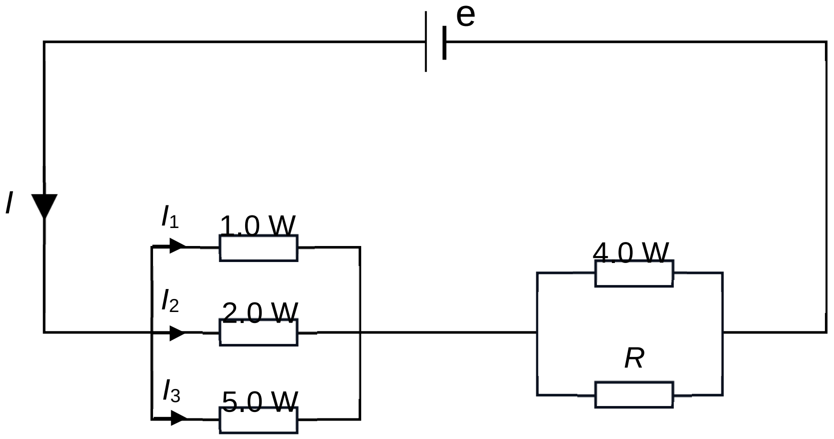



**Fig. 6.1**

The current from the cell is *I*.

**(i)** Determine the ratio of the currents $I_1 : I_2 : I_3$.

From $V = IR$, $I = \frac{V}{R}$ hence $I \propto \frac{1}{R}$

Ratio = 1 : 0.5 : 0.2 or 10 : 5 : 2

$I_1 : I_2 : I_3$ = …………………………………… [2]

**(ii)** $1.0 \times 10^{-3}$ mol of electrons flowed through the 4.0 ∧ resistor in a time interval of 320 s. During this time interval,

**1.** Show that the total charge that flowed through the 4.0 ∧ resistor is 96 C.

$Q = Ne = 1.0 \times 10^{-3} \times 6.02 \times 10^{23} \times 1.6 \times 10^{-19} = 96.32 \approx 96$ C (shown)

[1]

**2.** Show that the electrical energy dissipated in the 4.0 ∧ resistor is approximately 115 J.

Current through the resistor: $I = \frac{Q}{t} = \frac{96}{320} = 0.30$ A M[1]

Energy dissipated = Power x time

$= I^2Rt = (0.30)^2(4.0)(320)$ M[1]

$= 115.2 \approx 115$ J

[2]

**3.** The current through the 4.0 ∧ resistor is three times the current through resistor *R*. Determine *R*.

Let the current through $R$ be $I$

Current through the 4.0 ∧ resistor = $3I$

Since R and 4.0 ∧ are in parallel, they have the same p.d.

$IR = (3I)(4.0)$ ® $R = 12$ ∧

[2]

**(b)** Fig. 6.2 shows a circuit in which a non-ohmic device X is connected in series with a 20 ∧ resistor. The cell has e.m.f. 6.0 V and negligible internal resistance.

Fig 6.3 shows the I-V characteristics of X and the 20 ∧ resistor.

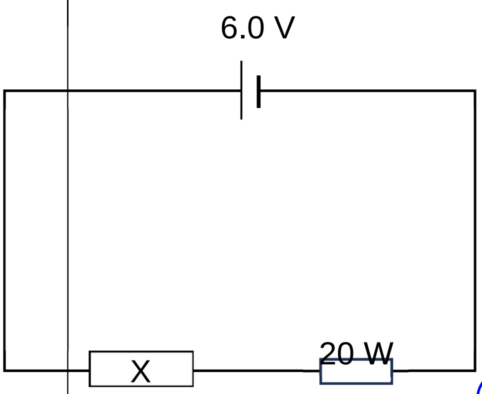



**Fig. 6.2**

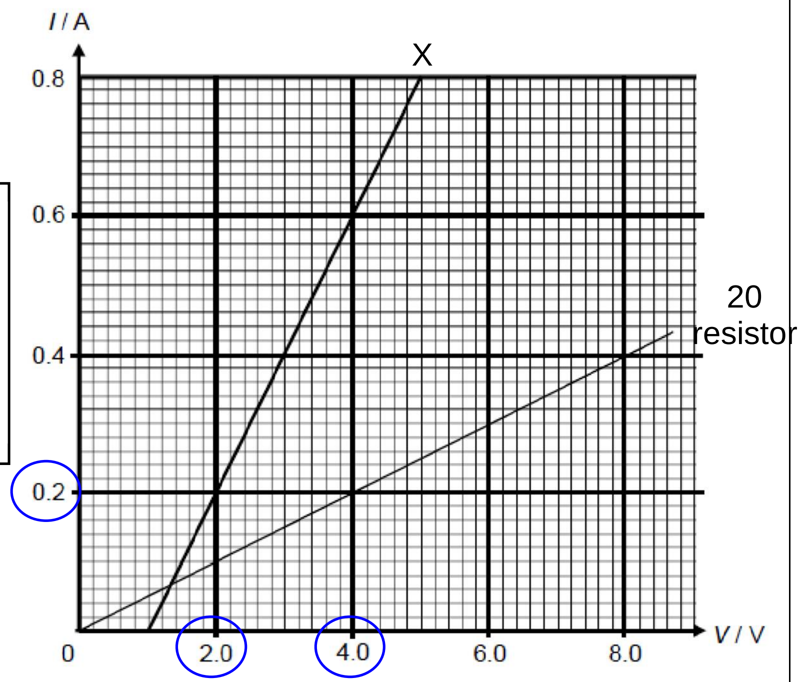



**Fig. 6.3**

**(ii)** Determine the current in the circuit.

In series, so same current. And p.d. across X + p.d. across 20 ∧ must = emf = 6.0

current = ……………0.20………………… A [1]

**(iii)**

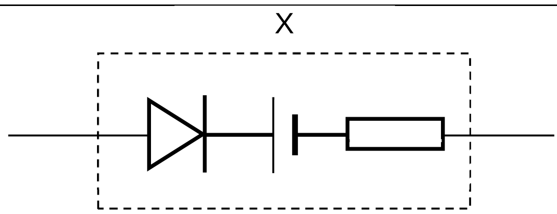



**Fig. 6.4**

e.m.f. = 1 V because diode starts to conduct when $V_X$ ε 1.0 V

resistance = …………. ∧ [1]

Choose any point on graph X: ($V_X$ = 2.0 V and I = 0.20 A)

| | | | |
|---|---|---|---|
| | | | $V_X$ = 1.0 + (0.20)$R$ = 2.0 ® $R$ = 5.0 ^ |

| | | | |
|---|---|---|---|
| **7** | **(a)** | A student performs an experiment to determine the half-life of a radioactive isotope. | |
| | | **(i)** | Define *half-life*.<br><br>It is the time taken for half the number of nuclide/isotope present in a sample to decay.<br><br>* nuclide refers to a particular species of nuclei. |
| | | **(ii)** | A radiation detector is used to determine the background radiation. The total radiation count in 10.0 minutes with no radioactive source present is found to be 2400 counts.<br><br>Determine the background count rate.<br><br>Background count rate = $\frac{2400}{10 \times 60}$ = 4.00 $s^{-1}$ (background count is constant)<br><br>background count rate = ……………………….. $s^{-1}$ [1] |
| | | **(iii)** | A sample of the radioactive source is placed close to the radiation detector. The count rate is determined once every hour.<br><br>The count rate *A*, corrected for background radiation, is recorded in Table 7.1.<br><br>**Table 7.1**<br><br>(see table below)<br><br>Determine the uncorrected count rate for *t* = 2.00 hours.<br><br>Uncorrected count rate = 264 + 4 = 268 $s^{-1}$.<br><br>count rate = …………………… $s^{-1}$ [1] |

**Table 7.1**

| *t* / hours | *A* / $s^{-1}$ | ln (*A* / $s^{-1}$) |
|---|---|---|
| 0.00 | 296 | 5.690 |
| 1.00 | 279 | 5.631 |
| 2.00 | 264 | 5.576 |
| 3.00 | 249 | 5.517 |
| 4.00 | 235 | 5.460 |

**(b)** Fig. 7.1 shows a graph of the data in Table 7.1

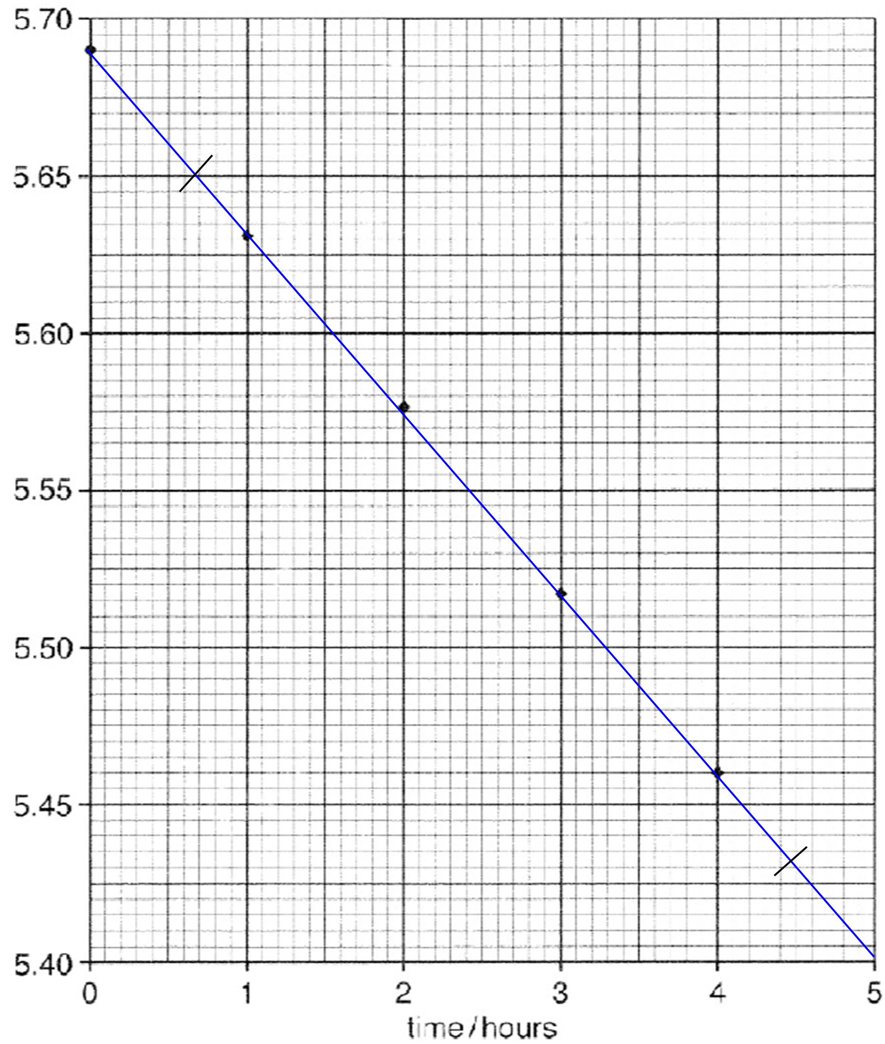



**Fig. 7.1**

**(i)** Add a line of best fit to the graph in Fig. 7.1.
[1]

**(ii)** The corrected count rate *A* is related to the time *t* by the equation

$$ln\, ln\, (A\ /\ s^{-1})\ =\ -\frac{0.693}{\tau}t + k$$

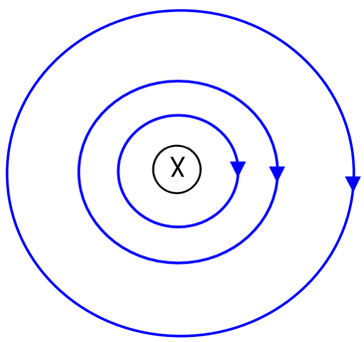
where $\tau$ is the half-life and *k* is a constant.

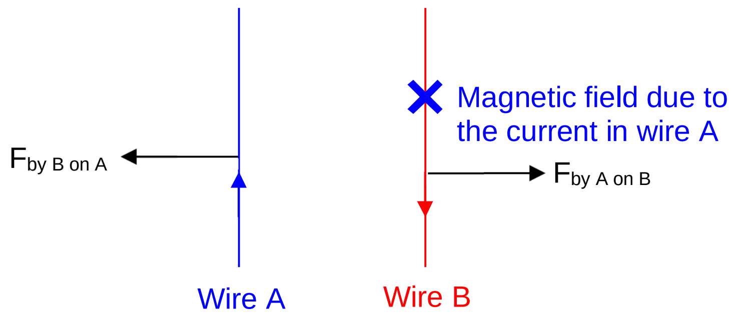
Use the graph to calculate a value for the half-life of the radioactive source.

| | | | |
|---|---|---|---|
| | | | Gradient = $\frac{5.65-5.43}{0.7-4.5} = -\frac{0.693}{\tau}$ Gradient coordinates must be as far apart as possible<br><br>$\tau$ = 11.97 ≈ 12.0 hours Do not use a plotted point as a gradient coordinate.<br><br>half-life = …………………….. hours [3]<br><br>[Total: 7] |

**Section B**

Answer **one** question from this section.

| | | | |
|---|---|---|---|
| **8** | **(a)** | Sketch three magnetic field lines due to a long straight current carrying wire. Indicate clearly the direction of the magnetic field. | |
| | | Top view<br>(Current flowing into the paper)<br><br>Circular (use compass to draw) with increasing separation.<br>Arrow points clockwise (according to Right Hand Grip rule) | [2] |
| | | | |
| | **(b)** | Two long straight parallel wires are separated by a distance *d*. Each carries current *I* in the opposite directions. Explain the origin of the forces which exist between the two wires and predict the directions of the forces. | |




There is a magnetic field associated with each current in the wire.

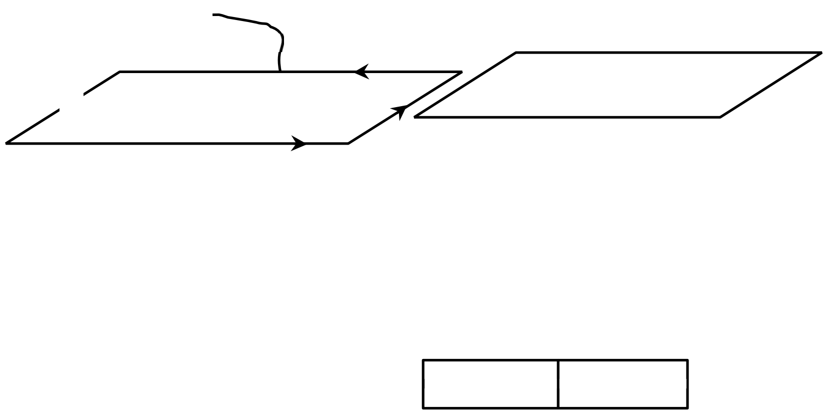
The magnetic fields due to the two currents may interact to produce a force between the wires or a current in the presence of an external magnetic field may experience a force exerted by the external magnetic field on it.

Magnetic field along wire B due to the current in wire A is directed into the page based on the Right Hand Grip rule.

The force, $F_{\text{by A on B}}$ exerted by this field on the current in wire B is towards the right according to Fleming Left Hand rule.

From Newton's 3rd law, the force $F_{\text{by B on A}}$ exerted by B on A is in the opposite direction (towards the left).

**(c)** In an experiment to determine the magnetic flux density due to a magnet, a wire frame ABCD supported on two knife edges P and Q is placed horizontally next to the magnet as shown in Fig. 8.1. Sides BC and AD are 5.0 cm and sides AB and DC are 8.0 cm. P and Q are at the midpoints of AB and DC respectively. When there is no current in the circuit, the frame is balanced horizontally.



A
D

B
C
Q
P
to battery
to battery
*I*
*I*
S
N
S
N
D
C
side view
**Fig. 8.1**
Q
*I*

**(i)** When there is a current flowing as shown in Fig 8.1, state the directions of the magnetic force, if any, on

1. side QC,

No force (because the current is parallel to the field ie. F = BILsin0° = 0) [1]

2. side BC.

Downwards (from Fleming's Left Hand rule) [1]

**(ii)** A mass of 21.0 g has to be placed on side AD to balance the wire frame when the current is 2.0 A. Determine the magnetic flux density experienced by side BC.

Sum moments about the pivot QP:

$$mg \times \left(\frac{4.0}{100}\right) = (BIL)\left(\frac{4.0}{100}\right)$$

$B = \frac{mg}{IL} = \frac{21.0\times10^{-3}\times9.81}{2.0\times0.05} = 2.06$ T

magnetic flux density = ............................. T [3]

**(d)** There are two situations in which a charged particle in a magnetic field does not experience a magnetic force.

State these two situations. Recall: Magnetic force on a charged particle in a B field: $F = Bqv \sin \sin \theta$

| | | | |
|---|---|---|---|
| | | **1.** | Particle is stationary ($v$ = 0) |
| | | **2.** | Particle is moving parallel to the magnetic field ($sin\ sin\ \theta$ = 0) |

**(e)** Fig 8.2 shows a cyclotron comprising two D-shaped hollow metal conductors, known as the *dees*, separated by a very narrow gap.

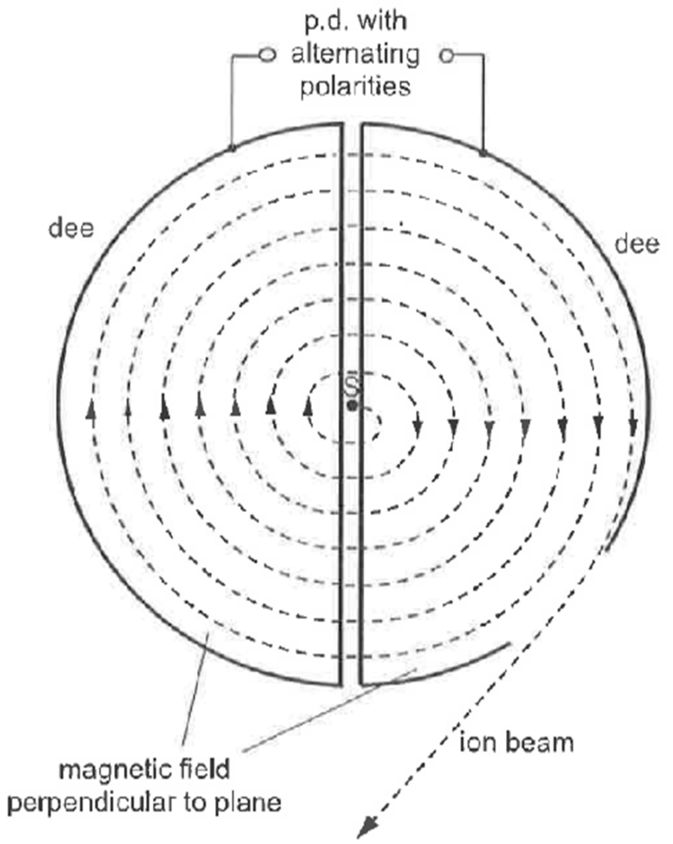



**Fig. 8.2**

Ions of mass $m$ and charge $q$, are emitted from the source S. They maintain nearly circular paths due to the uniform magnetic field of flux density $B$ in the *dees*.

Each time the ions enter the gap between the *dees*, they are accelerated by a constant potential difference (p.d.) applied between the *dees*. The polarity of the p.d. across the *dees* change every half cycle so that the ions are always accelerated when they cross the gap.

After many revolutions, the ions acquire high kinetic energy and exit the outer edge of the cyclotron.

| | | | |
|---|---|---|---|
| | | **(i)** | A small cyclotron is used to accelerate a proton of mass $m$ and charge $q$. |

**1.** By considering the magnetic force acting on the proton moving within the *dees*, show that the time $T$ taken by the proton to complete one revolution is given by the expression

$$T = \frac{2\pi m}{qB}$$

where $B$ is the magnitude of the magnetic flux density in the *dees*. You may use the expression $a = v\omega$ for the centripetal acceleration where $v$ is the linear speed and $\omega$ is the angular speed of the proton.

Resultant force on the proton is just the magnetic force (weight = mg of the proton is negligible compared to the magnetic force).

From Newton's 2nd law, resultant force = ma where a = centripetal acceleration

$$Bqv = m(v\omega)$$

$Bq = m(\omega) = m\left(\frac{2\pi}{T}\right)$ since angular speed, $\omega = \frac{2\pi}{T}$

Period, $T = \frac{2\pi m}{qB}$ (shown)

[2]

**2.** The magnetic flux density in the *dees* is 1.7 T.

Determine the frequency for the changing polarity of the p.d.

Frequency, $f = \frac{1}{T} = \frac{qB}{2\pi m} = \frac{1.6\times10^{-19}\times1.7}{2\pi\times1.67\times10^{-27}} = 2.6 \times 10^{7}$ Hz

frequency = ……………… Hz [1]

**(ii)** The proton exiting the cyclotron is moving in a circular path of radius 0.25 m.

Show that the kinetic energy of the proton is $1.4 \times 10^{-12}$ J. k.e. $= \frac{1}{2}mv^2 = \frac{p^2}{2m}$

From Newton's 2nd law, resultant force on proton = ma

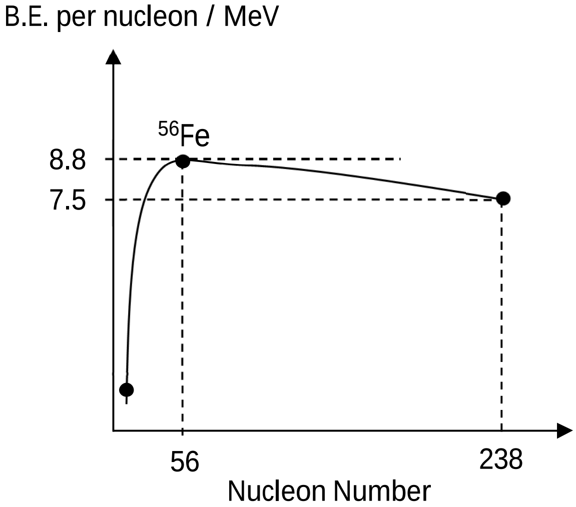
$Bqv = m\left(\frac{v^2}{r}\right)$ ® $mv = Bqr = (1.7)(1.6 \times 10^{-19})(0.25) = 6.8 \times 10^{-20}$

Kinetic energy $= \frac{1}{2}mv^2 = \left(\frac{mv^2}{2}\right)\left(\frac{m}{m}\right) = \frac{(mv)^2}{2m} = \frac{\left(6.8\times10^{-20}\right)^2}{2\times1.67\times10^{-27}} = 1.38 \times 10^{-12} \approx 1.4 \times 10^{-12}$ (shown)

[2]

**(iii)** The proton starts from rest at the centre of the cyclotron and complete 100 revolutions before it exits from the cyclotron.

| | | | | |
|---|---|---|---|---|
| | | | **1.** | Calculate the kinetic energy gained for each revolution.<br><br>Kinetic energy gained per revolution = $\frac{1.4\times10^{-12}}{100}$ = 1.4 × $10^{-14}$ J<br><br>Kinetic energy gained for each revolution = …………………….. J [1] |
| | | | **2.** | For each revolution, the proton crosses the gap between the *dees* twice and hence it is accelerated twice by the p.d. *V* across the gap. The kinetic energy gained each time it crosses the gap is given by *qV* where *q* is the charge on the proton.<br><br>Determine the p.d. applied across the *dees* as the proton crosses the gap between them.<br><br>Proton crosses a gap twice in each revolution.<br><br>Hence, $2qV$ = 1.4 × $10^{-14}$<br><br>$V = \frac{1.4\times10^{-14}}{2\times1.6\times10^{-19}}$ = 43,750 ≈ 44,000 V<br><br>*V* = …………………… V [2]<br><br>[Total: 20] |

| | | | |
|---|---|---|---|
| **9** | **(a)** | | V and X are different isotopes of helium.<br><br>State one similarity and one difference between a nucleus of V and a nucleus of X.<br><br>Similarity: They have the same number of protons. [1]<br><br>Difference: They have different number of neutrons. [1] |
| | **(b)** | **(i)** | The nuclear binding energy per nucleon varies with nucleon number.<br><br>On Fig 9.1, draw a graph showing this variation for nuclei with nucleon number from 1 to 250. Label the axes with appropriate values.<br>[3]<br><br><br><br>**Fig. 9.1** |
| | | **(ii)** | Explain the significance of the nuclear binding energy per nucleon for nuclear fusion.<br><br>When two very light nuclides with very low binding energy per nucleon fuses to produce a heavier nuclide with a higher binding energy per nucleon, energy is released in the process. The amount of energy released in each reaction is equal to the difference in total binding energy between the products and the reactants.<br><br>[2]<br><br>*nuclide refers to a particular nuclear species. |

**(c)** A $24He$ nucleus is formed in this nuclear reaction:

$$12H + 23He \rightarrow 24He + Y$$

**(i)** State **three** quantities that are conserved in all nuclear reactions.

1. Proton Number (or electric charge)

2. Nucleon Number

3. Total relativistic energy

4. Total momentum

**(ii)** Identify particle Y.

Y is a proton.

[1]

**(iii)** Explain, in terms of mass, why this nuclear reaction occurs.

The total rest mass of the reactants ($12H + 23He$) is larger than the total rest mass of the products ($24He + Y$). This reaction will result in a release of energy and hence it occurs.

[1]

**(iv)** Calculate the amount of energy released in the nuclear reaction.

mass of $12H$ is 2.0141 u

mass of $23He$ is 3.0160 u

mass of $24He$ is 4.0026 u

mass of Y is 1.0078 u

Total rest mass of reactants = $2.0141u + 3.0160u = 5.0301u$

Total rest mass of products = $4.0026u + 1.0078u = 5.0104u$

Difference in mass = $5.0301u - 5.0104u = 0.0197u$

Energy released = $0.0197uc^2 = (0.0197)(1.66 \times 10^{-27})(3 \times 10^8)^2$
$= 2.94 \times 10^{-12}$ J

energy released = ………………… J [3]

**(v)** Calculate the number of $23He$ nuclei which must each fuse with a $12H$ nucleus per second in order to emit energy at a rate of 20.0 W.

In one second, we need 20.0 J of energy.

Number of reactions needed in one second = $\frac{20.0}{2.94\times10^{-12}}$ = $6.80 \times 10^{12}$

Hence, number of $23He$ nuclei needed = $6.80 \times 10^{12}$ $s^{-1}$

Number = ................................ $s^{-1}$ [2]

**(vi)** In a house, there are fifteen lamps which consume electrical energy at a rate of 20.0 W each. The lamps are only switched on in the evenings.

Estimate the mass of $23He$ that is required in order for this reaction to release the same amount of energy as the lamps in the house consume in one year.

State any assumption made.

Assumption: Lamps are switched on for 5 hours every evening.

Total energy consumed by 15 lamps in one year = 15 x 20 x 365 x 5 x 60 x 60
= $1.971 \times 10^{9}$ J

Number of $23He$ nuclei required = $\frac{1.971\times10^{9}}{2.94\times10^{-12}}$ = $6.70 \times 10^{20}$

Mass of $23He$ required = $6.70 \times 10^{20} \times 3 \times 1.66 \times 10^{-27} = 3.34 \times 10^{-6}$ kg

mass = ........................ kg [3]

[Total: 20]