SERANGOON JUNIOR COLLEGE
General Certificate of Education Advanced Level
Higher 2

NAME			
CG		**INDEX NO.**	

PHYSICS **9646**
Preliminary Examination
Paper 3 Longer Structured Questions **2 hours**

Candidates answer on the Question Paper.
No additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and index number in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A
Answer **all** questions.

Section B
Answer any **two** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in bracket [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	
2	
3	
4	
5	
Section B	
6	
7	
8	
Total	

This document consist of **24** printed pages and **no** blank page

DATA AND FORMULAE

Data

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_0	=	8.85×10^{-12} F m^{-1}
			$(1 / (36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	e	=	1.60×10^{-19} C
the Planck constant,	h	=	6.63×10^{-34} J s
unified atomic mass constant,	u	=	1.66×10^{-27} kg
rest mass of electron,	m_e	=	9.11×10^{-31} kg
rest mass of proton,	m_p	=	1.67×10^{-27} kg
molar gas constant,	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant,	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant,	k	=	1.38×10^{-23} J K^{-1}
gravitational constant,	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall,	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion,	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas,	W	=	$p\Delta V$
hydrostatic pressure,	p	=	ρgh
gravitational potential,	ϕ	=	$-\dfrac{Gm}{r}$
displacement of particle in s.h.m.,	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.,	v	=	$v_o \cos \omega t$
	v	=	$\pm \omega \sqrt{(x_0^2 - x^2)}$
resistors in series,	R	=	$R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential,	V	=	$Q / 4\pi\varepsilon_o r$
alternating current/voltage,	x	=	$x_0 \sin \omega t$
transmission coefficient,	T	$\propto$	$\exp(-2kd)$
			where $k = \sqrt{\dfrac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	=	$x_0 \exp(-\lambda t)$
decay constant,	λ	=	$\dfrac{0.693}{t_{\frac{1}{2}}}$

For Examiner's Use

Section A

Answer **all** the questions in this section

1 **(a)** Define *gravitational potential at a point*.

....

....

....[1]

(b) Two masses m_1 and m_2 are placed at positions as shown in the diagram, where m_1 = 25 000 kg and m_2 = 15 000 kg.

(i) Determine the gravitational potential at the origin due to m_1 and m_2 respectively.

$r_1 = \sqrt{3.0^2 + 4.0^2} = 5.0\text{cm}$

$r_2 = \sqrt{18.0^2 + 9.0^2} = 20.12\text{cm}$ [M1]

$\phi = -\dfrac{GM_1}{r_1} = -\dfrac{(6.67\times10^{-11})(25000)}{0.050} = -3.335\times10^{-5}\,\text{Jkg}^{-1}$ [A1]

$\varphi = -\dfrac{GM_2}{r_2} = -\dfrac{(6.67\times10^{-11})(15000)}{0.2012} = -4.973\times10^{-6}\,Jkg^{-1}$ [A1]

gravitational potential due to m_1 = ... J kg^{-1}

gravitational potential due to m_2 = ... J kg^{-1} [3]

For Examiner's Use

(ii) Hence, or otherwise, determine the total gravitational potential energy of a 1000 kg mass placed at the origin.

$\phi_T = -3.335\times10^{-5} + (-4.973\times10^{-6}) = -3.83\times10^{-5}\,\mathrm{Jkg^{-1}}$ [M1]

$U = m\phi = (1000)(-3.83\times10^{-5}) = -3.83\times10^{-2}\,\mathrm{J}$ [A1]

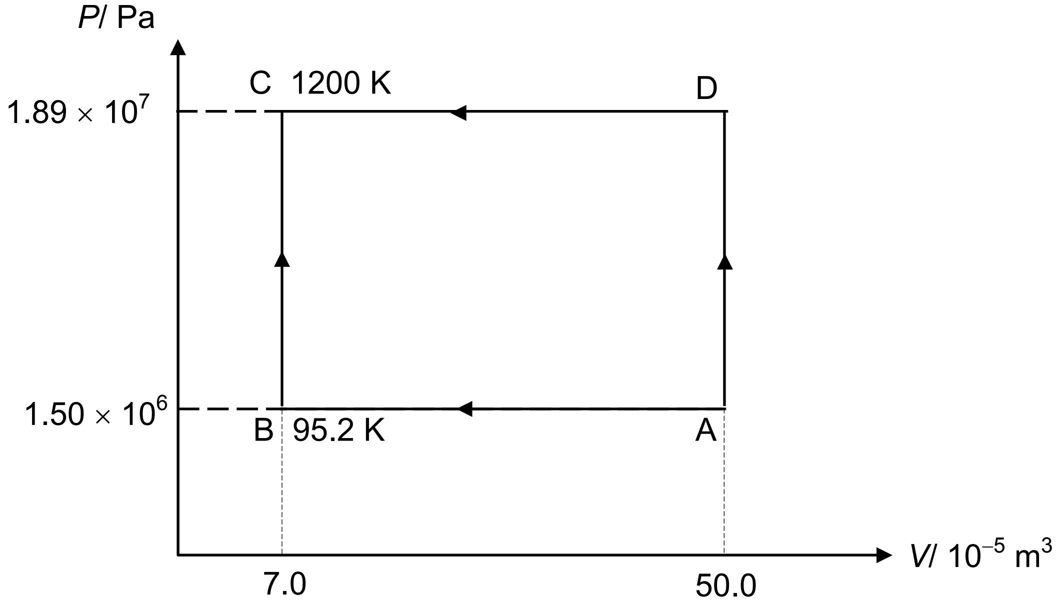
total gravitational potential energy = ... J [2]

(iii) State the work required to move the 1000 kg mass from the origin to infinity.

$W = 3.83\times10^{-2}\,\mathrm{J}$

work done = ... J [1]

2 The figure below shows the variation of pressure with volume for a fixed mass of ideal gas. The gas is taken from state A to state C through two different paths ABC and path ADC.



For Examiner's Use

(a) Calculate the number of moles in the fixed mass of gas.

Consider point C,

$pV = nRT$

$$n = \frac{pV}{RT} = \frac{1.89\times10^{7}\times7.0\times10^{-5}}{8.31\times1200}$$

$= 0.133$ [A1]

number of moles of gas = …………………… [1]

(b) (i) During process BC, the temperature of the gas rises from 95.2 K to 1200 K at constant volume. The molar heat capacity of the gas at constant volume is 12.5 J K^{-1} mol^{-1}. During process AB, 1613 J of thermal energy is lost.

By showing your working clearly, calculate the change in internal energy from A to C.

[Note: Molar heat capacity is the amount of thermal energy required to raise the temperature of a mole of gas by one degree celcius]

$$\Delta U_{AB} = Q_{AB} + W_{AB}$$
$$= -1613 + p\Delta V_{AB}$$
$$= -1613 + 1.5\times10^{6}\left(5.0\times10^{-4} - 7.0\times10^{-5}\right)$$
$$= -1613 + 645$$
$$= -968$$ [M1]

$$\Delta U_{BC} = Q_{BC} + W_{BC}$$
$$= 0.133\times(1200 - 95.2)\times12.5 + 0$$
$$= 1837$$ [M1]

$$\Delta U_{AC} = \Delta U_{AB} + \Delta U_{BC}$$
$$= -968 + 1837$$
$$= 869\text{ J}$$ [A1]

change in internal energy = …………………….. J [3]

(ii) Hence, calculate the thermal energy lost during process ADC.

$$\Delta U_{AC} = Q_{AC} + W_{AC}$$
$$Q_{AC} = \Delta U_{AC} - (W_{AD} + W_{DC})$$
$$= 869 - \left[0 + 1.89\times10^{7}\left(5.0\times10^{-4} - 7.0\times10^{-5}\right)\right] \quad \text{[C1]}$$
$$= 869 - 8127$$
$$= -7260\,\text{J} \quad \text{[A1]}$$

thermal energy lost = …………………….. J [2]

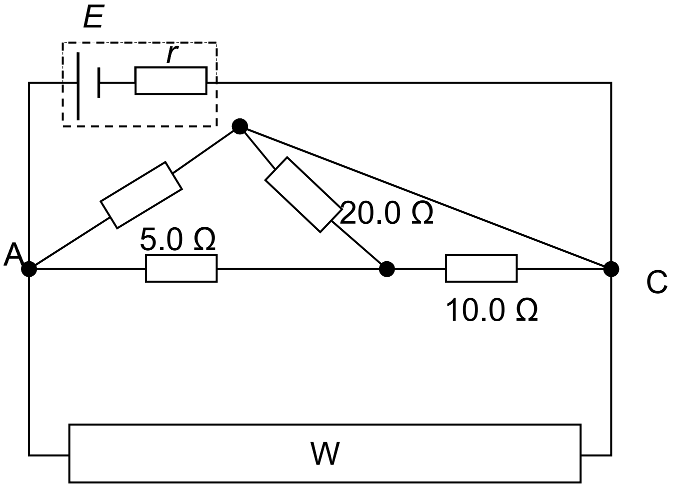
(c) To bring the gas from state A to state C, less heat is needed for process ADC, compared to process ABC. Explain why.

The change in internal energy for both processes are the same as the change in internal energy is independent of the path taken [B1].

Since the work done on the gas for process ADC is higher than that for process ABC, the amount of heat supplied for process ADC is less [B1].

…………………………………………………………………………………… [2]

3 A cell of e.m.f. E with an internal resistance r is connected in an electrical circuit consisting four resistors and a resistance wire W as shown below.



When the current flowing through the cell is 12.0 A, the potential difference across AC is 6.0 V.

(a) 1.875×10^{19} electrons pass through the cell in *t* seconds.

(i) Show that *t* = 0.25 s. [1]

$$I = \frac{Q}{t} = \frac{Ne}{t}$$

$$t = \frac{Ne}{I} = \frac{(1.875 \text{ x } 10^{19})(1.6x10^{-19})}{12} = 0.25s$$

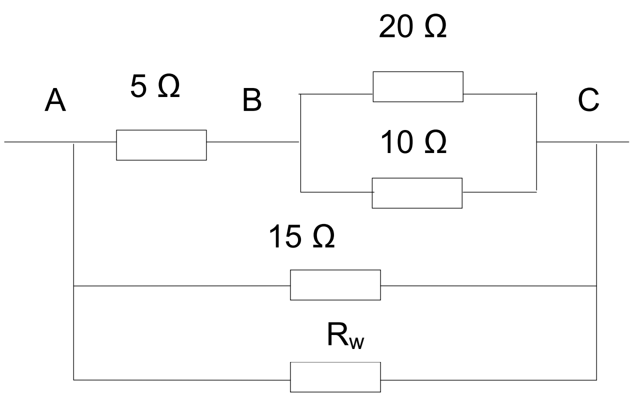
(ii) Calculate the amount of electrical energy converted by the cell between the points A and C during this time period.

$$W = QV = NeV = (1.875x10^{19})(1.6x10^{-19})(6) = 18J$$

energy = ………………….. J [1]

(b) The resistivity of W is 1.36×10^{-5} Ω m, its length is 0.5 m, and its diameter is 4.0×10^{-3} m. Show that the effective resistance across AC due to the four resistors and W is 0.5 Ω.

[3]



Redrawing the circuit to the figure above,

$$R_W = \frac{\rho l}{\pi d^2/4} = \frac{4\rho l}{\pi d^2} = \frac{4(1.36 \times 10^{-5})(0.5)}{\pi (4 \times 10^{-3})^2} = 0.541\Omega \text{ [1]}$$

$$\frac{1}{R_{eff}} = \frac{1}{15} + \frac{1}{0.541} + \frac{1}{5 + \frac{20 \times 10}{20+10}} \Rightarrow R_{eff} = 0.5\Omega \text{ [2]}$$

(c) Calculate,

(i) the potential difference across BC.

For Examiner's Use

By potential divider principle, $V_{BC} = \dfrac{\dfrac{20\times 10}{20+10}}{\dfrac{20\times 10}{20+10}+5}\times 6 = 3.43V$

[M1] for formula and [A1] for answer

potential difference = ………………….. V [2]

(ii) the ratio of the currents passing through the 20 Ω and 5 Ω resistors respectively, $\dfrac{I_{20\Omega}}{I_{5\Omega}}$.

By current divider principle, $\dfrac{I_{20\Omega}}{I_{10\Omega}} = \dfrac{1}{2}$

Since $I_{5\Omega} = I_{20\Omega} + I_{10\Omega}$, $\dfrac{I_{20\Omega}}{I_{5\Omega}} = \dfrac{1}{3}$ [A1]

ratio = ………………….. [1]

(d) The 5 Ω resistor is replaced by a light-dependent resistor. Explain how the potential difference across BC would change when the room in which the circuit is placed becomes brighter.

In a brighter room, the resistance of the light-dependent resistor would decrease. [M1]
This would result in a smaller potential difference across itself and hence a greater potential difference across BC. [A1]

……………………………………………………………………………………………………

……………………………………………………………………………………………………[2]

4 Fig. 4.1 shows a high voltage supply set up to produce energetic electrons to bombard the cool sodium gas in the discharge tube, giving rise to a line spectrum through a diffraction grating. Fig. 4.2 shows some energy levels of sodium.

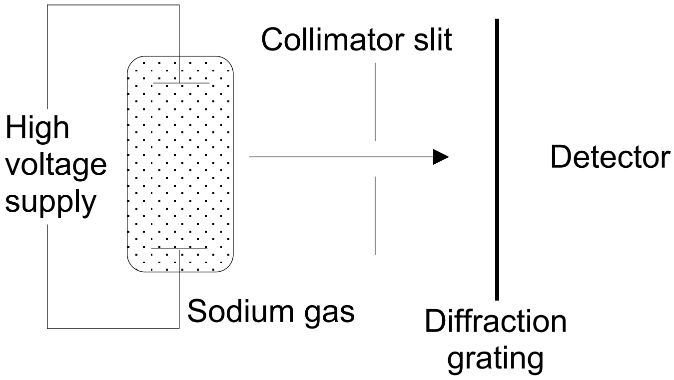


Fig. 4.1

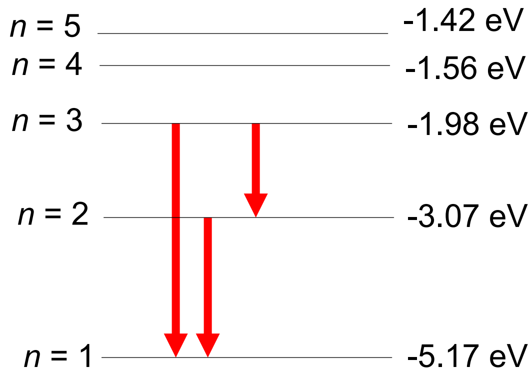


Fig. 4.2

Given that each bombarding electron has a kinetic energy of 3.20 eV.

(a) On Fig. 4.2 draw all the possible transitions that lead to emission of radiation. [2]

[Deduct 1 mark for each incorrect / missing transition. No mark rewarded for upward arrows]

(b) Determine the range of kinetic energy of the recoiling electrons in joules after they have excited the sodium atoms.

$3.20 - (5.17 - 1.98) = 0.01 \text{ eV} = 1.60 \times 10^{-21} \text{ J}$

$3.20 - (5.17 - 3.07) = 1.10 \text{ eV} = 1.76 \times 10^{-19} \text{ J}$

range of KE = ………………………. to ……………………... J [2]

(c) Another sample of cool gas X is placed between the discharged tube and the collimator as shown in Fig. 4.3.

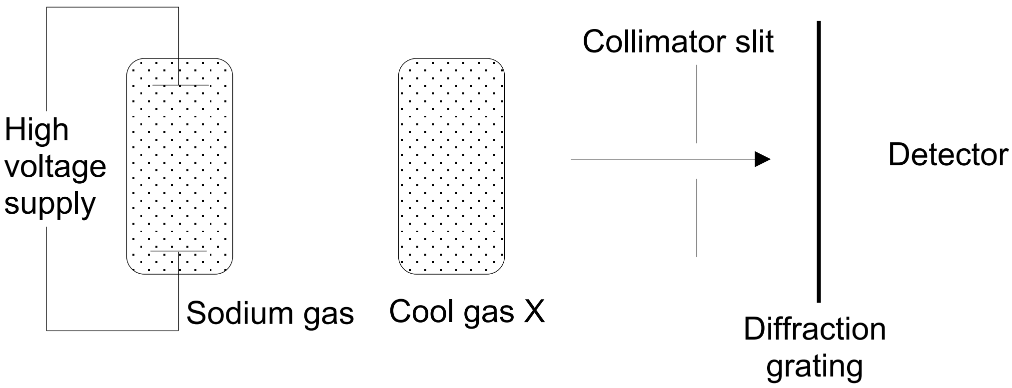


Fig. 4.3

Fig. 4.4 shows the energy levels in cool gas X.

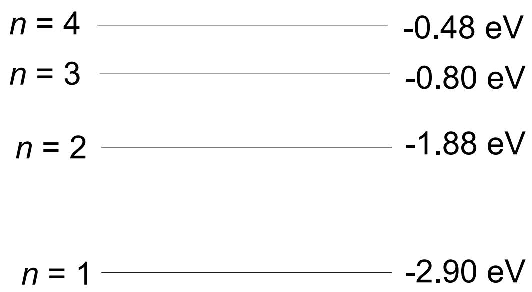


Fig. 4.4

Two extra spectral lines are detected as compared to **(a)**.

Explain the process that results in this. Assume that the detector is very sensitive and is able to detect a single photon.

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

…………………………………………………………………………………………..

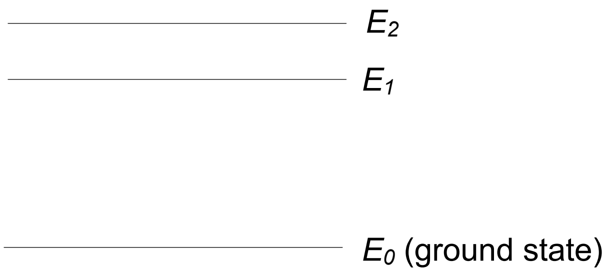
…………………………………………………………………………………………..

…………………………………………………………………………………...…[3]

The photons of energy 2.10 eV (*n* = 2 to 1 in sodium, *n* = 1 to 3 in gas X) will be absorbed by gas X [B1] because only photons of energy corresponding exactly to the difference between the two energy levels will be absorbed. [B1]
The two extra lines com e from the emission of photones from *n* = 3 to 2 and *n* = 2 to 1 in gas X. [B1]

For Examiner's Use

5 **(a)** The energy level diagram shows a three-level laser.



Explain how a laser is produced.

....

....

....

....

....

....

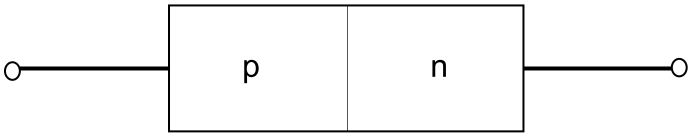
....[3]

Atoms from the ground state E_0 are optically pumped up to an excited state E_2 by the absorption of energy from an external intense light source.[B1]

From E_2, atoms decay rapidly to a state of energy E_1. For lasing to occur, this E_1 state must be a metastable state, so that E_1 can become more heavily populated than state E_0. [B1]

An incident photon can then trigger an avalanche of emissions by stimulated emission, resulting in the production of laser light. [B1]

(b) The diagram below shows a p-type semiconductor placed in contact with an n-type semiconductor.



(i) Explain how a depletion layer is formed between the p-type and n-type semiconductors.

....

....

....

....

....

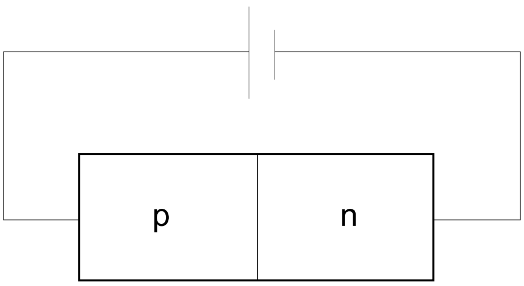
....[3]

Due to concentration gradient, the mobile electrons from the n-side and the mobile holes from the p-side diffuse across the junction and combine. [B1]

This process leaves the n-side with a positive charge layer, and the p-side with a negative charge layer.The positive and negative charge layers on the 2 sides of the junction set up an electric field E in the junction. [B1]

This electric field prevents any further movement of charge from the n-side and p-side across the junction. Hence, a depletion layer is formed. [B1]

(ii) With reference to the diagram below, state and explain how the width of depletion layer changes.



....

....

For Examiner's Use

....

....

....

....

....[2]

The emf source pushes electrons in the n-side and holes in the p-side towards the junction.[B1]

The depletion layer narrows. [B1]

OR

The external E-field generated by the emf source across the diode acts in the opposite direction to the internal E-field in the junction. [B1]

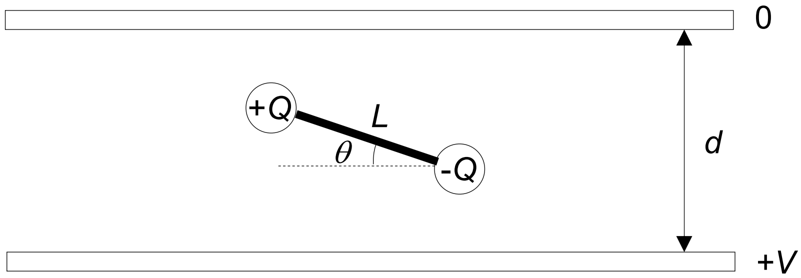
The external E-field reduces the junction potential, thus decreasing the width of the depletion layer. [B1]

For Examiner's Use

Section B

Answer **two** questions in this section

6 **(a)** An electric dipole consists of a positive charge +*Q* and a negative charge –*Q* which are a distance *L* apart. The electric dipole of negligible mass is placed into a region between a pair of charged plates as shown in the figure below. The plates are at potentials of 0 V and +*V* respectively, and are a distance *d* apart.



(i) Describe the initial motion of the electric dipole.

....

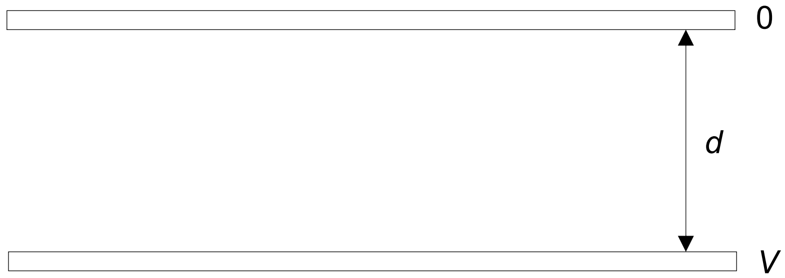
....[1]

(ii) Derive, in terms of *Q*, *L*, *V*, *d* and θ, the net torque on the dipole at this instant. [2]

$\tau = F \times L\cos\theta$ [1]

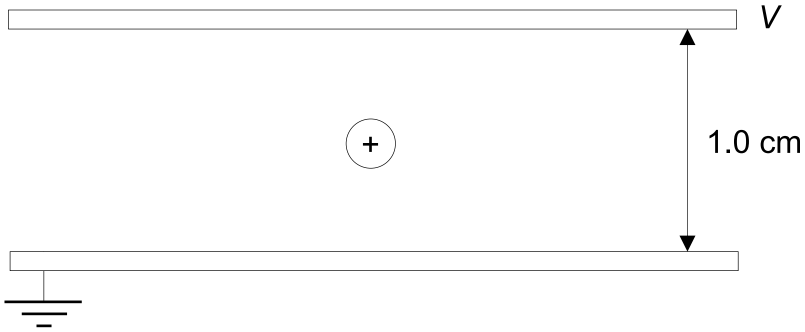
$= Eq \times L\cos\theta = \frac{V}{d} Q\, L\cos\theta = \frac{VQL\cos\theta}{d}$ [1]

(ii) Hence sketch the orientation of the electric dipole within the region when it experiences zero torque. [1]



For Examiner's Use

(b) An isolated proton is now placed in the middle of another pair of parallel plates separated by a distance of 1.0 cm. One of the plates is earthed, while the potential of the other is maintained at V, where $V = 8.0 \times 10^{-12} \cos(7.8t)$.



(i) State the angular frequency of the oscillation.

7.8 rad s^{-1}

angular frequency = ……………………… rad s^{-1} [1]

(ii) Calculate the maximum force acting of the charge, assuming that the weight of the proton is negligible.

$$F = qE = 1.6 \times 10^{-19} \times \frac{8 \times 10^{-12}}{0.01}$$
$$= 1.28 \times 10^{-28} \text{ N}$$

force = ……………………… N [2]

(iii) If the proton is performing simple harmonic motion, calculate the amplitude of its oscillation.

$$a = \frac{F}{m} = -\omega^2 x$$
$$\therefore \frac{F_{max}}{m} = -\omega^2 x_o$$
$$|x_o| = \frac{F_{max}}{m\omega^2} = \frac{1.28 \times 10^{-28}}{1.67 \times 10^{-27} \times 7.8^2} = 1.26 \times 10^{-3} \text{ m}$$

amplitude = ……………………… m [2]

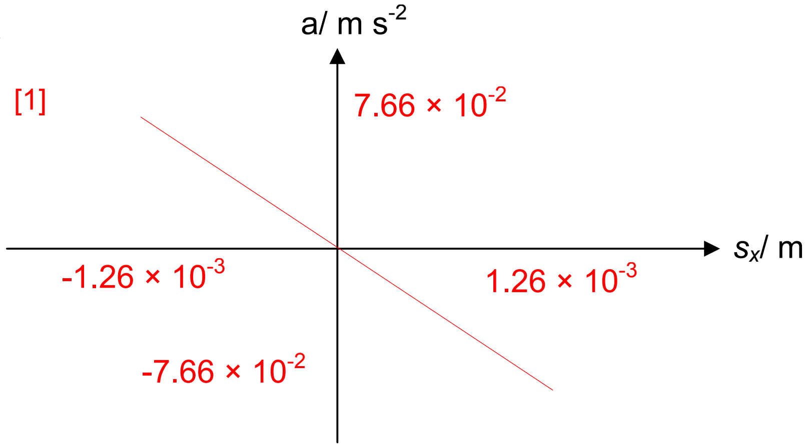
For Examiner's Use

(iv) Sketch, on the axes below, the acceleration – displacement graph of the motion of the proton, indicating all critical values. [2]

$a = \dfrac{F}{m} = \dfrac{1.28 \times 10^{-28}}{1.67 \times 10^{-27}}$

$= 7.66 \times 10^{-2}$ [1]

correct shape [1]



(v) Write down the equation which describes the displacement of the proton. [1]

$s = 1.26 \times 10^{-3} \cos(7.80t)$ [1]

(vi) Sketch, on the axes below:

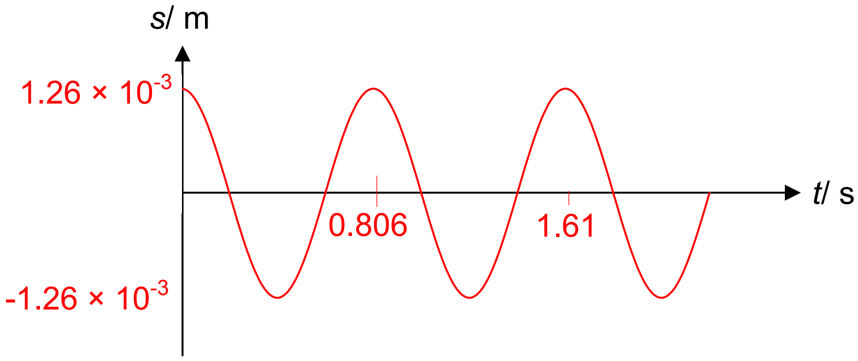
1. the displacement – time graph of the proton for 2 oscillations, and [2]

$\omega = 7.80$

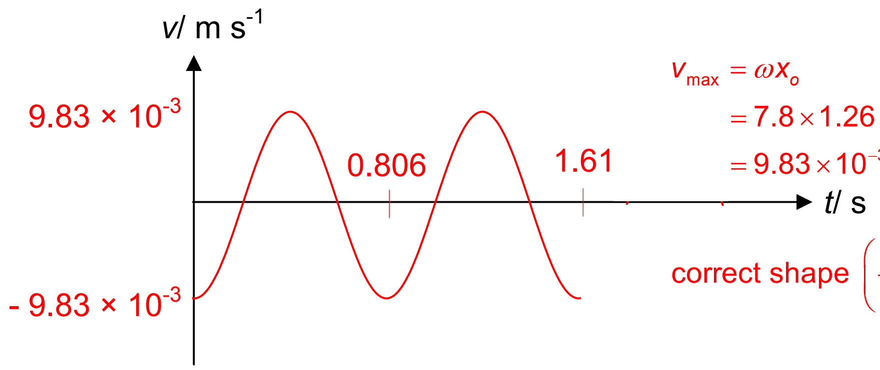
$\dfrac{2\pi}{T} = 7.80$

$T = 0.806$ s [1]

2 cycles [1]



2. the velocity – time graph of the proton for 2 oscillations. [2]



$v_{max} = \omega x_o$

$= 7.8 \times 1.26 \times 10^{-3}$

$= 9.83 \times 10^{-3}$ m s^{-1} [1]

correct shape $\left(\dfrac{ds_x}{dt}\right)$ [1]

(vii) Describe the changes in energy forms throughout one cycle.

when the proton moves downwards from the equilibrium position, KE $\rightarrow$ EPE

when the proton moves upwards towards the equilibrium position, EPE $\rightarrow$ KE

when the proton moves upwards from the equilibrium position, KE $\rightarrow$ EPE

when the proton moves downwards towards the equilibrium position, EPE $\rightarrow$ KE

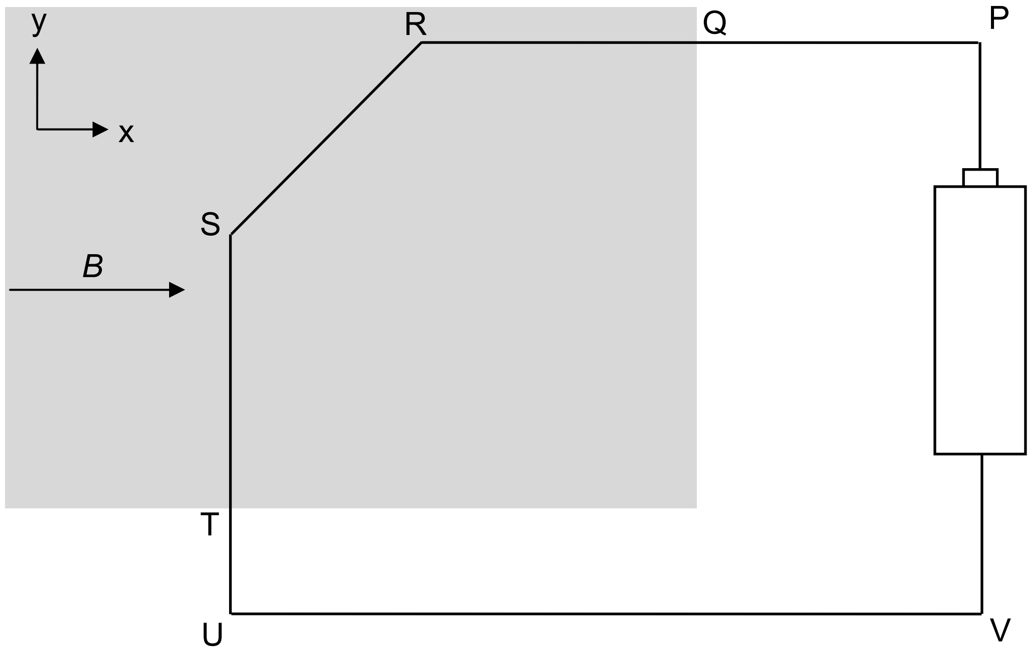
at amplitude positions: max EPE & zero KE

at equilibrium position: max KE and zero EPE [4]

For Examiner's Use

7 **(a)** The diagram below shows the full scale diagram of a circuit. Part of the circuit QRST is placed in a region of uniform field *B* of 0.530 T that is directed in the positive x-direction. The battery supplies a current I of 2.50 A. The wire experiences a force as a result.

The region of magnetic field is represented by the shaded region.



SIZE A4: Do not change the size!!!!

(i) Define *tesla.*

....

....

....[1]

Magnetic flux density when there is a force of 1 N acting on a current of 1 A of 1 m placed perpendicularly to a magnetic flux density of 1T

(ii) State and explain the direction of the resultant force acting on the wire.

....

....

....

....

....[3]

Only the component of the current flowing in the negative y direction results in a magnetic force experienced by the wire. [B1]
By Fleming's LHR, [B1]
the force is out of the paper. [B1]

or
By Fleming's LHR,
No force on QR
Force on RS out of paper
Force on ST out of paper
Resultant force out of paper. -1 for 1 missing point

(iii) Calculate the resultant force acting on the wire.

$$F = BIL\sin\theta$$
$$= (0.530)(2.50)(0.0615)\sin 90 \quad \text{[C1]}$$
$$= 0.0815\text{N}$$
[A1]

or

$$F_{RS} = BIL\sin\theta$$
$$= (0.530)(2.50)(0.036)\sin 45^\circ$$
$$= 0.0337\text{N}$$

$$F_{ST} = BIL\sin\theta$$
$$= (0.530)(2.50)(0.036)\sin 90^\circ$$
$$= 0.0477\text{N}$$

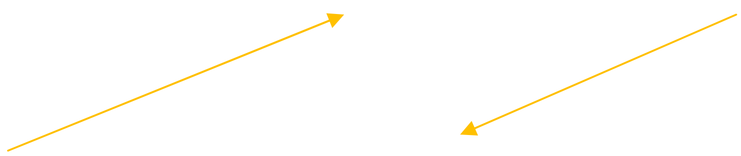
[M1 for correct F_{RS} and F_{ST}]

$$F_R = 0.0337 + 0.477 = 0.0814\text{N}$$
[A1]

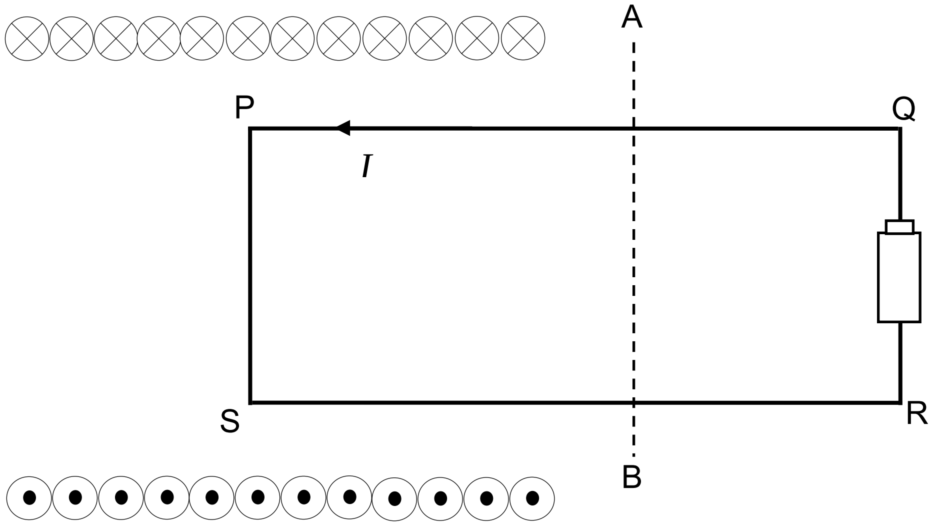
resultant force = ... N [2]

(iv) It is possible that there is no resultant force acting on the wire if the field points in one particular direction.

Draw the field in this direction in the figure above and label it P. [1]



(b) The figure below shows the top view of a current balance where the rectangular wire loop PQRS pivoted at AB is in equilibrium. It is connected in series with a battery of 300 g and an e.m.f. of 2.0 V. Part of the wire loop is placed inside a solenoid. The mass of the loop can be taken to be negligible.



(i) Draw the magnetic field lines in the solenoid. [2]

(ii) The length of the side PS is 6.0 cm and SB = $\frac{3}{5}$ SR. Given that the magnetic flux density in the solenoid is 0.40 T and the wire has no resistance, calculate the internal resistance of the battery.

$$\text{CWM} = \text{ACWM}$$
$$F_B(L_{SB}) = W(L_{BR})$$
$$(BIL_{PS})(L_{SB}) = mgL_{BR}$$
$$(0.40)(I)(0.060)(3L) = (0.300)(9.81)(2L)$$
$$I = 81.75\text{A}$$

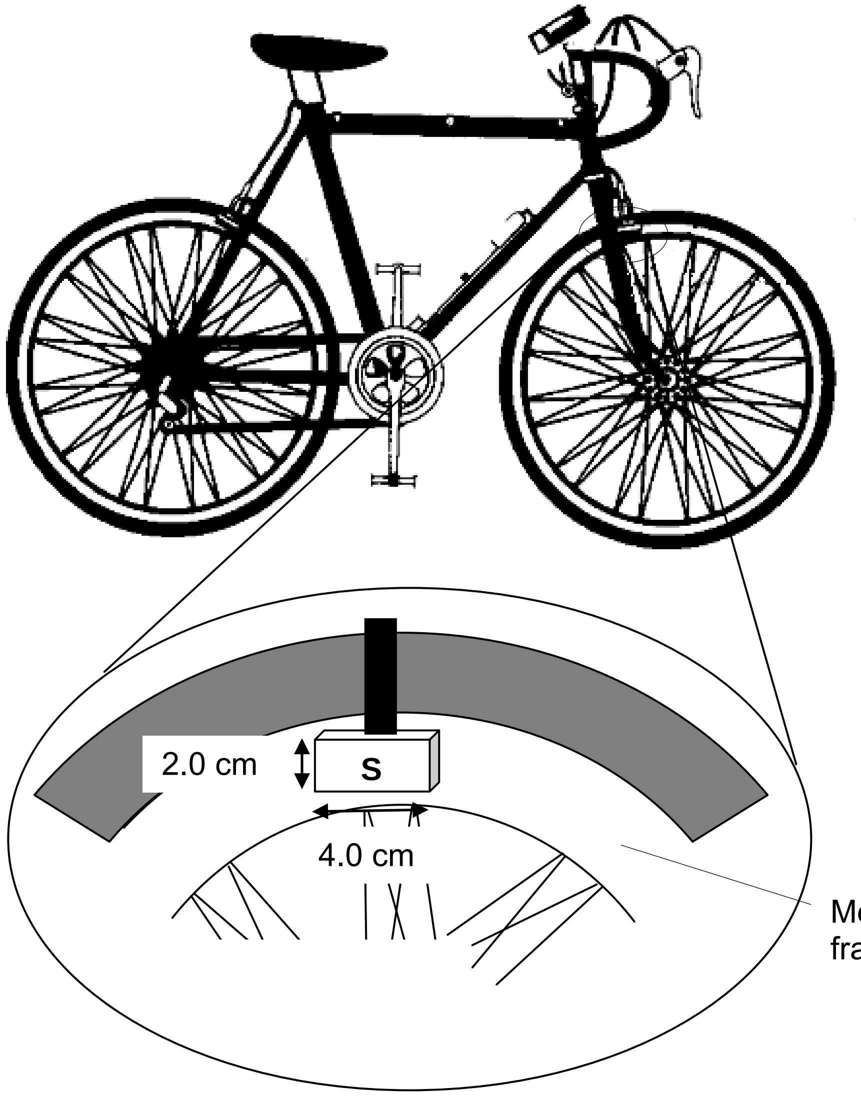
[M1,M1]

$$E = IR$$
$$2.0 = (81.75)R$$
$$R = 0.0245\Omega$$

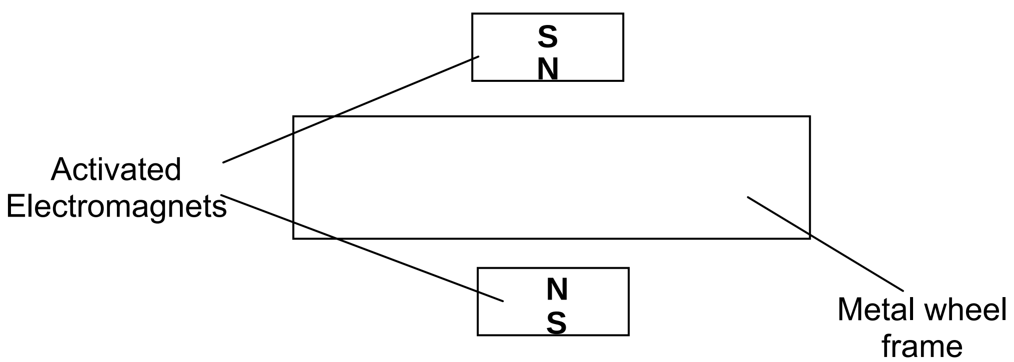
[A1]

internal resistance = ... Ω [3]

(c) A student designs a bicycle that uses electromagnetic braking instead of braking by friction. Two pairs of electromagnets are attached to the brakes of front and back wheels of the bicycle. When the brakes are activated, magnetic north poles face the wheels.



(i) The diagram below shows the top view of the cross section of the braking system. Sketch the magnetic field lines in the metal wheel frame. [2]



For Examiner's Use

(ii) Using energy consideration, explain how the above set up acts as a braking system.

....

....

....

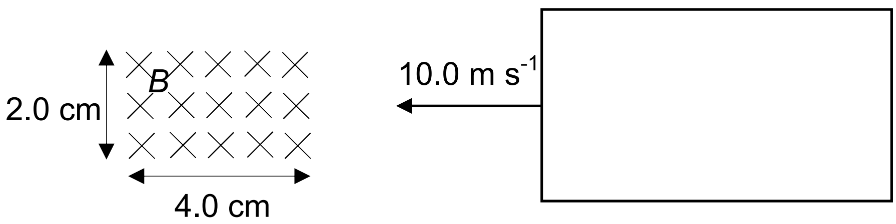
....

....

....[3]

As the wheel passes the electromagnet, the flux linking the different parts of the wheel changes. [B1]
By Faraday's law, this produces an induced e.m.f. and an induced current in the frame. [B1]
Hence, mechanical energy is transformed into electrical energy. [B1]

(iii) An experiment is conducted before fitting the electromagnet to the bicycle. To test the effectiveness of the braking system, the student places the electromagnet at a fixed position, with the field produced pointing into the plane of the paper. The surface of the magnet facing the wheel has a dimension of 4.0 cm by 2.0 cm. A wire loop is moved at a speed of 10.0 m s^{-1} towards the magnet.



Assuming that magnetic flux density *B* of 0.700 T is uniform, calculate the e.m.f induced in the wire as it cuts the field.

$$E = \frac{d\Phi}{dt} = \frac{d(NBA\cos\theta)}{dt} = \frac{BdA}{dt} = Bw\frac{dl}{dt} = (0.700)(0.020)(10)$$ [M1, A1]

$= 0.14\text{V}$

e.m.f = ... V [2]

(iv) Suggest, using your answer from **(b)(iii),** why the braking system is an effective one.

....

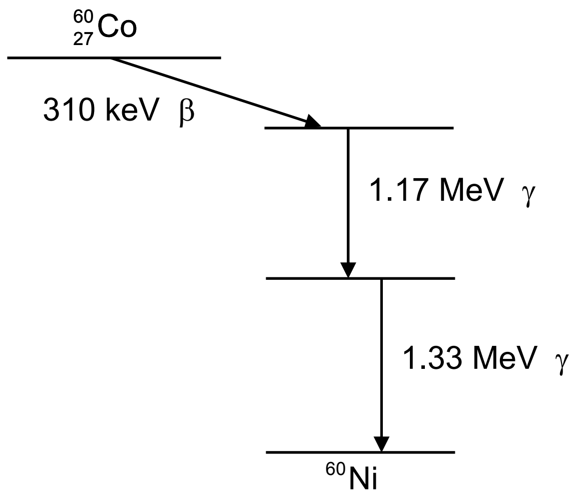
....

....[1]

Though e.m.f. induced is small, the resistance of the wheel frame is small and hence can result in large electrical power generated. [B1]

For Examiner's Use

8 **(a)** Cobalt-60 undergoes nuclear decay to form the stable isotope nickel-60. In the process of decay, Cobalt-60 emits one electron with an energy of 310 keV and then two gamma rays with energies of 1.17 MeV and 1.33 MeV, respectively.



Some rest mass information relating to the above reaction is as shown.

Rest mass of a neutron	=	1.008665 *u*
Rest mass of a proton	=	1.007825 *u*
Rest mass of an electron	=	0.00055 *u*

(i) Write down the number of protons and neutrons in the nickel nuclide produced when the cobalt-60 nuclide decays.

number of protons = ……28……………….

number of neutrons = ……32………………. [1]

For Examiner's Use

(ii) The binding energy per nucleon of a cobalt-60 nuclide is 8.74 MeV. Calculate, to 5 decimal places, the rest mass of cobalt-60 in terms of *u.*

Binding energy = Δmc^2

$$=\left(\sum m - M_{co}\right)c^2$$

$$M_{co} = \left(33 \times 1.008665u + 27 \times 1.007825u\right) - \frac{\left(8.74 \times 10^6 \times 60 \times 1.6 \times 10^{-19}\right)}{\left(3.0 \times 10^8\right)^2 \times 1.66 \times 10^{-27}}u$$

$$= 59.93561u$$

Accept also if mass of electrons considered as part of M_{co}.

rest mass = ... *u* [2]

(iii) Calculate, to 5 decimal places, the rest mass of the stable nickel nuclide in terms of *u*.

Considering the rest mass of energy components,

$$M_e = \frac{\left(0.31 + 1.17 + 1.33\right) \times 10^6 \times 1.6 \times 10^{-19}}{\left(3.0 \times 10^8\right)^2 \times 1.66 \times 10^{-27}}u = 3.01 \times 10^{-3}\,u \qquad \text{[M1]}$$

Rest mass of nickel

= $59.93561u - 0.000549u - 0.00301u$ [M1]

$= 59.93205u$ [A1]

rest mass = ... *u* [3]

(iv) In practice, the above radioactive decay of cobalt-60 could be used for the treatment of cancer.

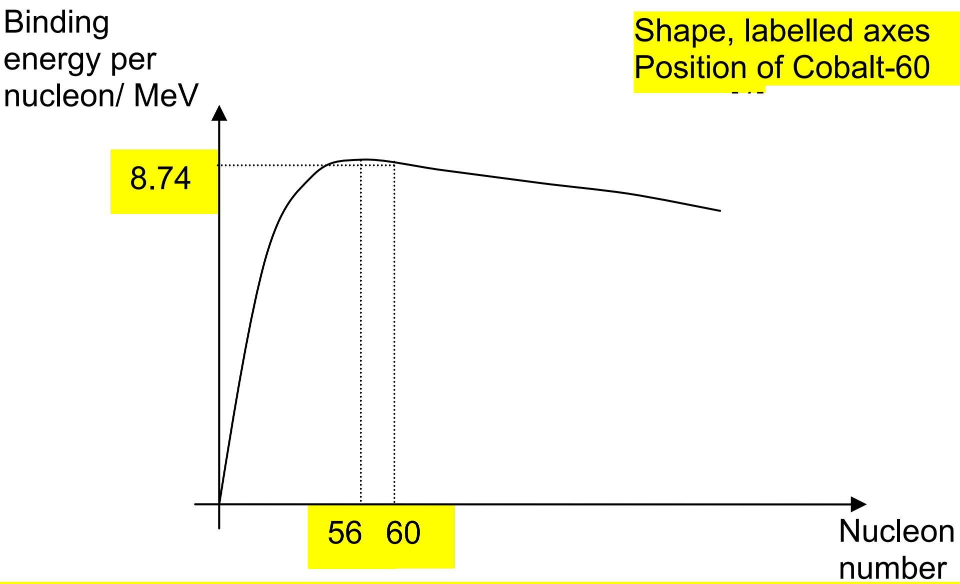
Suggest and explain which aspect of the decay is used for the purpose of tumour treatment.

The gamma radiation emitted from the process is used to treat the cancer cells as it has a very high penetrative power [B1].

....[1]

(v) **1.** Sketch a graph to show the variation of binding energy per nucleon with nucleon number, and mark the binding energy per nucleon of a cobalt-60 nuclide on the graph. [2]

Shape, labelled axes [1]
Position of Cobalt-60



2. Hence explain why fusion of nuclei having small nucleon numbers is associated with a release of energy.

When particles with small nucleon numbers fuse with other nucleus, the products will have higher nuclear binding energy per nucleon.[B1]
This implies a larger mass defect per nucleon which implies that the total mass of the products has decreased compared to the reactants.[B1]
The decrease in the mass of the products is a result of energy being released instead of absorbed.[B1] ....

OR ....[3]

When particles with small nucleon numbers fuse with other nucleus, the products will have higher nuclear binding energy per nucleon.[B1]
The higher the binding energy per nucleon of a nucleus, the more stable the nucleus is.[B1]
The increase in stability resulted from the release of energy during the fusion.[B1]

(b) A carbon-14 $\left({}^{14}_{6}\text{C}\right)$ nuclide undergoes spontaneous and random beta decay to transform into a stable nitrogen-14 $\left({}^{14}_{7}\text{N}\right)$ nuclide.

$${}^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + {}^{0}_{-1}\beta$$

(i) Explain the terms *spontaneous* and *random*.

Spontaneous - Not affected by physical conditions e.g. temperature, pressure, electric and magnetic fields etc. [1]

Random - Impossible to predict exactly when a particular nucleus will decay. [1]

……………………………………………………………………………………[2]

(ii) The nuclide of carbon-14 has a half-life of 5730 years. If a carbon-14 source emits n β-particles in one second today, calculate the time taken for the source to emit the same number of β-particles 10,000 years later.

$$\frac{N'}{N} = \left(\frac{1}{2}\right)^{\frac{10000}{5730}}$$

$N' = 0.298N$ [M1]

10,000 years later, source emits $0.298N$ β-particles in 1 s.

$\therefore$ Time taken to emit N β-particles $= \dfrac{1}{0.298}$ =3.35 s [A1]

time taken = ……………… s [2]

(iii) Calculate the number of years that must lapse so that the source will take one year to emit n β-particles.

The new activity = $\dfrac{N}{1\text{year}}$

$$= \frac{N}{365 \times 24 \times 60 \times 60}$$

$= 3.17 \times 10^{-8} N$ [M1]

$$\frac{3.17 \times 10^{-8} N}{N} = \left(\frac{1}{2}\right)^{\frac{t}{5730}}$$

$t = 1.45 \times 10^{5}$ years

number of years = ……………… [2]

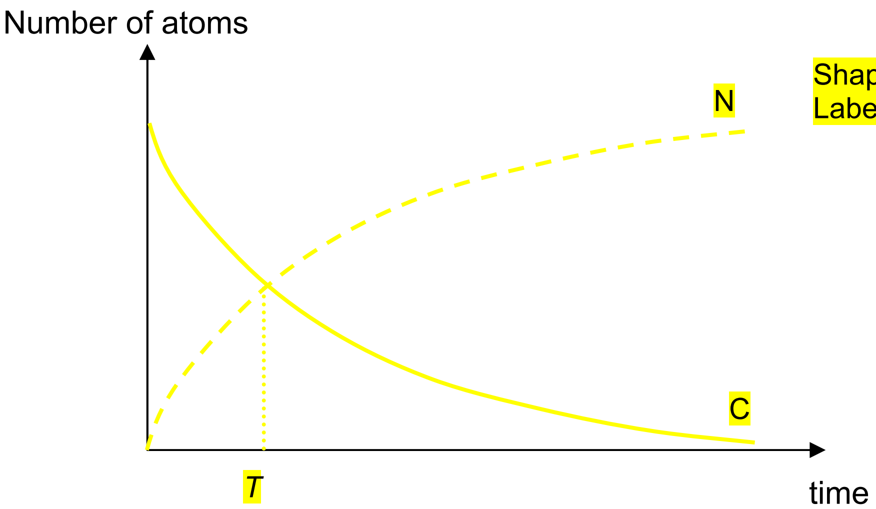
For Examiner's Use

(iv) In a sample initially containing only radioactive carbon-14, the number of remaining carbon-14 and number of stable nitrogen-14 produced are recorded over time. The recording ends when there is negligible number of carbon-14 nuclides left in the sample.

Sketch and label, in the same axes below, the graphs of

1. the number of remaining carbon-14 nuclides (Graph C)
2. the number of nitrogen-14 nuclides produced (Graph N)

Label the position of the half-life, *T*, in the graph. [2]



Shape of graphs – [1]
Labeling of T – [1]