Anglo-Chinese Junior College

Physics Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		CLASS	
CENTRE NUMBER	S 3 0 0 4	INDEX NUMBER	

PHYSICS **9749/02**

Paper 2 Structured Questions

23 August 2023

2 hours

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

READ THESE INSTRUCTIONS FIRST

Write your name, class 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 an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiners' use only	
1	/ 8
2	/ 8
3	/ 8
4	/ 10
5	/ 8
6	/ 8
7	/ 10
8	/ 20
Total	/ 80

DATA AND FORMULAE

Data

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	=	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	=	$\rho g h$
gravitational potential,	ϕ	=	$-\frac{Gm}{r}$
temperature	T/K	=	T/°C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule,	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.,	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.,	v	=	$v_o \cos \omega t$
		=	$\pm\,\omega\sqrt{x_o^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series,	R	=	$R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential,	V	=	$\frac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage,	x	=	$x_o \sin \omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_o n I$
radioactive decay,	x	=	$x_o \exp(-\lambda t)$
decay constant,	λ	=	$\frac{\ln 2}{t_{1/2}}$

[Turn over

For Examiner's Use

Answer **all** the questions in the spaces provided.

1 A student times the fall of a small metal ball. Data for the time t taken for a ball of mass m to fall a vertical distance h from rest are given in the table below.

h	588 ± 1 cm
m	10 ± 1 g
t	1.1 ± 0.1 s

(a) Use the data to determine a value of the acceleration of free fall, g.

g = ………………………… m s $^{-2}$ [2]

(b) The student collects 5 more sets of data at different heights.

Explain how the student can use the data to get a more accurate value of g.

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………………………………………………………………………………………………

………………………………………………………………………………………………

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

For Examiner's Use

(c) Use your answer in **(a)** to determine the loss in gravitational potential energy *U* for the ball.

loss in gravitational potential energy = ………………………… J [1]

(d) Hence, express *U* to an appropriate number of significant figures with its uncertainty.

U = …………………… ± …………………… J [3]

[Total: 8]

[Turn over

For Examiner's Use

2 **(a)** Car A is traveling along a straight path at a constant speed of 8.5 m s^{-1}. When car A passes car B at t = 0 s, car B accelerates uniformly from rest at 2.5 m s^{-2}.

(i) Determine the distance travelled by car B when it overtakes car A.

distance = ... m [2]

(ii) On Fig. 2.1, sketch a well labelled graph to show the variation with time of the displacement of car A and car B.

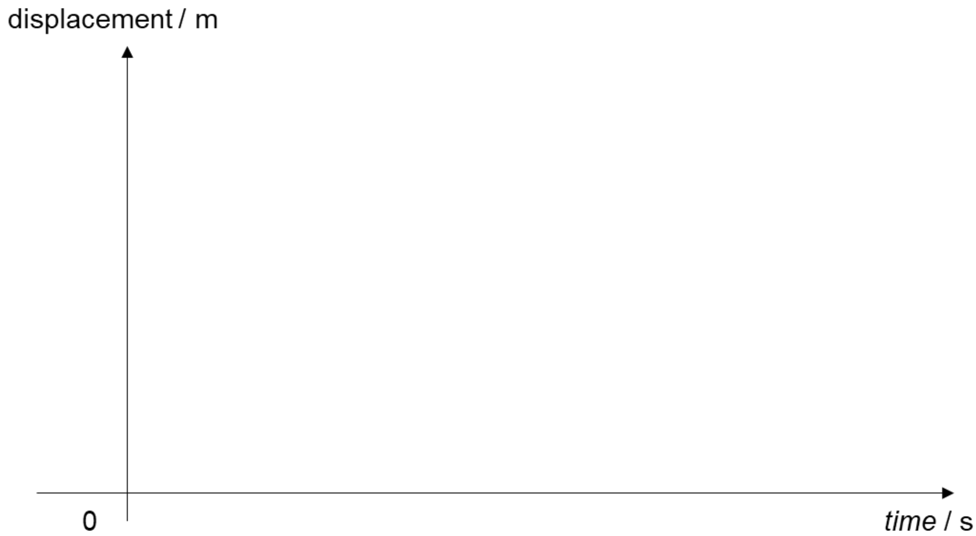

Fig. 2.1

[2]

For Examiner's Use

(b) After overtaking car A, car B is traveling at a speed of 11.5 m s^{-1} just before it falls off a cliff of height 6.5 m. The effect of air resistance is negligible.

(i) Determine the angle θ car B makes with the horizontal just before it hits the ground.

θ = ………………………… ° [2]

(ii) Car A subsequently falls off the same cliff as car B.

State and explain how the angle it makes with the horizontal will differ, if any, with that of car B found in **(b)(i)**.

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…………………………………………………………………………………… [2]

[Total: 8]

[Turn over

For Examiner's Use

3 **(a)** Explain what is meant by *upthrust*.

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……………………………………………………………………………………………….

……………………………………………………………………………………………….. [1]

(b) Weather balloons are an important tool for meteorologists. They provide data that is used to improve weather forecasts and to understand the atmosphere.

Fig. 3.1 shows a helium inflated weather balloon tethered to the ground by a rope. The balloon is spherical in shape and has a diameter of 1.5 m.

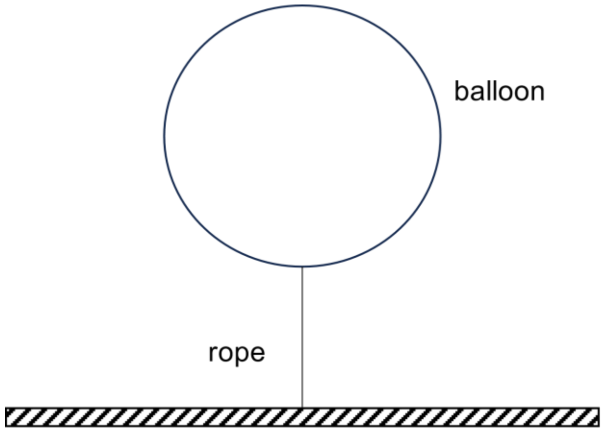

Fig. 3.1

(i) On Fig. 3.1, draw and label the forces acting on the balloon. [2]

(ii) The density of the air surrounding the balloon is 1.3 kg m^{-3}. The mass of the helium filled balloon is 300 g.

Determine the tension of the rope.

tension = ………………………… N [2]

(c) The rope is cut and the balloon rise to an equilibrium altitude of up to 30 km.

For Examiner's Use

Explain how the balloon rises and reaches this height.

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

[Total: 8]

[Turn over

For Examiner's Use

4 **(a)** Using energy considerations, distinguish between electromotive force (e.m.f.) and potential difference (p.d.).

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……………………………………………………………………………………………

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

For Examiner's Use

(b) A cell is connected to identical resistors arranged in series as shown in Fig. 4.1.

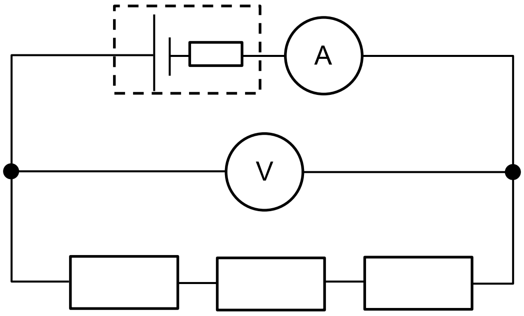

Fig. 4.1

A student recorded both the voltmeter and the ammeter readings as he varied the number of resistors arranged in series. He plotted both the voltmeter and ammeter readings in the grid in Fig. 4.2.

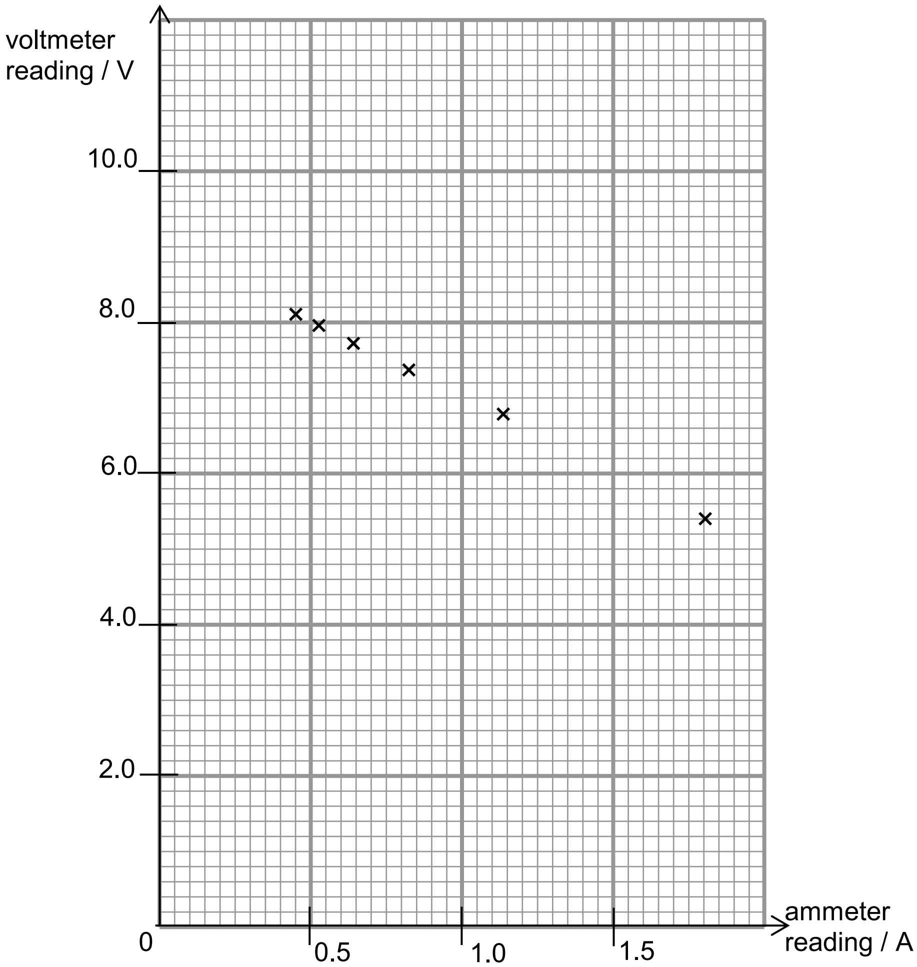

Fig. 4.2

(i) On Fig 4.2, draw the line of best fit for all the points and state the e.m.f. of the cell.

.... [1]

For Examiner's Use

(ii) Using Fig. 4.2, determine the internal resistance of the cell.

internal resistance = ………………………… Ω [2]

(iii) On Fig. 4.1, draw a component that can be added to the circuit so that the emf of the cell can be obtained directly from the voltmeter reading.

Explain your answer.

…………………………………………………………………………………………

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…………………………………………………………………………………………

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

For Examiner's Use

(c) A circuit is set up as shown in Fig. 4.3.

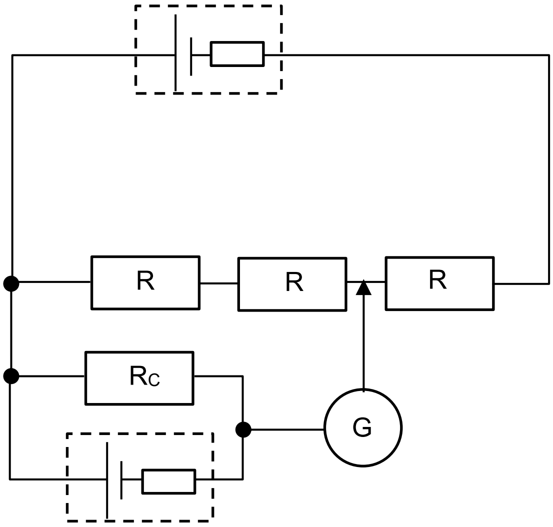

Fig. 4.3

The table below shows the specifications for the components in the circuit.

Internal resistance of cell	15 Ω
External resistor R	25 Ω

The two cells are identical and the galvanometer shows null deflection.

Calculate the resistance R_C.

R_C = ………………………… Ω [3]

[Total: 10]

[Turn over

For Examiner's Use

5 **(a)** An electron enters a region of uniform magnetic field as shown in Fig. 5.1.

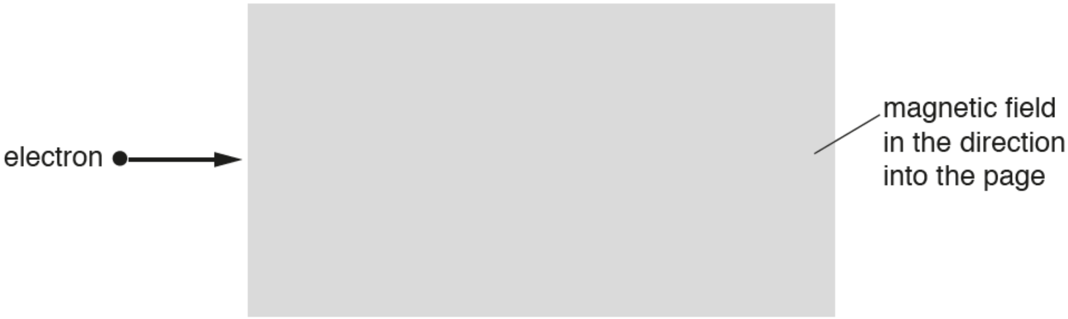

Fig. 5.1

On Fig. 5.1, draw a possible path that the electron will take in the magnetic field. [1]

(b) A thin slice of conducting material has its faces PQRS and VWXY normal to a uniform magnetic field of flux density *B* of 0.28 T as shown in Fig. 5.2. The side PQ is 20 mm, side PS is 9.0 mm and side PV is 1.0 mm.

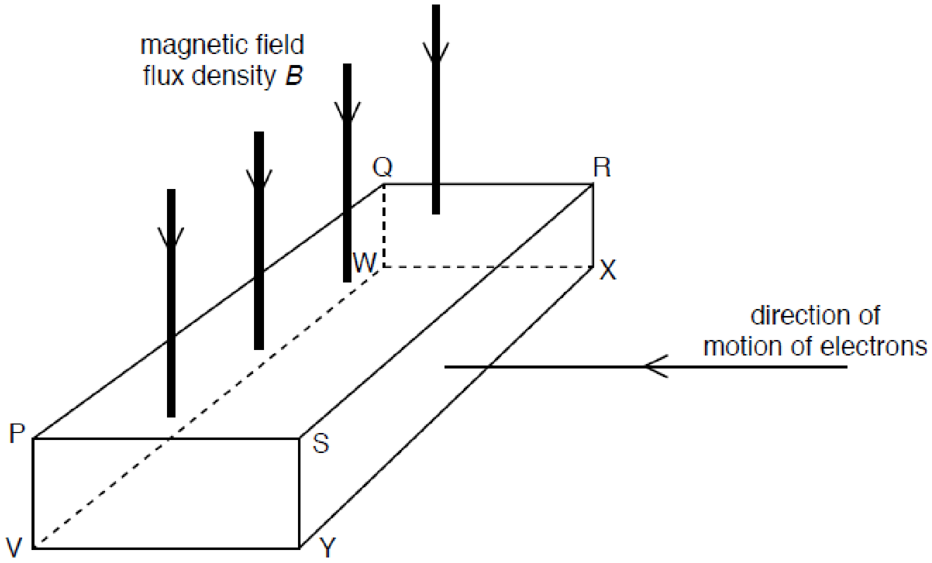

Fig. 5.2 (not to scale)

Electrons enter the slice at right-angles to face SRXY at an average speed of 56 m s^{-1}.

As the electrons flow, a potential difference is produced between two faces of the slice which increases to a steady value called the hall voltage V_H.

(i) State the face of the slice that is at a higher potential.

.... [1]

For Examiner's Use

(ii) Explain why the hall voltage is produced between two faces of the slice.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(iii) Calculate V_H.

V_H = ………………………… V [2]

(iv) State and explain how the polarity of the hall voltage will change, if any, if the charge carriers are positively charged.

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

[Total: 8]

[Turn over

For Examiner's Use

6 Charles' law states that for a fixed amount of ideal gas, the volume is directly proportional to the thermodynamic temperature if the pressure is kept constant.

A student is investigating the validity of Charles' law. The student uses a syringe that has a volume of 100 cm^3 as shown in Fig. 6.1.

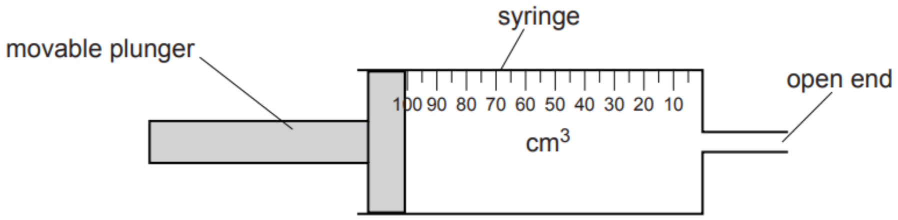

Fig. 6.1

The student moves the plunger of the syringe so that the volume of the air in the syringe is approximately 50 cm^3. The student then seals the open end of the syringe and clamps the syringe so that it is immersed in a large beaker of water, as shown in Fig. 6.2. The plunger is air-tight but free to move up and down.

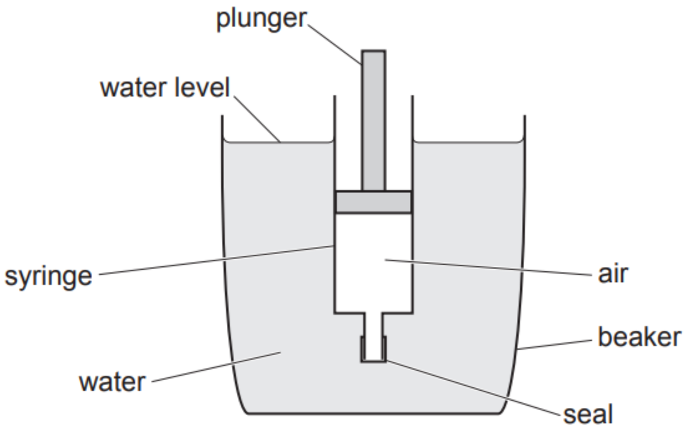

Fig. 6.2

The water in the beaker is heated, and the volume of air in the syringe is recorded at different temperatures of the water.

(a) The student recorded that at a temperature of 41 °C the volume of the air in the syringe was 52.1 cm^3.

Calculate the expected volume of the air in the syringe when the temperature is 58 °C.

expected volume = ... cm^3 [2]

For Examiner's Use

(b) The student recorded that at a temperature of 58 °C the volume of the air in the syringe was 54.3 cm^3.

Suggest a reason the calculated value in **(a)** is not the same as the experimental value.

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……………………………………………………………………………………………..

…………………………………………………………………………………………… [1]

(c) The experimental set-up ensures that the physical quantities, pressure and the amount of gas, remains constant.

Describe how the set-up of the experiment ensures these physical quantities remain constant.

Pressure: …………………………………………………………………………………

……………………………………………………………………………………………..

Amount of gas: ……………………………………………………………………………

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

(d) Use the kinetic theory to explain the variation of *V* with *T* while pressure remains constant.

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

[Total: 8]

[Turn over

For Examiner's Use

7 **(a)** State what is meant by the *activity* of a radioactive sample.

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

……………………………………………………………………………………….. [1]

(b) Radon ($^{222}_{86}Rn$) can decay into polonium ($^{218}_{84}Po$) by emitting an alpha radiation as shown.

$$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

The half-life of radon is 3.8 days.

In a 1.0 g sample of radon, determine

(i) the number of radioactive nuclei,

number of radioactive nuclei = ………………………… [1]

(ii) its initial activity,

activity = ………………………… decay s^{-1} [2]

For Examiner's Use

(iii) the time taken for its activity to decline to 1.0% of its initial level, and

time = ………………………… s [2]

(iv) the energy that will be released when all the radon has decayed.

Fig. 7.1 shows the masses of the particles.

particle	mass / u
helium	4.002602
polonium	218.008966
radon	222.017576

Fig. 7.1

energy = ……………………… MeV [3]

(c) A Geiger–Müller tube attached to a counter is placed near the sample at the start of the decay. The count rate measured is far lower than that calculated in **(b)(ii)**.

Suggest a possible reason for this.

………………………………………………………………………………………………

………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

[Total: 10]

[Turn over

For Examiner's Use

8 Read the passage below and answer the questions that follow.

Magnetic Confinement Fusion

As the world's demand for energy increases, harnessing energy from the process of nuclear fusion promises to be an attractive long-term solution in addressing future energy problems.

The most widely studied nuclear fusion reaction involves the nuclei of deuterium ($^{2}_{1}H$) and tritium ($^{3}_{1}H$) which are isotopes of hydrogen. Each reaction produces an α-particle and a neutron, releasing 17.6 MeV of energy as shown by the nuclear equation below.

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

For the positively charged nuclei to fuse, they must be heated to sufficiently high temperatures to overcome the Coulomb barrier. At such temperatures, the atoms in the fuel are ionised, forming a mixture of electrons and nuclei known as a plasma. Maintaining the plasma at this temperature to produce fusion energy requires it to be confined long enough in the reactor and this is achieved using magnetic fields.

Fig. 8.1 shows the magnetic field lines of a magnetic mirror configuration involving two current-carrying coils. When a charged particle is placed between the two coils, it experiences a magnetic force and can be trapped. However, the trapping is not perfect. For instance, if the particle travels along the central axis, it can escape the trap.

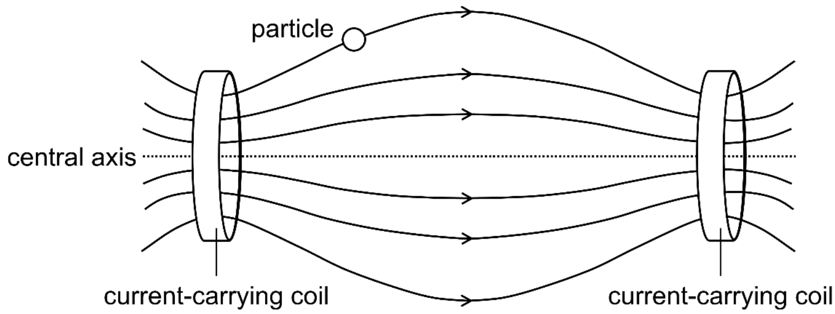

Fig. 8.1

Hence, to prevent the loss of particles, the ends of the magnetic mirror configuration can be joined together to form a torus (doughnut-like shape). Fig. 8.2 shows a cross-section of the toroidal nuclear fusion reactor where *R* is the major radius while *a* is the minor radius of the reactor. Multiple current-carrying coils, known as the toroidal field coils, are used to produce the magnetic field in the plasma.

The toroidal magnetic field causes the charged particles to move in a circular motion about the magnetic field. In addition, when current is sent through the central solenoid, it acts like the primary coil of a transformer, inducing current in the plasma around the torus. The combination of the circular motion in the cross-sectional plane of the torus and translational motion in a direction perpendicular to the plane results in the charged particles moving in a helical path.

For Examiner's Use

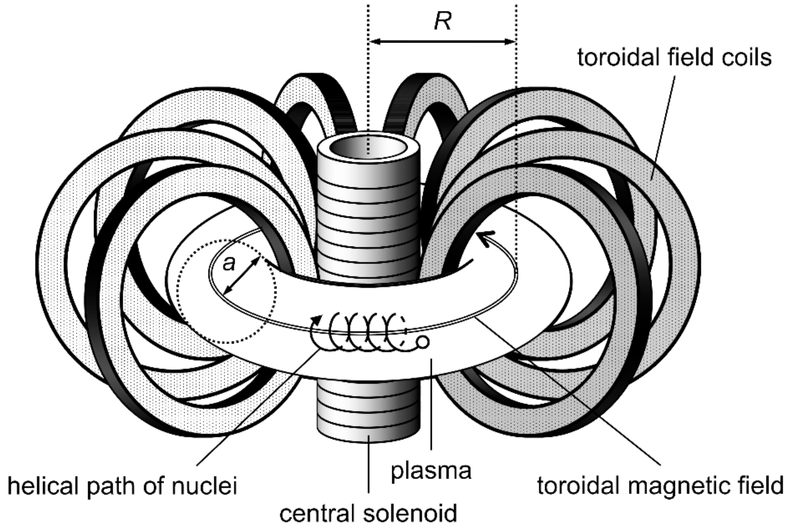

Fig. 8.2

The collisions between the nuclei and the electrons cause a resistance to the flow of charges. Similar to how a current-carrying wire heats up over time, the current in the plasma dissipates power and heats up the plasma in a process known as ohmic heating. Fig. 8.3 shows the variation with temperature of the resistivity of the plasma.

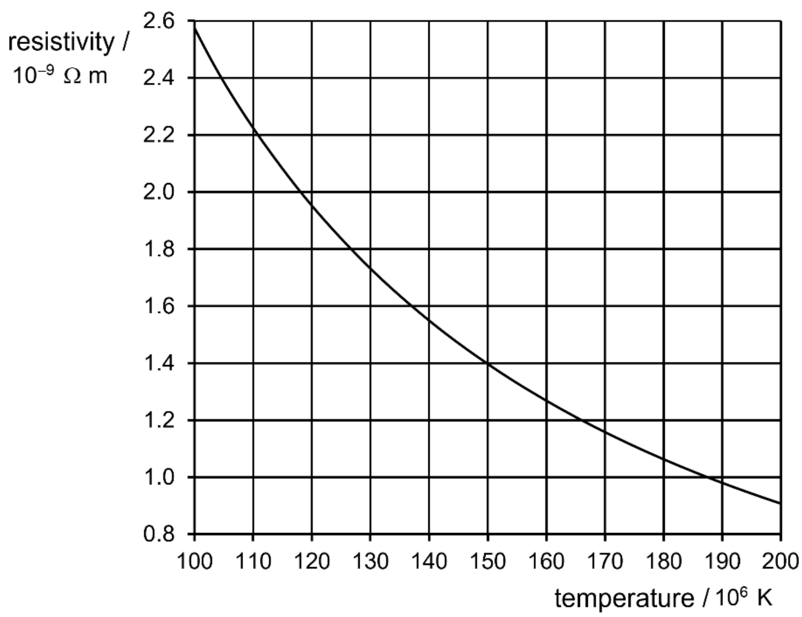

Fig. 8.3

As the resistivity of the plasma decreases when temperature rises, ohmic heating is not sufficient to raise the temperature of the plasma to the required value for fusion reactions. Hence, the plasma is further heated using two external methods – cyclotron resonance heating and neutral beam injection. In cyclotron resonance heating, radio frequency waves are transmitted to the plasma to increase the energy of the particles. In neutral beam injection, electrically neutral particles enter the plasma in a straight-line beam at high speeds and collide with the existing particles to increase the energy of the particles in the plasma.

[Turn over

For Examiner's Use

Table 8.1 summarises the data for the operation of a proposed nuclear fusion reactor.

Table 8.1

major radius, R	6.2 m
minor radius, a	2.0 m
total number density of deuterium and tritium nuclei, n	10^{20} m^{-3}
toroidal magnetic field, B	5.3 T
plasma current, I	15 MA
average temperature, T	127×10^{6} K
cyclotron resonance heating power, P_{CRH}	20 MW
neutral beam injection heating power, P_{NBI}	33 MW

(a) The binding energy per nucleon for the nuclei in the deuterium-tritium fusion reaction are given in Table 8.2.

Table 8.2

nucleus	binding energy per nucleon / MeV
deuterium $^{2}_{1}H$	1.115
tritium $^{3}_{1}H$	2.833
α-particle $^{4}_{2}He$	7.092

Show that the energy released in this reaction is 17.6 MeV.

[2]

(b) Suggest what is meant by the 'Coulomb barrier' in a nuclear fusion reaction.

....

....

.... [1]

For Examiner's Use

(c) The particle shown in Fig. 8.1 is a deuterium nucleus travelling perpendicularly into the plane of the paper.

(i) On Fig. 8.1,

1. mark with a letter X a position along the central axis where the magnetic flux density is a maximum, [1]

2. mark with a letter Y a position along the central axis where the magnetic flux density is a minimum, and [1]

3. draw an arrow and label it with a letter F to show the force acting on the deuterium nucleus. [1]

(ii) Explain why a deuterium nucleus that travels along the central axis cannot be trapped by the magnetic mirror configuration.

……………………………………………………………………………………………

…………………………………………………………………………………………… [1]

(d) **(i)** Using Faraday's law, explain how varying the current through the central solenoid of a nuclear fusion reactor produces plasma current around the torus.

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

(ii) Using Fig. 8.3 and Table 8.1, show that the resistance of the plasma at the operating temperature in the proposed nuclear fusion reactor is $5.6 \times 10^{-9}\ \Omega$.

[2]

[Turn over

For Examiner's Use

(iii) Hence, calculate the ohmic heating power at the operating temperature in the proposed nuclear fusion reactor.

power = ………………… W [1]

(e) In cyclotron resonance heating, energy is transferred to the particles most efficiently when the frequency of the electromagnetic waves is equal to the frequency of the circular motion in the helical path of the particles.

Determine the frequency, in MHz, of the electromagnetic waves required for cyclotron resonance heating of deuterium nuclei.

frequency = ………………… MHz [3]

(f) Suggest why the particles used for neutral beam injection must be electrically neutral.

………………………………………………………………………………………………

………………………………………………………………………………………………

……………………………………………………………………………………………….. [1]

For Examiner's Use

(g) The power gain factor Q of a nuclear fusion reactor is the ratio of the power produced from the fusion reactions to the external heating power supplied to the plasma via cyclotron resonance heating and neutral beam injection.

The fusion power produced per unit volume S is given by

$$S = kn^2E$$

where k is 3.57×10^{-23} m^3 s^{-1} and E is the energy produced for each deuterium-tritium fusion reaction.

Determine Q for the proposed nuclear fusion reactor.
$\left[\text{volume of a torus} = 2\pi^2Ra^2\right]$

Q = ………………… [3]

[Total: 20]

End of Paper

[Turn over