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

25 August 2022
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	/ 6
2	/ 12
3	/ 8
4	/ 9
5	/ 11
6	/ 14
7	/ 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,	$\phi = -\dfrac{Gm}{r}$
temperature	$T/\text{K} = T/^{\circ}\text{C} + 273.15$
pressure of an ideal gas	$p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule,	$E = \dfrac{3}{2}kT$
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,	$V = \dfrac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage,	$x = x_o \sin \omega t$
magnetic flux density due to a long straight wire	$B = \dfrac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \dfrac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o n I$
radioactive decay,	$x = x_o \exp(-\lambda t)$
decay constant,	$\lambda = \dfrac{\ln 2}{t_{\frac{1}{2}}}$

[Turn over

For Examiner's Use

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

1 (a) In an experiment to determine the thickness of a typical \$1 coin, a student used a half meter rule to determine the thickness of one \$1 coin and the thickness T of N such coins, as shown in Fig. 1.1.

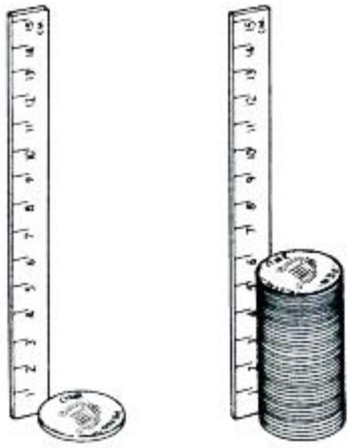

Fig. 1.1

The thickness of a typical \$1 coin is then taken to be $\frac{T}{N}$.

(i) In finding the thickness of a \$1 coin, explain how dividing T by N reduces random error as compared to measuring the thickness of only 1 coin.

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(ii) Suggest a method to further improve the accuracy in determining the thickness of the coin. Explain your answer.

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

For Examiner's Use

(b) The ideal gas law states that $pV = nRT$

where p is the pressure of the gas,
V is the volume of the gas,
n is the number of moles and
T is the thermodynamic temperature.

In an experiment, the student was attempting to calculate the value of p for a sample of 2.00 millimoles of gas trapped in a sphere.

Assuming ideal gas conditions, if the diameter of the sphere is (50.0 ± 0.1) mm and the temperature of the gas is (36.7 ± 0.1) °C, determine the value of p with its associated uncertainty.

p = (………………….. ± …………………..) Pa [3]

[Total: 6]

[Turn over

For Examiner's Use

2 **(a)** A man wants to knock down a coconut from the tree by throwing a stone at it as shown in Fig. 2.1. The coconut is 18.0 m above the ground. The man's hand is 2.2 m above the ground when he releases the stone with an initial velocity of 20.0 m s^{-1}. Assume that air resistance is negligible.

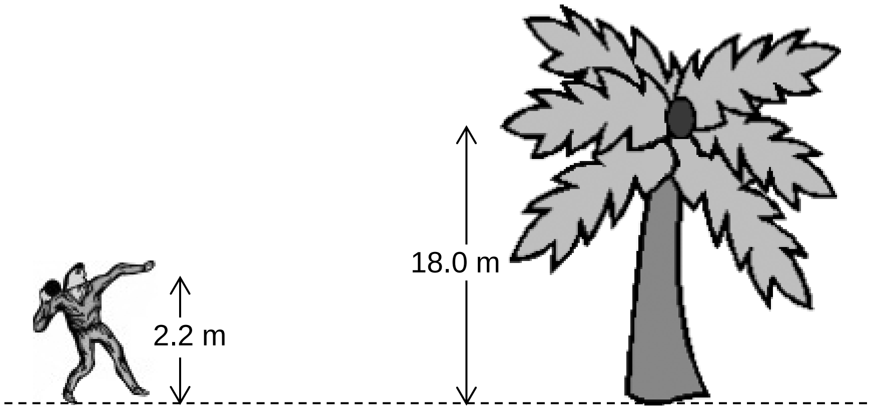

Fig. 2.1 (not to scale)

(i) Explain qualitatively, in terms of acceleration and velocity, why the path taken by the stone is *parabolic*.

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

(ii) Show that the angle at which the stone should be released from the horizontal so that it would hit the coconut horizontally is 62°.

[2]

(iii) Hence, calculate the time taken for the stone to reach its maximum height when it is projected at the angle in **(a)(ii)**.

time taken = ……………………… s [2]

(b) A spaceship engine uses solar power to ionise and eject xenon atoms from the spaceship. The speed of the ejected xenon ions is 3.0×10^4 m s^{-1} relative to the spaceship as shown in Fig. 2.2.

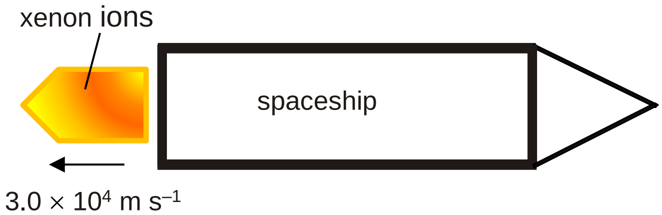

Fig. 2.2

Fig. 2.3 shows the variation with time t of the acceleration a of the spaceship due to the ejection of xenon ions.

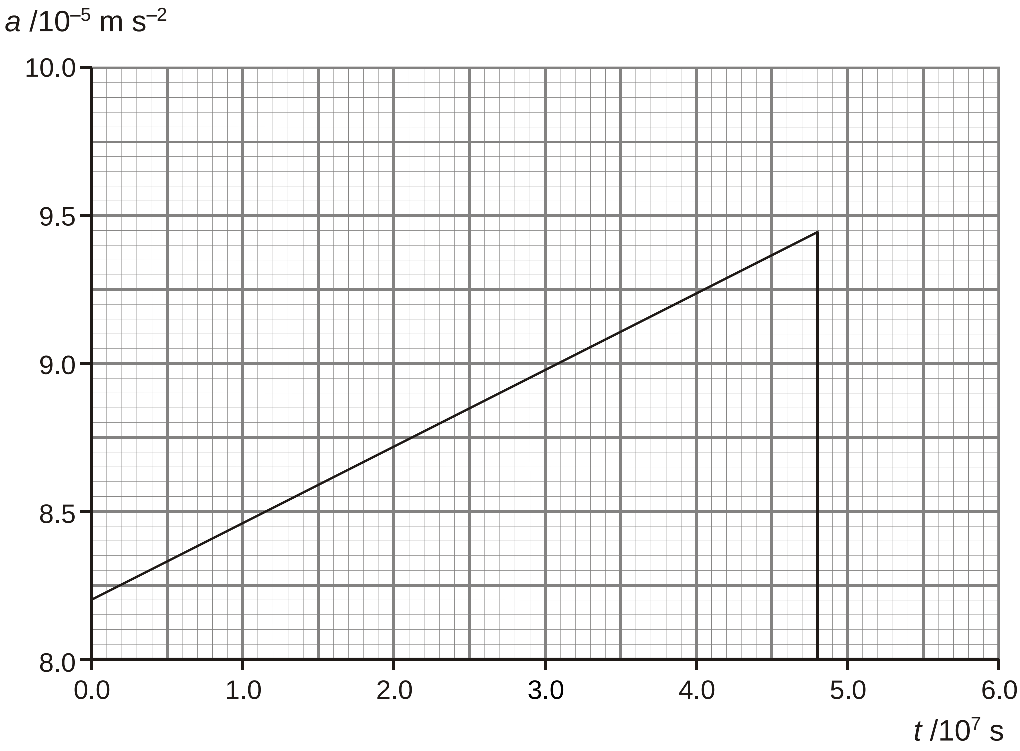

Fig. 2.3

[Turn over

For Examiner's Use

(i) Explain why the acceleration of the spaceship is increasing.

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

(ii) Given that the ions are ejected at a constant rate of 1.7×10^{-6} kg s^{-1}, calculate the magnitude of the force exerted on the spaceship by the ions.

magnitude of force = ……………………… N [2]

(iii) The spaceship is initially stationary and its engine is switched on at time $t = 0$ s.

Using Fig. 2.3, calculate the final velocity of the spaceship when the xenon ions run out completely.

velocity = ……………………… m s^{-1} [2]

(iv) On Fig. 2.4, draw the corresponding variation with time t of the velocity v of the spaceship from $t = 0$ to $t = 6.0 \times 10^7$ s.

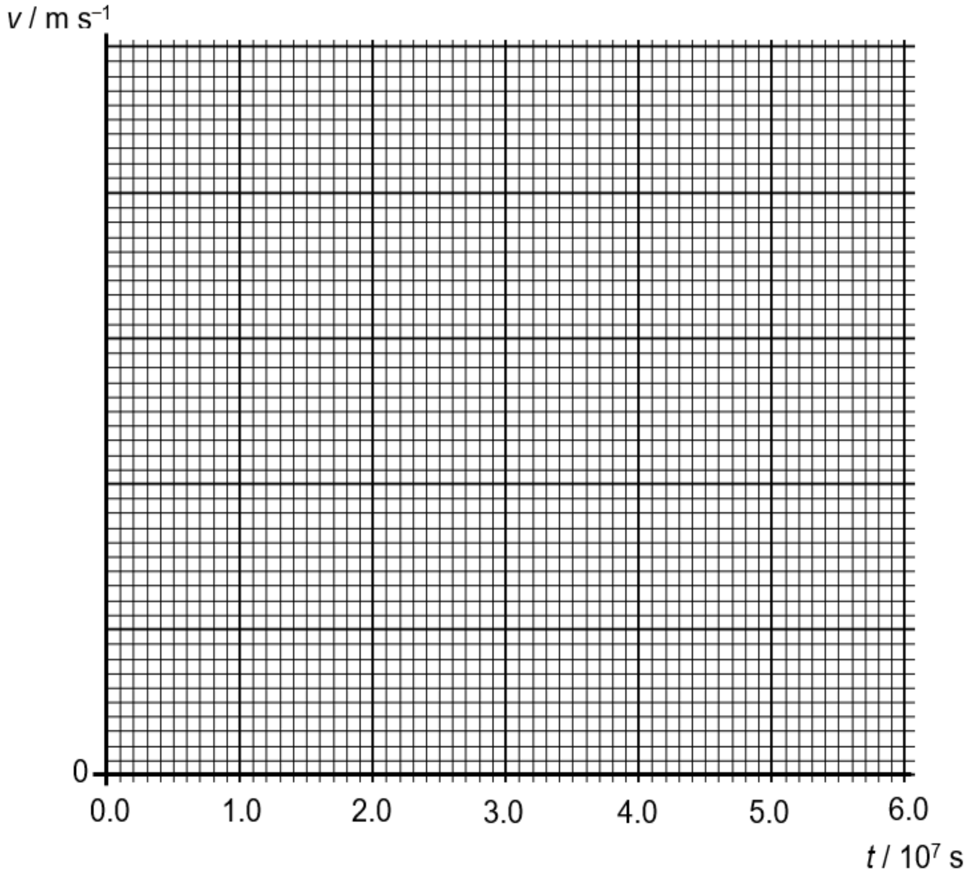

Fig. 2.4

[2]

[Total: 12]

For Examiner's Use

3 **(a)** A metal ball is released in a liquid. With the aid of a free body diagram, explain how the metal ball falling through the liquid can reach terminal velocity.

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(b) Fig. 3.1 shows a ladder resting against a smooth vertical wall at point A and on a rough ground at point B. Three forces, *P*, *Q* and *W* are acting on the uniform ladder which is 6.0 m long and has a weight of 150 N.

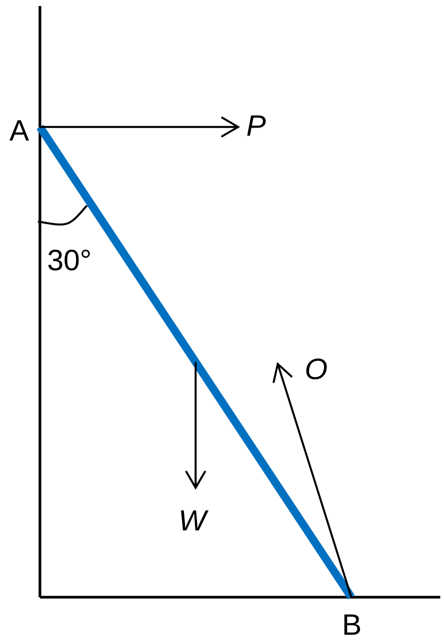

Fig. 3.1 (not to scale)

For Examiner's Use

(i) Show that the magnitude of force *P* is 43 N.

[1]

(ii) Explain why the ground must exert a force on the ladder at B to keep the ladder in equilibrium.

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

(iii) Calculate the magnitude of force *Q*.

force Q = ………………….. N [1]

[Turn over

For Examiner's Use

(iv) Assuming that there is now friction between the ladder and the vertical wall, draw possible directions of the forces acting on points X and Y in Fig. 3.2.

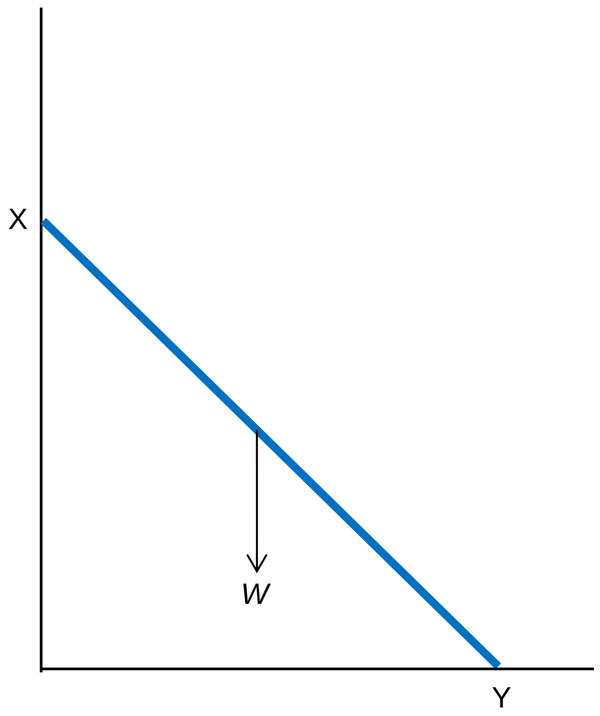

Fig. 3.2

[1]

[Total: 8]

For Examiner's Use

4 The Earth has mass M and radius R, and a uniform density ρ.

(a) Using the definition of gravitational field strength g, show that the magnitude of gravitational field strength g and distance from the centre of the Earth r in terms of G, ρ and R is given by

$$g = \frac{4\pi \rho G R^3}{3 r^2}$$

[2]

(b) The magnitude of the gravitational field strength g at a distance r inside the Earth is given by

$$g = \frac{4\pi \rho G r}{3}$$

On Fig. 4.1, sketch a graph showing the variation with distance r from the centre of the Earth of the gravitational field strength g. Values of g are not required.

Take the positive direction of g to be in the positive horizontal axis.

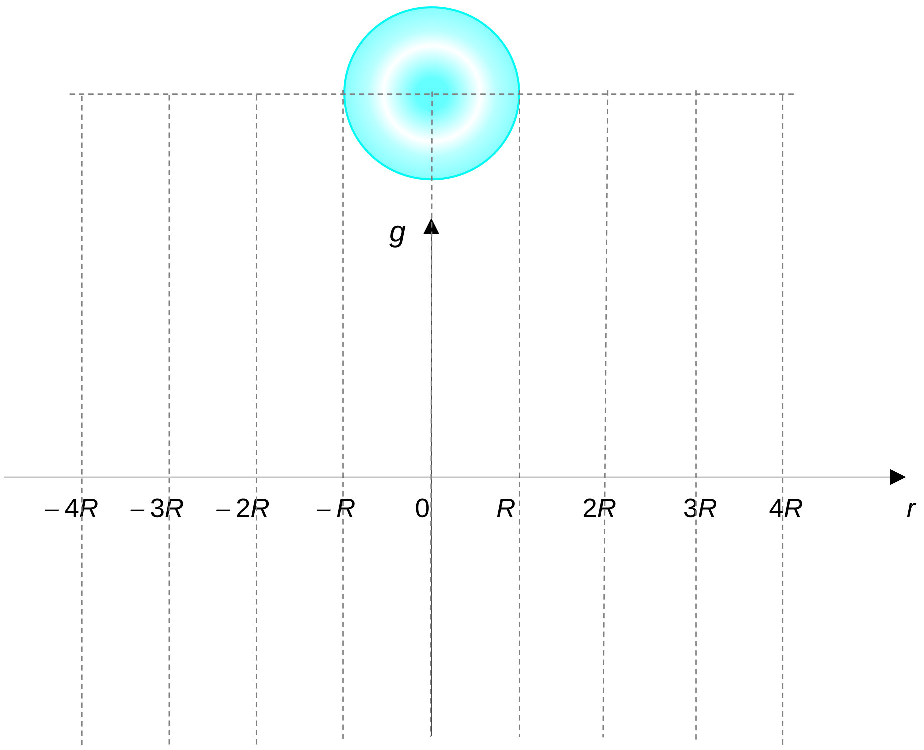

Fig. 4.1

[3]

[Turn over

For Examiner's Use

(c) Quito, Ecuador is the antipodal city of Singapore as it is situated at the other end of the straight line passing through the centre of the Earth. The two countries have built a very narrow frictionless tunnel through the centre of the Earth between Singapore and Quito as shown in Fig. 4.2.

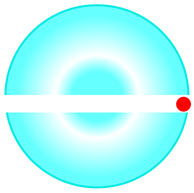

Fig. 4.2

(i) A parcel of medical supplies is released at the Singapore end of the tunnel. The Earth's gravitational field causes the parcel to oscillate with simple harmonic motion about the centre of the Earth with a period of T.

Derive an expression for T, in terms of G and ρ.

[2]

(ii) The density of the Earth ρ is 5.51 g cm^{-3}.

Hence, determine the time taken for a medical supply parcel from Singapore to arrive in Quito.

time taken = ………………….. s [2]

[Total: 9]

For Examiner's Use

5 **(a)** Two circuits are set up using the light dependent resistor LDR in Fig. 5.1(a) and Fig. 5.1(b).

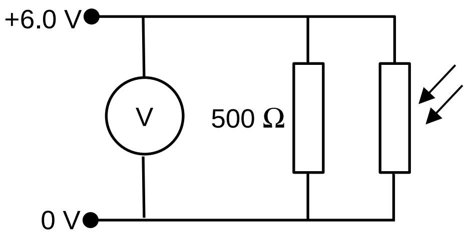

Fig. 5.1(a)

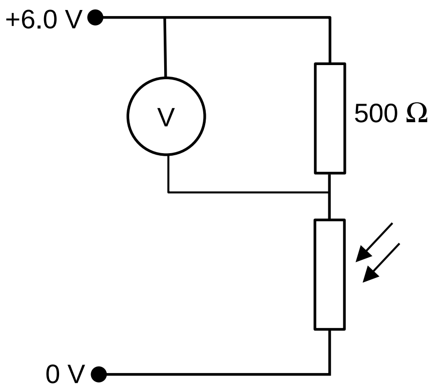

Fig. 5.1(b)

(i) For the circuit to function as a light meter, the voltmeter reading V must increase as the light intensity increases.

Explain why only the circuit in Fig. 5.1(b) can fulfil this function.

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

(ii) Calculate the resistance of the LDR when V = 3.75 V for the circuit in Fig. 5.1(b).

resistance of LDR = ………………….. Ω [2]

[Turn over

For Examiner's Use

(b) The light-emitting diode, LED, is a semiconductor light source that emits light when current flows through it.

Fig. 5.2 shows a circuit designed by a student.

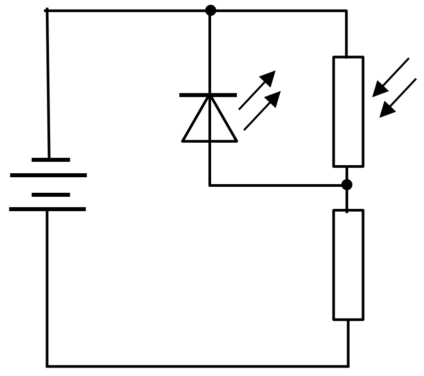

Fig. 5.2

The LED is very close to and facing the LDR. The circuit is taken into a dark room.

(i) The student thought that the LED would switch on.

Instead the LED was found to repeatedly switch on and off.

Explain this behaviour of the LED in the circuit.

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.... [2]

(ii) Suggest a possible refinement so that the LED switches on permanently when taken into the dark room.

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.... [1]

For Examiner's Use

(c) A variable resistor is connected directly across the terminals of a cell with an e.m.f. of 6.0 V. A voltmeter is connected across the variable resistor and Fig. 5.3 is obtained as the resistance of the variable resistor R changes.

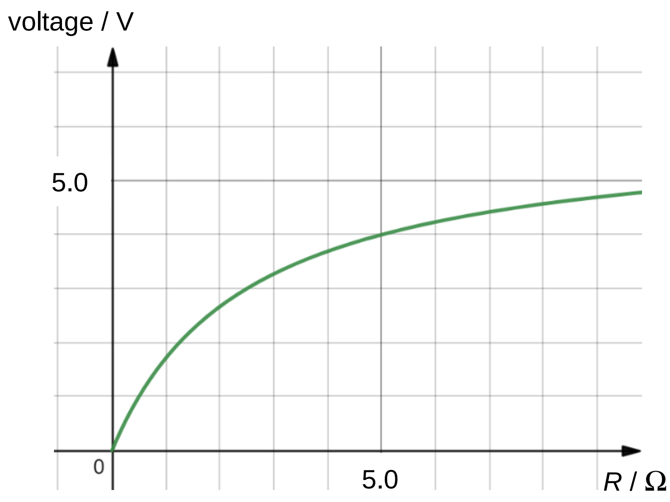

Fig. 5.3

(i) On Fig. 5.3, draw the graph representing the variation in the voltmeter reading if the cell was ideal with no internal resistance. Label the graph **N**. [1]

(ii) Using Fig. 5.3, estimate the internal resistance of the cell.

internal resistance = …………………. Ω [2]

[Total: 11]

[Turn over

For Examiner's Use

6 **(a)** Define *half-life*.

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

(b) Explain what is meant by the terms *spontaneous* and *random* when describing radioactive decay.

spontaneous: ……………………………………………………………………………

……………………………………………………………………………………………

random: …………………………………………………………………………………

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

(c) Carbon-14 ($^{14}_{6}C$) undergoes β^{-} decay to form Nitrogen (N).

(i) Complete the nuclear equation below for the decay of carbon-14 to form nitrogen.

$$^{14}_{6}C \rightarrow \,^{.....}_{.....}N + \,^{.....}_{.....}..... + \text{ energy}$$

[1]

(ii) The half-life of Carbon-14 is 5730 years.

Calculate the decay constant λ of Carbon-14.

λ = ………………….. s^{-1} [2]

For Examiner's Use

(iii) A fossil of a Neanderthal (an extinct species of archaic humans) was found. Carbon-14 dating was used to determine the age of this fossil.

A 10 kg sample of this fossil was found to have an activity rate of 5.4 Bq. On the other hand, a fresh 1.0 g sample taken from a living organism is expected to have an activity rate of 0.23 Bq.

Determine the age of the fossil.

age = ………………….. years [3]

(d) A sample of polonium-210 (Po) undergoes α-decay forming lead-206 (Pb) with no other products.

The Po nucleus was stationary before the decay and the α-particle was emitted with a velocity of v_α.

(i) Using momentum considerations, show that $\dfrac{\text{kinetic energy of Pb nucleus}}{\text{kinetic energy of } \alpha\text{-particle}}$ is 0.0194.

[3]

[Turn over

For Examiner's Use

(ii) Fig. 6.1 shows the initial positions of of the α-particle and Pb nucleus right after the decay.

The radioactive decay took placed in a magnetic field directed into the plane of the page.

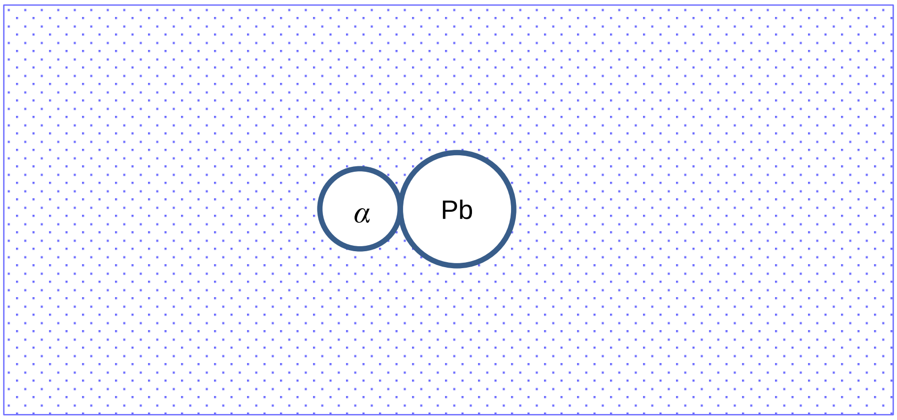


Fig. 6.1

On Fig. 6.1, sketch the paths of the emitted Pb nucleus and α-particle.

[2]

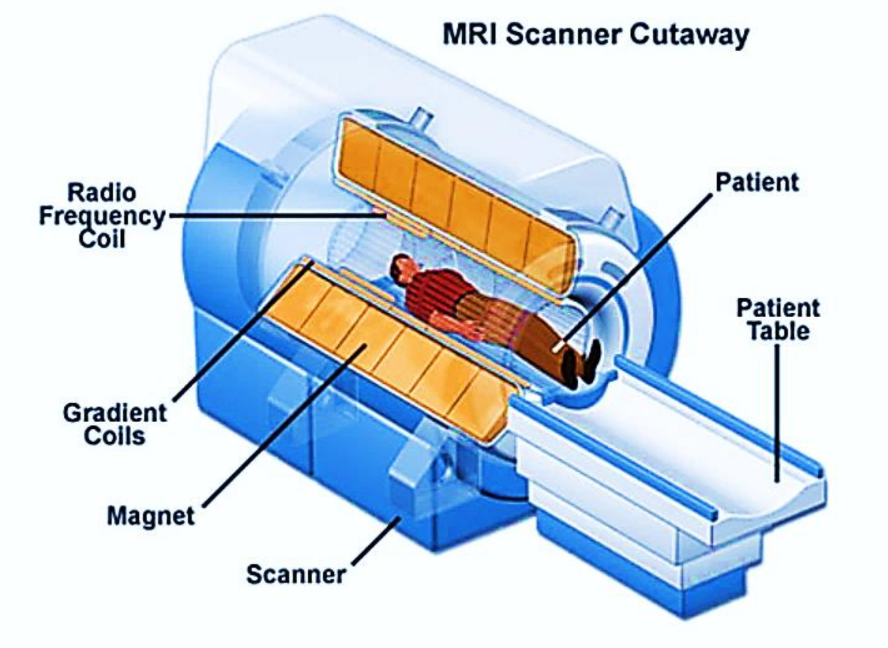
[Total: 14]

For Examiner's Use

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

Magnetic resonance imaging (MRI) is a medical imaging technique used in radiology to form pictures of the anatomy and the physiological processes of the body. MRI is widely used in hospitals and clinics for medical diagnosis, staging and follow-up of disease and provides excellent contrast in images of soft tissues, e.g., in the brain or abdomen. However, it may be perceived as less comfortable by patients, due to the usually longer and louder measurements with the subject in a long, confining tube. Additionally, implants and other non-removable metal in the body can pose a risk and may exclude some patients from undergoing an MRI examination safely.

Fig. 7.1 illustrates the basic design of an MRI scanner. The scanner consists of a main magnet of magnetic flux density 0.50 to 2.0 T, a Radio Frequency (RF) coil, gradient coils, patient table, and a computer system.



Source: https://snc2dmri.weebly.com/components--functions.html

Fig. 7.1

MRI is based on the magnetisation properties of atomic nuclei. A powerful, uniform, external magnetic field is used to align the protons that are normally randomly oriented within the water nuclei of the tissue being examined. This alignment (or magnetisation) is next disrupted by introduction of an external RF energy. The nuclei absorb the RF energy and return to their resting alignment through various relaxation processes and emit RF energy while doing so. After a certain period following the initial RF, the emitted signals are measured. The computer system then converts the signals to create different types of images.

Spin is a fundamental property of nature like electrical charge or mass. It comes in multiples of $\frac{1}{2}$. Protons and neutrons possess spin. Individual unpaired protons and neutrons each possesses a spin of $\frac{1}{2}$ while paired protons and neutrons have no spin. For example, in the deuterium nuclei ${}^{2}_{1}H$, with one unpaired proton and one unpaired neutron, the net spin is 1.

When placed in a magnetic field of magnetic flux density *B*, a particle with a net nuclear spin can absorb a photon of a particular resonance frequency ν. This is related to *B* by the equation

$$\nu = \gamma B$$

where γ is a constant called the gyromagnetic ratio, which is specific to the particle.

This process of absorption of photons by particles is called nuclear magnetic resonance. Fig. 7.2 shows the γ values of some nuclei with a net nuclear spin that are of interest in MRI.

nuclei	γ / MHz T^{-1}
${}^{1}_{1}H$	42.58
${}^{2}_{1}H$	6.54
${}^{31}_{15}P$	17.25
${}^{23}_{11}Na$	11.27

Fig. 7.2

Two factors that influence the strength of the MRI signal are the natural abundance of the isotope and biological abundance. The natural abundance of an isotope is the fraction of the element's nuclei having a given mass number while the biological abundance is the fraction of one element in the human body. Fig. 7.3 lists the natural and biological abundances of some nuclei studied in MRI.

element	nuclei	natural abundance	biological abundance
Hydrogen	${}^{1}_{1}H$	0.99985	0.63
	${}^{2}_{1}H$	0.00015	
Phosphorus	${}^{31}_{15}P$	1.00	0.0024
Sodium	${}^{23}_{11}Na$	1.00	0.00041

Fig. 7.3

Since its development in the 1970s and 1980s, in addition to detailed spatial images, MRI can also be used to form images of non-living objects, such as mummies and capture neuronal tracts and blood flow in the human nervous system.

For Examiner's Use

(a) To generate the magnetic field, the MRI scanner uses a solenoid-shaped coil made of alloys cooled in liquid helium to a temperature of 10 K to create a superconducting magnet. Fig. 7.4 shows the side view of this coil.

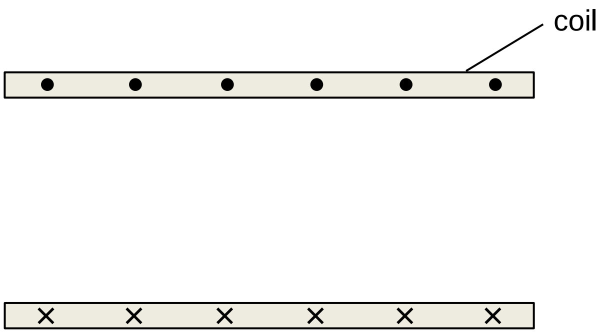


Fig. 7.4

(i) On Fig. 7.4, sketch the magnetic field generated by the coil when current flows in the coil as shown. [2]

(ii) Suggest why the coil is cooled to a temperature of 10 K.

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.... [1]

(b) Suggest why patients with implants and other non-removable metal in the body may not be allowed to undergo an MRI examination.

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.... [1]

(c) **(i)** State and explain the net spin for a Hydrogen ${}^{1}_{1}H$ nuclei.

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.... [2]

[Turn over

For Examiner's Use

(ii) Suggest why a Carbon $^{12}_{6}C$ nuclei cannot undergo nuclear magnetic resonance.

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

(d) Determine the energy of the photon that will be absorbed by a Hydrogen $^{1}_{1}H$ nuclei in a magnetic field of magnetic flux density 1.5 T.

energy = ………………….. eV [3]

(e) MRI is considered a safe imaging technique as it uses radiation that is non-ionising. The ionisation energy for a typical organic molecule is 6.0×10^{-19} J.

(i) State one effect of ionising radiation on living tissues and cells.

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

(ii) Using appropriate calculations, show that X-rays are ionising.

[2]

For Examiner's Use

(f) **(i)** Explain the significance of the Phosphorous $^{31}_{15}P$ nuclei having a natural abundance value of 1.00.

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……………………………………………………………………………………… [1]

(ii) Using the information in Fig. 7.3, explain why the hydrogen $^{1}_{1}H$ nuclei gives the strongest MRI signal among the nuclei listed.

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(iii) Hence, describe how MRI can produce excellent contrast in the images of soft tissues.

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[Total: 20]

End of Paper

[Turn over