

Class 25S	Index Number	Name
----------------------------	---------------------	-------------

ST. ANDREW'S JUNIOR COLLEGE
JC 2 2026
Preliminary Examination

PHYSICS, Higher 2

9478/02

Paper 2 Structured Questions

2nd September 2026
2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, index number and class in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- You may use an approved calculator.

INFORMATION

- The total mark for this paper is 75.
- The number of marks for each question or part question is shown in brackets [].

For Examiner's Use	
1	/ 9
2	/ 10
3	/ 6
4	/ 13
5	/ 8
6	/ 9
7	/ 20
Total	/ 75

This document has **25** pages. Any blank pages are indicated.

Data

speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permeability of free space	$\mu_0 = 4 \pi \times 10^{-7} \text{ H m}^{-1}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass constant	$u = 1.66 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on / by a gas	$W = p \Delta V$
pressure	$p = \frac{F}{A}$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T / \text{K} = T / ^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
mean translational kinetic energy of an ideal gas particle	$E = \frac{3}{2} kT$

displacement of particle in s.h.m.

$$x = x_0 \sin \omega t$$

velocity of particle in s.h.m.

$$v = v_0 \cos \omega t = \pm \omega \sqrt{x_0^2 - x^2}$$

electric current

$$I = nAvq$$

resistors in series

$$R = R_1 + R_2 + \dots$$

resistors in parallel

$$1/R = 1/R_1 + 1/R_2 + \dots$$

capacitors in series

$$1/C = 1/C_1 + 1/C_2 + \dots$$

capacitors in parallel

$$C = C_1 + C_2 + \dots$$

energy in a capacitor

$$U = \frac{1}{2} QV = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} C V^2$$

charging a capacitor

$$Q = Q_0 [1 - e^{-\frac{t}{\tau}}]$$

discharging a capacitor

$$Q = Q_0 e^{-\frac{t}{\tau}}$$

RC time constant

$$\tau = RC$$

electric potential

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

alternating current / voltage

$$x = x_0 \sin \omega t$$

magnetic flux density due to a long straight wire

$$B = \frac{\mu_0 I}{2\pi d}$$

magnetic flux density due to a flat circular coil

$$B = \frac{\mu_0 NI}{2r}$$

magnetic flux density due to a long solenoid

$$B = \mu_0 nI$$

energy states for quantum particle in a box

$$E_n = \frac{h^2}{8mL^2} n^2$$

radioactive decay

$$x = x_0 e^{-\lambda t}$$

radioactive decay constant

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

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

- 1 (a) Define acceleration.

.....
 [1]

- (b) A diver stands on a platform above a pool of water, as shown in Fig. 1.1.

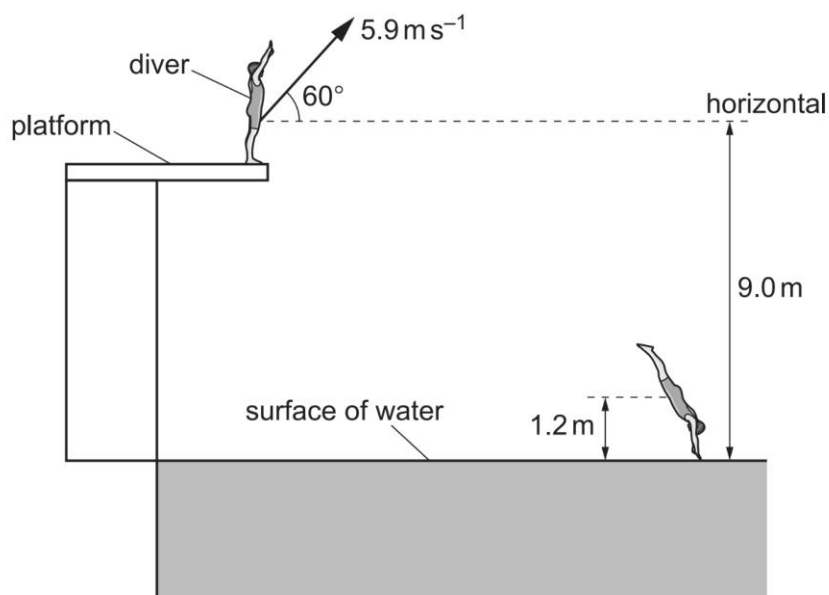


Fig. 1.1 (not to scale)

When the diver is on the platform his centre of gravity is at a vertical height of 9.0 m above the surface of the water. The diver jumps from the platform with a velocity of 5.9 m s^{-1} at an angle of 60° to the horizontal.

Air resistance is negligible.

When the diver hits the surface of the water, his centre of gravity is at a vertical height of 1.2 m above the surface of the water.

Calculate the speed of the diver at the instant he hits the surface of the water.

speed = m s^{-1} [3]

- (c) After entering the water, the 78 kg diver experiences an upward drag force of 950 N and a buoyant force of 740 N at a particular instant.
- (i) Calculate the magnitude of the resultant force and the acceleration of the diver at this instant.

resultant force = N

acceleration = m s^{-2} [3]

- (ii) Describe and explain the variation of the drag force acting on the diver in the water as he moves downwards.

.....

.....

.....

..... [2]

- 2 A steel ball is placed on the inside surface of a hollow circular cone. The ball moves in a horizontal circle at constant speed, as shown in Fig. 2.1.

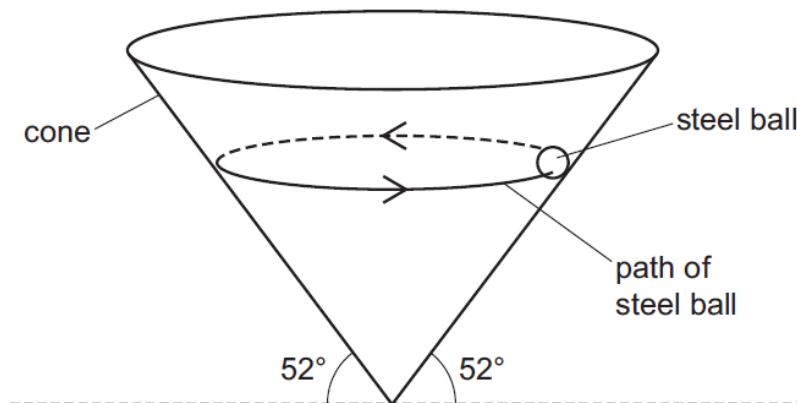


Fig. 2.1

The angle of the side of the cone to the horizontal is 52° . There is no friction between the ball and the cone.

- (a) Fig. 2.2 shows a cross-section through the cone and the steel ball.

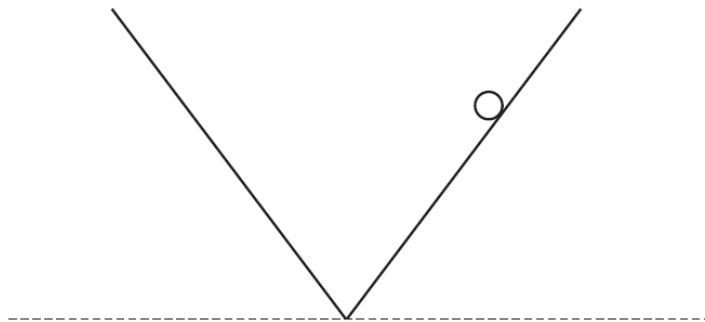


Fig. 2.2

On Fig. 2.2, draw labelled arrows to show the two forces acting on the ball. [2]

- (b) Describe how the forces acting on the ball cause its acceleration to be centripetal.

.....

 [2]

- (c) The ball moves in a circle of radius 0.15 m. Show that the speed of the ball is 1.4 m s^{-1} .

- (d) Calculate the angular speed ω of the ball.

[3]

$\omega = \dots\dots\dots \text{ rad s}^{-1}$ [1]

- (e) The speed of the ball is increased. State and explain what happens to the radius of the circular path of the ball.

.....

 [2]

- 3 A sample of gas contains a fixed amount of gas. The gas has pressure p , volume V and thermodynamic temperature T .

Fig. 3.1 shows the variation of pV with kT for the sample, where k is the Boltzmann constant.

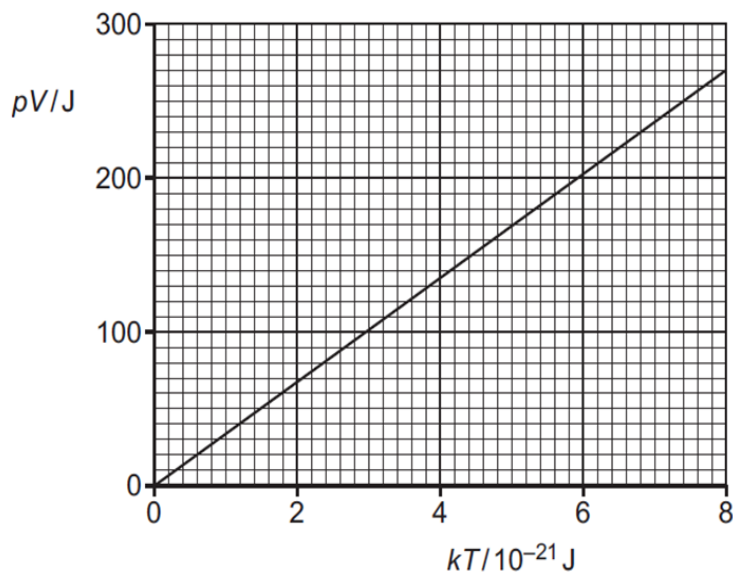


Fig. 3.1

- (a) (i) Explain what is indicated about the nature of the gas from the variation shown in Fig. 3.1.

..... [1]

- (ii) Determine the amount n of molecules of the gas in the sample.

$n = \dots\dots\dots$ mol [2]

- (b) The root-mean-square (r.m.s.) speed of the molecules of the gas is 1900 m s^{-1} when pV is equal to 270 J .

Determine the mass of one molecule of the gas.

mass = u [3]

- 4 (a) Define electric potential at a point.

.....

 [2]

- (b) A hydrogen atom may be considered to consist of a proton and an electron separated by a distance of 120 pm, as shown in Fig. 4.1.

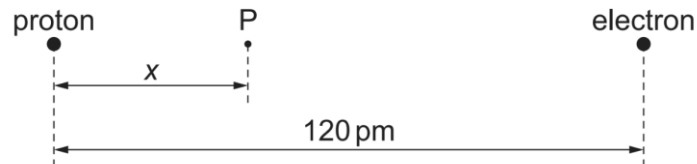


Fig. 4.1

The two particles may be considered as point charges.

Point P lies on the line joining the electron and the proton and is at a variable distance x from the proton.

- (i) 1. Show that the electric potential V at point P when $x = 10$ pm is equal to 130 V.

[2]

2. Calculate V when $x = 30$ pm.

$V = \dots\dots\dots V$ [1]

3. On Fig. 4.1, draw a cross (×) at one position, other than infinity, where the electric potential is zero. [1]

4. On Fig. 4.2, sketch the variation of V with x between $x = 10$ pm and $x = 110$ pm. [3]

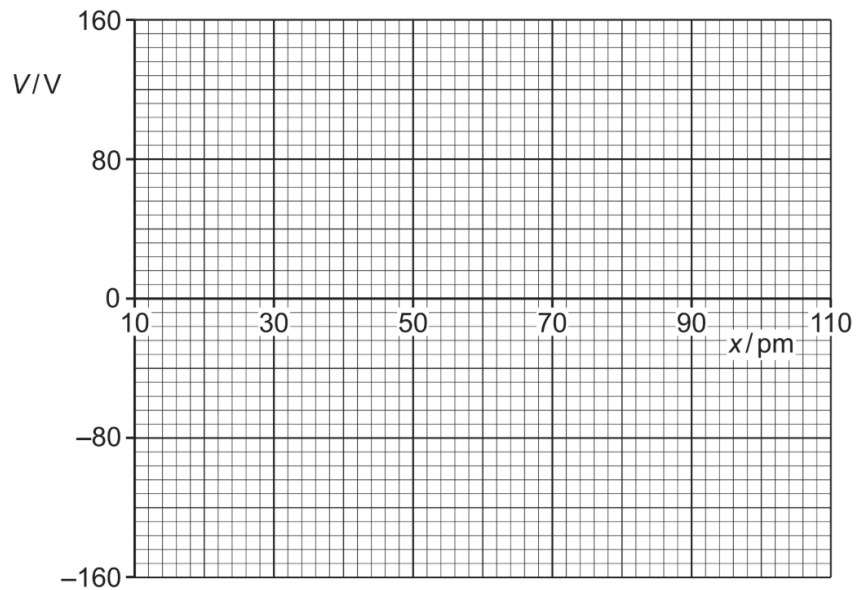


Fig. 4.2

- (ii) Calculate the resultant electric field strength at the position identified in (b)(i)3.

electric field strength = N C^{-1} [2]

- (iii) Fig. 4.3 shows the hydrogen atom placed in a non-uniform electric field E , for which field lines are shown. Describe the initial motion of the hydrogen atom at this instant.

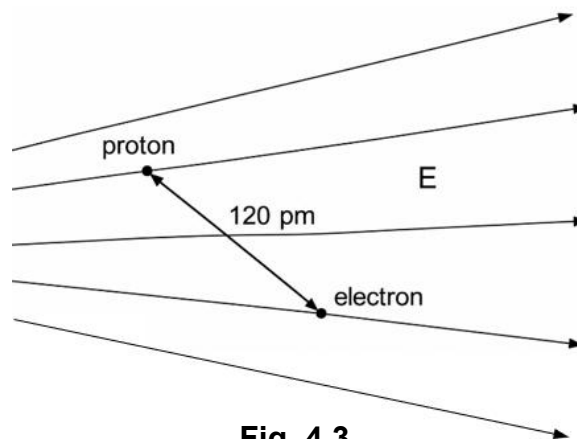


Fig. 4.3

.....
 [2]

- 5 (a) Define *magnetic flux density*.

.....

 [2]

- (b) A cyclotron accelerates charged particles to high energies. The simplified diagram in Fig. 5.1 shows the two 'dees' of a cyclotron with a gap in between. There is an electric field at the gap created by a high frequency alternating potential difference. The dashed line shows the path of an accelerated proton. In the shaded region, a uniform magnetic field of 0.80 T acts perpendicularly to the plane of the paper.

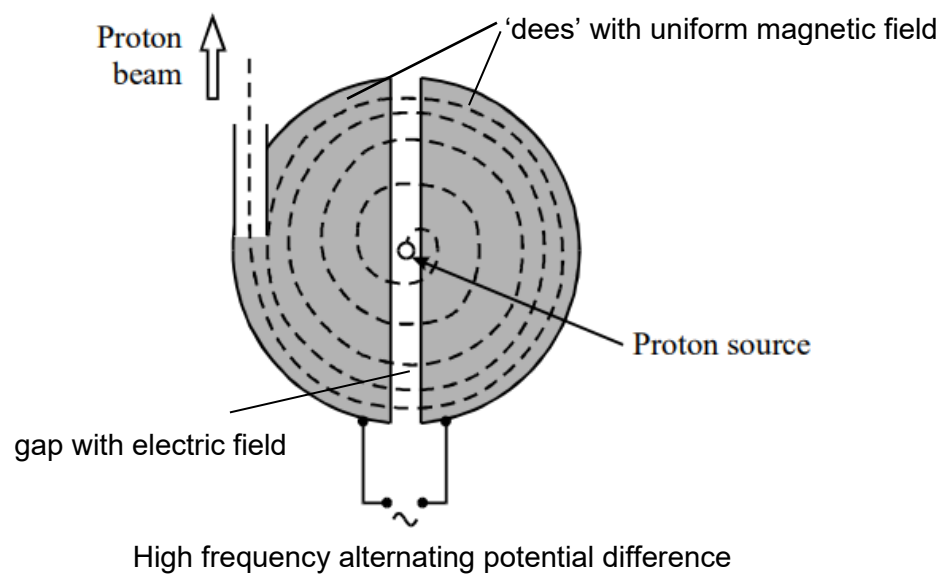


Fig. 5.1

- (i) State and explain if the direction of the magnetic field is into the plane or out of the plane of the paper.

.....

 [2]

- (ii) By considering a proton of mass m and charge e moving in a circle of radius r in a uniform magnetic field B , show that the kinetic energy KE can be expressed as

$$KE = \frac{B^2 e^2 r^2}{2m}$$

[2]

- (iii) The potential difference across the gap is reversed every time the proton completes half a revolution. Explain how the alternating potential difference increases the kinetic energy of the proton continuously.

.....

.....

.....

.....

..... [2]

- 6 (a) A small coil of wire is situated in a non-uniform magnetic field, as shown in Fig. 6.1.

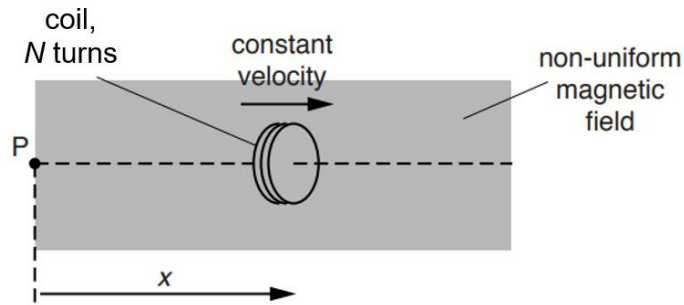


Fig. 6.1

The coil consists of N turns of wire and moves with a constant speed in a straight line.

The coil has displacement x from a fixed point P.

The variation with x of the e.m.f. E induced in the coil for values of x from $x = 0$ to $x = 6.0$ cm is shown in Fig. 6.2.

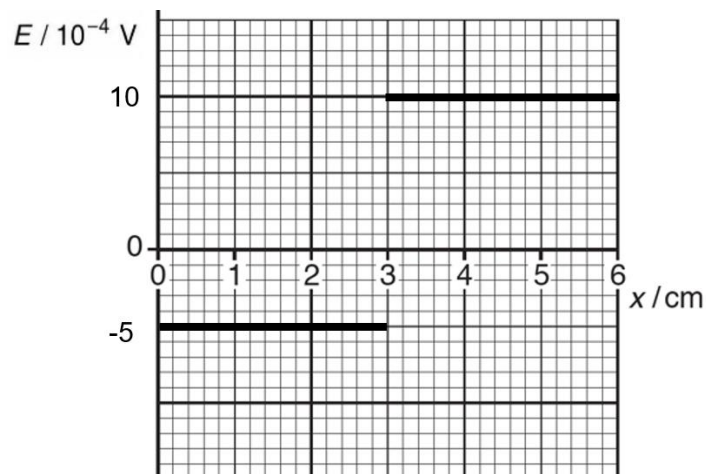


Fig. 6.2

- (i) The increase in the magnetic flux linkage of the coil is 8.0×10^{-5} Wb-turns when the coil moves from point P to the point where $x = 3.0$ cm. Using Fig. 6.2, determine the speed of the coil.

speed = m s^{-1} [2]

- (ii) The magnetic flux at P is 3×10^{-6} Wb and the magnetic flux at $x = 3$ cm is 5×10^{-6} Wb. Determine N , the number of turns in the coil.

$N = \dots\dots\dots$ turns [1]

- (iii) On Fig. 6.3, sketch the variation with x of the magnetic flux linkage Φ for values of x from $x = 0$ cm to $x = 6.0$ cm. [2]

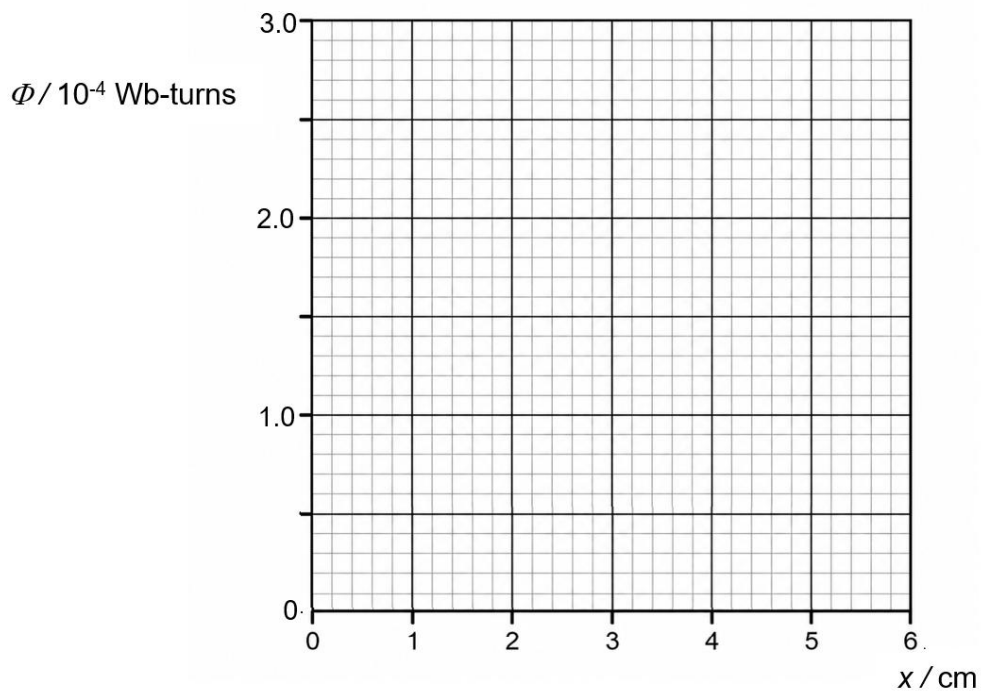


Fig. 6.3

- (b) A metal ring is suspended from a fixed point P by means of a thread, as shown in Fig. 6.4.

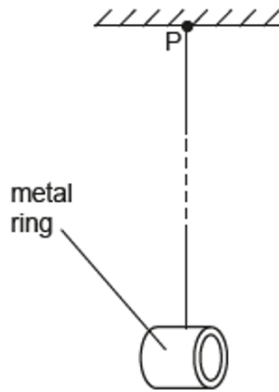


Fig. 6.4

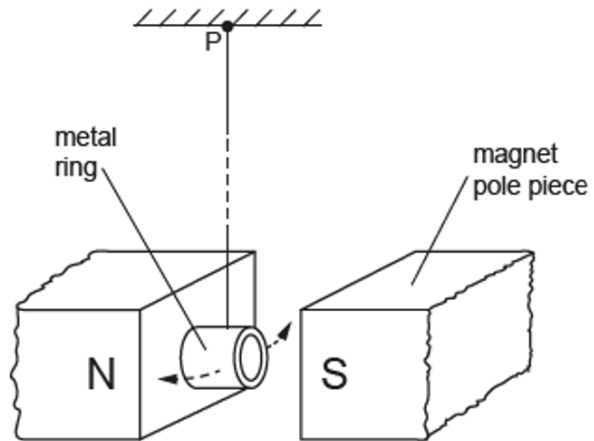


Fig. 6.5

The ring is displaced a distance d and then released. The ring completes many oscillations before coming to rest.

The poles of a magnet are now placed near to the ring so that the ring hangs midway between the poles of the magnet, as shown in Fig. 6.5.

The ring is again displaced a distance d and then released.

Explain why the ring completes fewer oscillations before coming to rest.

.....

.....

.....

.....

.....

.....

..... [4]

BLANK PAGE

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

X-ray and magnetic resonance imaging (MRI) are some modern imaging techniques in medicine that uses externally placed devices to obtain diagnostic information from underneath the skin.

A modern form of X-ray tube used to obtain the internal body structure of a patient is shown in Fig. 7.1.

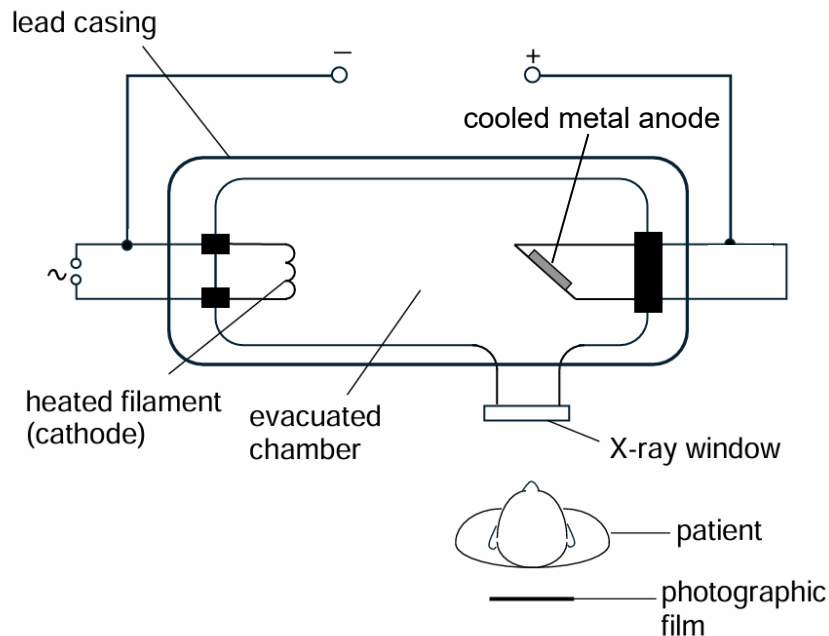


Fig. 7.1 (not to scale)

In the X-ray tube, electrons emitted from the heated filament are accelerated through a large potential difference towards the cooled metal anode, producing X-rays. The filament at the cathode is typically made of thin tungsten wire which is heated to about 2000 °C to produce electrons via thermionic emission. The X-rays produced are controlled and directed to leave the X-ray tube via a window.

As the X-ray beams pass through the patient, varying degrees of X-ray gets absorbed, depending on the composition of the body. The remaining X-rays then reach the photographic film where a contrast image of the internal body structure is obtained.

Good contrast is achieved if there is a clear difference in the blackening of the photographic film as the X-ray passes through and gets absorbed by different types of tissue in the patient. Typically, a good contrast is obtained when the ratio of **the intensity of the** transmitted X-rays between different body parts has an order of magnitude of at least 1.

The decrease in intensity of a beam of X-ray as it passes through matter is represented by the equation:

$$I = I_0 e^{(-\mu x)}$$

where

I_0 is the initial intensity,

x is the thickness of the material,

I is the transmitted intensity and μ is the absorption (attenuation) coefficient.

Table 7.1 shows the absorption (attenuation) coefficient of some matter with 30 keV X-rays.

Table 7.1

matter	μ / cm^{-1}
blood	0.41
bone	2.46
brain	0.41
muscle	0.40

- (a) Suggest a reason why tungsten is used for the filament at the cathode of an X-ray tube.

.....
 [1]

- (b) Using the data in Table 7.1, determine the thickness of bone required to reduce the intensity of 30 keV X-rays to half of its initial value.

thickness = cm [2]

- (c) A cross-section of a model arm is shown in Fig. 7.2. In an investigation into the absorption of X-ray radiation in the model arm, parallel X-ray beams of 30 keV are directed along the line MM and along the line BB.

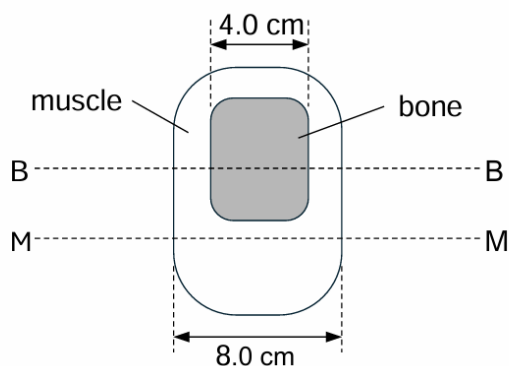


Fig.7.2

- (i) Show that the ratio of

$$\frac{\text{intensity of transmitted X-ray beam from model}}{\text{intensity of incident X-ray beam on model}}$$

for a parallel X-ray beam directed along

1. the line MM is 0.041.

[1]

2. the line BB is 0.000011.

[2]

- (ii) Explain whether the X-ray image obtained has good contrast.

.....

.....

..... [2]

Magnetic resonance imaging (MRI) is another imaging technique that relies on the fact that some atomic nuclei behave like tiny magnets in an external magnetic field. In MRI, it is usually the nuclei of hydrogen atoms that are studied, since hydrogen is abundant in the human body. The nucleus of a hydrogen atom consists of a single proton, which has a property called spin.

When a strong external magnetic field is applied, the spin axis of a hydrogen nucleus does not simply align directly along the external magnetic field. Instead, it rotates about the direction of the magnetic field, similar to the axis of a spinning top, as shown in Fig. 7.3. This rotational motion of the spin axis is known as precession.

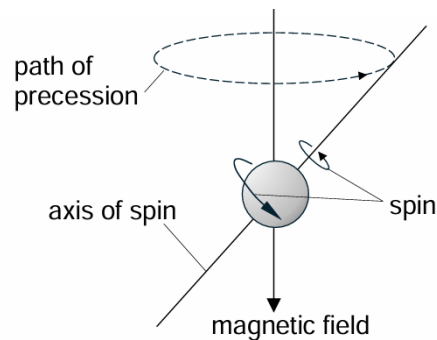


Fig. 7.3

The angular frequency of precession is called the Larmor frequency, ω_0 , and depends on the individual nucleus and the magnetic flux density B_0 of the magnetic field.

$$\omega_0 = \gamma B_0$$

The quantity γ is the gyromagnetic ratio for the nucleus and is a measure of its magnetism. For hydrogen nucleus, the ratio is approximately $2.68 \times 10^8 \text{ rad s}^{-1} \text{ T}^{-1}$.

Fig. 7.4 shows an MRI scanner comprising three sets of coils: a main coil, gradient coils and a radio frequency (RF) coil.

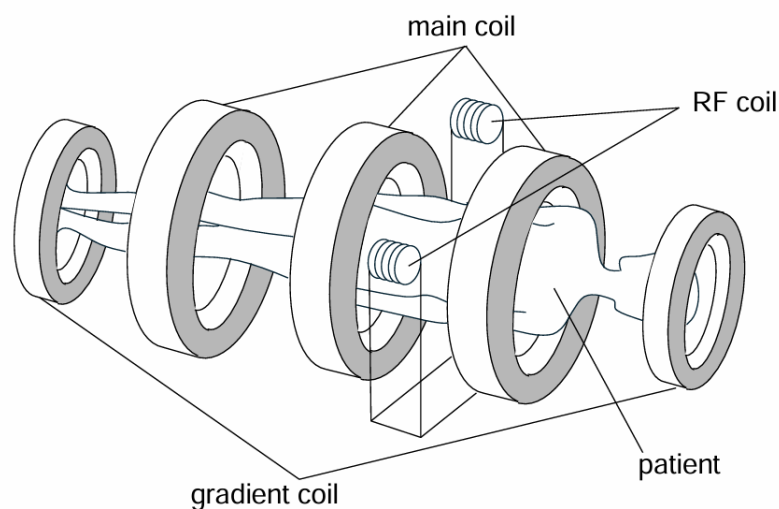


Fig. 7.4

The main coil is a solenoid 2.2 m long. It carries a current of 750 A to produce a strong uniform magnetic flux density of 1.5 T. To achieve superconductivity to carry the high current, the main coil is cooled using liquid helium to a temperature slightly below the boiling point of helium at 4.2 K.

The gradient coils produce additional magnetic fields that cause the magnetic flux density to vary with position across the patient. This allows signals from different regions of the body to be distinguished.

The RF coil sends RF pulses into the body, causing the hydrogen nuclei to oscillate. When the RF pulse is switched off, the nuclei relax and release energy as RF waves. The rate of relaxation depends on the type of tissue and is characterised by the spin-lattice relaxation time, t .

Table. 7.2 shows typical values of t for different tissues at a magnetic flux density of 1.5 T.

Table 7.2

matter	t / ms
blood, oxygenated	1200-1600
bone	< 100
brain, gray matter	900-1300
brain, white matter	600-800
muscle	900-1000

Different tissues can be distinguished by the different rates at which they release energy after they have been forced to oscillate.

- (d) State the function of the gradient coils in the MRI scanner and suggest how this function is achieved.

.....

 [2]

- (e) MRI scanning typically takes 30 minutes to more than 1 hour. Explain why MRI is particularly suitable for producing detailed images of the brain consisting of blood and brain matter compared to X-ray, despite the longer duration compared to X-ray.

.....

 [2]

- (f) Suggest two disadvantages of using MRI.

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

- (g) Determine the number of turns in the main coil of the MRI scanner.

number of turns = [2]

- (h) Using the Larmor frequency, determine the frequency of the pulse of the RF waves required to cause nuclear magnetic resonance of hydrogen nuclei in the MRI scanner with an external magnetic field produced by the solenoid.

frequency = Hz [2]

- (i) During an MRI procedure, a small segment of the main coil loses its superconductivity, and the resistance of the wire suddenly increases to $0.0045\ \Omega$. An increase in temperature of the main coil occurs, causing liquid helium to rapidly vaporise. The latent heat of vaporisation of helium is $21\ \text{kJ kg}^{-1}$.

Determine the initial rate of vaporisation of liquid helium.

initial rate of vaporisation = kg s^{-1} [2]

End of Paper