Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2018 Preliminary Examination

PHYSICS **9749/03**
Higher 2

18 September 2018
Paper 3 Longer Structured Questions **2 hours**

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

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.

Section B
Answer **one** question only and **circle the question number** on the cover page.

You are advised to spend one and half hours on Section A and half an hour on Section B.
The number of marks is given in brackets [ ] at the end of each question or part question.

***This booklet only contains Section A.**

For Examiner's Use		
Section A	1	/ 10
	2	/ 12
	3	/ 12
	4	/ 13
	5	/ 13
Section B (circle 1 question)	6	/ 20
	7	/ 20
Deduction		
Total		/ 80

This document consists of **15** printed pages.

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	=	$-Gm/r$
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	=	$x_0 \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos\omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
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	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

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

1 During a space expedition on the Moon, a table tennis ball is dropped in a large, enclosed container on the surface of the Moon. The container contains air from the Earth. Special arrangements are made to ensure that the pressure of the air is maintained at the Earth's atmospheric pressure. The variation with time *t* of the speed *v* of the table tennis ball is shown in Fig. 1.1.

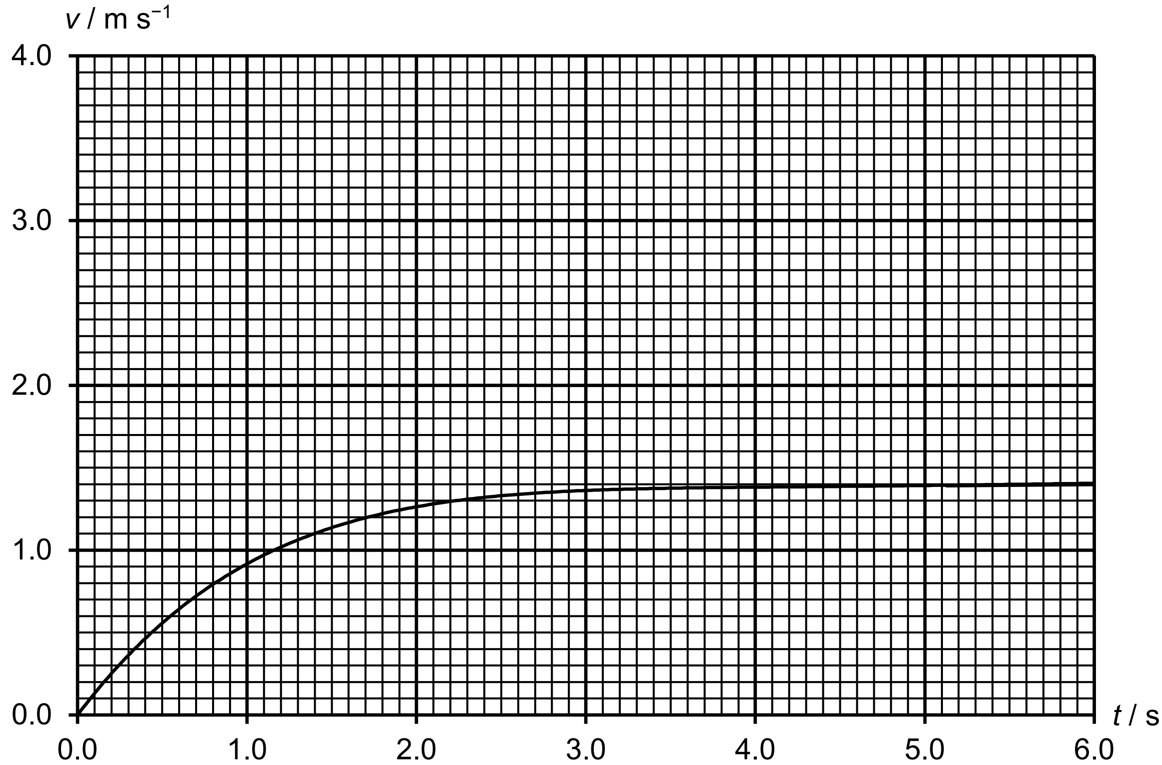

Fig. 1.1

The mass of the table tennis ball is 2.7 g.

(a) **(i)** Use Fig. 1.1 to determine the acceleration of free fall *g* of the ball on the surface of the Moon. Show your construction on Fig. 1.1.

g = ... m s^{-2} [2]

(ii) If the table tennis ball were dropped *outside* the container, determine the time taken for it to reach the value of the constant speed in Fig. 1.1.

time = ... s [1]

(b) The resistive force F acting on the table tennis ball is related to its speed v by the equation

$$F = kv$$

where k is a constant.

(i) Calculate the maximum resistive force experienced by the ball as it falls inside the container.

maximum resistive force = ... N [1]

(ii) Using your answer in **(b)(i)**, deduce the value of k.

k = ... kg s^{-1} [1]

(iii) Determine the maximum speed of the table tennis ball if this experiment is conducted on the surface of the Earth.

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

(iv) Sketch, on Fig. 1.1, a new graph showing the variation with time t of the speed v of the table tennis ball when the experiment is repeated with the following changes made independently:

1. Liquid nitrogen of 1.5 times the mass of the ball is injected into the ball. Label this graph P.

2. The ball is thrown vertically downwards with an initial speed of 4.0 m s^{-1}. Label this graph Q.

[3]

2 **(a)** **(i)** Define gravitational field strength.

....

.... [1]

(ii) Hence, state with a reason, if gravitational field strength is a scalar or vector quantity.

....

.... [1]

(iii) State Newton's law of gravitation and use your definition in **(a)(i)** to write down an expression for the gravitational field strength *g* at a distance *R* from a point mass *M*.

....

....

....

....

.... [2]

(b) The mass of planet Jupiter is 1.90×10^{27} kg and its radius is 7.14×10^{7} m. The radius of Jupiter's orbit around the Sun is 7.79×10^{11} m. The mass of the Sun is 1.99×10^{30} kg.

(i) Calculate the ratio

$$\frac{\text{gravitational field strength on the surface of Jupiter due to the Sun}}{\text{gravitational field strength on the surface of Jupiter due to the mass of Jupiter}}.$$

ratio = ... [2]

(ii) Hence explain if the gravitational field strength due to the Sun on the surface of Jupiter can be neglected.

....

.... [1]

(c) The Galilean moons are the largest moons of Jupiter which were first discovered by Galileo in January 1610. Some of the data of the 3 Galilean moons closest to Jupiter are given in Fig. 2.1.

Name of moon	Io	Europa	Ganymede
Average orbital radius / m	4.22×10^{8}	6.71×10^{8}	1.07×10^{9}

Fig. 2.1

(i) For moons revolving around a planet in circular orbits, determine that the orbital period T of a moon is given by

$$T^2 = KR^3$$

where R is the radius of the orbit and K is a constant. Explain your working clearly.

[3]

(ii) Hence, show that the orbital period of Io : Europa : Ganymede is 1 : 2 : 4 approximately.

[2]

3 A test-tube is partially loaded with small ball bearings such that it is able to float upright in water of density ρ as shown in Fig. 3.1. The bottom of the test-tube is a distance H below the water surface.

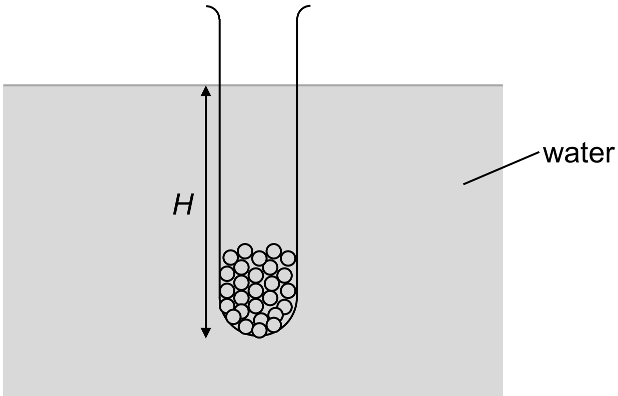

Fig. 3.1

Ignoring its rounded bottom, the test-tube may be regarded as a cylinder of cross sectional area A and mass m. The mass of the ball bearings added is M.

(a) Derive an expression that relates H to A, ρ, M and m.

[2]

(b) The test-tube is displaced vertically by displacement y and then released. Ignoring dissipative forces,

(i) write down, in terms of ρ, A, g and y, an expression for the net force acting on the loaded test-tube,

.... [1]

(ii) show that the acceleration of the test-tube is given by

$$a = -\left(\frac{\rho A g}{M + m}\right) y$$

where g is the acceleration of free fall.

[1]

(c) It is given that $\rho = 1.00 \times 10^3$ kg m^{-3}
$A = 6.0 \times 10^{-4}$ m^2
$M = 0.012$ kg
$m = 0.025$ kg

Show that the period of oscillation of the test-tube is 0.50 s.

[3]

(d) In practice, it is observed that the variation with time t of the vertical displacement y of the test-tube is as shown in Fig. 3.2.

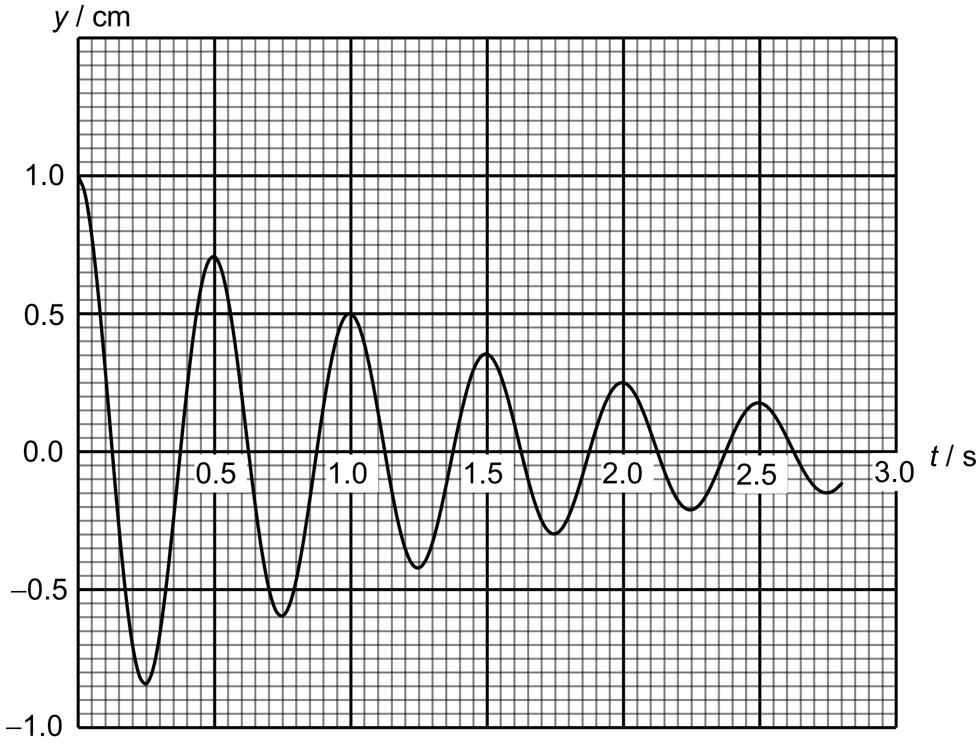

Fig. 3.2

Explain why the amplitude of the oscillations decreases gradually over time.

....

....

.... [2]

(e) To sustain the oscillations of the test-tube, low-amplitude water waves of frequency 0.30 Hz are generated on the surface of the water.

(i) Sketch a graph to show the variation with time *t* of the vertical displacement *y* of the test-tube when it is oscillating steadily. Numerical values are not required for the graph.

[1]

(ii) It is observed that the amplitude of the vertical oscillations of this test-tube is rather small. Without changing the water waves, suggest with reasoning how the amplitude of the oscillations of this test-tube may be increased.

....

....

....

.... [2]

4 **(a)** **(i)** State the principle of superposition.

....

....

.... [2]

(ii) Use Huygen's principle to explain the interference pattern formed when waves of a single wavelength pass through a single slit.

....

.... [1]

(b) A parallel beam of light of wavelength 600 nm from a point source is incident normally on a rectangular slit of width 0.30 mm as shown in Fig. 4.1. Light passing through the slit is incident on a screen placed a distance *D* from the slit.

The centre of the interference pattern formed on the screen is at O. The angle a light ray emerging from the slit makes with the normal line between the slit and the screen is θ.

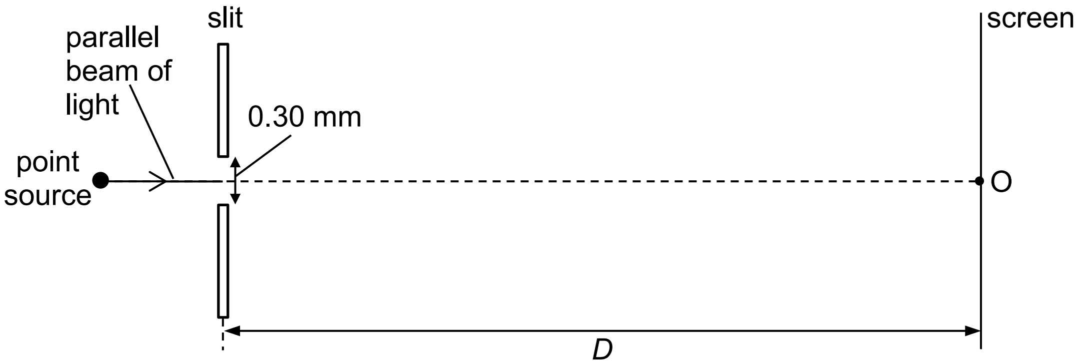

Fig. 4.1 (not to scale)

(i) On the axes in Fig. 4.2, sketch a graph to show the variation with $\sin\theta$ of the intensity I of the light on the screen. Include appropriate values along the $\sin\theta$ axis.

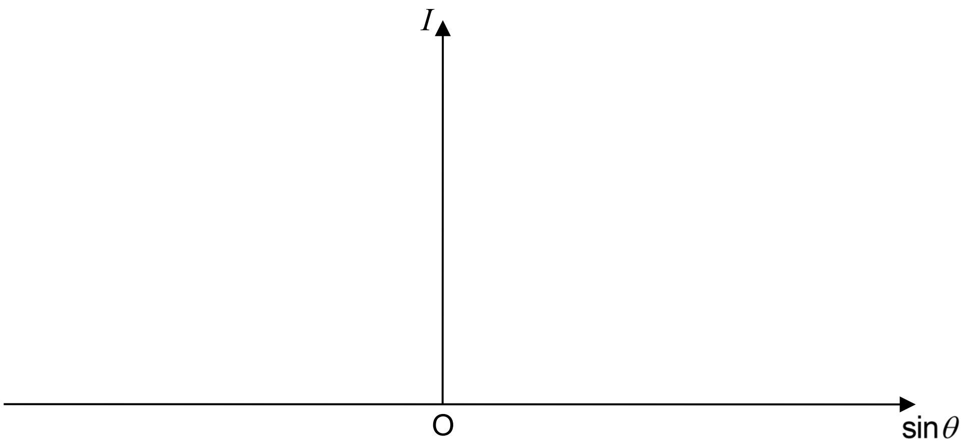

Fig. 4.2

[3]

(ii) Another identical point source of light is placed at a distance of 1.0 mm from the first point source as shown in Fig. 4.3. Both sources are 0.25 m from the slit. Light from each source forms a separate interference pattern on the screen.

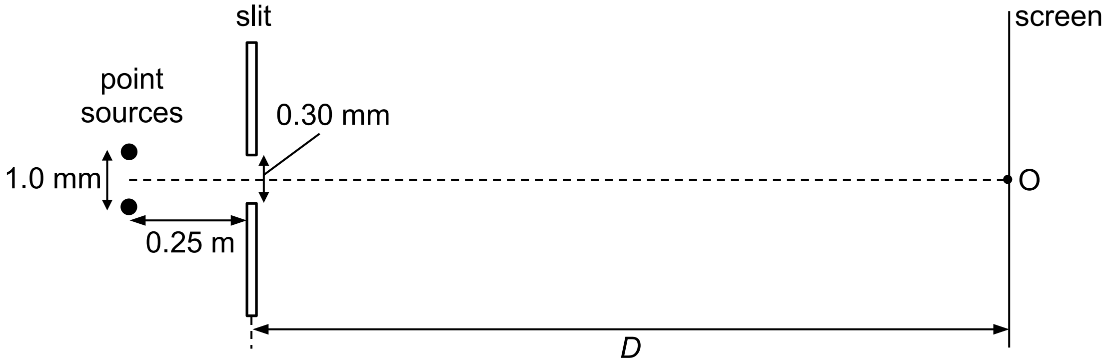

Fig. 4.3 (not to scale)

Determine, with appropriate calculations, if it is possible to resolve the images of the two sources on the screen.

The two interference patterns can / cannot be resolved. [2]

(c) The single slit in Fig. 4.1 is replaced with double slits each with the same slit width of 0.30 mm and with a slit separation of 1.2 mm. There is only one point source and light from the point source is incident normally on the slits.

(i) Determine the number of maxima observed within the central fringe of the single slit interference pattern. Explain your working clearly.

number of maxima = ... [3]

(ii) If the width of the central fringe is 12 mm, calculate the perpendicular distance *D* between the double slits and the screen.

D = ... m [2]

5 **(a)** State Faraday's law of electromagnetic induction.

....

....

.... [1]

(b) Fig. 5.1 shows a coil of 400 turns and cross-sectional area of 4.2×10^{-4} m^2 placed in the middle of a long solenoid. The coil is connected to a sensitive ammeter. The solenoid is connected to a variable resistor and a sinusoidally-alternating voltage supply.

The variation with time *t* of the magnetic flux density *B* in the solenoid is shown in Fig. 5.2.

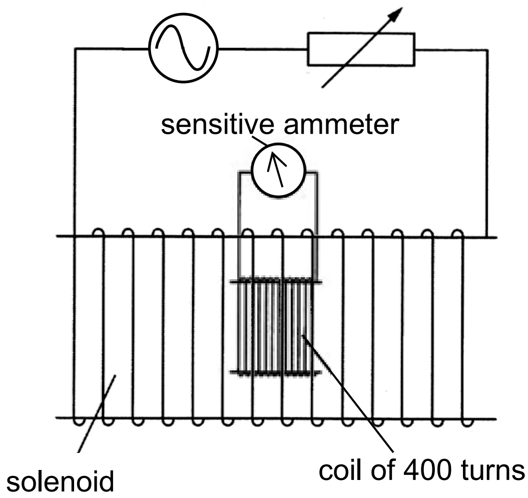

Fig. 5.1

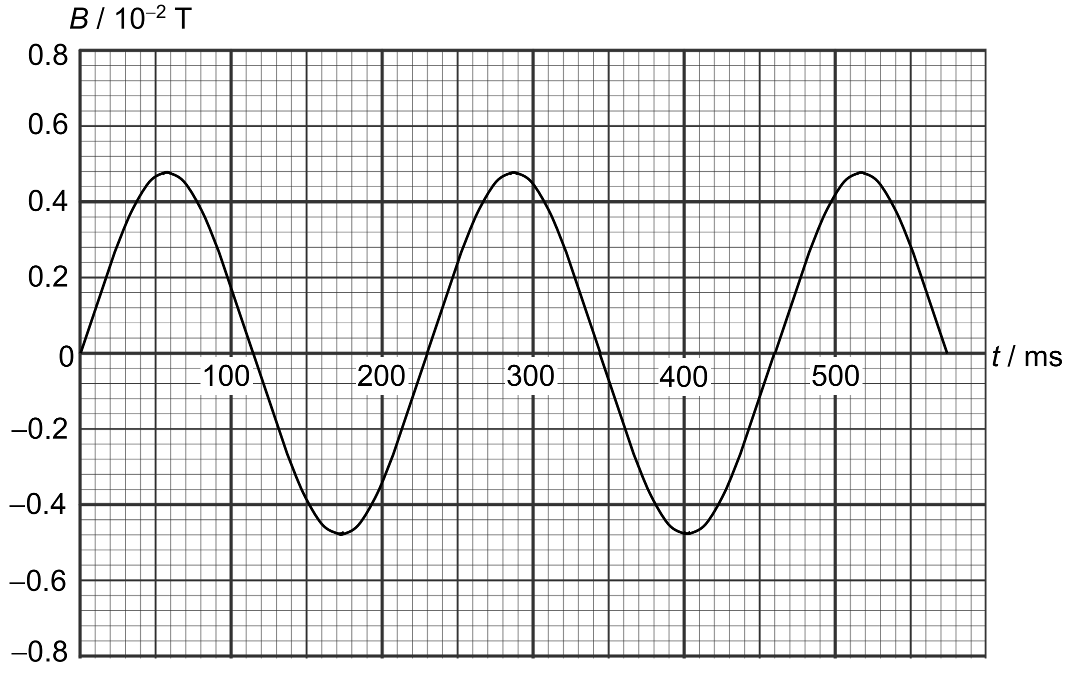

Fig. 5.2

(i) Explain, with reference to the magnetic field in the solenoid, why the sensitive ammeter deflects in opposite directions.

....

....

....

....

.... [2]

(ii) Using Fig. 5.2,

1. state a value of t when the magnitude of the induced e.m.f. is maximum,

t = ... s [1]

2. hence determine the maximum induced current in the coil given that the resistance of the coil is 5.0 Ω,

maximum induced current = ... A [3]

3. calculate the mean power dissipated by the coil.

mean power dissipated = ... W [2]

(iii) Sketch on Fig. 5.3, a graph to show the variation with time t of the induced current i in the coil from t = 0 ms to t = 460 ms. Include appropriate scale markings on the vertical axis.

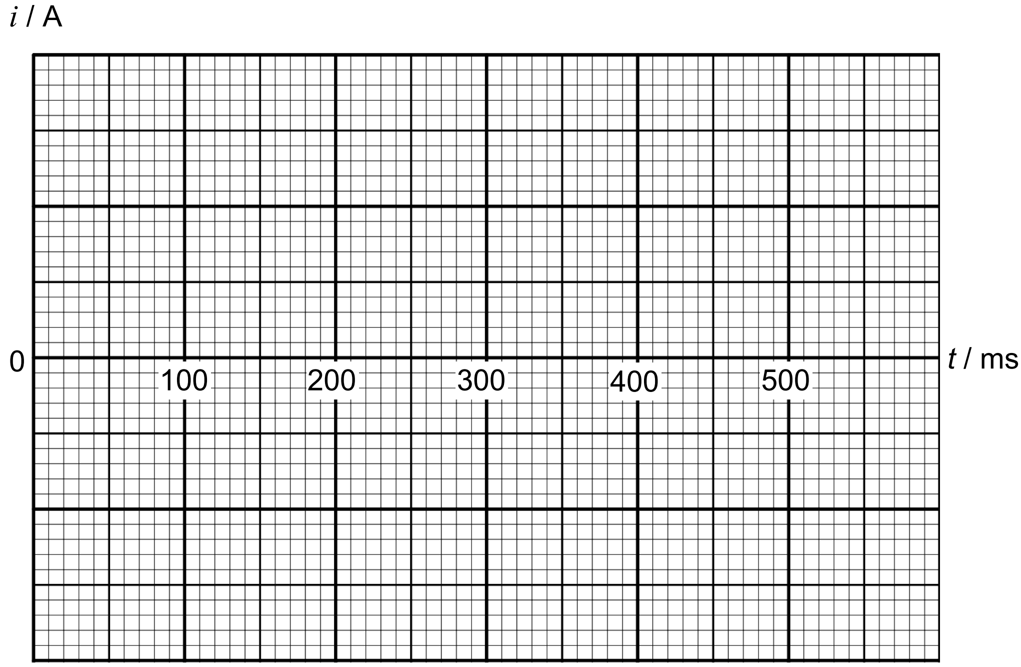

Fig. 5.3

[2]

(iv) Sketch on Fig. 5.4, a graph to show the variation with time t of the power P dissipated in the coil from t = 0 ms to t = 460 ms. Include appropriate scale markings on the vertical axis.

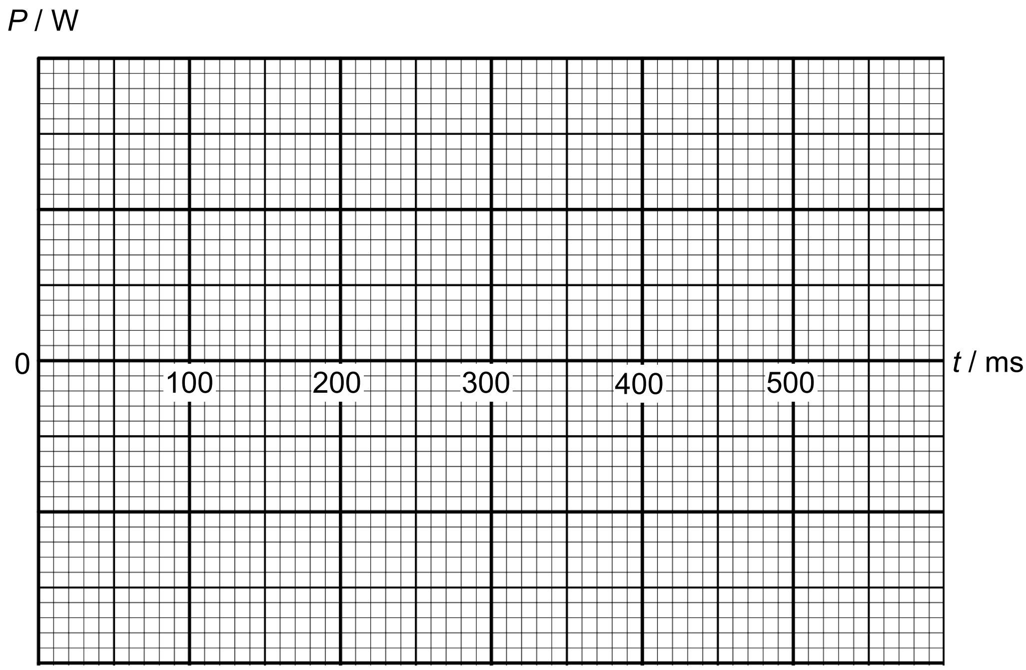

Fig. 5.4

[2]

Section B

Answer **one** question from this Section in the spaces provided.

6 **(a)** The energy levels of a hypothetical one-electron atom are given by

$$E_n = -\frac{27.90}{n^2} \text{ eV}$$

where $n = 1, 2, 3, \ldots$

(i) Calculate the energies of the four lowest energy levels and construct a clearly labelled energy level diagram.

[3]

(ii) If the atoms are in the ground state and are bombarded by electrons of kinetic energy 26.5 eV, determine the highest energy level that an atom can reach. Show your working clearly.

highest energy level = ... [3]

(iii) Indicate, with arrows, in your energy level diagram in **(a)(i)** all the possible transitions that produce emission lines when these atoms de-excite.

[2]

(iv) Calculate the longest and the shortest wavelengths of the photons emitted during these transitions.

longest wavelength = ... nm

shortest wavelength = ... nm [2]

(b) In a modern X-ray tube, electrons are accelerated through a large potential difference and the X-rays are produced when electrons strike a metal target embedded in a large piece of copper.

Fig. 6.1 shows an energy level diagram of an atom of a hypothetical metal.

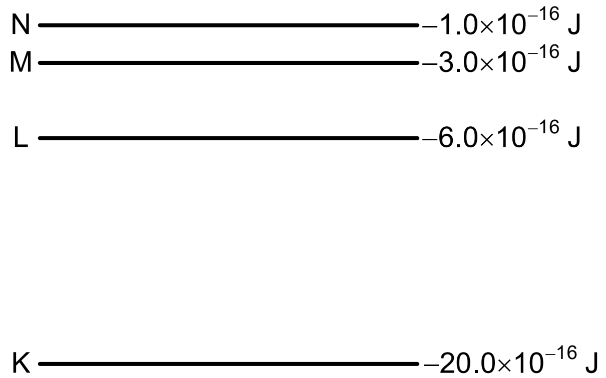

Fig. 6.1

The emission spectrum of the metal when it is bombarded by a beam of fast-moving electrons is shown in Fig. 6.2.

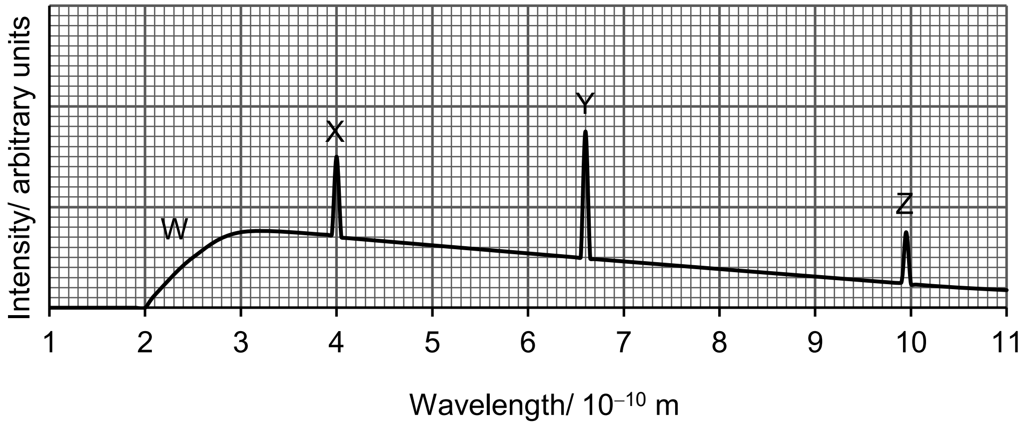

Fig. 6.2

(i) Describe the processes that occur at the target which produce the continuous spectrum W.

....

....

....

....

....

....

....

....

.... [4]

(ii) Calculate the accelerating potential of the X-ray tube.

accelerating potential = ... V [3]

(iii) Using Fig. 6.1, deduce which of the lines X, Y and Z in Fig. 6.2 correspond to L_α, L_β and M_α lines.

L_α = ...

L_β = ...

M_α = ... [2]

(iv) Explain why the K spectral lines are missing from Fig. 6.2.

....

.... [1]

7 The count rate C of a mixture of two radioactive nuclides X and Y is measured and the variation with time t of ln C is plotted and shown in Fig. 7.1. The readings show the count rate after the background count rate has been subtracted from it.

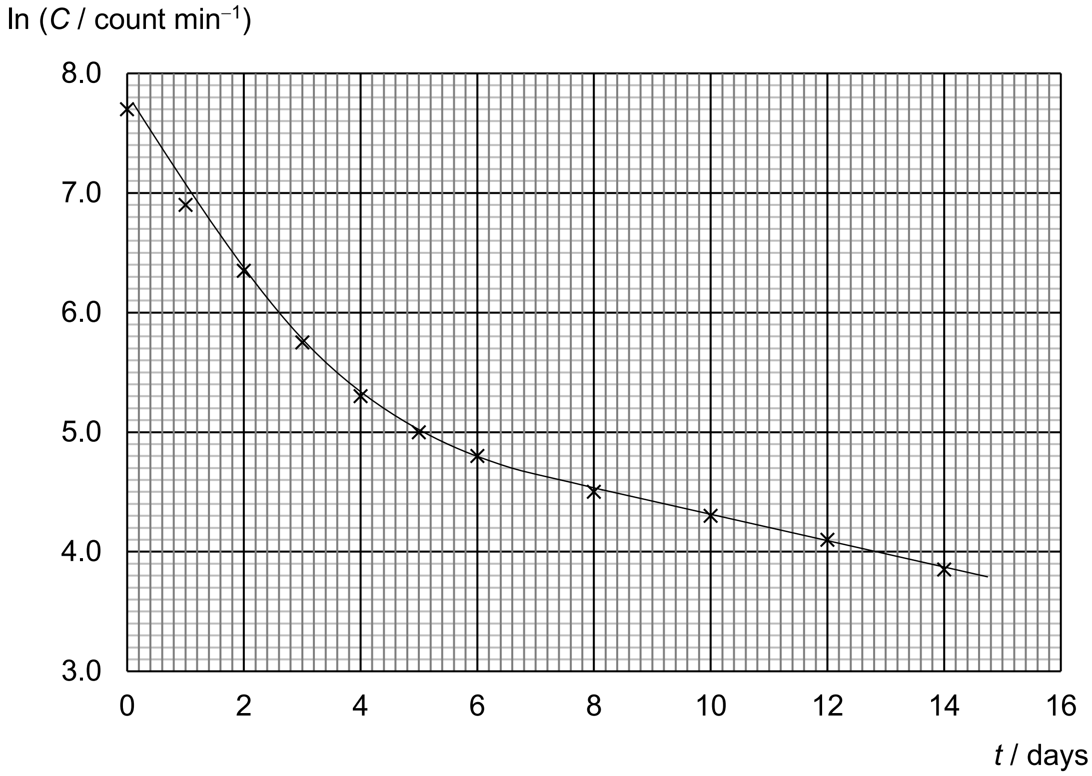

Fig. 7.1

It is known that the half-life of X is much longer than that of Y. The graph approaches a straight line eventually.

(a) By using an equation with the symbols defined below, explain why the graph approaches a straight line eventually.

Given C_X : count rate of X at time t,
C_{X_0} : initial count rate of X,
λ_X : decay constant of X.

....

....

....

....

.... [3]

(b) **(i)** Determine the initial count rate of X and its half-life using information from Fig. 7.1.

initial count rate = ... count min^{-1}

half-life = ... days [5]

(ii) Estimate the count rate of the mixture at t = 19 days.

count rate = ... count min^{-1} [2]

(c) One of the radioactive nuclides in the mixture can be used as a tracer to check whether the thyroid gland is absorbing iodine normally from the blood in a human body. The tracer nuclei decay by emitting beta particles and gamma rays, and the gamma rays are monitored from outside the body close to the thyroid using a detector.

A dose of iodine with the tracer is injected into a patient's blood, and 20% of that dose is absorbed by the thyroid gland. The detector records 0.40% of the gamma rays emitted.

(i) Suggest a reason why the beta particles are not monitored.

....

.... [1]

(ii) Suggest a reason why the detector records only 0.40% of the gamma rays emitted from the radioactive nuclei inside the thyroid.

....

.... [1]

(iii) In administering radioactive nuclides for medical applications, factors such as the half-life of the source must be considered.

Suggest two other significant factors that should be considered.

....

....

....

....

.... [2]

(d) Source Y has a half-life of 20 hours. In the absence of source Y, a constant average count-rate of 15 s^{-1} is recorded by a radiation detector.

Immediately after source Y is placed 30 cm from the detector, the average count-rate rises to 100 s^{-1}.

Determine the distance the detector should be placed from source Y in order to detect the same average count-rate of 100 s^{-1} 60 hours later.

Assume that source Y is a point source emitting radiation in all direction.

(Sample X is not present in this part of the experiment.)

distance = ... cm [4]

(e) Fig. 7.2 shows the variation with time of the cumulative counts (total count) of a small sample of X and of the background radiation.

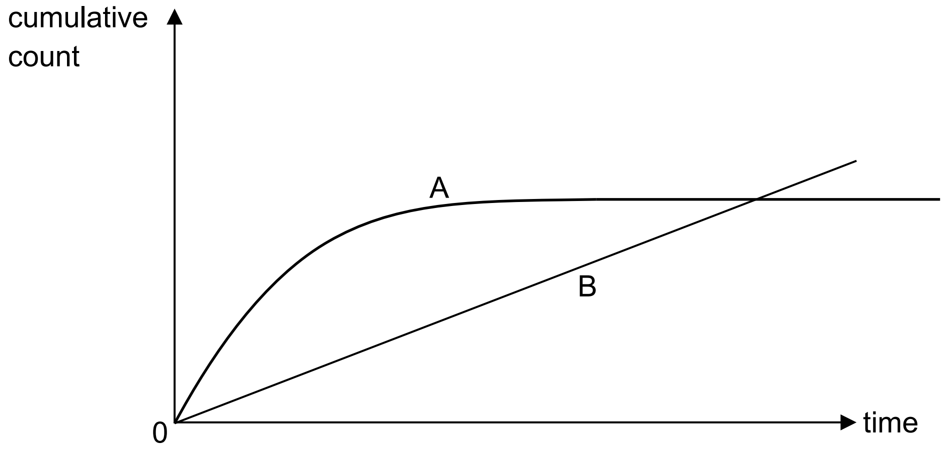

Fig. 7.2

(i) State and explain which graph, A or B, in Fig. 7.2 represents the cumulative count of the background radiation.

....

.... [1]

(ii) Sketch and label on Fig. 7.2, a graph that represents the cumulative count of a sample of Y that has half the initial number of nuclei as that of sample X.

[1]

End of Paper 3 Section B