* 0018369306501 *

H

MINISTRY OF EDUCATION, SINGAPORE
in collaboration with
CAMBRIDGE ASSESSMENT INTERNATIONAL EDUCATION
General Certificate of Education Advanced Level
Higher 2

CANDIDATE NAME

CENTRE NUMBER S

INDEX NUMBER

* 9 8 1 8 3 9 3 5 3 7 *

PHYSICS

9749/03

Paper 3 Longer Structured Questions

October/November 2023

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number and name 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.
DO **NOT** WRITE ON ANY BARCODES.

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

Section A
Answer **all** questions.

Section B
Answer **one** question only.

You are advised to spend one and a 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.

PILOT
The Centre of Physics

This document consists of **27** printed pages and **1** blank page.

Singapore Examinations and Assessment Board

Cambridge Assessment International Education

© UCLES & MOE 2023

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	$\varepsilon_0 = 8.85 \times 10^{-12}\,\text{F m}^{-1}$
	$(1/(36\pi)) \times 10^{-9}\,\text{F m}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19}\,\text{C}$
the 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	$R = 8.31\,\text{J K}^{-1}\,\text{mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\text{mol}^{-1}$
the 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	$g = 9.81\,\text{m s}^{-2}$

PIVOT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

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	$p = \rho gh$
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 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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

DO NOT WRITE IN THIS MARGIN

PIVOT

The Centre of Physics

Section A

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

1 A light wooden metre rule of thickness t and width w is placed horizontally on two supports a distance L apart.

An object of mass M is suspended from the midpoint of the rule and the rule bends by a distance x, as shown in Fig. 1.1.

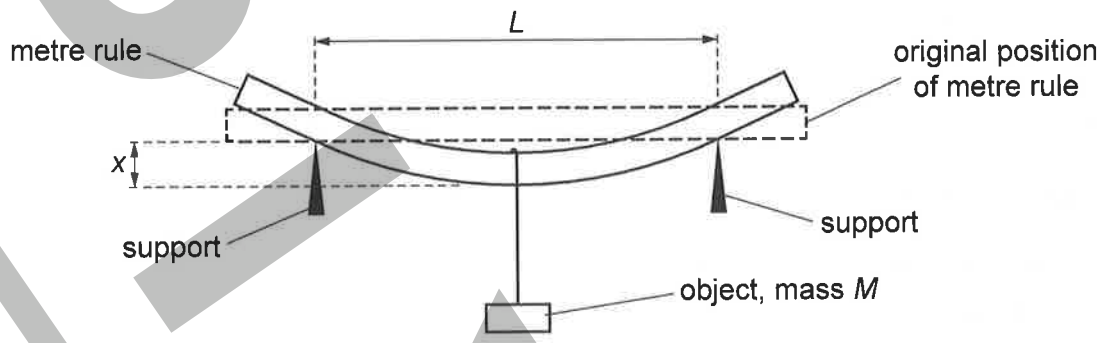


Fig. 1.1

The amount of bending x of the metre rule is related to the mass M of the object by the equation:

$$x = \frac{L^3 gM}{4wt^3 E}$$

where E is a constant measured in Pa and g is the gravitational field strength.

(a) Use SI base units to show that this equation is homogenous.

① $[LHS] = [x] = m$

② $[RHS] = \left[\frac{L^3 gM}{4wt^3 E}\right] = \frac{m(ms^{-2})(kg)}{(m)(m)^3(kg\,ms^{-2}m^{-2})} = m$

③ Since $[LHS] \equiv [RHS]$, this eqn. is homo. *

[3]

PiXOT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

(b) Data for Fig. 1.1 is given in Table 1.1.

Table 1.1

w/cm	2.10±0.02
t/mm	4.56±0.01
L/m	0.800±0.005
M/g	300±2
x/cm	1.00±0.01

Use this data to calculate E and the percentage uncertainty in its value.

① $E = \dfrac{L^3 g M}{4wt^3 x}$

② $E_{true} = \dfrac{(0.8)^3(9.81)\left(\frac{300}{1000}\right)}{4\left(\frac{2.1}{100}\right)(4.56\times10^{-3})^3(1\times10^{-2})} = 1.89184\times10^{10}$

③ $\dfrac{\Delta E}{E} = 3\dfrac{\Delta L}{L} + \dfrac{\Delta g}{g} + \dfrac{\Delta M}{M} + \dfrac{\Delta w}{w} + 3\dfrac{\Delta t}{t} + \dfrac{\Delta x}{x}$

$\therefore \Delta E = (1.89184\times10^{10})\left[3\left(\frac{0.005}{0.8}\right) + \frac{2}{300} + \frac{0.02}{2.1} + 3\cdot\frac{0.01}{4.56} + \frac{0.01}{1}\right]$

$= 9.7466\times10^{8}$

④ $1.89184\times10^{10} \pm 9.7466\times10^{8}$ $E =$ ..19G.. Pa ± ..5.3.. % [4]

$= 189.184\times10^{8} \pm 9.7466\times10^{8}$

$= 189.184\times10^{8} \pm 10\times10^{8}$

$= 18.9184\times10^{9} \pm 1\times10^{9}$

$= (19 \pm 1)\times10^{9}$

⑤ % uncertainty $= \dfrac{1}{19}\times100\% = 5.263\% = 5.3\%$ (2sf)

[Total: 7]

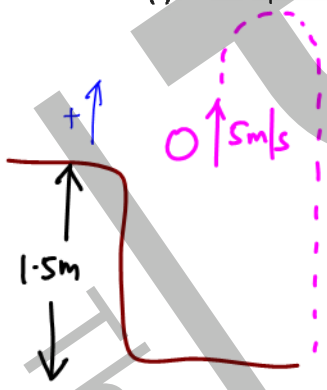
PLAN
The Centre of Physics
DO NOT WRITE IN THIS MARGIN

2 A student throws a ball vertically upwards with a speed of $5.0\,m\,s^{-1}$. The ball is released at this speed at a height of 1.5 m above the ground.

Air resistance is negligible.

(a) Calculate:

(i) the speed of the ball as it hits the ground



$v^2 = u^2 + 2as$

$\therefore v = \sqrt{(5)^2 + 2(-9.81)(-1.5)}$

$= 7.377$

$= 7.38\,m/s$ (3sf)

speed = ... 7.38 ..... $m\,s^{-1}$ [2]

(ii) the time between the ball being released and the ball hitting the ground.

$v = u + at$

$\therefore t = \frac{v-u}{a}$

$= \frac{-7.38 - 5}{-9.81}$

$= 1.2619$

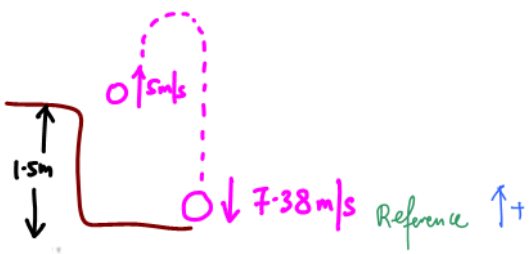
$= 1.27\,s$ (3sf)

time = ... 1.27 ..... s [2]

(b) Using your answers to **(a)(i)** and **(a)(ii)**, draw on Fig. 2.1 the variations with time t of the displacement s, the velocity v and the acceleration a of the ball.

Add a suitable scale to each vertical axis.

Take ground level as the zero of displacement and the upwards direction as positive.



Time to reach max. height

$v = u + at$

$\therefore t = \frac{v-u}{a}$

$= \frac{0-5}{-9.81}$

$= 0.5096$

$= 0.510\,s$ (3sf)

Max. height reached

$v^2 = u^2 + 2as$

$\therefore s = \frac{v^2 - u^2}{2a}$

$= \frac{0^2 - 5^2}{2(-9.81)}$

$= 1.274$

$= 1.27\,m$ (3sf)

© UCLES & MOE 2023

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

PIVOT
The Centre of Physics

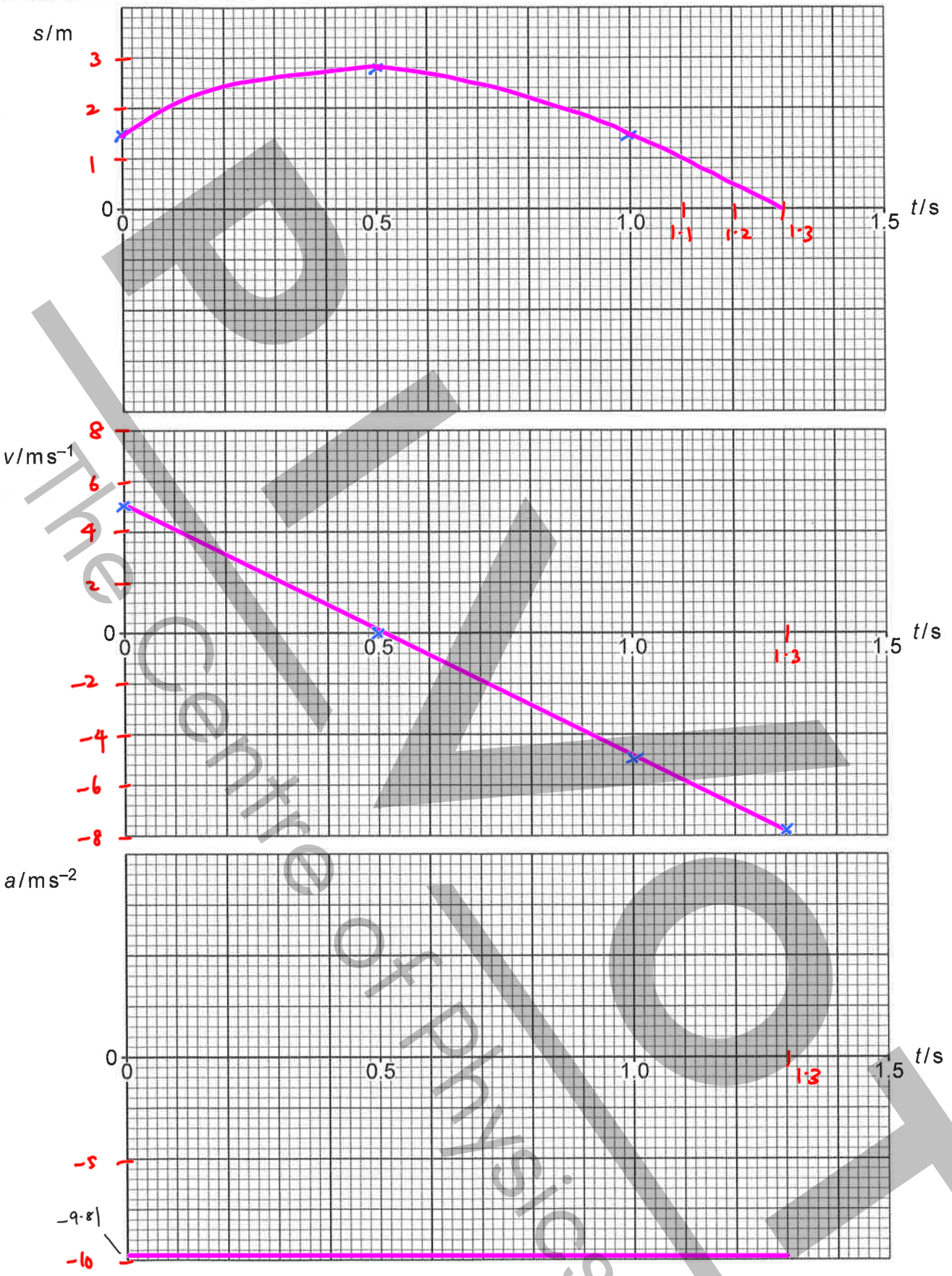


Fig. 2.1

[5]

[Total: 9]

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

© UCLES & MOE 2023

3 **(a)** State what is meant by electric current.

Rate of flow of charges (positive and negative) with respect to time

[1]

(b) A current-carrying conductor has length l and cross-sectional area A, as shown in Fig. 3.1.

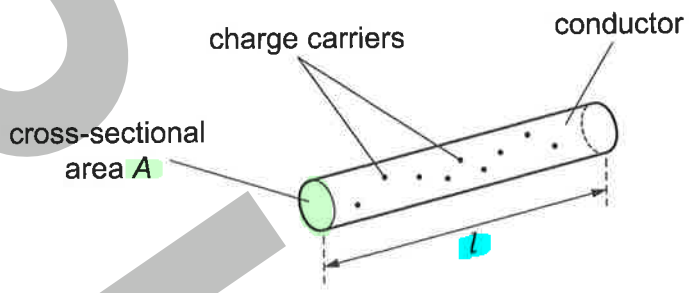


Fig. 3.1

The number density of charge carriers in the conductor is n. The charge carriers move with a drift velocity v when a potential difference (p.d.) is applied across the conductor.

Show that the current I in the conductor is given by the equation:

$$I = nAvq$$

where q is the charge on each of the charge carriers.

$Q = \frac{n}{V} q \cdot V$ (n : no. of charges)

$It = nq \cdot Al$

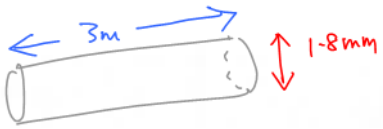
$\therefore I = \frac{nAql}{t}$ (where $v = \frac{l}{t}$)

Hence $I = nAvq$ (shown) (n : no. density)

[3]

PLAN OT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN



(c) There is a current of 2.00A in a tungsten wire of diameter 1.80 mm and length 3.00 m. There are 1.45×10^{23} conduction electrons in the wire.

(i) Calculate the drift velocity v of the conduction electrons in the wire.

$I = nAvq$

$\therefore v = \frac{I}{nAq} = \frac{I}{\frac{n}{Al} \cdot A \cdot q} = \frac{Il}{nq} = \frac{2(3)}{(1.45\times10^{23})(1.6\times10^{-19})}$

$= 2.586 \times 10^{-4}$

$= 2.59 \times 10^{-4}$ m/s (3sf)

$v =$ 2.59×10^{-4} ..... ms^{-1} [3]

(ii) The mean speed of a conduction electron in the tungsten wire is very much greater than the answer obtained in **(c)(i)**.

Explain this observation.

The drift velocity is the average velocity of the electrons due to an externally set up Electric field (value in part ci). This value is much smaller than the mean speed of a conduction electron, because, due to an external electric field (pd source), current flows and the temperature of the wire rises. This causes more collisions between the electrons and hence the drift velocity decreases. [2]

[Total: 9]

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

PI XOT
The Centre of Physics

4 (a) Define magnetic flux density.

The magnetic force acting per unit current, per unit length on a constant current carrying conducting wire, placed at right angles to the magnetic field.

[2]

(b) A metal rod XY is fixed horizontally, perpendicular to the uniform magnetic field of a magnet. The length of the rod in the magnetic field is 12 cm.

The magnet is on a balance and the North and South poles of the magnet are as shown in Fig. 4.1.

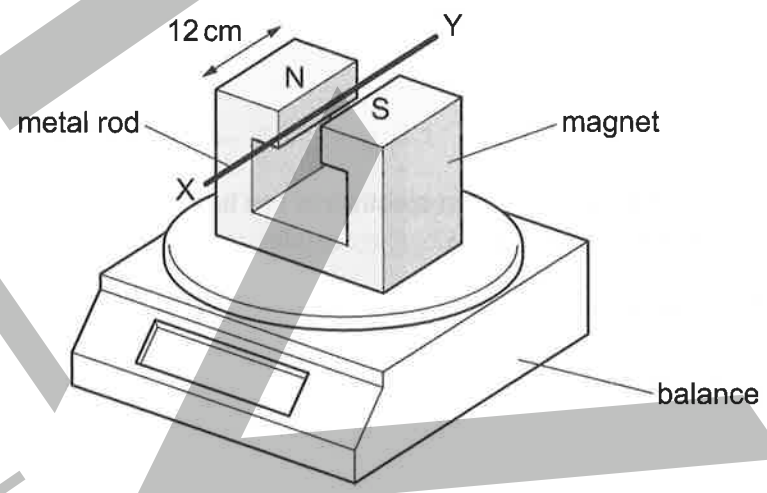


Fig. 4.1

(i) The ends of the rod are connected to a d.c. power supply. When the power supply is switched on, the reading on the balance decreases.

State and explain the direction of the current in the rod.

X to Y. When balance reading decreases, it means the magnet experiences a magnetic force upwards. From Newton's 3rd law, the wire experiences a magnetic force downwards. From Fleming's Left Hand rule, the current flows from X→Y.

[3]

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

DRAFT
The Centre of Physics

(ii) The current in the rod is 1.60A and the reading on the balance is 201.62g.

The direction of the current in the rod is reversed and its magnitude remains at 1.60A. The new reading on the balance is 202.17g.

Calculate the magnetic flux density of the uniform magnetic field.

① Reading = 201.62g (Magnet pushed up)

② Reading = 202.17g (Magnet pushed down)

③ ∴ Reading = $\frac{201.62 + 202.17}{2}$ = 201.895g (Magnet in equilibrium)

④ $F = BIL$

$\therefore B = \frac{F}{IL} = \frac{mg}{IL} = \frac{\left[\frac{0.275}{1000}\right][9.81]}{(1.6)\left(\frac{12}{100}\right)} = 0.01405$

$= 0.0141\ T$ (3sf)

magnetic flux density = ... 0.0141 ..... T [4]

(iii) The rod is replaced with another rod of the same dimensions but made of a material with a lower resistivity.

The current in the rod is 1.60A.

State and explain the difference, if any, this change has on the readings on the balance when the current is reversed as in **(b)(ii)**.

Since the current in the rod is constant, there will be no change on the readings on the balance

..... [1]

[Total: 10]

PIVOT
The Centre of Physics

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

The work done by an external agent in bringing a small, unit test mass (point mass) from infinity to that point without acceleration.

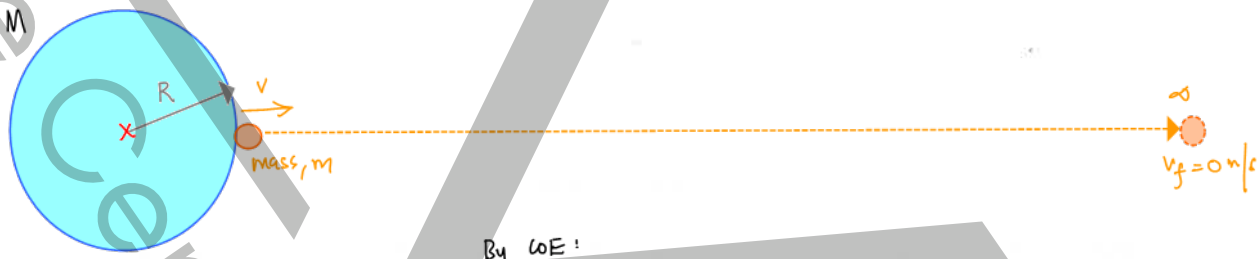
[2]

(b) A planet of radius R is isolated in space. It has no atmosphere, and its mass M can be assumed to be concentrated at its centre.

A projectile is launched from the surface of the planet with a speed v, where v is the minimum speed required for the projectile to not return to the planet.

By considering energy, derive an expression for v in terms of G, M and R, where G is the gravitational constant.

Explain your working.



By COE:

$PE_s + KE_s = PE_\infty + KE_\infty$

$-\frac{GM_m}{R} + \frac{1}{2}mv^2 = 0$

$\therefore \frac{1}{2}mv^2 = \frac{GM_m}{R}$

$\therefore v = \sqrt{\frac{2GM}{R}}$ ✱ Derived.

[3]

SPECIMEN

The Centre of Physics

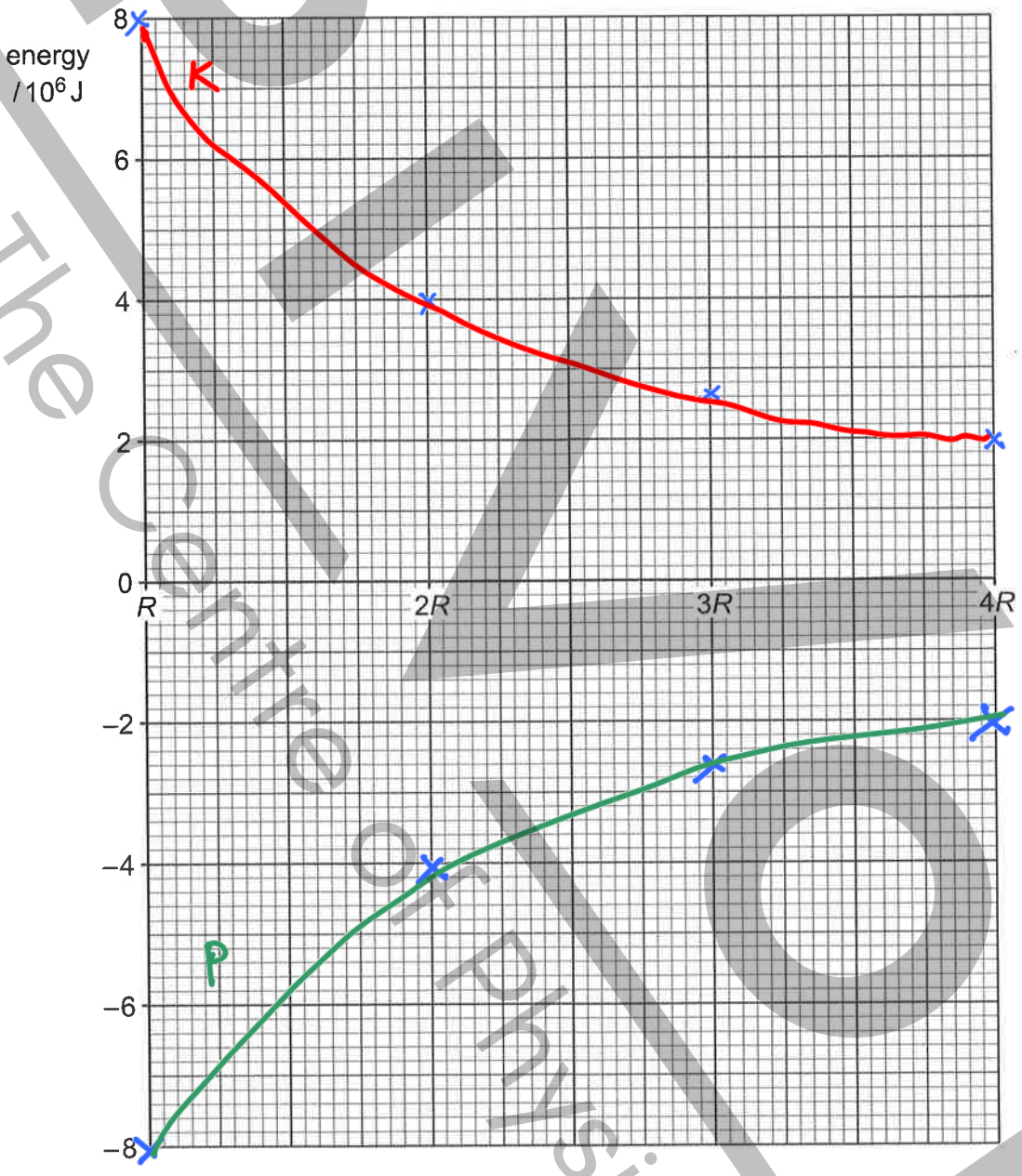
DO NOT WRITE IN THIS MARGIN

(c) The projectile in **(b)** has a mass of 1.0 kg and is launched with a kinetic energy of 8.0×10^6 J.

On Fig. 5.1, draw:

(i) a line, labelled **P**, to show how the gravitational potential energy of the projectile varies with distance from the centre of the planet as it moves from R to $4R$ [2]

(ii) a line, labelled **K**, to show how the kinetic energy of the projectile varies with distance from the centre of the planet as it moves from R to $4R$. [2]



$PE_S = -\frac{GMm}{R}$

$PE_D = -\frac{GMm}{4R}$

By CoE:

GPE gain = KE loss

4× ↑ $U \propto -\frac{1}{R}$ ↑ 4×

∴ KE ↓ 4×

$KE_f = 2 \times 10^6$ J

Fig. 5.1

[Total: 9]

The Centre of Physics

DO NOT WRITE IN THIS MARGIN

6 Two containers A and B contain ideal gases, as shown in Fig. 6.1.

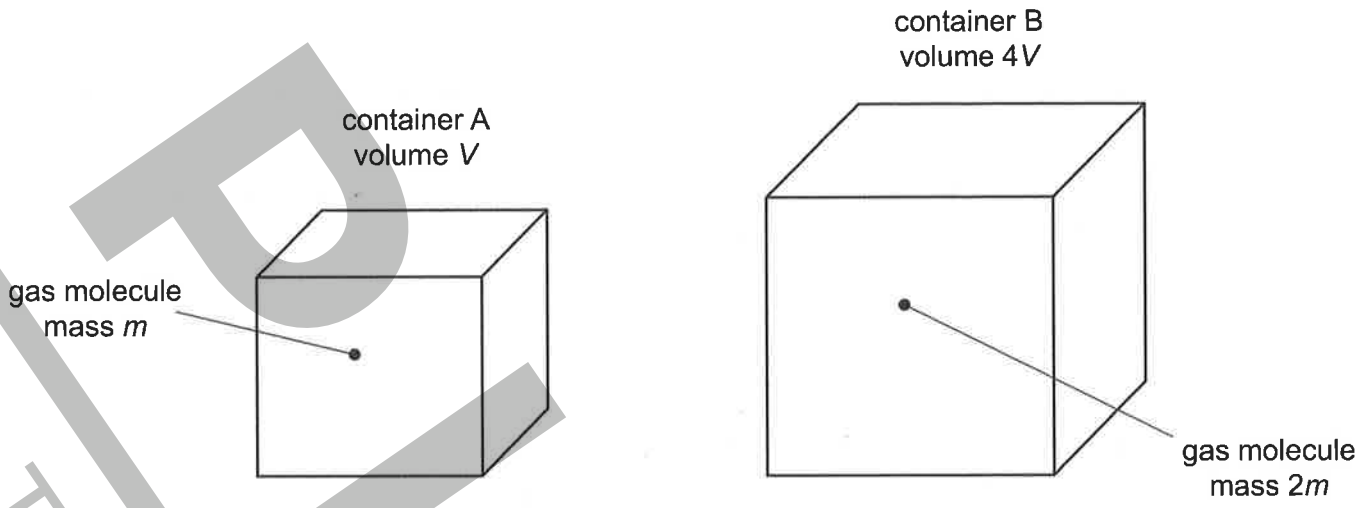


Fig. 6.1 (not to scale)

The volume of container A is V, and the volume of container B is $4V$.

The molecules of the gas in container A each have mass m and those in container B each have mass $2m$.

The gases in the containers are at the same temperature and pressure.

(a) Deduce a value for the ratio:

(i) $\dfrac{\text{mean kinetic energy of a gas molecule in container A}}{\text{mean kinetic energy of a gas molecule in container B}}$

① $\langle KE \rangle \propto T$

② $\therefore$ Ratio = 1.00 (3sf) *

ratio = ... 1.00 ..... [1]

PLAN NOT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

(ii) $\dfrac{\text{number of gas molecules in container A}}{\text{number of gas molecules in container B}}$

① $pV = NkT$ $\therefore N = \dfrac{pV}{kT}$

② $\therefore \dfrac{N_A}{N_B} = \dfrac{\frac{pV_A}{kT}}{\frac{pV_B}{kT}} = \dfrac{V_A}{V_B} = \dfrac{V}{4V} = 0.250$ (3sf) #

ratio = 0.250 [1]

(iii) $\dfrac{\text{root-mean-square (r.m.s.) speed of gas molecules in container A}}{\text{r.m.s. speed of gas molecules in container B}}$

① $c_{rms} \propto \sqrt{\frac{T}{m}}$ (T const)

② $\dfrac{c_{rms-A}}{c_{rms-B}} = \dfrac{\frac{1}{\sqrt{m_A}}}{\frac{1}{\sqrt{m_B}}} = \sqrt{\dfrac{m_B}{m_A}} = \sqrt{\dfrac{2m}{m}} = 1.41$ (3sf) #

ratio = 1.41 [2]

(b) There are 1.6 moles of gas in container A. The gas in container A has a molar mass of 4.0 g.

The r.m.s. speed of the molecules in container B is 940 m s^{-1}.

Calculate the temperature of the gases.

① $M_{r-A} = 4$

② $n = \dfrac{m}{m_r}$

① $\dfrac{v_{rms-A}}{v_{rms-B}} = 1.41$ $\therefore v_{rms-A} = (1.41)(940) = 1325.4$ m/s

② $m_A = 4u$

③ $\langle KE \rangle = U$

$\frac{1}{2} m v_{rms}^2 = \frac{3}{2} kT$

$\therefore T = \dfrac{m v_{rms}^2}{3k} = \dfrac{4(1.66 \times 10^{-27})(1325.4)^2}{3(1.38 \times 10^{-23})} = 281.74 = 282\,k$ (3sf) #

temperature of gases = 282 K [4]

[Total: 8]

PLYMOUTH The Centre of Physics

7 **(a)** Define electric field strength at a point.

Electric force per unit positive test charge (point charge) placed at that point.

[2]

(b) Fig. 7.1 shows an isolated conducting sphere that has a charge of −Q.

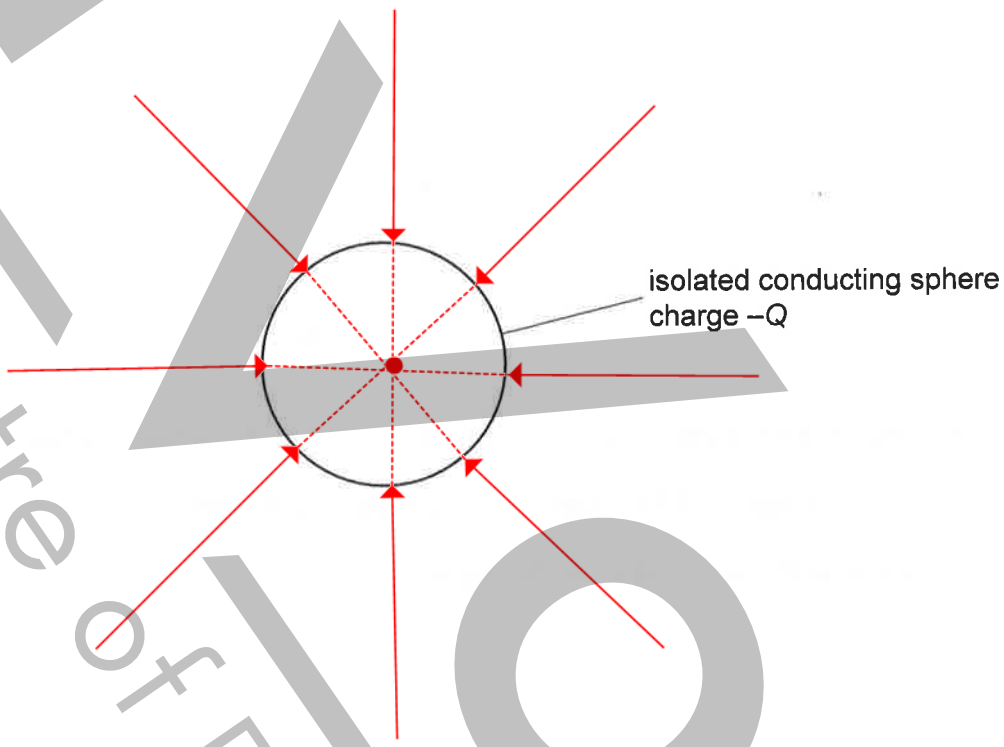


Fig. 7.1

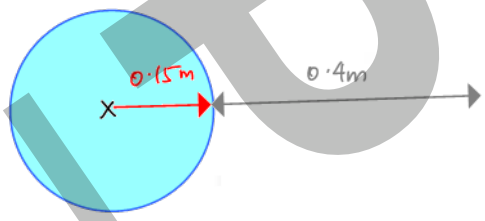
(i) On Fig. 7.1, draw **eight** field lines to represent the electric field surrounding the sphere. [3]

PIXOT
The Centre of Physics

(ii) The radius of the sphere is 15 cm. The charge on the sphere may be considered to be a point charge at its centre. The potential gradient at a distance of 40 cm from the surface of the sphere is 130 V m^{-1}.

Calculate the magnitude of the charge Q on the sphere.

Explain your working.



① $|E| = \left|\frac{dV}{dr}\right| = 130$

② $E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$\therefore Q = E(4\pi\varepsilon_0 r^2)$

$= (130)(4\pi)(8.85\times10^{-12})(0.15+0.4)^2$

$= 4.37\text{nC}$ (3sf)

#

$Q =$ 4.37n ..... C [3]

[Total: 8]

PIVOT
The Centre of Physics

Section B

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

8 The force–extension graph for a light spring is shown in Fig. 8.1.

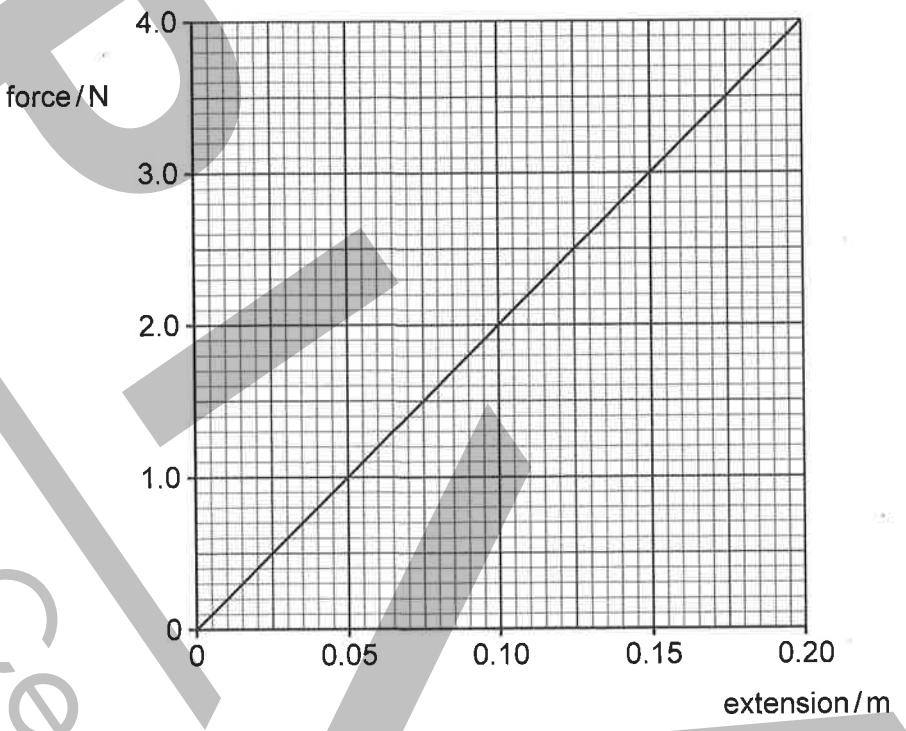


Fig. 8.1

The light spring hangs vertically from a fixed point.

An object of weight 3.0 N is attached to the free end of the unstretched spring. The object stretches the spring until stationary equilibrium is reached, as shown in Fig. 8.2.

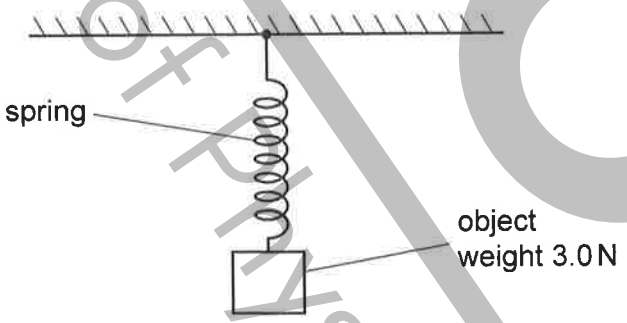


Fig. 8.2

PIXOT
The Centre of Physics

(a) Calculate:

(i) the force constant k of the spring

$F = ke$

$\therefore k = \frac{F}{e} = \frac{4}{0.2} = 20.0 \text{ Nm}^{-1}$ (3sf)

*

$k =$ 20.0 Nm^{-1} [1]

(ii) the energy stored in the spring due to the extension caused by the object

$EPE = \frac{1}{2}kx^2$

$= \frac{1}{2}(20)(0.15)^2$

$= 0.225 \text{ J}$ (3sf)

*

energy = 0.225 J [2]

(iii) the total gravitational potential energy (GPE) transferred by the object.

$GPE = mg\Delta h = W\Delta h = (3)(0.15) = 0.450 \text{ J}$ (3sf)

*

GPE transferred = 0.450 J [1]

(b) Explain, in terms of energy, why the answers to **(a)(ii)** and **(a)(iii)** are different.

Work done by external agent to lower the mass at a constant speed to its final equilibrium position must be negative.

[2]

PIXOT
The Centre of Physics

(c) The object is now held stationary at a distance of 3.2 cm below the equilibrium position, as shown in Fig. 8.3.

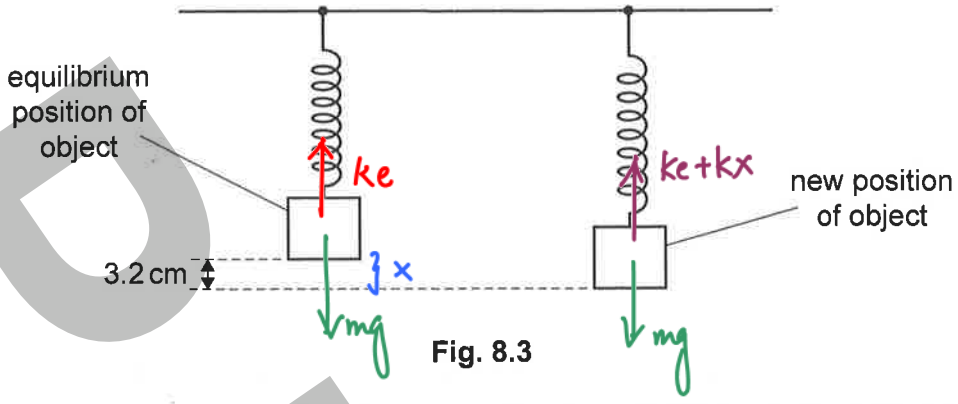


Fig. 8.3

Show that, when released, the object's acceleration a is related to its displacement x from the equilibrium position by the equation:

$$a = -\frac{k}{m}x$$

where m is the mass of the object.

Explain your working.

↓+

From N2L, $F_{net} = ma$

$\therefore mg - ke - kx = ma$

Since at eqm, $mg = ke$

$\therefore -kx = ma$

& $a = -\left(\frac{k}{m}\right)x$

shown.

[3]

PILOT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

(d) The object undergoes simple harmonic oscillations described by the equation in **(c)**. The amplitude of the oscillations is 3.2 cm. The object first passes through the equilibrium position at time $t = 0$.

When $t = 0.50$ s, calculate the magnitude of:

(i) the displacement of the object from its equilibrium position

① $X_0 = 3.2\,\text{cm}$

② $\omega^2 = \frac{k}{m} \therefore \omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{k}{\frac{W}{g}}} = \sqrt{\frac{gk}{W}} = \sqrt{\frac{(9.81)(20)}{3}} = 8.08702$

③ $x = X_0 \sin(\omega t)$

$= 3.2 \sin(8.08702 \times 0.5)$

$= -2.51\,\text{cm}$ (3sf)

#

displacement = ... −2.51 ..... cm [2]

(ii) the velocity of the object.

$|v| = |\pm \omega \sqrt{X_0^2 - x^2}|$

$= |\pm (8.08702) \sqrt{3.2^2 - (-2.51)^2}|$

$= 16.052$

$= 16.1\,\text{m/s}$ (3sf)

#

velocity = ... 16.1 ..... cm s^{-1} [2]

PIVOT
The Centre of Physics

(e) In practice, the oscillations of the object are lightly damped.

On Fig. 8.4, sketch a graph to show a possible variation of the displacement x of the object from its equilibrium position with time t. The graph should extend from $t = 0$ to $t = 3T$, where T is the period of the oscillations.

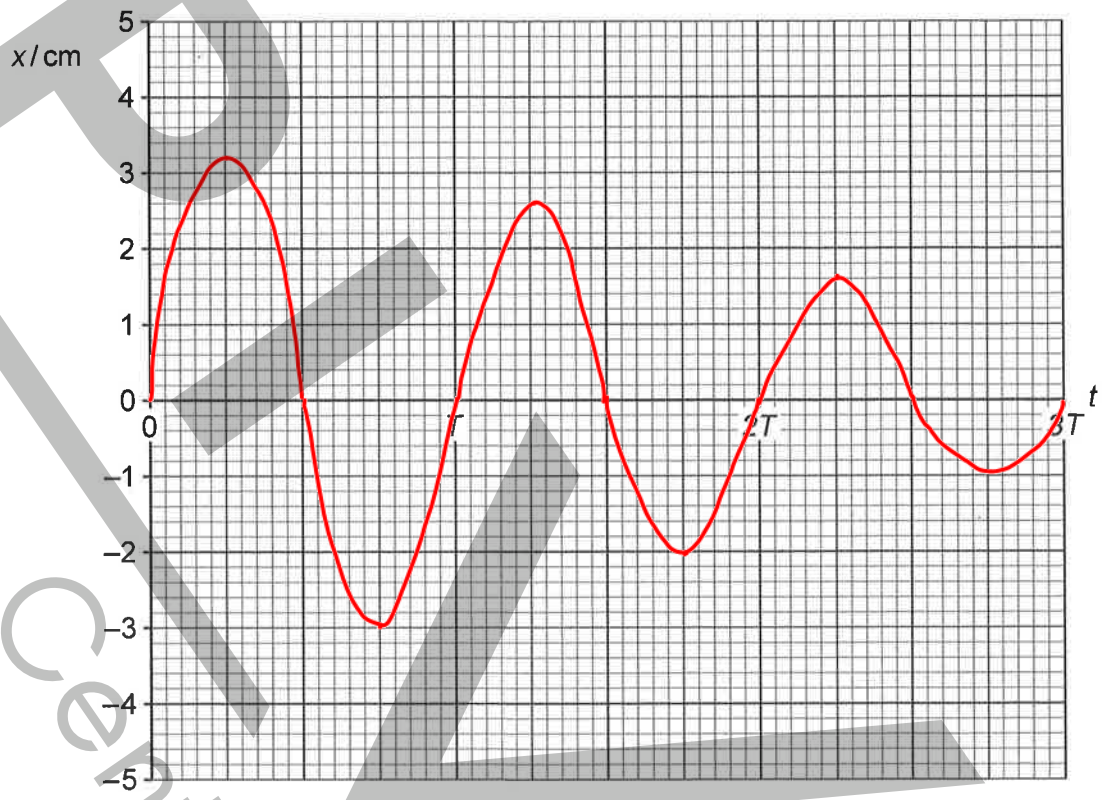


Fig. 8.4

[3]

PMT
The Centre of Physics

(f) An identical spring is now attached to the original spring.

The original object is attached to the spring combination and the system is in equilibrium, as shown in Fig. 8.5.

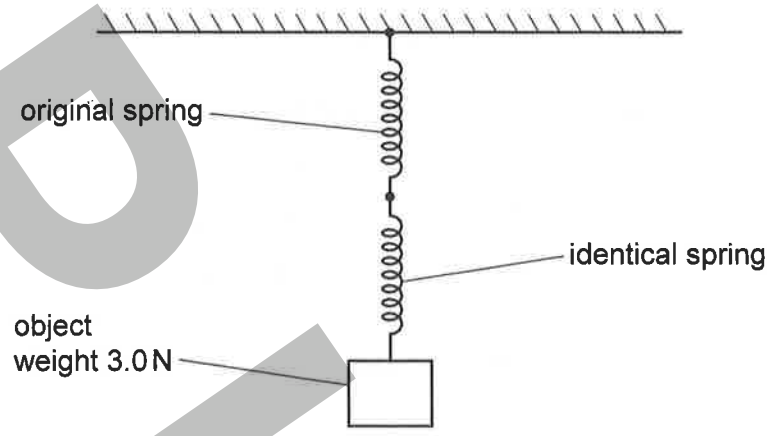


Fig. 8.5

(i) State and explain how the extension of the spring combination compares with the extension of the single original spring.

The effective spring constant is halved. With the same force, by Hooke's Law, the extension doubles.

[2]

(ii) The object is pulled down a small distance and released so that it oscillates.

State and explain how the period of these oscillations compares with the period of oscillations in **(c)**.

The period of a spring-mass system is inversely proportional to the square root of the spring constant. Hence, the new period increases by a factor of $\sqrt{2}$.

[2]

[Total: 20]

PIXOT
The Centre of Physics

DO NOT WRITE IN THIS MARGIN

9 The radioactive isotope americium-241 ($^{241}_{95}$Am) emits an α-particle as it decays to neptunium-237 ($^{237}_{93}$Np).

(a) Data for the decay are given in Table 9.1.

Table 9.1

nucleus	mass of nucleus / 10^{-27} kg
americium-241	400.19774
neptunium-237	393.54304
helium-4	6.64466

(i) Show that the energy released in the decay of an americium-241 nucleus is 9.0×10^{-13} J.

① $^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}He + Energy$

② $|\Delta BE| = |\Delta mc^2| = |m_{RHS} - m_{LHS}|\,c^2$

$= |(393.54304 + 6.64466 - 400.19774)(10^{-27})(3\times10^{8})^2|$

$= |-9.036\times10^{-13}|$

③ $\therefore E_{released} = 9.0\times10^{-13}$ J

shown [2]

(ii) State the principle of conservation of linear momentum.

The total momentum of a closed system is always constant provided no net external force acts on it. [2]

PI VOT
The Centre of Physics

(iii) The kinetic energy of an α-particle emitted by the decay of a stationary americium-241 nucleus is 8.784×10^{-13} J.

Show that the kinetic energy of the neptunium-237 nucleus after the decay is 1.483×10^{-14} J.

① $KE = E = \frac{p^2}{2m}$ $\therefore p = \sqrt{2mE}$

$\therefore p_\alpha = \sqrt{2(6.64466 \times 10^{-27})(8.784 \times 10^{-13})} = 1.08043 \times 10^{-19}$

② $Tot.\ p_i = Tot.\ p_f$

$0 = p_{Np} + (-p_\alpha)$

$\therefore p_{Np} = 1.08043 \times 10^{-19}$

③ $KE_{Np} = \frac{p^2}{2m} = \frac{(1.08043 \times 10^{-19})^2}{2(393.54304 \times 10^{-27})} = 1.4831 \times 10^{-14} = 1.483 \times 10^{-14}$ J (shown)

[4]

(iv) Suggest why the sum of the kinetic energies of the α-particle and the neptunium-237 nucleus after the decay is not equal to the energy released in the decay given in **(a)(i)**.

Energy released in the form of γ-photons was not considered.

[1]

PIXOT
The Centre of Physics

(b) Americium-241 has a decay constant of $5.08 \times 10^{-11}\,s^{-1}$.

A sample of pure americium-241 has an activity of 8.13 kBq at time $t = 0$.

(i) Calculate the number of nuclei in the sample at $t = 0$.

$A = \lambda N$

$\therefore N = \frac{A}{\lambda} = \frac{8.13 \times 10^{3}}{5.08 \times 10^{-11}} = 1.60039 \times 10^{14} = 1.60 \times 10^{14}$ (3sf)

*

number of nuclei = 1.60×10^{14} [2]

(ii) Calculate the half-life of americium-241.

$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{5.08 \times 10^{-11}} = 1.364 \times 10^{10} = 1.36 \times 10^{10}\,s$ (3sf)

#

half-life = 1.36×10^{10} s [1]

(iii) On Fig. 9.1, draw a graph to show the variation of the number of americium-241 nuclei with t from $t = 0$ to $t = 6.0 \times 10^{10}$ s. Label this line **A**.

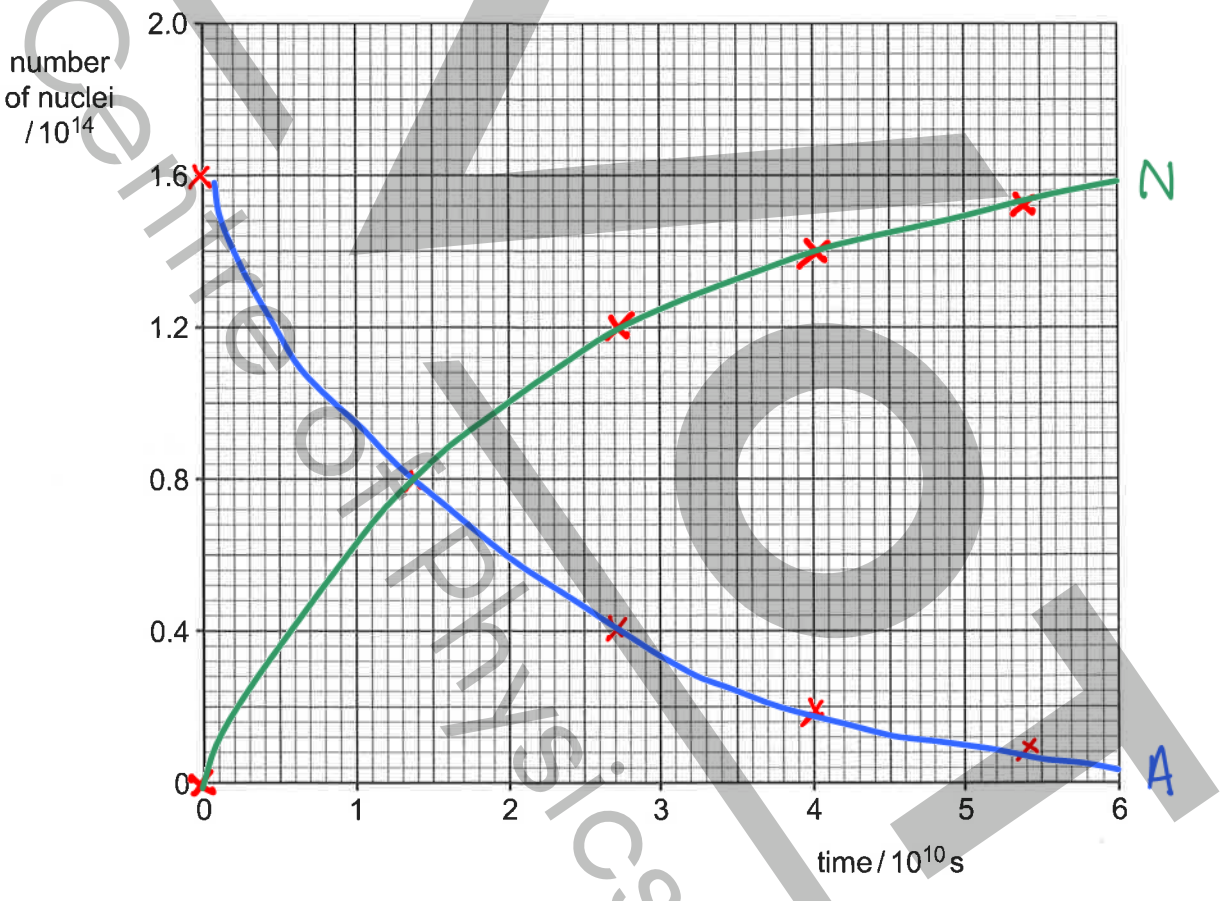


Fig. 9.1

[2]

(iv) Draw a second line on Fig. 9.1 to show how the number of neptunium-237 nuclei present in the sample varies from $t = 0$ to $t = 6.0 \times 10^{10}$ s. Neptunium-237 does not decay significantly over this time. Label this line **N**. [2]

DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN
DO NOT WRITE IN THIS MARGIN

PLTO
The Centre of Physics

(c) A sample of a pure beta emitter has the same initial number of nuclei as the sample of americium-241 in **(b)**. The pure beta emitter decays to a stable isotope. The probability of decay per unit time of a nucleus of the beta emitter is much greater than that of a nucleus of americium-241.

Describe and explain, without calculation, any difference in:

(i) the initial activity of the sample of the beta emitter compared with the initial activity of the sample of americium-241

Activity is directly proportional to the number of radioactive nuclei present. Hence, the initial activity of the beta-emitter is larger than that of americium-241.

[2]

(ii) the time taken for the activity of the sample of the beta emitter to fall to 1 Bq compared with the time taken for the activity of the sample of americium-241 to fall to 1 Bq.

The half-life of a radioactive nuclei is inversely proportional to the decay constant. Hence, by ratio and proportion, the time taken to fall to 1Bq for the beta-emitter is much smaller than that of americium-241. [2]

[Total: 20]

PIVOT
The Centre of Physics