RIVER VALLEY HIGH SCHOOL
JC2 PRELIMINARY EXAM

H2 PHYSICS 9749
PAPER 2

13 SEP 2021

CONFIDENTIAL

2 HOURS

CANDIDATE NAME										
CENTRE NUMBER	S					**INDEX NUMBER**				
CLASS	2	0	J							

INSTRUCTIONS TO CANDIDATES

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

Read these notes carefully.
Write your name, centre number, index number and class 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 or graphs.
Do not use staples, paper clips, glue or correction fluid.

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

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

*Answer **all** questions.*

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

FOR EXAMINERS' USE	
1	/ 7
2	/ 10
3	/ 15
4	/ 10
5	/ 5
6	/ 8
7	/ 5
8	/ 20
Deduction	
TOTAL	/ 80

This document consists of 23 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	$p = \rho gh$
gravitational potential	$\phi = -Gm/r$
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	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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

1 A student takes measurements to determine the acceleration of a ball as it rolls down a slope. He uses the apparatus illustrated in Fig. 1.1.

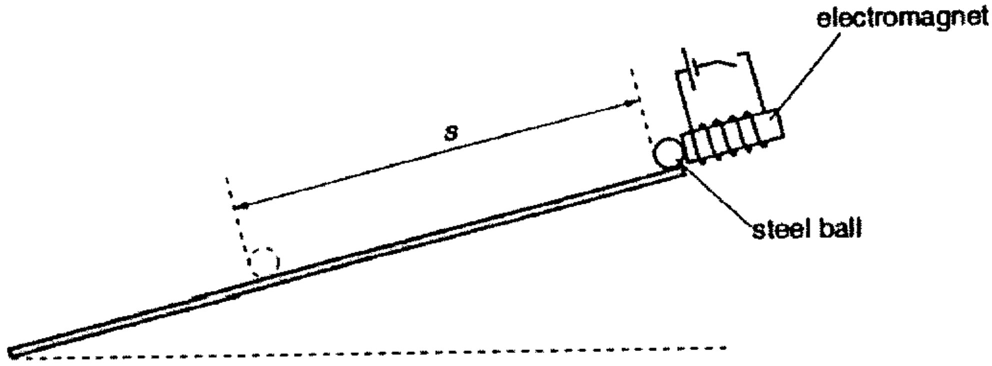


Fig. 1.1

The student measures the time t for the ball to roll a distance s down the slope after the ball has been released from the electromagnet.

The variation with t^2 of the distance is shown in Fig. 1.2.

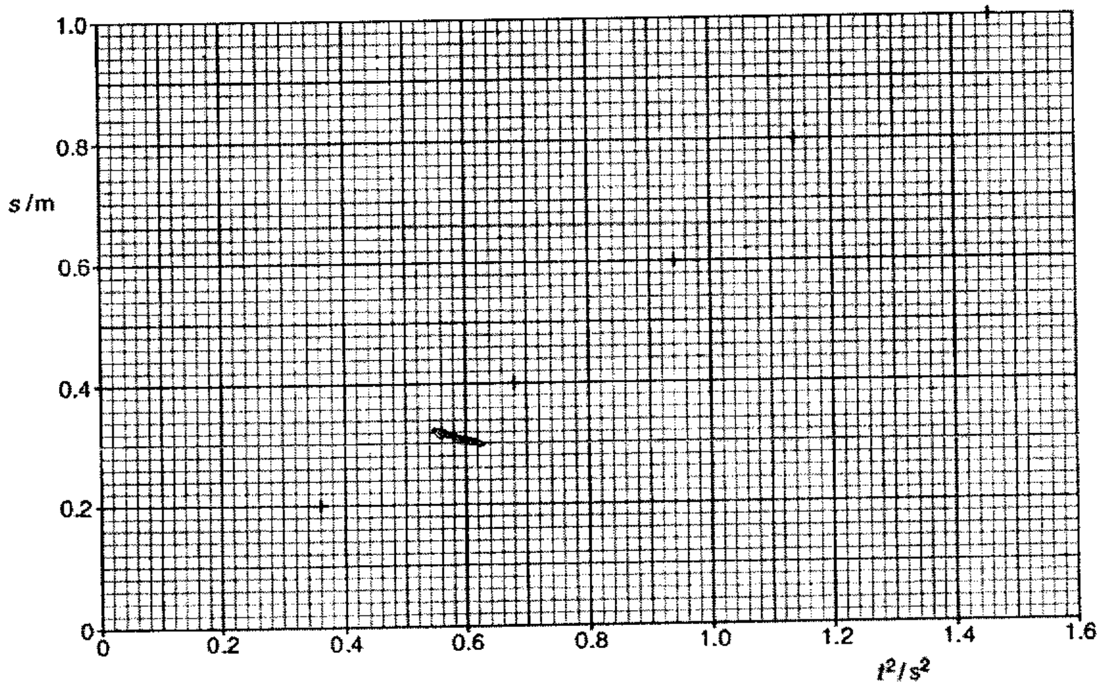
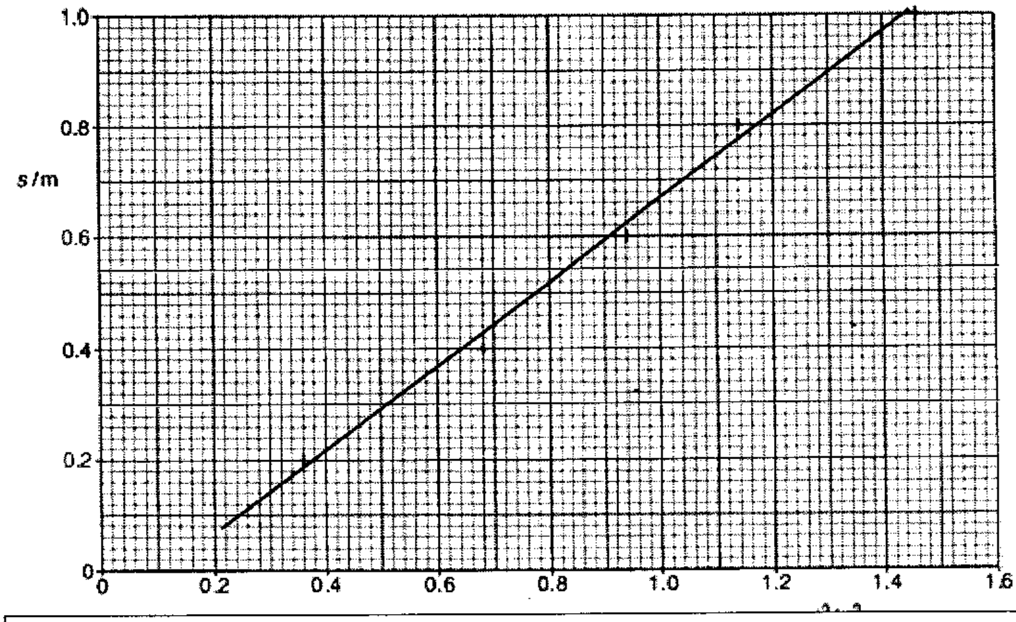


Fig. 1.2

(i) Use Fig. 1.2 to determine a value for the acceleration of the ball down the slope.



BFL

Using $s = ut + \frac{1}{2}at^2$ and initial velocity is zero, the gradient of graph is $\frac{1}{2}a$.

Using (0.40, 0.22) and (1.20, 0.82) to find gradient,

$gradient = \frac{0.82-0.22}{1.20-0.40} = 0.75$ [M1] (0.73 → 0.77)

Hence, acceleration = $0.75 \times 2 = 1.50\ ms^{-2}$.

acceleration = ... m s^{-2} [5]

(ii) State the feature of the data shown in Fig. 1.2 that indicates the presence of

1. random error,

The data points are scattered about the line of best fit. [1]

2. and systematic error.

The best-fit line does not pass through the origin since the ball has zero displacement when the ball starts to move. [1]

2 Fig. 2.1 shows a block of mass M_1 = 4.0 kg released from a vertical height of 6.0 m on a curved frictionless track. It slides down the track and makes a head-on elastic collision with a block of mass M_2 = 9.0 kg that is initially at rest.

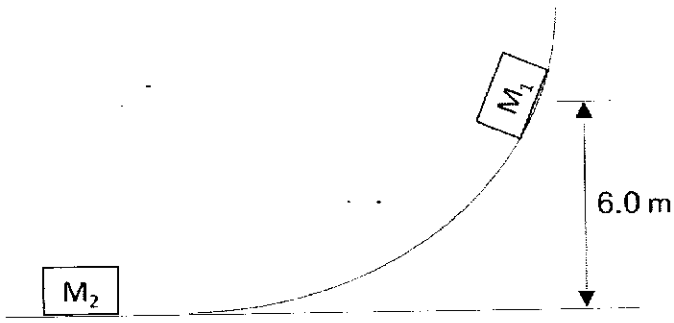


Fig. 2.1

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

The total momentum of a system remains constant provided no external resultant force acts on the system.

[1]

(b) Calculate the velocity of M_1 just after it collision with M_2.

loss in GPE = gain in KE

$M_1gh = \frac{1}{2} M_1u_1^2$ [M1]

$u_1 = \sqrt{2gh} = \sqrt{2 \times 9.81 \times 6.0}$

$= 10.8$ m s^{-1}

By Conservation of Momentum

$M_1u_1 + M_2u_2 = M_1v_1 + M_2v_2$

$(4.0)(10.8) = (4.0)v_1 + (9.0)v_2$

Since is elastic collision, using relative speed of approach/separation

$10.8 - 0 = -(v_1 - v_2)$

$10.8 + v_1 = v_2$

$(4.0)(10.8) = (4.0)v_1 + (9.0)(10.8 + v_1)$

Therefore $v_1 = -4.15$ (-4.17) m s^{-1}

velocity of M_1 just after collision = ... m s^{-1} [4]

(c) Calculate the maximum height to which M_1 rises after the collision.

loss in KE = gain in GPE

$\frac{1}{2} M_1v_1^2 = M_1gh$

$h = \frac{1}{2} v_1^2/g = \frac{1}{2} (4.15)^2/(9.81)$

$= 0.878$ (0.886) m

maximum height M_1 rises after collision = ... m [2]

	(d)	Sketch a graph, on the given axes in Fig. 2.2, to show how the velocity of M_1 varies from the time of its release to the time it reaches maximum height on its return.		[3]

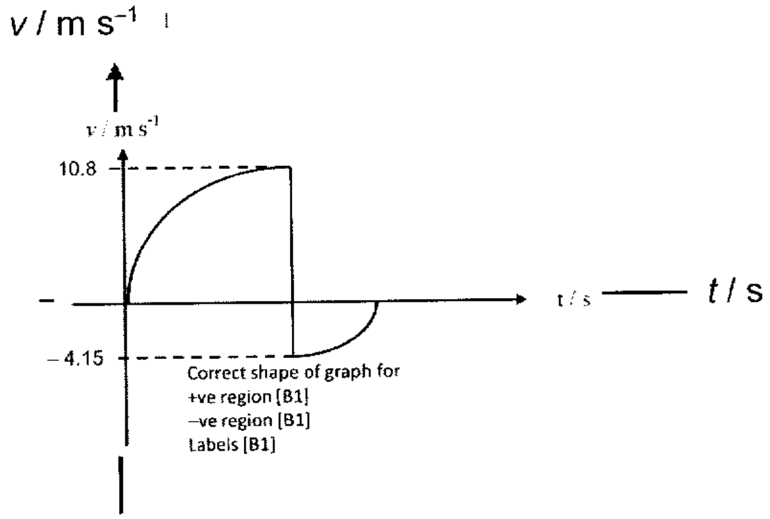


Fig. 2.2

3	**(a)**	**(i)**	Explain what is meant by the term *escape speed*.	
			minimum velocity that the body must have at the Earth's surface in order to escape from the influence of the Earth's gravitational field	[2]
		(ii)	Mars has a radius of approximately 3.4×10^6 m and a mass of 6.4×10^{23} kg. Show that the escape speed from Mars is approximately 5 km s^{-1}.	

gain in gravitational potential energy in reaching infinity is

$$\Delta E_P = 0 - (-\frac{GMm}{r}) = \frac{GMm}{r}$$

minimum kinetic energy required is equal to the gain in gravitational potential energy in reaching infinity:

$$\frac{1}{2} m v_{min}^2 = \frac{GMm}{r}$$

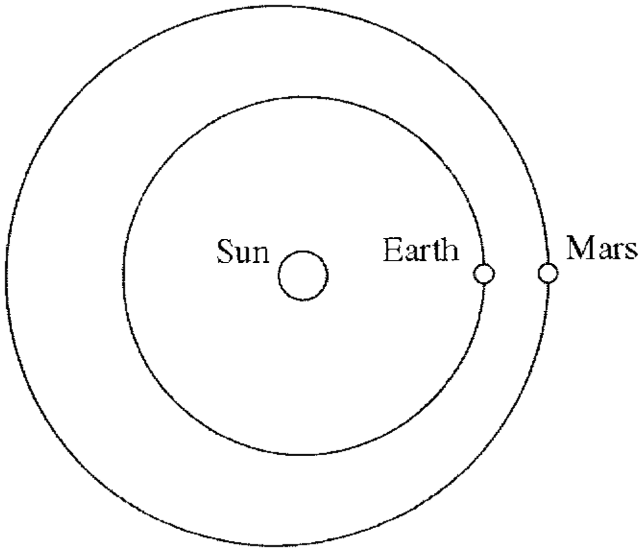
$$v_{min} = \sqrt{\frac{2GM}{r}} = \sqrt{\frac{2(6.67 \times 10^{-11})6.4 \times 10^{23}}{3.4 \times 10^6}} = 5011$$

$$\approx 5 \text{ km s}^{-1}$$

[3]

		(iii)	Suggest why a rocket would be able to escape from Mars with an initial speed much less than the escape speed given in part (a)(ii).	
			can be done at any speed given sufficient fuel	
			....	
			OR differentiates from escape speed – unpowered etc \ OR fuel/chemical energy	
			....	[1]

(b) Fig. 3.1 shows the Sun, Earth and Mars in alignment. Earth and Mars rotate around the Sun in the same directional sense.



Not to scale

Fig. 3.1

A rocket of mass 2.05×10^6 kg leaves the surface of Mars closest to Earth and heads for Earth.

Fig. 3.2 below gives data relevant to the rocket at the start of its journey.

astronomical object (AO)	mass of AO / kg	distance of rocket from the centre of AO / m	rocket's gravitational potential due to AO / J kg^{-1}	sign of gravitational potential
Mars	6.4×10^{23}	3.4×10^6	1.26×10^7	
Earth	6.0×10^{24}	5.6×10^{10}		negative
Sun	2.0×10^{30}	2.3×10^{11}	5.80×10^6	

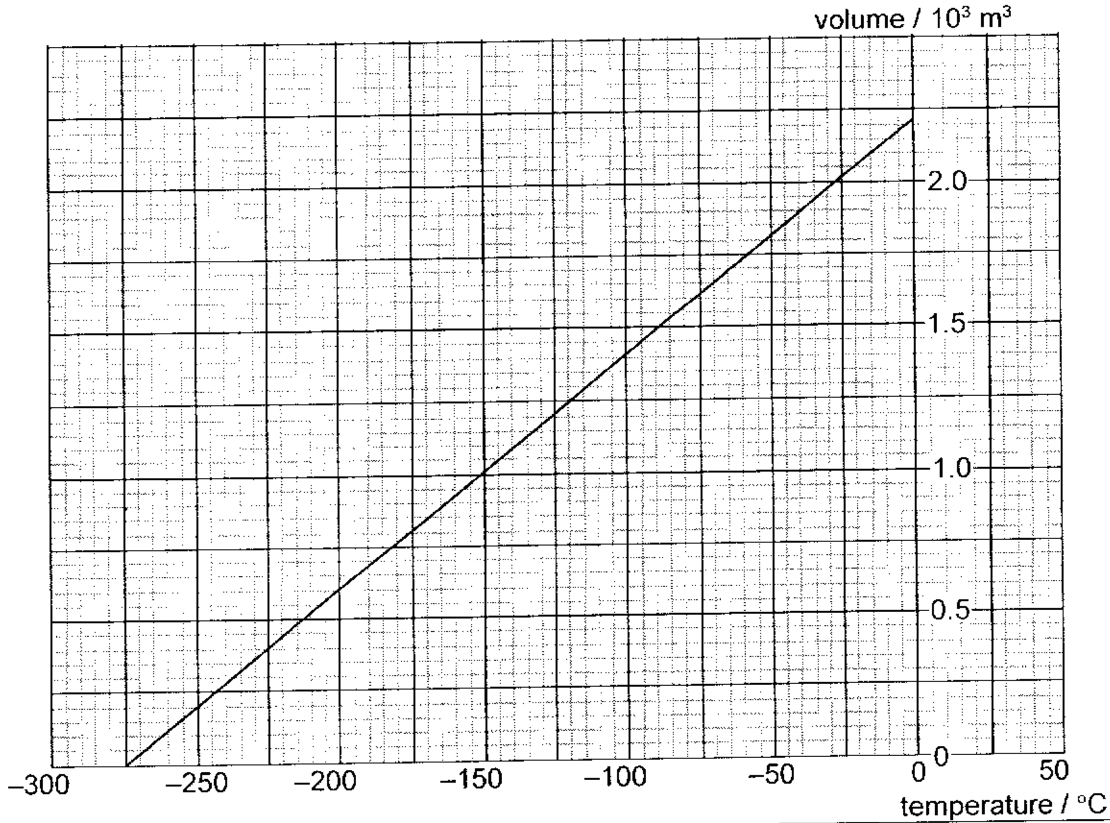
Fig. 3.2

		(i)	Complete Fig. 3.2 by calculating the gravitational potential of the rocket due to the presence of Earth and the signs of the gravitational potential energies due to Mars itself and the Sun.	
			$\phi = -\frac{GM}{r} = -\frac{(6.67\times10^{-11})(6.0\times10^{24})}{5.6\times10^{10}}$ $= -7.15\times10^{3}$ J kg^{-1} (formula provided hence no mark) negative, negative	
				[2]
		(ii)	Calculate the total gravitational potential energy of the rocket on the surface of Mars.	
			As rocket is at surface of Mars, i.e. start of journey, and there is potential due to all 3 Aos, thus total GPE of rocket = m($\Sigma\phi$) = 2.05×10^{6} (-5.80×10^{6} + -1.26×10^{7} + -7.15×10^{3}) = -3.77×10^{13} (ecf from table)	
			total gravitational potential energy = ... J	[2]
	(c)	**(i)**	Derive an expression to show that for satellites in a circular orbit $T^2 \propto r^3$ where T is the period of orbit and r is the radius of the orbit.	
			LO9c gravitational force provides centripetal force $\frac{GM_s m}{r^2} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$ $\Rightarrow \quad T^2 = \frac{4\pi^2}{GM_s} r^3$ $\Rightarrow \quad T^2 \propto r^3$	
				[2]
		(ii)	The orbits of the Earth and Mars can be approximated to be circular orbits around the Sun. Hence, estimate the orbital period of Mars.	
			$T^2 \propto r^3$ $\frac{T_{Mars}^2}{365^2} = \frac{(2.3\times10^{11} + 3.4\times10^{6})^3}{(2.3\times10^{11} - 5.6\times10^{10})^3}$ T = 554 days $\approx$ 600 days (1 s.f.)	
			orbital period of Mars = ... days	[3]

4 A fixed mass of ideal gas at a low temperature is trapped in a container at constant pressure. The gas is then heated and the volume of the container changes so that the pressure stays at 1.00×10^5 Pa.

When the gas reaches a temperature of 0.00 °C the volume is 2.20×10^{-3} m^3.

(a) Draw a graph on the axes below to show how the volume of the gas varies with temperature in °C. [2]



graph passes through given point 2.2×10^{-3} m^3 at 0.00 °C straight line with positive gradient
(straight) line to aim or pass through –273 °C at zero volume

(b) Calculate the number of moles of gas in the container.

LO8d
n = P V/R T
= $1.00 \times 10^5 \times 2.20 \times 10^{-3}/(8.31 \times 273.15)$ □
= 0.0969 (moles)

number of moles = ... mol [2]

(c) Calculate the average kinetic energy of a molecule when this gas is at a temperature of 50.0 °C.

LO8h
mean kinetic energy = 3/2 K T
= $3/2 \times 1.38 \times 10^{-23} \times 323.15$ □
= 6.69×10^{-21} (J)

kinetic energy = ... J [2]

(d) Hence or otherwise, calculate the total internal energy of the gas at a temperature of 50.0 °C.

total internal energy = $6.69 \times 10^{-21} \times 0.0969 \times 6.02 \times 10^{23}$
= 390 (J)

internal energy = ... J [2]

(e) By considering the collisions of gas molecules with the walls of the container, explain why the volume of the container must change if the pressure is to remain constant as the temperature increases.

As mean square speed of molecules is proportional to temperature, as temperature increases so does change of momentum or change in velocity, hence pressure will increase.

....

Increasing the volume compensates for longer time between collisions (rate of collision decreases) as the temperature increases, also as the volume increases the surface area increases which reduces the pressure

....

....

.... [2]

5 A graph of the voltage input to an ideal transformer is shown in Fig. 5.1. The 45:1 step-down transformer has a mean input power of 25 W.

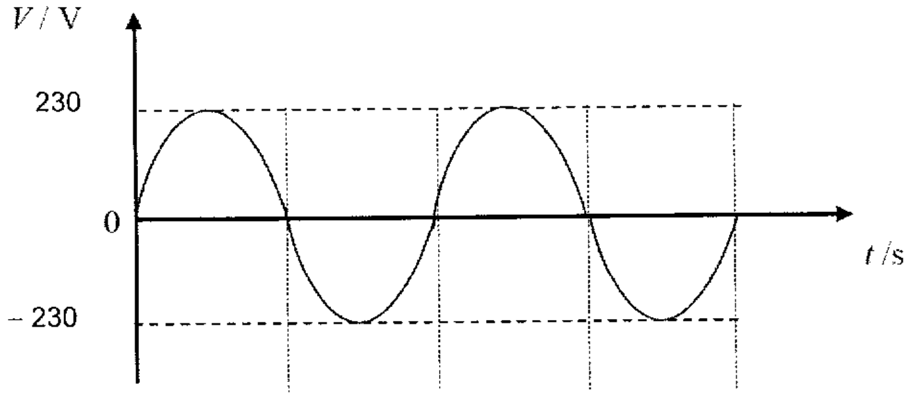


Fig. 5.1

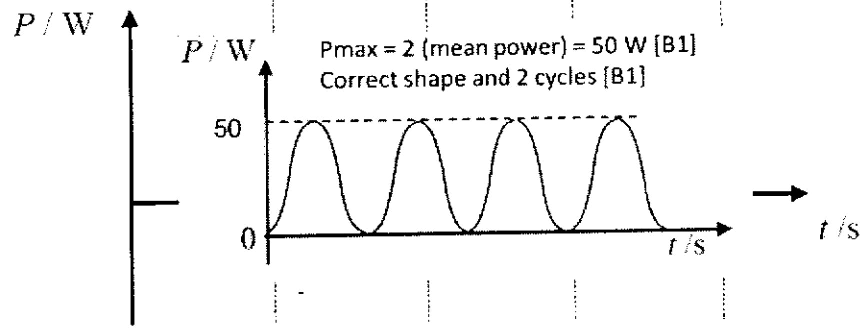


Fig. 5.2

(a) On the *P-t* graph in Fig 5.2, sketch the variation of power input to the transformer with time for two complete cycles. Indicate the value for the maximum input power. [2]

(b) Calculate the r.m.s. value of the output voltage.

$$\frac{V_{0,s}}{V_{0,p}} = \frac{N_s}{N_p}$$

$$V_{0,s} = V_{0,p}\frac{N_s}{N_p} = 230\left(\frac{1}{45}\right) = 5.11\ V$$

$$V_{rms,s} = \frac{V_{0,s}}{\sqrt{2}}$$

$$= 3.6(1)\ V$$

...of output voltage = ... V [3]

6 (a) Using energy considerations, distinguish between *electromotive force* and *potential difference*.

The electromotive force (e.m.f.) of a source is defined as the amount of energy transferred from non-electrical forms of energy to electrical energy per unit charge as the charge passes through a complete circuit.

The potential difference *V* between two points of a circuit is defined as the amount of electrical energy converted to **other** forms of energy **per unit charge** moved between these two points.

....

....

....

....

....

.... [2]

(b) An electric hotplate is designed to operate on a power supply of 240 V and has two coils of wire of resistivity of 9.8×10^{-7} Ω m. Each coil of wire has a length of 16 m and cross-sectional area 0.20 mm^2.

(i) For one of the coils, calculate

1. its resistance,

$R = (9.8 \times 10^{-7})(16) / (0.20 \times 10^{-6})$
$R = 78.4$ Ω

resistance = ... Ω [2]

2. the power dissipation when a 240 V supply is connected across it.

$P = (240)^2 / 78.4$
$P = 735$ W

power = ... W [2]

(ii) Fig. 6.1 shows how the two coils can be connected for the heating coil to operate at different powers.

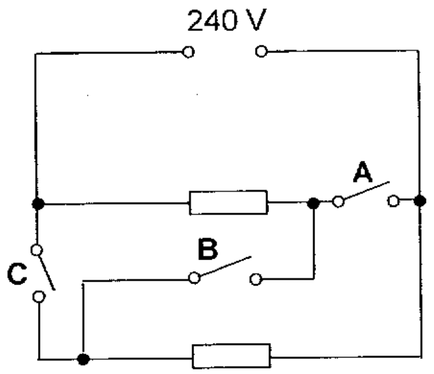


Fig. 6.1

On Fig. 6.2, fill up the table with "ON" or "OFF" to obtain the lowest and highest levels of operating power.

	switch A	switch B	switch C
Lowest			
Highest			

Fig. 6.2

[2]

	switch A	switch B	switch C

Lowest	OFF	ON	OFF
Highest	ON	OFF	ON

B1 for each Lowest and Highest row

7 Fig. 7.1 shows a microwave transmitter aimed at a metal plate.

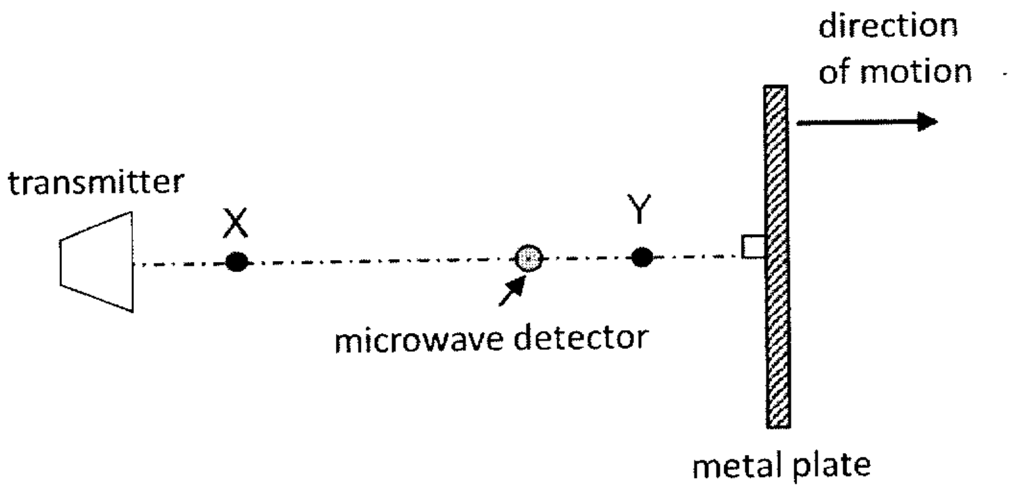


Fig. 7.1

(a) A small detector, moved along the line XY, travels 16 cm in moving from the first to the 12th consecutive nodal position.

Show that the microwaves emitted have a frequency of 10 GHz. [3]

Between the 1st and 12th nodes there are 11 half-wavelengths ($\lambda/2$)
Hence $11 \times \lambda/2 = 16$ cm $\rightarrow \lambda = 0.0291$ m
Therefore frequency of the microwaves emitted $= c/\lambda$
$= (3 \times 10^8)/(0.0291)$
$= 10.3 \times 10^9$ Hz ~ 10 GHz

(b) The detector is now at position Y and the metal plate is moved to the right, along the direction XY at a constant speed.

State and explain what is observed at the detector.

The detector will continue to <u>detect a series of maxima and minima</u>.
The <u>path/phase difference between the incident and reflected waves changes</u> as the metal plate shifts to the right.

....

.... [2]

8 During radioactive decay, which is spontaneous and random, γ-ray (gamma ray) photons may be emitted. When these photons are incident on a sodium iodide crystal, some of the photons may be absorbed in the crystal. The absorption of a γ-ray photon causes the emission of a short pulse of light known as a scintillation. The scintillations may be detected and converted into electrical pulses using *a photomultiplier tube*, which, when connected to a counter, gives the *count rate* and enables γ-ray *activity* to be measured. The arrangement is illustrated in Fig. 8.1.

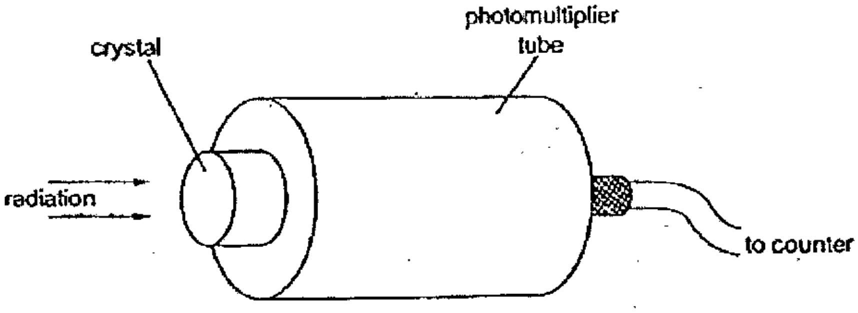


Fig. 8.1

The crystals used in such counters may be of different shapes. Fig. 8.2 shows a solid cylindrical crystal.

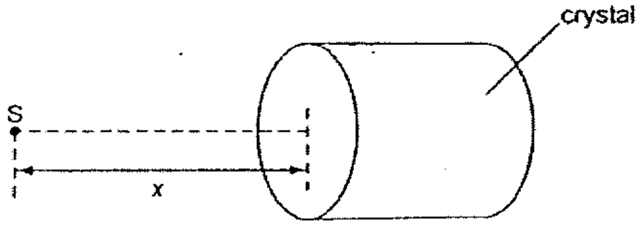


Fig. 8.2

The small γ-ray source S is placed a distance x in front of one face of the crystal. The source is assumed to emit photons uniformly in all directions. Not all of the emitted photons will be absorbed by the crystal. The efficiency Q of detection is defined by the equation

$$Q = \frac{\text{number of photons producing scintillations in the crystal}}{\text{total number of photons emitted by the source}}$$

(a) By reference to the passage, explain what is meant by

(i) *count rate*

Count rate is a measure of the rate of radiation received by a radioactivity detector

....

....

....

.... [1]

(ii) *activity*

Activity of a radioactive isotope is defined as the number of nuclear disintegrations per unit time.

....

....

....

.... [1]

(b) Suggest two reasons why the γ-ray photons emitted by the source are not all absorbed in the crystal.

The source emits photons in all directions and many will travel in directions away from the face of the crystal and not be absorbed.

Only those photons that arrive at the small circular window area of the face of the crystal will have a probability of being absorbed.

1. ....

....

....

.... [1]

γ-rays are highly penetrating hence not every γ-ray photon that enters the crystal will interact with a sodium iodide molecule.

Some of the higher energy photons will penetrate through the crystal without any interaction taking place.

2. ....

....

....

.... [1]

(c) Fig. 8.3 shows the variation with γ-ray photon energy E of the efficiency Q. Curves are drawn for various values of the distance x of the source S from the face of the crystal.

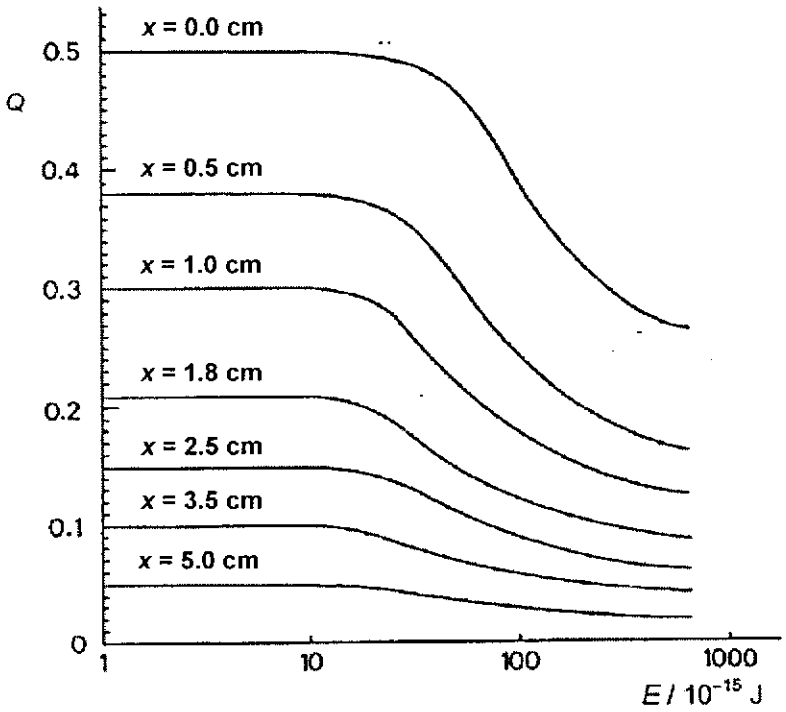


Fig. 8.3

(i) Suggest why at any one particular value of energy, the efficiency Q decreases as x increases.

Intensity $I = P/A = P / 4\pi x^2$ where P is the power emitted by the radioactive source which is a constant.

As x increases, the photons are spread out over a larger spherical surface area A, and the intensity of the radiation incident on the face of the crystal will be lower.

A lower intensity means fewer photons arriving per unit area per unit time which will give a smaller Q value.

....

....

....

....

....

....

.... [3]

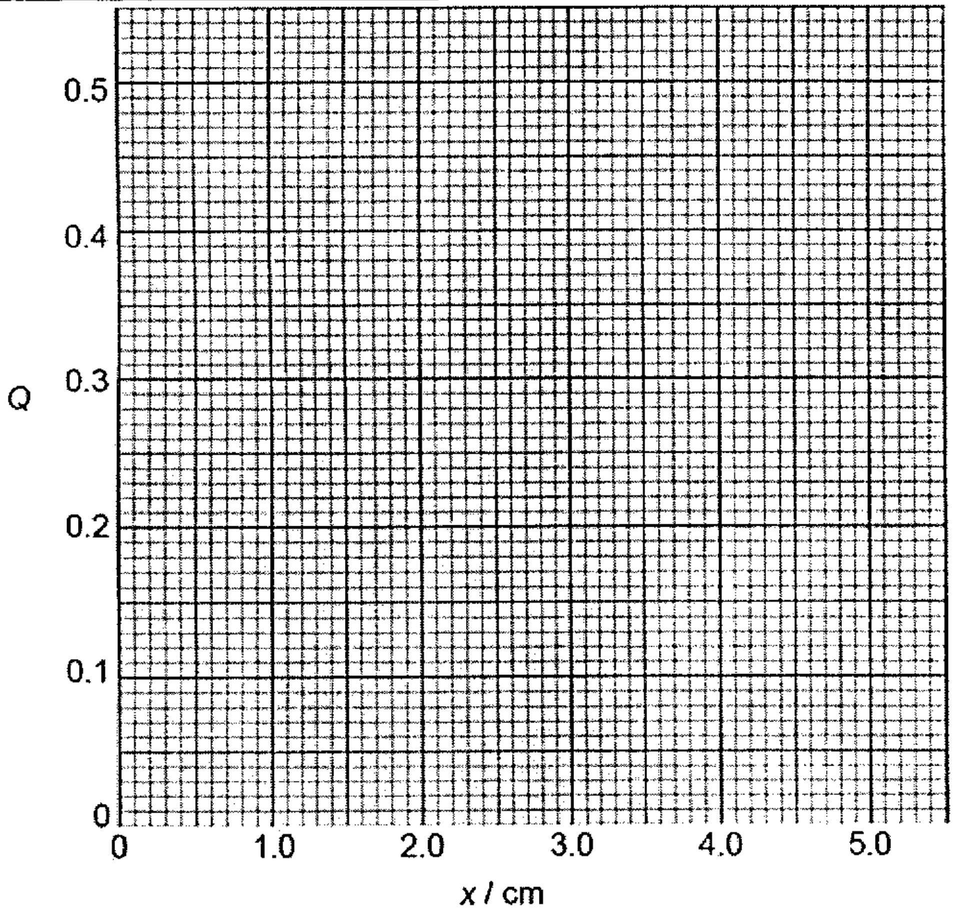
(ii) With reference to Fig. 8.3 and considering γ-ray photons of energy 8×10^{-15} J, complete Fig. 8.4 with corresponding values of Q with for γ-ray photons of this energy.

Q	x / cm

Fig. 8.4 [2]

Q	x / cm
0.05	5.0
0.10	3.5
0.15	2.5
0.21	1.8
0.30	1.0
0.38	0.5
0.50	0.0

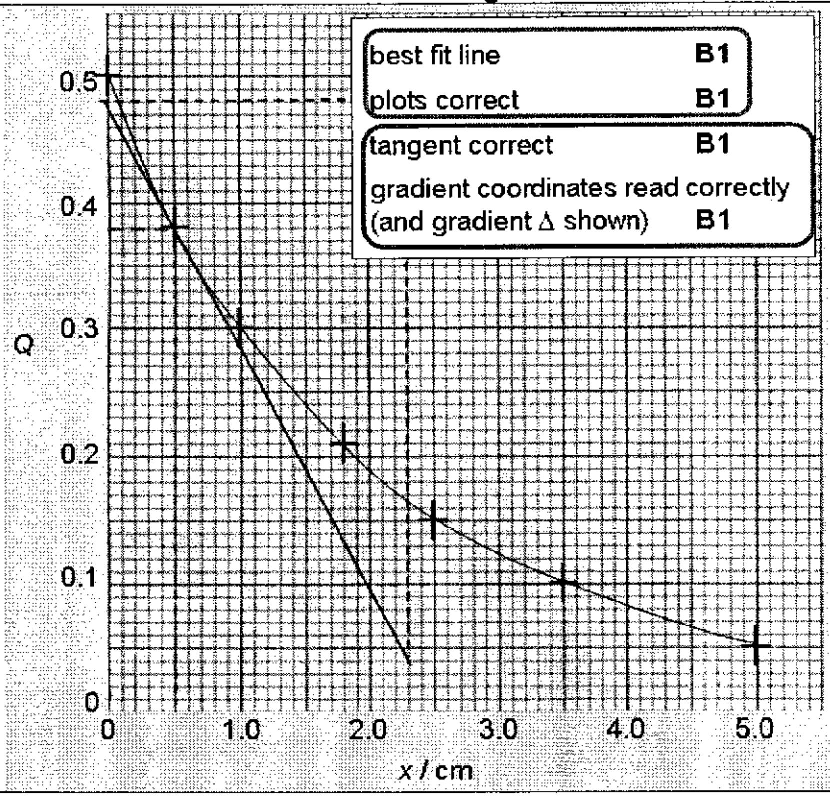
(d) (i) Use your values in Fig. 8.4 to draw a graph of Q against x in Fig. 8.5.



Q
0.5
0.4
0.3
0.2
0.1
0
1.0
2.0
3.0
4.0
5.0
x / cm

Fig. 8.5

[2]



best fit line B1
plots correct B1
tangent correct B1
gradient coordinates read correctly
(and gradient Δ shown) B1
Q
0.5
0.4
0.3
0.2
0.1
0
1.0
2.0
3.0
4.0
5.0
x / cm

		(ii)	Use Fig. 8.5 to determine the rate of change of Q with x when $x = 0.5$ cm.	
			Gradient = $\Delta y/\Delta x$ -0.19 to -0.21 cm^{-1}	
			rate of change = ... cm^{-1}	[4]
		(iii)	It may be deduced from Fig. 8.5 that Q is related to x by an expression of the form $$Q = ae^{-bx}$$ where a and b are constants. Explain how Fig. 8.5 shows this.	
			The equation of the form $Q = ae^{-bx}$ is an exponentially decreasing function with respect to x. *An exponentially decreasing function, similar to the one for radioactive decay with respect to time, will fall to half its value for every fixed interval.* It can be seen from the graph that this fixed interval is approximately 1.5 cm. (i.e. the efficiency Q falls to half its value every 1.5 cm).	
			....	
			....	
			....	
			....	
			....	[2]

	(e)	(i)	Suggest why the maximum efficiency that can be achieved with low-energy γ-ray photons using the crystal illustrated in Fig. 8.2 is 0.50.	
			The maximum efficiency is achieved when $x = 0$ cm, i.e. the source is placed right at the face of the crystal. In this case, half the γ-ray photons emitted (those to the right side of the source within a hemispherical surface area) will be captured by the crystal.	
			....	
			....	

			....	
			....	
			....	[2]
		(ii)	A second crystal consists of a hollow cylinder, as shown in Fig. 8.6.	

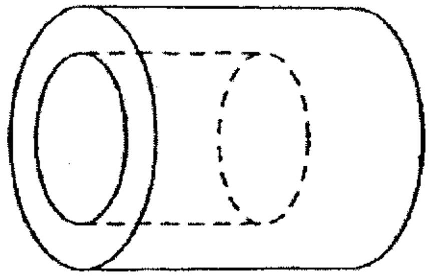


Fig. 8.6

			State the effect of this change of shape on the maximum efficiency Q of the detector if the source is placed inside the hollow region.	
			The maximum efficiency Q will be greater as the available area for capturing the γ-ray photons is larger.	
			....	
			....	[1]

END OF PAPER