Catholic Junior College
JC2 Preliminary Examinations
Higher 2

CANDIDATE NAME	MARK SCHEME
CLASS	2T

PHYSICS — 9749/02

Paper 2 Structured Questions

August 2025

2 hours

Candidates answer on the Question Paper.

READ THESE INSTRUCTIONS FIRST

Write your name 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.
Answer **all** questions.

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

FOR EXAMINER'S USE		
Q1		/ 10
Q2		/ 8
Q3		/ 12
Q4		/ 8
Q5		/ 9
Q6		/ 11
Q7		/ 22
PAPER 2		/ 80

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} mol^{-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	$\phi = -\frac{Gm}{r}$
temperature	$T / K = T / {}^\circ C + 273.15$
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	$V = \frac{Q}{4\pi\varepsilon_o r}$
alternating current / voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o n I$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

[Turn over

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

1 A toy car of mass 0.42 kg is released from rest and accelerates along a straight track towards a wall. It hits the wall and rebounds in the opposite direction. The variation with time t of the momentum p of the toy car when not in contact with the wall is shown in Fig. 1.1

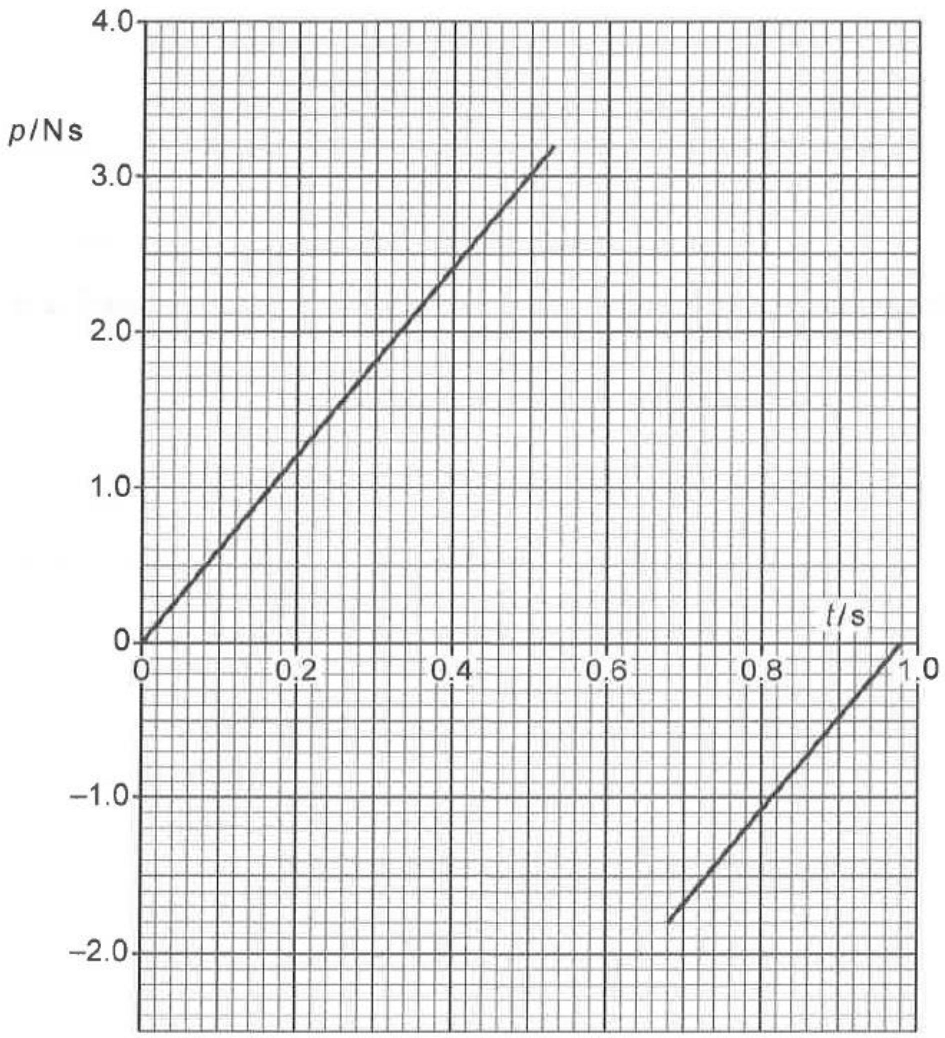


Fig 1.1

(a) Using Fig 1.1, calculate the impulse acting on the toy car during the collision.

impulse = ……………….. N s [2]

Solution:

Impulse = change in momentum

$= p_f - p_i$ M1

$= -1.80 - (3.20)$

$= -5.00$ N s A1

(b) Calculate the magnitude of the average acceleration of the car during the collision and state the direction of this acceleration relative to the initial motion of the car.

average acceleration = …………………………..m s^{-2}

direction = …………………..…………………………………… [3]

Solution:

$\Delta v=\dfrac{\Delta p}{m}=\dfrac{-5.00}{0.42}=-11.9\ m\ s^{-1}$ M1

$a=\dfrac{\Delta v}{\Delta t}=\dfrac{-11.9}{0.15}=-79.3\ m\ s^{-2}$

$|a|=79.3\ m\ s^{-2}$ A1

Direction: opposite to the initial motion of the car A1

(c) Explain why the collision was inelastic.

……………………………………………………………………………………………………...

…………………………………………………………………………………………………….

…………………………………………………………………………………………………….

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

Solution:

The momentum and hence speed of the car before and after the collision is different. The wall is stationary and hence has no momentum and no KE. B1

The total initial KE and the total final KE of the system of the car and wall is not the same. B1

Therefore, collision is inelastic. A0

	(d)	Calculate the percentage change in the kinetic energy of the car as a result of the collision.	
		percentage change = ……………………… %	[3]
		Solution: $E_{K,i}=\frac{p_i^2}{2m}=\frac{3.20^2}{2(0.42)}=12.2\ J$ and $E_{K,f}=\frac{p_f^2}{2m}=\frac{1.80^2}{2(0.42)}=3.86\ J$ $\%\Delta E_K=\frac{E_{K,f}-E_{K,i}}{E_{K,i}}\times 100\%$ $=\frac{3.86-12.2}{12.2}\times 100\%$ $=-68.4\%$ (including -ve sign)	M1 C1 A1

[Total: 10]

2	**(a)**	State what is meant by the centre of gravity of an object.	
		…………………………………………………………………………………………………	
		…………………………………………………………………………………………………	[1]
		Solution: The centre of gravity of an object is <u>a point where the **entire** weight</u> of the object is taken to act.	B1

(b) A hollow plastic sphere is attached at one end of a bar. The sphere is partially submerged in water and the bar is attached to a fixed vertical support by a pivot P, as shown in Fig. 2.1.

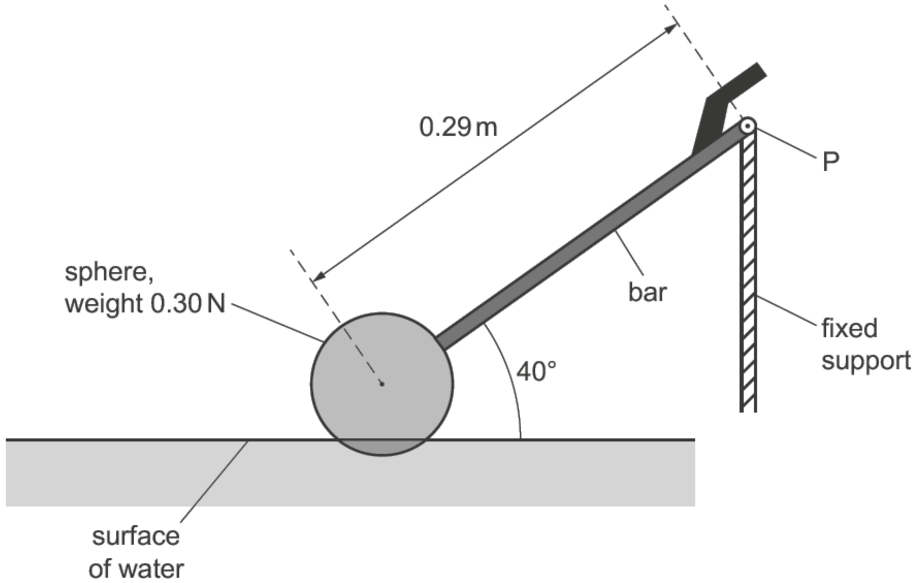


Fig. 2.1 (not to scale)

The sphere has weight 0.30 N. The distance from P to the centre of gravity of the sphere is 0.29 m. The weight of the bar is negligible.

The system shown in Fig. 2.1 is part of a mechanism that controls the amount of water in a tank. Water enters the tank and causes the sphere to rise. This results in the bar becoming horizontal as shown in Fig. 2.2.

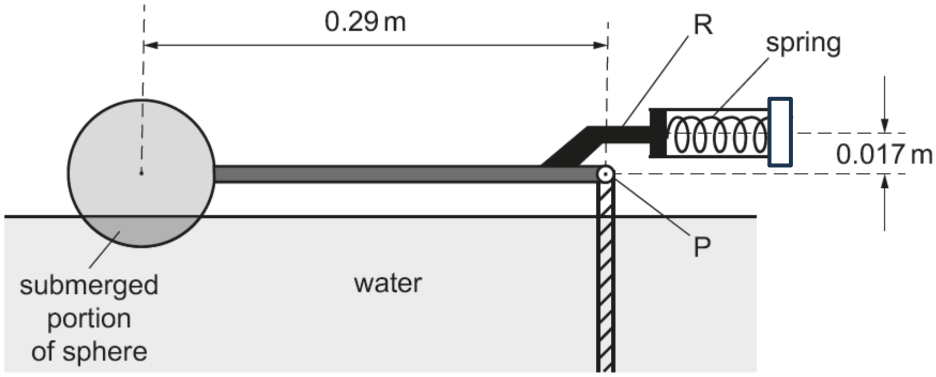


Fig. 2.2 (not to scale)

At the position shown in Fig. 2.2, the system is stationary and in equilibrium. The rod R exerts a force to compress a horizontal spring that controls the water supply to the tank. The spring has a spring constant of 2100 N m^{-1}. R is positioned at a perpendicular distance of 0.017 m above P.

(i) The radius of the sphere is 0.0480 m and 26.0% of the volume of the sphere is submerged.

The density of water is 1.00×10^3 kg m^{-3}.

Show that the upthrust on the sphere is 1.18 N.

[2]

Solution:

Volume V of the sphere = $\frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi(0.0480)^3$

$= 4.63 \times 10^{-4}$ m^3 M1

Upthrust, $U = \rho V g = 1000(0.26)(4.63 \times 10^{-4})(9.81)$ M1

$= 1.18$ N

(ii) For the position shown in Fig 2.2, by taking moments about P, determine the force exerted on the spring by the rod R.

force = ……………………………..……… N [2]

Solution:

The force exerted on the spring by the rod is equal to the force exerted on the rod by the spring. Let the force be F.

Taking moments about P,

$(U - 0.30)(0.29) = F(0.017)$ M1

$(1.18 - 0.30)(0.29) = F(0.017)$

$F = 15$ N A1

(iii) Calculate the elastic potential energy E_P of the compressed spring.

E_P = ……………………………..……… J [2]

			Solution: Compression *x* of the spring = *F* / *k* = 15 / 2100 (ecf for F) = 0.00715 m $E_P = \frac{1}{2} kx^2$ = ½ (2100)(0.00715)² = 0.054 J	 M1 A1
	(c)	When the sphere moves from the position shown in Fig. 2.1 to the position shown in Fig. 2.2, the upthrust on the sphere does work. Assume that resistive forces are negligible. Explain why the work done by the upthrust is not equal to the gain in elastic potential energy of the spring. …………………………………………………………………………………………… ……………………………………………………………………………………………		
		……………………………………………………………………………………………		[1]
		Solution: By conservation of energy, the work done by the upthrust is equal to the sum of the gain in elastic potential energy of the spring and the gain in gravitational potential energy of the sphere. The gain in gravitational potential energy of the sphere has not been considered.		B1

[Total: 8]

3 (a) Fig. 3.1 shows a string stretched between two fixed points P and Q.

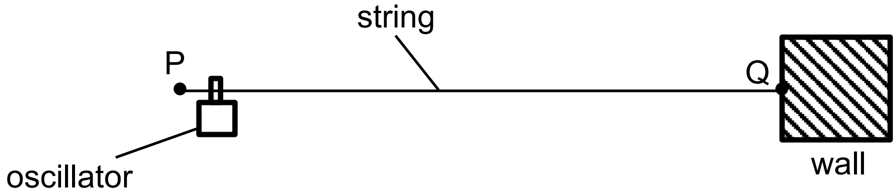


Fig. 3.1

An oscillator is attached near end P of the string. End Q is fixed to a wall. The oscillator has a frequency of 480.0 Hz.

The stationary wave produced on PQ at an instant time *t* is shown in Fig. 3.2. Each point on the string is at its maximum displacement.

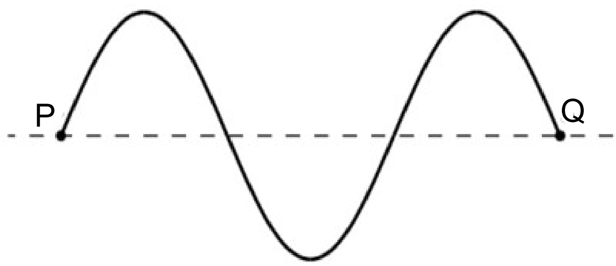
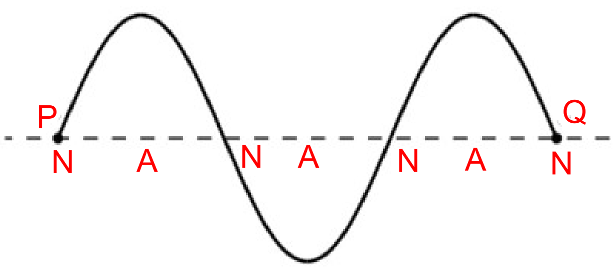


Fig. 3.2

(i) On Fig. 3.2, label all the nodes with the letter **N** and the antinodes with the letter **A** along the dotted line PQ.

[2]

Solution



Correct position of nodes drawn. B1
Correct position of antinodes drawn. B1

(ii) Calculate the lowest possible frequency of the wave that can be formed between end P and Q of the string.

frequency = ……………………………… Hz [3]

Solution

Using $v = f\lambda$, therefore $f = \frac{v}{\lambda}$.

There are 1.5 wavelengths of wave formed between end P and Q for the string in Fig. 3.2.

Length L of string between end P and Q: $L = \frac{3\lambda_3}{2}$

Frequency in Fig. 3.2: $f = \frac{v}{\lambda_3} = \frac{v}{\frac{2L}{3}} = \frac{3v}{2L} = 480.0$ Hz — C1

For lowest possible frequency formed between end P and Q of string, it corresponds to 0.5 wavelength.

Length L of string between end P and Q: $L = \frac{\lambda_1}{2}$

Lowest possible frequency: $f' = \frac{v}{\lambda_1} = \frac{v}{2L} = \frac{3v}{2L}\left(\frac{1}{3}\right) = \frac{480.0}{3}$ — M1

$= 160.0$ Hz — A1

(b) A loudspeaker is connected to a signal generator. It is then oriented to face a wall as shown in Fig. 3.3. Sound waves are produced between the speaker and the wall to form a stationary wave.

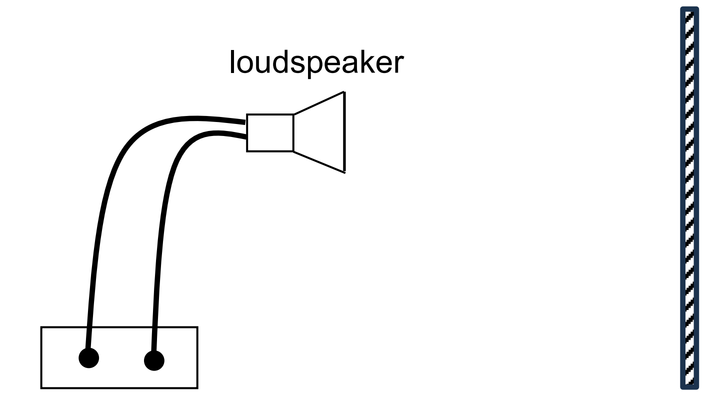


Fig. 3.3

(i) Explain why there are alternate regions of high and low intensity detected between the loudspeaker and the wall.

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.... [3]

Solution

The sound waves propagate and reflect off the wall, the incident and reflected waves have the same amplitude, wavelength/ frequency/ speed, — B1

			They move in opposite direction and overlap/superpose/meet. When they experience constructive interference, they form regions of high intensity and when they experience destructive interference, they form regions of low intensity.	B1 B1
		(ii)	Outline how you would use this setup to obtain the speed of sound waves in air.	
			....	
			....	
			....	
			....	
			....	
			....	
			....	
			....	
			....	[4]
			Solution A microphone is moved between the speaker and the wall to detect maximum and minimum intensities. The microphone is connected to a cathode ray oscilloscope (CRO). The frequency is calculated from the period obtained from the CRO. Measure the separation between the positions of adjacent minimum/maximum intensities which is equivalent to half a wavelength. Repeat the measurements of the distance between these positions and find the average. Multiply the average inter-nodal distance to obtain the wavelength of the wave. Use $v = f\lambda$ to determine the speed of sound waves in air.	 B1 B1 B1 B1

[Total: 12]

4 A battery B, a variable resistor R and a uniform resistance wire PQ are connected in series, as shown in Fig. 4.1

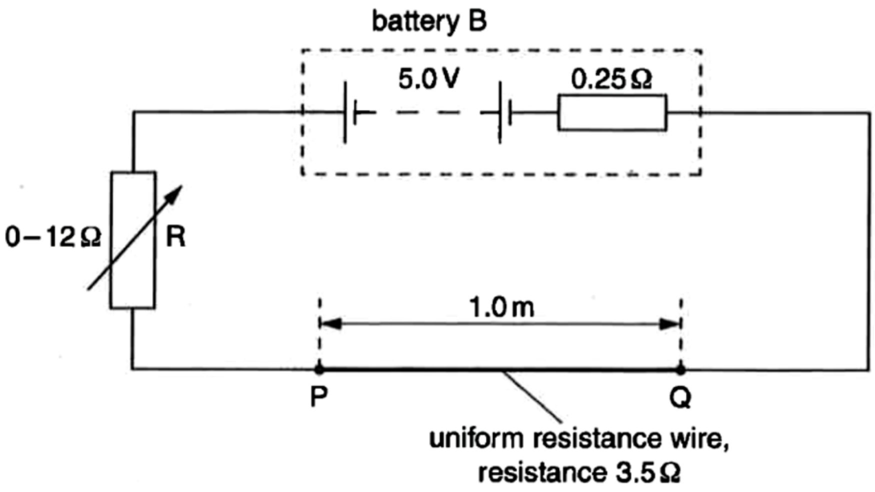

Fig. 4.1

Battery B has electromotive force (e.m.f.) 5.0 V and internal resistance 0.25 Ω.

Wire PQ has length 1.0 m and resistance 3.5 Ω at room temperature.

(a) The resistance of R is set to 4.0 Ω.

Calculate, when the circuit is just turned on,

(i) the potential difference across wire PQ,

p.d. = ... V [2]

Solution

Current in circuit = 5.0 / (0.25 + 4.0 + 3.5) = 0.645 A — M1

the p.d. across wire PQ = 0.645 (3.5) = 2.26 V — A1

OR,

p.d. across wire PQ = 5.0 – (0.645)(0.25 + 4.0) = 2.26 V

OR,

p.d. across wire PQ = (5.0)(3.5) / (4.0 + 3.5 + 0.25) = 2.26 V

(ii) the percentage of total power transferred to wire PQ.

percentage = ... % [2]

		Solution Power transferred to wire PQ = IV = 0.645(2.26) Power generated by Battery B = IE = 0.645 (5.0) Percentage power transferred = [Power transferred to wire PQ/ power generated by Battery B] x 100% = [0.645 (2.26) / 0.645 (5.0)] x 100% = 45.2 %		 M1 A1
	(b)	The temperature of the wire gradually increased from room temperature to maximum steady temperature.		
		(i)	Describe and explain the variation in the terminal potential difference (p.d.) across B. Numerical values are not required.	
			…………………………………………………………………………………………… …………………………………………………………………………………………… ……………………………………………………………………………………………	
			……………………………………………………………………………………	[2]
		Solution: As the temperature increases, its resistance increases, hence the total resistance increases and the current decreases terminal p.d. = E – Ir will be increased since I decreases and E and r are constants		 B1 B1
		(ii)	Suggest why the temperature of the wire will reach a steady maximum value.	
			…………………………………………………………………………………………… ……………………………………………………………………………………………	
			……………………………………………………………………………………	[2]
		Solution: When the maximum temperature is reached, the electrical power absorbed is equal to the power dissipated to the surroundings. There is no net energy absorbed by the wire so the temperature will remain constant.		 B1 B1

[Total: 8]

5	(a)	An ideal gas is said to consist of molecules that are hard elastic identical spheres. State two further assumptions of the kinetic theory of gases.	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
		Solution Any two of the following assumptions: Total volume of molecules negligible compared to the volume of vessel. No intermolecular forces between the molecules. Molecules are in random motion. Time of collision small compared with the time between collisions. Larger number of molecules.	 B1 B1
	(b)	The number of molecules per unit volume in an ideal gas is n. If it is assumed that all the molecules are moving with speed v_x in the x-direction, the pressure p exerted by the gas on the walls of the vessel is given by $$p = nm{v_x}^2$$ where m is the mass of one molecule. Explain the reasoning by which this expression is modified to give the formula $$p = \frac{1}{3}nm\langle c^2 \rangle.$$ where $\langle c^2 \rangle$ is the mean square speed of the molecules.	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	
		…………………………………………………………………………………………	[2]
		Solution In the actual scenario, there is a range of velocities of molecules in any given direction. Thus, the average of v^2 of the molecules should be considered. Molecules move in random direction and can move in x, y and z-direction. Since the probability of the movement of molecules in either direction is the same, $\langle {v_x}^2 \rangle = \langle {v_y}^2 \rangle = \langle {v_z}^2 \rangle$ $\langle {v_x}^2 \rangle = \frac{1}{3}\langle c^2 \rangle$	 B1 B1

	(c)	The density of an ideal gas is 1.2 kg m^{-3} at a pressure of 1.0 × 10^5 Pa and a temperature of 27 °C.		
		(i)	Calculate the root-mean-square (r.m.s.) speed of the molecules of the gas at 27 °C.	
			root-mean-square speed = …………………...………… m s^{-1}	[3]
			Solution Nm = mass of gas $\rho = \frac{M}{V} = \frac{Nm}{V} = nm$ Therefore, $p = \frac{1}{3}nm\langle c^2\rangle = \frac{1}{3}\rho\langle c^2\rangle$ $1.0\times10^5 = \frac{1}{3}(1.2)\langle c^2\rangle$ $\langle c^2\rangle = 2.5\times10^5$ $C_{\text{r.m.s.}} = \sqrt{2.5\times10^5}$ $= 500$ m s^{-1}	C1 M1 A1
		(ii)	Calculate the mean-square speed of the molecules at 207 °C.	
			mean-square speed = ………………………..………… m^2 s^{-2}	[2]
			Solution $E = \frac{3}{2}kT = \frac{1}{2}m\langle c^2\rangle$ $\langle c^2\rangle \propto T$ $\frac{\langle c^2\rangle_{207^0\text{C}}}{\langle c^2\rangle_{27^0\text{C}}} = \frac{207+273.15}{27+273.15}$ $\langle c^2\rangle_{207^0\text{C}} = \left(\frac{207+273.15}{27+273.15}\right)(2.5\times10^5)$ $= 4.0\times10^5$ m^2 s^{-2}	M1 A1

[Total: 9]

6 (a) When ultraviolet radiation of a specific frequency is incident on a metal surface, electrons are emitted with a range of kinetic energies up to a maximum value.

Explain why the emitted electrons have a range of kinetic energies up to a maximum value.

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....[3]

Solution:

Each photon provides a fixed amount of energy E = hf.	B1
Electrons at the **surface require the least energy (or work function energy)** to escape and can emerge with the maximum kinetic energy.	B1
Electrons inside the metal require **greater amounts of energy to escape (**those deeper inside lose energy due to collisions and electrostatic attraction) and hence **emitted with lower KE**.	B1

(b) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is measured for different wavelengths λ of the electromagnetic radiation. The variation of E_{MAX} with $\frac{1}{\lambda}$ is shown in the Fig. 6.1.

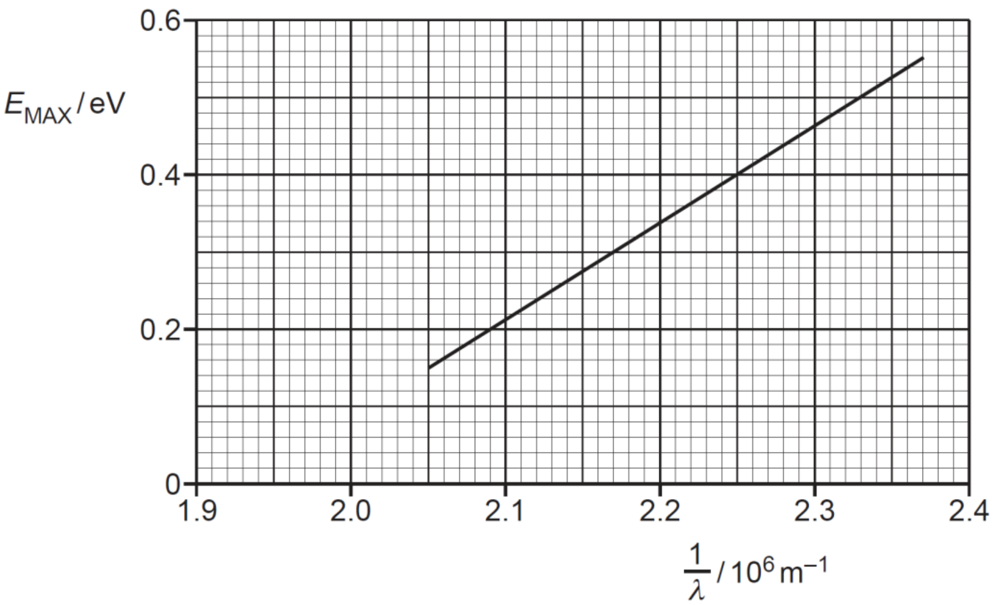
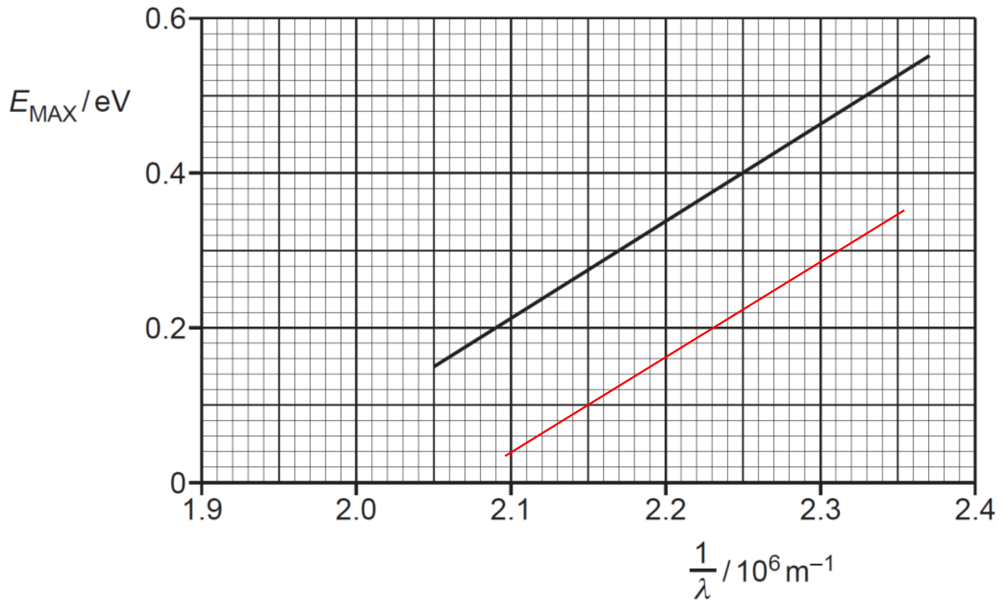


Fig. 6.1

Use the graph to:

		(i)	determine the threshold frequency f_0 of the metal. f_0 = ... Hz	[2]
			Solution: Extrapolate graph and find the x-intercept For $E_{MAX} = 0$, $\frac{1}{\lambda} = 1.93 \times 10^6$ $f_0 = \frac{c}{\lambda_0} = 3.00 \times 10^8 \times 1.93 \times 10^6$ $= 5.79 \times 10^{14}$ Hz	M1 A1
		(ii)	determine a value for the Planck constant h. Explain your working clearly.	
			h = ... J s	[3]
			Solution: $E_{MAX} = \frac{hc}{\lambda} - \phi$ gradient = hc $= \frac{(0.4 - 0.2) \times 1.6 \times 10^{-19}}{(2.25 - 2.09) \times 10^6} = 2.0 \times 10^{-25}$ $h = \frac{2.0 \times 10^{-25}}{3 \times 10^8}$ $= 6.7 \times 10^{-34}$ J s	C1 M1 A1
	(c)		The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in **(b)**. On Fig 6.1, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}.	[1]

Solution:



With a larger work function, the threshold frequency required is larger and hence as f_0 is proportional to $\frac{1}{\lambda_0}$, the value of the x axis-intercept is larger. The gradient *hc*, which is a constant, remains the same.

Straight line with same gradient as original and x-axis intercept greater than 1.93×10^6 m^{-1}. B1

(d) Infrared radiation of the same intensity is now incident on the same metal surface used in **(b)**.

Explain why no electrons are emitted from the metal surface.

....

....

....

....[2]

[Total: 11]

Solution:

Infrared photons have **lower energy** than ultraviolet photons because they have a **lower frequency** since($E = hf$). B1

The energy of an infrared photon is **less than the metal's work function**, so no electrons have enough energy to be emitted. B1

7 Read the passage and answer the questions that follow.

Zircon ($ZrSiO_4$) crystals found in rocks serve as reliable timekeepers for determining the age of geological formations. These crystals readily incorporate uranium atoms into their crystal lattice during formation but strongly exclude lead. As a result, any lead found in a zircon crystal can be assumed to be the product of radioactive decay, making the crystal an effective record of the time that has passed since it solidified.

Two uranium decay chains are used in zircon dating: uranium-238 (U-238) decaying to lead-206 (Pb-206), and uranium-235 (U-235) decaying to lead-207 (Pb-207). These decay processes follow predictable rates, governed by their half-lives: 4.47 billion years for U-238 and 704 million years for U-235. By measuring the ratio of lead to uranium isotopes in a zircon, geologists can determine its age, and thus the age of the rock in which it was found.

The age of a sample of zircon can be derived from the radioactive decay equation and the measured ratio of the lead to uranium isotopes $\frac{D}{N}$. For each parent isotope, the number of daughter atoms D accumulated over time is given by:

$$D = N_0 - N$$

where N_0 is the initial number of the parent atom and N is the number of remaining parent atoms.

When both decay systems (U-238 to Pb-206 and U-235 to Pb-207) are measured in a single zircon sample, the results can be plotted on a Concordia diagram—a graph of the isotopic ratios $\frac{\text{Pb-206}}{\text{U-238}}$ against $\frac{\text{Pb-207}}{\text{U-235}}$. The curve on this graph, known as the Concordia curve, represents points where both decay systems yield the same age, as shown in Fig. 7.1.

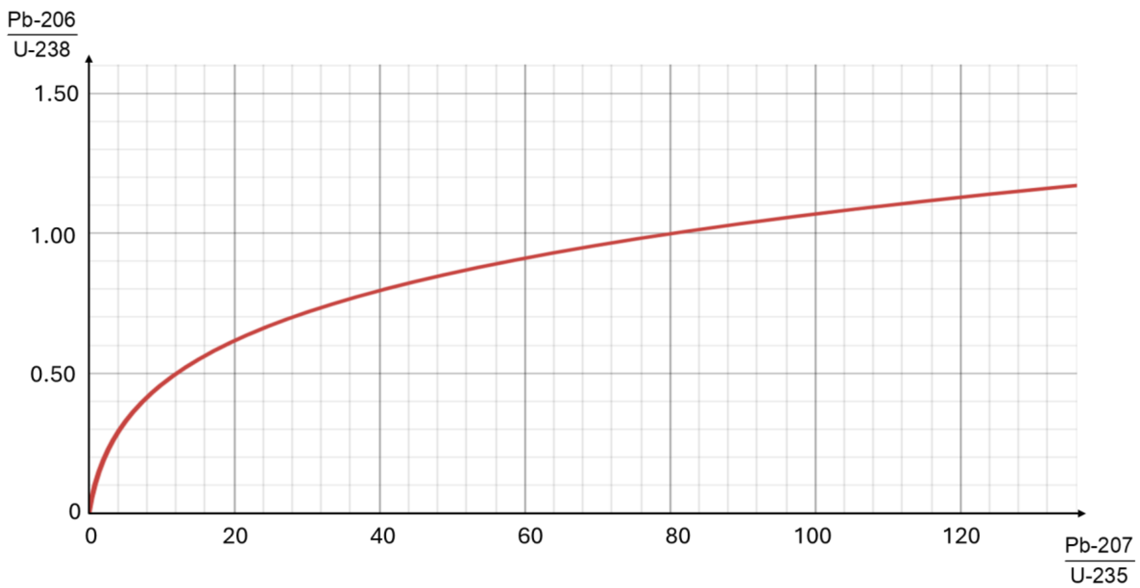


Fig 7.1

A zircon that has remained isolated from chemical changes since its formation will have ratios of isotopes that lie on this curve, and its age can be confidently determined. If the sample has been altered by natural processes, the resulting isotopic ratios will not be on the curve, indicating that further analysis is required.

To determine these isotopic ratios, geologists use a technique called Secondary Ion Mass Spectrometry (SIMS). In SIMS, a focused primary ion beam (typically O^- or Cs^+) bombards the zircon crystal, releasing atoms from its surface. Some of these atoms are ionised, forming secondary ions that include the uranium and lead isotopes of interest. These ions are then accelerated through a potential difference of 10 kV, gaining kinetic energy as they do so.

After acceleration, the ions enter a uniform magnetic field of 0.75 T that is perpendicular to their velocity. The magnetic force causes the ions to move in circular arcs, with their radius determined by their mass-to-charge ratio. The mass spectrometer thus separates the ions by isotope, as ions like $^{206}Pb^{+}$ and $^{238}U^{+}$ follow different trajectories and strike the detector at different positions. The relative intensities of the ion signals are used to calculate the isotopic ratios. Fig. 7.2 below shows the path of the ions in a mass spectrometer.

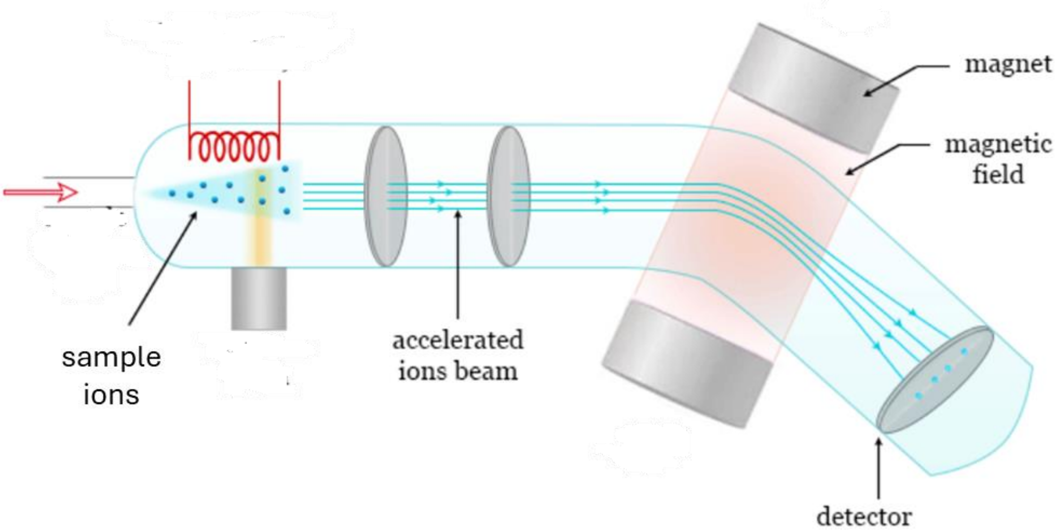


Fig 7.2

SIMS allows highly precise measurement of isotope ratios in microscopic regions within a single zircon grain. By comparing these measured ratios with those expected from known decay rates and plotting the results on the Concordia diagram, geologists can derive robust and accurate age estimates—often within a few million years—even for samples that are over 4 billion years old.

(a) Explain, using the ratio of daughter to parent nuclei, why isotopes with long half-lives are more suitable than those with short half-lives for dating very old geological samples.

....

....

.... [1]

Solution:

Isotopes with shorter half-lives would have decayed almost completely, **leaving too few parent nuclei** (or too high daughter-to-parent ratio) to **measure accurately.** **B1**

Note: Instruments may not be sensitive enough to detect or count such small quantities precisely. With a very large daughter-to-parent ratio, any small measurement error in the number of remaining parent atoms results in a large error in the calculated age.

[Turn over

	(b)	Uranium-238 decays into stable lead-206 via a series of alpha and beta decays.		
		(i)	In the first step of the uranium-238 decay chain, a uranium-238 nucleus undergoes alpha decay to form a thorium-234 nucleus and an alpha particle. The atomic masses of the nuclei involved are: Mass of uranium-238 nucleus = 238.0508 u Mass of thorium-234 nucleus = 234.0436 u Mass of helium-4 nucleus = 4.0026 u Calculate the energy released in this decay in MeV.	
			energy released = …………………. MeV	**[4]**
			Solution: **Calculating mass defect** Mass defect (Δm) is the difference between the mass of the parent nucleus and the total mass of the decay products. Δm = mass of uranium-238 − (mass of thorium-234 + mass of helium-4) Δm = 238.0508 u − (234.0436 u + 4.0026 u) Δm = 0.0046 u = $(0.0046 \times 1.66 \times 10^{-27})$ kg Δm = 7.6385×10^{-30} kg (correct delta m) **Calculating energy** $E = \Delta mc^2 = 7.6385 \times 10^{-30} \times (3.00 \times 10^8)^2$ (correct substitution and E value) $E = 6.8746 \times 10^{-13}$ J 1 MeV = 1.602×10^{-13} J $E = 6.8746 \times 10^{-13} \div 1.602 \times 10^{-13}$ **E = 4.29 MeV (converted correctly)**	M1 M1 M1 A1
		(ii)	Calculate the total number of alpha and beta decays in the decay chain of uranium-238 ($^{238}_{92}U$) to lead-206 ($^{206}_{82}Pb$).	

			number of alpha decays = ... number of beta decays = ...	[3]
			Solution: **Mass number decreases from 238 to 206: decrease of 32 nucleons** Since each alpha decay reduces the mass number by 4, there must be 8 alpha decays **Atomic number decreases from 92 to 82: decrease of 10 protons** Each alpha decay decreases Z by 2: decrease of 16 protons Since only 10 protons were lost, 6 must have been gained via beta decay Final solution**: 8 alpha decays, 6 beta decays**	M1 M1 A1
	(c)	**(i)**	Using the radioactive decay equation and the information in the passage, show that the age of a sample of zircon t with a ratio of daughter to parent isotopes $\frac{D}{N}$ is given by $$t = \frac{1}{\lambda}\ln(\frac{D}{N}+1)$$ where λ is the decay constant of the parent isotope.	[2]
			Solution: The number of undecayed parent nuclei after time t is $N = N_0 e^{-\lambda t}$ Since $D = N_0 - N$, therefore $N_0 = D + N$ Substituting into the first equation:	M1 M1

$$N = (D + N)\,e^{-\lambda t}$$

$$e^{\lambda t} = \frac{D}{N} + 1$$

$$\lambda t = \ln\left(\frac{D}{N} + 1\right)$$

$$t = \frac{1}{\lambda}\ln\left(\frac{D}{N} + 1\right)$$

A0

(ii) In a particular sample of zircon found in Western Australia, the ratio of lead-206 to uranium-238 isotope was found to be 0.978.

Determine the age of the zircon sample *t* in years.

t = ... years [2]

Solution:

Decay constant

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{4.47 \times 10^{9}} = 1.55 \times 10^{-10}\ \text{yr}^{-1}$$

Using the equation from (c)(ii)

$$t = \frac{1}{1.55 \times 10^{-10}}\ln(0.978 + 1)$$ M1

$$t = 4.41 \times 10^{9}\ \text{years}$$ A1

(iii) The ratio of lead-207 to uranium-235 ratio for the same sample was measured to be 76.0. Using the Concordia diagram (Fig 7.1), determine whether the two ratios agree on the age of this zircon sample.

....

....

			………………………………………………………………………… [2]	
			Solution: **The point (76.0, 0.978) lies on the Concordia curve.** Therefore, **the two ratios agree** on the age of the zircon sample.	 M1 A1
		(iv)	Natural processes may change the number of lead or uranium nuclei in a sample. Suggest what changes may have occurred to the number of nuclei in a certain sample for it to have a data point that lies below the Concordia curve. ………………………………………………………………………… ………………………………………………………………………… [1]	
			Solution: It suggests **a loss of lead isotopes** after their formation in the decay process. OR **Reintroduction of new uranium isotopes** into the zircon lattice.	 B1 B1
	(d)	**(i)**	The ions from a zircon crystal in a SIMS device are accelerated through a potential difference of V before entering a uniform magnetic field of magnetic flux density B where they move in a circular arc of radius r. Show that the mass to charge ratio of the ions $\frac{m}{q}$ is given by $$\frac{m}{q}=\frac{B^2r^2}{2V}$$ [3]	
			Solutions: The kinetic energy gained by the ions come from the electric potential energy change due to the p.d. $qV=\frac{1}{2}mv^2$ The centripetal force of the circular arc is provided by the magnetic force:	 M1

			$\frac{mv^2}{r} = Bqv$ $v = \frac{Bqr}{m}$ Combining the two equations and rearranging for the mass to charge ratio: $qV = \frac{1}{2}m\left(\frac{Bqr}{m}\right)^2 = \frac{q^2B^2r^2}{2m}$ $\frac{m}{q} = \frac{B^2r^2}{2V}$	M1 M1 A0
		(ii)	For the SIMS described in the passage, determine the expected arc radius *r* for a singly charged $^{206}Pb^+$ ion. The mass of a $^{206}Pb^+$ ion is 205.974 u.	
			r = …………………… m	[2]
			Solution: $r = \sqrt{\frac{2Vm}{qB^2}}$ $r = \sqrt{\frac{2 \times 1.00 \times 10^4 \times 205.974 \times 1.66 \times 10^{-27}}{1.60 \times 10^{-19} \times 0.75^2}}$ $r = 0.276$ m	M1 A1
		(iii)	State and explain whether the arc radius of the singly charged $^{238}U^+$ ion will be larger or smaller than that of the lead ion from **(d)(ii).** …………………………………………………………………………………… …………………………………………………………………………………… [2]	
			[Total: 22 marks]	
			Solution: All other variables being constant, **the mass is proportionate to the square of the radius**. (must include relationship between variables) **Therefore, the radius will be larger** for the heavier uranium ion.	M1 A1

END OF PAPER