HWA CHONG INSTITUTION
JC2 Preliminary Examination
Higher 2

CANDIDATE NAME		**CT GROUP**	**24S**
CENTRE NUMBER		**INDEX NUMBER**	

PHYSICS **9749/02**

Paper 2 Structured Questions **16 September 2025**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre Number, Index Number, Name and CT Group 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 a soft 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.

The number of marks is given in brackets [ ] at the end of each question or part question.
You are reminded of the need for good English and clear presentation in your answers.

For Examiner's Use		
Paper 2		
1		**7**
2		**8**
3		**12**
4		**7**
5		**9**
6		**8**
7		**8**
8		**21**
Deductions		
Total		**80**

Data	Formulae	
speed of light in free space, $c = 3.00 \times 10^{8}$ m s^{-1}	uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
permeability of free space, $\mu_o = 4\pi \times 10^{-7}$ H m^{-1}	work done on / by a gas	$W = p\,\Delta V$
permittivity of free space, $\varepsilon_o = 8.85 \times 10^{-12}$ F m^{-1} $\approx (1/(36\pi)) \times 10^{-9}$ F m^{-1}	hydrostatic pressure	$p = \rho gh$
	gravitational potential	$\phi = -\frac{Gm}{r}$
elementary charge, $e = 1.60 \times 10^{-19}$ C	temperature	T/K = T/ °C + 273.15
	pressure of an ideal gas	$P = \frac{1}{3}\frac{Nm}{V} < c^2 >$
the Planck constant, $h = 6.63 \times 10^{-34}$ J s	mean kinetic energy of a molecule of an ideal gas	$E = \frac{3}{2}kT$
unified atomic mass constant, $u = 1.66 \times 10^{-27}$ kg	displacement of particle in s.h.m.	$x = x_o \sin \omega t$
rest mass of electron, $m_e = 9.11 \times 10^{-31}$ kg	velocity of particle in s.h.m.	$v = v_o \cos \omega t$ $= \pm \omega \sqrt{(x_o^2 - x^2)}$
rest mass of proton, $m_p = 1.67 \times 10^{-27}$ kg	electric current	$I = Anvq$
molar gas constant, $R = 8.31$ J K^{-1} mol^{-1}	resistors in series	$R = R_1 + R_2 + \ldots$
	resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
the Avogadro constant, $N_A = 6.02 \times 10^{23}$ mol^{-1}	electric potential	$V = \frac{Q}{4\pi\varepsilon_o r}$
the Boltzmann constant, $k = 1.38 \times 10^{-23}$ J K^{-1}	alternating current / voltage	$x = x_o \sin \omega t$
gravitational constant, $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}	magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
acceleration of free fall, $g = 9.81$ m s^{-2}	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	$x = x_o \exp(-\lambda t)$
	decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

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1 (a) Fig 1.1 shows a fluid of density ρ in a rectangular container. The height of the liquid is *h.*

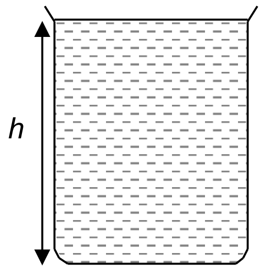

Fig 1.1

Show that the pressure P at the bottom of the container due to the fluid is given by

$$P = \rho g h$$

[2]

(b) (i) An object of mass m and density d is surrounded by air of density ρ.

Show that the resultant force F acting downward on the object is given by

$$F = mg\left(1 - \frac{\rho}{d}\right)$$

[2]

(ii) A chemist uses an accurate balance to weigh a sample as shown in Fig. 1.2.

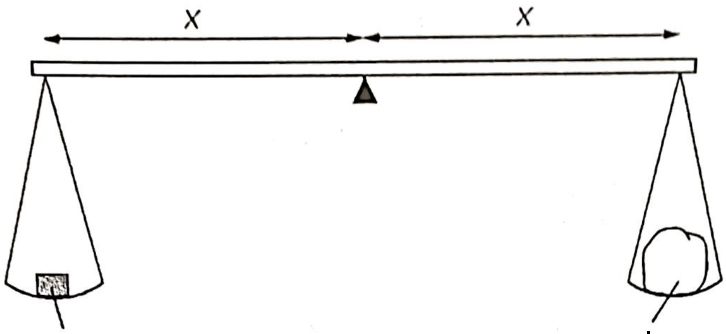

Fig. 1.2

The mass of the standard mass is 0.17851 kg. The density of the sample is 940.0 kg m^{-3}, the density of the standard mass is 8493 kg m^{-3}, and the density of air is 1.29 kg m^{-3}.

Using your answer in **(b)(i)**, calculate the mass of the sample.

Leave your answer to 5 decimal places.

mass = …………………….. kg [3]

[Total: 7 marks]

2 An object of mass *m* of 0.42 kg is attached to a spring S and the system is made to oscillate with simple harmonic motion on a horizontal, frictionless surface, as shown in Fig 2.1. The mass passes through the equilibrium position at P 200 times per minute.

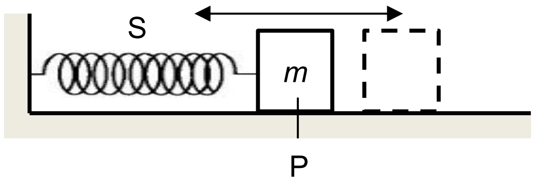

Fig 2.1

The kinetic energy of the mass as it passes through the equilibrium position is 500 mJ.

(a) **(i)** Determine the period of the oscillation.

period = …………………….. s [1]

(ii) Show that the amplitude of the oscillation is approximately 15 cm.

[3]

(iii) Sketch in Fig 2.2 the variation with time of the velocity of the mass for 2 cycles. Label the axes with appropriate values.

Fig 2.2 [2]

(b) Deduce the change, if any, to the frequency of the oscillation if the following modifications are made separately to the experiment:

(i) the experiment is done on Mars instead of the Earth,

……..

…………………………………………………………………………………………………….... [1]

(ii) another spring identical to S is connected in parallel, as shown in Fig 2.3.

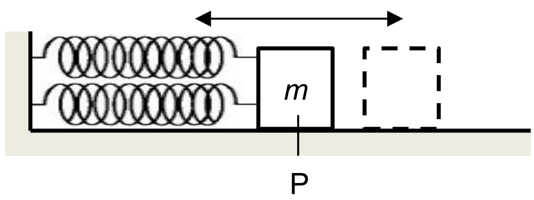

Fig 2.3

……..

…………………………………………………………………………………………………….... [1]

[Total: 8 marks]

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

………

……….. [2]

(b) The neutral point is the point where the gravitational field strength due to Earth is equal in magnitude and opposite in direction to the gravitational field strength due to the Moon.

The gravitational potentials at the Earth's and Moon's surfaces are $–62.3 \times 10^6$ J kg^{-1} and $–3.90 \times 10^6$ J kg^{-1} respectively.

A 10.0 kg mass projected from the Earth's surface needs 6.10×10^8 J of kinetic energy to just reach the neutral point from the Earth. The effects of air resistance may be neglected.

(i) Determine the gravitational potential at the neutral point.

gravitational potential = ……………… J kg^{-1} [2]

(ii) Determine the minimum kinetic energy needed to send a 1.4 kg rock from the surface of the Moon to the surface of the Earth.

minimum kinetic energy =…………………. J [3]

(c) Two stars of mass *M* and *2M*, a distance of *3R* apart, rotate in circles about their common centre of mass O.

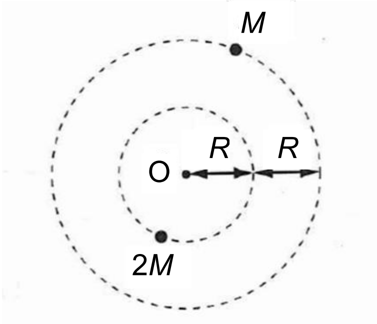

Fig 3.1

The period of this binary star system is 3.42×10^5 s. The value of *M* is 3.14×10^{30} kg.

(i) Explain why the two stars experience the same magnitude of centripetal force.

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

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

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

(ii) Determine the distance *R.*

R = ………………………… m [3]

[Total: 12 marks]

4 (a) Waves from a point source pass through an area that is 1.6 cm wide, as shown in Fig. 4.1.

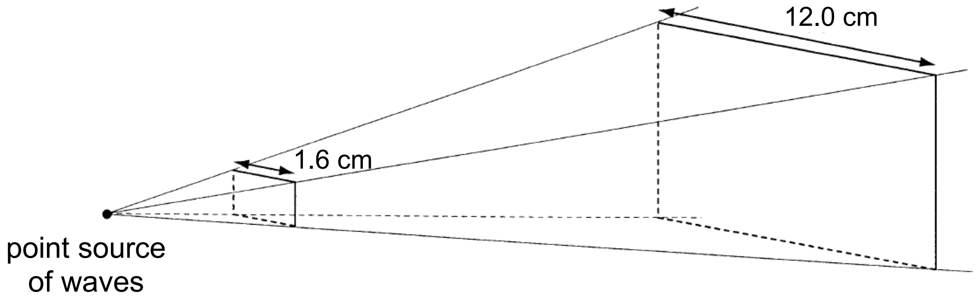

Fig. 4.1

Within this area, the intensity of the waves is I_0 and their amplitude is A_0. The waves reach a second area of width 12.0 cm.

Determine the amplitude of the waves when they reach the second area in terms of A_0.

Show your working clearly.

amplitude = …………………… [2]

(b) A stationary wave is formed on a stretched string between two fixed points A and B.

The variation of the displacement y of particles of the string with distance x along the string for the wave at time t = 0 is shown on Fig. 4.2.

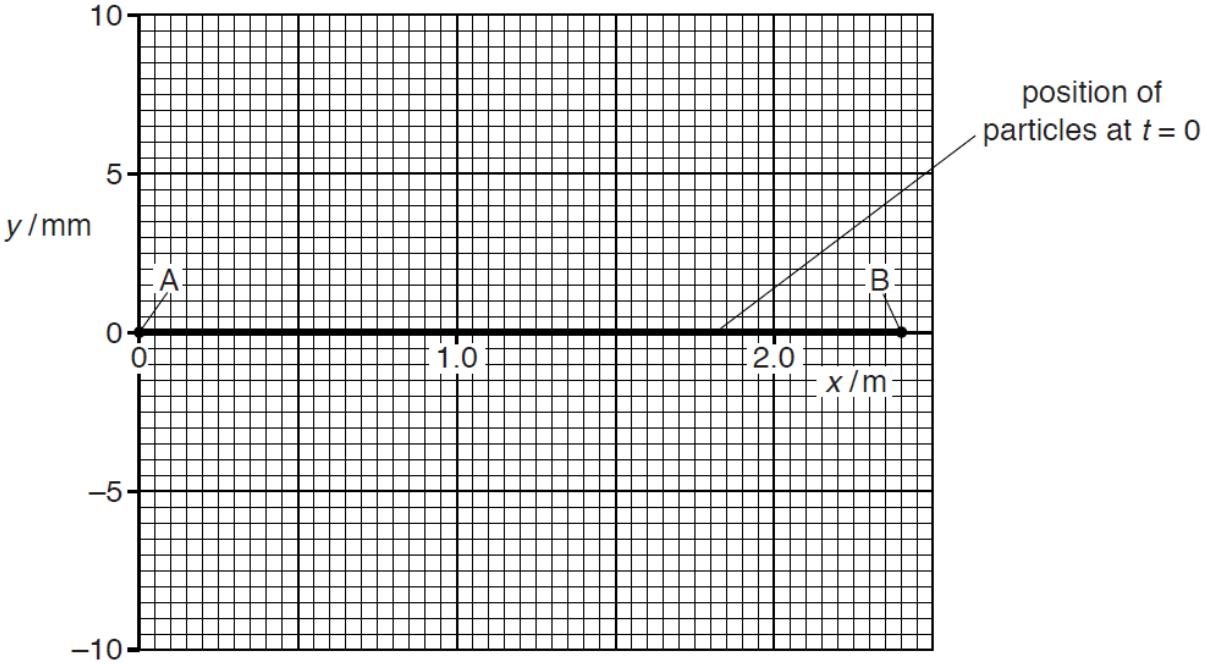

Fig. 4.2

The wave has a period of 20 ms and a wavelength of 1.2 m. The maximum amplitude of the particles of the string is 5.0 mm.

(i) On Fig. 4.2, sketch the variation with position of the displacement of the string at

1. t = 12.5 ms (label this Y) [2]

2. t = 5.0 ms (label this Z) [2]

(ii) State the phase difference between the particles of the string at x = 0.40 m and at x = 0.80 m.

phase difference = …………………… [1]

[Total: 7 marks]

5 Two charged metal spheres A and B of diameters 18.0 cm and 12.0 cm respectively, are isolated in space, as shown in Fig. 5.1.

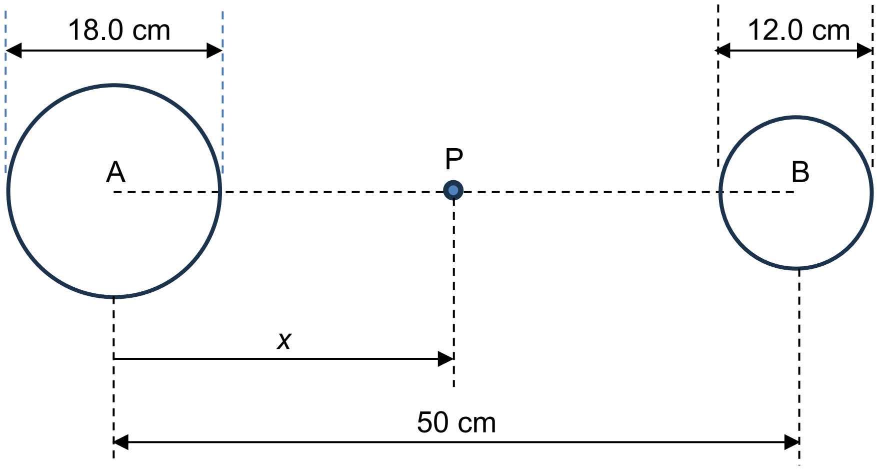

Fig. 5.1

The centres of the spheres are separated by a distance of 50.0 cm. Point P is at a distance *x* from the centre of sphere A along the line joining the centres of the two spheres.

The variation with *x* of the electric potential *V* at P is shown in Fig. 5.2.

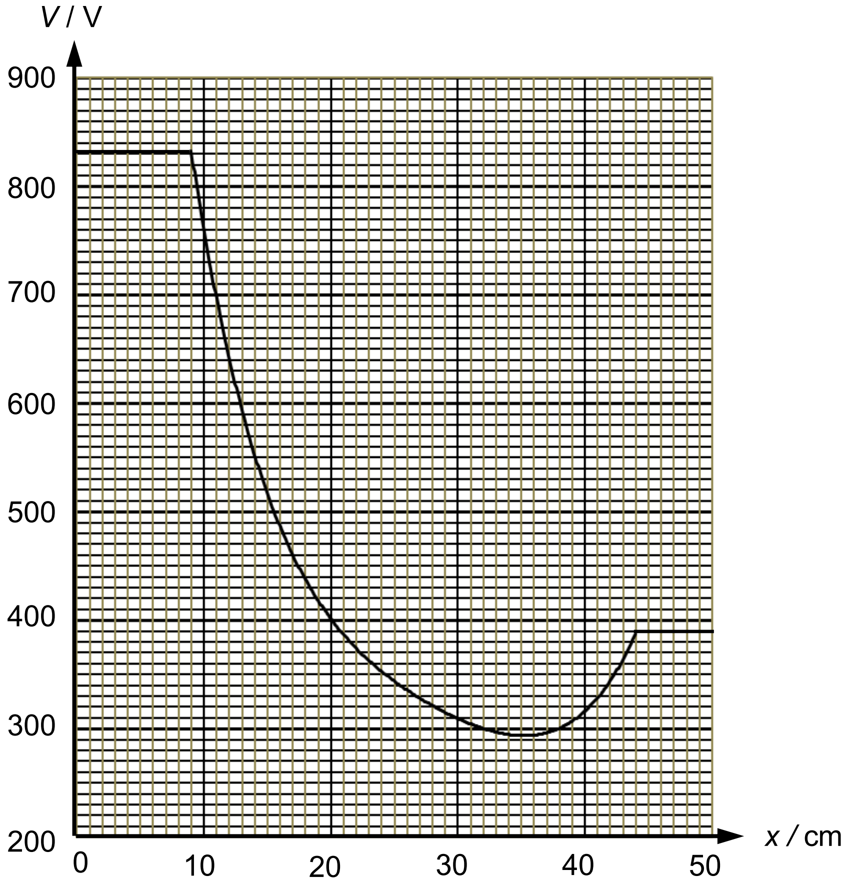

Fig. 5.2

(a) **(i)** State and explain the direction of the electric field at the point P when x = 25.0 cm.

……

……

…… [2]

(ii) Use Fig. 5.2 to determine the magnitude of the electric field strength on an electron placed at point P when x = 25.0 cm

electric field strength = …………………… V cm^{-1} [3]

(iii) By making reference to electric fields, explain why the potential is constant between x = 0.0 cm and x = 9.0 cm.

……

……

……

…… [2]

(b) A positively-charged ion is released from rest at x = 25.0 cm.

Describe the subsequent motion of the ion.

……

……

……

…… [2]

[Total: 9 marks]

6 In a metallic conductor, conduction electrons do not travel in a straight line through the conductor.

Fig. 6.1 shows some of the conduction electrons in a copper wire. The arrows represent the velocities of these electrons.

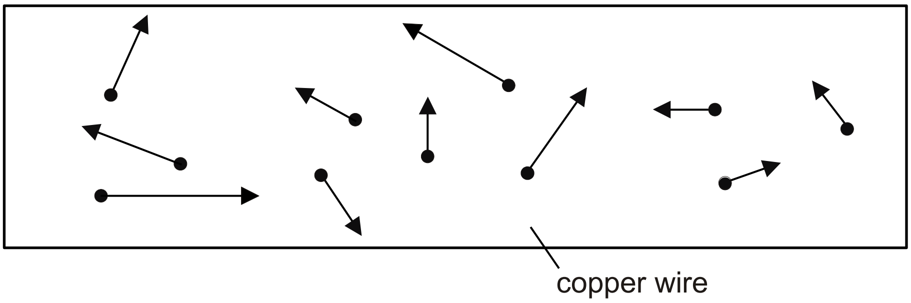

Fig. 6.1

(a) Explain, by reference to the motion of the electrons, why there is no current in the wire.

....

.... [2]

(b) An electric field is established inside the copper wire directed as shown in Fig. 6.2.

The dots represent electrons. The velocities of the electrons are not shown.

The average velocity that an electron travels along the conductor is called the drift velocity.

Draw on Fig. 6.2 an arrow to indicate the direction of the drift velocity of the electrons.

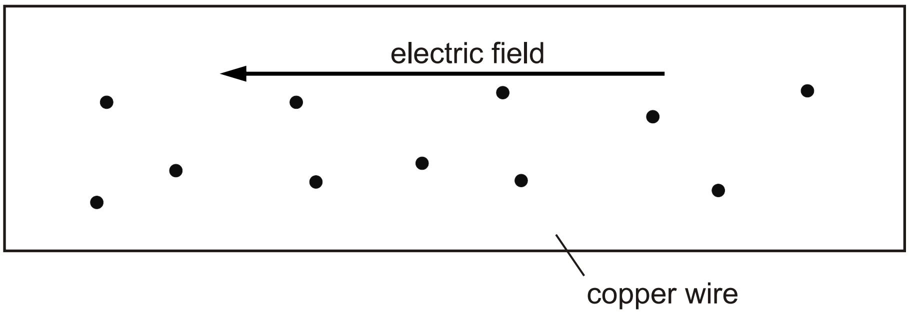

Fig. 6.2

[1]

(c) In the circuit in Fig. 6.3, the length of the copper wire joining the negative terminal of the battery to the lamp is 0.50 m and has a radius of 0.40 mm. There are 8.5×10^{28} mobile electrons per cubic metre in copper.

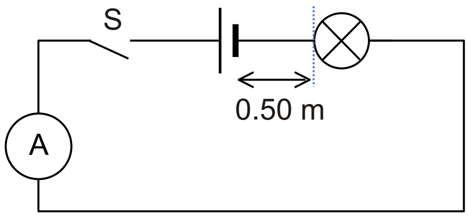

Fig. 6.3

(i) When the switch S is closed, the ammeter reads 2.0 A. Calculate the average time it would take for an electron to move from the negative terminal of the battery to the lamp.

average time = ………………….. s [2]

(ii) The lamp lights up in a much shorter time than that calculated in **(c)(i)**. Explain this observation.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………[1]

(iii) The circuit is now connected with two copper wires of different thickness as shown in Fig. 6.4.

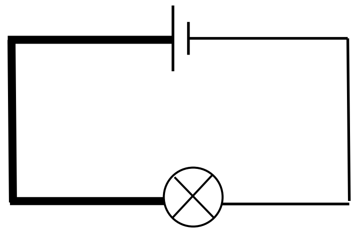

Fig 6.4

State and explain whether the drift velocity of electrons in the thicker wire is smaller than, equal to, or larger than that in the thinner wire.

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

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

[Total: 8 marks]

7 **(a)** State experimental evidence to suggest that the process of radioactive decay is

(i) random

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

…………………………………………………………………………………………………. [1]

(ii) spontaneous

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

…………………………………………………………………………………………………. [1]

(b) A student determines the half-life of the radioactive isotope of phosphorous-32. Phosphorous-32 decays by beta emission to form sulfur-32 which is stable.

The student measures the average count-rate from a sample of phosphorous-32 at various times *t*. The background-subtracted count rate, *R*, is shown in Fig. 7.1.

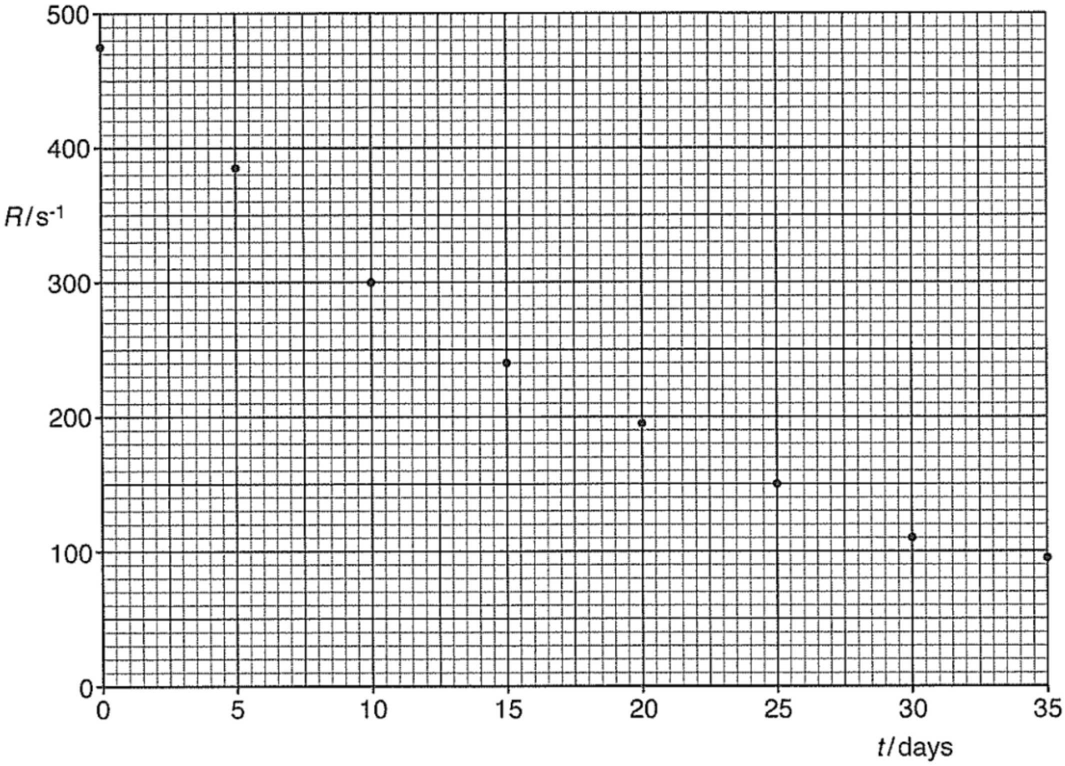

Fig. 7.1

(i) Use Fig. 7.1 to determine a value for the half-life of phosphorous-32. Show your working clearly.

half-life = ………………….. days [3]

(ii) Explain why, although the count rates are too low for the radiation to cause immediate symptoms in the student, careful shielding of the source is necessary.

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

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

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

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

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

(iii) Suggest why the determination of the half-life of phosphorus-32 by this method requires that the product of the decay is stable.

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

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

……………………………………………………………………………………………………… [1]

[Total: 8 marks]

8 Read the passage and answer the questions that follow.

Laser cooling of atoms

Atoms in a gas are always in motion. The temperature of a gas is related to the average kinetic energy of its atoms—the faster they move, the higher the temperature. Physicists have found ways to slow atoms down using laser light, and in doing so, cool the atoms to extremely low temperatures. This process is called laser cooling, illustrated in Fig. 8.1.

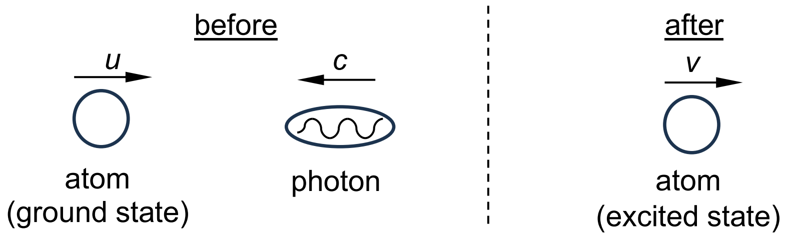

Fig. 8.1

Each photon has a small momentum. When the energy of the photon is just right, it can be absorbed by an atom, bringing it into an excited state. To slow an atom down, scientists shine light in the opposite direction that the atom is moving, so the atom absorbs photons, reducing its speed. Of course, after a short time, the atom will de-excite, emitting another photon – but this is in a random direction, rarely in the same direction as the first photon, and so generally the net effect is still that the atom's velocity in that axis is decreased.

Laser cooling experiments are often performed on rubidium (Rb) atoms. A simplified energy level diagram of the ^{87}Rb atom is shown in Fig. 8.2, showing the ground state, the first two excited states (labelled A and B), and their energies.

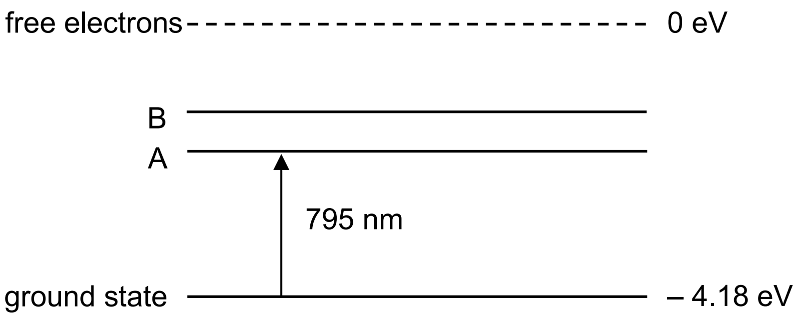

Fig. 8.2 (not to scale)

When an ^{87}Rb atom absorbs a photon of wavelength 795 nm, it transitions from the ground state to state A.

Table 8 shows some data about rubidium-87 (^{87}Rb).

atomic number	37
nucleon number	87
atomic mass	86.9 u
melting point at 1 atm	39.3 °C
boiling point at 1 atm	688 °C
lifetime of state A	27.6 ns
lifetime of state B	26.2 ns
emission wavelength from state A	795 nm
emission wavelength from state B	780 nm

Table 8

The setup of a laser cooling experiment is shown in Fig. 8.3 below.

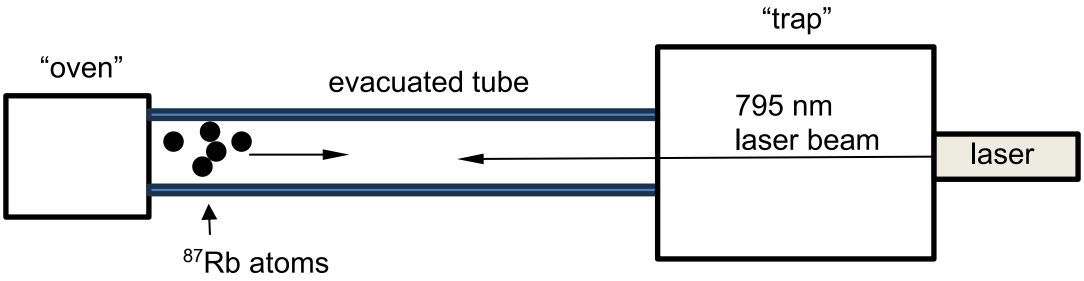

Fig. 8.3

A hot "oven" serves as a source of ^{87}Rb atoms, which travel through the evacuated tube towards the "trap". A laser is directed in the opposite direction to the atoms' motion, slowing them down significantly. When they reach the "trap", they are slowed and cooled even further using other methods.

Laser cooling and other trapping methods have allowed physicists to make exciting discoveries, such as the first-ever creation of a Bose-Einstein Condensate in 1995 by Eric Cornell and Carl Wieman. A Bose-Einstein Condensate (BEC) is a new state of matter. In 1925, Bose and Einstein theorized that, as a consequence of wave-particle duality, at very low temperatures, the matter wave of atoms could have a wavelength λ greater than the average separation d between the atoms. When this happens, the matter waves of the individual atoms overlap to form a single wave, allowing the atoms to seemingly occupy the same space!

Of interest is the critical temperature T_C at which a BEC is formed, which depends on several factors, including the separation d between the atoms. This can be estimated using the relationship:

$$d \approx \frac{1}{\sqrt[3]{n}}$$

where n is the number of particles per unit volume.

Fig. 8.4 shows data from a laser cooling experiment when the temperature T of the cloud of atoms is $T > T_C$, $T \approx T_C$, and $T < T_C$.

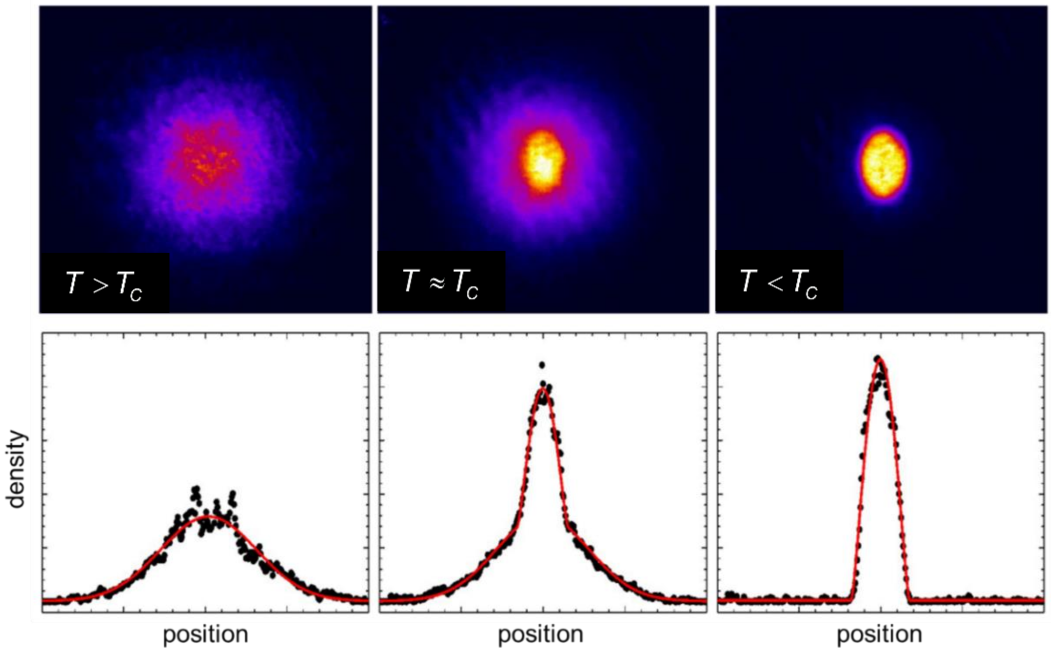

Fig. 8.4

(a) **(i)** With reference to Fig. 8.2, explain why rubidium-87 atoms (^{87}Rb) only absorb photons of certain frequencies.

....

....

....

....[2]

(ii) With reference to Fig. 8.2, determine the energy of state A in electron-volts.

energy = ... eV [3]

(iii) When an ^{87}Rb atom transitions from state A to the ground state, a photon is released. Suggest why this photon is difficult to observe with the naked eye.

....

....[1]

(b) A collection of ^{87}Rb atoms in the gaseous state emerge from the "oven" at a temperature of 1000 K.

Treating the ^{87}Rb atoms as an ideal gas, determine the average speed of an ^{87}Rb atom.

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

(c) Suggest what is meant by the “lifetime” of state A and state B in Table 8.

………

………[1]

(d) **(i)** Using the principle of conservation of linear momentum, determine the magnitude of the change in momentum of an ^{87}Rb atom after it absorbs a photon from the laser, as in Fig. 8.1.

Show your working clearly.

change in momentum = ……………………… kg m s^{-1} [3]

(ii) Explain why, when an excited ^{87}Rb atom de-excites and emits a photon, the average change in momentum of the ^{87}Rb atom over many such emissions is zero.

………

………[1]

(iii) Hence, using data from Table 8, determine the average force on the ^{87}Rb atom through the entire process of absorbing and emitting a photon.

force = ……………………… N [2]

(iv) Give one reason why the ^{87}Rb atoms could be cooled faster if the laser emitted photons that excite the atoms to state B instead of state A.

………

………[1]

(e) State how Fig. 8.4 shows that a Bose-Einstein Condensate forms when the temperature *T* of the cloud of atoms is equal to or below the critical temperature T_C .

………...

……..…[1]

(f) The momentum of an ^{87}Rb atom in the "trap" is given by:

$$p = \sqrt{3mkT}$$

where *m* is the mass of an ^{87}Rb atom, *T* is the thermodynamic temperature of the collection of atoms, and *k* is the Boltzmann constant.

Using the de Broglie relation, calculate the critical temperature T_C at which a collection of ^{87}Rb atoms forms a BEC in a "trap" where $n = 1.00 \times 10^{19}\ m^{-3}$.

T_C = ……………………… K [4]

[Total: 21 marks]

End of paper

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Copyright Acknowledgements:

A. Steck, "Rubidium 87 D Line Data," available online at http://steck.us/alkalidata (revision 2.3.3, 28 May 2024) (Table 8)

Fallani, L. & Kastberg, A.. (2015). Cold atoms: A field enabled by light. EPL (Europhysics Letters). 110. 53001. 10.1209/0295-5075/110/53001. (Fig. 8.4)