Answer **all** the questions.

Section A

1 Here is a list of units.

kg m s^{-1} **kg m s^{-2}** **kg m^{-3}** **kg m^{2} s^{-2}**

(a) Which **one** is the correct unit for momentum?

$p = mv$ answer .... kg m s^{-1} .... **[1]**

(b) Which **one** is the correct unit for kinetic energy?

$E_K = \frac{mv^2}{2} = kg(ms^{-1})^2 =$ answer .... kg m^2 s^{-2} .... **[1]**

2 Fig. 2.1 shows a sealed bag of air in a container.

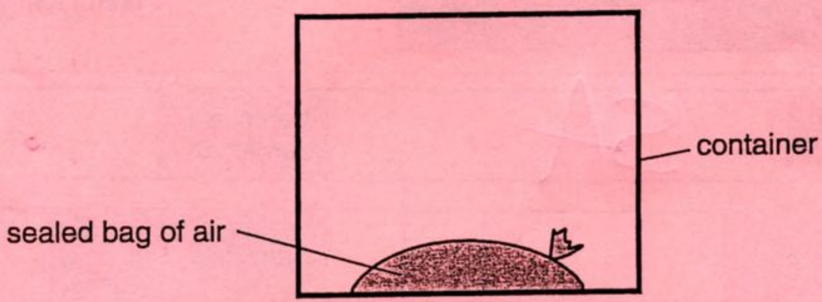

Fig. 2.1

In Fig. 2.2, some of the air in the container has been removed.

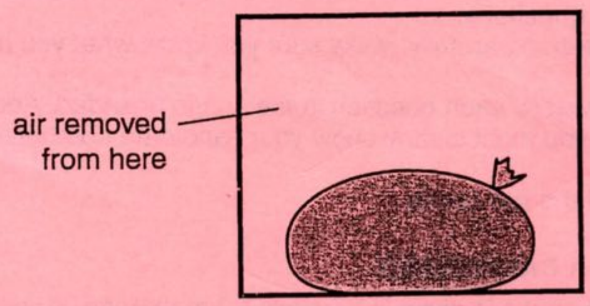

Fig. 2.2

Explain why the sealed bag expands when air is removed from the container.

Pressure in box falls ($pV = NkT$)

so pressure inside balloon is now greater so

more frequent collisions on inside. V rises **[2]**

as $pV = NkT$

3 The top graph of Fig. 3.1 shows how the displacement of an object in simple harmonic motion varies with time.
Complete the other two graphs to show how the velocity and kinetic energy of the object vary with time over the same time interval. **[2]**

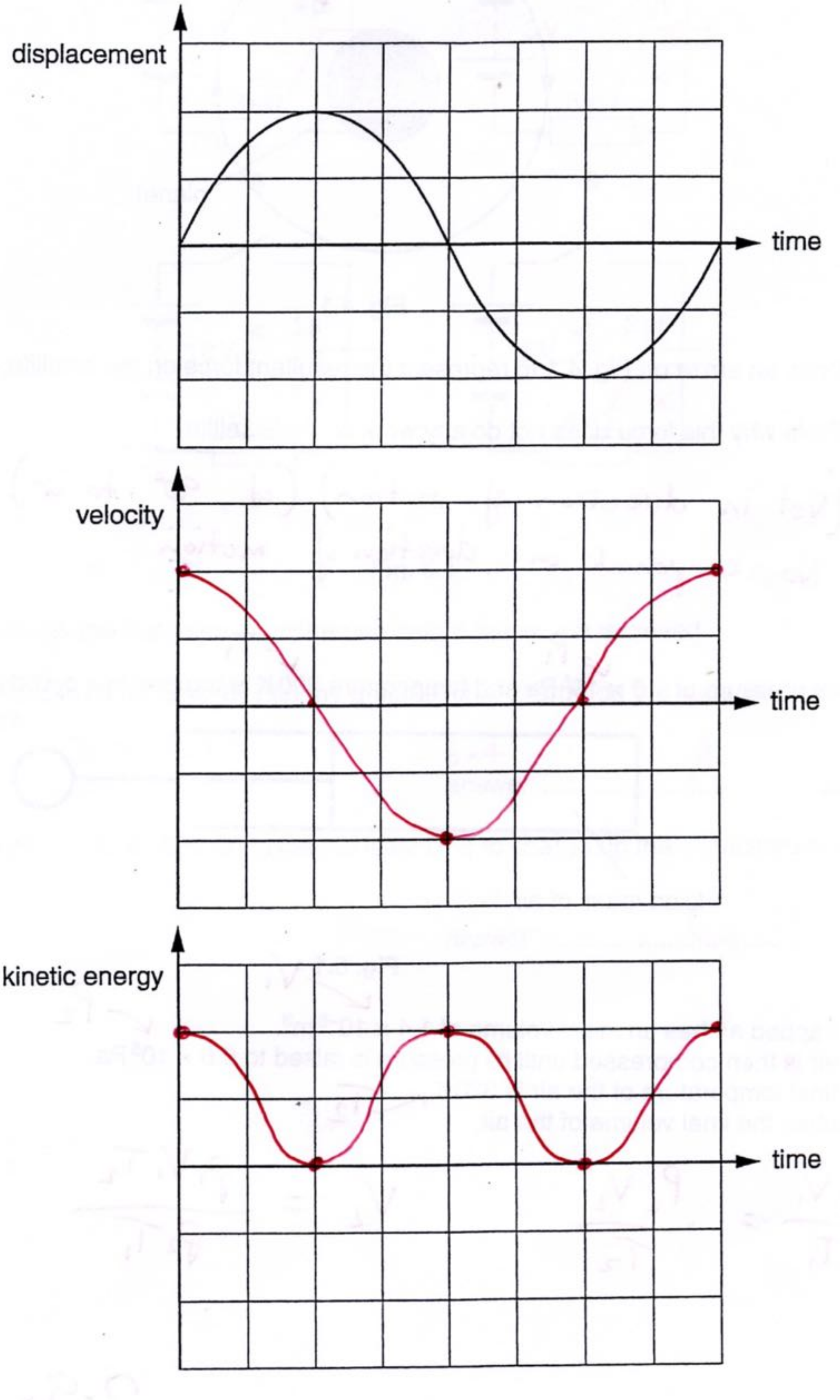

Fig. 3.1

4 Fig. 4.1 shows a satellite in a circular orbit around a planet.

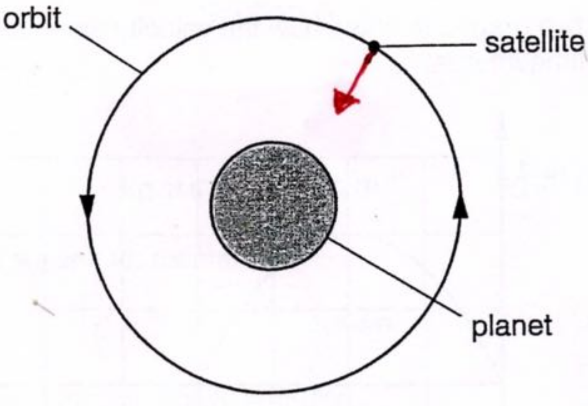

Fig. 4.1

(a) Draw an arrow on Fig. 4.1 to represent the resultant force on the satellite. **[1]**

(b) State why this force does not do any work on the satellite.

(Not in direction of motion) (at 90° to it)
No component in direction of motion

[1]

$\swarrow P_1$ $\swarrow T_1$

5 Air at a pressure of 1.0×10^5 Pa and temperature 280 K is trapped in a cylinder by a piston.

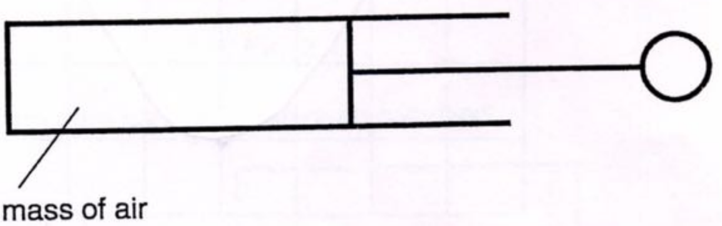

Fig. 5.1 V_1 P_2

The trapped air has an initial volume of $1.4 \times 10^{-6}\,\text{m}^3$.
The air is then compressed until its pressure is raised to 5.6×10^5 Pa.
The final temperature of the air is 320 K. $\leftarrow T_2$
Calculate the final volume of the air.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \qquad V_2 = \frac{P_1 V_1 T_2}{P_2 T_1}$$

volume = 2.9×10^{-7} m³ **[2]**

6 Fig. 6.1 shows four versions of the same circuit with different component values.

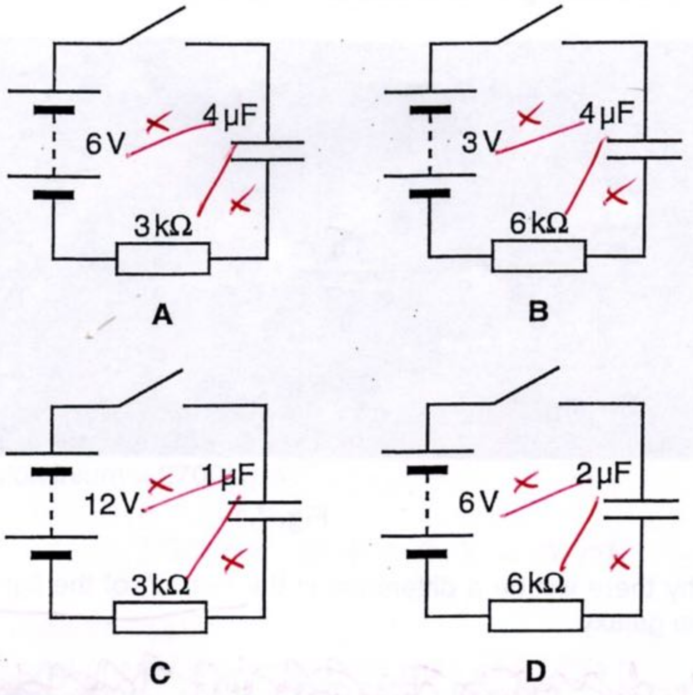

Fig. 6.1

$\tau = RC$

In all four circuits the capacitor is uncharged before the switch is closed.

(a) Which circuit (**A**, **B**, **C** or **D**) has the greatest final charge on the capacitor when the switch is closed?

$Q = CV$

6×4

answer ....A........ **[1]**

(b) Which circuit (**A**, **B**, **C** or **D**) takes the least time to charge up the capacitor when the switch is closed?

3×1

answer ....C........ **[1]**

7 The rate of rotation of a distant spiral galaxy, like that shown in Fig. 7.1, can be found by comparing the light from the left and right hand side of the galaxy.

Fig. 7.1

(a) Explain why there will be a difference in the redshift of the light from the left and right hand sides of the galaxy.

one side moves away faster than the other side due to rotation so red shift different $\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$

[2]

(b) State what effect, if any, the motion of a distant galaxy relative to Earth has on the speed of light from it measured by observers on the Earth.

None

[1]

8 Slabs of aluminium with insulated handles are used in some restaurants to keep dishes hot at the table.

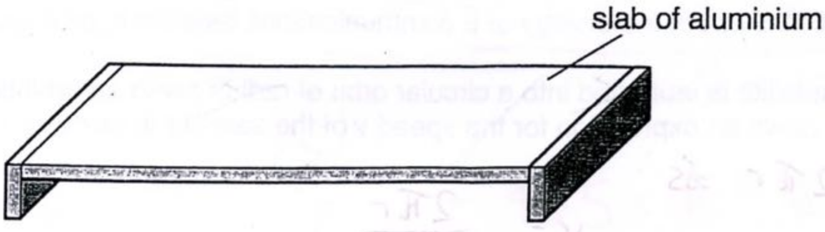

Fig. 8.1

(a) Show that an aluminium slab with dimensions 0.40 m × 0.20 m × 0.01 m will have a mass of about 2 kg.

density of aluminium = 2700 kg m^{-3}

$\rho = \frac{m}{V}$ $m = \rho V = 2700 \times 0.4 \times 0.2 \times 0.01 = 2.16$ kg

[1]

(b) Calculate the thermal energy released by the plate as it cools from an initial temperature of 100 °C to room temperature of 20 °C.

specific thermal capacity of aluminium = 920 J kg^{-1} °C^{-1}

$\Delta E = mc\Delta\theta = 2.16 \times 920 \times 80 =$

energy released = 1.59×10^5 J .... J **[2]**

9 A gas cylinder of internal volume 2.9×10^{-2} m^3 is filled with helium gas to a pressure of 2.1×10^7 Pa at a temperature of 290 K.
Calculate the mass of helium in the cylinder.

$R = 8.3$ mol^{-1} K^{-1}
molar mass of helium is 4.0×10^{-3} kg mol^{-1}

$pV = nRT \therefore n = \frac{pV}{RT} = \frac{2.1 \times 10^7 \times 2.9 \times 10^{-2}}{8.31 \times 290}$

$= 253$ mol

$m = n \times MM = 253 \times 4 \times 10^{-3}$

mass of helium = 1.0 .... kg **[2]**

[Section A Total: 20]

Section B

10 This question is about the energy of a communications satellite in orbit around the Earth.

(a) The satellite is launched into a circular orbit of radius *r* with an orbit time *T*. Write down an expression for the speed *v* of the satellite in terms of *r* and *T*.

$C = 2\pi r = \Delta s$

$v = \frac{\Delta s}{\Delta T}$ $\qquad v = \frac{2\pi r}{T}$

[1]

(b) By equating the centripetal force on the satellite of mass *m* with its gravitational attraction to the Earth of mass *M*, show that the radius *r* of its orbit is given by the expression

$$r^3 = \frac{GMT^2}{4\pi^2}.$$

$\frac{mv^2}{r} = \frac{GMm}{r^2} = \qquad v^2 = \frac{GM}{r}$

$\left(\frac{2\pi r}{T}\right)^2 = \frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$

$\therefore\ r^3 = \frac{GMT^2}{4\pi^2}$

[2]

(c) A useful communications satellite has an orbit time of 24 hours (8.6×10^4 s). Show that the radius *r* of its orbit is about 4×10^7 m.

mass of Earth = 6.0×10^{24} kg
$G = 6.7 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$

$r = \sqrt[3]{\frac{GMT^2}{4\pi^2}} = \sqrt[3]{\frac{6.7 \times 10^{-11} \times 6 \times 10^{24} \times (8.6 \times 10^4)^2}{4\pi^2}}$

$= \underline{4.22 \times 10^7\ m}$

[1]

(d) Calculate the gravitational potential energy of a satellite of mass 4.7×10^2 kg when it is in this orbit.

$$E_{grav} = -\frac{GMm}{r} = \frac{-6.7\times10^{-11}\times 6\times10^{24}\times 4.7\times10^{2}}{4.2\times10^{7}}$$

$$= -4.5\times10^{9}\ \text{J}$$

gravitational potential energy = ... J [3]

(e) The speed of the satellite in its orbit is $3.1 \times 10^3\,\text{m s}^{-1}$.
Calculate the total energy of the satellite.

$$E_K = \frac{mv^2}{2} = 4.7\times10^{2}\times(3.1\times10^{3})^2/2$$

$$= 2.26\times10^{9}\ \text{J}$$

$$E_{TOTAL} = (-4.5 + 2.26)\times10^{9}$$

total energy = -2.24×10^{9} J [2]

[Total: 9]

Turn over

11 Fig. 11.1 is an incomplete circuit diagram to measure the conductance of an electrical component called a thermistor.

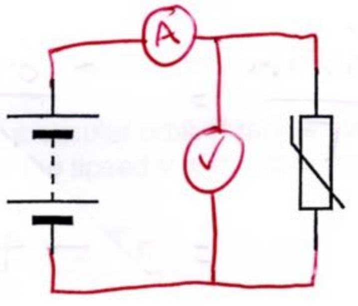

Fig. 11.1

(a) Complete the circuit diagram, including an ammeter and voltmeter. **[2]**

(b) At 300 K, the current in the thermistor is 1.4 mA when the p.d. across it is 5.6 V. Show that the conductance of the thermistor is about 3×10^{-4} S.

$G = I/V = 1.4 \times 10^{-3} / 5.6 = 2.5 \times 10^{-4}$ S

[1]

(c) The electrical behaviour of a thermistor can be modelled as follows:

- most electrons are bound to atoms
- those few electrons with an extra energy ε are able to move freely

(i) Use ideas about the Boltzmann factor to explain why the conductance of a thermistor increases with increasing temperature.

Your answer should use correct spelling and grammar.

The Boltzman factor $e^{-\varepsilon/kT}$ gives the fraction of electrons with energy ε at temperature T. so as T increases B.F. increases and a greater fraction of electrons are able to conduct (are 'free') so the conductance increases **[3]**

(ii) The Boltzmann factor can be used with the model to predict that the conductance G of the thermistor at temperature T is given by the relationship

$$G = G_0 e^{\frac{-\varepsilon}{kT}}.$$

Use your answer to **(b)** to calculate the conductance of the thermistor at 400 K.

$\varepsilon = 5.0 \times 10^{-20}$ J
$k = 1.4 \times 10^{-23}$ J K^{-1}

$$G_0 = G / e^{-\varepsilon/kT} = 2.5\times10^{-4} / e^{(-5\times10^{-20}/1.4\times10^{-23}\times 300)}$$

$$= 37\ \mathrm{S}$$

$$G = 37\, e^{-2.5\times10^{-4}/(1.4\times10^{-23}\times 400)}$$

conductance = 4.9×10^{-3} S **[3]**

[Total: 9]

12 Fig. 12.1 shows the worldline of a spacecraft which passes the Earth and then returns.

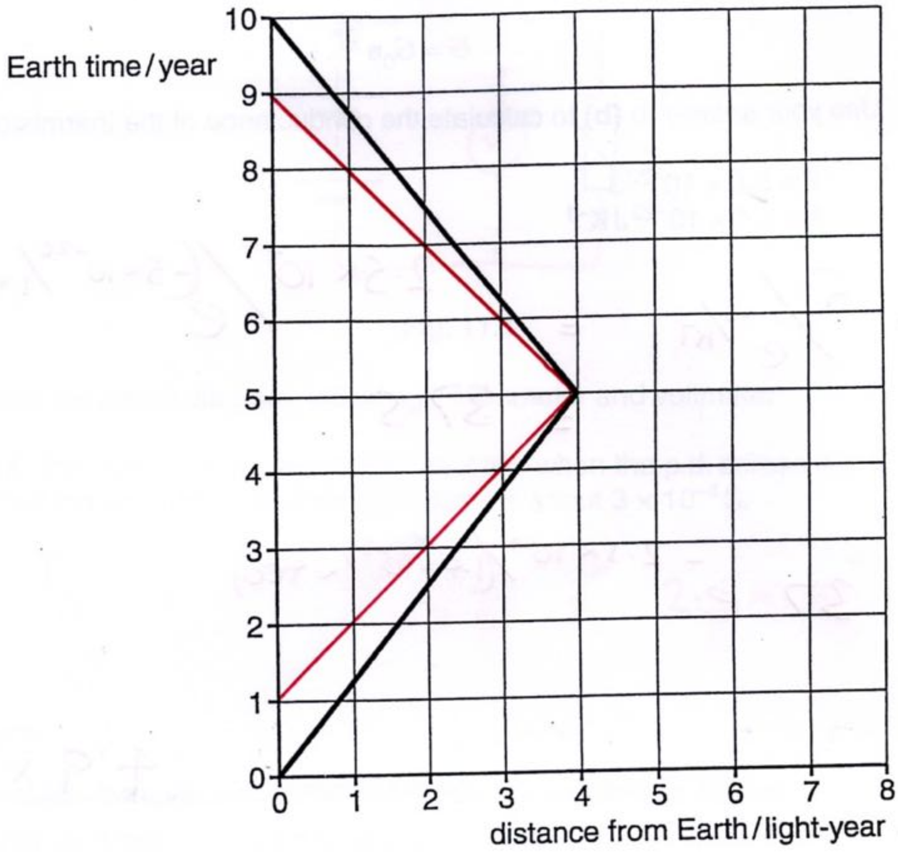

Fig. 12.1

Clocks on the Earth and spacecraft are zeroed at the instant that the spacecraft passes the Earth.

(a) The worldline for the spacecraft is a straight line until $t = 5$ year.
What does this tell you about the motion of the spacecraft?

constant

[1]

(b) A single pulse of light is sent towards the spacecraft from the Earth when the Earth clock reads $t = 1.0$ year. It reflects off the spacecraft and returns to Earth.

(i) Why is the worldline for light always at 45° on Fig. 12.1?

light traves a 1 ly per yr. and yr & ly have same size on scale

[1]

(ii) Draw the complete worldline of the pulse of light on Fig. 12.1. **[2]**

(c) The arrival of the pulse of light at the spacecraft is the signal for it to turn around and return to the Earth.

(i) Explain how an observer on Earth can use the times of emission and reception of the pulse to calculate that the spacecraft was 4.0 light-year from the Earth when the pulse reached it.

Pulse took 9-1 = 8 yrs so distance must be half that. 8/2 = 4 light years

[2]

(ii) Explain how an observer on the Earth can use the time of emission and return of the pulse to deduce that the spacecraft turned round when the Earth clock reads $t = 5.0$ year.

pulse must have took 4 yrs to reach craft. (out & in vel same) and it left at 1 yr.
1 + 4 = 5 years.

[2]

(iii) Show that the outward speed of the spacecraft relative to the Earth is $2.4 \times 10^8\,\mathrm{m\,s^{-1}}$.

$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$

$s = d/t = \frac{4\text{ ly}}{5\text{ years}} = \frac{4}{5}$ of speed of light

$4/5 \times 3 \times 10^8 = 2.4 \times 10^8\,\mathrm{ms^{-1}}$

[1]

(d) (i) Show that the time dilation factor γ for a spacecraft travelling relative to the Earth at velocity $v = 2.4 \times 10^8\,\mathrm{m\,s^{-1}}$ is about 1.7.

$\gamma = 1/\sqrt{1-\frac{v^2}{c^2}} = 1/\sqrt{1-0.8^2} = 1.67$

[1]

(ii) Here are some possible times in year for the round trip according to observers on the spacecraft. Put a ring around the correct value.

6.0   8.0   10   17

[1]

[Total: 11]

10 years/1.67 = 6 yrs.

(Faster = slower clocks ∴ time less)

13 Fig. 13.1 shows an experiment where liquid bromine is released into an **evacuated** tube. The brown bromine vapour is seen to fill the tube very quickly, in less than a second.

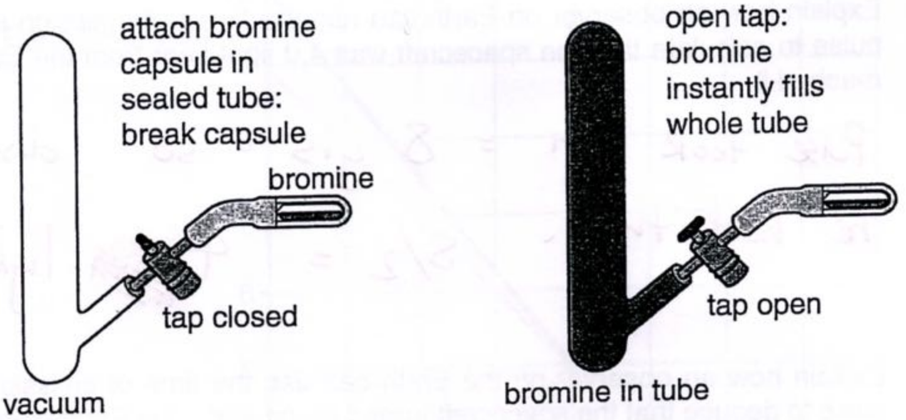

Fig. 13.1

(a) Show that the average energy of a bromine molecule at room temperature (17 °C) is about 5×10^{-21} J.

$k = 1.4 \times 10^{-23}\,\mathrm{J\,K^{-1}}$

$E_K \approx kT = 1.4 \times 10^{-23} \times (273 + 17) = 4.1 \times 10^{-21}\,\mathrm{J}$

[2]

(b) Calculate the mean speed of the bromine molecules in the bromine vapour.

molar mass of bromine vapour = 0.16 kg
$N_A = 6.0 \times 10^{23}\,\mathrm{mol^{-1}}$

$E_K = \frac{mv^2}{2} \quad \therefore \quad v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2 \times 4.1 \times 10^{-21}}{0.16/6 \times 10^{23}}}$

$= 1.7 \times 10^{2}\,\mathrm{ms^{-1}}$

OR $pV = \cancel{N}kT = \frac{1}{3}\cancel{N}m\overline{c^2}$

speed = ... $\mathrm{m\,s^{-1}}$ **[3]**

$\therefore \sqrt{\overline{c^2}} = \sqrt{\frac{3kT}{m}} = 2.1 \times 10^{2}$

(c) When liquid bromine is released into a tube full of air at atmospheric pressure, it can take up to an hour for the brown colour to completely fill the tube. This is because the bromine molecules follow a random walk through the air.

(i) Explain what is meant by a *random walk* and why the bromine molecules in the air-filled tube undergo a random walk.

Your answer should clearly link the behaviour of the molecules to their motion.

molecules travel in straight line of varying (random) length & direction between collisions with other molecules which then changes their speed & direction

e.g. 

[3]

(ii) The average displacement of a particle which follows a random walk of N steps is proportional to $\sqrt{N}$. Explain how this rule can be used to justify the relationship $x = C\sqrt{t}$, where x is the average displacement of a bromine molecule in a time t and C is a constant.

Average speed is fixed so the average distance between collisions is constant so distance is propational to time since distance $\propto \sqrt{N}$

$x \propto \sqrt{N}$ and $N \propto t$

so $x \propto \sqrt{t}$

[3]

[Total: 11]

[Section B Total: 40]

END OF QUESTION PAPER