Q1.

Examiner's Use

2 The pressure p of an ideal gas is given by the expression

$$p = \frac{1}{3}\frac{Nm}{V}<c^2>.$$

(a) Explain the meaning of the symbol $<c^2>$.

....

.... [2]

(b) The ideal gas has a density of $2.4\,\text{kg}\,\text{m}^{-3}$ at a pressure of 2.0×10^5 Pa and a temperature of 300 K.

(i) Determine the root-mean-square (r.m.s.) speed of the gas atoms at 300 K.

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

(ii) Calculate the temperature of the gas for the atoms to have an r.m.s. speed that is twice that calculated in **(i)**.

temperature = ... K [3]

Q2.

2 **(a)** State what is meant by an *ideal* gas.

....

....

....[2]

(b) The product of pressure p and volume V of an ideal gas of density ρ at temperature T is given by the expressions

$$p = \tfrac{1}{3}\rho\langle c^2\rangle$$

and

$$pV = NkT,$$

where N is the number of molecules and k is the Boltzmann constant.

(i) State the meaning of the symbol $\langle c^2\rangle$.

....[1]

(ii) Deduce that the mean kinetic energy E_K of the molecules of an ideal gas is given by the expression

$$E_K = \tfrac{3}{2}kT.$$

[2]

(c) In order for an atom to escape completely from the Earth's gravitational field, it must have a speed of approximately $1.1 \times 10^4\,\mathrm{m\,s^{-1}}$ at the top of the Earth's atmosphere.

(i) Estimate the temperature at the top of the atmosphere such that helium, assumed to be an ideal gas, could escape from the Earth. The mass of a helium atom is 6.6×10^{-27} kg.

temperature = ... K [2]

(ii) Suggest why some helium atoms will escape at temperatures below that calculated in **(i)**.

....

....[1]

Q3.

Us

2 **(a)** The equation

$$pV = constant \times T$$

relates the pressure p and volume V of a gas to its kelvin (thermodynamic) temperature T.

State two conditions for the equation to be valid.

1. ....

....

2. ....

.... [2]

(b) A gas cylinder contains 4.00×10^4 cm^3 of hydrogen at a pressure of 2.50×10^7 Pa and a temperature of 290 K.

The cylinder is to be used to fill balloons. Each balloon, when filled, contains 7.24×10^3 cm^3 of hydrogen at a pressure of 1.85×10^5 Pa and a temperature of 290 K.

Calculate, assuming that the hydrogen obeys the equation in **(a)**,

(i) the total amount of hydrogen in the cylinder,

amount = ... mol [3]

(ii) the number of balloons that can be filled from the cylinder.

number = ... [3]

Q4.

2 (a) Explain qualitatively how molecular movement causes the pressure exerted by a gas.

....

....

....

.... [3]

(b) The density of neon gas at a temperature of 273 K and a pressure of 1.02×10^5 Pa is $0.900\,\text{kg}\,\text{m}^{-3}$. Neon may be assumed to be an ideal gas.

Calculate the root-mean-square (r.m.s.) speed of neon atoms at

(i) 273 K,

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

(ii) 546 K.

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

(c) The calculations in **(b)** are based on the density for neon being 0.900 kg m^{-3}.
Suggest the effect, if any, on the root-mean-square speed of changing the density at constant temperature.

....

....

....[2]

Exa

Q5.

2 Sources of α-particles are frequently found to contain traces of helium gas.
A radioactive source emits α-particles at a constant rate of $3.5 \times 10^6\,s^{-1}$. The α-particles are collected for a period of 40 days. Each α-particle becomes one helium atom.

(a) By reference to the half-life of the source, suggest why it may be assumed that the rate of emission of α-particles is constant.

....

.... [1]

(b) The helium gas may be assumed to be an ideal gas. Calculate the volume of gas that is collected at a pressure of 1.5×10^5 Pa and at a temperature of 17 °C.

volume = ... m^3 [3]

Q6.

2 **(a)** Some gas, initially at a temperature of 27.2 °C, is heated so that its temperature rises to 38.8 °C.
Calculate, in kelvin, to an appropriate number of decimal places,

(i) the initial temperature of the gas,

initial temperature = ... K [2]

(ii) the rise in temperature.

rise in temperature = ... K [1]

(b) The pressure p of an ideal gas is given by the expression

$$p = \tfrac{1}{3}\rho\langle c^2\rangle$$

where ρ is the density of the gas.

(i) State the meaning of the symbol $\langle c^2\rangle$.

....

.... [1]

(ii) Use the expression to show that the mean kinetic energy $\langle E_K\rangle$ of the atoms of an ideal gas is given by the expression

$$\langle E_K\rangle = \tfrac{3}{2}kT.$$

Explain any symbols that you use.

....

....

....

....

.... [4]

(c) Helium-4 may be assumed to behave as an ideal gas.
A cylinder has a constant volume of $7.8 \times 10^3\,\text{cm}^3$ and contains helium-4 gas at a pressure of $2.1 \times 10^7\,\text{Pa}$ and at a temperature of 290 K.

Calculate, for the helium gas,

(i) the amount of gas,

amount = ... mol [2]

(ii) the mean kinetic energy of the atoms,

mean kinetic energy = ... J [2]

(iii) the total internal energy.

internal energy = ... J [3]

Q7.

2 **(a)** State what is meant by the *Avogadro constant* N_A.

....

....

....[2]

(b) A balloon is filled with helium gas at a pressure of 1.1×10^5 Pa and a temperature of 25 °C.
The balloon has a volume of 6.5×10^4 cm^3.
Helium may be assumed to be an ideal gas.

Determine the number of gas atoms in the balloon.

number = ... [4]

Q8.

2 **(a)** State what is meant by a *mole*.

....

....

.... [2]

(b) Two containers A and B are joined by a tube of negligible volume, as illustrated in Fig. 2.1.

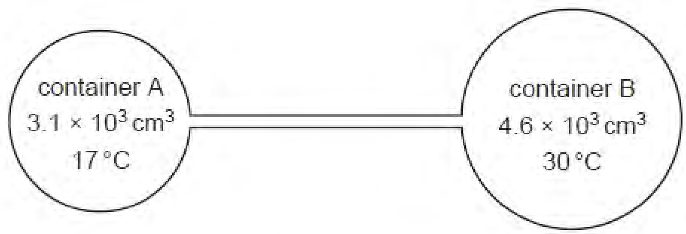

Fig. 2.1

The containers are filled with an ideal gas at a pressure of 2.3×10^5 Pa.
The gas in container A has volume 3.1×10^3 cm^3 and is at a temperature of 17 °C.
The gas in container B has volume 4.6×10^3 cm^3 and is at a temperature of 30 °C.

Calculate the total amount of gas, in mol, in the containers.

amount = ... mol [4]

Q9.

2 **(a)** The kinetic theory of gases is based on some simplifying assumptions.
The molecules of the gas are assumed to behave as hard elastic identical spheres.
State the assumption about ideal gas molecules based on

(i) the nature of their movement,

....

.... [1]

(ii) their volume.

....

....

.... [2]

For Examiner's Use

(b) A cube of volume V contains N molecules of an ideal gas. Each molecule has a component c_X of velocity normal to one side S of the cube, as shown in Fig. 2.1.

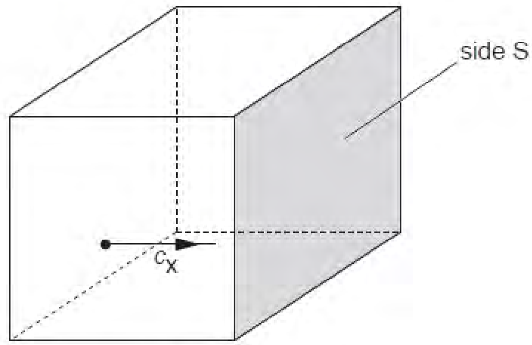

Fig. 2.1

The pressure p of the gas due to the component c_X of velocity is given by the expression

$$pV = Nmc_X^2$$

where m is the mass of a molecule.

Explain how the expression leads to the relation

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

where $\langle c^2\rangle$ is the mean square speed of the molecules.

[3]

(c) The molecules of an ideal gas have a root-mean-square (r.m.s.) speed of 520 $m s^{-1}$ at a temperature of 27 °C.

Calculate the r.m.s. speed of the molecules at a temperature of 100 °C.

r.m.s. speed = ... $m s^{-1}$ [3]

Q10.

2 **(a)** State what is meant by an *ideal gas*.

....

....

....

....[3]

(b) Two cylinders A and B are connected by a tube of negligible volume, as shown in Fig. 2.1.

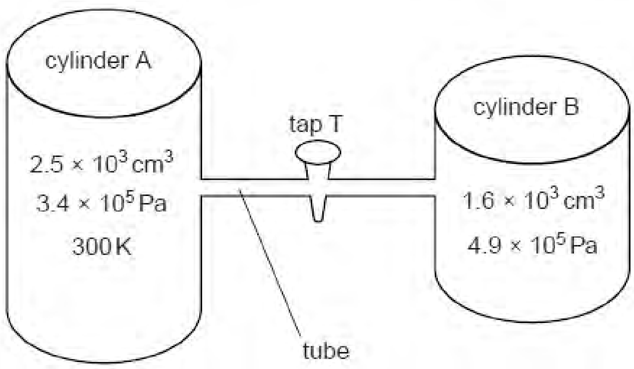

Fig. 2.1

Initially, tap T is closed. The cylinders contain an ideal gas at different pressures.

(i) Cylinder A has a constant volume of $2.5 \times 10^3 cm^3$ and contains gas at pressure $3.4 \times 10^5 Pa$ and temperature 300 K.

Show that cylinder A contains 0.34 mol of gas.

[1]

(ii) Cylinder B has a constant volume of $1.6 \times 10^3\,cm^3$ and contains 0.20 mol of gas. When tap T is opened, the pressure of the gas in both cylinders is $3.9 \times 10^5\,Pa$. No thermal energy enters or leaves the gas.

Determine the final temperature of the gas.

temperature = ... K [2]

(c) By reference to work done and change in internal energy, suggest why the temperature of the gas in cylinder A has changed.

....

....

....

....[3]

For Examiner's Use

Q11.

2 (a) The volume of an ideal gas in a cylinder is $1.80 \times 10^{-3}\,m^3$ at a pressure of $2.60 \times 10^5\,Pa$ and a temperature of 297 K, as illustrated in Fig. 2.1.

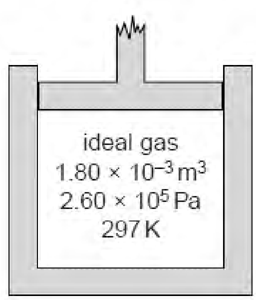

Fig. 2.1

The thermal energy required to raise the temperature by 1.00 K of 1.00 mol of the gas at constant volume is 12.5 J.

The gas is heated at constant volume such that the internal energy of the gas increases by 95.0 J.

For Examiner's Use

(i) Calculate

1. the amount of gas, in mol, in the cylinder,

amount = ... mol [2]

2. the rise in temperature of the gas.

temperature rise = ... K [2]

(ii) Use your answer in **(i) part 2** to show that the final pressure of the gas in the cylinder is 2.95×10^5 Pa.

[1]

(b) The gas is now allowed to expand. No thermal energy enters or leaves the gas. The gas does 120 J of work when expanding against the external pressure.

State and explain whether the final temperature of the gas is above or below 297 K.

....

....

....

.... [3]

Q12.

2 The air in a car tyre has a constant volume of $3.1 \times 10^{-2}\,m^3$. The pressure of this air is 2.9×10^5 Pa at a temperature of 17 °C. The air may be considered to be an ideal gas.

(a) State what is meant by an *ideal* gas.

....

....

.... [2]

(b) Calculate the amount of air, in mol, in the tyre.

amount = ... mol [2]

(c) The pressure in the tyre is to be increased using a pump. On each stroke of the pump, 0.012 mol of air is forced into the tyre.
Calculate the number of strokes of the pump required to increase the pressure to 3.4×10^5 Pa at a temperature of 27 °C.

number = ... [3]

Q13.

2 **(a)** An amount of 1.00 mol of Helium-4 gas is contained in a cylinder at a pressure of 1.02×10^5 Pa and a temperature of 27 °C.

(i) Calculate the volume of gas in the cylinder.

volume = ... m^3 [2]

(ii) Hence show that the average separation of gas atoms in the cylinder is approximately 3.4×10^{-9} m.

[2]

(b) Calculate

(i) the gravitational force between two Helium-4 atoms that are separated by a distance of 3.4×10^{-9} m,

force = ... N [3]

(ii) the ratio

$$\frac{\text{weight of a Helium-4 atom}}{\text{gravitational force between two Helium-4 atoms with separation } 3.4 \times 10^{-9}\text{ m}}.$$

ratio = ...[2]

(c) Comment on your answer to **(b)(ii)** with reference to one of the assumptions of the kinetic theory of gases.

....

....

....[2]

Q14.

5 Two deuterium ($^2_1$H) nuclei are travelling directly towards one another. When their separation is large compared with their diameters, they each have speed *v* as illustrated in Fig. 5.1.

Fig. 5.1

The diameter of a deuterium nucleus is 1.1×10^{-14} m.

(a) Use energy considerations to show that the initial speed *v* of the deuterium nuclei must be approximately $2.5 \times 10^{6}\,\mathrm{m\,s^{-1}}$ in order that they may come into contact.
Explain your working.

[3]

(b) For a fusion reaction to occur, the deuterium nuclei must come into contact.
Assuming that deuterium behaves as an ideal gas, deduce a value for the temperature of the deuterium such that the nuclei have an r.m.s. speed equal to the speed calculated in **(a)**.

temperature = ... K [4]

(c) Comment on your answer to **(b)**.

....

.... [1]

Q15.

2 An ideal gas occupies a container of volume $4.5 \times 10^3\,cm^3$ at a pressure of $2.5 \times 10^5\,Pa$ and a temperature of 290 K.

For Examiner's Use

(a) Show that the number of atoms of gas in the container is 2.8×10^{23}.

[2]

(b) Atoms of a real gas each have a diameter of $1.2 \times 10^{-10}\,m$.

(i) Estimate the volume occupied by 2.8×10^{23} atoms of this gas.

volume = ... m^3 [2]

(ii) By reference to your answer in **(i)**, suggest whether the real gas does approximate to an ideal gas.

....

....

.... [2]

Q16.

2 (a) (i) State the basic assumption of the kinetic theory of gases that leads to the conclusion that the potential energy between the atoms of an ideal gas is zero.

....

....[1]

(ii) State what is meant by the *internal energy* of a substance.

....

....

....[2]

(iii) Explain why an increase in internal energy of an ideal gas is directly related to a rise in temperature of the gas.

....

....

....[2]

(b) A fixed mass of an ideal gas undergoes a cycle PQRP of changes as shown in Fig. 2.1.

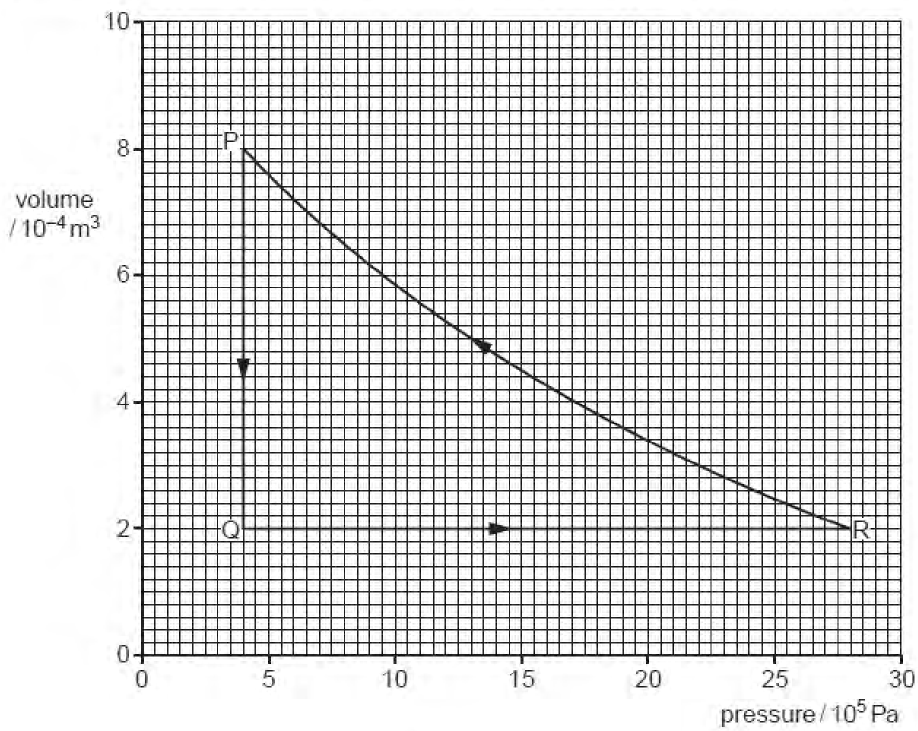

Fig. 2.1

(i) State the change in internal energy of the gas during one complete cycle PQRP.

change = ... J [1]

(ii) Calculate the work done on the gas during the change from P to Q.

work done = ... J [2]

(iii) Some energy changes during the cycle PQRP are shown in Fig. 2.2.

change	work done on gas / J	heating supplied to gas / J	increase in internal energy / J
P → Q	....	–600	....
Q → R	0	+720	....
R → P	....	+480	....

Fig. 2.2

Complete Fig. 2.2 to show all of the energy changes. [3]

Q17.

2 (a) State the basic assumptions of the kinetic theory of gases.

....

....

....

....

....

.... [4]

(b) Use equations for the pressure of an ideal gas to deduce that the average translational kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \frac{3}{2}\frac{R}{N_A}T$$

where R is the molar gas constant, N_A is the Avogadro constant and T is the thermodynamic temperature of the gas.

[3]

(c) A deuterium nucleus $^{2}_{1}H$ and a proton collide. A nuclear reaction occurs, represented by the equation

$$^{2}_{1}H + ^{1}_{1}p \longrightarrow ^{3}_{2}He + \gamma.$$

(i) State and explain whether the reaction represents nuclear fission or nuclear fusion.

....

....

.... [2]

(ii) For the reaction to occur, the minimum total kinetic energy of the deuterium nucleus and the proton is 2.4×10^{-14} J.
Assuming that a sample of a mixture of deuterium nuclei and protons behaves as an ideal gas, calculate the temperature of the sample for this reaction to occur.

For Examiner's Use

temperature = ... K [3]

(iii) Suggest why the assumption made in **(ii)** may not be valid.

....

.... [1]

Q18.

2 **(a)** One assumption of the kinetic theory of gases is that gas molecules behave as if they are hard, elastic identical spheres.

For Examiner's Use

State two other assumptions of the kinetic theory of gases.

1. ....

....

2. ....

....

[2]

(b) Using the kinetic theory of gases, it can be shown that the product of the pressure p and the volume V of an ideal gas is given by the expression

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

where m is the mass of a gas molecule.

(i) State the meaning of the symbol

1. N,

.... [1]

2. $\langle c^2\rangle$.

.... [1]

(ii) Use the expression to deduce that the mean kinetic energy $<E_K>$ of a gas molecule at temperature T is given by the equation

$$<E_K> = \frac{3}{2}kT$$

where k is a constant.

[2]

(c) (i) State what is meant by the *internal energy* of a substance.

....

....

.... [2]

(ii) Use the equation in **(b)(ii)** to explain that, for an ideal gas, a change in internal energy ΔU is given by

$$\Delta U \propto \Delta T$$

where ΔT is the change in temperature of the gas.

....

....

.... [2]

Q19.

For Examiner's Use

(c) The mean translational kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \frac{3}{2}kT$$

where T is the thermodynamic temperature of the gas and k is the Boltzmann constant.

(i) Determine the temperature at which the root-mean-square (r.m.s.) speed of hydrogen molecules is equal to the speed calculated in **(b)**.
Hydrogen may be assumed to be an ideal gas.
A molecule of hydrogen has a mass of 2 u.

temperature = ... K [2]

(ii) State and explain one reason why hydrogen molecules may escape from Mars at temperatures below that calculated in **(i)**.

....

....

.... [2]

Q20.

2 A student suggests that, when an ideal gas is heated from 100 °C to 200 °C, the internal energy of the gas is doubled.

For Examiner's Use

(a) **(i)** State what is meant by *internal energy*.

....

....

....[2]

(ii) By reference to one of the assumptions of the kinetic theory of gases and your answer in **(i)**, deduce what is meant by the internal energy of an ideal gas.

....

....

....

....[3]

(b) State and explain whether the student's suggestion is correct.

....

....

....[2]

Q21.

1 An ideal gas has volume V and pressure p. For this gas, the product pV is given by the expression

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

where m is the mass of a molecule of the gas.

(a) State the meaning of the symbol

(i) N,

....[1]

(ii) $\langle c^2\rangle$.

....[1]

(b) A gas cylinder of volume $2.1 \times 10^4\,cm^3$ contains helium-4 gas at pressure 6.1×10^5 Pa and temperature 12 °C. Helium-4 may be assumed to be an ideal gas.

(i) Determine, for the helium gas,

1. the amount, in mol,

amount = ... mol [3]

2. the number of atoms.

number = ...[2]

(ii) Calculate the root-mean-square (r.m.s.) speed of the helium atoms.

For Examiner Use

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

Q22.

For Examiner's Use

2 The product of the pressure p and the volume V of an ideal gas is given by the expression

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

where m is the mass of one molecule of the gas.

(a) State the meaning of the symbol

(i) N,

.... [1]

(ii) $\langle c^2\rangle$.

.... [1]

(b) The product pV is also given by the expression

$$pV = NkT.$$

Deduce an expression, in terms of the Boltzmann constant k and the thermodynamic temperature T, for the mean kinetic energy of a molecule of the ideal gas.

[2]

(c) A cylinder contains 1.0 mol of an ideal gas.

(i) The volume of the cylinder is constant.
Calculate the energy required to raise the temperature of the gas by 1.0 kelvin.

energy = ... J [2]

(ii) The volume of the cylinder is now allowed to increase so that the gas remains at constant pressure when it is heated.
Explain whether the energy required to raise the temperature of the gas by 1.0 kelvin is now different from your answer in **(i)**.

....

....

.... [2]

Q23.

2 **(a)** **(i)** State what is meant by the *internal energy* of a system.

For Examiner's Use

....

....

....[2]

(ii) Explain why, for an ideal gas, the internal energy is equal to the total kinetic energy of the molecules of the gas.

....

....

....[2]

(b) The mean kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \tfrac{3}{2}kT$$

where k is the Boltzmann constant and T is the thermodynamic temperature of the gas.

A cylinder contains 1.0 mol of an ideal gas. The gas is heated so that its temperature changes from 280 K to 460 K.

(i) Calculate the change in total kinetic energy of the gas molecules.

change in energy = ... J [2]

(ii) During the heating, the gas expands, doing 1.5×10^3 J of work.
State the first law of thermodynamics. Use the law and your answer in **(i)** to determine the total energy supplied to the gas.

....

....

total energy = ... J [3]

For Examiner's Use

Q24.

2 **(a)** Explain what is meant by the Avogadro constant.

....

....

.... [2]

(b) Argon-40 ($^{40}_{18}$Ar) may be assumed to be an ideal gas.
A mass of 3.2 g of argon-40 has a volume of 210 cm^3 at a temperature of 37 °C.

Determine, for this mass of argon-40 gas,

(i) the amount, in mol,

amount = ... mol [1]

(ii) the pressure,

pressure = ... Pa [2]

(iii) the root-mean-square (r.m.s.) speed of an argon atom.

r.m.s. speed = ... $m s^{-1}$ [3]

Q25.

2 A constant mass of an ideal gas has a volume of $3.49 \times 10^3 cm^3$ at a temperature of 21.0 °C. When the gas is heated, 565 J of thermal energy causes it to expand to a volume of $3.87 \times 10^3 cm^3$ at 53.0 °C. This is illustrated in Fig. 2.1.

Fig. 2.1

(a) Show that the initial and final pressures of the gas are equal.

[2]

(b) The pressure of the gas is 4.20×10^5 Pa.

For this heating of the gas,

(i) calculate the work done by the gas,

work done = ... J [2]

(ii) use the first law of thermodynamics and your answer in **(i)** to determine the change in internal energy of the gas.

change in internal energy = ... J [2]

(c) Explain why the change in kinetic energy of the molecules of this ideal gas is equal to the change in internal energy.

....

....

....

.... [3]

Q26.

3 (a) State what is meant by an *ideal* gas.

....

.... [1]

(b) A storage cylinder for an ideal gas has a volume of $3.0 \times 10^{-4}\,m^3$. The gas is at a temperature of 23 °C and a pressure of 5.0×10^{7} Pa.

(i) Show that the amount of gas in the cylinder is 6.1 mol.

[2]

(ii) The gas leaks slowly from the cylinder so that, after a time of 35 days, the pressure has reduced by 0.40%. The temperature remains constant.
Calculate the average rate, in atoms per second, at which gas atoms escape from the cylinder.

rate = ... s^{-1} [4]