Ideal gases – 2021 A2

1. Nov/2021/Paper_42/No.3

(a) One of the assumptions of the kinetic theory of gases is that all collisions involving molecules of the gas are elastic.

(i) State what is meant by an *elastic* collision.

....

.... [1]

(ii) State **two** other assumptions of the kinetic theory of gases.

1. ....

....

2. ....

....

[2]

(b) A molecule of an ideal gas has mass *m* and is contained in a cubic box of side length *L*. The molecule is moving with velocity *u* towards the face of the box that is shaded in Fig. 3.1.

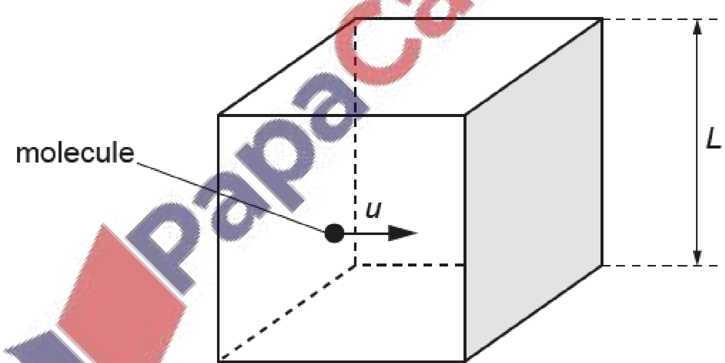

Fig. 3.1

The molecule collides elastically with the shaded face and the face opposite to it alternately.

Deduce expressions, in terms of *m*, *u* and *L*, for:

(i) the magnitude of the change in momentum of the molecule on colliding with a face

change in momentum = ... [1]

(ii) the time between consecutive collisions of the molecule with the shaded face

time = ... [1]

(iii) the average force exerted by the molecule on the shaded face

force = ... [1]

(iv) the pressure on the shaded face if the force in **(iii)** is exerted over the whole area of the face.

pressure = ... [1]

(c) When the model described in **(b)** is extended to three dimensions, and to a gas containing N molecules, each of mass m, travelling with mean-square speed $\langle c^2 \rangle$, it can be shown that

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

where p is the pressure exerted by the gas and V is the volume of the gas.

Use this expression, together with the equation of state of an ideal gas, to show that the average translational kinetic energy E_K of a molecule of an ideal gas is given by

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

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

[2]

(d) The mass of a hydrogen molecule is 3.34×10^{-27} kg.

Use the expression for E_K in **(c)** to determine the root-mean-square (r.m.s.) speed of a molecule of hydrogen gas at 25 °C.

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

[Total: 11]

2. June/2021/Paper_41/No.2

An ideal gas is contained in a cylinder by means of a movable frictionless piston, as illustrated in Fig. 2.1.

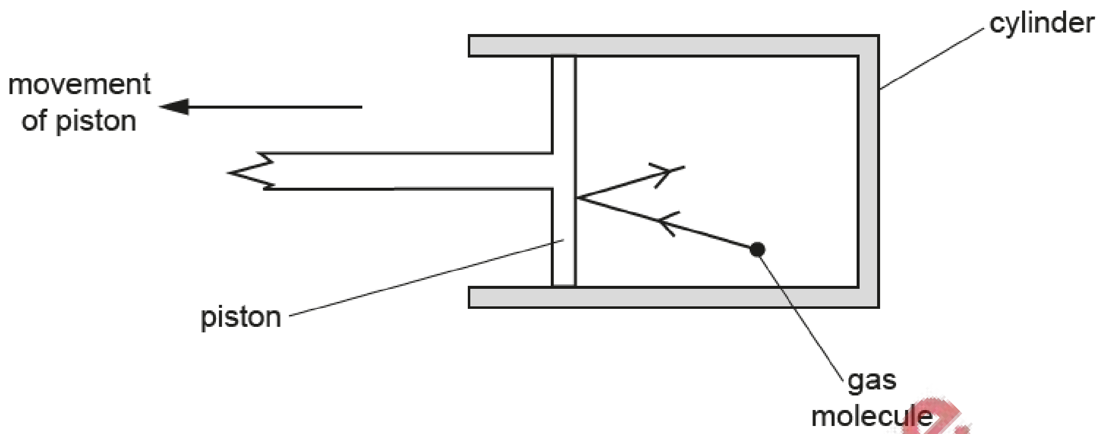

Fig. 2.1

Initially, the gas has a volume of $1.8 \times 10^{-3}\,m^3$ at a pressure of $3.3 \times 10^5\,Pa$ and a temperature of 310 K.

(a) Show that the number of gas molecules in the cylinder is 1.4×10^{23}.

[2]

(b) Use kinetic theory to explain why, when the piston is moved so that the gas expands, this causes a decrease in the temperature of the gas.

....

....

....

.... [3]

(c) The gas expands so that its volume increases to $2.4 \times 10^{-3}\,m^3$ at a pressure of $2.3 \times 10^5\,Pa$ and a temperature of 288 K, as shown in Fig. 2.2.

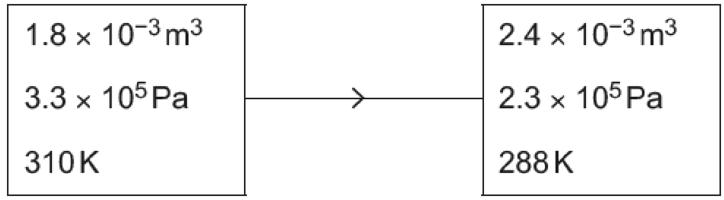

Fig. 2.2

(i) The average translational kinetic energy E_K of a molecule of an ideal gas is given by

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

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

Calculate the increase in internal energy ΔU of the gas during the expansion.

ΔU = ... J [3]

(ii) The work done by the gas during the expansion is 76 J.

Use your answer in (i) to explain whether thermal energy is transferred to or from the gas during the expansion.

....

....

.... [2]

[Total: 10]

3. June/2021/Paper_42/No.2

An ideal gas has a volume of $3.1 \times 10^{-3}\,m^3$ at a pressure of $8.5 \times 10^5\,Pa$ and a temperature of 290 K, as shown in Fig. 2.1.

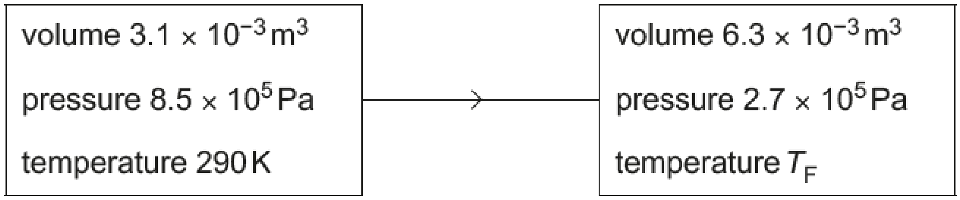

Fig. 2.1

The gas suddenly expands to a volume of $6.3 \times 10^{-3}\,m^3$. During the expansion, no thermal energy is transferred. The final pressure of the gas is $2.7 \times 10^5\,Pa$ at temperature T_F, as shown in Fig. 2.1.

(a) Show that the number of gas molecules is 6.6×10^{23}.

[3]

(b) **(i)** Show that the final temperature T_F of the gas is 190 K.

[1]

(ii) The average translational kinetic energy E_K of a molecule of an ideal gas is given by

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

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

Calculate the increase in internal energy ΔU of the gas.

ΔU = ... J [3]

(c) Use the first law of thermodynamics to explain why the external work w done on the gas during the expansion is equal to the increase in internal energy in **(b)(ii)**.

....

....

.... [2]

[Total: 9]

4. March/2021/Paper_42/No.2

A fixed mass of an ideal gas is at a temperature of 21 °C. The pressure of the gas is 2.3×10^5 Pa and its volume is 3.5×10^{-3} m^3.

(a) **(i)** Calculate the number *N* of molecules in the gas.

N = ... [2]

(ii) The mass of one molecule of the gas is 40 u.

Determine the root-mean-square (r.m.s.) speed of the gas molecules.

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

(b) The temperature of the gas is increased by 84 °C.

Calculate the value of the ratio

$$\frac{\text{new r.m.s. speed of molecules}}{\text{original r.m.s. speed of molecules}}.$$

ratio = ... [2]

[Total: 6]