CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



EXAM QUESTION PACK

15 IDEAL GASES

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Chapter 3

Ideal gases

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40. 9702_w19_qp_41 Q: 2

(a) The kinetic theory of gases is based on a number of assumptions about the molecules of a gas.

State the assumption that is related to the volume of the molecules of the gas.

.....

.....

..... [2]

(b) An ideal gas occupies a volume of $2.40 \times 10^{-2}\,m^3$ at a pressure of $4.60 \times 10^5\,Pa$ and a temperature of 23 °C.

(i) Calculate the number of molecules in the gas.

number = ... [3]

(ii) Each molecule has a diameter of approximately $3 \times 10^{-10}\,m$.

Estimate the total volume of the gas molecules.

volume = ... m^3 [3]

(c) By reference to your answer in **(b)(ii)**, suggest why the assumption in **(a)** is justified.

.....

..... [1]

[Total: 9]

41. 9702_w16_qp_42 Q: 2

(a) The equation of state for an ideal gas of volume V at pressure p is

$$pV = nRT$$

where R is the molar gas constant.

State what is meant by

(i) the symbol n,

.....

.....[1]

(ii) the symbol T.

.....

.....[1]

(b) An ideal gas is held in a container of volume $2.4 \times 10^3\,\text{cm}^3$ at pressure $4.9 \times 10^5\,\text{Pa}$. The temperature of the gas is 100 °C.

Show that the number of molecules of the gas in the container is 2.3×10^{23}.

[3]

(c) Use data from **(b)** to estimate the mean distance between molecules in the gas.

mean distance = ... cm [3]

[Total: 8]

42. 9702_m21_qp_42 Q: 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 $3.5 \times 10^{-3}\,m^3$.

(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]

---

43. 9702_s20_qp_42 Q: 2

(a) A square box of volume V contains N molecules of an ideal gas. Each molecule has mass m.

Using the kinetic theory of ideal gases, it can be shown that, if all the molecules are moving with speed v at right angles to one face of the box, the pressure p exerted on the face of the box is given by the expression

$$pV = Nmv^2. \qquad \text{(equation 1)}$$

This expression leads to the formula

$$p = \frac{1}{3}\rho\langle c^2\rangle \qquad \text{(equation 2)}$$

for the pressure p of an ideal gas, where ρ is the density of the gas and $\langle c^2\rangle$ is the mean-square speed of the molecules.

Explain how each of the following terms in equation 2 is derived from equation 1:

ρ: .....

.....

$\frac{1}{3}$: .....

.....

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

.....

[4]

(b) An ideal gas has volume, pressure and temperature as shown in Fig. 2.1.

volume $6.0 \times 10^{-3}\,m^3$
pressure $3.0 \times 10^5\,Pa$
temperature 17 °C

Fig. 2.1

The mass of the gas is 20.7 g.

Calculate the mass of one molecule of the gas.

mass = ... g [4]

[Total: 8]

44. 9702_m19_qp_42 Q: 2

The pressure p of an ideal gas having density ρ is given by the expression

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

(a) State what is meant by:

(i) an ideal gas

.....

.....

..... [2]

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

.....

..... [1]

(b) A cylinder contains a fixed mass of a gas at a temperature of 120 °C. The gas has a volume of $6.8 \times 10^{-3}\,m^3$ at a pressure 2.4×10^5 Pa.

(i) Assuming the gas acts like an ideal gas, show that the number of atoms of gas in the cylinder is 3.0×10^{23}.

[3]

(ii) Each atom of the gas, assumed to be a sphere, has a radius of 3.2×10^{-11} m.

Use the answer in **(i)** to estimate the actual volume occupied by the gas atoms.

volume = ... m^3 [2]

(iii) One of the assumptions of the kinetic theory of gases is related to the volume of the atoms.
State this assumption. Explain whether your answer in **(ii)** is consistent with this assumption.

.....

.....

.....

..... [2]

[Total: 10]

---

45. 9702_w19_qp_43 Q: 2

(a) The kinetic theory of gases is based on a number of assumptions about the molecules of a gas.

State the assumption that is related to the volume of the molecules of the gas.

.....

.....

..... [2]

(b) An ideal gas occupies a volume of $2.40 \times 10^{-2}\,m^3$ at a pressure of $4.60 \times 10^5\,Pa$ and a temperature of 23 °C.

(i) Calculate the number of molecules in the gas.

number = ... [3]

(ii) Each molecule has a diameter of approximately $3 \times 10^{-10}\,m$.

Estimate the total volume of the gas molecules.

volume = ... m^3 [3]

(c) By reference to your answer in **(b)(ii)**, suggest why the assumption in **(a)** is justified.

.....

..... [1]

[Total: 9]

46. 9702_w18_qp_42 Q: 2

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

.....

.....

.....[2]

(b) An ideal gas comprised of single atoms is contained in a cylinder and has a volume of $1.84 \times 10^{-2}\,m^3$ at a pressure of $2.12 \times 10^{7}\,Pa$.
The mass of gas in the cylinder is 3.20 kg.

(i) Determine, to three significant figures, the root-mean-square (r.m.s.) speed of the atoms of the gas.

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

(ii) The temperature of the gas in the cylinder is 22 °C.

Determine, to three significant figures,

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

amount = ... mol [2]

2. the mass of one atom of the gas.

mass = ... kg [2]

(c) Use your answer in **(b)(ii) part 2** to determine the nucleon number *A* of an atom of the gas.

A = ... [1]

[Total: 10]

47. 9702_s17_qp_43 Q: 4

(a) Describe the motion of molecules in a gas, according to the kinetic theory of gases.

.....

.....

.....[2]

(b) Describe what is observed when viewing Brownian motion that provides evidence for your answer in **(a)**.

.....

.....

.....[2]

(c) At a pressure of 1.05×10^5 Pa and a temperature of 27 °C, 1.00 mol of helium gas has a volume of 0.0240 m^3.
The mass of 1.00 mol of helium gas, assumed to be an ideal gas, is 4.00 g.

(i) Calculate the root-mean-square (r.m.s.) speed of an atom of helium gas for a temperature of 27 °C.

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

(ii) Using your answer in **(i)**, calculate the r.m.s. speed of the atoms at 177 °C.

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

[Total: 10]

48. 9702_w21_qp_42 Q: 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.

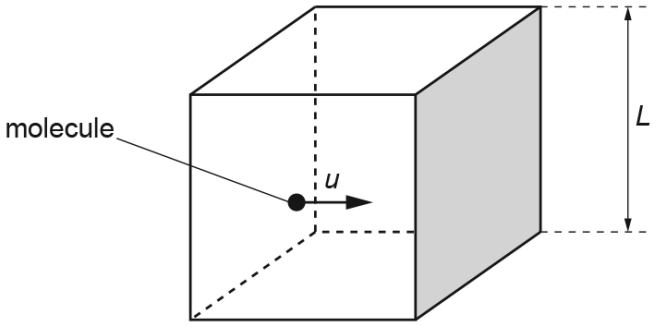


Fig. 3.1

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]

49. 9702_s18_qp_42 Q: 2

(a) Use one of the assumptions of the kinetic theory of gases to explain why the potential energy of the molecules of an ideal gas is zero.

.....

.....[1]

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

$$E_K = \frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

where m is the mass of a molecule and k is the Boltzmann constant.

State the meaning of the symbol

(i) $\langle c^2\rangle$,

.....[1]

(ii) T.

.....[1]

(c) A cylinder of constant volume $4.7 \times 10^4\,\text{cm}^3$ contains an ideal gas at pressure $2.6 \times 10^5\,\text{Pa}$ and temperature 173 °C.

The gas is heated. The thermal energy transferred to the gas is 2900 J. The final temperature and pressure of the gas are T and p, as illustrated in Fig. 2.1.

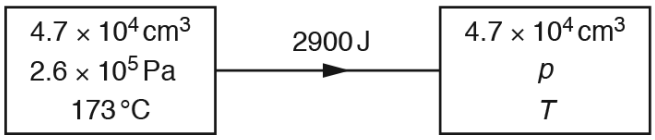


Fig. 2.1

(i) Calculate

1. the number N of molecules in the cylinder,

$N =$ .....[3]

2. the increase in average kinetic energy of a molecule during the heating process.

increase = ... J [1]

(ii) Use your answer in **(i) part 2** to determine the final temperature T, in kelvin, of the gas in the cylinder.

T = ... K [3]

[Total: 10]

50. 9702_s17_qp_41 Q: 4

(a) Describe the motion of molecules in a gas, according to the kinetic theory of gases.

.....

.....

.....[2]

(b) Describe what is observed when viewing Brownian motion that provides evidence for your answer in **(a)**.

.....

.....

.....[2]

(c) At a pressure of 1.05×10^5 Pa and a temperature of 27 °C, 1.00 mol of helium gas has a volume of 0.0240 m^3.
The mass of 1.00 mol of helium gas, assumed to be an ideal gas, is 4.00 g.

(i) Calculate the root-mean-square (r.m.s.) speed of an atom of helium gas for a temperature of 27 °C.

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

(ii) Using your answer in **(i)**, calculate the r.m.s. speed of the atoms at 177 °C.

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

[Total: 10]

Q1.

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

$$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle .$$

(a) Explain the meaning of the symbol $\langle c^2 \rangle$.

.....

..... [2]

(b) The ideal gas has a density of $2.4\,\text{kg m}^{-3}$ 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 = ... m 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.

Use

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 $1.1 \times 10^4\,\text{m s}^{-1}$ 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 $6.6 \times 10^{-27}\,\text{kg}$.

temperature = ... K [2]

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

.....

.....[1]

Q3.

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 $4.00 \times 10^4\,cm^3$ of hydrogen at a pressure of $2.50 \times 10^7\,Pa$ and a temperature of 290 K.

The cylinder is to be used to fill balloons. Each balloon, when filled, contains $7.24 \times 10^3\,cm^3$ of hydrogen at a pressure of $1.85 \times 10^5\,Pa$ 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.

For Examiner Use

.....

.....

.....

.....[3]

(b) The density of neon gas at a temperature of 273 K and a pressure of 1.02×10^5 Pa is $0.900\,kg\,m^{-3}$. 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 = ... $m\,s^{-1}$ [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]

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 $1.5 \times 10^5\,Pa$ 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

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

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

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

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.

E

.....

.....

.....[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 $6.5 \times 10^4\,cm^3$.
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*.

F
Exam
U

.....

.....

..... [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]

(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.

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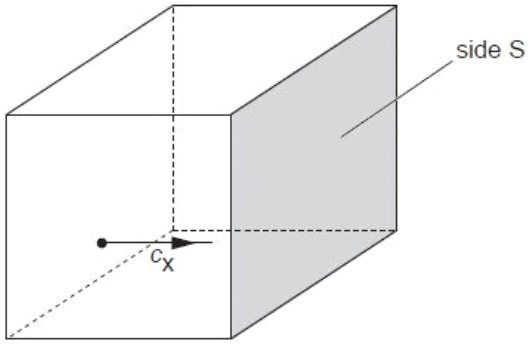


Fig. 2.1

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*.

For Examiner Use

.....

.....

.....

.....[3]

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

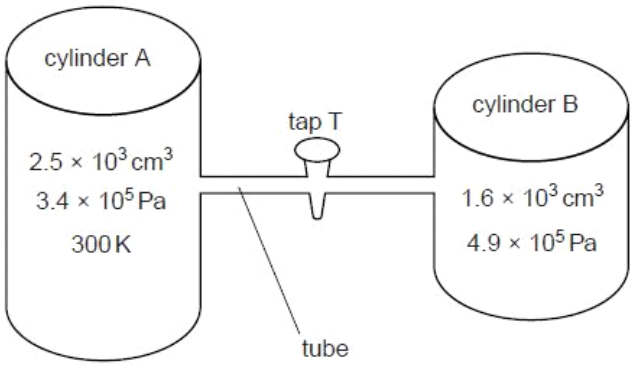


Fig. 2.1

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.

For Examiner's Use

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]

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.

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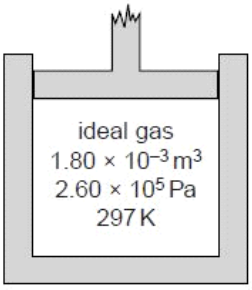


Fig. 2.1

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.

(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 3.1×10^{-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]

Use

Q14.

5 Two deuterium (^2_1H) 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.

For Examiner's Use



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 $2.5 \times 10^6 \, m\,s^{-1}$ 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.

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(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.

For Examiner Use

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.

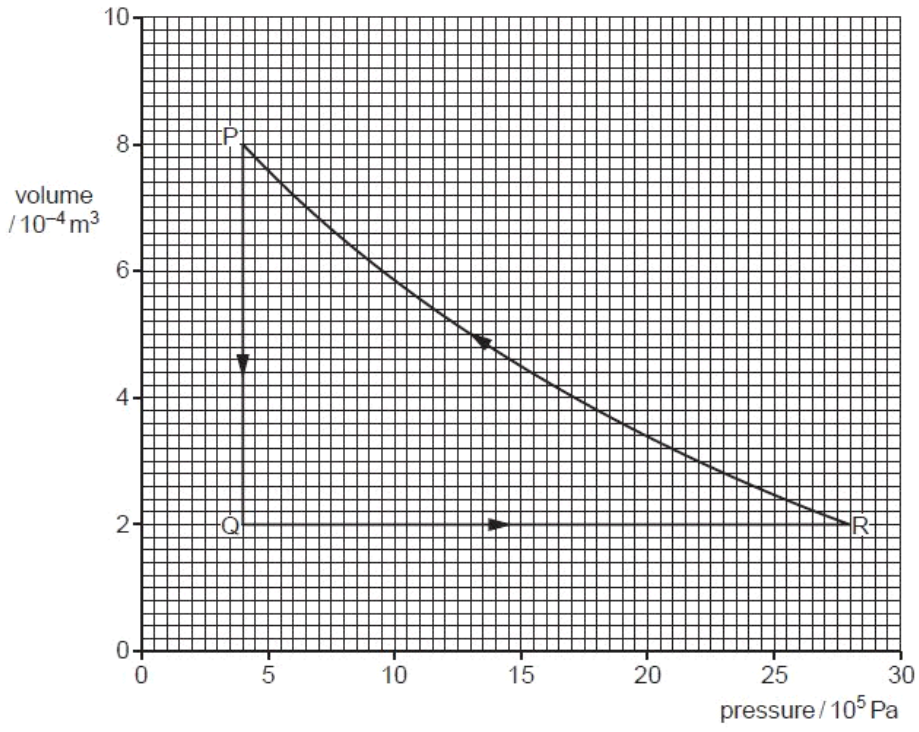


Fig. 2.1

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

change = ... J [1]

For Examiner's Use

(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.

Fo Exami Us

.....

.....

.....

.....

.....

.....[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 ${}^{2}_{1}\mathrm{H}$ and a proton collide. A nuclear reaction occurs, represented by the equation

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

(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 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 $\langle E_K \rangle$ of a gas molecule at temperature T is given by the equation

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

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.

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

For Examiner's Use

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

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.

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.

For Examiner's Use

(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.

For Examiner's Use

.....

.....

total energy = ... J [3]

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.

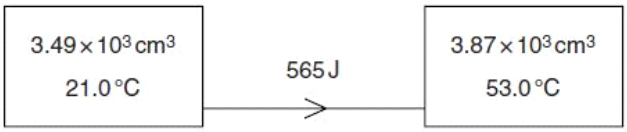


Fig. 2.1

(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 $5.0 \times 10^{7}\,Pa$.

(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]

Ideal gases – 2020 A2

1. Nov/2020/Paper_41/No.2

(a) The first law of thermodynamics may be expressed as

$$\Delta U = (+q) + (+w)$$

where ΔU is the increase in internal energy of the system.

State the meaning of:

$+q$ .....

.....

$+w$. .....

.....

[2]

(b) The variation with pressure p of the volume V of a fixed mass of an ideal gas is shown in Fig. 2.1.

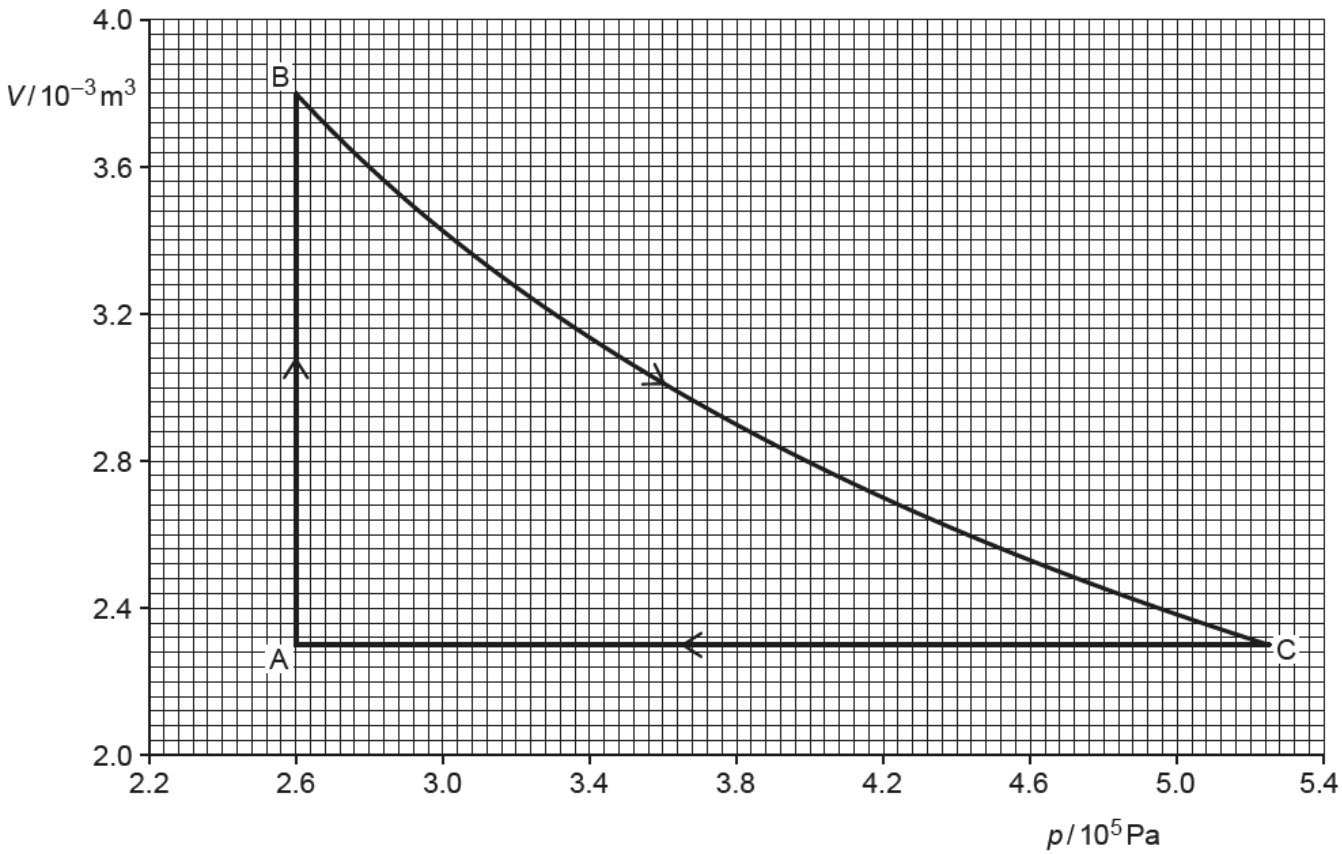


Fig. 2.1

The gas undergoes a cycle of changes A to B to C to A.

During the change A to B, the volume of the gas increases from $2.3 \times 10^{-3}\,m^3$ to $3.8 \times 10^{-3}\,m^3$.

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(i) Show that the magnitude of the work done during the change A to B is 390 J.

[1]

(ii) State and explain the total change, if any, in the internal energy of the gas during one complete cycle.

.....

.....

..... [2]

(c) During the change A to B, 1370 J of thermal energy is transferred to the gas.

During the change B to C, no thermal energy enters or leaves the gas. The work done on the gas during this change is 550 J.

Use these data and the information in **(b)** to complete Table 2.1.

Table 2.1

change	q/J	w/J	ΔU/J
A to B	.....	.....	.....
B to C	.....	.....	.....
C to A	.....	.....	.....

[4]

[Total: 9]

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2. Nov/2020/Paper_42/No.2

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

.....

.....

..... [2]

(b) The atoms of an ideal gas occupy a container of volume $2.30 \times 10^{-3}\,m^3$ at pressure $2.60 \times 10^5\,Pa$ and temperature 180 K, as illustrated in Fig. 2.1.

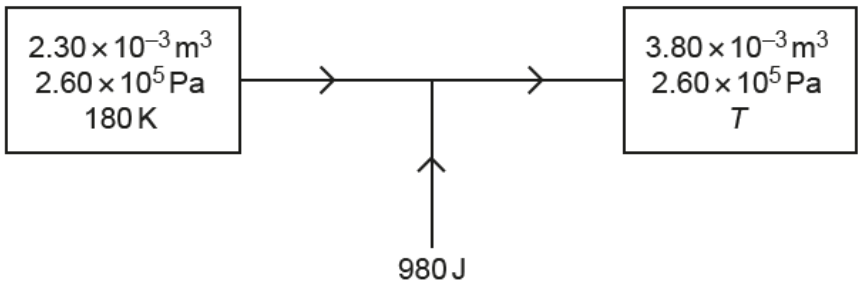


Fig. 2.1

The gas is heated at constant pressure so that its volume becomes $3.80 \times 10^{-3}\,m^3$ at a temperature T.

For the fixed mass of gas, calculate:

(i) the amount of substance, in mol

amount = ... mol [2]

(ii) the temperature T, in K.

T = ... K [2]

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(c) During the change in **(b)**, the thermal energy supplied to the gas is 980 J.

(i) Determine the work done on the gas during this change. Explain your working.

work done = ... J [3]

(ii) Determine the change ΔU in internal energy of the gas.

ΔU = ... J [1]

[Total: 10]

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3. June/2020/Paper_41/No.2

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

.....

.....

.....

..... [2]

(b) By reference to intermolecular forces, explain why the change in internal energy of an ideal gas is equal to the change in total kinetic energy of its molecules.

.....

.....

..... [2]

(c) State and explain the change, if any, in the internal energy of a solid metal ball as it falls under gravity in a vacuum.

.....

.....

.....

..... [3]

[Total: 7]

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4. June/2020/Paper_42/No.2

(a) A square box of volume V contains N molecules of an ideal gas. Each molecule has mass m.

Using the kinetic theory of ideal gases, it can be shown that, if all the molecules are moving with speed v at right angles to one face of the box, the pressure p exerted on the face of the box is given by the expression

$$pV = Nmv^2. \qquad \text{(equation 1)}$$

This expression leads to the formula

$$p = \frac{1}{3}\rho\langle c^2\rangle \qquad \text{(equation 2)}$$

for the pressure p of an ideal gas, where ρ is the density of the gas and $\langle c^2\rangle$ is the mean-square speed of the molecules.

Explain how each of the following terms in equation 2 is derived from equation 1:

ρ: .....

.....

$\frac{1}{3}$: .....

.....

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

.....

[4]

(b) An ideal gas has volume, pressure and temperature as shown in Fig. 2.1.

volume $6.0 \times 10^{-3}\,m^3$
pressure $3.0 \times 10^5\,Pa$
temperature 17 °C

Fig. 2.1

The mass of the gas is 20.7 g.

Calculate the mass of one molecule of the gas.

mass = ... g [4]

[Total: 8]

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5. March/2020/Paper_42/No.2

A large container of volume 85 m^3 is filled with 110 kg of an ideal gas. The pressure of the gas is 1.0×10^5 Pa at temperature T.

The mass of 1.0 mol of the gas is 32 g.

(a) Show that the temperature T of the gas is approximately 300 K.

[3]

(b) The temperature of the gas is increased to 350 K at constant volume. The specific heat capacity of the gas for this change is 0.66 $J\,kg^{-1}\,K^{-1}$.

Calculate the energy supplied to the gas by heating.

energy = ... J [2]

(c) Explain how movement of the gas molecules causes pressure in the container.

.....

.....

.....

.....

.....

.....

..... [3]

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(d) The temperature of a gas depends on the root-mean-square (r.m.s.) speed of its molecules.

Calculate the ratio:

$$\frac{\text{r.m.s. speed of gas molecules at } 350\,\text{K}}{\text{r.m.s. speed of gas molecules at } 300\,\text{K}}.$$

ratio = ... [2]

[Total: 10]

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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.

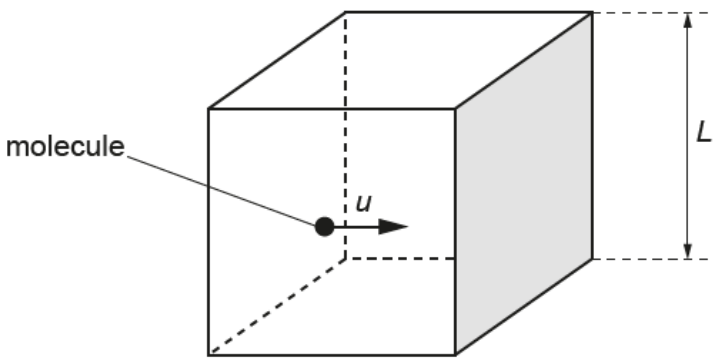


Fig. 3.1

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]

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(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]

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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.

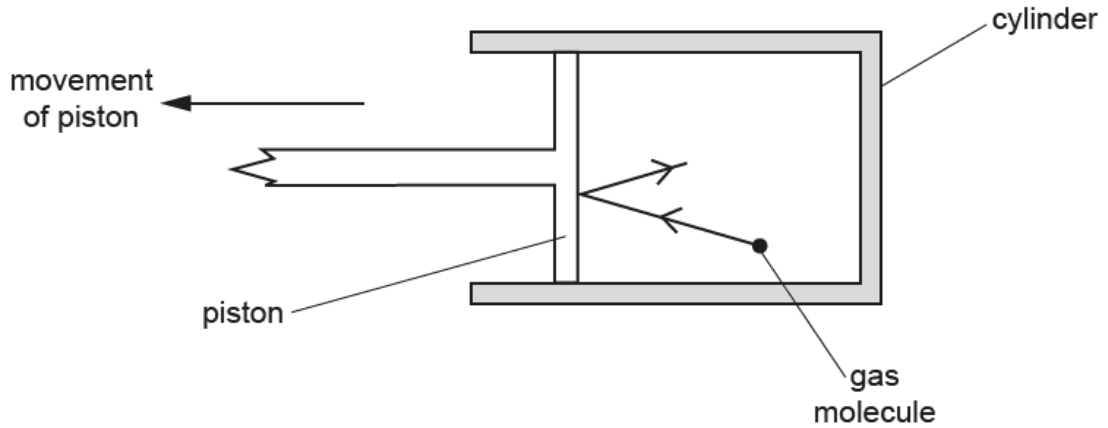


Fig. 2.1

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]

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(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.

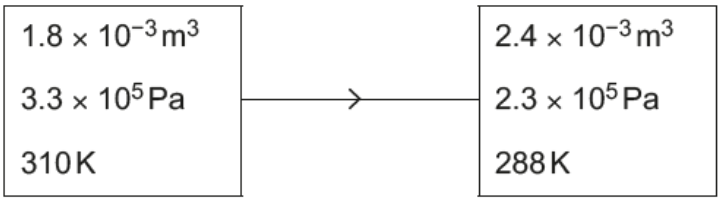


Fig. 2.2

(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]

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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.

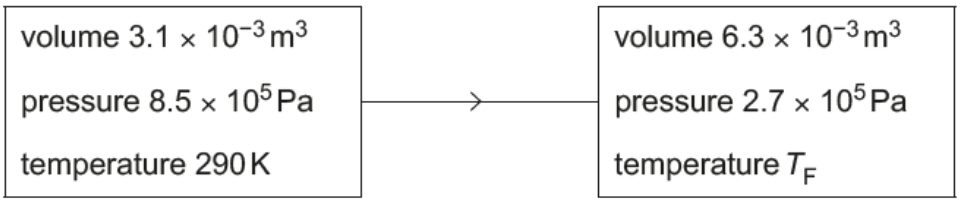


Fig. 2.1

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]

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(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]

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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 $3.5 \times 10^{-3}\,m^3$.

(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]

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(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]

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Ideal gases – 2023 A2 Physics 9702

1. Nov/2023/Paper_9702/41/No.3(a)

(a) The product pV for an ideal gas is given by

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

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

(i) State the meaning of the symbols N, m and $\langle c^2\rangle$ in this equation.

N: .....

m: .....

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

[3]

(ii) Use the equation of state for an ideal gas to show that the average translational kinetic energy E_K of a molecule of the gas at thermodynamic temperature T is given by

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

[2]

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2. Nov/2023/Paper_9702/42/No.2(d, e)

(d) Hydrogen may be assumed to be an ideal gas.
The mass of a hydrogen molecule is 3.34×10^{-27} kg.

Calculate the root-mean-square (r.m.s.) speed of a hydrogen molecule in hydrogen gas that is at a temperature of 400 K.

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

(e) The surface of the Moon reaches temperatures of approximately 400 K when in direct sunlight.

Use your answers in **(c)** and **(d)** to suggest a reason why the Moon does not have an atmosphere consisting of hydrogen.

.....

..... [1]

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3. June/2023/Paper_9702/41/No.4(a), (b) i

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

1 .....

.....

2 .....

.....

[2]

(b) An ideal gas has amount of substance n.
The gas is initially in state X, with pressure $2p$ and volume V.
The gas is cooled at constant volume to state Y, with pressure p.
The gas is then heated at constant pressure to state Z, with volume $2V$.
Finally, the gas returns at constant temperature to state X.

(i) Determine an expression for the temperature T of the gas in state X, in terms of n, p and V.
Identify any other symbols that you use.

[2]

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4. June/2023/Paper_9702/42/No.2

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

.....

.....

..... [2]

(ii) State the temperature, in degrees Celsius, of absolute zero.

temperature = ... °C [1]

(b) A sealed vessel contains a mass of 0.0424 kg of an ideal gas at 227 °C.
The pressure of the gas is 1.37×10^5 Pa and the volume of the gas is 0.640 m^3.

Calculate:

(i) the number of molecules of the gas in the vessel

number of molecules = ... [3]

(ii) the mass of one molecule of the gas

mass = ... kg [1]

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

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

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(c) The gas in **(b)** is now cooled gradually to absolute zero.

On Fig. 2.1, sketch the variation with thermodynamic temperature T of the r.m.s. speed of the molecules of the gas.

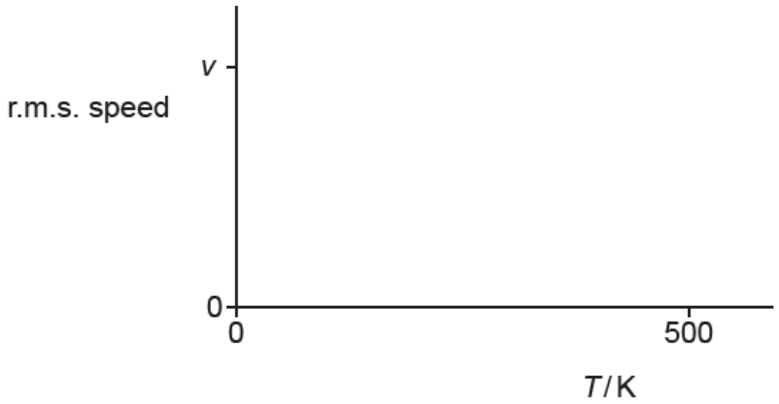


Fig. 2.1

[2]

[Total: 12]

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5. March/2023/Paper_9702/42/No.2(a), (b)i

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

.....

.....

..... [2]

(b) A fixed amount of helium gas is sealed in a container. The helium gas has a pressure of 1.10×10^5 Pa, and a volume of 540 cm^3 at a temperature of 27 °C.

The volume of the container is rapidly decreased to 30.0 cm^3. The pressure of the helium gas increases to 6.70×10^6 Pa and its temperature increases to 742 °C, as illustrated in Fig. 2.1.

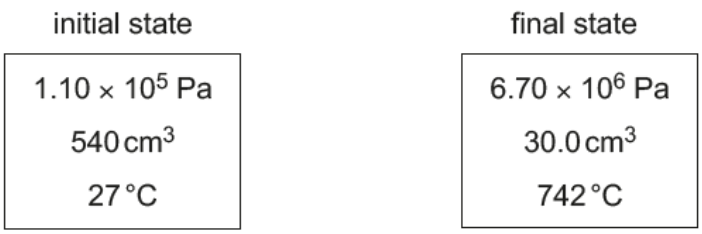


Fig. 2.1

No thermal energy enters or leaves the helium gas during this process.

(i) Show that the helium gas behaves as an ideal gas.

[2]

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