Ideal Gases and Thermodynamics
A-Level Worksheet

1 **(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.
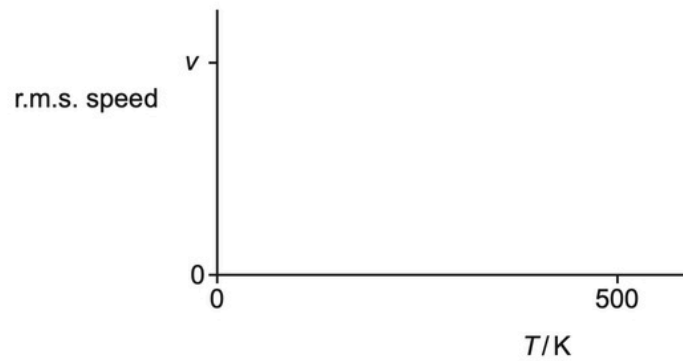

Fig. 2.1

[2]

[Total: 12]

2 **(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 $27 \degree C$.

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 $742 \degree C$, as illustrated in Fig. 2.1.

initial state   final state

| 1.10×10^5 Pa |
| $540 \, cm^3$ |
| $27 \degree C$ |

| 6.70×10^6 Pa |
| $30.0 \, cm^3$ |
| $742 \degree C$ |

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]

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

$$\Delta U = q + W.$$

Use the first law of thermodynamics to explain why the temperature of the helium gas increases.

....

....

....

....

.... [2]

(iii) 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 change in the total kinetic energy of the molecules of the helium gas.

change in kinetic energy = ... J [3]

(c) The mass of nitrogen gas in another container is 24.0 g at a temperature of 27 °C. The gas is cooled to its boiling point of −196 °C. Assume all the gas condenses to a liquid.

For this change the specific heat capacity of nitrogen gas is 1.04 kJ kg⁻¹ K⁻¹.

The specific latent heat of vaporisation of nitrogen is 199 kJ kg⁻¹.

Determine the thermal energy, in kJ, removed from the nitrogen gas.

energy = ... kJ [3]

[Total: 12]

3 **(a)** The equation of state for an ideal gas can be written as

$$pV = NkT.$$

State the meaning of each of the symbols in this equation.

p: ....

V: ....

N: ....

k: ....

T: ....
[3]

(b) Use the equation in **(a)** to show that the average translational kinetic energy E_K of a molecule of an ideal gas is given by

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

[2]

(c) The mass of an oxygen molecule is 5.31×10^{-26} kg. Assume that oxygen behaves as an ideal gas.

(i) Use the equation in **(b)** to determine the root-mean-square (r.m.s.) speed u of an oxygen molecule at 23 °C.

u = ... m s^{-1} [3]

(ii) A fixed mass of oxygen gas at initial pressure P is sealed in a cylindrical container by a movable piston at one end, as shown in Fig. 3.1.
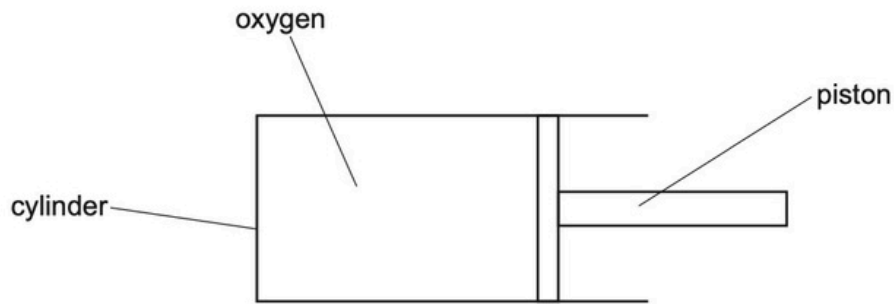

Fig. 3.1

The temperature of the gas is 23 °C.

The piston is slowly moved into the cylinder so that the oxygen gas is compressed. At all times, the gas and the container remain in thermal equilibrium with the surroundings.

On Fig. 3.2, sketch the variation with pressure of the r.m.s. speed of the oxygen molecules as the pressure increases.

Fig. 3.2

[2]

[Total: 10]

4   A fixed mass of an ideal gas is initially at a temperature of 17 °C.
    The gas has a volume of 0.24 m³ and a pressure of 1.2×10^5 Pa.

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

....

....

.... [2]

   (ii) Calculate the amount n of gas.

$n =$ .... mol [2]

(b) The gas undergoes three successive changes, as shown in Fig. 3.1.
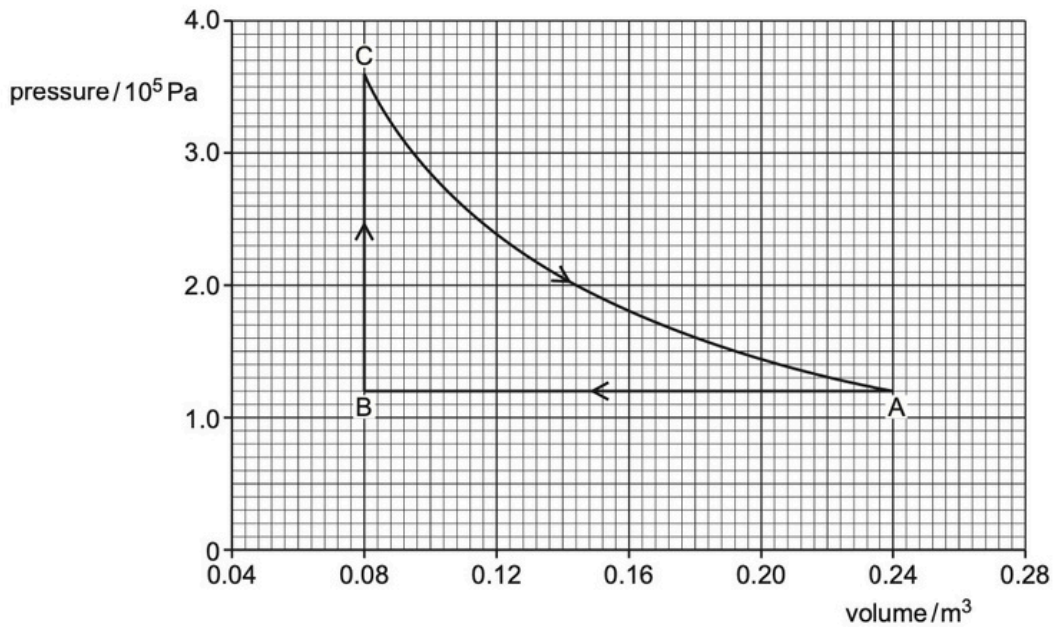
Fig. 3.1

The initial state is represented by point A. The gas is cooled at constant pressure to point B
by the removal of 48.0 kJ of thermal energy.

The gas is then heated at constant volume to point C.

Finally, the gas expands at constant temperature back to its original pressure and volume at
point A. During this expansion, the gas does 31.6 kJ of work.

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(i) Show that the magnitude of the work done during the change AB is 19.2 kJ.

[2]

(ii) Complete Table 3.1 to show the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas, for each of the changes AB, BC and CA.

Table 3.1

change	work done on gas/kJ	thermal energy supplied to gas/kJ	increase in internal energy of gas/kJ
AB		−48.0	
BC			
CA	−31.6		

[5]

[Total: 11]

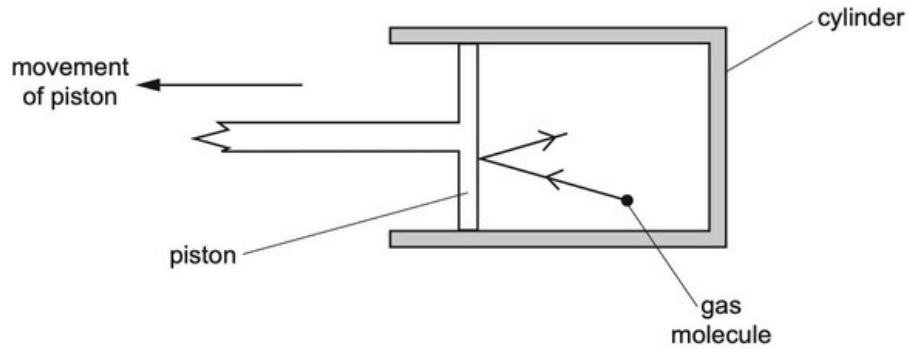5   An ideal gas is contained in a cylinder by means of a movable frictionless piston, as illustrated in Fig. 2.1.

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.

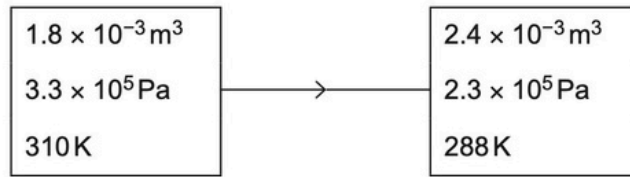| $1.8 \times 10^{-3}\,m^3$ | |
| $3.3 \times 10^5\,Pa$ | $\longrightarrow$ |
| 310 K | |

| $2.4 \times 10^{-3}\,m^3$ |
| $2.3 \times 10^5\,Pa$ |
| 288 K |

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.

$\Delta U =$ .... 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]

6   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.
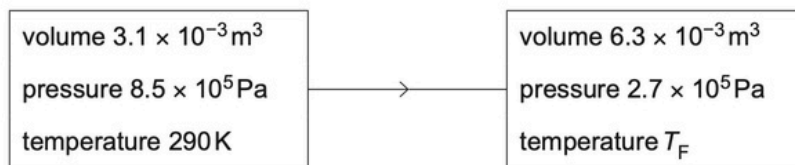
volume $3.1 \times 10^{-3} \, m^3$	volume $6.3 \times 10^{-3} \, m^3$
pressure $8.5 \times 10^5 \, Pa$	pressure $2.7 \times 10^5 \, Pa$
temperature 290 K	temperature T_F

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.

$\Delta U =$ .... 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]

7 (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]

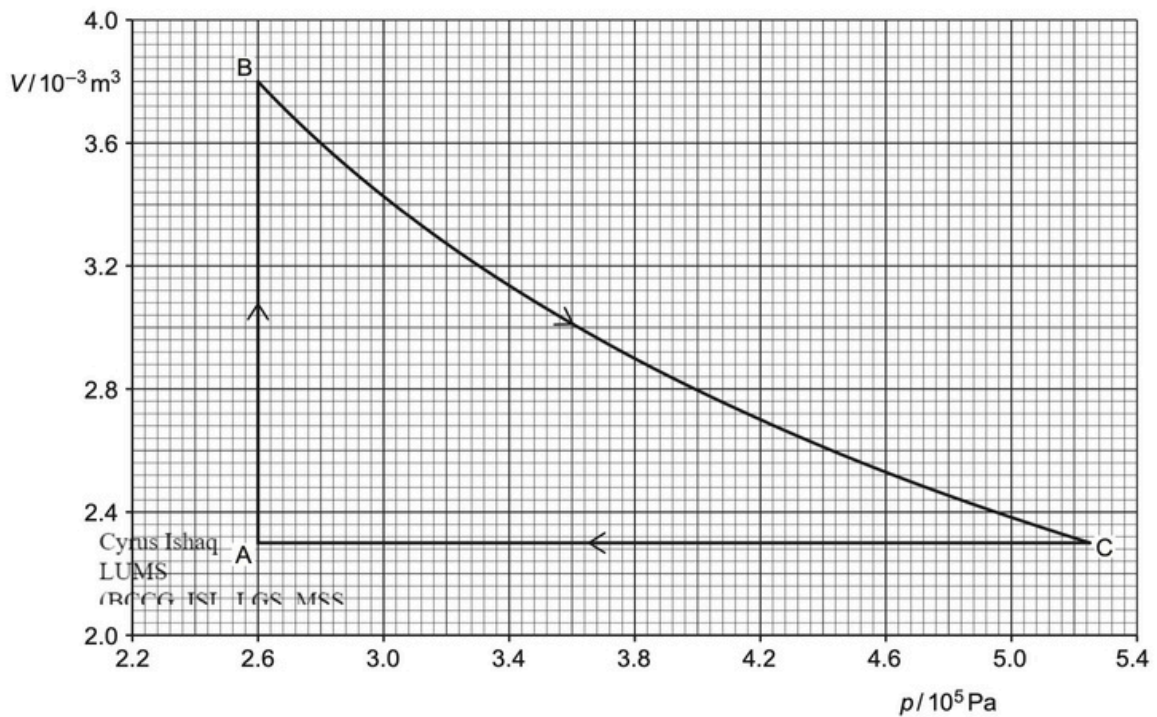(b) The variation with pressure p of the volume V of a fixed mass of an ideal gas is shown in Fig. 2.1.

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 $3.8 \times 10^{-3}\,m^3$.

(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	$\Delta U/J$
A to B	....	....	....
B to C	....	....	....
C to A	....	....	....

[4]

[Total: 9]

8 (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.
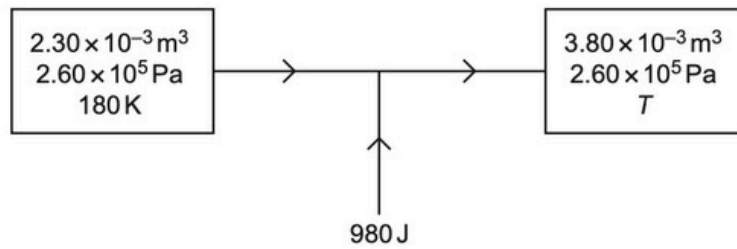
Fig. 2.1

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]

(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]

9 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]

10 A large container of volume $85 \, m^3$ is filled with $110 \, kg$ of an ideal gas. The pressure of the gas is $1.0 \times 10^5 \, Pa$ 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.

....

....

....

....

....

....

(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]

11 **(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 $6.0 \times 10^{-3}\,\text{m}^3$
pressure $3.0 \times 10^5\,\text{Pa}$
temperature $17\,°C$
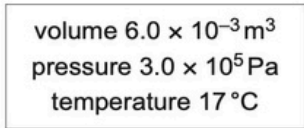
Fig. 2.1

The mass of the gas is 20.7 g.

Calculate the mass of one molecule of the gas.

mass = ... g [4]

[Total: 8]

12 **(a)** State what is meant by the *internal energy* of a system.   *S20/43/Q2*

....

....

....

.... [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]

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

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

(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 $2.4 \times 10^5\,Pa$.

(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 $3.2 \times 10^{-11}\,m$.

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

volume = ... m^3 [2¹

(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]

14 **(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]

15 **(a)** Smoke particles are suspended in still air. Brownian motion of the smoke particles is seen through a microscope.

Describe:

(i) what is seen through the microscope

....

.... [1]

(ii) how Brownian motion provides evidence for the nature of the movement of gas molecules.

....

....

.... [2]

(b) A fixed mass of an ideal gas has volume $2.40 \times 10^3 \, cm^3$ at pressure $3.51 \times 10^5 \, Pa$ and temperature 290 K. The gas is heated at constant volume until the temperature is 310 K at pressure $3.75 \times 10^5 \, Pa$, as illustrated in Fig. 2.1.

$2.40 \times 10^3 \, cm^3$		$2.40 \times 10^3 \, cm^3$
$3.51 \times 10^5 \, Pa$	$\longrightarrow$	$3.75 \times 10^5 \, Pa$
290 K		310 K
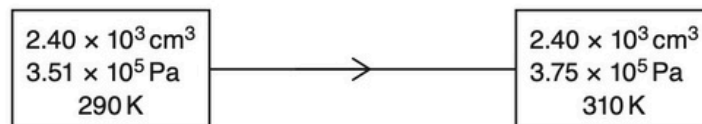
Fig. 2.1

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

Calculate, to three significant figures:

(i) the amount, in mol, of the gas

amount = ... mol [3]

(ii) the thermal energy transfer during the change.

energy transfer = ... J [2]

(c) For the change in the gas in **(b)**, state:

(i) the quantity of external work done on the gas

work done = ... J [1]

(ii) the change in internal energy, with the direction of this change.

change = ... J

direction ....

[2]

[Total: 11]

16 **(a)** The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w.$$

(i) State, for a system, what is meant by:

1. $+q$

....

....

2. $+w$.

....

....
[2]

(ii) State what is represented by a negative value of ΔU.

....

....[1]

(b) An ideal gas, sealed in a container, undergoes the cycle of changes shown in Fig. 2.1.

B
8.7 × 10⁻⁴ m³
6.6 × 10⁵ Pa
450 K

pressure /10⁵ Pa

2.4 × 10⁻³ m³
1.6 × 10⁵ Pa
300 K

8.7 × 10⁻⁴ m³
1.6 × 10⁵ Pa
110 K

C   A
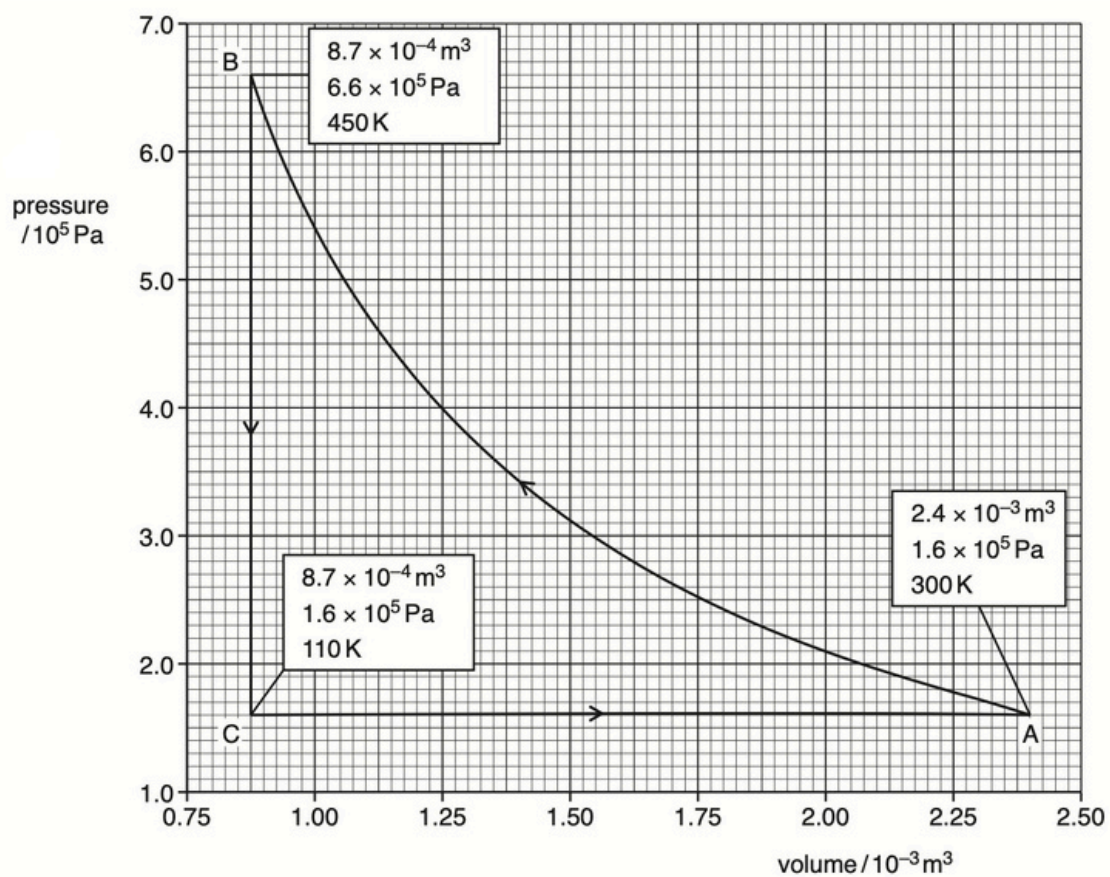
volume /10⁻³ m³

At point A, the gas has volume $2.4 \times 10^{-3}\,m^3$, pressure $1.6 \times 10^5\,Pa$ and temperature $300\,K$.

The gas is compressed suddenly so that no thermal energy enters or leaves the gas during the compression. The amount of work done is $480\,J$ so that, at point B, the gas has volume $8.7 \times 10^{-4}\,m^3$, pressure $6.6 \times 10^5\,Pa$ and temperature $450\,K$.

The gas is now cooled at constant volume so that, between points B and C, $1100\,J$ of thermal energy is transferred. At point C, the gas has pressure $1.6 \times 10^5\,Pa$ and temperature $110\,K$.

Finally, the gas is returned to point A.

(i) State and explain the total change in internal energy of the gas for one complete cycle ABCA.

....

....

....[2]

(ii) Calculate the external work done on the gas during the expansion from point C to point A.

work done = ... J [2]

(iii) Complete Fig. 2.2 for the changes from:

1. point A to point B

2. point B to point C

3. point C to point A.

change	+q/J	+w/J	ΔU/J
A → B	....	....	....
B → C	....	....	....
C → A	....	....	....

Fig. 2.2

[4]

(a) On Fig. 2.1, place a tick (✓) against those changes where the internal energy of the body is increasing. [2]

water freezing at constant temperature	....
a stone falling under gravity in a vacuum	....
water evaporating at constant temperature	....
stretching a wire at constant temperature	....

Fig. 2.1

(b) A jeweller wishes to harden a sample of pure gold by mixing it with some silver so that the mixture contains 5.0% silver by weight. The jeweller melts some pure gold and then adds the correct weight of silver. The initial temperature of the silver is 27 °C. Use the data of Fig. 2.2 to calculate the initial temperature of the pure gold so that the final mixture is at the melting point of pure gold.

	gold	silver
melting point / K	1340	1240
specific heat capacity (solid or liquid) / $J\,kg^{-1}\,K^{-1}$	129	235
specific latent heat of fusion / $kJ\,kg^{-1}$	628	105

Fig. 2.2

temperature = ... K [5]

(c) Suggest a suitable thermometer for the measurement of the initial temperature of the gold in (b).

.... [1]

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

$$pV = \frac{1}{3}Nm<c^2>$$

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

(a) State the meaning of the symbol

(i) N,

....[1]

(ii) $<c^2>$.

....[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).

....

....

aq   ....[2]

19 **(a)** State

(i) what may be deduced from the difference in the temperatures of two objects,

....

.... [1]

(ii) the basic principle by which temperature is measured.

....

.... [1]

(b) By reference to your answer in **(a)(ii)**, explain why two thermometers may not give the same temperature reading for an object.

....

....

.... [2]

(c) A block of aluminium of mass 670 g is heated at a constant rate of 95 W for 6.0 minutes.
The specific heat capacity of aluminium is 910 J kg^{-1} K^{-1}.
The initial temperature of the block is 24 °C.

(i) Assuming that no thermal energy is lost to the surroundings, show that the final temperature of the block is 80 °C.

[3]

(ii) In practice, there are energy losses to the surroundings.
The actual variation with time t of the temperature θ of the block is shown in Fig. 1.1.
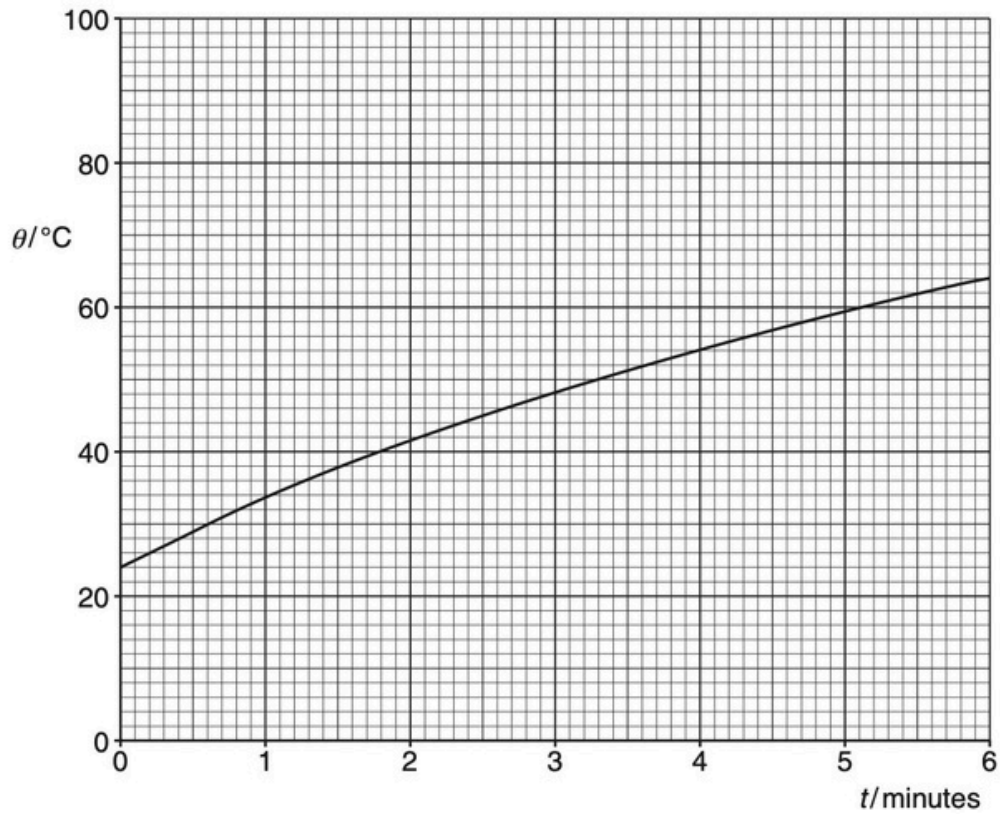
Fig. 1.1

1. Use the information in **(i)** to draw, on Fig. 1.1, a line to represent the temperature of the block, assuming no energy losses to the surroundings. [1]

2. Using Fig. 1.1, calculate the total energy loss to the surroundings during the heating process.

energy loss = ... J [2]

[Total: 10]

20 **(a)** Define specific heat capacity.

....

....

.... [2]

(b) An ideal gas of mass 0.35 kg is heated at a constant pressure of 2.0×10^5 Pa so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 m^3 to 0.063 m^3 and the temperature increases by 56 °C.

(i) Show that the magnitude of the work done on the gas is 5000 J.

[1]

(ii) Explain whether the work done on the gas is positive or negative.

....

....

.... [2]

(iii) Determine the magnitude of the thermal energy q transferred to the gas.

q = ... J [2]

(iv) Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

specific heat capacity = ... unit .... [2]

(c) The gas in **(b)** is now heated at constant volume rather than at constant pressure. The increase in internal energy of the gas is the same as in **(b)**.

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in **(b)(iv)**.

....

....

....

....

.... [3]

[Total: 12]

Q21   **(a)** The product pV for an ideal gas is given by   ON23/41/Q3

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

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]

(b) The surface of a star consists mainly of a gas that may be assumed to be ideal. The molecules of the gas have a root-mean-square (r.m.s.) speed of $9300\,\text{m s}^{-1}$.

The mass of a molecule of the gas is $3.34 \times 10^{-27}\,\text{kg}$.

Determine, to three significant figures, the temperature of the surface of the star.

temperature = ... K [2]

(d) The gas at the surface of a star has a very high pressure.

Use the basic assumptions of the kinetic theory to suggest why, in practice, a gas at the surface of a star is unlikely to behave as an ideal gas.

....

....

....

.... [2]

Q22 **(a)** State what is meant by the internal energy of a system.

....

....

.... [2]

(b) Use the first law of thermodynamics to explain what happens to the internal energy:

    (i) of a spring when it is stretched at constant temperature within its elastic limit

....

....

....

....

.... [3]

    (ii) of a sample of water when it evaporates from a rain puddle on a hot day.

....

....

....

....

.... [3]

[Total: 8]

Q23 **(a)** By referring to both kinetic energy and potential energy, explain what is meant by the internal energy of an ideal gas.

....

....

....

.... [2]

(b) A fixed mass of an ideal gas at a temperature of 20°C is sealed in a cylinder by a piston, as shown in Fig. 2.1.

cylinder ⎯

gas   piston
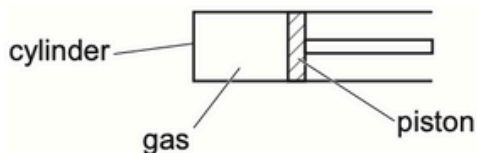
Fig. 2.1

The initial volume of the gas is $1.24 \times 10^{-4}\,\text{m}^3$.
Thermal energy is supplied to the gas and its volume increases by $5.20 \times 10^{-5}\,\text{m}^3$.

(i) The piston is freely moving so that the gas is always at atmospheric pressure.

Atmospheric pressure is $1.01 \times 10^5\,\text{Pa}$.

Calculate the work done by the gas.

work done by gas = ... J [2]

(ii) Calculate the final thermodynamic temperature T of the gas.

$T =$ .... K [2]

(iii) The mass of the gas is 16 g. For this expansion, there is a net transfer of 960 J of thermal energy to the gas.

Calculate the specific heat capacity c of the gas at this pressure.

c = ... $J\,kg^{-1}K^{-1}$ [2]

(c) The gas in **(b)** is allowed to return to its starting temperature. The piston is now fixed in position.

Thermal energy is supplied to increase the temperature to the same final temperature as in **(b)**.

Use the first law of thermodynamics to suggest and explain how the specific heat capacity of the gas for this situation compares with the value in **(b)(iii)**.

....

....

....

.... [3]

[Total: 11]

Q24 **(a) (i)** State what is meant by an ideal gas.

....

....

.... [2]

(ii) Use one of the basic assumptions of the kinetic theory to explain what can be deduced about the potential energy associated with the random motion of molecules in an ideal gas.

....

....

.... [2]

(b) A sample of 0.26 m^3 of an ideal gas is at pressure 2.0×10^5 Pa and temperature 290 K.

Determine:

(i) the number N of molecules of the gas

$N =$ .... [2]

(ii) the average translational kinetic energy E_K of one molecule of the gas

$E_K =$ .... J [2]

(iii) the internal energy of the gas. Explain your reasoning.

internal energy = ... J [2]

(c) The volume V of the gas in **(b)** is now varied, keeping its pressure constant.

On Fig. 3.1, sketch the variation with V of the internal energy U of the gas.

Fig. 3.1

[2]

[Total: 12]

Q25 **(a)** With reference to thermal energy, state what is meant by two objects being in thermal equilibrium.

....

....

.... [1]

(b) Two cylinders X and Y each contain a sample of an ideal gas. The samples are in thermal equilibrium with each other.

X has a volume of $0.0260\,m^3$ and contains $0.740\,mol$ of gas at a pressure of $1.20 \times 10^5\,Pa$. Y has a volume of $0.0430\,m^3$ and contains gas at a pressure of $2.90 \times 10^5\,Pa$. Data for the two cylinders are shown in Fig. 2.1.

X	Y
0.740 mol $1.20 \times 10^5\,Pa$ $0.0260\,m^3$	$2.90 \times 10^5\,Pa$ $0.0430\,m^3$

Fig. 2.1

(i) Show that the temperature of the gas in X is $234\,°C$.

[3]

(ii) Determine the number N of molecules of the gas in Y. Explain your reasoning.

N = ... [3]

(iii) The gas in X consists of molecules that each have a mass that is four times the mass of a molecule of the gas in Y.

Explain how the root-mean-square (r.m.s.) speed of the molecules in X compares with the r.m.s. speed of the molecules in Y.

....

....

....

....

.... [3]

[Total: 10]

Q26   **(a)** State what is meant by the internal energy of a system.

....

....

.... [2]

(b) With reference to molecular kinetic and potential energies, describe and explain how the internal energy of the system changes when:

     (i) a gas is heated at constant volume so that its temperature increases

....

....

....

....

.... [3]

     (ii) a wire is stretched within its elastic limit at constant temperature.

....

....

....

....

.... [3]

[Total: 8]

Question		Answer	Marks
1	2(a)(i)	(gas that obeys) $pV \propto T$ (for all values of p, V and T)	M1
		where T is thermodynamic temperature	A1
	(a)(ii)	temperature = –273.15 °C	A1
	2(b)(i)	$pV = NkT$	C1
		$N = (1.37 \times 10^5 \times 0.640) / (1.38 \times 10^{-23} \times (227 + 273))$	C1
		$= 1.27 \times 10^{25}$	A1
	(b)(ii)	mass $= 0.0424 / (1.27 \times 10^{25})$	A1
		$= 3.34 \times 10^{-27}$ kg	
	(b)(iii)	$\frac{1}{2}m\langle c^2 \rangle = (3/2)kT$	C1
		$3.34 \times 10^{-27} \times v^2 = 3 \times 1.38 \times 10^{-23} \times 500$	C1
		$v = 2490$ m s^{-1}	A1
		or	
		$pV = \frac{1}{3}(Nm) \langle c^2 \rangle$ <u>and</u> Nm = mass of gas	(C1)
		$0.0424 \times v^2 = 3 \times 1.37 \times 10^5 \times 0.640$	(C1)
		$v = 2490$ m s^{-1}	(A1)
	2(c)	sketch: line from (0, 0) to (500, v)	B1
		line with decreasing positive gradient throughout	B1

Question	Answer	Marks
2(a)	gas for which $pV \propto T$	M1
	where T is thermodynamic temperature	A1
2(b)(i)	evidence of two temperature conversions between °C and K	B1
	two calculations shown, one for each state e.g.	A1
	$\dfrac{1.10 \times 10^5 \times 540 \times 10^{-6}}{(273 + 27)} = 0.198$ **and** $\dfrac{6.70 \times 10^6 \times 30 \times 10^{-6}}{(273 + 742)} = 0.198$	
2(b)(ii)	work is done on the gas	M1
	internal energy increases (so temperature increases)	A1
2(b)(iii)	$pV = NkT$ e.g.	C1
	$N = \dfrac{1.10 \times 10^5 \times 540 \times 10^{-6}}{1.38 \times 10^{-23} \times 300}$	
	$= 1.435 \times 10^{22}$	
	$\Delta E_k = (3/2) k \Delta T N$	
	$= (3/2) \times 1.38 \times 10^{23} \times (742 - 27) \times \dfrac{1.10 \times 10^5 \times 540 \times 10^{-6}}{1.38 \times 10^{-23} \times 300}$	C1
	$= 212$ J	A1
2(c)	$E = mc\Delta\theta$ **and** $E = mL$	C1
	$\Delta\theta = (27 + 196)$ or 223	C1
	$E = 0.0240 \times 1.04 \times (27 + 196) + 0.0240 \times 199$	A1
	$= 10.3$ kJ	

Question	Answer	Marks
3(a)	p = pressure (of gas), V = volume (of gas) **and** k = Boltzmann constant	B1
	N = number of molecules	B1
	T = thermodynamic temperature	B1
3(b)	($pV = NkT$ and $pV = \frac{1}{3}Nm\langle c^2\rangle$ leading to) $NkT = \frac{1}{3}Nm\langle c^2\rangle$	M1
	algebra leading to $(3/2)kT = \frac{1}{2}m\langle c^2\rangle$ **and** use of $\frac{1}{2}m\langle c^2\rangle = E_K$ leading to $(3/2)kT = E_K$	A1
3(c)(i)	$T = 296\,K$	C1
	$\frac{1}{2}m\langle c^2\rangle = (3/2)kT$	C1
	$\frac{1}{2} \times 5.31 \times 10^{-26} \times u^2 = (3/2) \times 1.38 \times 10^{-23} \times 296$	
	$u = 480\,m\,s^{-1}$	A1
3(c)(ii)	line passing through (P, u)	B1
	horizontal straight line	B1

Question		Answer	Marks
4	(a)(i)	a gas that obeys $pV \propto T$	M1
		where p = pressure, V = volume, T = thermodynamic temperature	A1
	(a)(ii)	$T = (273 + 17)\,K$	C1
		$n = pV / RT$	A1
		$\quad = (1.2 \times 10^5 \times 0.24) / [8.31 \times (273 + 17)]$	
		$\quad = 12\,mol$	
	(b)(i)	work done $= p\Delta V$	C1
		$\quad = 1.2 \times 10^5 \times (0.24 - 0.08) = 19200\,J\ (= 19.2\,kJ)$	A1
	(b)(ii)	AB work done correct (19.2)	A1
		BC work done correct (0)	A1
		CA increase in internal energy correct (0) **and** CA thermal energy correct (31.6)	A1
		AB increase in internal energy calculated correctly from work done – 48.0	A1
		BC increase in internal energy correctly calculated so the final column adds up to zero **and** BC thermal energy same as increase in internal energy	A1
		(Fully correct table: | AB	19.2	−48.0	−28.8
BC	0	28.8	28.8
CA	−31.6	31.6	0	)	

5(a)	$pV = NkT$	C1
	$N = (1.8 \times 10^{-3} \times 3.3 \times 10^5) / (1.38 \times 10^{-23} \times 310) = 1.4 \times 10^{23}$	A1
	or	
	$pV = nRT$ **and** $nN_A = N$	(C1)
	$N = (1.8 \times 10^{-3} \times 3.3 \times 10^5 \times 6.02 \times 10^{23}) / (8.31 \times 310) = 1.4 \times 10^{23}$	(A1)
(b)	speed of molecule decreases on impact with moving piston	B1
	mean square speed (directly) proportional to (thermodynamic) temperature **or** mean square speed (directly) proportional to kinetic energy (of molecules) **or** kinetic energy (of molecules) (directly) proportional to (thermodynamic) temperature	B1
	kinetic energy (of molecules) decreases (so temperature decreases)	B1
(c)(i)	$\Delta U = 3/2 \times k \times \Delta T \times N$	C1
	$= 3/2 \times 1.38 \times 10^{-23} \times (288 - 310) \times 1.4 \times 10^{23}$	C1
	$= -64$ J	A1
(c)(ii)	decrease in internal energy is less than work done by gas	M1
	(thermal energy is) transferred <u>to</u> the gas (during the expansion)	A1

6 2(a)	$pV = nRT$	C1
	$pV = nRT$ **and** $N = nN_A$ **or** $pV = NkT$	C1
	$3.1 \times 10^{-3} \times 8.5 \times 10^5 = (N \times 290 \times 8.31) / (6.02 \times 10^{23})$ so $N = 6.6 \times 10^{23}$ or $3.1 \times 10^{-3} \times 8.5 \times 10^5 = N \times 1.38 \times 10^{-23} \times 290$ so $N = 6.6 \times 10^{23}$	A1
(b)(i)	$(3.1 \times 10^{-3} \times 8.5 \times 10^5) / 290 = (6.3 \times 10^{-3} \times 2.7 \times 10^5) / T$ so $T = 190$ K or $6.3 \times 10^{-3} \times 2.7 \times 10^5 = 6.6 \times 10^{23} \times 1.38 \times 10^{-23} \times T$ so $T = 190$ K	A1
(b)(ii)	$\Delta U = 3/2 \times k \times \Delta T \times N$	C1
	$= 3/2 \times 1.38 \times 10^{-23} \times (190 - 290) \times 6.6 \times 10^{23}$	C1
	$= -1400$ J	A1
2(c)	$\Delta U = q + w$	M1
	$q = 0$ so $\Delta U = w$	A1

6

7(a)	+q: thermal energy transfer to system	B1
	+w: work done on system	B1
(b)(i)	$(W =) 2.6 \times 10^5 \times (3.8 - 2.3) \times 10^{-3} = 390$ J	A1
(b)(ii)	no (total) change (in internal energy)	B1
	gas returns to its original temperature	B1
(c)	A to B row all correct (1370, − 390, 980)	B1
	B to C row all correct (0, 550, 550)	B1
	C to A row: ΔU adds to the other two ΔU values to give zero	B1
	C to A row: $w = 0$ **and** q adds to w to give ΔU value	B1

complete correct answer:

change	q / J	w / J	ΔU / J
A to B	(+)1370	−390	(+)980
B to C	0	(+)550	(+)550
C to A	−1530	0	−1530

8(a)	sum of potential energy and kinetic energy (of particles)	B1
	(total) energy of random motion of particles	B1
(b)(i)	$pV = nRT$	C1
	$2.60 \times 10^5 \times 2.30 \times 10^{-3} = n \times 8.31 \times 180$	A1
	$n = 0.400$ mol	
(b)(ii)	$(2.30 \times 10^{-3}) / 180 = (3.80 \times 10^{-3}) / T$	C1
	or	
	$2.60 \times 10^5 \times 3.80 \times 10^{-3} = 0.400 \times 8.31 \times T$	
	$T = 297$ K	A1
(c)(i)	$\Delta W = p\Delta V$	C1
	$= 2.60 \times 10^5 \times (2.30 - 3.80) \times 10^{-3}$	
	$= (-)390$ J	A1
	negative because work is done by gas **or** negative because work is done against atmospheric pressure **or** negative because volume of gas increases	B1
(c)(ii)	$\Delta U = (980 - 390)$	A1
	$= 590$ J	

9(a)(i)	$pV = NkT$ or $pV = nRT$ <u>and</u> $N = nN_A$	C1
	$N = \dfrac{2.3 \times 10^5 \times 3.5 \times 10^{-3}}{1.38 \times 10^{-23} \times 294}$	
	$= 2.0 \times 10^{23}$	A1
(a)(ii)	$pV = \dfrac{1}{3} Nmc^2$	C1
	$c^2 = \dfrac{3 \times 2.3 \times 10^5 \times 3.5 \times 10^{-3}}{2.0 \times 10^{23} \times 40 \times 1.66 \times 10^{-27}}$	
	$= 182\,000$	
	r.m.s. speed = **430 m s⁻¹**	
	or	A1
	$\frac{1}{2} mc^2 = \frac{3}{2} kT$	
	$c^2 = \dfrac{3 \times 1.38 \times 10^{-23} \times 294}{40 \times 1.66 \times 10^{-27}}$	(C1)
	$= 183\,000$	
	r.m.s.speed = 430 m s⁻¹	(A1)
(b)	$c^2 = \dfrac{3 \times 2.0 \times 10^{23} \times 1.38 \times 10^{-23} \times (294 + 84)}{2.0 \times 10^{23} \times 40 \times 1.66 \times 10^{-27}}$	C1
	$c^2 = 236\,000$	
	$c = 485$	

$ratio \left(= \dfrac{485}{430} \right) = 1.1$		A1
OR $v \propto \sqrt{T}$ or $v^2 \propto T$		(C1)
$ratio = \sqrt{\dfrac{273 + 21 + 84}{273 + 21}}$ or $\sqrt{\dfrac{378}{294}}$ ratio = **1.1**		(A1)

10 (a)	$n = 110 / 0.032$ or $110000 / 32$ or 3440	C1
	$pV = nRT$	C1
	$T = (1.0 \times 10^5 \times 85) / (8.31 \times (110 / 0.032)) = 300\,K$	A1
(b)	$E = mc\Delta\theta$	C1
	$= 110 \times 0.66 \times 50$	
	$= 3600\,J$	A1
(c)	Any 3 from: • molecule collides with wall • momentum of molecule changes during collision (with wall) • force on molecule so force on wall • many forces act over surface area of container exerting a pressure	B3
(d)	$KE \propto T$	C1
	$v \propto \sqrt{T}$	
	ratio $= \sqrt{(350 / 300)}$	A1
	$= 1.1$	

11	(a)	$p: Nm/V$	B1
		⅓: molecules move in three dimensions (not one) so ⅓ in any (one) direction	B1
		$<c^2>$: molecules have different speeds so take average	M1
		of (speed)^2	A1
	(b)	$pV = NkT$	C1
		$N = (3.0 \times 10^5 \times 6.0 \times 10^{-3})/(1.38 \times 10^{-23} \times 290)$	C1
		$= 4.5 \times 10^{23}$	C1
		mass $= 20.7/(4.5 \times 10^{23})$	A1
		$= 4.6 \times 10^{-23}$ g	

12	(a)	total potential energy and kinetic energy (of molecules/atoms)	M1
		reference to <u>random</u> motion of molecules/atoms	A1
	(b)	(in ideal gas,) no intermolecular forces	B1
		no potential energy (so change in kinetic energy is change in internal energy)	B1
	(c)	(random) potential energy of molecules does not change	M1
		(random) kinetic energy of molecules does not change	M1
		so internal energy does not change	A1
		or	
		decrease in total potential energy = gain in total kinetic energy	(M1)
		no external energy supplied	(M1)
		so internal energy does not change	(A1)
		or	
		no compression (of ball) so no work done on the ball	(M1)
		no resistive forces so no heating of the ball	(M1)
		so internal energy does not change	(A1)

13	(a)(i)	gas obeys formula pV/T = constant	M1
		symbols V and T explained	A1
	(a)(ii)	mean-square-speed (of atoms / molecules)	B1
	(b)(i)	use of $T = 393$	C1
		$pV = nRT$	C1
		$2.4 \times 10^5 \times 6.8 \times 10^{-3} = n \times 8.31 \times 393$ and $N = n \times 6.02 \times 10^{23} = 3.0 \times 10^{23}$	A1
		or $pV = NkT$	(C1)
		$2.4 \times 10^5 \times 6.8 \times 10^{-3} = N \times 1.38 \times 10^{-23} \times 393$ hence $N = 3.0 \times 10^{23}$	(A1)
	(b)(ii)	volume of one atom $= 4/3\pi r^3$	C1
		volume occupied $= 3.0 \times 10^{23} \times 4/3 \times \pi \times (3.2 \times 10^{-11})^3$	A1
		$= 4 \times 10^{-8}$ m^3	
	(b)(iii)	assumption: volume of atoms negligible compared to volume of container / cylinder	B1
		4×10^{-8} (m^3) << 6.8×10^{-3} (m^3) so yes	B1

14	(a)	(total volume of molecules is) negligible	M1
		compared with volume occupied by the gas	A1
	(b)(i)	$pV = NkT$	C1
		$4.60 \times 10^5 \times 2.40 \times 10^{-2} = N \times 1.38 \times 10^{-23} \times (273 + 23)$	C1
		or	
		$pV = nRT$	(C1)
		$4.60 \times 10^5 \times 2.40 \times 10^{-2} = n \times 8.31 \times (273 + 23)$	(C1)
		$n = 4.49$ (mol)	
		$N = nN_A$	
		$= 4.49 \times 6.02 \times 10^{23}$	
		$N = 2.7 \times 10^{24}$	A1
	(b)(ii)	volume of one atom $= d^3 \ (= 2.7 \times 10^{-29} \text{ m}^3)$	C1
		volume of all atoms $= 2.7 \times 10^{-29} \times 2.7 \times 10^{24}$	C1
		$= 7 \times 10^{-5} \text{ m}^3$	A1
		or	
		volume of one atom $= (4/3)\pi r^3 \ (= 1.41 \times 10^{-29} \text{ m}^3)$	(C1)
		volume of all atoms $= 2.7 \times 10^{24} \times 1.41 \times 10^{-29}$	(C1)
		$= 4 \times 10^{-5} \text{ m}^3$	(A1)
	(c)	numerical comparison between answer to **(b)(ii)** and 2.4×10^{-2} (m³) showing **(b)(ii)** is <u>much</u> less than 2.4×10^{-2} (m³)	B1

15	(a)(i)	specks of light moving haphazardly	B1
	(a)(ii)	(gas) molecules collide with (smoke) particles **or** random motion of the (gas) molecules	M1
		<u>causes</u> the (haphazard) motion of the smoke particles **or** <u>causes</u> the smoke particles to change direction	A1
	(b)(i)	$pV = nRT$	C1
		$n = (3.51 \times 10^5 \times 2.40 \times 10^{-3}) / (8.31 \times 290)$ **or** $n = (3.75 \times 10^5 \times 2.40 \times 10^{-3}) / (8.31 \times 310)$	C1
		or	
		$pV = NkT$	(C1)
		$n = (3.51 \times 10^5 \times 2.40 \times 10^{-3}) / (1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 290)$ **or** $n = (3.75 \times 10^5 \times 2.40 \times 10^{-3}) / (1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 310)$	(C1)
		$n = 0.350$ mol **or** 0.349 mol	A1
	(b)(ii)	energy transfer $= (0.349$ **or** $0.35) \times 12.5 \times (310 - 290)$	C1
		$= 87.3 \text{ J}$ **or** 87.5 J	A1
	(c)(i)	zero	A1
	(c)(ii)	87.3 J **or** 87.5 J	A1
		increase	B1

16	(a)(i)	1. energy transfer <u>to</u> the system by heating	B1
		2. (external) work done <u>on</u> the system	B1
	(a)(ii)	<u>decrease</u> in internal energy	B1
	(b)(i)	no change (in internal energy)	B1
		(because) no change in temperature	B1
	(b)(ii)	work done $= p\Delta V$	C1
		$= (-)1.6 \times 10^5 \times (2.4 - 0.87) \times 10^{-3}$	
		$= (-)240$ J	A1
	(b)(iii)	first row all correct (0, 480, 480)	A1
		second row all correct (−1100, 0, −1100)	A1
		final column of third row calculated correctly from the two values above it, so that the final column adds up to 0	A1
		second column in final row correct, with correct negative sign **and** first column in final row calculated correctly so that it adds to the second column to give the third column (fully correct table is:	A1

0	480	480
−1100	0	−1100
860	−240	620

)

17 (a)

(-1 for each error or omission) .... B2   [2]

(b) heat lost by liquid gold $= 0.95m \times 129 \times \Delta T$ C1
heat gained (silver) $= 0.05m \times 235 \times (1340 - 300) + 0.05m \times 105\,000$ ..C1, C1
$122.5m\Delta T = 17\,470m$
$\Delta T = 143$ K C1
temperature $= 143 + 1340 = 1483$ K .... A1   [5]

(c) e.g. thermocouple/resistance thermometer .... B1   [1]

18 (a) (i) N: (total) number of molecules   B1   [1]

(ii) $<c^2>$: mean square speed/velocity   B1   [1]

(b) $pV = \frac{1}{3}Nm<c^2> = NkT$
(mean) kinetic energy $= \frac{1}{2} m<c^2>$ C1
algebra clear leading to $\frac{1}{2} m<c^2> = (3/2)kT$ A1   [2]

(c) (i) *either*   energy required $= (3/2) \times 1.38 \times 10^{-23} \times 1.0 \times 6.02 \times 10^{23}$ C1
                     $= 12.5$ J (*12J if 2 s.f.*)   A1   [2]
     or   energy $= (3/2) \times 8.31 \times 1.0$ (C1)
                 $= 12.5$ J   (A1)

(ii) energy is needed to push back atmosphere/do work against atmosphere   M1
so total energy required is greater   A1   [2]

19	(a)(i)	direction or rate of transfer of (thermal) energy **or** (if different,) not in thermal equilibrium/energy is transferred	B1
	(a)(ii)	uses a property (of a substance) that changes with temperature	B1
	5(b)	• temperature scale assumes linear change of property with temperature • physical properties may not vary linearly with temperature • agrees only at fixed points *Any 2 points.*	B2
	(c)(i)	$Pt = mc(\Delta)\theta$	C1
		$95 \times 6 \times 60 = 0.670 \times 910 \times \Delta\theta$	M1
		$\Delta\theta = 56\,°C$ so final temperature = 56 + 24 = 80 °C	A1
		or	
		$95 \times 6 \times 60 = 0.67 \times 910 \times (\theta - 24)$	(M1)
		so final temperature or $\theta = 80\,°C$	(A1)
	(c)(ii)	1. sketch: straight line from (0,24) to (6,80)	B1
		2. temperature drop due to energy loss = (80 − 64) = 16 °C	C1
		energy loss = $0.670 \times 910 \times (80 - 64) = 9800\,J$	A1
		or	
		energy to raise temperature to 64 °C = $0.670 \times 910 \times (64 - 24)$	(C1)
		= 24400 J	(A1)
		loss = $(95 \times 6 \times 60) - 24400 = 9800\,J$	

Q20

	a)	(thermal) energy per unit mass (to change temperature)	B1
		(thermal) energy per unit change in temperature	B1
2(b)(i)		work done = $p\Delta V$	A1
		$= (2.0 \times 10^5) \times (0.063 - 0.038) = 5000\,J$	
2(b)(ii)		gas is expanding (against external pressure)	B1
		gas does work / work is done by gas, so (work done on gas is) negative	B1
2(b)(iii)		$\Delta U = q + W$	C1
		$7600 = q + (-5000)$	A1
		$q = 12\,600\,J$	
2(b)(iv)		specific heat capacity = $q / m\Delta T$	C1
		$= 12600 / (0.35 \times 56)$	
		$= 640\,J\,kg^{-1}\,K^{-1}$	A1
2(c)		same gain in internal energy so same temperature rise	B1
		no change in volume so no work done **or** no work done so less thermal energy needed (for same change in internal energy)	B1
		less thermal energy needed (for same temperature change) so lower specific heat capacity	B1

PHYSICS WITH
CYRUS

Q21 (i)	N:	number of molecules (of the gas)	B1
	m:	mass of one molecule (of the gas)	B1
	$<c^2>$:	mean square speed (of molecules)	B1
3(a)(ii)	$pV = NkT$		M1
	$NkT = \frac{1}{3}Nm<c^2>$ **and** $E_K = \frac{1}{2}m<c^2>$ leading to $E_K = (3/2)kT$		A1
3(b)	$\frac{1}{2} \times 3.34 \times 10^{-27} \times 9300^2 = (3/2) \times 1.38 \times 10^{-23} \times T$		C1
	$T = 6980\,K$		A1
3(d)	(very high pressure so) molecules are (very) close together (*not just 'nearer'*)		B1
	forces between molecules are not negligible **or** volume of molecules not negligible compared with gas volume		B1

Q22 a)	sum of potential energy and kinetic energy (of particles)	B1
	(total) energy of random motion of particles	B1
3(b)(i)	no thermal energy <u>transferred</u>	B1
	work is done on the spring (increasing the potential energy of particles)	M1
	so internal energy increases	A1
3(b)(ii)	thermal energy transferred to water	B1
	work is done by water (expanding against atmosphere as it vaporises)	B1
	more thermal energy transferred than work done so internal energy increases	B1

Q23 a)	total kinetic energy associated with random motion of molecules	M1
	plus total potential energy (of molecules) but potential energy is zero	A1
2(b)(i)	$W = p\Delta V$	C1
	$= 1.01 \times 10^5 \times 5.20 \times 10^{-5}$ $= (+)5.25\,J$	A1
2(b)(ii)	$V \propto T$ or $V/T = $ constant	C1
	$1.24 / (273 + 20) = (1.24 + 0.520) / T$	A1
	$T = 416\,K$	
2(b)(iii)	$c = Q / m\Delta T$	C1
	$= 960 / (0.016 \times (416 - 293))$ $= 490\,J\,kg^{-1}\,K^{-1}$	A1
2(c)	no change in volume so no work is done (by the gas)	B1
	(same temperature change so) same change in internal energy	B1
	less thermal energy needs to be supplied so c is less	B1

Q24

(a)(i)	gas for which $pV \propto T$		M1
	where T is thermodynamic temperature		A1
3(a)(ii)	no intermolecular forces		B1
	(so) potential energy is zero		B1
3(b)(i)	$pV = NkT$		C1
	$N = (2.0 \times 10^5 \times 0.26)/(1.38 \times 10^{-23} \times 290)$		A1
	$\quad = 1.3 \times 10^{25}$		
3(b)(ii)	$E_K = (3/2)\,kT$		C1
	$E_K = (3/2) \times 1.38 \times 10^{-23} \times 290$		A1
	$\quad = 6.0 \times 10^{-21}$ J		
3(b)(iii)	internal energy = total KE + PE of molecules **or** PE = 0 so internal energy = total KE of molecules		B1
	internal energy = $1.3 \times 10^{25} \times 6.0 \times 10^{-21}$		A1
	$\quad\quad = 7.8 \times 10^4$ J		
3(c)	straight line with positive gradient		B1
	line passing through the origin		B1

Q25

(a)	(if in thermal contact) no <u>net transfer</u> of (thermal) energy (between them)		B1
2(b)(i)	$pV = nRT$		C1
	$T = (1.20 \times 10^5 \times 0.0260)/(0.740 \times 8.31)$		M1
	$\quad (= 507$ K$)$		
	temperature = 507 – 273 = 234 °C		A1
2(b)(ii)	thermal equilibrium <u>so</u> temperatures (of X and Y) are equal		B1
	$pV = NkT$		C1
	$N = (2.90 \times 10^5 \times 0.0430)/(1.38 \times 10^{-23} \times 507)$		A1
	$\quad = 1.78 \times 10^{24}$		
2(b)(iii)	• (molecular) kinetic energy is proportional to temperature **or** kinetic energy (of molecules) is same in both cylinders • kinetic energy proportional to mass × mean-square speed **or** temperature proportional to mass × mean-square speed **or** r.m.s. speed proportional to √(temperature / mass) • mean-square speed inversely proportional to mass **or** r.m.s. speed inversely proportional to √(mass) *Any two bulleted points, 1 mark each*		B2
	r.m.s. speed (of molecules) in X is half r.m.s. speed (of molecules) in Y		B1

Q26 a)	sum of potential energy and kinetic energy	B1
	(total) energy of random motion of particles	B1
3(b)(i)	no change in separation so no change in (molecular) potential energy	B1
	temperature increases so kinetic energy (of molecules) increases	B1
	kinetic energy increases and potential energy unchanged, so internal energy increases	B1
3(b)(ii)	temperature constant so no change in (molecular) kinetic energy	B1
	separation increases so potential energy (of molecules) increases	B1
	potential energy increases and kinetic energy unchanged, so internal energy increases	B1