16 Thermodynamics Therm~ heat, dynamics — motion with reference to force,

An understanding of energy from Cambridge IGCSE/O Level Physics or equivalent is assumed.

16.1 Internal energy

Candidates should be able to:

1 understand that internal energy is determined by the state of the system and that it can be expressed as the sum of a random distribution of kinetic and potential energies associated with the molecules of a system

2 relate a rise in temperature of an object to an increase in its internal energy

16.2 The first law of thermodynamics

Candidates should be able to:

1 recall and use $W = p\Delta V$ for the work done when the volume of a gas changes at constant pressure and understand the difference between the work done by the gas and the work done on the gas

2 recall and use the first law of thermodynamics $\Delta U = q + W$ expressed in terms of the increase in internal energy, the heating of the system (energy transferred to the system by heating) and the work done on the system

INTERNAL ENERGY:-

Def. Microscopic sum of random distribution of K·E and P·E of particles of matter.

Symbol: U

Formula:

Solid: $U = \underset{K·E}{Vibrational} + \underset{to\ bonding}{Electric\ P·E\ due}$

Fluids: $U = \underset{K·E}{Translatory} + \underset{to\ bonding}{Electric\ P·E\ due}$

Note:

(1) For Ideal gas, no bonding/no cohesive force
So no Electric P·E.
$$U = K·E \text{ of particles}$$

Solid — +Q (Fusion) / –Q (Freezing) — Liquid
$\Delta T = 0$
$\Delta E_K = 0$
Solid — +Q (Sublimation) / –Q (Deposition) — Gas
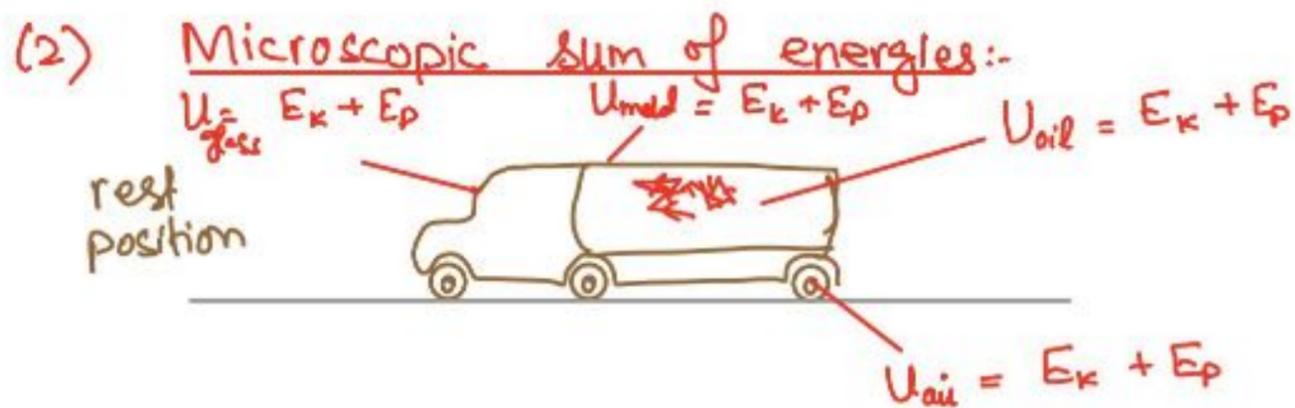Liquid — +Q (Vaporisation) / –Q (Condensation) — Gas

(1) If $Q = +ve$, $\Delta E_p \uparrow$, $\Delta U \uparrow$

(2) If $Q = -ve$, $\Delta E_p \downarrow$, $\Delta U \downarrow$

Q)

ice at $0°C$

water at $0°C$
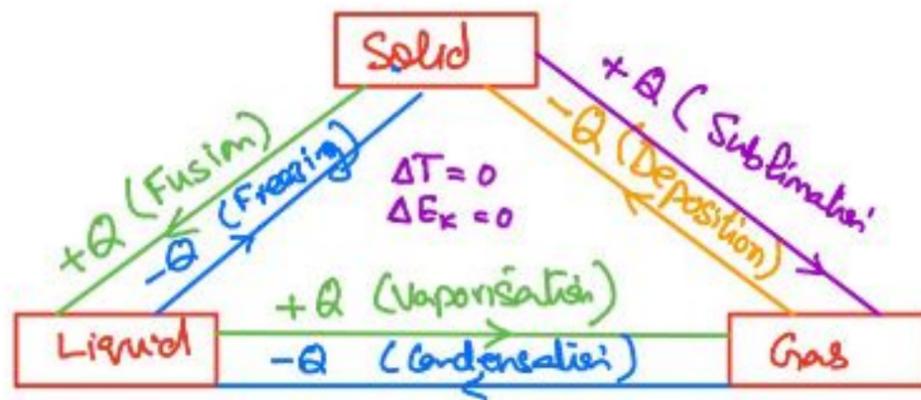
Pepsi — Student A
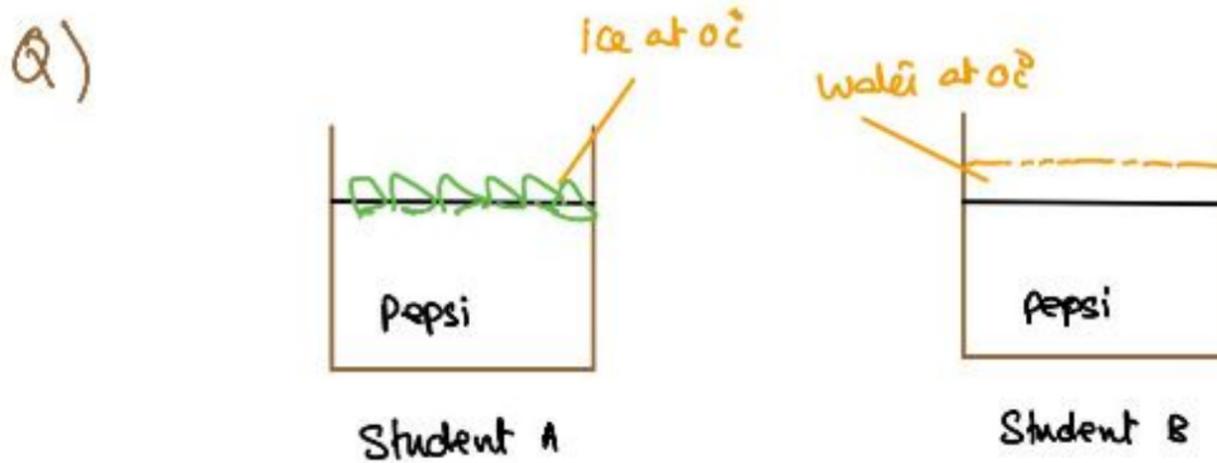
Pepsi — Student B

Δ Temperature of Student (A < B) because
of lesser internal energy of ice. Since ice absorbs
energy from pepsi in order to melt resulting a
decrease in the temp. of pepsi in lesser time.

Q) Why the burn of steam at $100°C$ is more
severe than boiling water also at $100°C$.

Electric E_p of (steam particles > boiling water)
So internal energy of (steam > boiling water)
but their K.E is same due to constant/same
temperature.

(2) <u>Microscopic sum of energies:-</u>

$U_{glass} = E_K + E_P$ $U_{metal} = E_K + E_P$ $U_{oil} = E_K + E_P$

rest position

$U_{air} = E_K + E_P$

<u>Dependance</u> : $\Delta U = \Delta E_K + \Delta E_P$

$(\Delta U) \uparrow$ if
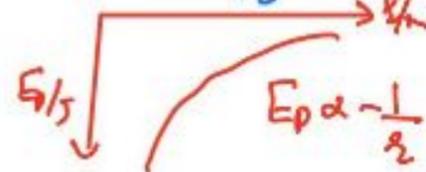
(a) $(\Delta E_K) \uparrow$ and $\Delta E_P = 0$ if

  (i) Heat is provided to increase Temperature.

$$\langle E_K \rangle = \frac{3}{2} K T$$
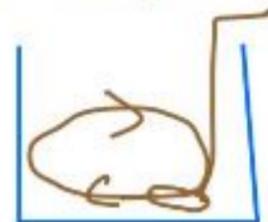$$\langle E_T \rangle \propto T$$

$$E_P = -\frac{1}{4\pi\varepsilon_0}\left(\frac{Q_+ Q_-}{r}\right)$$

$$E_P \propto -\frac{Q_+ Q_-}{r}$$

$E_P \propto -\frac{1}{r}$

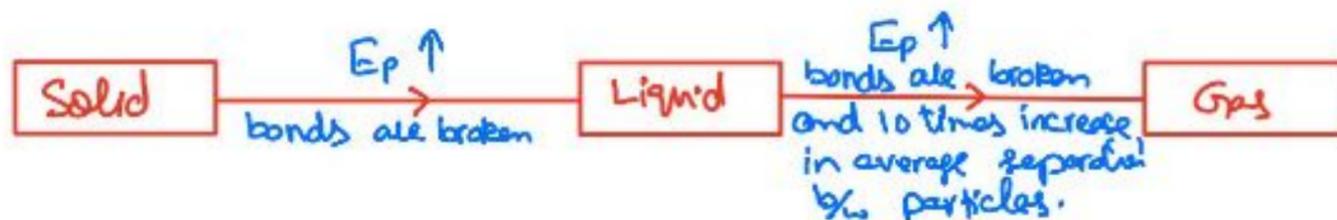 (ii) Work is done <u>ON</u> matter i.e hammering a solid, shake/stir a liquid or compress a gas.

$$E_K = \frac{1}{2} m \omega^2 (x_0^2 - x^2)$$

(b) $(\Delta E_P) \uparrow$ and $\Delta E_K = 0$ if

State of matter changes from solid to liquid to gas due to breaking of bonds and/or increase in average separation b/w particles.

| Solid | $\xrightarrow[\text{bonds are broken}]{E_P \uparrow}$ | Liquid | $\xrightarrow[\substack{\text{and 10 times increase}\\ \text{in average separation}\\ \text{b/w particles.}}]{\substack{E_P \uparrow \\ \text{bonds are broken}}}$ | Gas |

First law of Thermodynamics :-

Statement :- Increase in internal energy of a system is equal to the heat supplied to it and the amount of work done on it.

Mathematical form:

$$\Delta U = \Delta Q + \Delta W$$

Here ΔU - Increase of internal energy
ΔQ - Heat supplied to system.
ΔW - Work done ON the system.

Sign Convention :-

ΔU : +ve if internal energy of system increases.
ΔU : -ve if internal energy of system decreases.
ΔQ : +ve if Heat supplied / going into system
ΔQ : -ve if Heat is released by the system
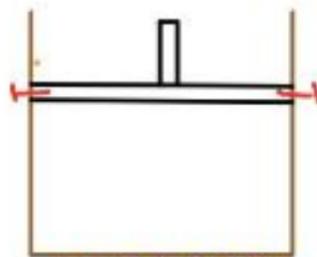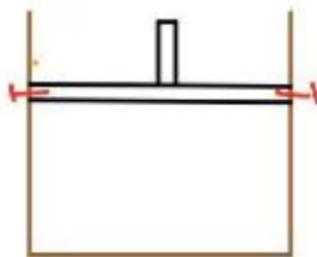ΔW : +ve if Work is done ON the system.
ΔW : -ve if Work done BY the system.

Applications of first law of Thermodynamics :

(a) Isovolumetric heating. Heating of a gas with no change in its volume

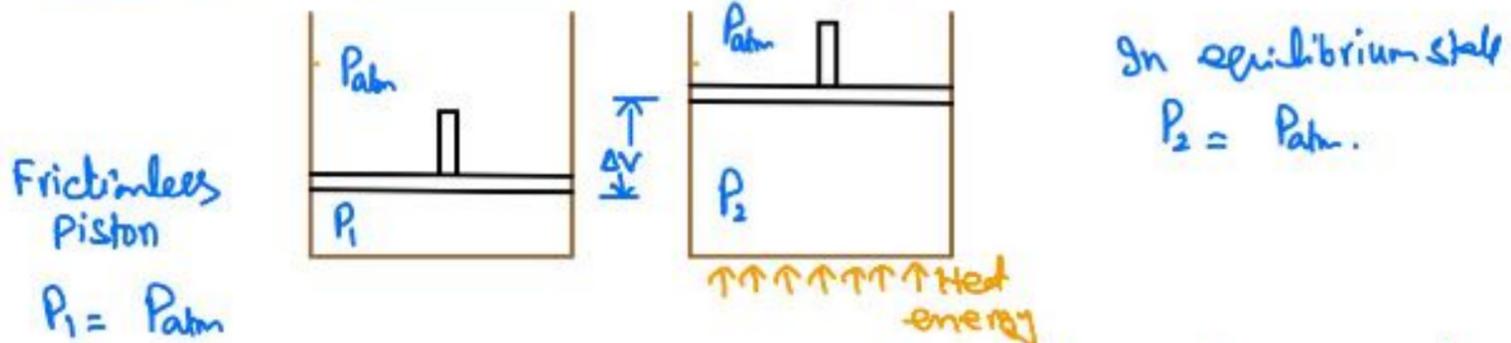Constant   volume

Fixed piston

↑↑↑↑↑↑ Heat energy

$\Delta U =$ +ve internal energy increases

ΔQ +ve

ΔW 0 because $\Delta W = P\Delta V$ fixed volume

(b) <u>Isobaric heating</u>: Heating of a gas at constant pressure.

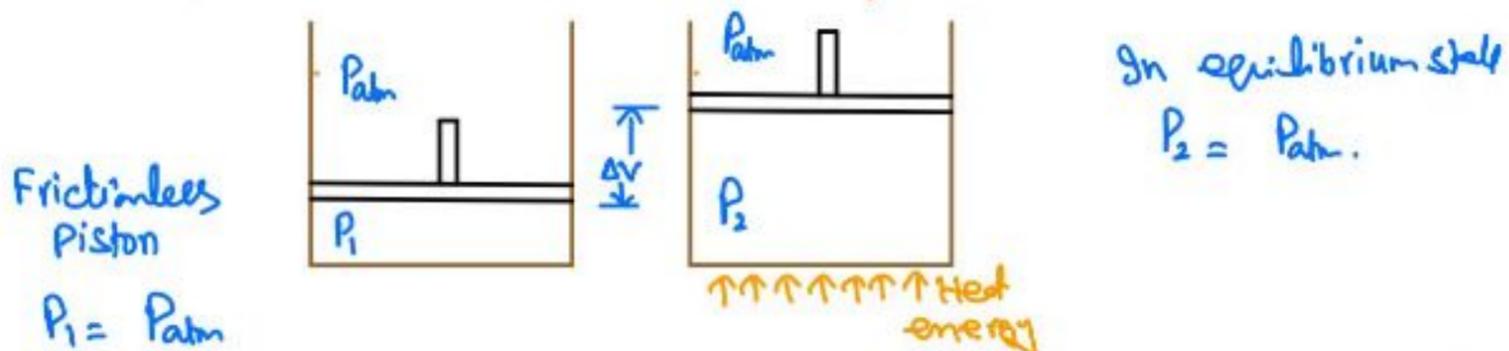Example:- Condition: $\longrightarrow$ temperature is constant

Frictionless Piston
$P_1 = P_{atm}$

In equilibrium state
$P_2 = P_{atm}$.

$P_1 = P_2$ i.e $\Delta P = P_1 - P_2 = 0$ (no change of pressure)

$$\Delta U = \Delta Q + \Delta W$$
Zero   +ve   −ve

Example:- Condition $\longrightarrow$ temperature increases

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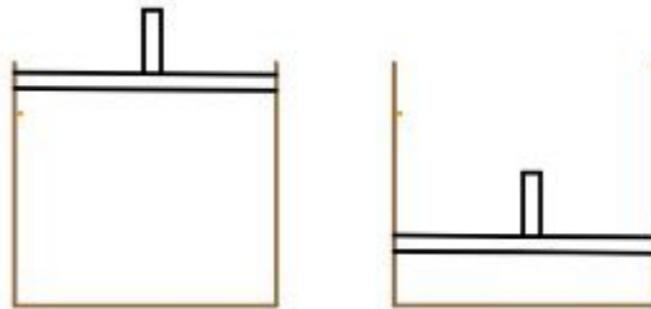$$\Delta U = \Delta Q + \Delta W$$
+ve   +ve   −ve

(c) <u>Isothermal Compression</u>:- Compression of a gas at constant temperature.

$$\Delta U = \Delta Q + \Delta W$$
0   −ve   +ve

Heat is released by gas to keep its temperature constant.
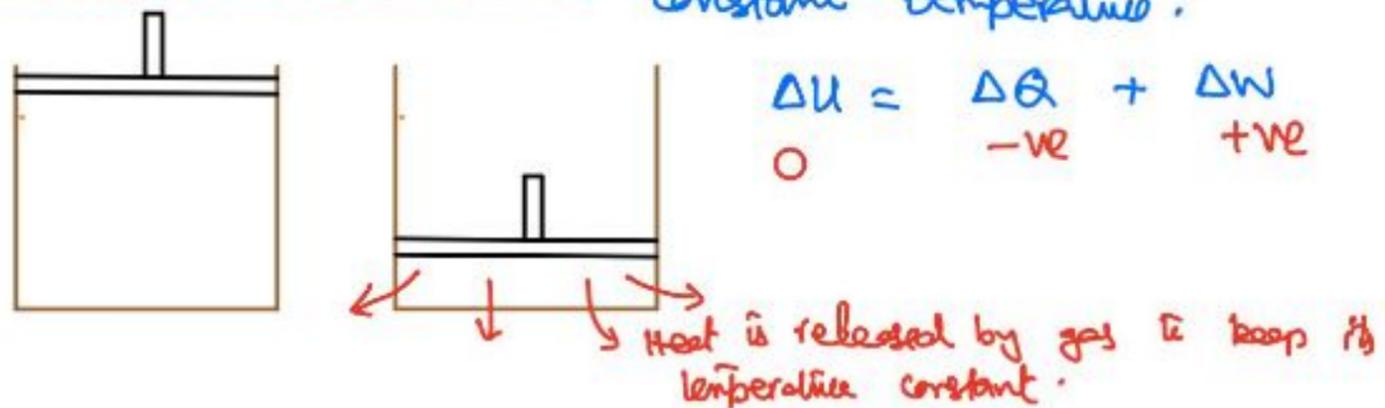
(d) <u>Adiabatic compression</u>:- Compression of a gas with no heat can enter or leave the system.

$$\Delta U = \Delta Q + \Delta W$$
+ve   0   +ve

(e) <u>Boiling water</u>:   [4]

Bunsen flame

$$\Delta U = \Delta Q + \Delta W$$
+ve   +ve   -ve
Heat is   volume of bubble increases
going into water   as it rises up

$$\Delta U = \Delta E_K + \Delta E_P$$
+ve   0   +ve
because temp is   bonds are broken and separation
constant   b/w molecules increases by 10 times
$\langle E_K \rangle \propto T$

1. Some water in a saucepan is boiling.

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(a) Explain why

(i) external work is done by the boiling water,

$$W = P\Delta V$$
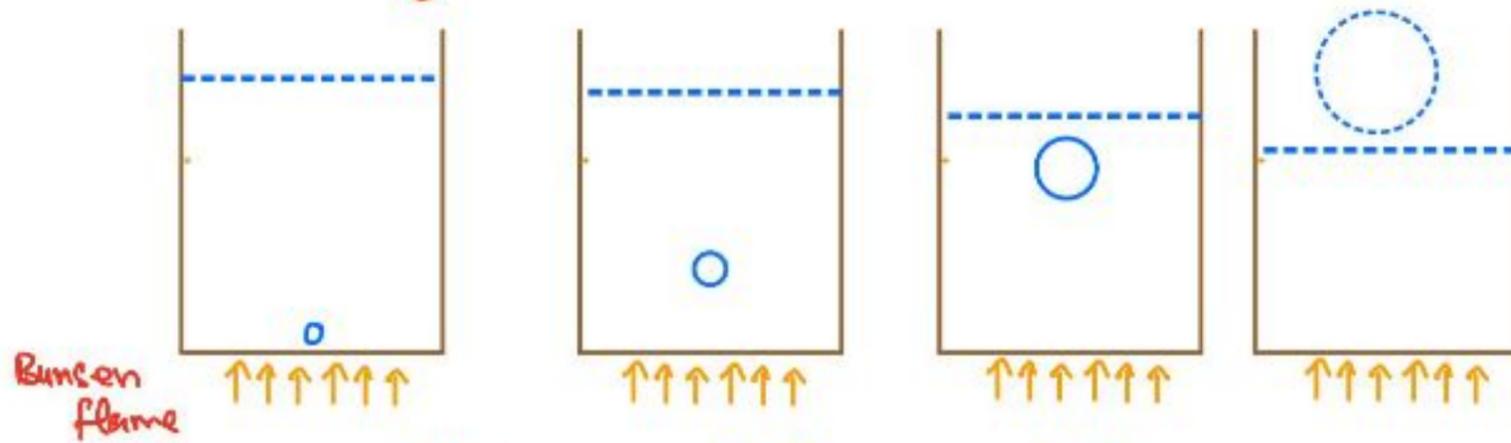
Since volume of bubble increases as it rise up. So work is done by boiling water on atmosphere.

(ii) there is a change in the internal energy as water changes to steam.

$$\Delta U = \Delta E_k + \Delta E_p$$

$(\Delta E_k \propto T) =$ Constant as temperature remain constant

$(\Delta E_p) \uparrow$ as bonds are broken and 10 times increase in average separation b/w particles. Hence $(\Delta U) \uparrow$ [5]

(b) By reference to the first law of thermodynamics and your answers in **(a)**, show that thermal energy must be supplied to the water during the boiling process.

$$\Delta U = \Delta Q + \Delta W$$
$$\text{+ve} \quad \text{+ve} \quad \text{-ve}$$

So $\Delta Q = $+ve ie heat must be supplied to increase internal energy. [2]

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

water freezing at constant temperature $\Delta E_p \downarrow$ $\Delta u \downarrow$, $\Delta E_k = 0$,	decrease
a stone falling under gravity in a vacuum	remain constant
water evaporating at constant temperature $\Delta E_k = 0$, $\Delta E_p \uparrow$, $\Delta u \uparrow$	increase
stretching a wire at constant temperature $\Delta E_k = 0$, $\Delta E_p \uparrow$	increase

3 The volume of some air, assumed to be an ideal gas, in the cylinder of a gas engine is 540 cm³ at a pressure of 1.1×10^5 Pa and a temperature of $27°C$. The air is suddenly compressed, so that no thermal energy enters or leaves the gas, to a volume of 30 cm³. The pressure rises to 6.5×10^6 Pa.

(a) Determine the temperature of gas after compression.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow \frac{(1.1\times10^5)(540)}{27+273.15} = \frac{(6.5\times10^6)(30)}{T_2} \Rightarrow T_2 = \underline{\quad}$$

P temperature: .... K [3]

(b) (i) State and explain the first law of thermodynamics.

$$\Delta U = \Delta Q + \Delta W$$

ΔU - Increase of Internal energy,
ΔQ - Heat supplied to system
ΔW - Work done on the system [2]

(ii) Use the law to explain why the temperature of the air changed during the compression.

$\Delta W = $+ve as work is done on gas
$\Delta Q = 0$ as no heat can enter or leave the system
$\Delta U = $+ve ie internal energy of system increases.
$\quad \hookrightarrow \Delta U = (\Delta E_k \propto T) + (\Delta E_p = 0)$. So $(\Delta E_k \propto T) \uparrow$ [4]

4. The first law of thermodynamics may be expressed in the form

$\Delta U = q + w,$

Where U is the internal energy of the system,

$\quad$ ΔU is the increase in internal energy,

$\quad$ q is the thermal energy supplied to the system,

$\quad$ w is the work done on the system.

Complete following table for each of the processes shown. Write down the symbol '+' for an increase, the symbol '-' to indicate a decrease and the symbol 'o' for no change, as appropriate.

	U	q	w
The compression of an ideal gas at constant temperature	O	−	+
The heating of a solid with no expansion	+	+	O
The melting of ice at $0°C$ to give water at $0°C$ (Note: ice is less dense than water)	+	+	+

[6]

$V\uparrow \quad V\downarrow$

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:

$+q$ ...Heat energy supplied to the system...................

....

$+w$. ...Work done ON the system.........................

....

[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.
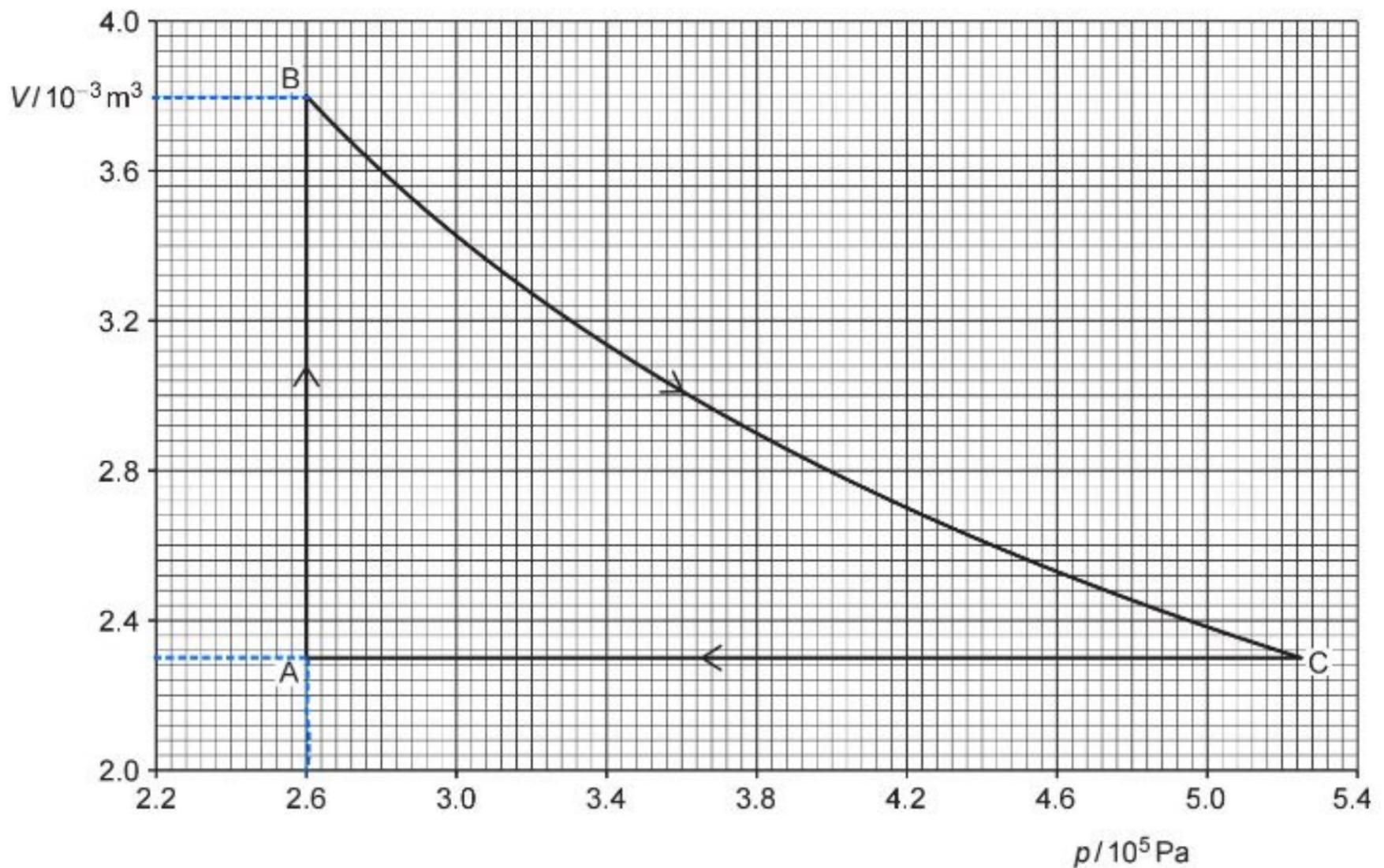

Fig. 2.1

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.

$$W = P\Delta V$$
$$= (2.6 \times 10^5)(3.8 - 2.8)\,10^{-3}$$
$$= 390\,J$$

[1]

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

For an Ideal gas, $\Delta E_p = 0$ and $\Delta U = (\Delta E_k \propto T)$
Here $\Delta T = 0$ as gas return to its initial condition.
So $\Delta U = 0$

[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	+1370	−390	+980
B to C	0	+550	+550
C to A	−1530	0	−1530

[4]

[Total: 9]

Handwritten annotations:

Diagram: triangle with vertices A (bottom left), B (top), C (bottom right). +Q =1370, −W = 390J, θ = 0, +W = 550J

$\Delta U = \Delta Q + \Delta W$
$= 1370 + (-390)$
$= 980\,J$

$\Delta U = 0 + 550$
$= 550\,J$

Total internal energy of system is zero.

because volume is constant by $W = P\Delta V$

$\Delta U = \Delta Q + \Delta W$
$-1530 = \Delta Q + 0$
$\Delta Q = -1530\,J$