

Thermodynamics

A-Level Physics 9702 · Topic 16 revision notes · A2

Internal energy, work done by and on a gas, and the first law of thermodynamics as energy conservation for heating and work.

4 definitions to learn word for word, 5 equations in their own column, 6 diagrams and graphs. Read it, cover it, test yourself.

1. 16.1 Internal energy.
2. 16.2a Work done by and on a gas
3. 16.2b The first law of thermodynamics

Definitions (mark-scheme wording) Equations Exam traps

16.1 Internal energy

Definitions

Internal energy: the sum of a random distribution of kinetic and potential energies of the molecules in a system.

Key points

- ✓ Internal energy is determined by the **state** of the system, not by how it reached that state.
- ✓ A rise in temperature raises the mean **random kinetic energy** of the molecules, so internal energy increases.
- ✓ During a change of state at constant temperature, the **potential energy** part of U changes, not the kinetic part.
- ✓ Ideal gas: no intermolecular forces, so **potential energy = 0** and U is kinetic energy only.
- ✓ So for an ideal gas $U \propto T$: $\Delta U = 0$ whenever the temperature is unchanged.
- ✓ Monatomic ideal gas: $U = N \times (3/2)kT = (3/2)nRT$.

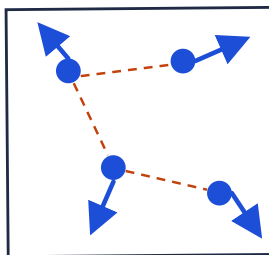
Equations

$$U = \sum E_k + \sum E_p$$

internal energy = total random kinetic + potential energy
J

$$U = (3/2)NkT$$

monatomic ideal gas only ($E_p = 0$)
J

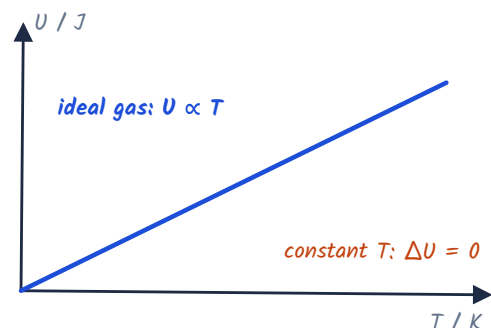


arrows: random kinetic energy

dashes: forces, potential energy

$$U = \sum E_k + \sum E_p$$

Internal energy: random kinetic energy (motion) plus potential energy (intermolecular forces).



Ideal gas: U depends on T alone (straight line through the origin in kelvin).

Watch out!

- ! For an ideal gas U depends on **temperature alone**; an isothermal change has $\Delta U = 0$.
- ! Internal energy is **random** energy; the kinetic energy of the whole container moving does not count.

16.2a Work done by and on a gas

Definitions

Work done by a gas: the work done when a gas expands against an external pressure; at constant pressure it equals $p\Delta V$.

Work done on a gas: the work done by the surroundings when the gas is compressed.

Equations

$$W = p\Delta V$$

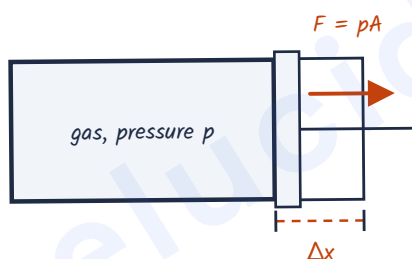
work done at constant pressure
J

$$F = pA$$

force of the gas on the piston
N

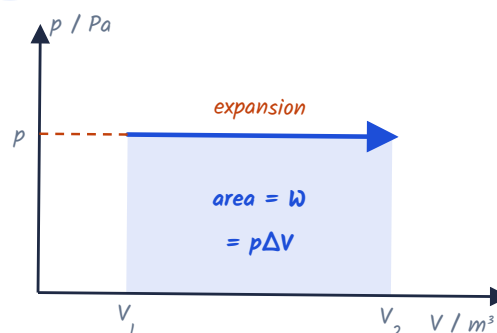
Key points

- ✓ Gas at pressure p pushes a piston of area A with force $F = pA$; moving Δx gives $W = pA\Delta x = p\Delta V$.
- ✓ **Expansion:** the gas does work on the surroundings. **Compression:** work is done on the gas.
- ✓ $W = p\Delta V$ holds only at **constant pressure**.
- ✓ In general, work done = **area under the p - V graph**.
- ✓ No volume change (rigid container) means **no work** is done.



$$W = F\Delta x = pA\Delta x = p\Delta V$$

A gas at pressure p pushes the piston out by Δx ; work done by the gas = $p\Delta V$.



Work done = area under the p - V graph (a rectangle $p\Delta V$ at constant pressure).

Watch out!

- ! Convert volumes to m^3 before using $W = p\Delta V$ ($1 \text{ cm}^3 = 10^{-6} \text{ m}^3$).
- ! Do not use $W = p\Delta V$ when the pressure changes; use the area under the p - V graph.

16.26 The first law of thermodynamics

Definitions

First law of thermodynamics: the increase in internal energy of a system is equal to the sum of the thermal energy supplied to the system and the work done on the system.

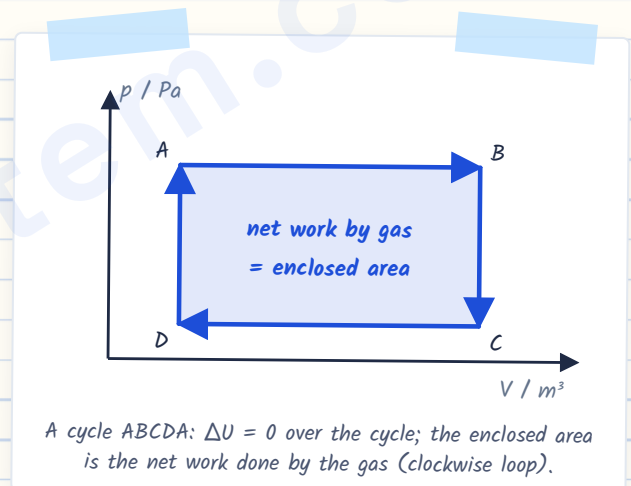
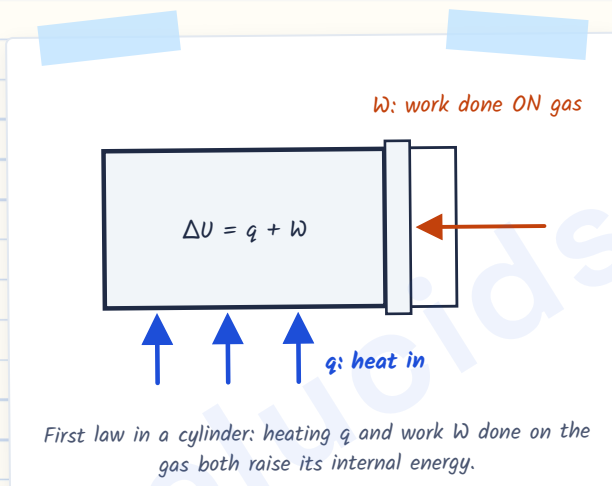
Equations

$$\Delta U = q + w$$

first law: increase in U = heat supplied to + work done on the gas
J

Key points

- ✓ Signs: q = thermal energy supplied **to** the gas; w = work done **on** the gas.
- ✓ Compression: w positive. Expansion: w **negative** (the gas does work).
- ✓ Heat lost by the gas: q negative. Temperature rises: ΔU positive.
- ✓ Isothermal (constant T , ideal gas): $\Delta U = 0$, so $q = -w$.
- ✓ Constant volume: $w = 0$, so $\Delta U = q$.
- ✓ No heat exchange (rapid or insulated): $q = 0$, so $\Delta U = w$; a gas compressed this way warms, one expanding cools.
- ✓ Complete cycle: back to the same state, so $\Delta U = 0$; net work = area enclosed by the loop.



Watch out!

- ! Get the sign of w right: an **expanding** gas has w negative in $\Delta U = q + w$.
- ! Isothermal does not mean $q = 0$; it means $\Delta U = 0$. It is the insulated (no heat flow) change that has $q = 0$.