Thermodynamics

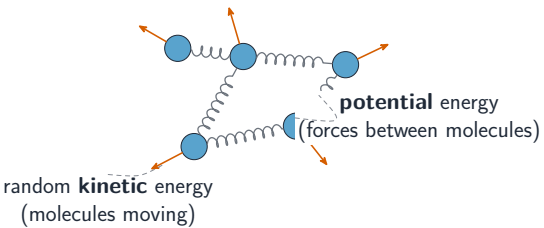
A2 Physics ▪ Topic 16

A-Level Physics

What we will cover

1. Internal energy
2. Work done on a gas
3. The sign convention
4. The first law $\Delta U = q + W$
5. The standard processes
6. Recap

Internal energy



steam turbine

Two things U is not

Not path-dependent

U depends only on the *state* – T, p, V, amount – never on how the gas got there.

Not bulk motion

a moving cylinder of gas has kinetic energy, but U counts only the *random* molecular motion.

Throw a sealed flask across the room and its U does not change – the molecules are no more agitated than before.

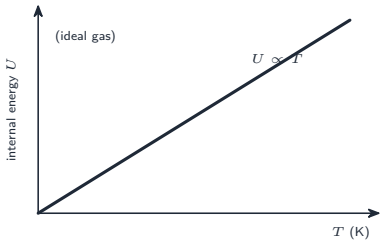
Temperature and internal energy

Each ideal-gas molecule carries $\frac{3}{2}kT$ on average (Topic 15), and there is no molecular PE, so

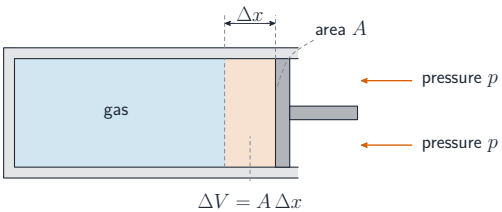
$$U = \tfrac{3}{2}NkT = \tfrac{3}{2}nRT$$

$U \propto T$: double the thermodynamic temperature, double the internal energy.

> This is exact only for an ideal gas. In a **phase change** 相变, U climbs while T stands still – the energy goes into potential, breaking bonds.



Work done by a gas

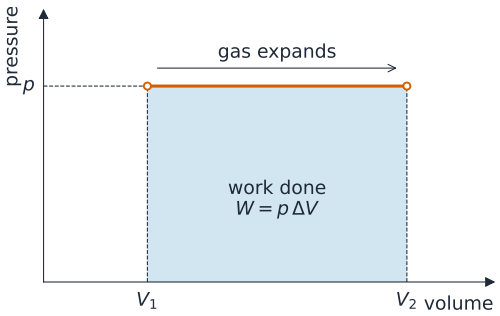


A gas pushing a **piston** 活塞 of area A out by Δx sweeps $\Delta V = A\Delta x$. At constant pressure the work is

$$W = p\,\Delta V$$

> It follows straight from $W = Fx$: the force is pA and the distance Δx, so $W = pA\Delta x = p\Delta V$.

Work is the area under a p–V graph

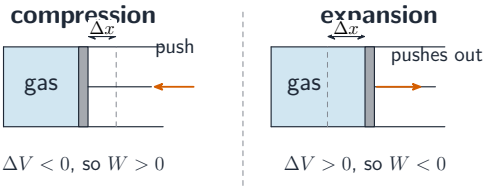


At constant pressure the area under the line is a rectangle, $p\,\Delta V$.

Gas at $1.0 \times 10^5\,\mathrm{Pa}$ expands from 2.0×10^{-3} to $5.0 \times 10^{-3}\,\mathrm{m}^3$. Find the work done *by* it.

$W = p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300\,\mathrm{J}$

The sign convention

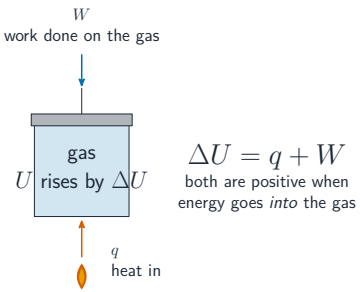


This syllabus writes $\Delta U = q + W$ with W the work done on the gas:

- compressed: $\Delta V < 0$, $W > 0$ – gas gains
- expands: $\Delta V > 0$, $W < 0$ – gas loses
- $\Delta V = 0$: no work at all

> Read the question's preposition. Work on the gas and work by the gas are the same size and opposite sign – most lost marks in this topic live here.

The first law of thermodynamics



Energy is conserved 能量守恒 when heat and work cross the boundary:

$$\Delta U = q + W$$

- q: energy added by heating
- W: work done on the gas

> Both terms are positive when energy goes in. That single rule fixes every sign in the topic.

Worked example – expanding while heated

A gas absorbs $500\,\mathrm{J}$ of heat while doing $200\,\mathrm{J}$ of work on its surroundings. Find ΔU.

The gas does the work, so the work done *on* it is negative: $W = -200\,\mathrm{J}$.

$$\Delta U = q + W = 500 + (-200) = 300\,\mathrm{J}$$

Translate the words before substituting: "does work on its surroundings" is the phrase that flips the sign.

Same ΔU, different routes

All heat, no work

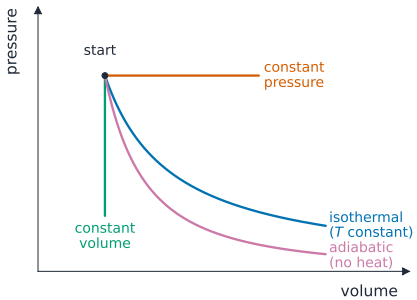
$\Delta U = q$ – heating a sealed rigid container

All work, no heat

$\Delta U = W$ – compressing an insulated cylinder

ΔU is fixed by the change of state (for an ideal gas, by ΔT alone). The mix of q and W that delivers it is up to the process.

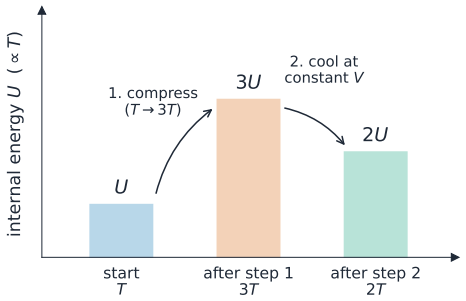
The four standard processes



Process	**fixed**	ΔU	**then**
Isothermal 等温	T	0	$q = -W$
Constant V	V	$\frac{3}{2}nR\Delta T$	$q = \Delta U$
Constant p	p	$\frac{3}{2}nR\Delta T$	$W = -p\Delta V$
Adiabatic 绝热	$q = 0$	W	—

Read every row off $\Delta U = q + W$. Isothermal: heat in comes straight back out as work. Adiabatic: the gas warms only because work is done on it.

Worked example – a two-step process



Gas at T with internal energy U: (1) compress to $3T$, work W done on it; (2) cool at constant volume to $2T$.

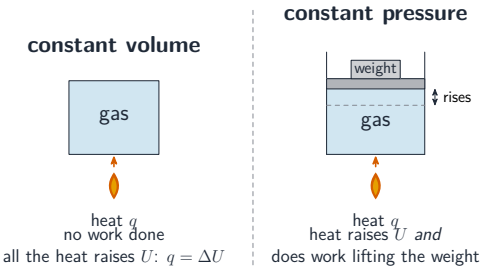
Since $U = \frac{3}{2}nRT$, U tracks T:

1. $U \to 3U$, so $\Delta U_1 = 2U$, $W_1 = +W$
$\Rightarrow q_1 = 2U - W$

2. $\Delta U_2 = -U$, $W_2 = 0 \Rightarrow q_2 = -U$ (out)

Check: total $\Delta U = 2U - U = U$, i.e. $T \to 2T$. Consistent.

Constant volume vs constant pressure



- constant V: no work, so all the heat raises $U - q = \frac{3}{2}nR\Delta T$
- constant p: the heat does two jobs – raise U *and* push the piston out

So heating a gas through the same ΔT costs more at constant pressure. Boiling water is the limit case: T holds still, U still climbs, and the vapour does expansion work – and $\Delta U = q + W$ holds throughout.

Topic 16 – key takeaways

1 Internal energy

random KE + molecular PE; a *state* function

2 Ideal gas

$U = \frac{3}{2}nRT$ – depends on T alone

3 Work

$W = p\Delta V$; *on* the gas is + when compressed

4 First law

$\Delta U = q + W$ – energy conservation for a gas

Check yourself

1. A gas is compressed. Sign of W in $\Delta U = q + W$?
2. Isothermal change: what is ΔU?
3. Adiabatic change: what is q?
4. Does a phase change raise U at constant T?

Answers **1.** positive **2.** zero **3.** zero **4.** yes – the PE rises