A LEVEL PHYSICS 9702 · A LEVEL · TOPIC 16 · ~4 MIN READ

Thermodynamics

Internal energy as the sum of random kinetic and potential energies of molecules, work done on or by a gas W = pΔV, and the first law of thermodynamics ΔU = q + W with its sign convention.

Internal energy | Random kinetic & potential energy | Temperature and internal energy | Work done W = pΔV | First law ΔU = q + W | Sign convention | Gas processes

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Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **Internal energy** is the sum of the random kinetic and potential energies of all the molecules. For an ideal gas there's no potential energy, so U depends only on T.
- **Work done on a gas when compressed at constant pressure:** W = pΔV (with ΔV the decrease in volume).
- **First law:** ΔU = q + W. ΔU is the increase in internal energy, q the energy supplied by heating, W the work done on the system.
- **Signs:** heat in → q positive; gas compressed → W positive; gas expands → W negative.

BY THE END YOU CAN

- Understand internal energy as the sum of a random distribution of molecular kinetic and potential energies.
- Relate a rise in temperature to an increase in the kinetic energy of the molecules.
- Use W = pΔV for work done when the volume of a gas changes at constant pressure.
- Recall and use the first law of thermodynamics, ΔU = q + W.

1 Internal energy

What it is

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

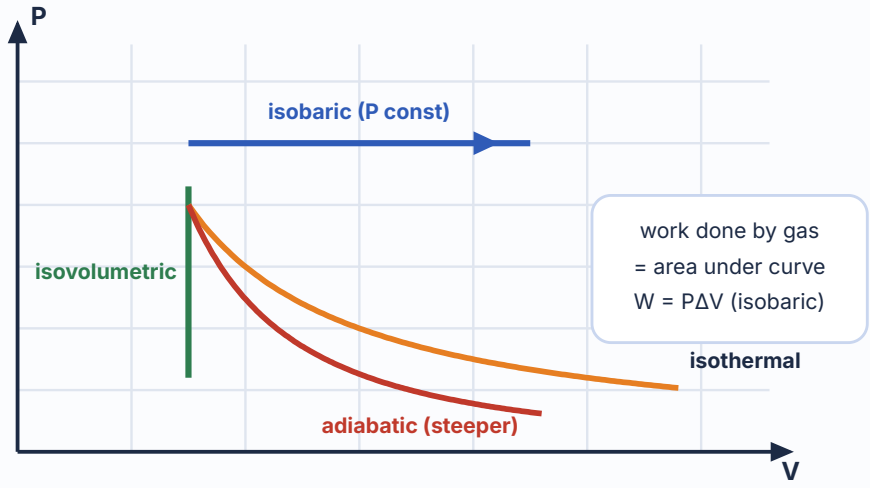
- **Raising the temperature** increases the mean kinetic energy of the molecules, so U increases.
- **Changing state** at constant temperature changes the potential energy (bonds), so U changes even though T doesn't.
- **Ideal gas:** no intermolecular forces, so U is all kinetic: U = (3/2)NkT. ΔU = 0 whenever T is unchanged.

2 The first law

ΔU = q + W

$$W = p\Delta V \; ; \; \Delta U = q + W$$ DATA & FORMULAE

W = work done ON the system



On a p–V graph, the work done equals the area under the line.

WORKED EXAMPLE

A gas at a constant 2.0×10^5 Pa expands from 1.5×10^{-3} m³ to 2.5×10^{-3} m³, while 500 J is supplied by heating. Find the change in internal energy.

1. work done by gas = $p\Delta V = 2.0 \times 10^5 \times 1.0 \times 10^{-3} = 200$ J, so $W = -200$ J C1 A1
2. **$\Delta U = q + W = 500 - 200 = +300$ J** A1

WORKED EXAMPLE

A gas is compressed quickly (no time for heat transfer) with 150 J of work done on it. Find ΔU and say what happens to its temperature.

1. q = 0, W = +150 J C1
2. **ΔU = +150 J, so the temperature rises** A1

Process	Condition	First law
Constant volume	W = 0	ΔU = q
Isothermal (ideal gas)	ΔU = 0	q = −W
No heat transfer (adiabatic)	q = 0	ΔU = W
Full cycle	back to start	ΔU = 0

COMMON MISTAKE

Sign errors with W. In this syllabus W is work done ON the gas. An expanding gas does work, so W is negative. The 2024 Paper 4 report flagged this every year.

LINKING QUESTION

Ideal gases and U = (3/2)NkT are in Ideal gases; specific heat capacity is in Temperature; and work = force × distance is from Work, energy and power.

Test yourself — cover the answers first

QUICK CHECK

1. Define internal energy.
2. A gas expands. Is W positive or negative?
3. What is ΔU for an ideal gas at constant temperature?
4. A gas is heated at constant volume with 80 J. Find ΔU.

5. Why does the internal energy of ice increase as it melts at 0 °C?

EXAM-STYLE

6. A gas is compressed at constant pressure 1.0×10^5 Pa from 4.0×10^{-4} m³ to 1.5×10^{-4} m³ and loses 40 J by heating. Find ΔU.
7. An ideal gas expands isothermally, doing 120 J of work. How much energy was supplied by heating?
8. Explain why a bicycle pump gets warm when used quickly.

Show answers

1. the sum of the random kinetic and potential energies of the molecules
2. negative (work is done by the gas)
3. zero
4. 80 J
5. the molecular potential energy increases
6. W = +25 J, q = −40 J ⇒ ΔU = −15 J
7. ΔU = 0, W = −120 J ⇒ q = +120 J
8. work is done on the air (W > 0) with little time for heat loss (q ≈ 0), so ΔU > 0 and T rises

Stuck on a question?

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