

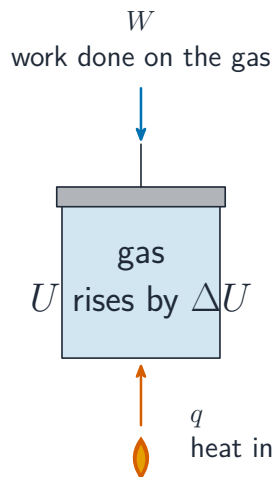
Exercise walk-through

16.2

The first law of thermodynamics

A-Level Physics

The first law of thermodynamics



$$\Delta U = q + W$$

both are positive when
energy goes *into* the gas

Conservation of energy,
written for heat and work crossing a
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.

Reading the equation

ΔU is fixed by the change of state (for an ideal gas, by the change in temperature).

- all heat, no work: $\Delta U = q$ (constant-volume heating).
- all work, no heat: $\Delta U = W$ (insulated compression or expansion).

The first law at work



A turbine takes in heat, does work, and rejects the rest – $\Delta U = q + w$ with every term non-zero.

Worked example – expanding while heated

A gas absorbs 500 J of heat while doing 200 J of work on its surroundings. Find ΔU .

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

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

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

$\Delta U = W$ – compress-
ing 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.

Exercises 2.1·2.3

2.1 State the **two ways** in which the internal energy of a system can be changed. [2]

2.2 Write the formula for the work done when a gas changes volume at **constant pressure**. [1]

2.3 A gas at 1.0×10^5 Pa expands by 3.0×10^{-3} m³. Find the work done **by** the gas. [2]

Exercises 2.1-2.3

2.1 State the **two ways** in which the internal energy of a system can be changed. [2]

2.1

- by **heating** it (transferring thermal energy to it)
- and by **doing work** on it

2.2 Write the formula for the work done when a gas changes volume at **constant pressure**. [1]

2.2

- $W = p\Delta V$

2.3 A gas at 1.0×10^5 Pa expands by 3.0×10^{-3} m³. Find the work done **by** the gas. [2]

2.3

- $W = p\Delta V$

$$W = p\Delta V = (1.0 \times 10^5 \text{ Pa})(3.0 \times 10^{-3} \text{ m}^3) = \mathbf{300 \text{ J}}$$

Exercises 2.4·3.1

2.4 State the **sign** of the work done **on** a gas when it is **compressed**. [1]

3.1 When a gas is **compressed**, the work done **on** the gas is: [1]

☐

A negative

B zero

C positive

D undefined

Exercises 2.4·3.1

2.4 State the **sign** of the work done **on** a gas when it is **compressed**. [1]

2.4

- **positive**

3.1 When a gas is **compressed**, the work done **on** the gas is: [1]

☐

A negative

B zero

C positive

D undefined

3.1 C

- work done **on** the gas is **positive** in this sign convention
- **A** would be work done *by* the gas; **B** would mean no volume change; **D** is not how the convention works

Exercises 3.2-3.3

3.2 A gas is heated with 500 J of energy, and 200 J of work is done **on** it. Find the change in **internal energy**. [2]

3.3 A gas at constant pressure 2.0×10^5 Pa is **compressed** from 4.0×10^{-3} to 1.0×10^{-3} m³, while 800 J is removed by cooling. Calculate the change in internal energy ΔU . [4]

Exercises 3.2-3.3

3.2 A gas is heated with 500 J of energy, and 200 J of work is done **on** it. Find the change in **internal energy**. [2]

3.2

- $\Delta U = q + W$

$$\Delta U = q + w = 500 \text{ J} + 200 \text{ J} = \mathbf{700 \text{ J}}$$

3.3 A gas at constant pressure $2.0 \times 10^5 \text{ Pa}$ is **compressed** from $4.0 \times 10^{-3} \text{ m}^3$ to $1.0 \times 10^{-3} \text{ m}^3$, while 800 J is removed by cooling. Calculate the change in internal energy ΔU . [4]

3.3

- compressed $\rightarrow$ work done **on** the gas is positive: $W = p|\Delta V|$

$$W = p|\Delta V| = (2.0 \times 10^5 \text{ Pa})(3.0 \times 10^{-3} \text{ m}^3) = 600 \text{ J}$$

- cooling removes energy, so $q = -800 \text{ J}$

$$\Delta U = q + W = -800 \text{ J} + 600 \text{ J} = \mathbf{-200 \text{ J}}$$

Exercise 3.4

3.4 Use the first law of thermodynamics to explain why a bicycle pump becomes **warm** when air is pumped quickly. [3]

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3.4

- the air is compressed quickly, so little heat leaves ($q \approx 0$)
- work is done **on** the gas, so W is positive
- by $\Delta U = q + W$, $\Delta U > 0$, so the internal energy and temperature **rise** – the pump feels warm