Exercise walk-through

The first law of thermodynamics ▪ 16.2

eXercise

You must be able to

- state the **two ways** to change a system's internal energy
- use $W = p\Delta V$ and the **sign** of work done on vs by a gas
- use the **first law** $\Delta U = q + W$ and apply it to real situations

Method — Two ways to change internal energy

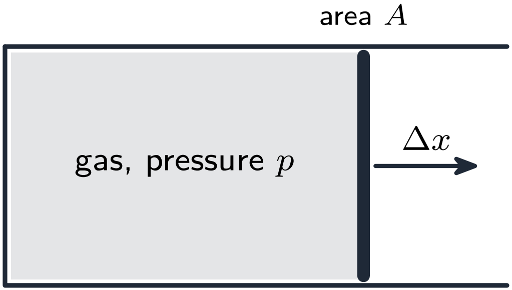
The internal energy of a system changes only by **heating it** (energy q) or by **doing work on it** (work W). The **first law** combines them.

Method — Work done by a gas

At constant pressure, a gas changing volume does work:

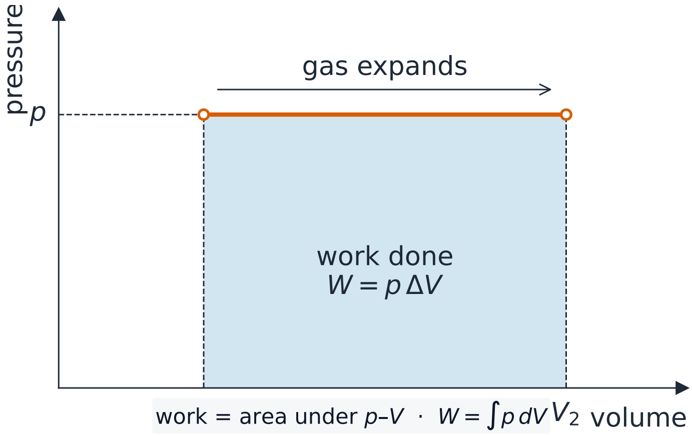
$$W = p\Delta V.$$

Method — Work done by a gas



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

Method — Work done by a gas



Work done by a gas is the area under p-V

Method — First law of thermodynamics

$$\Delta U = q + W,$$

where ΔU = increase in internal energy, q = energy added **by heating**, W = work done **on** the gas.

- **compressed:** W on the gas is **positive** (gas gains energy);
- **expands:** W on the gas is **negative** (gas does work on surroundings);
- **constant volume:** $W = 0$, so $\Delta U = q$.

Worked example. A gas at 1.0×10^5 Pa expands from 2.0 to 5.0×10^{-3} m^3: work done **by** the gas $= p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300$ J.

Method — Applying the first law

Worked example (a bicycle pump warms up). Air is compressed **quickly**, so almost no heat escapes ($q \approx 0$). Work is done **on** the gas ($W > 0$), so $\Delta U = q + W > 0$ — the internal energy and therefore the **temperature rise**. (An expanding gas does the opposite — it **cools**.)

Practice 2.1 ▪ 2 marks

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

Solution 2.1

Method: Two ways to change internal energy

Worked steps

By **heating** it (transferring thermal energy to it) and by **doing work** on it B1 B1.

Practice 2.2 ▪ 1 mark

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

Solution 2.2

Method: Work done by a gas

Worked steps

$W = p\Delta V$ **B1**.

Practice 2.3 ▪ 2 marks

A gas at 1.0×10^5 Pa expands by 3.0×10^{-3} m^3. Find the work done **by** the gas.

Solution 2.3

Method: First law of thermodynamics

Worked steps

$W = p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300\ \text{J}$ **M1** **A1**.

Practice 2.4 ▪ 1 mark

State the **sign** of the work done **on** a gas when it is **compressed**.

Solution 2.4

Worked steps

Positive B1.

Exam-style 3.1 ▪ 1 mark

When a gas is **compressed**, the work done **on** the gas is:

A negative

B zero

C positive

D undefined

Solution 3.1

A negative

B zero

C positive ✓

D undefined

Worked steps

C — positive.

Exam-style 3.2 ▪ 2 marks

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

Solution 3.2

Method: First law of thermodynamics

Worked steps

$\Delta U = q + W = 500 + 200 = 700$ J **M1** **A1**.

Exam-style 3.3 ▪ 4 marks

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

Solution 3.3

Method: First law of thermodynamics

Worked steps

Compressed $\rightarrow$ work done **on** gas is positive: $W = p|\Delta V| = (2.0 \times 10^5)(3.0 \times 10^{-3}) = 600$ J **M1** **A1**; cooling removes energy, so $q = -800$ J **M1**; $\Delta U = q + W = -800 + 600 = -200$ J **A1**.

Exam-style 3.4 ▪ 3 marks

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

Solution 3.4

Method: Applying the first law

Worked steps

The air is compressed quickly, so little heat leaves ($q \approx 0$) B1; work is done **on** the gas, so W is positive B1; by $\Delta U = q + W$, $\Delta U > 0$, so the internal energy and temperature **rise** — the pump feels warm B1.