

16.2 The first law of thermodynamics

Name: _____ Class: _____ Date: _____

Total: 16 marks

KEY WORDS first law of thermodynamics 热力学第一定律 • internal energy 内能 • pressure 压强
• volume 体积 • temperature 温度

Objective

Build the skills to answer exam questions on the **first law of thermodynamics** and work done by/on a gas.

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

1 Worked examples

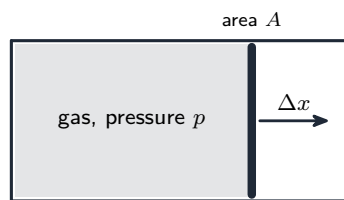
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Two ways to change internal energy

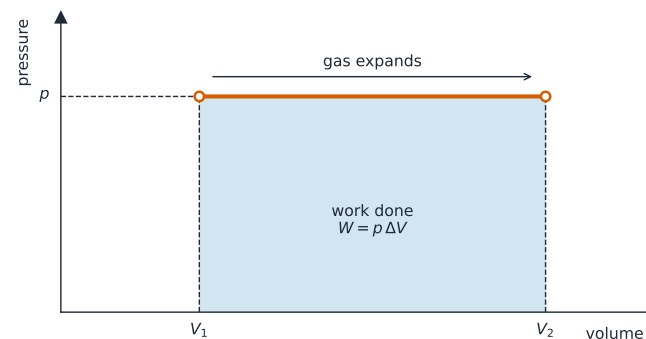
The internal energy of a system changes only by **heating it** (energy q) or by **doing work on it** (work W). The **first law** combines them.

■ Work done by a gas

At constant pressure, a gas changing volume does work:



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



$$\text{work} = \text{area under } p\text{-}V \cdot W = \int p \, dV$$

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

$$W = p\Delta V.$$

■ 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 $5.0 \times 10^{-3} \text{ m}^3$: work done **by** the gas $= p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300 \text{ J}$.

■ 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**.)

2 Practice

Now apply the methods above.

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 $3.0 \times 10^{-3} \text{ m}^3$. Find the work done **by** the gas. [2]

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

3 Exam-style questions

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

- A negative
- B zero
- C positive
- D undefined

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 $1.0 \times 10^{-3} \text{ m}^3$, while 800 J is removed by cooling. Calculate the change in internal energy ΔU . [4]

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

Solutions

Each answer shows the steps, then the **result**.

2.1

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

2.2

- $W = p\Delta V$

2.3

- $W = p\Delta V$

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

2.4

- **positive**

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

3.2

- $\Delta U = q + W$

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

3.3

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

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

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

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

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