A-LEVEL PHYSICS • EXERCISE SHEET

16.1 Internal energy

Name: ____________ Class: ________ Date: __________ **Total: 21 marks**

KEY WORDS internal energy 内能 • kinetic energy 动能 • temperature 温度 • ideal gas 理想气体 • thermodynamic temperature 热力学温度

Objective

Build the skills to answer exam questions on **internal energy**.

You must be able to:

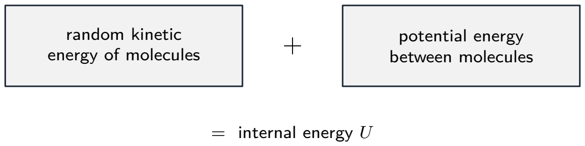
- describe internal energy as the random **kinetic + potential** energy of molecules
- relate a **temperature** rise to an internal-energy rise
- use $U = \frac{3}{2}nRT$ for an ideal gas

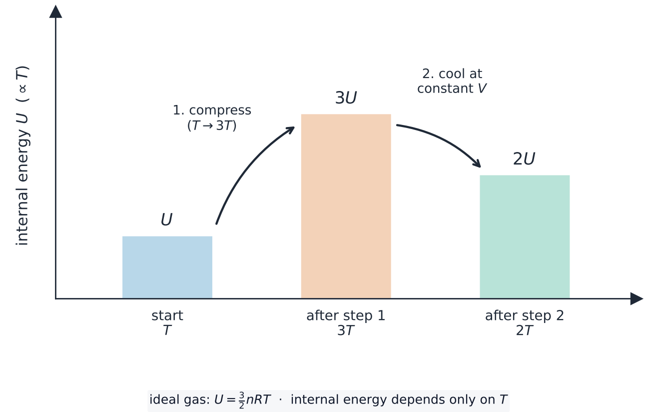
1 Worked examples

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.

■ Internal energy

The **internal energy** U is the sum of the **random kinetic** energy and the **potential** energy of all the molecules:





Internal energy rises with temperature

- U depends only on the **state** (T, p, V, amount) — not the path.
- For an **ideal gas**, intermolecular forces are ignored (PE $= 0$), so U is **all kinetic**: $U = \frac{3}{2}nRT$, directly proportional to T.
- Raising the temperature raises the molecules' KE, so raises U. During **boiling/melting**, U rises through **PE** (bonds breaking) at constant temperature.

2 Practice

Now apply the methods above.

2.1 State the **two** contributions to the internal energy of a substance. [2]

2.2 State what happens to a body's internal energy when its **temperature rises**. [1]

2.3 State why an **ideal gas** has zero molecular potential energy. [1]

2.4 Write the expression for the internal energy of an ideal gas. [1]

3 Exam-style questions

3.1 The internal energy of an **ideal gas** depends only on its: [1]

- **A** pressure
- **B** volume
- **C** thermodynamic temperature
- **D** mass

3.2 The thermodynamic temperature of an ideal gas is **doubled**. State what happens to its internal energy. [1]

3.3 Explain why a substance's internal energy **increases** during boiling, even though its **temperature** stays constant. [2]

3.4 Explain why the internal energy of a gas is **not** the same as the kinetic energy of the moving container it is in. [2]

3.5 A sealed cylinder contains an ideal gas at thermodynamic temperature T, with internal energy U. A piston compresses the gas, raising its temperature to $4T$, and work W is done on the gas during the compression. The gas is then cooled at **constant volume** until its temperature is $2T$.

(a) **State** what is meant by the internal energy of a system. [2]

(b) **Explain** why, for an **ideal** gas, the internal energy depends only on the thermodynamic temperature. [2]

(c) **Complete** the table, giving each entry in terms of some or all of W and U. [4]

process	**work done on the gas**	**thermal energy supplied to the gas**	**increase in internal energy**
compression to $4T$	W	________	________
cooling to $2T$	________	________	________

(d) **State and explain** what happens to the mean speed of the molecules during the cooling. [2]

Solutions

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

2.1

- the **random kinetic energy** of the molecules
- and the **potential energy** between the molecules

2.2

- it **increases** (the molecules' random kinetic energy rises)

2.3

- its molecules are assumed to have **no forces** between them (except during collisions), so there is no intermolecular potential energy

2.4

- $U = \frac{3}{2}nRT$ (or $\frac{3}{2}NkT$)

3.1 C

- for an ideal gas U depends only on **thermodynamic temperature**
- **A** pressure and **B** volume cancel for a given T; **D** mass matters only through n, not on its own once n is fixed

3.2

- it **doubles** ($U \propto T$ for an ideal gas)

3.3

- energy goes into increasing the molecular **potential energy** as bonds are broken/molecules separated
- the kinetic energy (temperature) stays the same, so U rises with constant T

3.4

- internal energy is the energy of the **random** molecular motion
- the container's motion is **bulk/ordered** kinetic energy of the whole body, which is separate from U

3.5

(a) the **sum of the random kinetic and potential energies** of all the molecules of the system

(b) the molecules of an ideal gas exert no forces on each other except in collisions, so their total **potential** energy is zero and the internal energy is purely kinetic

- the mean molecular kinetic energy is $\frac{3}{2}kT$, so the internal energy depends only on T — not on the volume or the pressure separately

(c) internal energy is proportional to T: it is U at T, $4U$ at $4T$ and $2U$ at $2T$

process	**work done on the gas**	**thermal energy supplied**	**increase in internal energy**
compression to $4T$	W	$3U - W$	$+3U$
cooling to $2T$	0	$-2U$	$-2U$

- $+3U$; $-2U$; the zero work at constant volume; both thermal-energy entries, from $\Delta U = q + w$

(d) the mean speed **decreases**

- because the mean kinetic energy $\frac{3}{2}kT$ falls with the temperature and the molecular mass is unchanged