Exercise walk-through

Internal energy ▪ 16.1

eXercise

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

Method — Internal energy

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

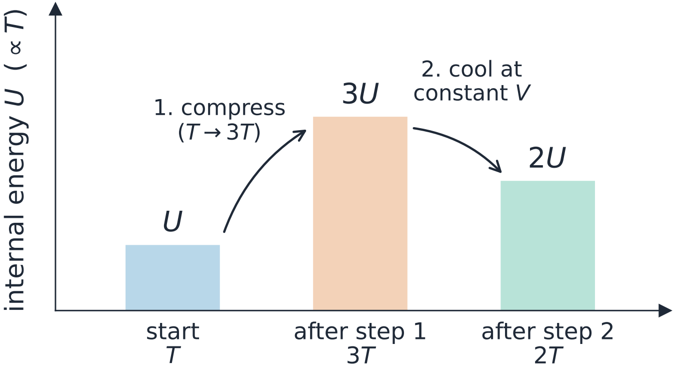
- U depends only on the **state** (T, p, V, amount) — not the path.
- For an **ideal gas**, intermolecular forces are ignored (PE $= 0$), so U is **all kinetic**: $U = \frac{3}{2}nRT$, directly proportional to T.
- Raising the temperature raises the molecules' KE, so raises U. During **boiling/melting**,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

Method — Internal energy

random kinetic energy of molecules	$+$	potential energy between molecules

$=$ internal energy U

Method — Internal energy



ideal gas: $U = \frac{3}{2}nRT$ · internal energy depends only on T

Internal energy rises with temperature

Practice 2.1 ▪ 2 marks

State the **two** contributions to the internal energy of a substance.

Solution 2.1

Method: Internal energy

Worked steps

The **random kinetic energy** of the molecules and the **potential energy** between the molecules B1 B1.

Practice 2.2 ▪ 1 mark

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

Solution 2.2

Method: Internal energy

Worked steps

It **increases** (the molecules' random kinetic energy rises) **B1**.

Practice 2.3 ▪ 1 mark

State why an **ideal gas** has zero molecular potential energy.

Solution 2.3

Method: Internal energy

Worked steps

Its molecules are assumed to have **no forces** between them (except during collisions), so there is no intermolecular potential energy **B1**.

Practice 2.4 ▪ 1 mark

Write the expression for the internal energy of an ideal gas.

Solution 2.4

Method: Internal energy

Worked steps

$U = \frac{3}{2}nRT$ (or $\frac{3}{2}NkT$) **B1**.

Exam-style 3.1 ▪ 1 mark

The internal energy of an **ideal gas** depends only on its:

A pressure

B volume

C thermodynamic temperature

D mass

Solution 3.1

Method: Internal energy

A pressure

B volume

C thermodynamic temperature ✓

D mass

Worked steps

C — thermodynamic temperature.

Exam-style 3.2 ▪ 1 mark

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

Solution 3.2

Method: Internal energy

Worked steps

It **doubles** ($U \propto T$ for an ideal gas) B1.

Exam-style 3.3 ▪ 2 marks

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

Solution 3.3

Method: Internal energy

Worked steps

Energy goes into increasing the molecular **potential energy** as bonds are broken/molecules separated **B1**; the kinetic energy (temperature) stays the same, so U rises with constant T **B1**.

Exam-style 3.4 ▪ 2 marks

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

Solution 3.4

Method: Internal energy

Worked steps

Internal energy is the energy of the **random** molecular motion **B1**; the container's motion is **bulk/ordered** kinetic energy of the whole body, which is separate from U **B1**.

Exam-style 3.5 ▪ 2 marks

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.

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

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

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

Exam-style 3.5 ▪ 2 marks

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

Solution 3.5

Method: Internal energy

Worked steps

(a) The **sum of the random kinetic and potential energies** of all the molecules of the system B1 B1.

(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 B1; 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 B1.

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

Solution 3.5

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

Solution 3.5

B1 **B1** **B1** **B1** *for* $+3U$*; for* $-2U$*; for the zero work at constant volume; for both thermal-energy entries, from* $\Delta U = q + w$

(d) The mean speed **decreases** **B1**, because the mean kinetic energy $\frac{3}{2}kT$ falls with the temperature and the molecular mass is unchanged **B1**.