Week 36

# A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

## Contents 目录





A-Level Physics Name: ____________ Score: ______

1. Internal energy is the sum of which energies?
   - ☐ the random kinetic energy of the molecules
   - ☐ the potential energy between the molecules
   - ☐ the bulk kinetic energy of the whole object
   - ☐ the weight of the object

   *Tick every correct option.*

2. The work done by a gas expanding at constant pressure is:
   - ☐ $p\,\Delta V$
   - ☐ $\dfrac{p}{\Delta V}$
   - ☐ $pV^2$
   - ☐ $\dfrac{\Delta V}{p}$

3. Which is the full two-mark definition of internal energy?
   - ☐ the sum of the random distribution of the kinetic and potential energies of the molecules
   - ☐ the total kinetic energy of the molecules
   - ☐ the energy of the object as it moves
   - ☐ the heat supplied to the object

4. When a gas expands, it does work on its surroundings.

   ☐ True ☐ False

5. A moving train's bulk kinetic energy counts as part of its internal energy.

   ☐ True ☐ False

6. A gas expands. In this syllabus's convention, what is the sign of W, the work done ON the gas?
   - ☐ negative, because the gas loses energy to its surroundings
   - ☐ positive, because work is being done
   - ☐ zero
   - ☐ it depends on the temperature

7. A tanker of gas driving along a motorway has more internal energy than the same tanker parked, at the same temperature.

☐ True ☐ False

8. The first law of thermodynamics: $\Delta U = q +$ ______.

_____________________________

9. Internal energy depends only on the state of the system, not on the path taken to reach it.

☐ True ☐ False

10. A two-mark statement of the first law must define its symbols with direction. Which are correct? Select **all** that apply.

☐ Delta U is the increase in internal energy of the system

☐ q is the thermal energy transferred TO the system by heating

☐ W is the work done ON the system

☐ W is the work done BY the system

*Tick every correct option.*



## 16. Thermodynamics

Answers · 答案

A-Level Physics

1. **the random kinetic energy of the molecules; the potential energy between the molecules**

   Internal energy = random molecular KE + intermolecular PE. The object's overall motion (bulk KE) is separate.

2. $p\,\Delta V$

   Force = $pA$, distance = $\Delta x$, so work = $pA\Delta x = p\,\Delta V$.

3. **the sum of the random distribution of the kinetic and potential energies of the molecules**

   Both marks need "kinetic and potential" and the word "random". Without "random" the phrase describes a moving object's energy instead.

4. **True**

   Yes — it pushes the piston/atmosphere outward. So the work done *on* the gas is negative.

5. **False**

   No — internal energy is the energy of the *random* molecular motion, not the whole object moving along.

6. **negative, because the gas loses energy to its surroundings**

   Work done BY the gas and work done ON it are equal in size and opposite in sign. Confusing the two is the commonest error in this topic.

7. **False**

   Bulk motion is not internal energy. The random molecular motion is unchanged, so U is the same; the lorry simply also has kinetic energy.

8. **W**

   $\Delta U = q + W$, where $W$ is the work done **on** the gas and $q$ is the heat added.

9. **True**

   Yes — $U$ is a function of state (T, p, V, amount); two routes to the same state give the same $U$.

10. **Delta U is the increase in internal energy of the system; q is the thermal energy transferred TO the system by heating; W is the work done ON the system**

    "To the system" and "on the system" are where the marks are. Defining W as the work done by the system flips the sign of the whole equation.

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.

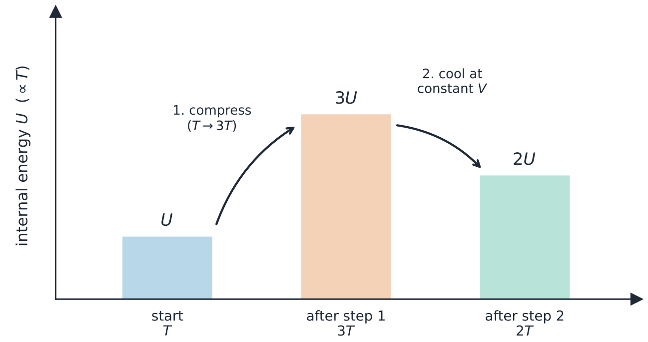
### ■ Internal energy

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

random kinetic energy of molecules + potential energy between molecules

= internal energy $U$






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

*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

**4** **(a)** **(i)** State what is meant by the internal energy of a system.

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**(ii)** Explain why the internal energy of an ideal gas is directly proportional to the thermodynamic temperature of the gas.

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**(b)** A sample of an ideal gas at thermodynamic temperature *T* has internal energy *U*.

The gas is compressed so that its temperature increases to 3*T*.
During this compression, work *W* is done on the gas.

The gas is then cooled at constant volume so that its temperature decreases to 2*T*.

Complete Table 4.1 to show, in terms of some or all of *W*, *T* and *U*, the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas for each of the two processes.

**Table 4.1**

| | work done on gas | thermal energy supplied to gas | increase in internal energy of gas |
|---|---|---|---|
| compression | +*W* | | |
| cooling | | | |

[4]

[Total: 8]





**4** **(a)** **(i)** State what is meant by the internal energy of a system.

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**(ii)** Explain why the internal energy of an ideal gas is directly proportional to the thermodynamic temperature of the gas.

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**(b)** A sample of an ideal gas at thermodynamic temperature *T* has internal energy *U*.

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The gas is then cooled at constant volume so that its temperature decreases to 2*T*.

Complete Table 4.1 to show, in terms of some or all of *W*, *T* and *U*, the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas for each of the two processes.

**Table 4.1**

| | work done on gas | thermal energy supplied to gas | increase in internal energy of gas |
|---|---|---|---|
| compression | +*W* | | |
| cooling | | | |

[4]

[Total: 8]

**3** **(a)** **(i)** State what is meant by an ideal gas.

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**(ii)** Use one of the basic assumptions of the kinetic theory to explain what can be deduced about the potential energy associated with the random motion of molecules in an ideal gas.

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**(b)** A sample of 0.26 $m^3$ of an ideal gas is at pressure $2.0 \times 10^5$ Pa and temperature 290 K.

Determine:

**(i)** the number *N* of molecules of the gas

*N* = ........................................................ [2]

**(ii)** the average translational kinetic energy $E_K$ of one molecule of the gas

$E_K$ = ..................................................... J [2]

**(iii)** the internal energy of the gas. Explain your reasoning.

internal energy = ..................................................... J [2]



**(c)** The volume *V* of the gas in **(b)** is now varied, keeping its pressure constant.

On Fig. 3.1, sketch the variation with *V* of the internal energy *U* of the gas.


**Fig. 3.1**

[2]

[Total: 12]

A-LEVEL PHYSICS • EXERCISE SHEET

# 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

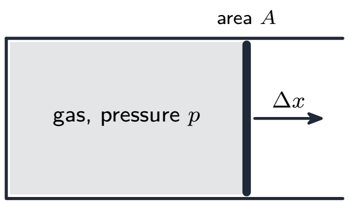
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

### ■ 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.

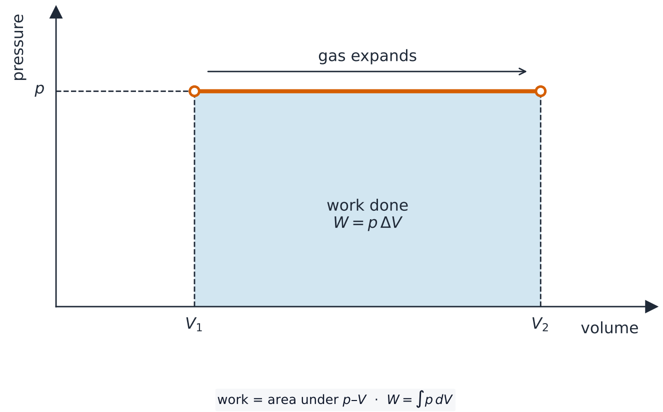
### ■ Work done by a gas

At constant pressure, a gas changing volume does work:




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






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

$$W = p\Delta V.$$

### ■ First law of thermodynamics

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

where $\Delta U$ = 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 $1.0 \times 10^5$ Pa expands from 2.0 to $5.0 \times 10^{-3}$ m$^3$: work done **by** the gas $= p\Delta V = (1.0 \times 10^5)(3.0 \times 10^{-3}) = 300$ 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 $1.0 \times 10^5$ Pa expands by $3.0 \times 10^{-3}$ 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 $2.0\times10^5$ Pa is **compressed** from $4.0\times10^{-3}$ to $1.0\times10^{-3}$ m$^3$, while 800 J is removed by cooling. Calculate the change in internal energy $\Delta U$. [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 → 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 $q = -800$ 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





**2 (a)** State **two** ways in which the first law of thermodynamics describes that the internal energy of a system may be changed.

1 ..........................................................................................................................

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2 ..........................................................................................................................

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[2]

**(b) (i)** Use the first law of thermodynamics to explain why a bicycle pump gets hot when it is used to pump up a tyre quickly.

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**(ii)** With reference to molecular energies, explain why the temperature of water remains at 100 °C when it vaporises in a kettle, even though it is being heated.

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[Total: 8]

**2** **(a)** Define specific heat capacity.

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**(b)** An ideal gas of mass 0.35 kg is heated at a constant pressure of $2.0 \times 10^5$ Pa so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 $m^3$ to 0.063 $m^3$ and the temperature increases by 56 °C.

**(i)** Show that the magnitude of the work done on the gas is 5000 J.

[1]

**(ii)** Explain whether the work done on the gas is positive or negative.

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**(iii)** Determine the magnitude of the thermal energy $q$ transferred to the gas.

$q$ = ...................................................... J [2]

**(iv)** Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

specific heat capacity = ........................................... unit ............. [2]





**(c)** The gas in **(b)** is now heated at constant volume rather than at constant pressure. The increase in internal energy of the gas is the same as in **(b)**.

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in **(b)(iv)**.

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[Total: 12]

**2** **(a)** State what is meant by an ideal gas.

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**(b)** A fixed amount of helium gas is sealed in a container. The helium gas has a pressure of $1.10 \times 10^5$ Pa, and a volume of $540\,cm^3$ at a temperature of 27 °C.

The volume of the container is rapidly decreased to $30.0\,cm^3$. The pressure of the helium gas increases to $6.70 \times 10^6$ Pa and its temperature increases to 742 °C, as illustrated in Fig. 2.1.

| initial state | final state |
| --- | --- |
| $1.10 \times 10^5$ Pa | $6.70 \times 10^6$ Pa |
| $540\,cm^3$ | $30.0\,cm^3$ |
| 27 °C | 742 °C |

**Fig. 2.1**

No thermal energy enters or leaves the helium gas during this process.

**(i)** Show that the helium gas behaves as an ideal gas.

[2]

**(ii)** The first law of thermodynamics may be expressed as

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

Use the first law of thermodynamics to explain why the temperature of the helium gas increases.

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.............................................................................................................................................. [2]





**(iii)** The average translational kinetic energy $E_K$ of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

Calculate the change in the total kinetic energy of the molecules of the helium gas.

change in kinetic energy = ...................................................... J [3]

**(c)** The mass of nitrogen gas in another container is 24.0 g at a temperature of 27 °C. The gas is cooled to its boiling point of –196 °C. Assume all the gas condenses to a liquid.

For this change the specific heat capacity of nitrogen gas is $1.04\ kJ\,kg^{-1}\,K^{-1}$.

The specific latent heat of vaporisation of nitrogen is $199\,kJ\,kg^{-1}$.

Determine the thermal energy, in kJ, removed from the nitrogen gas.

energy = .................................................... kJ [3]

[Total: 12]