**Week 1**

# A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

## Contents 目录

# 1. Atomic structure

**Starter Quiz · 课前小测**

A-Level Chemistry  Name: _____  Score: _____

1. A proton has a relative charge of +1 and a neutron has no charge.

   ☐ True  ☐ False

2. A positive ion (cation) is smaller than its parent atom.

   ☐ True  ☐ False

3. Isotopes of an element have:

   ☐ the same number of protons but a different number of neutrons

   ☐ a different number of protons

   ☐ a different number of electrons

   ☐ the same number of neutrons

4. The electron configuration of sodium (11 electrons) is $1s^2\ 2s^2\ 2p^6$ _____.

   _____

5. Each orbital can hold a maximum of two electrons, which must have opposite spins.

   ☐ True  ☐ False

6. Why are gaseous atoms specified in the definition of ionisation energy?

   ☐ so there are no forces between the particles

   ☐ because gases are cheaper

   ☐ so the atoms can react

   ☐ to make them heavier

7. Which particle has a relative charge of 0 and a relative mass of 1?

   ☐ the neutron

   ☐ the proton

   ☐ the electron

   ☐ the nucleus

8. Across a period, the atomic radius decreases because:

   ☐ the nuclear charge rises while shielding stays about the same, pulling the outer shell in

   ☐ a new shell is added each time

   ☐ shielding increases sharply

☐ the atom loses electrons

9. Isotopes of an element have the same number of protons but different numbers of _____.

_____

10. How many electrons can a p sub-shell hold?

☐ 6 (three orbitals of 2)

☐ 2

☐ 10

☐ 8

# 1. Atomic structure

**Answers · 答案**

A-Level Chemistry

1. **True**

   Electrons carry −1; protons +1; neutrons 0.

2. **True**

   Losing the outer-shell electrons reduces shielding and shrinks the ion.

3. **the same number of protons but a different number of neutrons**

   Isotopes share the proton number Z but differ in neutron number, so they have different nucleon numbers A.

4. **3s1**

   Sodium has one electron in the 3s sub-shell.

5. **True**

   This is why 'electrons in boxes' show at most two arrows, pointing opposite ways.

6. **so there are no forces between the particles**

   Using gaseous atoms means there are no interactions between particles, so the value measures only the atom's own attraction.

7. **the neutron**

   A neutron is neutral (charge 0) with relative mass 1; the proton is +1 mass 1; the electron is −1 and almost massless.

8. **the nuclear charge rises while shielding stays about the same, pulling the outer shell in**

   Electrons go into the same outer shell, so rising nuclear charge with similar shielding pulls them closer.

9. **neutrons**

   Same protons (so same element), different mass.

10. **6 (three orbitals of 2)**

    A p sub-shell has 3 orbitals, each holding 2 electrons, so 6 in total (s = 2, d = 10).

A-LEVEL CHEMISTRY • EXERCISE SHEET

# 1.1 Particles in the atom and atomic radius

Name: _____ Class: _____ Date: _____ **Total: 13 marks**

**KEY WORDS** electron 电子 • proton 质子 • neutron 中子 • shell 壳层 • atomic radius 原子半径

## Objective

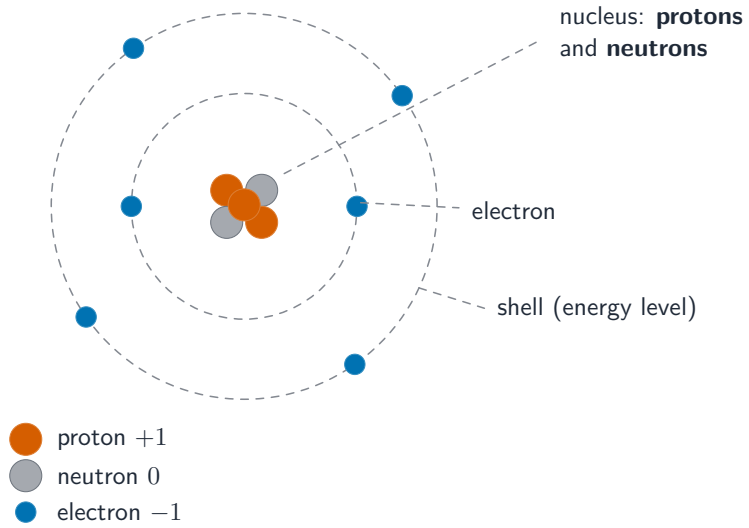
Build the skills to answer exam questions on **particles in the atom and atomic radius** — the **proton** 质子, **neutron** 中子 and **electron** 电子, counting particles in atoms and **ions** 离子, and trends in **atomic radius** 原子半径.

**You must be able to:**

- describe the relative charge and mass of protons, neutrons and electrons
- count protons, neutrons and electrons in an atom or ion from $Z$, $A$ and charge
- describe the behaviour of particle beams in an electric field and explain radius trends

## 1 Worked examples

### The sub-atomic particles

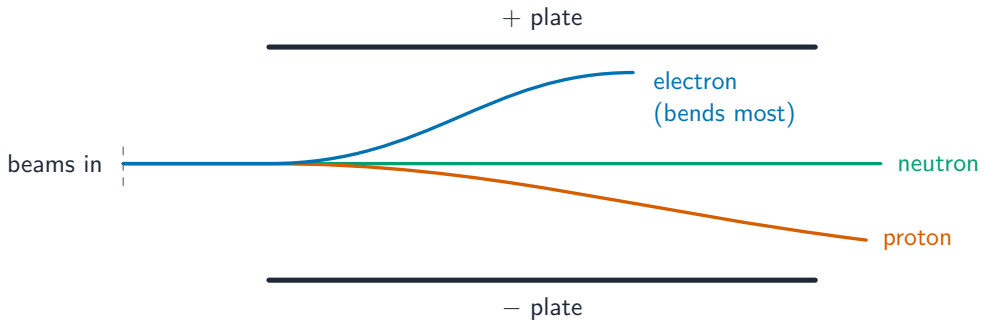



*Protons and neutrons sit in the tiny nucleus; electrons move in shells around it*

| particle | relative charge | relative mass |
|---|---|---|
| proton | $+1$ | 1 |
| neutron | 0 | 1 |
| electron | $-1$ | $\frac{1}{1836}$ $(\approx 0)$ |

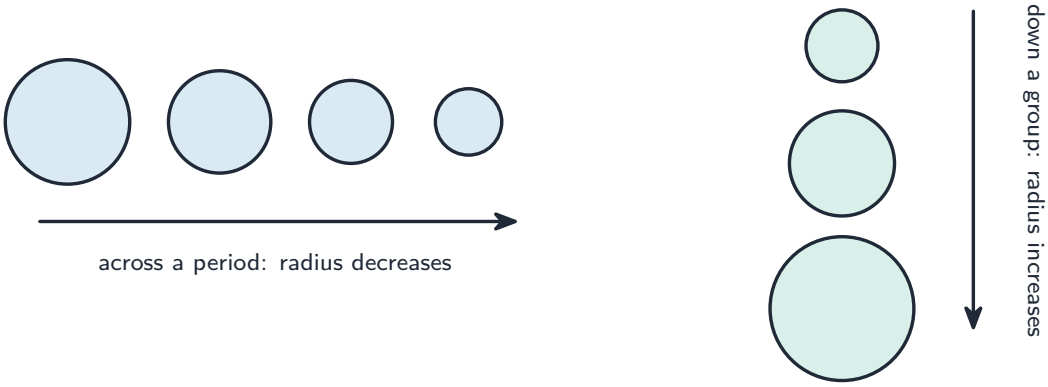
**Proton number** $Z$ = protons; **nucleon number** $A$ = protons + neutrons; neutrons = $A - Z$. In an ion, electrons = $Z-$ charge. E.g. $^{27}_{13}\mathrm{Al}^{3+}$: 13 protons, 14 neutrons, 10 electrons.

## Beams in an electric field




*The proton bends to the − plate; the electron bends the opposite way and far more (it is lighter); the neutron goes straight*

## Atomic and ionic radius




*Across a period atoms shrink (stronger nuclear pull, same shell); down a group they grow (each step adds a shell)*

A **cation** 阳离子 is smaller than its atom (lost a shell); an **anion** 阴离子 is larger (more electron repulsion). Among ions with the same electrons, more protons → smaller.

## 2 Practice

**2.1** State the relative charge and relative mass of a neutron. [2]

**2.2** Give the number of protons, neutrons and electrons in $^{40}_{20}Ca^{2+}$. [3]

## 3 Exam-style questions

**3.1** Which particle is deflected **most** in an electric field, and toward which plate? [1]

- **A** the proton, toward the positive plate
- **B** the electron, toward the positive plate
- **C** the neutron, toward the negative plate
- **D** the electron, toward the negative plate

**3.2** Across Period 3, the atomic radius decreases because: [1]

- **A** more shells are added
- **B** the nuclear charge increases while shielding stays about the same
- **C** the electrons repel each other more
- **D** the atoms gain neutrons

**3.3** (a) Explain why a sodium ion, $Na^+$, is smaller than a sodium atom. [2]

(b) The ions $Na^+$, $Mg^{2+}$ and $Al^{3+}$ all have 10 electrons. State and explain which is smallest. [2]

**3.4** Explain why the atomic radius increases down Group 2. [2]

## Solutions

**2.1** relative charge 0; relative mass 1.

**2.2** protons 20; neutrons $40 - 20 = 20$; electrons $20 - 2 = 18$.

**3.1 B**. The electron is lightest, so it deflects most, toward the positive plate.

**3.2 B**. The rising nuclear charge with similar shielding pulls the outer shell in.

**3.3** (a) $Na^+$ has lost its outer (third) shell, so it has one fewer shell; the remaining electrons are pulled in more strongly by the same nucleus.
(b) $Al^{3+}$ is smallest; it has the most protons (13) for the same 10 electrons, so the strongest pull per electron.

**3.4** each step down Group 2 adds a shell, so the outer electrons are further out and more shielded from the nucleus.

**1** Helium forms an ion $^{3}_{2}He^{+}$.

Three statements about this ion are listed.

1 It contains two protons.

2 It contains three neutrons.

3 It contains one electron.

Which statements are correct?

**A** 1, 2 and 3 **B** 1 and 3 only **C** 2 and 3 only **D** 2 only

**2** The table shows the first five ionisation energies of element X.

| element | ionisation energy / kJ mol$^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th |
| X | 736 | 1450 | 7740 | 10 500 | 13 600 |

Element X is in Period 3 of the Periodic Table.

What is element X?

**A** sodium

**B** magnesium

**C** silicon

**D** argon

**3** Methanethiol, $CH_3SH$, burns as shown.

$$CH_3SH + 3O_2 \rightarrow CO_2 + SO_2 + 2H_2O$$

A sample of 10 cm$^3$ of methanethiol gas was reacted with 60 cm$^3$ of oxygen. Both samples were measured at room conditions.

What would be the final volume of the resultant mixture of gases measured at room temperature?

**A** 20 cm$^3$ **B** 30 cm$^3$ **C** 50 cm$^3$ **D** 70 cm$^3$

**1** Manganese, Mn, and its compounds are widely used in many chemical reactions.

**(a)** Mn is usually found as a single isotope, manganese-55.

**(i)** Determine the number of protons, neutrons and electrons in an atom of manganese-55.

number of protons ..... neutrons ..... electrons .....
[1]

**(ii)** Define isotopes.

.....

..... [1]

**(iii)** A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, $A_r$, of manganese in this sample.

1 .....

2 .....
[2]

**(b)** The shorthand electronic configuration of manganese is [Ar] $3d^5\ 4s^2$.

**(i)** Complete the full electronic configuration of manganese.

..... $3d^5\ 4s^2$ [1]

**(ii)** Deduce the total number of unpaired electrons in an atom of manganese.

..... [1]

**(c)** Manganese(IV) oxide reacts with methanal, $CH_2O$, in acidic conditions to produce carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

half-equation 1 $CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

half-equation 2 $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

**(i)** Identify the species that is reduced in half-equation 2. Explain your answer.

.....

..... [1]

**(ii)** The oxidation state of carbon in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

**(iii)** Construct the ionic equation for the reaction of manganese(IV) oxide with methanal in acidic conditions.

..... [2]

[Total: 10]

# 1.2 Isotopes

Name: _____ Class: _____ Date: _____ **Total: 12 marks**

**KEY WORDS** isotope 同位素 • relative atomic mass 相对原子质量 • chemical properties 化学性质 • physical properties 物理性质 • density 密度

## Objective

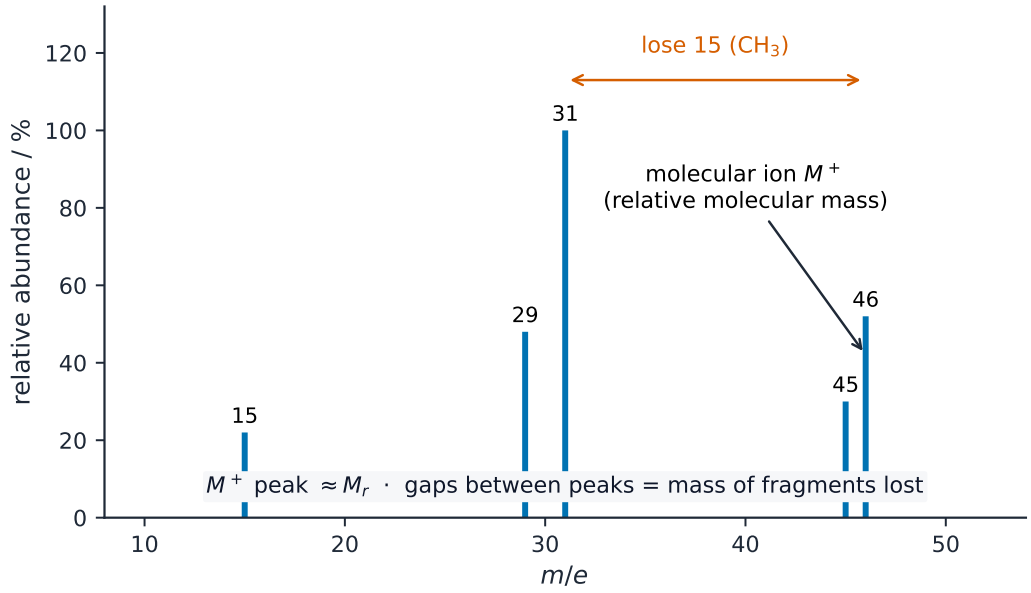
Build the skills to answer exam questions on **isotopes** 同位素 — what they are, the ${}^{A}_{Z}\mathrm{X}$ notation, their properties, and calculating **relative atomic mass** 相对原子质量 from isotopic abundances.

**You must be able to:**

- define isotope and use the ${}^{A}_{Z}\mathrm{X}$ notation
- explain why isotopes have the same chemical but different physical properties
- calculate relative atomic mass from isotopic abundances

## 1 Worked examples

### ■ What isotopes are




*A mass spectrum reveals isotopes and their abundance*

**Isotopes** are atoms of the same element with the same number of **protons** but a

different number of **neutrons** — same proton number $Z$, different nucleon number $A$. E.g. chlorine has $^{35}_{17}\text{Cl}$ and $^{37}_{17}\text{Cl}$.

■ **Same chemical, different physical properties**

Chemical properties depend on the **electrons** (especially the outer ones). Isotopes have the same electron arrangement, so they react the same way — **same chemical properties**. Some physical properties depend on **mass**, so they differ: a heavier isotope has a higher **density** 密度.

■ **Relative atomic mass from abundances**

$$A_r = \frac{\sum(\text{isotope mass} \times \%\ \text{abundance})}{100}$$

**Example.** Chlorine is 75% $^{35}\text{Cl}$ and 25% $^{37}\text{Cl}$:

$$A_r = \frac{(35 \times 75) + (37 \times 25)}{100} = \frac{3550}{100} = 35.5.$$

## 2 Practice

**2.1** Define the term **isotope**. [2]

**2.2** State the number of protons, neutrons and electrons in an atom of $^{37}_{17}\text{Cl}$. [3]

## 3 Exam-style questions

**3.1** Two isotopes of the same element always have the same: [1]

- **A** number of neutrons
- **B** number of protons
- **C** nucleon number
- **D** density

**3.2** Why do isotopes of an element have identical chemical properties? [1]

- **A** they have the same mass

- **B** they have the same number and arrangement of electrons
- **C** they have the same number of neutrons
- **D** they have different densities

---

**3.3** Boron has two isotopes: $^{10}B$ (20%) and $^{11}B$ (80%).

(a) Calculate the relative atomic mass of boron. [2]

(b) Explain why $^{11}B$ is denser than $^{10}B$. [1]

---

**3.4** A sample of copper contains 69% $^{63}Cu$ and 31% $^{65}Cu$. Calculate its relative atomic mass to 1 decimal place. [2]

## Solutions

**2.1** atoms of the same element (same number of protons) with different numbers of neutrons.

**2.2** protons 17; neutrons $37 - 17 = 20$; electrons 17.

**3.1 B**. Isotopes have the same number of protons.

**3.2 B**. The same electron arrangement gives the same chemistry.

**3.3** (a) $A_r = \dfrac{(10 \times 20) + (11 \times 80)}{100} = \dfrac{1080}{100} = 10.8$.
(b) $^{11}$B has one more neutron, so more mass in the same volume.

**3.4** $A_r = \dfrac{(63 \times 69) + (65 \times 31)}{100} = \dfrac{6362}{100} = 63.6$.

**1** Chromium, Cr, and its compounds are widely used in many chemical reactions.

**(a)** Cr exists as four stable isotopes.

**(i)** The most common isotope of Cr is chromium-52.

Determine the number of protons, neutrons and electrons in an atom of chromium-52.

number of protons ..... neutrons ..... electrons .....
[1]

**(ii)** Describe how an atom of chromium-54 differs from an atom of chromium-52. Refer to numbers of particles in your answer.

.....

..... [1]

**(iii)** The relative isotopic masses of the isotopes of Cr can be determined using mass spectrometry.

State what other information is needed to calculate the relative atomic mass, $A_r$, of Cr.

..... [1]

**(iv)** Atoms of $^{52}Cr$, $^{53}Cr$ and $^{54}Cr$ make up more than 95% of naturally occurring chromium atoms. The $A_r$ of naturally occurring Cr is 51.996.

Suggest what these statements imply about the relative isotopic mass of the fourth stable isotope of chromium.

..... [1]

**(b)** The shorthand electronic configuration of chromium is [Ar] $3d^5 4s^1$.

**(i)** Complete the full electronic configuration of chromium.

..... $3d^5 4s^1$ [1]

**(ii)** Deduce the total number of unpaired electrons in an atom of chromium.

..... [1]

**(c)** Acidified dichromate(VI) ions will convert methanal, $CH_2O$, to carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

half-equation 1 $CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

half-equation 2 $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$

**(i)** Identify the species that is reduced in half-equation 2. Explain your answer.

..... [1]

**(ii)** The oxidation state of the carbon atom in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

**(iii)** Construct the ionic equation for the reaction of dichromate(VI) ions with methanal in acidic conditions.

..... [2]

**(iv)** Methanal is a liquid at –30 °C but carbon dioxide is a gas at this temperature. Explain why.

.....

.....

.....

..... [2]

**(d)** In acidic conditions, a dynamic equilibrium is established between $CrO_4^{2-}(aq)$ and $Cr_2O_7^{2-}(aq)$.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l) \qquad \Delta H > 0$$

**(i)** State what is meant by dynamic equilibrium.

.....

..... [1]

**(ii)** Identify the condition necessary to establish dynamic equilibrium.

..... [1]

**(iii)** $CrO_4^{2-}(aq)$ ions are yellow and $Cr_2O_7^{2-}(aq)$ ions are orange.

State what is observed when the following changes are made to an equilibrium mixture of acidified $CrO_4^{2-}(aq)$ and $Cr_2O_7^{2-}(aq)$ ions.

Explain your answers.

- The equilibrium mixture is warmed gently.

  observation .....

  explanation .....

  .....

  .....

- Dilute HC*l*(aq) is added to the equilibrium mixture.

  observation .....

  explanation .....

  .....

  .....

[4]

**(e)** Chromium(IV) fluoride, $CrF_4$, is a covalent molecule that shows similar chemical properties to $SiCl_4$.

Suggest the type of reaction that occurs when $CrF_4$ is placed in water.

Construct a relevant equation for this reaction.

type of reaction .....

equation ..... .....

[2]



[Total: 20]

**1** Manganese, Mn, and its compounds are widely used in many chemical reactions.

**(a)** Mn is usually found as a single isotope, manganese-55.

**(i)** Determine the number of protons, neutrons and electrons in an atom of manganese-55.

number of protons ..... neutrons ..... electrons .....
[1]

**(ii)** Define isotopes.

.....

..... [1]

**(iii)** A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, $A_r$, of manganese in this sample.

1 .....

2 .....
[2]

**(b)** The shorthand electronic configuration of manganese is [Ar] $3d^5\ 4s^2$.

**(i)** Complete the full electronic configuration of manganese.

..... $3d^5\ 4s^2$ [1]

**(ii)** Deduce the total number of unpaired electrons in an atom of manganese.

..... [1]

**(c)** Manganese(IV) oxide reacts with methanal, $CH_2O$, in acidic conditions to produce carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

half-equation 1 $CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

half-equation 2 $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

**(i)** Identify the species that is reduced in half-equation 2. Explain your answer.

.....

..... [1]

**(ii)** The oxidation state of carbon in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

**(iii)** Construct the ionic equation for the reaction of manganese(IV) oxide with methanal in acidic conditions.

..... [2]

[Total: 10]

# 1.3 Electrons, energy levels and atomic orbitals

Name: _____ Class: _____ Date: _____ **Total: 10 marks**

**KEY WORDS** electronic configuration 电子排布 • orbital 轨道 • sub-shell 亚层 • shell 壳层 • spin 自旋

## Objective

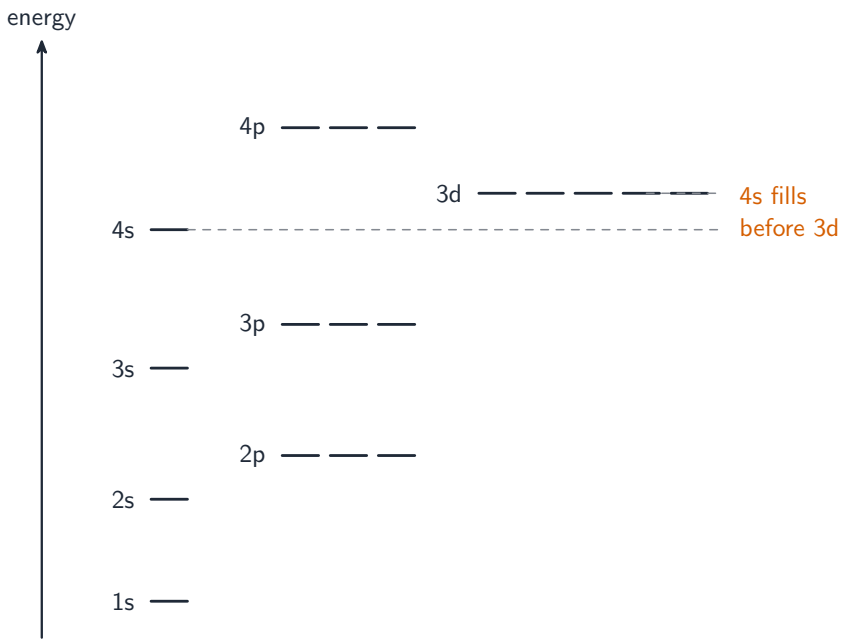
Build the skills to answer exam questions on **electrons, energy levels and atomic orbitals** — **shells, sub-shells and orbitals** 壳层、亚层和轨道, the order of filling, **electronic configurations** 电子排布, and orbital shapes.

**You must be able to:**

- describe the orbitals and electron capacity of s, p and d sub-shells
- write the electronic configuration of an atom or ion (full and shorthand)
- use the electrons-in-boxes notation and describe s and p orbital shapes

## 1 Worked examples

### ■ Sub-shells and filling order

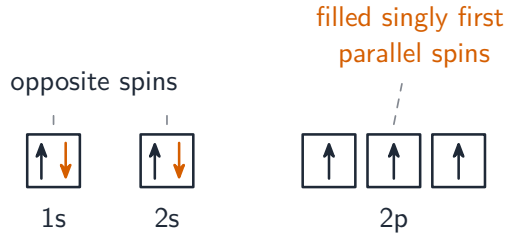



*Order of rising energy: 1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p (4s fills before 3d)*

| sub-shell | orbitals | max electrons |
|---|---|---|
| s | 1 | 2 |
| p | 3 | 6 |
| d | 5 | 10 |

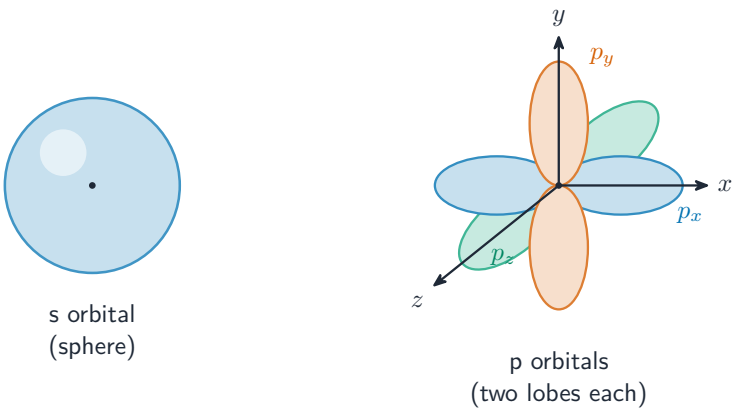
## Electronic configuration

For iron (Fe, $Z = 26$): $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,3d^6\,4s^2$, or shorthand $[Ar]\,3d^6\,4s^2$. For a transition-metal ion, remove the **4s electrons first**: $Fe^{3+} = [Ar]\,3d^5$.




*Paired electrons point opposite ways; within a sub-shell, orbitals fill singly first (parallel spins)*

## Orbital shapes




*An s orbital is a sphere; each p orbital is a dumbbell along one axis*

## 2 Practice

**2.1** State the maximum number of electrons in (a) a p sub-shell and (b) a d sub-shell. [2]

**2.2** Write the full electronic configuration of a calcium atom ($Z = 20$). [1]

## 3 Exam-style questions

**3.1** Which sub-shell is filled **before** the 3d sub-shell? [1]

- **A** 3p
- **B** 4s
- **C** 4p
- **D** 4d

**3.2** What is the shape of a p orbital? [1]

- **A** spherical
- **B** dumbbell (two lobes)
- **C** a flat ring
- **D** a cube

**3.3** (a) Write the shorthand electronic configuration of an iron atom ($Z = 26$). [1]

(b) Write the electronic configuration of the $Fe^{3+}$ ion, and explain which electrons are lost first. [2]

**3.4** Using electrons-in-boxes, explain why the three 2p electrons of nitrogen occupy separate orbitals with parallel spins. [2]

## Solutions

**2.1** (a) 6; (b) 10.

**2.2** $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2$.

**3.1 B**. 4s is slightly lower in energy than 3d, so it fills first.

**3.2 B**. A p orbital is a dumbbell (two lobes).

**3.3** (a) $[Ar]\,3d^6\,4s^2$.
(b) $[Ar]\,3d^5$; the 4s electrons are removed before the 3d electrons.

**3.4** each electron is negative and they repel; occupying separate orbitals keeps them apart, lowering repulsion — the lowest-energy (most stable) arrangement.

**1** What is the electronic configuration for the particle $^{27}_{13}Al^{+}$?

**A** $1s^2 2s^2 2p^6 3s^1 3p^1$

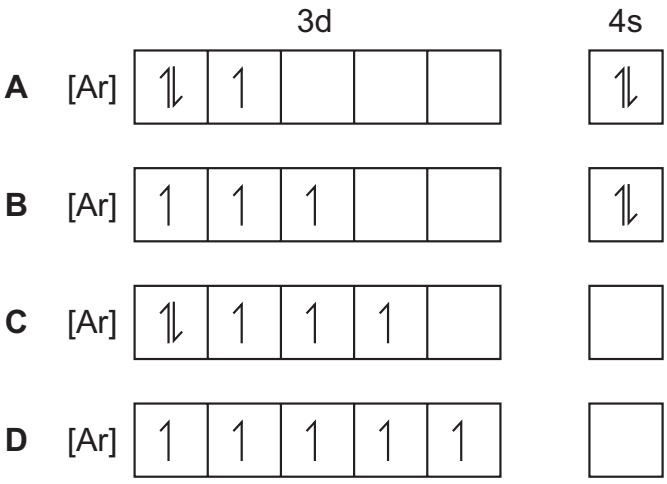
**B** $1s^2 2s^2 2p^6 3s^2$

**C** $1s^2 2s^2 2p^6 3s^2 3p^2$

**D** $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^1$



**1** What is the electrons in boxes notation for the $Fe^{3+}$ ion?




**4** Which statement is correct?

**A** The relative atomic mass of a $^{35}Cl$ atom is 35.5.

**B** The relative molecular mass of $O_2$ is 16.0.

**C** The relative formula mass of $CaCO_3$ is 100.1.

**D** The relative isotopic mass of a $^{24}Mg$ atom is 24.3.



**1** What is the electronic configuration for the particle $^{27}_{13}Al^{+}$?

**A** $1s^2 2s^2 2p^6 3s^1 3p^1$

**B** $1s^2 2s^2 2p^6 3s^2$

**C** $1s^2 2s^2 2p^6 3s^2 3p^2$

**D** $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^1$

**1** Manganese, Mn, and its compounds are widely used in many chemical reactions.

**(a)** Mn is usually found as a single isotope, manganese-55.

**(i)** Determine the number of protons, neutrons and electrons in an atom of manganese-55.

number of protons ..... neutrons ..... electrons .....
[1]

**(ii)** Define isotopes.

.....

..... [1]

**(iii)** A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, $A_r$, of manganese in this sample.

1 .....

2 .....
[2]

**(b)** The shorthand electronic configuration of manganese is [Ar] $3d^5\ 4s^2$.

**(i)** Complete the full electronic configuration of manganese.

..... $3d^5\ 4s^2$ [1]

**(ii)** Deduce the total number of unpaired electrons in an atom of manganese.

..... [1]

**(c)** Manganese(IV) oxide reacts with methanal, $CH_2O$, in acidic conditions to produce carbon dioxide. The movement of electrons to or from relevant species is shown in the following half-equations.

half-equation 1 $CH_2O + H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

half-equation 2 $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

**(i)** Identify the species that is reduced in half-equation 2. Explain your answer.

.....

..... [1]

**(ii)** The oxidation state of carbon in methanal is 0.

Calculate the oxidation state of carbon in carbon dioxide.

..... [1]

**(iii)** Construct the ionic equation for the reaction of manganese(IV) oxide with methanal in acidic conditions.

..... [2]

[Total: 10]

A-LEVEL CHEMISTRY • EXERCISE SHEET

# 1.4 Ionisation energy

Name: _____ Class: _____ Date: _____ **Total: 11 marks**

**KEY WORDS** ionisation energy 电离能 • first ionisation energy 第一电离能 • spin-pair repulsion 自旋成对排斥 • successive ionisation energies 逐级电离能 • shielding 屏蔽

## Objective

Build the skills to answer exam questions on **ionisation energy** 电离能 — defining the **first ionisation energy** 第一电离能, writing equations, explaining trends, and using **successive ionisation energies** 逐级电离能.

**You must be able to:**

- define first ionisation energy and write equations for first and successive ionisations
- explain trends across a period (and the dips) and down a group
- deduce electronic configuration and group from successive ionisation energy data

## 1 Worked examples

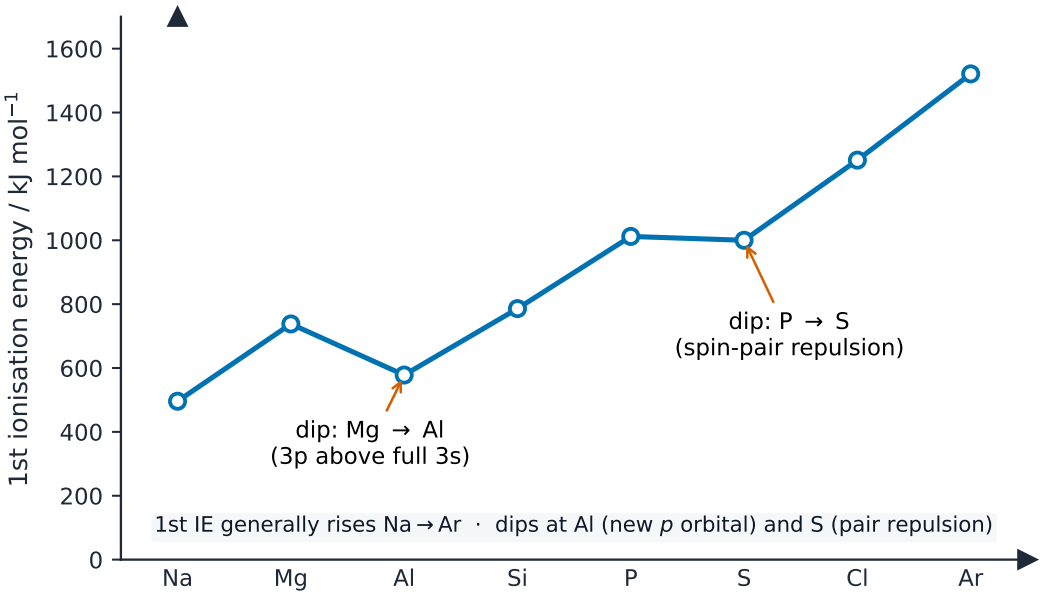
### ■ First ionisation energy

The energy to remove one electron from each atom in one mole of **gaseous** atoms, forming one mole of gaseous +1 ions:

$$\mathrm{X(g)} \rightarrow \mathrm{X^{+}(g)} + \mathrm{e^{-}}$$

It depends on **nuclear charge** (more protons → higher), **atomic radius** (further out → lower), and **shielding** (more inner shells → lower).

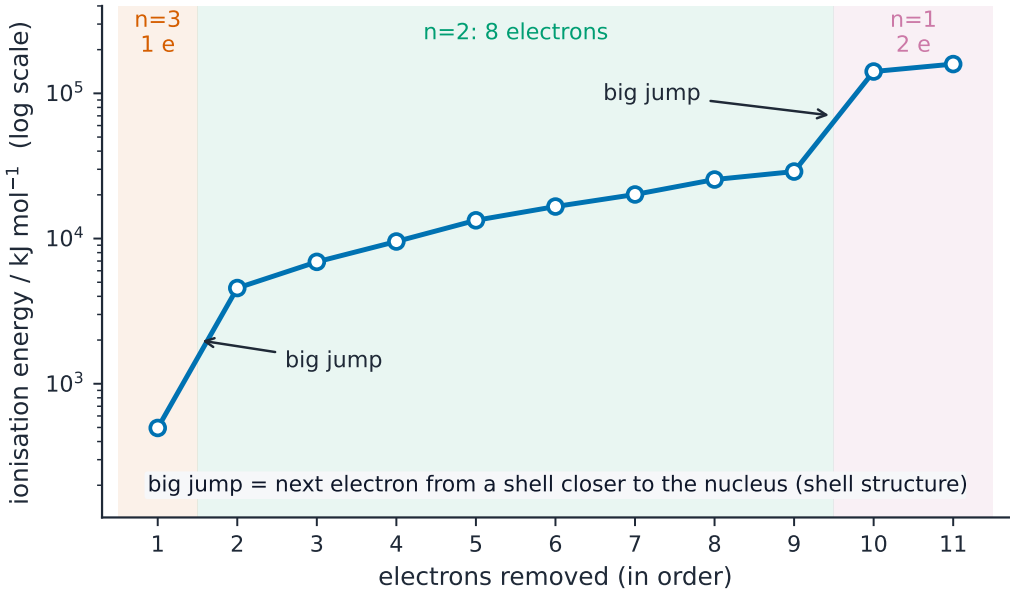
### ■ Trends across Period 3




*IE rises across the period but dips at Al (3p above 3s) and at S (spin-pair repulsion) — evidence for sub-shells*

It rises across a period (rising nuclear charge, similar shielding) and falls down a group (more shielding, larger radius). The two dips: **Mg→Al** (Al's electron is in a higher 3p sub-shell) and **P→S** (S has a paired 3p electron, so spin-pair repulsion makes it easier to remove).

## ■ Successive ionisation energies




*Big jumps reveal the shell structure (Na = 2,8,1); the electrons removed before the first big jump = the group number*

## 2 Practice

**2.1** Write an equation, with state symbols, for the first ionisation energy of magnesium. [2]

**2.2** State **two** factors that affect the size of an ionisation energy. [2]

## 3 Exam-style questions

**3.1** Why is the second ionisation energy of an element always larger than the first? [1]

- **A** the atom is now a gas
- **B** the electron is removed from a more positive ion
- **C** there are more neutrons
- **D** shielding increases

**3.2** The first ionisation energy of sulfur is lower than that of phosphorus because: [1]

- **A** sulfur has fewer protons
- **B** sulfur's removed electron is one of a pair in a 3p orbital (spin-pair repulsion)
- **C** sulfur is in a different period
- **D** sulfur has more shielding

**3.3** Explain why the first ionisation energy decreases down Group 2. [3]

**3.4** The first six ionisation energies of an element (kJ $mol^{-1}$) are: 590, 1150, 4940, 6480, 8120, 10500. Deduce which group the element is in, and explain your answer. [2]

## Solutions

**2.1** $Mg(g) \rightarrow Mg^{+}(g) + e^{-}$.

**2.2** any two: nuclear charge; atomic radius; shielding; (spin-pair repulsion).

**3.1 B**. The electron is pulled from a more positive ion, needing more energy.

**3.2 B**. The paired 3p electron in sulfur is easier to remove (spin-pair repulsion).

**3.3** down the group each element has more shells, so more shielding and a larger atomic radius; the outer electron is held less tightly, so it is easier to remove.

**3.4** Group 2; there is a large jump between the 2nd and 3rd ionisation energies, showing 2 easily-removed outer electrons before reaching a full inner shell.

**2** The data in the table gives the 5th to the 10th ionisation energies of three elements from Period 3 of the Periodic Table.

| element | ionisation energy / kJ mol$^{-1}$ | | | | | |
|---|---|---|---|---|---|---|
| | 5th | 6th | 7th | 8th | 9th | 10th |
| X | 6274 | 21 269 | 25 398 | 29 855 | 35 868 | 40 960 |
| Y | 7012 | 8 496 | 27 107 | 31 671 | 36 579 | 43 140 |
| Z | 6542 | 9 362 | 11 018 | 33 606 | 38 601 | 43 963 |

What are the correct identities of these three elements?

| | element X | element Y | element Z |
|---|---|---|---|
| **A** | Na | Mg | A$l$ |
| **B** | Mg | A$l$ | Si |
| **C** | P | S | C$l$ |
| **D** | S | C$l$ | Ar |



**2** Which equation has an energy change that is equal to the first ionisation energy of bromine?

**A** $Br(g) \rightarrow Br^{+}(g) + e^{-}$

**B** $Br(g) \rightarrow Br^{-}(g) - e^{-}$

**C** $\frac{1}{2}Br_2(g) \rightarrow Br^{+}(g) + e^{-}$

**D** $\frac{1}{2}Br_2(g) \rightarrow Br^{-}(g) - e^{-}$

**7** X and Y are different elements in Period 3.

Atoms of X and Y each have only one completely filled orbital in their highest occupied energy sub-shell.

Y has a greater first ionisation energy than X.

Which row shows the structure and bonding in X and Y?

| | X | Y |
|---|---|---|
| **A** | giant metallic | giant metallic |
| **B** | giant metallic | simple molecular |
| **C** | giant covalent | simple molecular |
| **D** | simple molecular | simple molecular |

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