Week 1

A-Level Chemistry

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

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: 24 marks**

KEY WORDS electron 电子 • proton 质子 • neutron 中子 • nucleon 核子 • shell 壳层

Objective

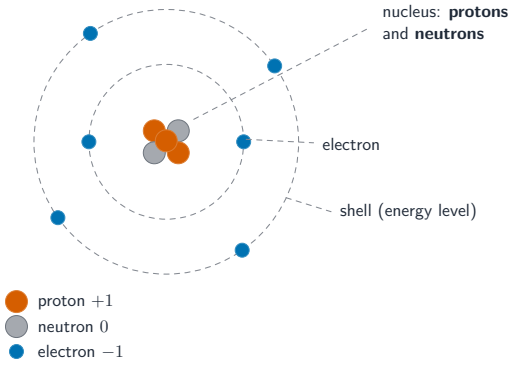
Build the skills to answer exam questions on **particles in the atom and atomic radius** — the **proton** 质子, **neutron** 中子 and **electron** 电子, counting particles in atoms and **ions** 离子, and trends in **atomic radius** 原子半径.

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

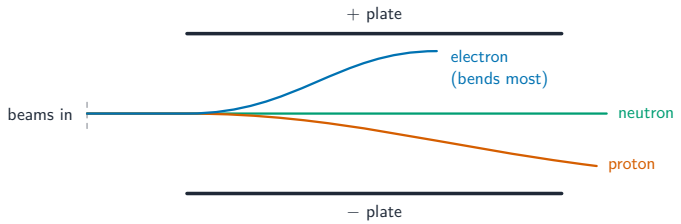


Protons and neutrons sit in the tiny nucleus; electrons move in shells around it

particle	relative charge	relative mass
proton	+1	1
neutron	0	1
electron	−1	$\frac{1}{1836}$ (≈ 0)

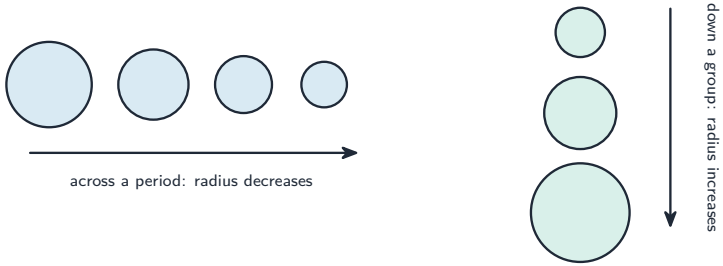
Proton number Z = protons; **nucleon number** A = protons + neutrons; neutrons = $A - Z$. In an ion, electrons = $Z-$ charge. E.g. $^{27}_{13}Al^{3+}$: 13 protons, 14 neutrons, 10 electrons.

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]

3.5 The table gives the particles in four species.

Species	Protons	Neutrons	Electrons
A	12	12	10
B	8	10	10
C	12	14	12
D	17	18	18

(a) Identify each species, giving its symbol with mass number and any charge. [4]

(b) State which two species contain nuclei of the same element, and explain how you can tell. [2]

(c) Explain, in terms of shells and of the attraction between the nucleus and the outer electrons, why **A** is much smaller than **C**. [3]

(d) Predict, with a reason, whether **D** is larger or smaller than a neutral chlorine atom. [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.

3.5 (a) **A** $^{24}Mg^{2+}$, **B** $^{18}O^{2-}$, **C** ^{26}Mg, **D** $^{35}Cl^-$. Mass number = protons + neutrons; the charge is protons − electrons.
(b) **A** and **C** — both have 12 protons, and the proton number is what fixes the element.
(c) **A** has lost both 3s electrons, so its outermost occupied shell is now the second, not the third; the same 12 protons now hold only 10 electrons, so the pull per electron is greater; there is also less electron–electron repulsion, so the remaining shells are drawn in.
(d) Larger. The extra electron adds repulsion within the same third shell while the nuclear charge is unchanged, so the shell expands.

1 Helium forms an ion $^3_2He^+$.

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]

A-LEVEL CHEMISTRY • EXERCISE SHEET

1.2 Isotopes

Name: _____ Class: _____ Date: _____ **Total: 22 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

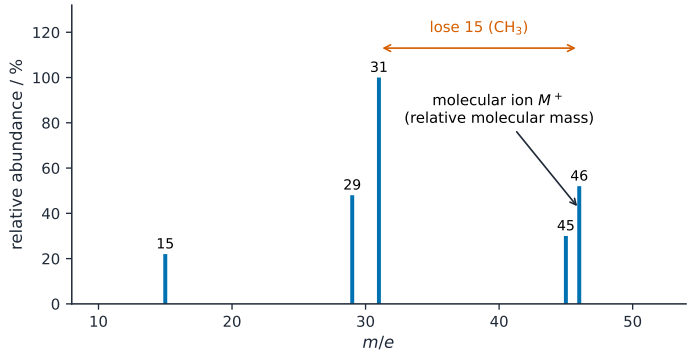
Build the skills to answer exam questions on **isotopes** 同位素 — what they are, the ${}^{A}_{Z}\mathrm{X}$ notation, their properties, and calculating **relative atomic mass** 相对原子质量 from isotopic abundances.

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



M^+ peak $\approx M_r$ · gaps between peaks = mass of fragments lost

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 ${}^{35}_{17}\mathrm{Cl}$ and ${}^{37}_{17}\mathrm{Cl}$.

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% ${}^{35}\mathrm{Cl}$ and 25% ${}^{37}\mathrm{Cl}$:

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

2 Practice

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

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

3.5 The mass spectrum of a sample of element **X** gives the following peaks.

m/z	**64**	**66**	**67**	**68**	**70**
Relative abundance / %	48.6	27.9	4.1	18.8	0.6

(a) Calculate the relative atomic mass of **X** to three significant figures and identify the element. [4]

(b) A second sample of **X**, taken from a meteorite, gives the same five peaks at different heights. State, with a reason, whether the two samples have the same chemical properties. [2]

(c) Explain why the peak at $m/z = 67$ is so much shorter than the others. [2]

(d) A student writes "the relative atomic mass of **X** is 65.5 g". Give **two** things wrong with that statement. [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 $A_r = \dfrac{(63 \times 69) + (65 \times 31)}{100} = \dfrac{6362}{100} = 63.6$.

3.5 (a) $A_r = \dfrac{(64 \times 48.6) + (66 \times 27.9) + (67 \times 4.1) + (68 \times 18.8) + (70 \times 0.6)}{100} = \dfrac{6546.9}{100} = 65.469 = 65.5$; this is **zinc**.
(b) Yes. Chemical properties depend on the electron arrangement, which is fixed by the proton number and is the same for every isotope — the extra neutrons take no part in bonding.
(c) The height of a peak is proportional to the relative abundance of that isotope; only 4.1% of the atoms are ^{67}X, so few ions of that mass reach the detector.
(d) Relative atomic mass is a **ratio** of masses, so it has no units; and it is a weighted mean over all the isotopes, not the mass of any single atom.

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 HCl(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]

A-LEVEL CHEMISTRY • EXERCISE SHEET

1.3 Electrons, energy levels and atomic orbitals

Name: _____ Class: _____ Date: _____ **Total: 29 marks**

KEY WORDS electronic configuration 电子排布 • orbital 轨道 • sub-shell 亚层 • shell 壳层 • proton number 质子数

Objective

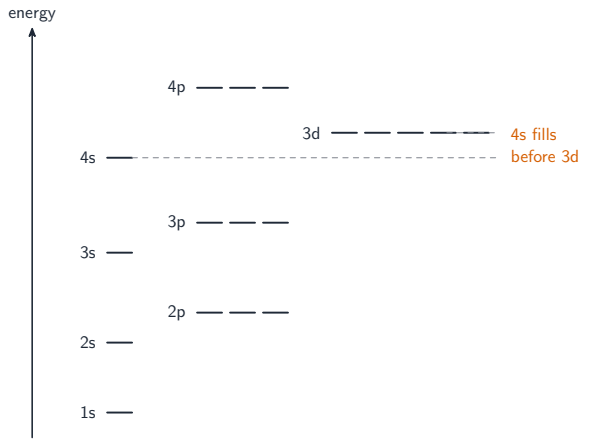
Build the skills to answer exam questions on **electrons, energy levels and atomic orbitals** — **shells, sub-shells and orbitals** 壳层、亚层和轨道, the order of filling, **electronic configurations** 电子排布, and orbital shapes.

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

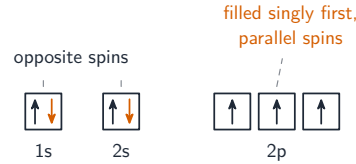


Order of rising energy: 1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p (4s fills before 3d)

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

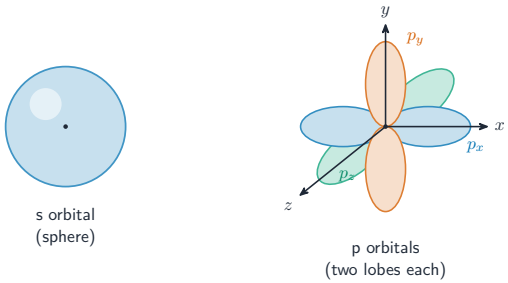
Electronic configuration

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

■ Sub-shells, orbitals, and the two rules that fix an order

An **orbital** 轨道 is a region that can hold **at most two electrons**, and only if they have **opposite spins**. The sub-shells and their capacities:

Sub-shell	Orbitals	Maximum electrons	Shape
s	1	2	spherical
p	3	6	dumb-bell, along x, y, z
d	5	10	more complex

The filling order follows increasing energy, and the one crossover that matters is that **4s fills before 3d**:

1s 2s 2p 3s 3p **4s** 3d 4p

Hund's rule: within a sub-shell, electrons occupy the orbitals **singly with parallel spins** before any orbital is doubled up, because electrons repel. That is why an electrons-in-boxes diagram for nitrogen ($2p^3$) shows three separate up-arrows, not one pair and one single.

Two exceptions, both explained the same way — a half-filled or filled d sub-shell is more stable: **chromium** is $[Ar]\,3d^5 4s^1$ and **copper** $[Ar]\,3d^{10}4s^1$.

△ **When an ion forms, the 4s electrons leave FIRST**, even though 4s filled first. Fe is $[Ar]\,3d^6 4s^2$ but Fe^{2+} is $[Ar]\,3d^6$ and Fe^{3+} is $[Ar]\,3d^5$.

Ionisation energy is the evidence. Successive ionisation energies rise steadily within a shell and **jump sharply** when the next electron must come from a shell closer to the nucleus. Counting the electrons removed before the big jump gives the **group** — a jump after the second electron means Group II.

Worked example. Write the electronic configuration of a Cu^{2+} ion, and explain the shape of the graph of successive ionisation energies for magnesium.

1. Cu is $[Ar]\,3d^{10}4s^1$ (an exception); remove the 4s electron first, then one 3d: Cu^{2+} is $[Ar]\,3d^9$.
2. Magnesium's first two ionisation energies are relatively low and close together (both 3s electrons). The third shows a large jump, because that electron comes from the 2p sub-shell — closer to the nucleus and less shielded — which is the evidence that magnesium is in Group II.

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]

2.3 State the maximum number of electrons in a p sub-shell and explain why. [2]

2.4 Give the electronic configuration of a Cr atom and explain why it is an exception. [2]

2.5 Explain what a large jump between successive ionisation energies tells you. [2]

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]

3.5 (a) Give the full electronic configuration of a vanadium atom (proton number 23). [2]

(b) Give the electronic configuration of a V^{3+} ion, and state which electrons are lost first. [2]

(c) Draw an electrons-in-boxes diagram for the 3d and 4s sub-shells of a vanadium atom, and state the rule that determines the arrangement. [3]

(d) The first six ionisation energies of an element, in kJ mol^{-1}, are 786, 1580, 3230, 4360, 16 100, 19 800. Deduce the group of the element and explain your reasoning. [3]

(e) Explain why the first ionisation energy of aluminium is lower than that of magnesium, despite aluminium having a greater nuclear charge. [3]

Solutions

2.1 (a) 6; (b) 10.

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

2.3 Six; a p sub-shell has three orbitals and each orbital holds at most two electrons, with opposite spins.

2.4 $[Ar]\,3d^5 4s^1$; a half-filled d sub-shell is more stable than the expected $3d^4 4s^2$.

2.5 The next electron is being removed from a shell closer to the nucleus, which is less shielded and more strongly attracted, so far more energy is needed.

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.

3.5 (a) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$.
(b) $[Ar]\,3d^2$; the two 4s electrons are lost first, then one 3d electron.
(c) 4s shown as one box with two opposed arrows; 3d shown as five boxes with three single arrows all pointing the same way; Hund's rule — electrons occupy orbitals singly with parallel spins before pairing, because they repel.
(d) Group IV; the large jump comes between the fourth and fifth ionisation energies, so four electrons are removed from the outer shell before the next must come from a shell closer to the nucleus.
(e) Magnesium's outer electron is in a 3s orbital and aluminium's in a 3p orbital; the 3p sub-shell is slightly higher in energy and better shielded by the 3s electrons; that outweighs the extra proton, so less energy is needed to remove it.

Name: A-Level Chemistry: **w25 11**

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

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

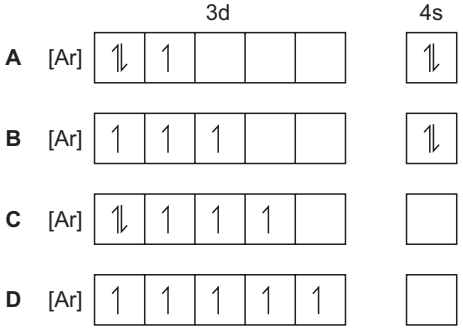
B $1s^2 2s^2 2p^6 3s^2$

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

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

A-Level Chemistry: **w25 12**

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.

A-Level Chemistry: **w25 13**

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 • successive ionisation energies 逐级电离能 • spin-pair repulsion 自旋成对排斥 • 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

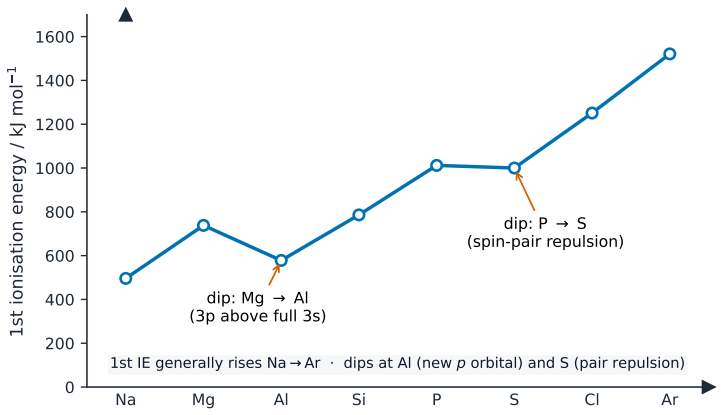
First ionisation energy

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

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

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

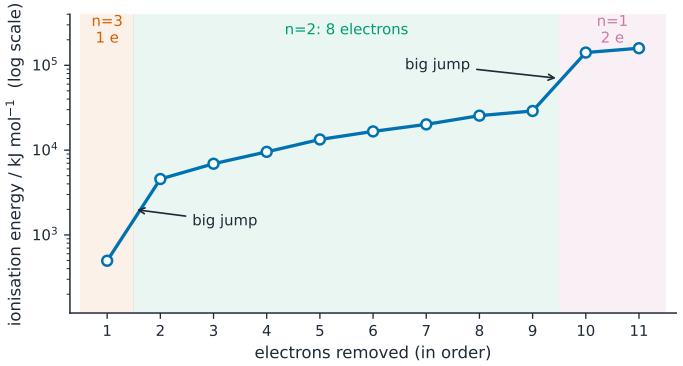
Trends across Period 3



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 jump = next electron from a shell closer to the nucleus (shell structure)

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	Al
B	Mg	Al	Si
C	P	S	Cl
D	S	Cl	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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What are the correct identities of these three elements?

	element X	element Y	element Z
A	Na	Mg	Al
B	Mg	Al	Si
C	P	S	Cl
D	S	Cl	Ar