Atomic Structure and Properties

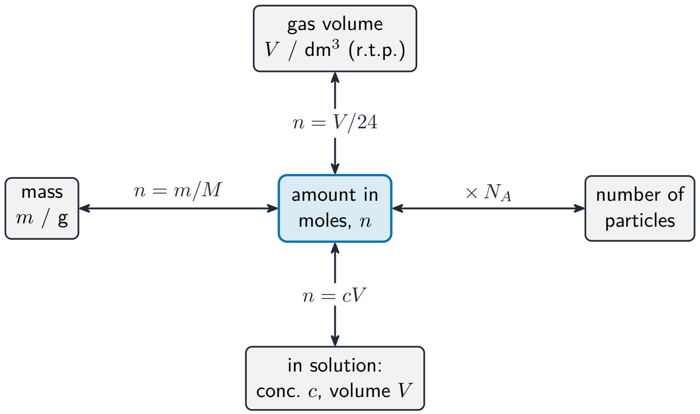
AP Chemistry

Moles and Molar Mass

Because atoms are far too small to count, chemists count in **moles** 摩尔. One mole is **Avogadro's number** 阿伏伽德罗常数 of particles, $N_A = 6.022 \times 10^{23}$. The **molar mass** 摩尔质量 (grams per mole, read off the periodic table) converts between mass and moles:

$$n = \frac{m}{M}.$$

Moles are the bridge between the lab (grams you weigh) and the equation (particles that react).



The mole is the hub: convert between mass, particles, gas volume, and concentration

Worked example. How many moles, and how many molecules, are in 36.0 g of water ($M = 18.0$ g/mol)?

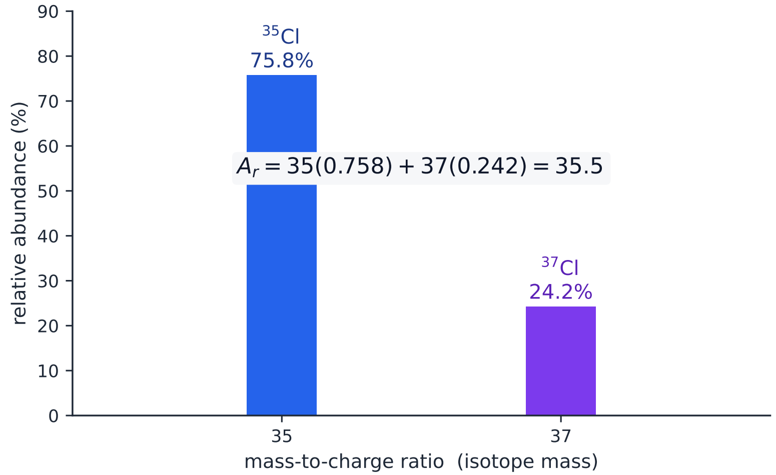
$$n = \frac{m}{M} = \frac{36.0}{18.0} = 2.0 \text{ mol}, \qquad N = n\,N_A = 2.0 \times 6.022 \times 10^{23} = 1.2 \times 10^{24} \text{ molecules.}$$

Mass Spectra of Elements

A **mass spectrometer** 质谱仪 separates atoms by mass, giving a **mass spectrum** 质谱: peaks at each **isotope** 同位素 (same element, different neutron count) with heights showing their **relative abundance** 相对丰度. The element's average **atomic mass** is the abundance-weighted average of its isotope masses.

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

Relative atomic mass is the abundance-weighted average of the isotopes



The mass spectrum of chlorine: two isotopes with different abundances

Worked example. Chlorine is 75.8% chlorine-35 and 24.2% chlorine-37. Its average atomic mass is

$$A_r = (35)(0.758) + (37)(0.242) = 26.5 + 8.95 = 35.5.$$

The average lies closer to 35 because that isotope is more abundant – which is why the periodic-table value is 35.5, not a whole number.

Elemental Composition of Pure Substances

The **percent composition** 百分组成 of a compound is each element's mass fraction. From it you find the **empirical formula** 实验式 (simplest whole-number ratio of atoms) by converting each element's mass to moles and dividing by the smallest. The **molecular formula** 分子式 is a whole-number multiple of the empirical formula, found from the molar mass.

element	% by mass	$\div A_r \to$ moles	$\div$ smallest (3.33)	ratio
C	40.0	$40.0/12 = 3.33$	1.0	1
H	6.7	$6.7/1 = 6.7$	2.0	2
O	53.3	$53.3/16 = 3.33$	1.0	1

empirical formula CH_2O - if $M_r = 180$, it fits $180/30 = 6$ times: molecular formula $C_6H_{12}O_6$

Finding the empirical formula: mass to moles, divide by the smallest, read the ratio

Worked example. A compound is 40.0% C, 6.7% H, and 53.3% O by mass. Assuming 100 g, convert each mass to moles and divide by the smallest:

$$\mathrm{C}: \frac{40.0}{12} = 3.33, \quad \mathrm{H}: \frac{6.7}{1} = 6.7, \quad \mathrm{O}: \frac{53.3}{16} = 3.33 \xrightarrow{\div 3.33} 1:2:1,$$

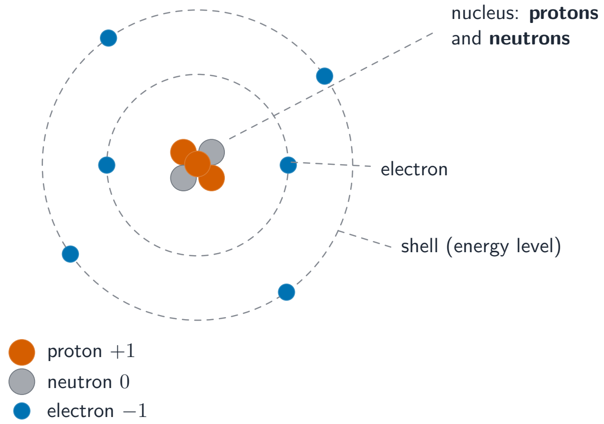
so the empirical formula is CH_2O. If the molar mass were 180 g/mol ($= 6 \times 30$), the molecular formula would be $C_6H_{12}O_6$ – glucose.

Composition of Mixtures

Unlike a pure compound, a **mixture** 混合物 has variable composition – its parts keep their own identities. Describe a mixture by the mass or mole fraction of each component; these do not follow a fixed formula. Spectroscopy (like PES or absorption) can measure how much of each component is present.

Atomic Structure and Electron Configuration

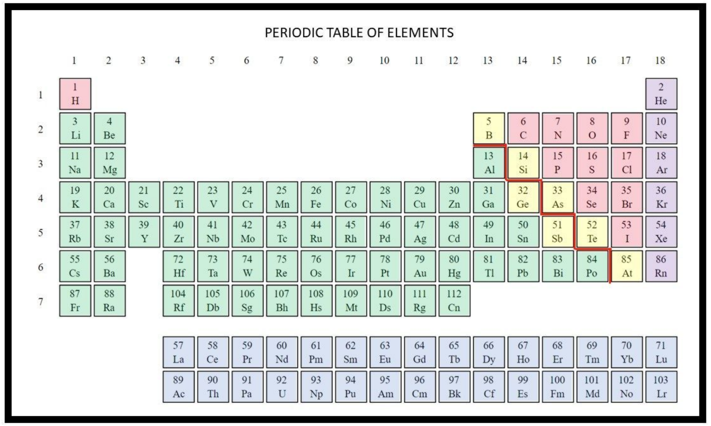
An atom is a tiny **nucleus** 原子核 (protons and neutrons) surrounded by electrons in **shells** and **subshells** (s, p, d, f). The **electron configuration** 电子排布 lists how electrons fill these, lowest energy first (e.g. $1s^2\,2s^2\,2p^6$). The outermost, highest-energy electrons – the **valence electrons** 价电子 – control chemistry. **Coulomb's law** explains their energies: electrons closer to, and less shielded from, the nucleus are held more tightly.



An atom: a tiny nucleus of protons and neutrons, with electrons in shells

Flame tests: each metal ion gives its own colour because heat excites its electrons and, as they drop back down, they emit light of specific wavelengths

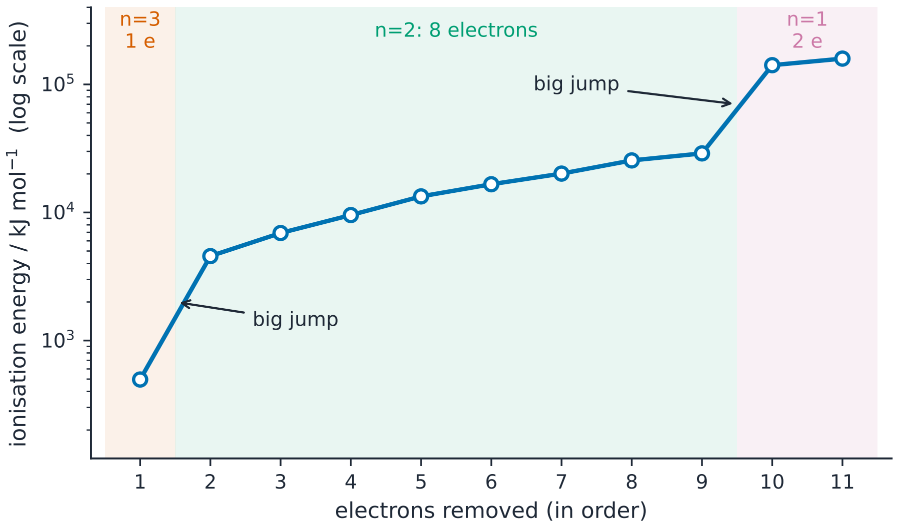
Worked example. Write the electron configuration of sulfur ($Z = 16$). Fill subshells in order until 16 electrons are placed: $1s^2\,2s^2\,2p^6\,3s^2\,3p^4$. The $3s$ and $3p$ electrons (six in total) are the valence electrons, so sulfur tends to gain two electrons to complete its octet.



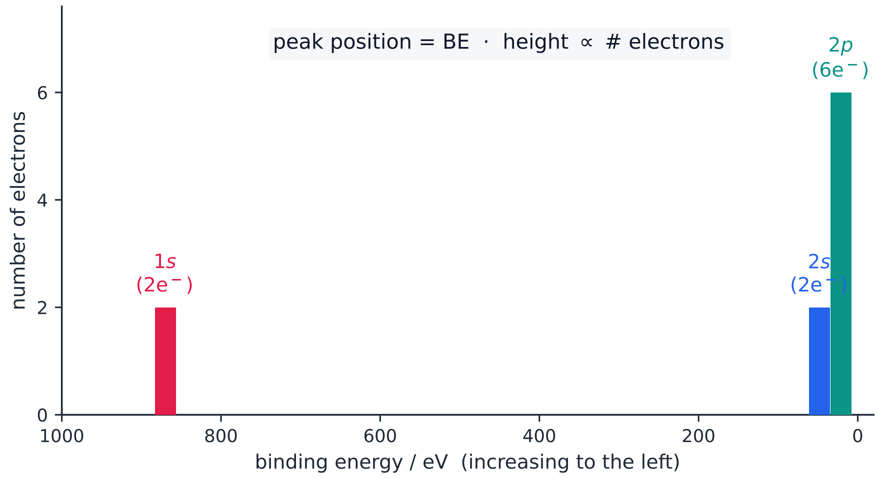
The periodic table organises elements by atomic structure — electron configuration explains the patterns

Photoelectron Spectroscopy

Photoelectron spectroscopy 光电子能谱 (PES) measures the energy needed to remove electrons from each subshell. Each peak is a subshell: its **position** gives the binding energy (how tightly held) and its **height** gives the number of electrons in it. PES data let you read an element's electron configuration and confirm shell structure directly.



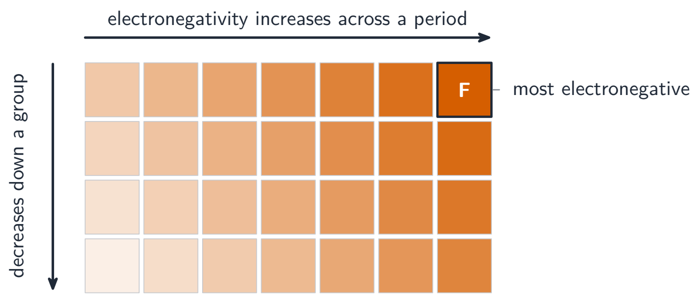
Successive ionisation energies reveal the shell structure through big jumps



The photoelectron spectrum of neon: one peak per subshell, height set by electron count

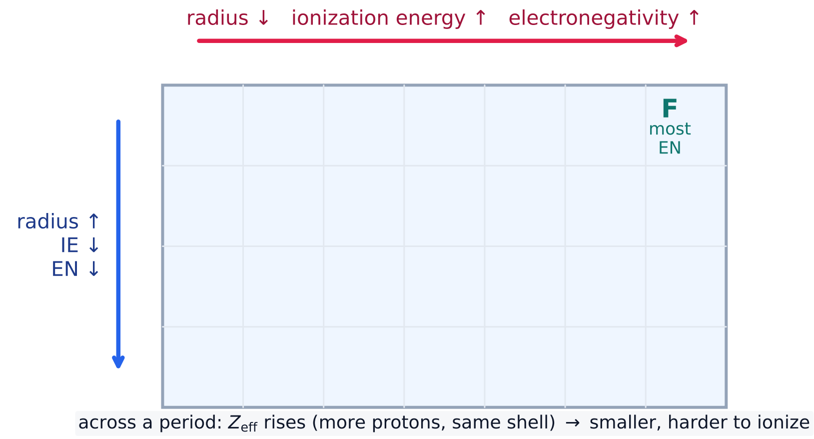
Periodic Trends

Trends across the periodic table follow from **nuclear charge** and **shielding**:



Electronegativity rises across a period and falls down a group

- **Atomic radius** 原子半径 decreases across a period (stronger pull) and increases down a group (more shells).
- **Ionization energy** 电离能 (energy to remove an electron) increases across, decreases down – opposite to radius.
- **Electronegativity** 电负性 (pull on shared electrons) increases across and up, toward fluorine.



Periodic trends: how radius, ionization energy, and electronegativity change across and down

Valence Electrons and Ionic Compounds

Atoms gain, lose, or share **valence electrons** to reach stable configurations. Metals (low ionization energy) lose electrons to form **cations** 阳离子; nonmetals gain electrons to form **anions** 阴离子. Oppositely charged ions attract into an **ionic compound** 离子化合物, whose formula balances the charges to make the whole neutral. For example, aluminium (3+) and oxide (2−) combine as Al_2O_3 so the +6 and −6 cancel.

Exam tips

- Use the mole as the hub: convert grams↔moles with $n = m/M$ and moles↔particles with Avogadro's number.
- Relative atomic mass is the **abundance-weighted average** of the isotopes — it lies closer to the more abundant one, not halfway.
- For an **empirical formula**, turn each element's mass into moles and divide by the smallest; scale up to whole numbers.
- Read **periodic trends** from nuclear charge and shielding: atomic radius decreases across a period, ionisation energy and electronegativity increase across (and up).
- Fill electron configurations in energy order; the outer **valence electrons** control the chemistry.