# Unit 4 · Classification of Elements

STUDY NOTES

### WHAT NEB'S GRADE 11 EXAM ASKS

- **CDC's grid (2077):** Physical Chemistry (Units 1–8 together): 28 of 75 marks; CDC's curriculum puts this unit there
- **The paper:** 11 MCQs × 1 · 8 short × 5 · 3 long × 8; 3 hours; 1 mark per expected point
- **CDC's model paper:** short question (with Unit 3): X with 2, 8, 5 electrons; why $X^{3-}$ is larger than X; **OR** a table of first ionization energies of period 2: define it, one factor it depends on, the hardest atom to ionize, why the rise from C to N is steep
- **MCQ (1 mark)**
  - same number for group and period; outer electrons of group 13, period 2
  - highest first IE from configurations; most metallic; what a group shares
  - order of electronegativity; Li–Mg, Be–Al (diagonal); higher EA than F (Cl)
  - adding an electron (energy released); the shielding effect
  - B above A, C left of A: order of EN; what gives the period
- **Short (5 marks, in parts)**
  - differences: period/periodicity, nuclear/effective nuclear charge, atomic/ionic radius, EN/EA
  - reasons: C smaller than Li; Mg harder to ionize than Ca; N and O are p-block
  - modern periodic law, how it mends Mendeleev's; smallest and largest atom in a table
  - periodicity and its cause; properties falling across a period
  - Z and $Z_{\text{eff}}$ down a group, and the trends they explain
  - atomic radius: define, trends, why a cation is smaller
  - IE table of period 2; isoelectronic $O^{2-}$ … $Al^{3+}$: protons, electrons, order of size
  - EA table: trend, the minus sign, highest; F's $\Delta H = -328$: name, define, N's
  - a period drawn: which, colors, gap between Mg and Al, metallic or covalent radius
- **Long (8 marks)**: period 3 (metalloid, EN order, easiest cation, metallic character); $Z_{\text{eff}}$ and shielding, its trends and effects; metallic character and wires; …$4p^5$ (Br): Z, period, group, block, $X^+$ and $X^-$; s-block (Ca's configuration, soft alkali metals, sizes, diagonal pairs); a table's largest atom, highest IE, smallest EA, most metallic; groups by property

## Key terms

**Modern periodic law** (Moseley, 1913): properties of the elements are periodic functions of their **atomic numbers**.

**Group**: vertical column (18); same valence electrons, similar properties.

**Period**: horizontal row (7); period number = number of shells.

**Block**: s, p, d, f, by the subshell the last electron enters.

**Periodicity**: properties repeat at regular intervals along the atomic numbers; cause: outer configuration repeats.

**Nuclear charge Z**: charge of the nucleus = atomic number.

**Shielding (screening) effect**: inner electrons cut the nucleus's pull on outer ones.

**Effective nuclear charge** $Z_{\text{eff}}$: net positive charge an electron really feels.

**Atomic radius**: half the distance between the nuclei of two identical bonded atoms (covalent, metallic, van der Waals).

**Ionic radius**: distance from the nucleus of an ion to the edge of its cloud.

**Isoelectronic**: same number of electrons ($O^{2-}$, $F^-$, Ne, $Na^+$, $Mg^{2+}$, $Al^{3+}$: 10).

**First ionization energy**: least energy to remove 1 mol of electrons from 1 mol of isolated gaseous atoms to give 1 mol of gaseous +1 ions; always positive.

**Electronegativity**: tendency of an atom in a molecule to pull the shared pair towards itself; no unit (Pauling).

**Electron affinity**: energy released when 1 mol of electrons is added to 1 mol of isolated gaseous atoms to give 1 mol of −1 ions.

**Metallic character**: how readily an atom loses electrons and shows metal properties.

**Diagonal relationship**: Li–Mg, Be–Al, B–Si alike (similar charge-to-size ratio).

## Formulas

| | |
|---|---|
| $Z_{\text{eff}} = Z - S$ | $S$ ($\sigma$): shielding constant<br>**Use:** net pull on an electron |
| $S = 0.35a + 0.85b + 1.00c$ | $a$ same group, $b$ shell $n-1$, $c$ lower<br>**Use:** Slater, s or p electron |
| $\text{Na(g)} \longrightarrow \text{Na}^+\text{(g)} + \text{e}^-$ | $\Delta H = +496$ kJ/mol<br>**Use:** first IE |
| $\text{F(g)} + \text{e}^- \longrightarrow \text{F}^-\text{(g)}$ | $\Delta H = -328$ kJ/mol<br>**Use:** first EA |

- Slater's groups: (1s) (2s 2p) (3s 3p) (3d) (4s 4p); none from groups to the right; 0.30 within 1s

- 1 eV per atom = 96.5 kJ/mol; 1 Å = 100 pm = $10^{-10}$ m

## From Mendeleev to Moseley

**Mendeleev** (and Lothar Meyer, 1869): by atomic weight; left gaps (Sc, Ga, Ge predicted)

**Defects**

- anomalous pairs: Ar before K, Co before Ni, Te before I
- isotopes would need separate places
- hydrogen's place (like group 1 and group 17)
- Cu, Ag, Au with the alkali metals; lanthanides crowded
- no noble gases; no reason for the repeating

**Moseley (1913)**: $\sqrt{}$(X-ray frequency) rises one step per element → order by **atomic number**: the pairs fall right, isotopes share one place, the missing Z (43, 61, 72, 75) shown

## The table

- groups 1–18 (old IA … VIIA, 0, IB … VIIIB); 1 alkali, 2 alkaline earth, 3–12 transition, 15 pnictogens, 16 chalcogens, 17 halogens, 18 noble gases
- periods: 1 has 2 elements; 2, 3 have 8; 4, 5 have 18; 6, 7 have 32

| Block | Last electron | Outer configuration | Where |
|---|---|---|---|
| s | ns | $ns^{1-2}$ | groups 1, 2 (+He) |
| p | np | $ns^2\,np^{1-6}$ | 13–18 |
| d | (n − 1)d | $(n-1)d^{1-10}\,ns^{1-2}$ | 3–12 |
| f | (n − 2)f | 4f, 5f | lanthanides, actinides |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H | | s block: groups 1–2 | | | | | | | | | | | | | | | He |
| Li | Be | d block: groups 3–12 | | | | | | | | | | B | C | N | O | F | Ne |
| Na | Mg | p block: groups 13–18 | | | | | | | | | | Al | Si | P | S | Cl | Ar |
| K | Ca | Sc | Ti | V | Cr | Mn | Fe | Co | Ni | Cu | Zn | Ga | Ge | As | Se | Br | Kr |
| Rb | Sr | Y | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I | Xe |
| Cs | Ba | * | Hf | Ta | W | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| Fr | Ra | ** | Rf | Db | Sg | Bh | Hs | Mt | Ds | Rg | Cn | Nh | Fl | Mc | Lv | Ts | Og |
| | | * 4f | La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| | | ** 5f | Ac | Th | Pa | U | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lr |

The table by block.

- s: soft reactive metals, low IE, electropositive, strong bases
- p: non-metals, metalloids, some metals; non-metals electronegative
- d: transition metals, hard, high melting points, conduct, several oxidation states, colored compounds ($K_2Cr_2O_7$ orange, $KMnO_4$ purple)
- f: inner transition; rare earths = Sc, Y and the lanthanides (not rare, hard to purify)
- $3d^6\,4s^2$ = Fe: d block, period 4, group 8; …$4p^5$ (Z = 35, Br): period 4, group 17, p block; $Br^+ < Br < Br^-$
- metals left and middle (electropositive, reducing); non-metals top right (electronegative, oxidizing); metalloids B, Si, Ge, As, Sb, Te (At) on the staircase: semiconductors

## Effective nuclear charge

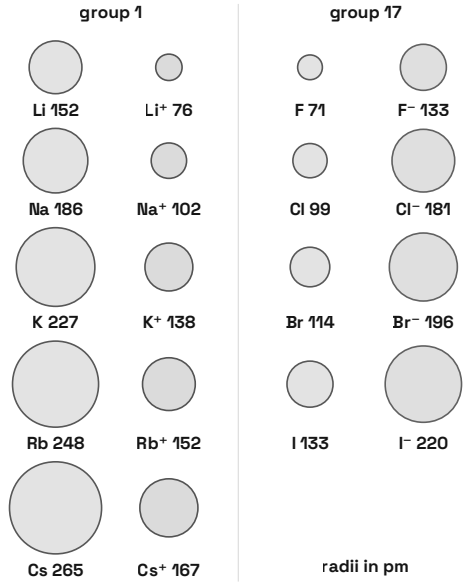
- simple: $S$ = inner electrons → Na 11 − 10 = +1, Cl 17 − 10 = +7, K +1
- Slater, Na's 3s: $S = 8 \times 0.85 + 2 \times 1.00 = 8.8 \rightarrow Z_{\text{eff}} = 2.2$
- **across a period**: Z up, same shell shields poorly → $Z_{\text{eff}}$ **rises**, electrons pulled in
- **down a group**: Z rises a lot but so do inner shells → $Z_{\text{eff}}$ about the same (Na, K, Rb, Cs all 2.2); the outer electron is **farther away**, so the **pull falls**

## Trends

| | Across a period → | Down a group ↓ |
|---|---|---|
| atomic radius | decreases | increases |
| ionization energy | increases | decreases |
| electronegativity | increases | decreases |
| electron affinity | increases (dips) | decreases |
| metallic character | decreases | increases |

**Atomic radius**: shells (more, larger) and $Z_{\text{eff}}$ (larger, smaller atom)

- covalent < metallic < van der Waals (Cl: 99, —, 175 pm)
- period 3: Na 166, Mg 141, Al 121, Si 111, P 107, S 105, Cl 102 pm; C smaller than Li (same shells, more $Z_{\text{eff}}$)
- transition series: nearly the same (d electrons inner)
- H: covalent 37 pm; Bohr radius 0.53 Å = 53 pm




Cations smaller than their atoms, anions larger; all grow down a group.

**Ions**

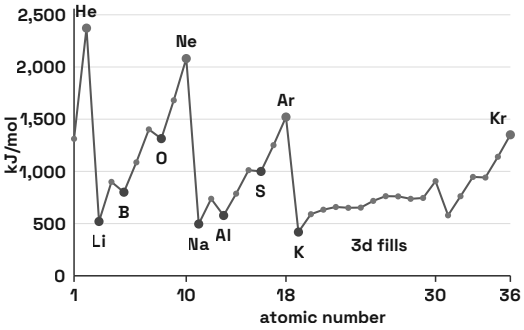
- cation smaller: outer shell gone, same Z on fewer electrons
- anion larger: same Z on more electrons, more repulsion
- isoelectronic: more protons, smaller: $\mathbf{Al^{3+} < Mg^{2+} < Na^+ < Ne < F^- < O^{2-}}$ (13, 12, 11, 10, 9, 8 protons; 10 electrons each)

**Ionization energy**: lower for a farther electron, higher for a larger $Z_{eff}$

- group 1: Li 520, Na 496, K 419, Rb 403, Cs 376 kJ/mol; Mg harder than Ca
- second IE always larger; Na's 4562 (inner shell) → $Na^+$, never $Na^{2+}$
- atoms gaseous: alone, no neighbors' pull

| Li | Be | B | C | N | O | F | Ne |
|---|---|---|---|---|---|---|---|
| 520 | 900 | 801 | 1086 | 1402 | 1314 | 1681 | 2081 |

- highest: **Ne** (full shell, highest $Z_{eff}$ in the period)
- **Be > B**: B's 2p electron higher, shielded by $2s^2$
- **N > O**: N's $2p^3$ half-filled; O's paired electron repelled
- C → N steep: N's half-filled 2p; the same dips in period 3 (Mg > Al, P > S)
- O's second IE > N's ($O^+$ is $2p^3$, half-filled)




First IE against Z: each period climbs from an alkali metal to a noble gas, with dips at B, O, Al and S.

**Electronegativity** (Pauling): smaller atom, larger $Z_{eff}$ → higher

- F 3.98 > O 3.44 > Cl 3.16 > N 3.04; Cs 0.79
- period 2: Li 0.98, Be 1.57, B 2.04, C 2.55, N 3.04, O 3.44, F 3.98
- B above A, C left of A: C < A < B

| Bond | ΔEN | Example |
|---|---|---|
| non-polar | 0 to ~0.4 | H–H 0; C–H 0.35 |
| polar covalent | ~0.4 to 1.7 | H–Cl 0.96 |
| ionic | over ~1.7 | NaF 3.05 |

- 1.7 is a guide: HF (1.78) is polar covalent

**Electron affinity**: given as energy released (328 kJ/mol) or as ΔH (−328 kJ/mol); minus means released

| | C | N | O | F | Si | P | S | Cl |
|---|---|---|---|---|---|---|---|---|
| ΔH | −122 | >0 | −141 | −328 | −134 | −72 | −200 | −349 |

- **no gain**: noble gases, Be, Mg ($ns^2$), N (half-filled): ΔH > 0
- **Cl > F** (349 > 328, the highest of all): F so small its 2p is crowded; S > O likewise
- adding a second electron to $O^-$: energy taken in (repelled by the negative ion)
- EA (energy, gaseous atom) ≠ EN (no unit, atom in a bond)

**Metallic character**: low IE, large atom

- period 3: Na, Mg, Al metals; Si metalloid; P, S, Cl non-metals
- group 14: C non-metal, Si, Ge metalloids, Sn, Pb metals; Cs, Fr most metallic
- groups 1, 2: one or two loosely held electrons → strongly metallic; 16, 17 non-metallic (gain electrons)
- transition metals for wires: free electrons conduct; ductile

**Diagonal pairs**: Li and Mg both burn to a normal oxide and form a nitride ($Li_3N$, $Mg_3N_2$)

### COMMON MISTAKES

✗ $Z_{eff}$ decreases down a group
✓ stays about the same; the pull falls because the electron is farther away.

✗ order by atomic mass
✓ by **atomic number** (Ar 18 before K 19).

✗ HF (ΔEN 1.78) is the model polar bond
✓ HCl (0.96); HF shows 1.7 is only a guide.

✗ H radius "0.53 Å = 37 pm"
✓ Bohr radius 0.53 Å = 53 pm; covalent radius 37 pm.

✗ electron affinity table in eV
✓ kJ/mol.

✗ fluorine has the highest electron affinity
✓ chlorine (F is the most electronegative).

✗ O's first IE is higher than N's
✓ lower; N's $2p^3$ is half-filled.

✗ the actinides are the rare earths
✓ Sc, Y and the lanthanides.

✗ $K_2Cr_2O_7$ purple, $KMnO_4$ orange
✓ dichromate orange, permanganate purple.