Unit 6 · Periodic Table

STUDY NOTES

Key terms

Modern periodic law: physical and chemical properties of the elements are periodic functions of their atomic numbers.

Period / group: 7 rows / 18 columns; period = number of the outermost shell; group = same outer electrons.

Orbital: region where an electron is likely to be found; at most 2 electrons.

Ionization potential: minimum energy to remove the most loosely held electron from one isolated gaseous atom; $X(g) \rightarrow X^{+}(g) + e^{-}$.

Electron affinity: energy released when an electron is added to one isolated gaseous atom; $X(g) + e^{-} \rightarrow X^{-}(g) +$ energy.

Electronegativity: tendency of an atom in a molecule to attract the shared pair to itself; no unit.

Covalent radius: half the distance between nuclei of two identical atoms in a single bond.

Valency: electrons an atom loses, gains or shares in a compound.

Periodic table

- order: atomic number, not mass; chemistry is done by electrons, and neutrons take no part
- by mass out of order, by Z right: Ar 39.95 before K 39.10; Co 58.93 before Ni 58.69; Te 127.60 before I 126.90
- 118 elements; period 7 complete since oganesson (2016)

Period	Subshells filled	Elements
1	1s	2
2, 3	ns, np	2 + 6 = 8
4, 5	ns, (n − 1)d, np	2 + 10 + 6 = 18
6, 7	ns, (n − 2)f, (n − 1)d, np	2 + 14 + 10 + 6 = 32

Merits (over Mendeleev's):

- based on atomic number
- Ar–K, Co–Ni, Te–I no longer anomalies
- isotopes need no separate places
- explains why properties repeat (outer configuration repeats)
- metals, non-metals, metalloids in separate regions, transition metals in a block

Limitations:

- hydrogen has no proper place ($1s^1$ like group 1, but a non-metal gaining one electron like halogens)
- helium s block by electrons, placed in group 18
- lanthanides and actinides outside the main table

Electronic configuration

Subshell	s	p	d	f
orbitals	1	3	5	7
electrons	2	6	10	14

- **Aufbau**: lowest energy first: 1s < 2s < 2p < 3s < 3p < 4s < 3d < 4p
- $(n + l)$ rule: s, p, d, f = 0, 1, 2, 3; smaller sum first; equal sums: smaller n. 4s = 4, 3d = 5 → 4s first
- **Pauli**: at most 2 in an orbital, opposite spins, ↑↓ (1925: no two electrons in exactly the same state)
- **Hund**: one in each orbital, same spin, then pair up
- C 2p: ↑ · ↑ · empty (2 unpaired); N: ↑ · ↑ · ↑ (3); O: ↑↓ · ↑ · ↑ (2)
- short form: Na = [Ne] $3s^1$; core takes no part in reactions
- **Exceptions**: Cr [Ar] $4s^1$ $3d^5$ (6 unpaired); Cu [Ar] $4s^1$ $3d^{10}$: 4s and 3d very close; d^5, d^{10} especially stable
- **Ions**: 4s lost first: Fe [Ar] $4s^2$ $3d^6$ (4 unpaired) → Fe^{2+} [Ar] $3d^6$ → Fe^{3+} [Ar] $3d^5$ (half-filled, more stable in air)
- either order earns marks: [Ar] $4s^2$ $3d^6$ or [Ar] $3d^6$ $4s^2$

Place from configuration

- period = highest n; block = subshell of the last electron (Aufbau)
- group: s block: s electrons; p block: 12 + p electrons; d block: (n − 1)d + ns electrons
- Z = 17 [Ne] $3s^2$ $3p^5$: period 3, p, group 17. Z = 24: period 4, d, 5 + 1 = group 6

Blocks

	s	p	d	f
where	groups 1, 2 (and He)	13–18	3–12	two rows below the table
outer	ns^{1-2}	$ns^2\ np^{1-6}$	$(n-1)d^{1-10}\ ns^{1-2}$	$(n-2)f^{1-14}\ (n-1)d^{0-1}\ ns^2$
kinds	metals (not H, He); soft, light, low m.p.	metals, metalloids, non-metals, noble gases	all metals; hard, high m.p. (W 3,422 °C highest); Hg, Zn odd ones out	all metals, silvery, fairly reactive
valency	fixed: 1 or 2	often variable: P 3, 5; S 2, 4, 6	variable: Fe 2, 3; Cu 1, 2; Mn 2–7	mostly 3
bonding	mostly ionic; low ionization potential; strong reducing agents	covalent with each other, ionic with s-block metals	alloys (stainless steel, brass); complex ions, $[Cu(NH_3)_4]^{2+}$	very similar in a series; lanthanide contraction
oxides / color	basic (NaOH, KOH alkalis); compounds usually white; flame colors	non-metals' acidic (CO_2, SO_2, P_4O_{10}); Al_2O_3 amphoteric	most compounds colored; catalysts: Fe (Haber), V_2O_5, Ni, Pt, Pd, Rh	lanthanides La–Lu (4f); actinides Ac–Lr (5f), all radioactive

- **Flames**:
  - Li crimson
  - Na yellow
  - K lilac
  - Ca orange-red
  - Sr red
  - Ba pale green
- **Color (d block)**: electrons jump between d orbitals, absorbing part of the light; d^0 (Sc^{3+}), d^{10} (Zn^{2+}) → colorless or white; Cu^{2+} $3d^9$ blue
- paramagnetic: unpaired d electrons; ferromagnetic: Fe, Co, Ni
- **Zn**, Cd, Hg: full d, strictly not transition elements; in the exam Sc to Zn are the transition metals, Zn not typical
- rare earths mostly not rare: Ce commoner than Cu in the crust
- f uses:
  - Nd magnets
  - Eu red in older TVs, energy-saving lamps
  - Ce flints
  - U fuel
  - Am smoke detectors
- Seaborg, 1944: actinides moved to their own row; Nobel 1951; element 106

Trends

- **Nuclear charge** pulls; **inner electrons shield**; same-shell electrons shield little
- pull felt ≈ protons − inner electrons: Na +1, Cl +7, K +1
- across a period: pull felt ↑; down a group: about same, but a shell farther out

	Across →	Down ↓
atomic size	decreases	increases
ionization potential	increases	decreases
electron affinity	increases (generally)	decreases (generally)
electronegativity	increases	decreases
valency	changes	same
metallic character	decreases	increases

Size (pm, covalent)

- period 2: Li 128, Be 96, B 84, C 76, N 71, O 66, F 57
- period 3: Na 166, Mg 141, Al 121, Si 111, P 107, S 105, Cl 102
- group 1: Li 128, Na 166, K 203, Rb 220, Cs 244
- group 17: F 57, Cl 102, Br 120, I 139
- Sc 170 → Zn 122; most 120–140: new electron goes to inner 3d, shields 4s
- ions: Na 166 → Na^+ 102 (whole shell lost); Cl 102 → Cl^- 181 (more repulsion, same protons)
- noble gases shown larger? van der Waals radius, not covalent (Ar 188); in the exam size decreases group 1 to 18

Valency, period 3

	Na	Mg	Al	Si	P	S	Cl
with H	1	2	3	4	3	2	1
with O	1	2	3	4	5	6	7

- oxides: Na_2O, MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_3, Cl_2O_7; noble gases 0

Ionization potential (kJ/mol): eV per atom or kJ/mol; 1 eV per atom = 96.5 kJ/mol

- depends on
  - nuclear charge
  - size
  - shielding
  - stable arrangements
- H: 13.6 eV = 1,312; Na: 5.14 eV = 496
- period 3: Na 496, Mg 738, Al 578, Si 787, P 1,012, S 1,000, Cl 1,251, Ar 1,521
- group 1: Li 520, Na 496, K 419, Rb 403, Cs 376
- **dips**: Mg > Al (Al's 3p higher than 3s); P > S (half-filled 3p; S's fourth electron shares an orbital)

kJ/mol	1st	2nd	3rd	4th
Na	496	**4,562**	6,910	9,543
Mg	738	1,451	**7,733**	10,543
Al	578	1,817	2,745	**11,577**

- huge jump = electron from the full core; electrons before it = valency (1, 2, 3)

Electron affinity (kJ/mol): Cl 349, Na 53

- F 328, Cl 349, Br 325, I 295; O 141, S 200, Se 195
- **Cl highest of all**: F so small its crowded 2p repels; S > O too
- no stable negative ion:
  - Be, Mg (full s)
  - noble gases
  - N (half-filled p)
- sign: −349 and +349 say the same; write "349 kJ/mol released"

Electronegativity (Pauling, 1932)

- F 3.98, O 3.44, Cl 3.16, N 3.04, C 2.55, H 2.20, Na 0.93, 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
- group 17: 3.98, 3.16, 2.96, 2.66
- top right highest (not noble gases), bottom left lowest

Reactivity

- **metal** = loses electrons: lower ionization potential → more reactive; ↑ down, ↓ across
- **non-metal** = takes electrons: higher affinity, electronegativity → more reactive; ↓ down, ↑ across

Group 1 (ns^1): Li < Na < K < Rb < Cs

- $2M + 2H_2O \rightarrow 2MOH + H_2$:
  - Li fizzes
  - K burns lilac
  - Na melts, darts
  - Rb, Cs explode
- $4Na + O_2 \rightarrow 2Na_2O$ (kept under oil); in plenty of air Na_2O_2, KO_2
- $2Na + Cl_2 \rightarrow 2NaCl$

Group 2 (ns^2): Be < Mg < Ca < Sr < Ba; less reactive than group 1 in the same period

- Be: none, even steam. Mg: slow cold, quick in steam: $Mg + H_2O \rightarrow MgO + H_2$
- $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ (steady); $2Mg + O_2 \rightarrow 2MgO$ (dazzling); $Ca + Cl_2 \rightarrow CaCl_2$
- Nepal: limestone (Udayapur, Palpa, Dang) for cement; magnesite (Kharidhunga); MgO melts at about 2,800 °C, furnace bricks

Group 15 ($ns^2\ np^3$): N, P non-metals; As, Sb metalloids; Bi metal; oxides N_2O_5, P_4O_{10} acidic → Bi_2O_3 basic

- valency 3, and 5 except N (PCl_5)
- N_2 unreactive: N≡N, about 945 kJ/mol. $N_2 + O_2 \rightarrow 2NO$ (lightning); $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (Haber: 450 °C, 200 atm, Fe)
- white P reactive: strained P_4 (60°), burns at about 30 °C, under water: $P_4 + 5O_2 \rightarrow P_4O_{10}$; $2P + 3Cl_2 \rightarrow 2PCl_3$; $PCl_3 + Cl_2 \rightarrow PCl_5$
- red P: chains, safe, matchbox

Group 16 ($ns^2\ np^4$): O > S > Se > Te; O, S non-metals, Se mostly, Te metalloid, Po metal

- valency 2; S also 4, 6. $2H_2 + O_2 \rightarrow 2H_2O$; $H_2 + S \rightarrow H_2S$ (heated); $Fe + S \rightarrow FeS$ (heated)

Group 17 ($ns^2\ np^5$): F > Cl > Br > I

- $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$ (orange); $Cl_2 + 2KI \rightarrow 2KCl + I_2$ (brown); $Br_2 + 2KI \rightarrow 2KBr + I_2$; $I_2 + KCl$: none
- with H_2:
  - F_2 explodes cold and dark
  - Cl_2 explodes in sun
  - Br_2 heated or Pt
  - I_2 slow, partial, $H_2 + I_2 \rightleftharpoons 2HI$
- $2Fe + 3Cl_2 \rightarrow 2FeCl_3$; $Fe + I_2 \rightarrow FeI_2$ (weaker oxidizer, lower valency)
- F more reactive than Cl despite lower affinity: F–F weak (159 against Cl–Cl 243 kJ/mol); F's bonds strong

Period 3

- water:
  - Na violent
  - Mg slow, fast in steam
  - Al none (oxide layer)
  - Si, P, S none
  - $Cl_2 + H_2O \rightleftharpoons HCl + HOCl$
  - Ar none
- oxides:
  - Na_2O, MgO basic
  - P_4O_{10}, SO_3 acidic
  - Al_2O_3 amphoteric
  - Cl_2O_7 strongly acidic
  - SiO_2 weakly acidic

COMMON MISTAKES

✗ Fe^{2+} = [Ar] $4s^2\ 3d^4$
✓ 4s lost first: **[Ar] $3d^6$**.

✗ Cr = [Ar] $4s^2\ 3d^4$
✓ [Ar] $4s^1\ 3d^5$ (Cu likewise).

✗ $4s^2$ in Mn → s block
✓ last electron in 3d: d block, group 7.

✗ more protons, bigger atom
✓ F 57 pm, Li 128 pm: size set by the outer shell.

✗ F has highest electron affinity
✓ **Cl**; F has highest electronegativity.

✗ electronegativity in kJ/mol
✓ no unit.

✗ P burns easily so it is "more reactive" than S
✓ reactive non-metal = takes electrons; P_4 just falls apart.