Topic 12 – The Periodic Table

Subject content:

Content

- Periodic trends
- Group properties
- Transition elements

Learning outcomes

Periodic trends

(a) describe the Periodic Table as an arrangement of the elements in the order of increasing proton (atomic) number
(b) describe how the position of an element in the Periodic Table is related to proton number and electronic structure
(c) describe the relationship between group number and the ionic charge of an ion of an element
(d) explain the similarities between the elements in the same group of the Periodic Table in terms of their electronic structure
(e) describe the change from metallic to non-metallic character from left to right across a period of the Periodic Table
(f) describe the relationship between group number, number of valency electrons and metallic / non-metallic character
(g) predict the properties of elements in Group I and Group VII using the Periodic Table.

Group properties

(a) describe lithium, sodium and potassium in Group I (the alkali metals) as a collection of relatively soft, low-density metals showing a trend in melting point and in their reaction with water
(b) describe chlorine, bromine and iodine in Group VII (the halogens) as a collection of diatomic, nonmetals showing a trend in colour, state and their displacement reactions with solutions of other halide ions
(c) describe the elements in Group 0 (the noble gases) as a collection of monatomic elements that are chemically unreactive and hence important in providing an inert atmosphere, e.g. argon and neon in light bulbs; helium in balloons; argon in the manufacture of steel
(d) describe the lack of reactivity of the noble gases in terms of their electronic structures.

Transition elements

(a) describe typical transition elements as metals having high melting point, high density, variable oxidation state and forming coloured compounds
(b) state that the elements and/or their compounds are often able to act as catalysts (see also 6.1(d)).

12.1 Features of the Periodic Table

Periodic Table: list of elements arranged in order of increasing proton number

Group

I	II											III	IV	V	VI	VII	0
							1 H hydrogen 1										2 He helium 4
3 Li lithium 7	4 Be beryllium 9		Key proton (atomic) number atomic symbol name relative atomic mass									5 B boron 11	6 C carbon 12	7 N nitrogen 14	8 O oxygen 16	9 F fluorine 19	10 Ne neon 20
11 Na sodium 23	12 Mg magnesium 24											13 Al aluminium 27	14 Si silicon 28	15 P phosphorus 31	16 S sulfur 32	17 Cl chlorine 35.5	18 Ar argon 40
19 K potassium 39	20 Ca calcium 40	21 Sc scandium 45	22 Ti titanium 48	23 V vanadium 51	24 Cr chromium 52	25 Mn manganese 55	26 Fe iron 56	27 Co cobalt 59	28 Ni nickel 59	29 Cu copper 64	30 Zn zinc 65	31 Ga gallium 70	32 Ge germanium 73	33 As arsenic 75	34 Se selenium 79	35 Br bromine 80	36 Kr krypton 84
37 Rb rubidium 85	38 Sr strontium 88	39 Y yttrium 89	40 Zr zirconium 91	41 Nb niobium 93	42 Mo molybdenum 96	43 Tc technetium –	44 Ru ruthenium 101	45 Rh rhodium 103	46 Pd palladium 106	47 Ag silver 108	48 Cd cadmium 112	49 In indium 115	50 Sn tin 119	51 Sb antimony 122	52 Te tellurium 128	53 I iodine 127	54 Xe xenon 131
55 Cs caesium 133	56 Ba barium 137	57 – 71 lanthanoids	72 Hf hafnium 178	73 Ta tantalum 181	74 W tungsten 184	75 Re rhenium 186	76 Os osmium 190	77 Ir iridium 192	78 Pt platinum 195	79 Au gold 197	80 Hg mercury 201	81 Tl thallium 204	82 Pb lead 207	83 Bi bismuth 209	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89 – 103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –		114 Fl flerovium –		116 Lv livermorium –		

lanthanoids	57 La lanthanum 139	58 Ce cerium 140	59 Pr praseodymium 141	60 Nd neodymium 144	61 Pm promethium –	62 Sm samarium 150	63 Eu europium 152	64 Gd gadolinium 157	65 Tb terbium 159	66 Dy dysprosium 163	67 Ho holmium 165	68 Er erbium 167	69 Tm thulium 169	70 Yb ytterbium 173	71 Lu lutetium 175
actinoids	89 Ac actinium –	90 Th thorium 232	91 Pa protactinium 231	92 U uranium 238	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –

Divides elements into

Division	Description	Numbering	Properties of atoms of elements
1. **Periods**	Vertical column	8 groups (I to VIII)	Same number of electron shells
2. **Groups**	Horizontal row	7 periods (1 to 7)	Same number of valence electrons

12.2 Periodic Trends

Metallic and non-metallic properties

Metallic properties: determined by how easily / readily atom of element loses electrons

Trend	Atom	Attractive forces between valence electrons & nucleus	Lose valence electrons
Going down group	size increases	weaker	more easily / readily
Across period	no. of proton increases	stronger	harder

Electronic structure

Period number = no. of electron shells
Group number = no. of valence electrons

<u>Charge of ion</u>

Group number and ion formed

Group	Type of ion	Charge	Example	Explanation
I	positive	+1	Na^{+}	• Metals: lose electrons → positive ion • Group number = charge
II		+2	Mg^{2+}	
III		+3	Al^{3+}	
IV	covalent		CH_4	• Share electrons → covalent bond • Group number = maximum oxidation state
V			PCl_5	
VI	negative	-2	O^{2-}	• Non-metals • Gain electrons → positive
VII		-1	Cl^{-}	
0	-			• Stable electronic structure • Do not form compounds

12.3 Group I Elements – Alkali Metals

Alkali metals (Group I)

- Electronic structure
  - 1 valence electron
- Physical properties
  - Soft metals
  - Low melting and boiling points
  - Low densities
- Chemical properties
  - React with water to form alkali and hydrogen
  - Powerful reducing agents
  - Form ionic compounds
- Group trends
  - Going down group,
    - melting & boiling points decrease
    - density increases
    - reactivity increases

Physical properties	Chemical properties
1. Soft (can be cut easily) 2. Low *mp* & *bp* 3. Low density (Li, Na, K float on water)	1. React with cold water to form alkali + hydrogen 2. Powerful reducing agents (give away electrons readily) 3. Form ionic compounds

Trend: going down group I,

Physical properties	Chemical properties
1. *mp* & *bp* ↓ 2. Density ↑	Reactivity increases (Li < Na < K)

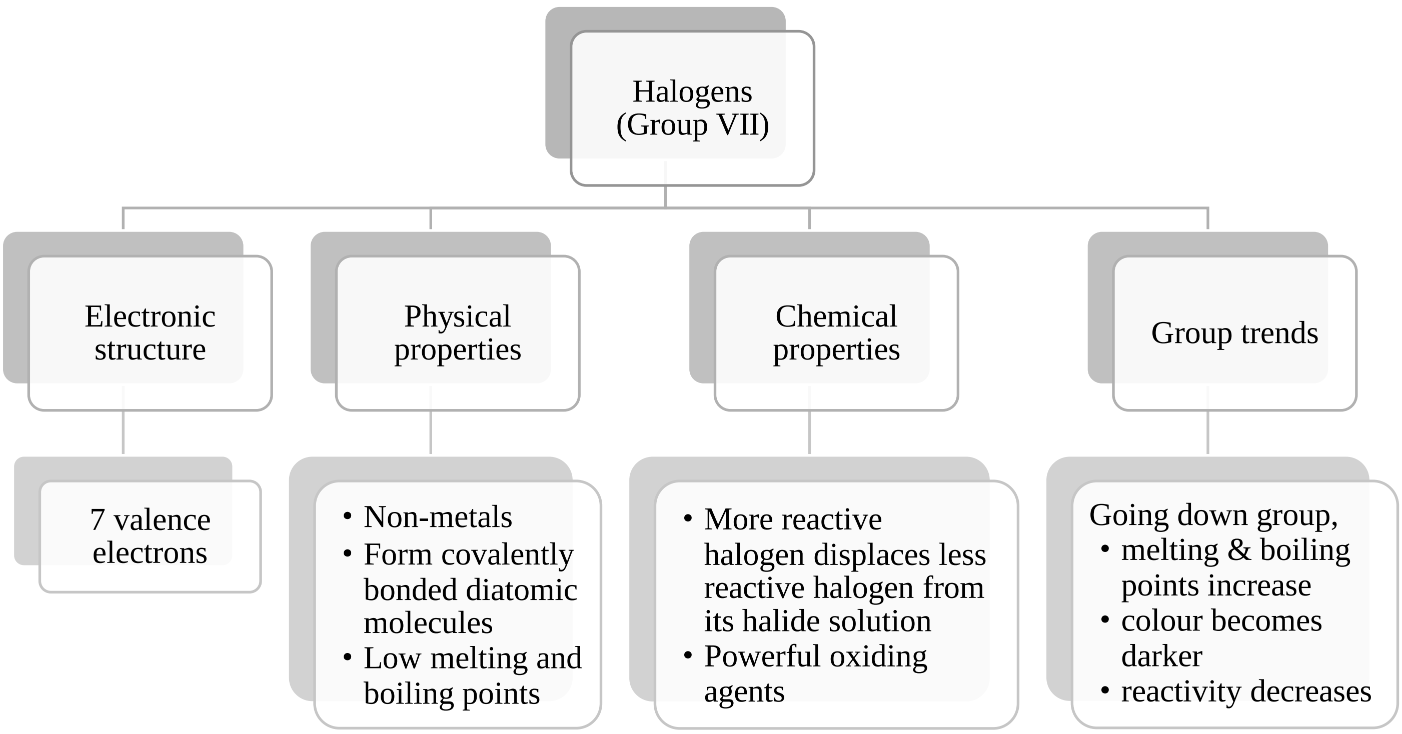
Metal atom lose valence electrons more readily → more reactive

- Size of atom increases
- Valence electrons become further from nucleus
- Force of attraction between valence electrons & nucleus becomes weaker
- Easier to lose valence electrons

React with cold water (single displacement reaction)

Alkali metal	Reactivity with cold water	Storage
1. **Lithium** (Li)	$2\ Li(s) + 2\ H_2O(l) \rightarrow 2\ LiOH(aq) + H_2(g)$ • React vigorously • Float on water • Effervescence of H_2	Stored in oil (highly reactive metals) – prevent from reacting with air and water
2. **Sodium** (Na)	$2\ Na(s) + 2\ H_2O(l) \rightarrow 2\ NaOH(aq) + H_2(g)$ • Reacts violently • Melt → silvery ball • Dart about on surface of water quickly • Burn with yellow flame • H_2 catch fire & explode (enough heat produced)	
3. **Potassium** (K)	$2\ K(s) + 2\ H_2O(l) \rightarrow 2\ KOH(aq) + H_2(g)$ • React very violently • Dart about on surface of water very quickly • Burns with lilac flame • H_2 catch fire & explode (enough heat produced)	

12.4 Group VII Elements – Halogens



Physical properties	Chemical properties
1. Diatomic covalent molecules 2. Low melting and boiling points 3. Coloured	1. Undergo displacement reactions with halide solutions 2. Halogens are powerful oxidising agents

Trend: going down group VII,

Physical properties	Chemical properties
Melting and boiling points increase Colours become darker	Reactivity decreases (F > *Cl* > Br > I > At)

Physical states:

Element	State (r.t.p.)	Melting point (°C)	Boiling point (°C)
fluorine (F)	pale yellow **gas**	-220	-188
chlorine (Cl)	greenish-yellow **gas**	-101	-34
bromine (Br)	<u>reddish-brown</u> **liquid**	-7	59
iodine (I)	<u>purplish-black</u> **solid**	114	184
astatine (At)	black **solid**	302	337

Displacement reaction: more reactive halogen displaces less reactive halogen from its halide solution

	Potassium chloride (K*Cl*)	Potassium bromide (KBr)	Potassium iodide (KI)
Chlorine (Cl_2)		Cl_2 (*aq*) + 2 KBr (*aq*) → 2 K*Cl* (*aq*) + $\mathbf{Br_2}$ (*aq*) **Reddish-brown** mixture	Cl_2 (*aq*) + 2 KI (*aq*) → 2 K*Cl* (*aq*) + $\mathbf{I_2}$ (*aq*) **Brown** mixture
Bromine (Br_2)	No reaction		BR_2 (*aq*) + 2 KI (*aq*) → 2 KBr (*aq*) + $\mathbf{I_2}$ (*aq*) **Brown** mixture
Iodine (I_2)	No reaction	No reaction	

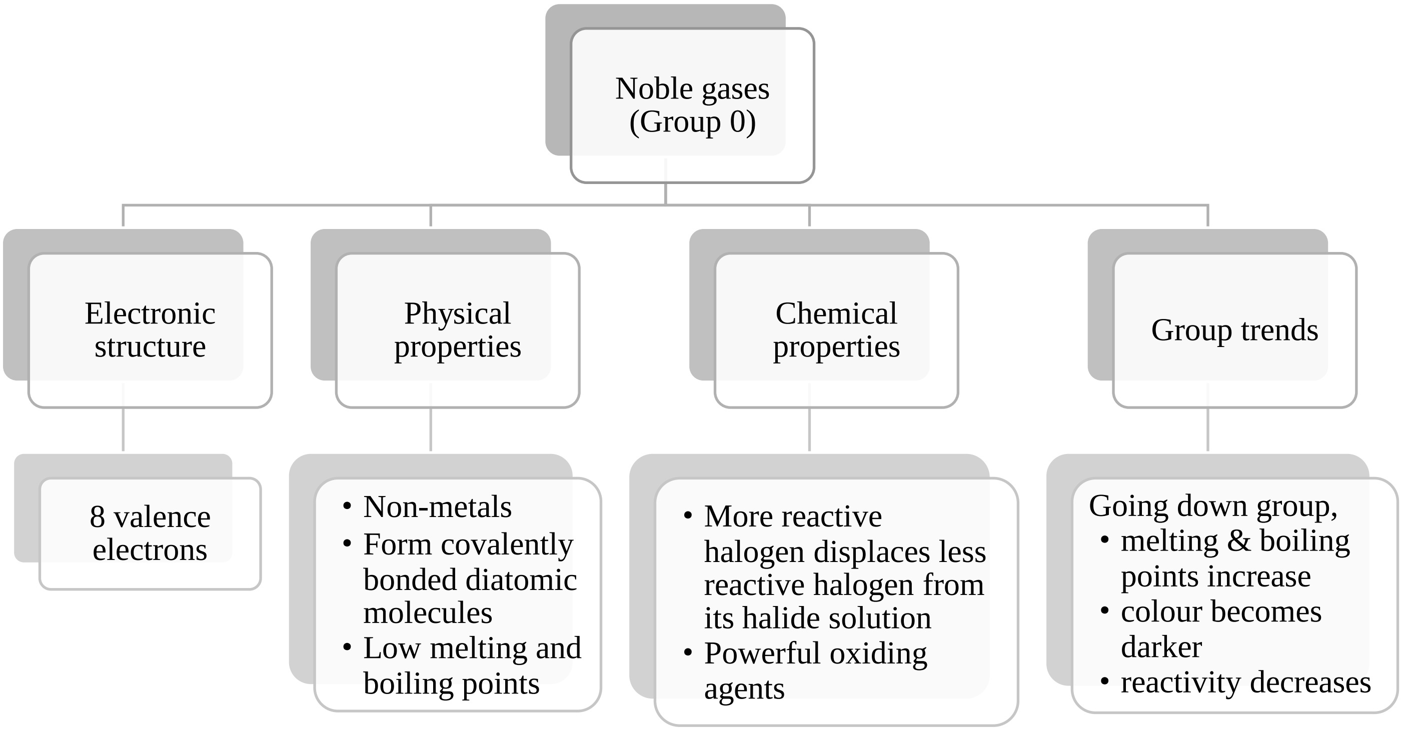
React with most metals → **metal halides** (exothermic)
2 Na_2 (s) + Cl_2 (g) → 2 Na*Cl* (s)

React with hydrogen → hydrogen halides (exothermic)
H_2 (g) + Cl_2 (g) → 2 H*Cl* (g)

Different states of iodine (I_2):

Iodine	Colour
I_2 (*s*)	Purple solid
I_2 (*l*)	(sublimes)
I_2 (*g*)	Purple gas
I_2 (*aq*)	Brown solution • Low solubility in water • High solubility in alcohol → purple solution

12.5 Group 0 Elements – Noble Gases



Physical properties	Chemical properties
1. Colourless gases (r.t.p.) 2. Low *mp* & *bp* 3. Insoluble in water	1. Monoatomic 2. Unreactive

Noble gases are unreactive:

- Full valence electron shell → full electronic structure
- Do not lose, gain or share electrons
- Stable & rarely react to form compounds

<u>Uses</u>

Mostly used to provide **inert atmosphere**

Gas	Usage
1. **Helium** (He)	Fill weather balloons
2. **Neon** (Ne)	Fill lights and advertising signs
3. **Argon** (Ar)	Fill light bulbs / provide inert atmosphere during welding
4. **Krypton** (Kr)	Flash bulbs for photography
5. **Xenon** (Xe)	Vehicle headlamps and lasers

12.6 Transition Elements

Properties

Physical and chemical properties

<table>
<tr><th>Property</th><th>Explanation</th></tr>
<tr><td>1. High mp & bp</td><td rowspan="2">Compared Group I & II metals (other metals)</td></tr>
<tr><td>2. High densities</td></tr>
<tr><td>3. Variable oxidation states</td><td>• Metals in Group I & II: form one type of positive ion only
→ oxidation state: +1 / +2
• Transition metals: form ions with different oxidation states</td></tr>
<tr><td>4. Form coloured compounds</td><td>• Different colours of compounds of transition metal at different oxidation states
• Colour of hydrated compound: different from anhydrous compound
• Compounds of transition metals → produce different colours
(a) dyes
(b) pigments
(c) paints
(d) stained glass</td></tr>
<tr><td>5. Good catalysts</td><td>• Important catalysts for many reactions (laboratory + industry)
• Some uses:
<table>
<tr><th>Catalyst</th><th>Industrial process</th></tr>
<tr><td>iron</td><td>Haber process (manufacture ammonia)</td></tr>
<tr><td>nickel</td><td>hydrogenation of vegetable oil (manufacture margarine)</td></tr>
<tr><td>platinum-rhodium</td><td>catalytic converter</td></tr>
<tr><td>titanium(III) chloride</td><td rowspan="2">polymerisation of alkenes</td></tr>
<tr><td>titanium (VI) chloride</td></tr>
<tr><td>manganese(IV) oxide</td><td>decomposition of hydrogen peroxide
$2\ H_2O_2 \xrightarrow{MnO_2} 2\ H_2O + O_2$</td></tr>
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Differences in properties of Group I metals and transition metals

Group I metals	Transition metals
• Lower melting point • Lower density	• Higher melting point • Higher density
• Form white compounds • Form ions with oxidation state +1	• Form coloured compounds • Form ions with different oxidation states

Typical questions

Structured questions

1. Suggest a reason why alkali metals are commonly stored in oil.

   Alkali metals are highly reactive metals. They are stored in oil to prevent them from reacting with air and water.

2. Describe a simple test carried out to:

   (a) test the pH of the solution formed after reaction of alkali metals with water.

   Add a few drops of Universal indicator into the solution. Universal indicator will change from green to purple.

   (b) identify the gas evolved when lithium reacts with water.

   Place a lighted splint where the gas evolved. The lighted splint is extinguished with a 'pop' sound. The gas is hydrogen.

3. Study the table below about some properties of elements in Period 4.

Element	Electronic configuration	Melting point (°C)	Density (g/cm^3)	Formula of oxide(s)	Colour of one of its chlorides
Potassium	2.8.8.1	63.5	0.86	K_2O	white*
Calcium	2.8.8.2	842	1.55	CaO	white*
Scandium	2.8.9.2	1541	2.99	Sc_2O_3	white*
Titanium	2.8.10.2	1668	4.51	TiO, TiO_2, Ti_2O_3	violet
Vanadium	2.8.11.2	1910	6.11	VO, VO_2, V_2O_3, V_2O_5	pale green
Chromium	2.8.13.1	1907	7.14	CrO, CrO_2, CrO_3, Cr_2O_3	dark green
Manganese	2.8.13.2	1246	7.47	MnO, MnO_2, Mn_2O_3	pink
Iron	2.8.14.2	1538	7.87	FeO, Fe_2O_3, Fe_3O_4	pale green
Cobalt	2.8.15.2	1495	8.90	CoO, Co_2O_3, Co_3O_4	red
Nickel	2.8.16.2	1455	8.91	NiO, Ni_2O_3	green
Copper	2.8.18.1	1084	8.92	Cu_2O, CuO	blue-green
Zinc	2.8.18.2	419	7.14	ZnO	white*

   Describe the trend in the melting point of the elements from potassium to copper.

   The melting point increases from potassium to vanadium, then decreases from vanadium to zinc, except for manganese.