

NEET | JEE

ESSENTIALS

Class
XI

Maximise your chance of success, and high rank in NEET, JEE (Main and Advanced) by reading this column. This specially designed column is updated year after year by a panel of highly qualified teaching experts well-tuned to the requirements of these Entrance Tests.

Unit 5

Hydrogen | The s-Block Elements

HYDROGEN

INTRODUCTION

Hydrogen is the first and lightest element in the periodic table. It was discovered by Henry Cavendish in 1766. He prepared the gas by treating iron with dil. H_2SO_4 . Name 'hydrogen' was proposed by Lavoisier because it produces water on burning with oxygen (in Greek : hydra means water, gene means producing).

H Hydrogen

Symbol : H

Atomic Number : 1

Electronic configuration : $1s^1$

Molecular forms : H_2 , D_2 , T_2 , HD

Isotopes : Protium, ${}^1_1\text{H}$; Deuterium, ${}^2_1\text{H}$
or D; Tritium, ${}^3_1\text{H}$ or T

Ionic forms : H^- , H^+ , H_2^+ , H_3^+

Resemblance with alkali metals due to

1. Electronic configuration (ns^1): $1s^1$
2. Electropositive character, (M^+): H^+
3. Oxidation state (+1) : $\overset{+1}{\text{H}}\overset{-1}{\text{Cl}}$, $\overset{+1}{\text{Na}}\overset{-1}{\text{Cl}}$

Resemblance with halogens due to

1. Electronic configuration : One e^- less than the nearest inert gas configuration.
2. Electronegative character : Both have tendency to accept one e^- to form anions.
3. Ionisation energy : Comparable with halogens.

Differences from alkali metals and halogens

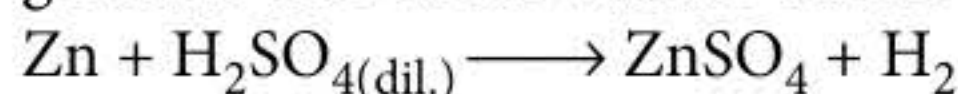
1. Less electropositive than alkali metals and less electronegative than halogens.
2. Nature of oxides : Oxide of hydrogen is neutral *i.e.* H_2O while alkali metals form basic and halogens form acidic oxides.
3. Size of ions : H^+ is much smaller than alkali metal ions and H^- is much larger than halide ions.

Position of Hydrogen in Periodic Table

DIHYDROGEN

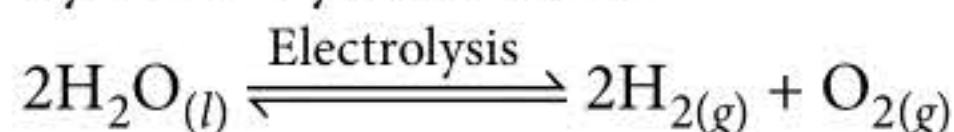
Preparation

- **Laboratory Method :** In laboratory, hydrogen is prepared by the action of dilute sulphuric acid on granular zinc in the Woulfe bottle.

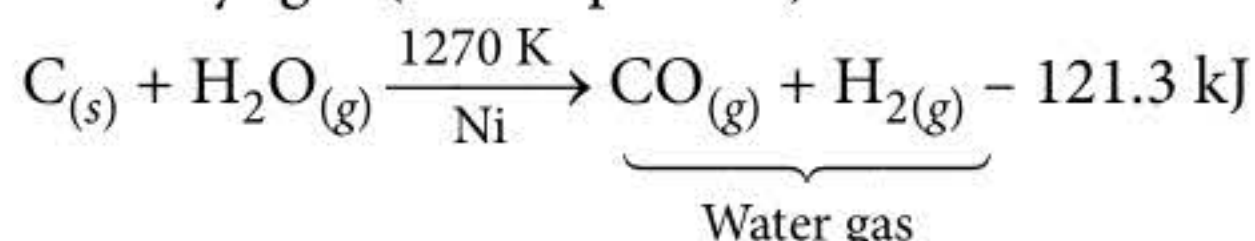


- **Commercial methods :**

- By electrolysis of water

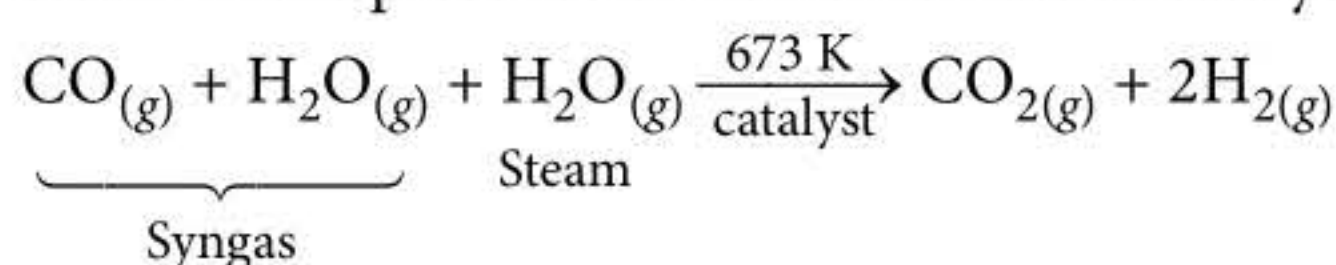


- From syngas (Bosch process)



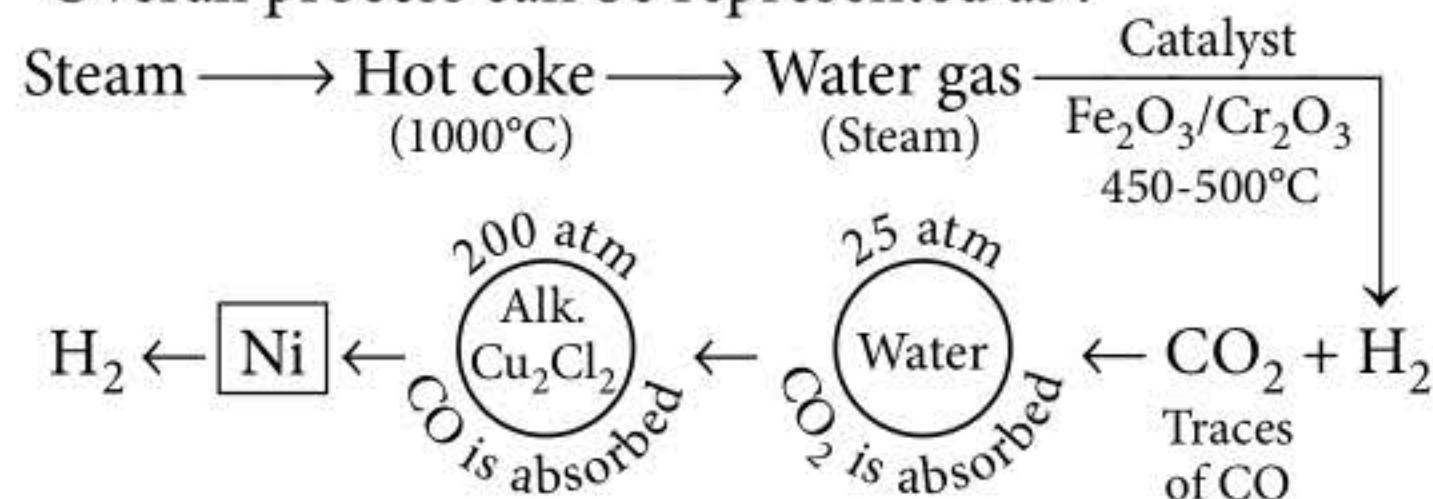
This process is called coal gasification.

The production of dihydrogen can be increased by reacting carbon monoxide of syngas mixtures with steam in the presence of iron chromate as catalyst.

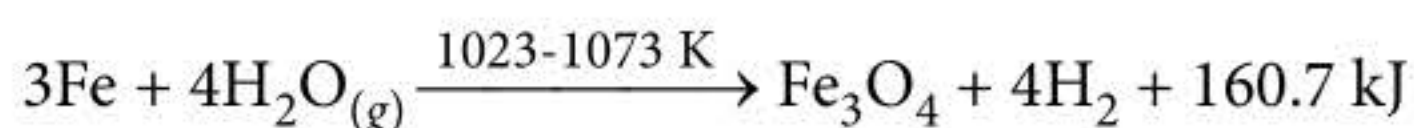


This is called water-gas shift reaction.

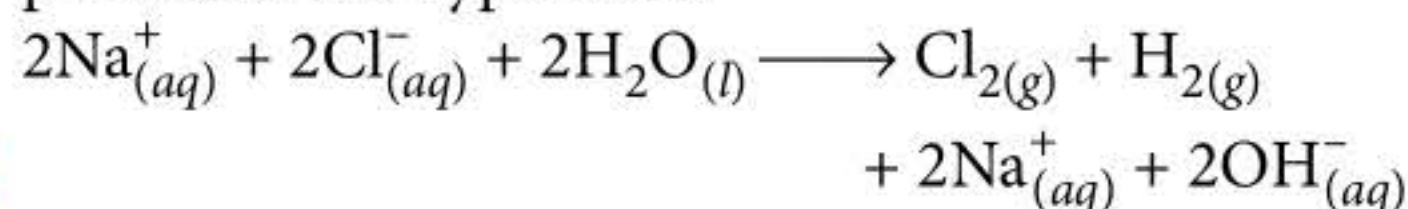
Overall process can be represented as :



- **Lane's Process**



- **As a byproduct :** In the manufacture of NaOH and Cl₂ by electrolysis of brine solution, hydrogen is produced as a byproduct.



INFOSHOTS

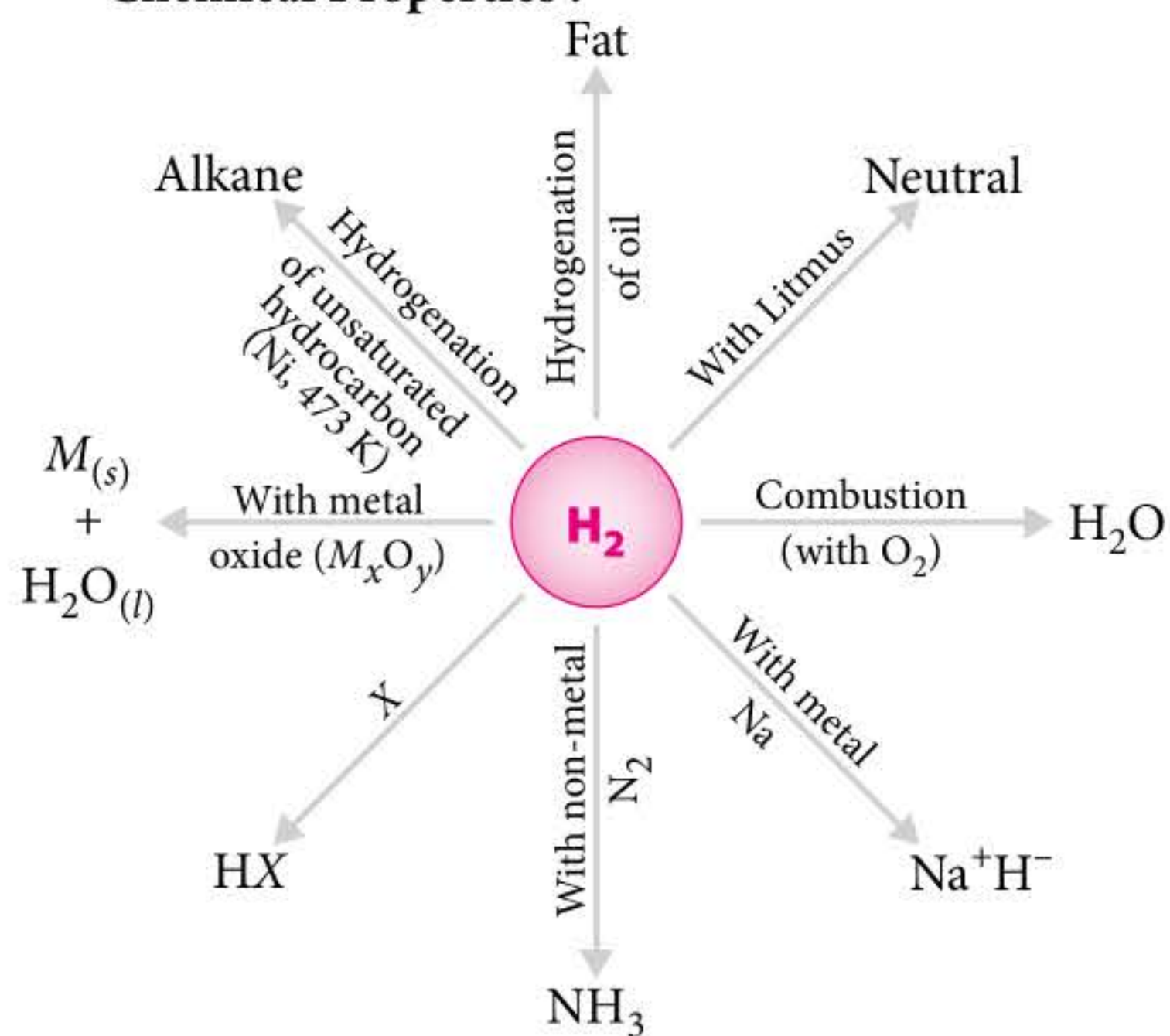
A new photocatalyst for extraction of hydrogen from seawater !

Hydrogen can be produced to power fuel cells by extracting the gas from seawater, but the electricity required to do it makes the process costly. Recently, UCF researchers has come up with a new hybrid nanomaterial that harnesses solar energy and uses it to generate hydrogen from seawater more cheaply and efficiently than current materials. This catalyst not only harvest a much broader spectrum of light than other materials, but also stand up to the harsh conditions found in seawater.

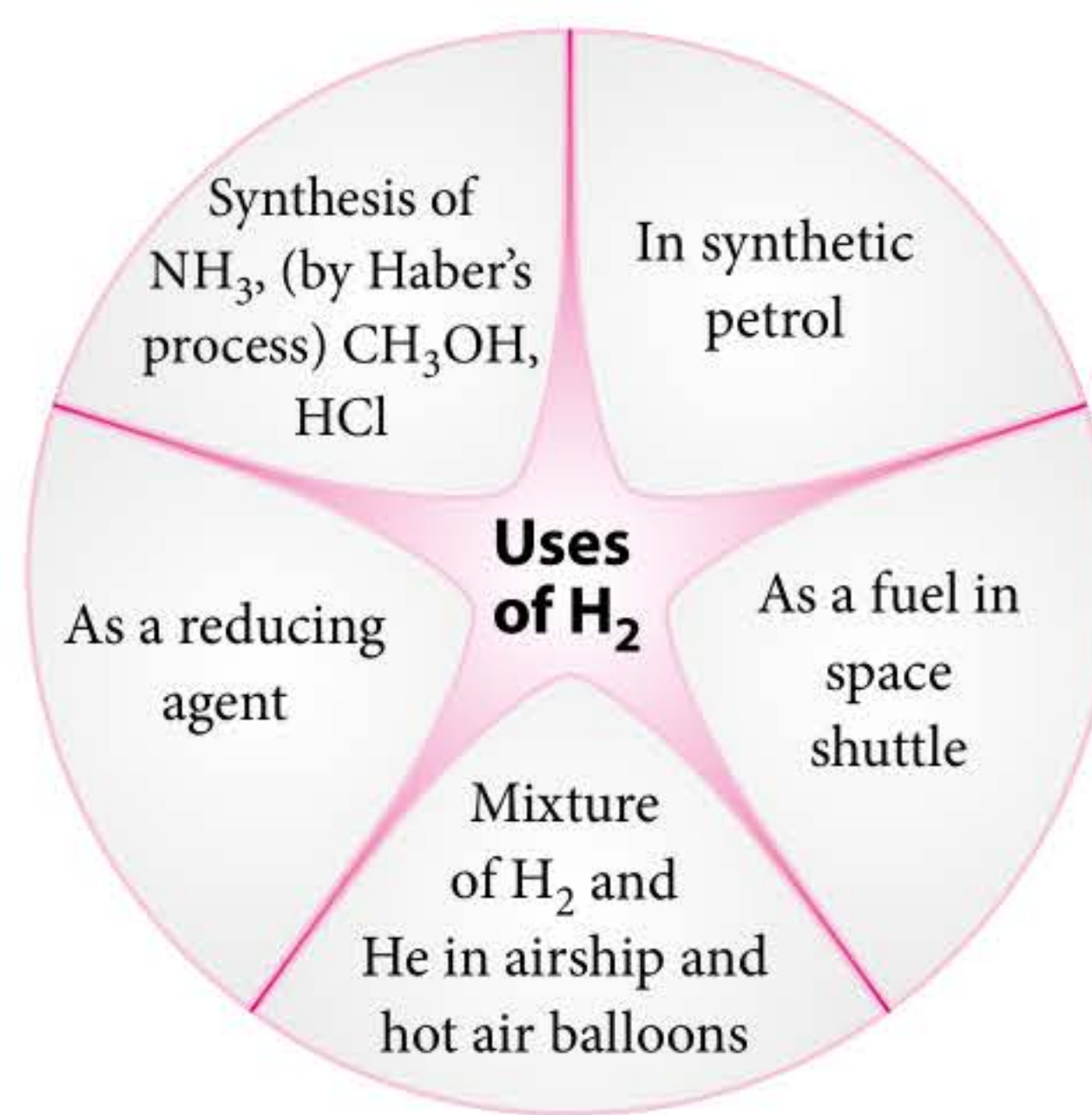
Properties

- **Physical Properties :**
 - ▶ Colourless, odourless and tasteless gas.
 - ▶ Non-polar in nature and slightly soluble in water.
 - ▶ Liquefied under low temperature and high pressure.

- **Chemical Properties :**



- **Uses of hydrogen :**

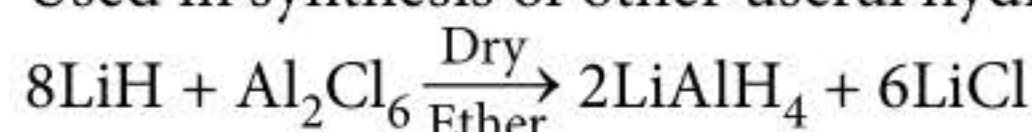


Hydrides

Hydrogen form binary hydrides with elements of *s*, *p*, (except noble gases), *d* and *f*-block.

Ionic or Saline Hydrides

- Group-1,2 elements form ionic hydrides, e.g., NaH, CaH₂, CsH, SrH₂ etc.
- BeH₂, MgH₂ have slightly covalent character.
- Used in synthesis of other useful hydrides.



Metallic or Interstitial Hydrides

- *d* and *f*-block elements form metallic hydrides. These are non-stoichiometric, being deficient in hydrogen, e.g., LaH_{2.87}, YbH_{2.55}, etc.
- Metals of group-7, 8, 9 do not form hydrides and this region of periodic table is referred as hydride gap.
- Metallic hydrides can be used as hydrogen storage media.

Covalent or Molecular Hydrides

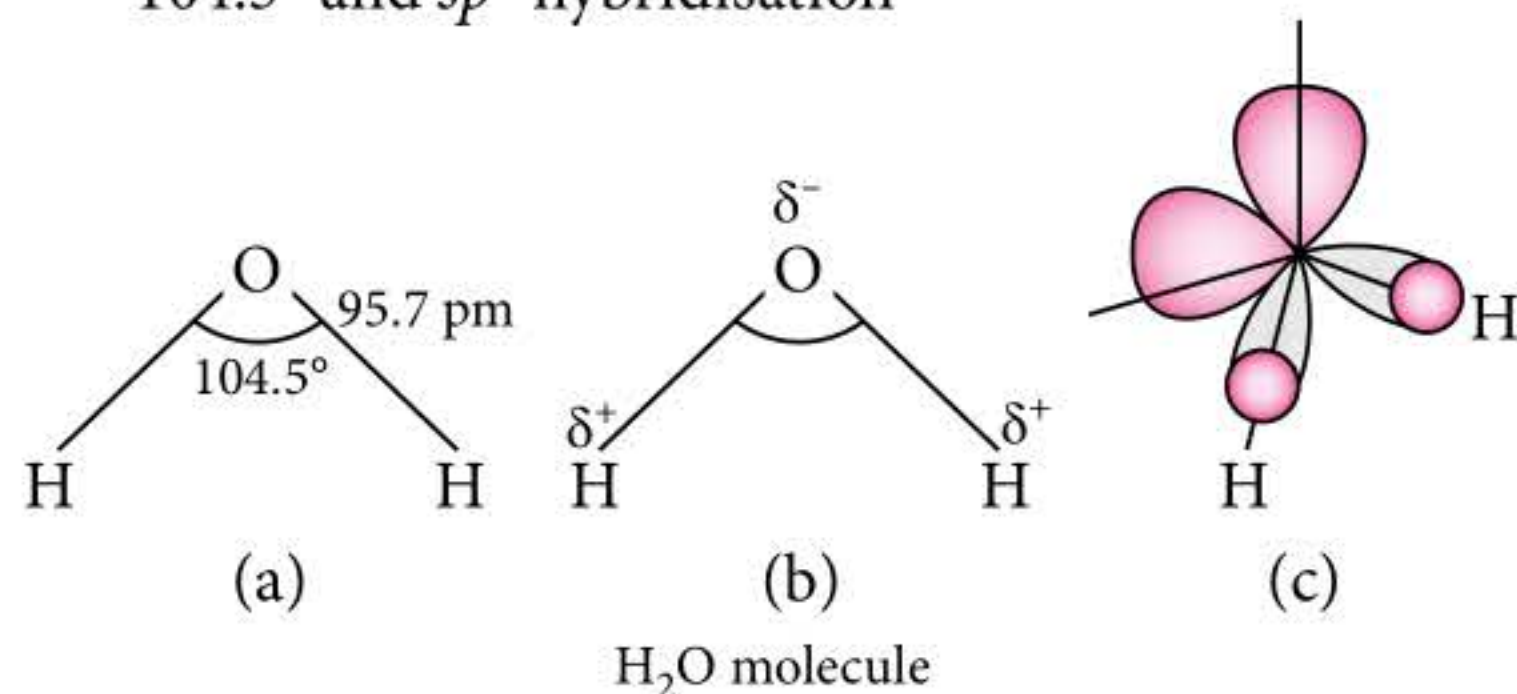
- *p*-Block elements form molecular or covalent hydrides. These are usually volatile compounds with low m.pt. and b.pt. These are of three types :
 - **Electron-deficient hydrides** : Formed by group-13 elements, e.g. B₂H₆, (AlH₃)_{*n*}, etc.
 - **Electron-precise hydrides** : Formed by group-14 elements, e.g., CH₄, SiH₄, etc.
 - **Electron-rich hydrides** : Formed by group-15, 16 and 17 elements, e.g., NH₃, H₂O, HCl, etc.

WATER

It is a crucial compound for the survival of all life forms. Human body has about 65% water and some plants have as much as 95% of water. It is a solvent of great importance.

Properties

- **Structure of water** : Bent structure with bond angle 104.5° and sp³ hybridisation



- **Physical Properties** :

- ▶ Pure water is colourless, odourless and tasteless.

- ▶ It freezes at 0 °C and boils at 100 °C.
- ▶ It has maximum density 1 g cm⁻³ at 4 °C.

- **Chemical Properties** :

- ▶ Amphoteric nature
$$\text{H}_2\text{O}_{(l)} + \text{H}_2\text{O}_{(l)} \longrightarrow \text{H}_3\text{O}^+_{(aq)} + \text{OH}^-_{(aq)}$$

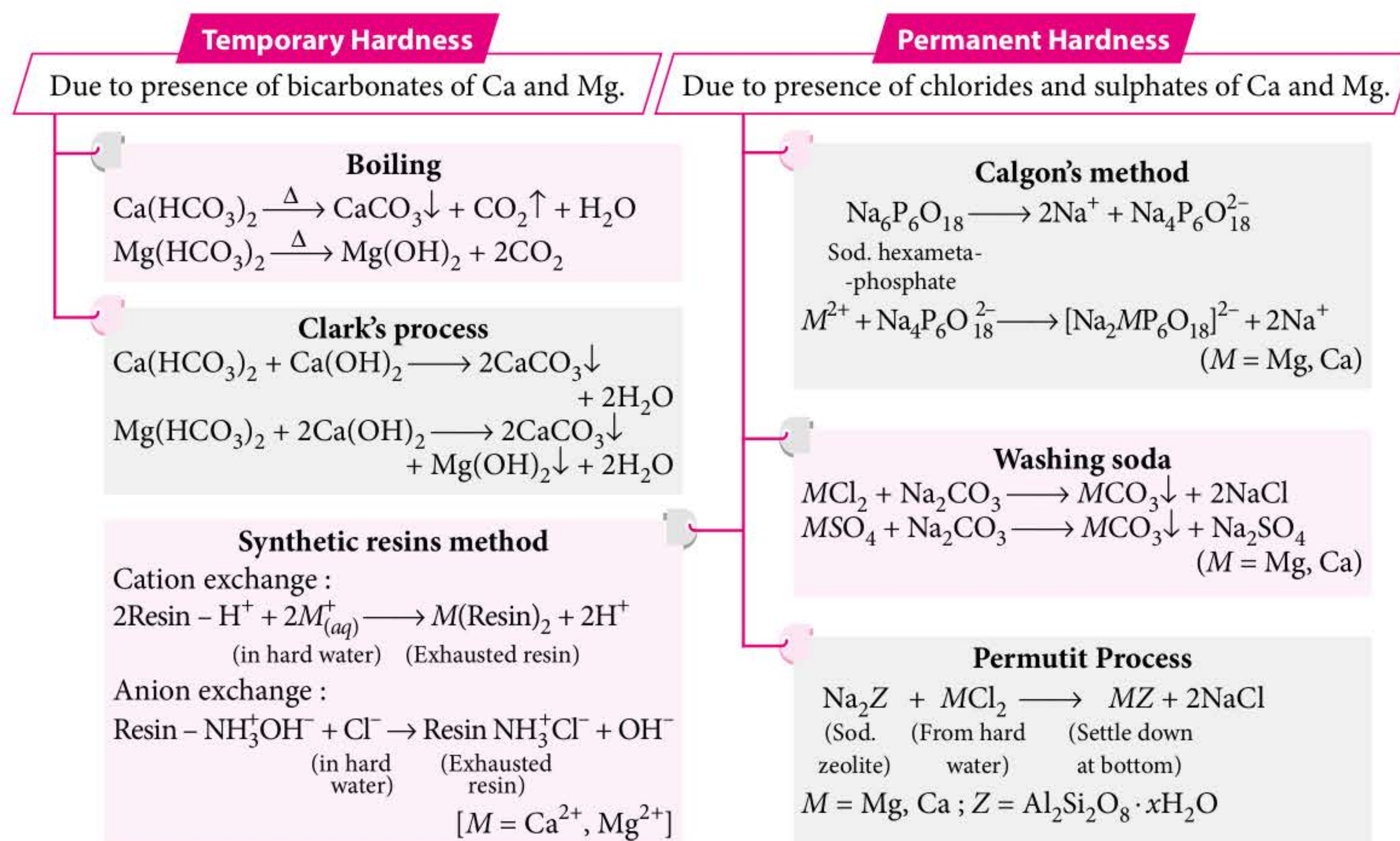
Acid 1 Base 2 Acid 2 Base 1

This self-ionisation of water is also called auto-protolysis.
- ▶ Hydrolytic reaction
$$\text{CaO}_{(s)} + \text{H}_2\text{O}_{(l)} \longrightarrow \text{Ca}(\text{OH})_{2(aq)}$$
- ▶ As reducing agent
$$x\text{CO}_2 + y\text{H}_2\text{O} \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} \text{C}_x(\text{H}_2\text{O})_y + x\text{O}_2$$
- ▶ Hydrate formation : Water combine with ionic salts is called water of crystallisation and such crystals are called hydrated salts.
 - Coordinated water : [Ni(H₂O)₆]²⁺
 - Hydrogen bonded water : CuSO₄·5H₂O
 - Interstitial water : BaCl₂·2H₂O

Hard and Soft Water

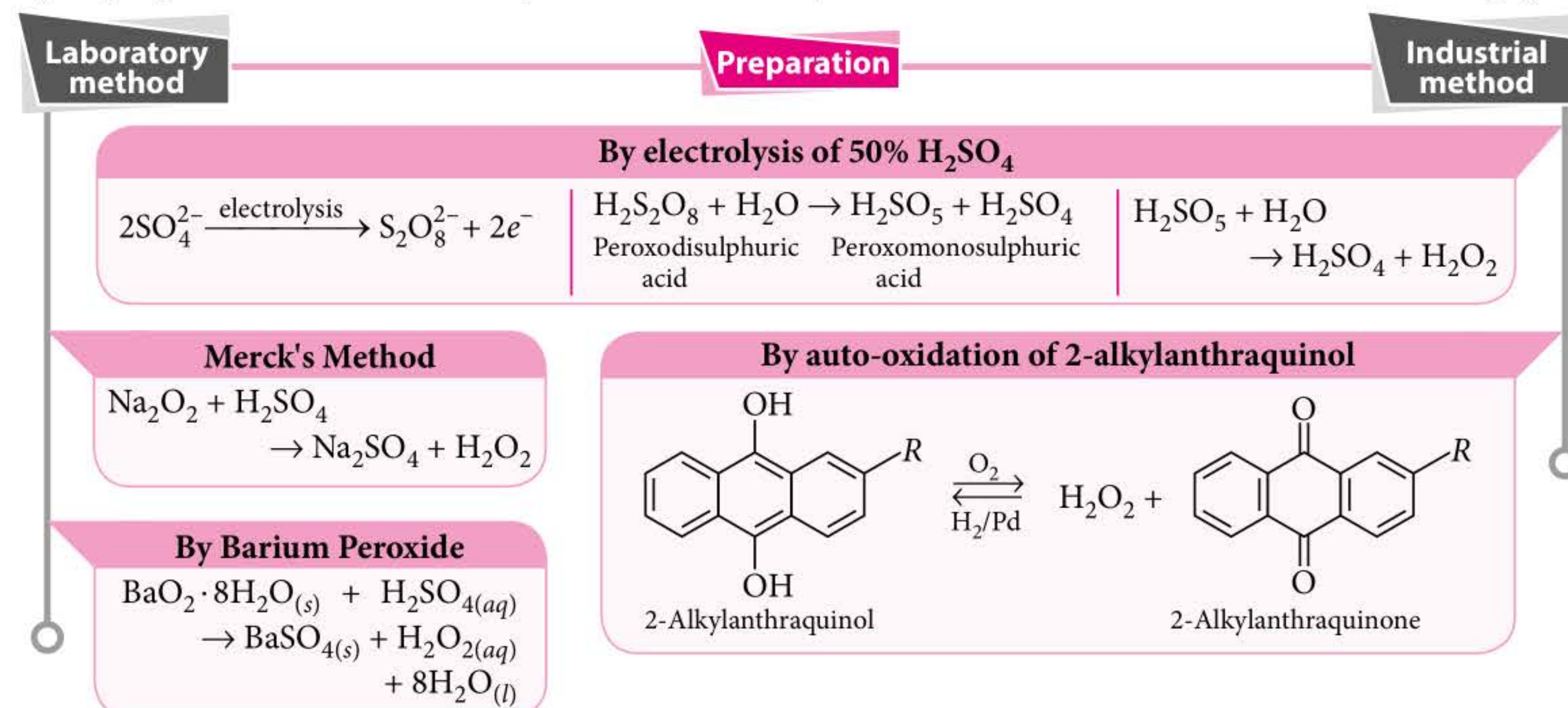
- Water free from soluble salts of Ca and Mg, and which forms lather with soap readily is called soft water.
- Hard water does not form lather with soap.

Hardness of Water and Methods for Removal



HYDROGEN PEROXIDE

Hydrogen peroxide was discovered by the French chemist J.L. Thenard in 1818. Its molecular formula is H₂O₂.



Physical Properties

- Very pale blue liquid, soluble in water, alcohol and ether.
- It boils at 152 °C and freezes at -0.89 °C.

Strength of H₂O₂

- Volume strength means volume of O₂ liberated at N.T.P. by the decomposition of 1 mL of H₂O₂. 30 volume H₂O₂ means 30 mL of O₂ liberated at NTP from 1 mL H₂O₂.
Volume strength = 5.6 × N = 11.2 × M

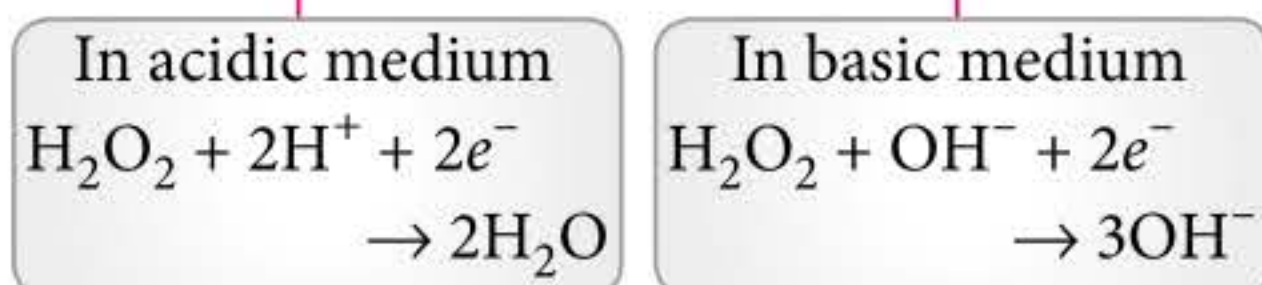
Chemical Properties

- Decomposition
 $2\text{H}_2\text{O}_2(l) \longrightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g) : \Delta H_{(g)} = -196.0 \text{ kJ}$
This is an example of auto-oxidation and auto-reduction.

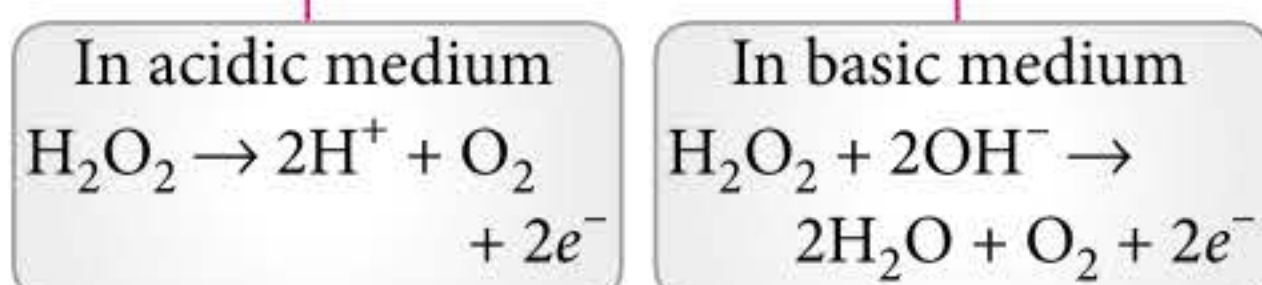
- Acidic nature



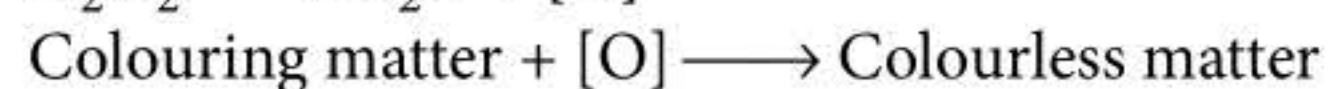
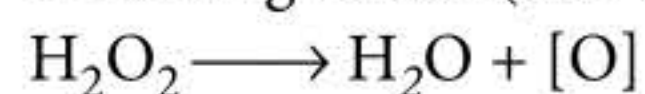
- Oxidising character



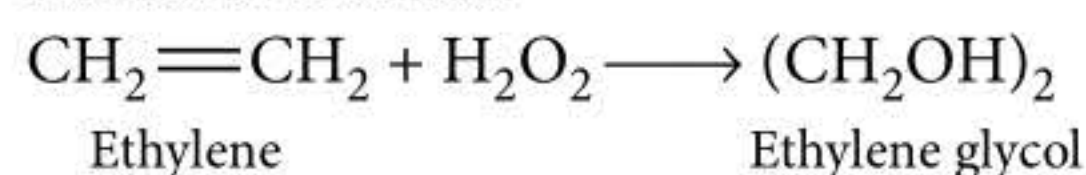
- Reducing character



- Bleaching action (due to nascent O)



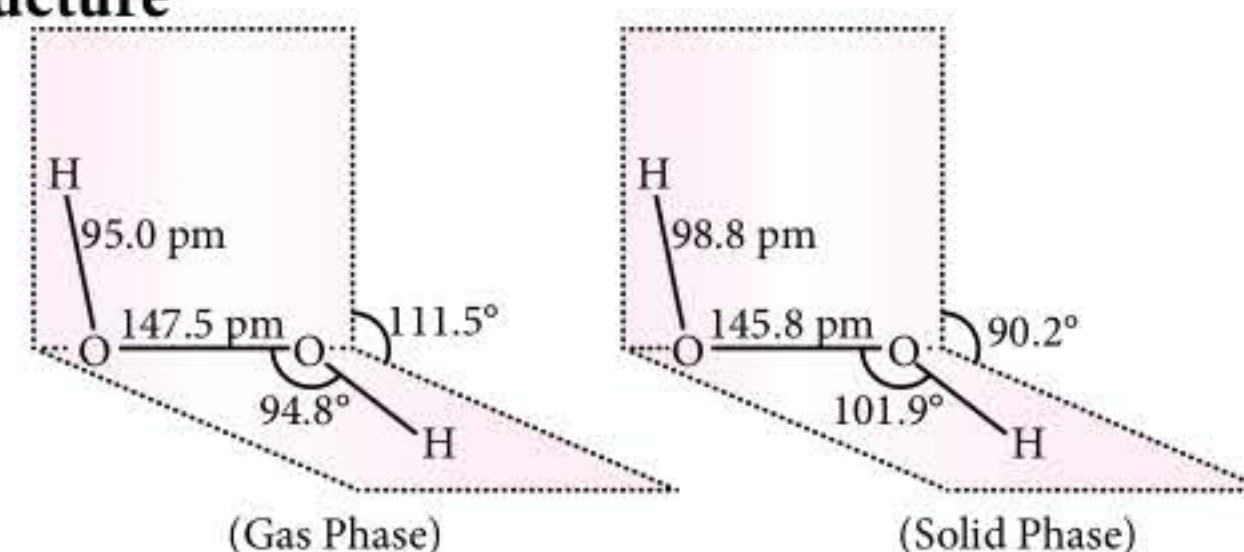
- Addition reaction



Uses

- As bleaching agent and disinfectant.
- Mixture of H₂O₂ and hydrazine hydrate used as rocket propellant.
- For restoring the colour of old painting.
- As an antiseptic under the name perhydrol.

Structure



Heavy Water (D₂O)

- Prepared by prolonged electrolysis of ordinary water.
- Used to prepare deuterium compounds like
 $\text{CaC}_2 + 2\text{D}_2\text{O} \longrightarrow \text{C}_2\text{D}_2 + \text{Ca}(\text{OD})_2$
 $\text{SO}_3 + \text{D}_2\text{O} \longrightarrow \text{D}_2\text{SO}_4$
- Used as a moderator in nuclear reactor and in reaction mechanism.

Dihydrogen as a fuel

- Hydrogen economy is the transportation and storage of energy in the form of liquid or gaseous dihydrogen.
- Pollutants in combustion of dihydrogen will be less than petrol.

THE s-BLOCK ELEMENTS

INTRODUCTION

Elements of periodic table in which the last electron enters the outermost s-orbital, are called s-block elements. They are classified in two groups :

ELECTRONIC CONFIGURATIONS OF s-BLOCK ELEMENTS

Group	1 (alkali metals)	2 (alkaline earth metals)
Electronic configuration	ns ¹	ns ²

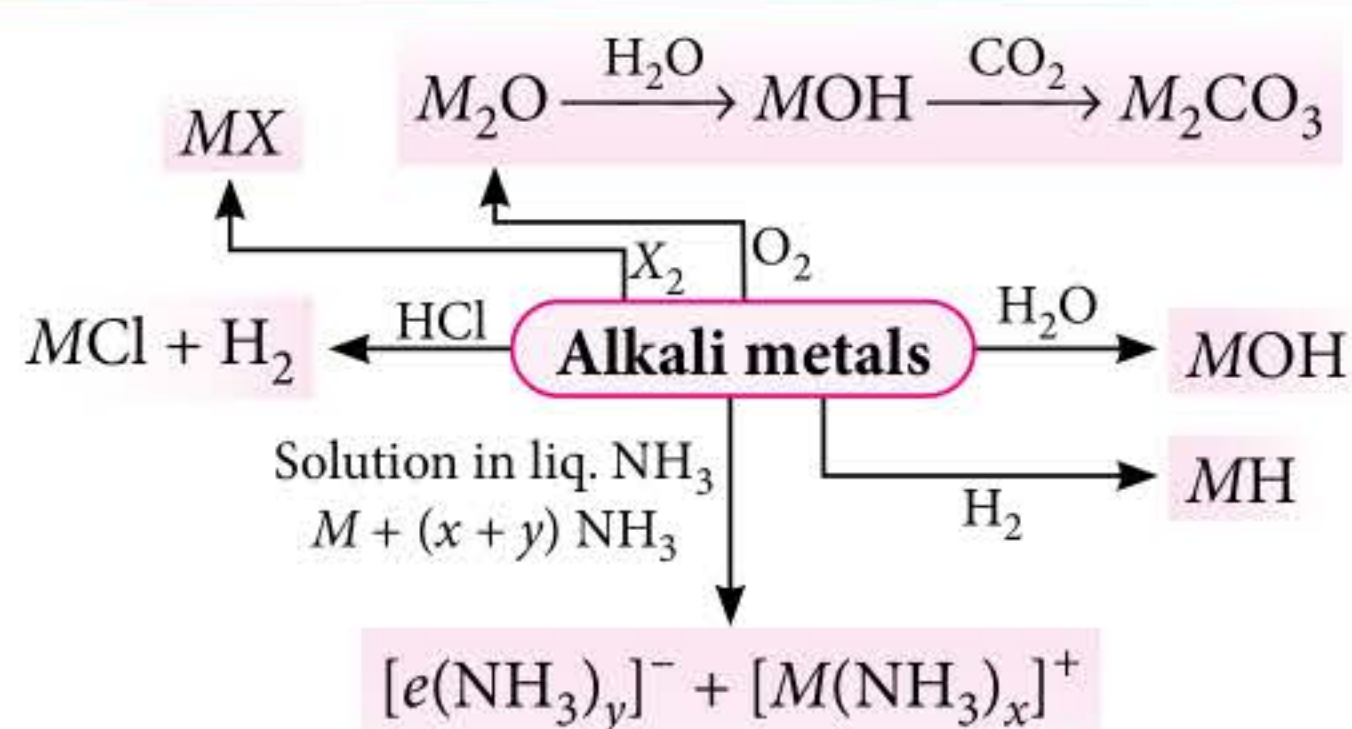
Alkali metals			Alkaline earth metals		
Elements	Atomic Number	Electronic configuration	Elements	Atomic Number	Electronic configuration
Lithium (Li)	3	[He] 2s ¹	Beryllium (Be)	4	[He] 2s ²
Sodium (Na)	11	[Ne] 3s ¹	Magnesium (Mg)	12	[Ne] 3s ²
Potassium (K)	19	[Ar] 4s ¹	Calcium (Ca)	20	[Ar] 4s ²

Rubidium (Rb)	37	[Kr] 5s ¹	Strontium (Sr)	38	[Kr] 5s ²
Caesium (Cs)	55	[Xe] 6s ¹	Barium (Ba)	56	[Xe] 6s ²
Francium (Fr)	87	[Rn] 7s ¹	Radium (Ra)	88	[Rn] 7s ²

GENERAL PROPERTIES OF S-BLOCK ELEMENTS

Alkali metals	Alkaline earth metals
Atomic/ionic radii	
<ul style="list-style-type: none"> Increase on moving down from Li to Cs. 	<ul style="list-style-type: none"> Smaller than group-1 elements and increase from Be to Ra.
Ionization enthalpy	
<ul style="list-style-type: none"> Decreases down the group as the size increases. 	<ul style="list-style-type: none"> 1st I.E. of group-2 is higher than group-1 due to small size. In general, on moving down the group I.E. decreases.
Hydration enthalpy	
<ul style="list-style-type: none"> Decreases with increase in size. Li⁺ > Na⁺ > K⁺ > Rb⁺ > Cs⁺ 	<ul style="list-style-type: none"> Decreases with increase in size. Be²⁺ > Mg²⁺ > Ca²⁺ > Sr²⁺ > Ba²⁺
Physical appearance	
<ul style="list-style-type: none"> Silvery white due to presence of mobile electron. 	<ul style="list-style-type: none"> Silver white lustre but harder than alkali metals.
Melting and boiling point	
<ul style="list-style-type: none"> Decreases with increase in atomic number. 	<ul style="list-style-type: none"> Higher than group-1 and there is no regular trend in their m.pt. and b.pt.

CHEMICAL PROPERTIES OF ALKALI METALS



TRENDS IN ALKALI METALS

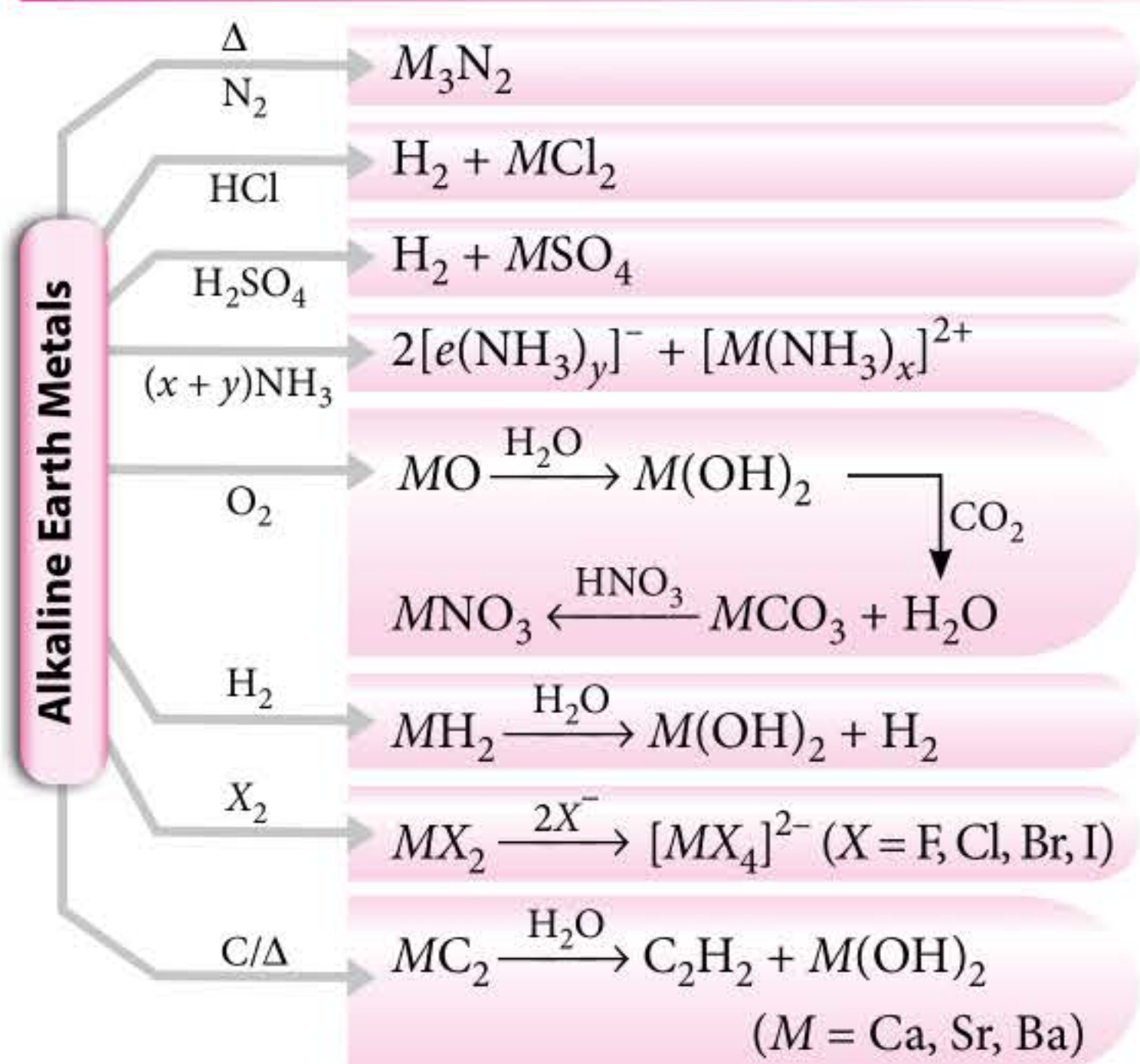
- Strength of hydroxide (basicity) : CsOH > RbOH > KOH > NaOH > LiOH

- Stability of carbonates : Cs₂CO₃ > Rb₂CO₃ > K₂CO₃ > Na₂CO₃ > Li₂CO₃
- Reactivity towards H₂/X : Li > Na > K > Rb > Cs
- M.pt. and b.pt. of halides : MF > MCl > MBr > MI

Uses of Alkali Metals

<p>Li</p> <ul style="list-style-type: none"> In alloy formation. Used in armour plate and aircraft parts. In refining of Cu and Ni to treat rheumatism. 	<p>Na</p> <ul style="list-style-type: none"> Used for making antiknocking compounds. In sodium vapour lamps. Used in many organic compounds formation. As a liquid coolant in nuclear power stations.
<p>K</p> <ul style="list-style-type: none"> As a fertilizer. In biological systems. In manufacturing of soap. As an excellent adsorbent of CO₂. 	<p>Cs</p> <ul style="list-style-type: none"> In devising photoelectric cells (solar cells).

CHEMICAL PROPERTIES OF ALKALINE EARTH METALS



TRENDS IN ALKALINE EARTH METALS

- **Basic character/solubility :** $\text{Be}(\text{OH})_2 < \text{Mg}(\text{OH})_2 < \text{Ca}(\text{OH})_2 < \text{Sr}(\text{OH})_2 < \text{Ba}(\text{OH})_2$
- **Lattice enthalpy :** $\text{Be}(\text{OH})_2 > \text{Mg}(\text{OH})_2 > \text{Ca}(\text{OH})_2 > \text{Sr}(\text{OH})_2 > \text{Ba}(\text{OH})_2$
- **Thermal stability :** $\text{BeCO}_3 < \text{MgCO}_3 < \text{CaCO}_3 < \text{SrCO}_3 < \text{BaCO}_3$
- **Hydration enthalpy :** $\text{Be}^{2+} > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{Sr}^{2+} > \text{Ba}^{2+}$
- **Basicity of oxides :**

$\text{BeO} < \text{MgO} < \text{CaO} <$	Amphoteric	Weakly basic	Basic
$\text{SrO} < \text{BaO}$			
Strongly basic			
- **Solubility of halides :**
 $\text{BeX}_2 < \text{MgX}_2 < \text{CaX}_2 < \text{SrX}_2 < \text{BaX}_2$
- **Reducing nature :**
 $\text{Be} < \text{Mg} < \text{Ca} < \text{Sr} < \text{Ba}$

Uses of Alkaline Earth Metals

Be

- In alloy formation.
- In windows of X-ray tubes.
- In high strength spring.

Mg

- Its alloy used in aircraft construction.
- In toothpaste.
- In aluminothermy.
- In Grignard reagent.

Ca

- In the extractions of metals.
- In casting and forging.
- In cement and mortar.

ANOMALOUS BEHAVIOUR

Anomalous behaviours of the first element of a group is due to

- small atomic and ionic radii
- high electronegativity and ionization enthalpy
- high polarising power
- absence of *d*-electrons in its valence shell.

Diagonal Relationship

Diagonal similarity is known as diagonal relationship, is due to similarity in ionic sizes and/or charge/radius ratio of the elements.

	Group 1	Group 2	Group 3	Group 4
2 nd period	Li	Be	B	C
3 rd period	Na	Mg	Al	Si

Points of Difference

Li with other alkali metals	Be with other alkaline earth metals
<ul style="list-style-type: none"> • Much harder • Higher m.pt. and b.pt. • Li forms monoxide while others form peroxides (M_2O_2) and superoxides (MO_2). • Ability to form nitrides. • LiOH is weak base while others are strong. • Ability to form hydrates $\text{LiCl} \cdot 2\text{H}_2\text{O}$ • LiNO_3 forms the oxide on gentle heating while others form nitrites. $4\text{LiNO}_3 \rightarrow 2\text{Li}_2\text{O} + 4\text{NO}_2 + \text{O}_2$ $2\text{NaNO}_3 \rightarrow 2\text{NaNO}_2 + \text{O}_2$ 	<ul style="list-style-type: none"> • Harder than magnesium. • Higher m.pt. and b.pt. • Does not react with cold water while other metals (except Mg) do, e.g., $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$ • Be forms covalent compound while others form ionic. • Does not exhibit coordination number more than four. • Oxide and hydroxide of Be are amphoteric in nature. • Be_2C reacts with water, forming methane while others give alkyne. $\text{Be}_2\text{C} + 4\text{H}_2\text{O} \rightarrow 2\text{Be}(\text{OH})_2 + \text{CH}_4$ Methane $\text{Mg}_2\text{C}_3 + 4\text{H}_2\text{O} \rightarrow 2\text{Mg}(\text{OH})_2 + \text{C}_3\text{H}_4$ Propyne

Compounds of Sodium

Sodium Carbonate (Washing soda, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$)

Preparation :

- By solvay process.
 $2\text{NH}_3 + \text{H}_2\text{O} + \text{CO}_2 \longrightarrow (\text{NH}_4)_2\text{CO}_3$
 $(\text{NH}_4)_2\text{CO}_3 + \text{H}_2\text{O} + \text{CO}_2 \longrightarrow 2\text{NH}_4\text{HCO}_3$
 $\text{NH}_4\text{HCO}_3 + \text{NaCl} \longrightarrow \text{NH}_4\text{Cl} + \text{NaHCO}_3$
 $2\text{NaHCO}_3 \xrightarrow{\Delta} \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O}$

Properties :

- White crystalline solid, exist as $\text{Na}_2\text{CO}_3 \cdot 3\text{H}_2\text{O}$.
- Its anhydrous form is known as soda ash.

Uses :

- For softening of hard water.
- In washing.
- In textile industry.
- Metal refining.
- As a laboratory reagent.

Sodium Hydroxide (Caustic soda, NaOH)

Preparation :

- By electrolysis of NaCl in Castner-Kellner cell.
Cathode : $\text{Na}^+ + e^- \xrightarrow{\text{Hg}} \text{Na-amalgam}$
Anode : $\text{Cl}^- \longrightarrow 1/2\text{Cl}_2 + e^-$
 $2\text{Na-amalgam} + 2\text{H}_2\text{O} \longrightarrow 2\text{NaOH} + 2\text{Hg} + \text{H}_2$

Properties :

- White, translucent and deliquescent solid, soluble in water.
- Its aqueous solution is soapy to touch and corrosive.

Uses :

- In manufacturing of soap, paper and artificial silk.
- In petroleum refining.
- In purification of bauxite.
- In textile industries for mercerising cotton fabrics.

Sodium Chloride (NaCl)

Preparation :

- Sea water is the major source. Concentrated solution of sea water is saturated with HCl gas.

Properties :

- White crystalline solid, soluble in water.
- Density of pure NaCl is 2.17 g/mL.
- Pure NaCl is non-hygroscopic.
- It has high m.pt. and b.pt.
- It is insoluble in alcohol.

Uses :

- As a table salt.
- As a freezing mixture.
- In manufacturing of Na_2CO_3 , NaOH, etc.
- In textile industries.
- Impure salt (rock salt) is used to de-ice roads.
- As a preservative of food articles like fish, meat, etc.

Sodium Hydrogen Carbonate (Baking powder, NaHCO_3)

Preparation :



Properties :

- White crystalline solid, sparingly soluble in water.
- Aqueous solution is alkaline in nature.
- Aqueous solution is weakly basic.
 $\text{NaHCO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NaOH} + \text{H}_2\text{CO}_3$
- The solution gives yellow colour with methyl orange but no colour with phenolphthalein.

Uses :

- In fire extinguishers.
- In preparation of baking powder.
- As an antiseptic and antacid.
- In manufacturing of soda.

COMPOUNDS OF CALCIUM

Calcium Hydroxide (Slaked Lime) ; Ca(OH)_2

Preparation :

- $\text{CaO} + \text{H}_2\text{O} \longrightarrow \text{Ca(OH)}_2$
- $\text{CaCl}_2 + 2\text{NaOH} \longrightarrow \text{Ca(OH)}_2 + 2\text{NaCl}$

Properties :

- White amorphous powder, sparingly soluble in water.
- Its aqueous solution is known as lime water and suspension of it in water is known as milk of lime.
- $\text{Ca(OH)}_2 + \text{CO}_2 \longrightarrow \text{CaCO}_3 + \text{H}_2\text{O}$
(Milkinsess)
- $2\text{Ca(OH)}_2 + 2\text{Cl}_2 \longrightarrow \text{CaCl}_2 + \text{Ca(OCl)}_2 + 2\text{H}_2\text{O}$
Bleaching Powder
- $\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \longrightarrow \text{Ca(HCO}_3)_2$
Soluble

Uses :

- In the manufacture of bleaching powder.
- For absorbing acidic gases.
- For detection of CO_2 .
- As a disinfectant.

Calcium Oxide (Quick Lime) ; CaO

Preparation :

- $\text{CaCO}_3 \xrightarrow{\Delta} \text{CaO} + \text{CO}_2$

Properties :

- It is a white amorphous solid.
- On heating in oxyhydrogen flame, emits brilliant white light (known as limelight).
- When exposed to atmosphere,
 $\text{CaO} + \text{H}_2\text{O} \longrightarrow \text{Ca(OH)}_2$
(Moisture) (Slaked Lime)
- $\text{CaO} + \text{CO}_2 \longrightarrow \text{CaCO}_3$
(Limestone)
- Being a basic oxide, can combine with acidic impurities.
 $\text{CaO} + \text{SiO}_2 \xrightarrow{\Delta} \text{CaSiO}_3$

Uses :

- Purification of sugar.
- Important constituent of cement, mortar, caustic soda lime ($\text{CaO} + \text{NaOH}$) etc.

Calcium Carbonate (Limestone) ; CaCO_3

Preparation :

- From slaked lime :
 $\text{Ca(OH)}_2 + \text{CO}_2 \longrightarrow \text{CaCO}_3 + \text{H}_2\text{O}$
- From calcium chloride :
 $\text{CaCl}_2 + \text{Na}_2\text{CO}_3 \longrightarrow \text{CaCO}_3 + 2\text{NaCl}$

Properties :

- White fluffy solid and insoluble in water.
- $\text{CaCO}_3 \xrightarrow{\Delta} \text{CaO} + \text{CO}_2$
- Liberates CO_2
 $\text{CaCO}_3 + 2\text{HCl} \longrightarrow \text{CaCl}_2 + \text{CO}_2\uparrow + \text{H}_2\text{O}$
 $\text{CaCO}_3 + \text{H}_2\text{SO}_4 \longrightarrow \text{CaSO}_4 + \text{CO}_2\uparrow + \text{H}_2\text{O}$

Uses :

- In building material, in the manufacturing of quick lime, Na_2CO_3 .
- In the extraction of metals.
- As an antacid, abrasive in toothpaste, filler in cosmetics.

Calcium Sulphate (Plaster of Paris) ; $(\text{CaSO}_4)_2 \cdot \text{H}_2\text{O}$

Plaster of Paris is calcium sulphate hemihydrate
 $\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$.

Preparation :

- $2(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) \xrightarrow[393 \text{ K}]{\Delta} 2(\text{CaSO}_4) \cdot \text{H}_2\text{O} + 3\text{H}_2\text{O}$
Gypsum Plaster of Paris
- $2(\text{CaSO}_4) \cdot \text{H}_2\text{O} \xrightarrow[473 \text{ K}]{\Delta} 2\text{CaSO}_4 + \text{H}_2\text{O}$
(Dead burnt plaster)

Properties :

- It is white powder.
- On mixing with water, it sets into hard mass after sometime.
 $(\text{CaSO}_4)_2 \cdot \text{H}_2\text{O} + 3\text{H}_2\text{O} \longrightarrow 2(\text{CaSO}_4 \cdot 2\text{H}_2\text{O})$
Gypsum

Uses :

- For producing moulds for pottery, ceramic etc.
- For making statues, models and other decorative materials.
- In surgical bandages.
- In dentistry.

Cement

It was first introduced in England in 1824 by Joseph Aspdin. It is also called Portland cement because it resembles with the famous building stone found near Portland in England. It is a finely ground mixture of calcium silicates and aluminates which set to a hard mass when treated with water.

Composition of Cement

$\text{CaO} = 50\text{-}60\%$	$\text{MgO} = 2\text{-}3\%$
$\text{SiO}_2 = 20\text{-}25\%$	$\text{Fe}_2\text{O}_3 = 1\text{-}2\%$
$\text{Al}_2\text{O}_3 = 5\text{-}10\%$	$\text{SO}_3 = 1\text{-}2\%$