10.2 Alkali Metals

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🎯 Learning outcomes

After the completion of the chapter, learners should be able to:

10.2.1 Describe the general characteristics of alkali metals.
10.2.2 Explain the extraction of sodium from Downs' process.
10.2.3 Describe properties of sodium (action with Oxygen, water, acids, nonmetals and ammonia) and uses.
10.2.4 Explain properties (precipitation reaction and action with carbon monoxide) and uses of sodium hydroxide.
10.2.5 State and explain properties (action with CO_2, SO_2, water, precipitation reactions).and uses of sodium carbonate

Periodic discussion and general characteristics

The elements in Group IA of the periodic table, other than hydrogen, are called – the **alkali metals**. They earn this name because they dissolve in water, giving alkali.

e.g., $2\ Li + H_2O \longrightarrow 2\ LiOH + H_2$

$2\ Na + H_2O \longrightarrow 2\ NaOH + H_2$

Element	Symbol (Z)	Full Electron configuration	Shorthand Electron configuration
Lithium	Li (3)	$1s^2\ 2s^1$	[He] $2s^1$
Sodium	Na (11)	$1s^2 2s^2 2p^6 3s^1$	[Ne] $3s^1$
Potassium	K (19)		[Ar] $4s^1$
Rubidium	Rb (37)		[Kr] $5s^1$
Caesium	Cs (55)		[Xe] $6s^1$
Francium	Fr (87)		[Rn] $7s^1$

- Due to one electron in the valence shell, their valency is 1, and the oxidation number is +1 in the combined state.
- Highly electropositive and extremely reactive elements.
- Low ionisation potential and low electronegativity.
- Typical metals possess metallic lustre, malleability and ductility.
- Silvery white when freshly cut but tarnish in the air.
- Good conductors of electricity and heat.
- Relatively soft solids that can be cut with a knife. These have relatively low densities.
- Low melting and boiling points. And the m. pt. and b. pt. decrease down the group.
- Powerful reducing agents.

The flame test — chemistry's fireworks

Heat an alkali metal salt in a Bunsen flame and electrons absorb energy, jumping to a higher level. As they fall back almost instantly, they release that energy as a flash of visible light — a different colour for each element. This makes the flame test a quick, reliable way to identify alkali metals.

Metal	Flame colour
Lithium (Li)	yellow
Sodium (Na)	Golden Yellow
Potassium (K)	Lilac (violet)
Rubidium / Caesium	Reddish-violet / Blue-violet

Exam question

1. Alkali metals impart a characteristic colour to the flame. Give a reason.

Answer: When alkali metal atoms/ions are heated in a flame, their electrons absorb energy and jump to a higher energy level. As they fall back to the ground state almost instantly, they release that energy as visible light of a characteristic colour.

Sodium

Occurrence

Sodium is far too reactive to exist freely in nature — you always find it locked inside compounds. Its main minerals are as follows:

1. Sodium chloride: The most abundant mineral and ore of Sodium. Found in seawater, various lakes and as rock salt. Sea water normally contains 1.5% NaCl. The Dead Sea contains 8% NaCl.
2. Chile Saltpetre ($NaNO_3$)
3. Glauber's Salt ($Na_2SO_4.10H_2O$)
4. Borax ($Na_2B_4O_7.10H_2O$) etc.

Extraction from Down's process

Sodium is generally extracted from the most common, abundant and cheap mineral (ore), Sodium chloride.

However, it cannot be extracted by a chemical (Carbon or aluminium) reduction process because

1. Sodium chloride cannot be easily roasted to get Sodium oxide. Besides, Sodium oxide cannot be reduced by Carbon, itself being a stronger reducing agent.
2. Carbon reduction has to be carried out at a high temperature where sodium forms sodium carbide rather than free sodium metal.

Even electrolytic reduction encountered the following difficulties.

a. NaCl melts at 802^0C. The boiling point of Na is 883^0C. Therefore, if sodium metal is produced at such a temperature, Na metal forms a metallic fog with NaCl. Such fog can corrode and short-circuit the cell, and it is difficult to handle and separate.
b. Both sodium and chlorine produced are highly reactive, so they can corrode the cell.

To overcome these difficulties, JC Down mixed sodium chloride with calcium chloride in a ratio of 2:3, which lowers the melting point to about 600^0C. At this temperature, neither sodium nor chlorine corrodes the cell nor is metallic fog formed. Even less energy is enough to maintain the temperature.

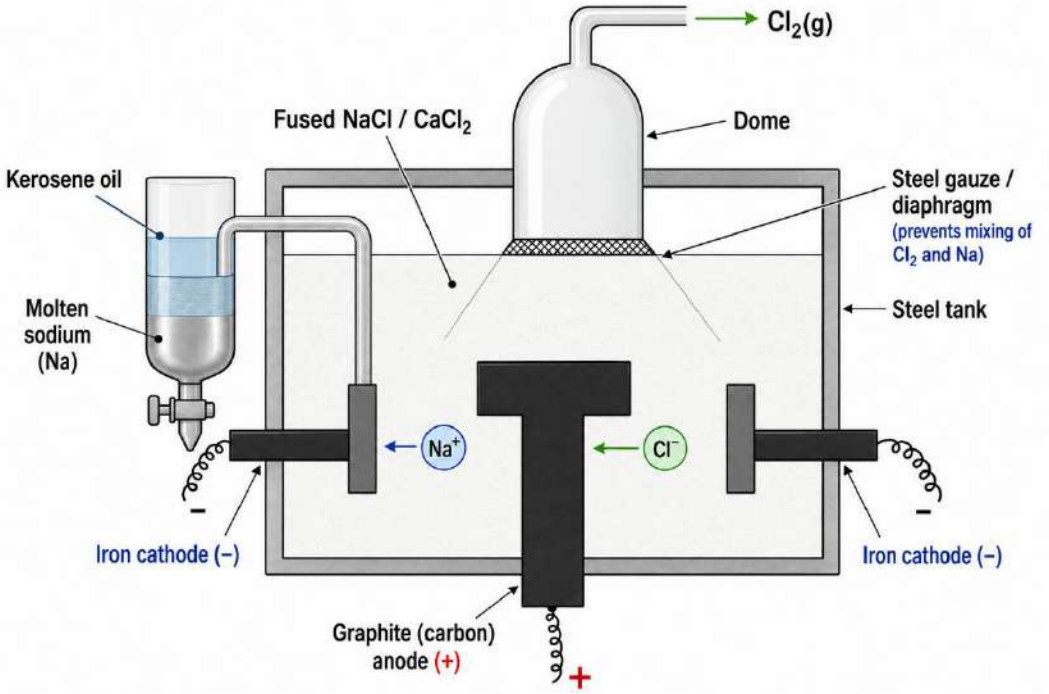

Figure: Downs' Cell for the Extraction of Sodium

The Downs cell is a cylindrical iron tank lined inside with refractory material. The Graphite anode is kept at the centre, and a cylindrical iron cathode surrounds it. The anode and cathode are separated by an iron gauze, which keeps the products of electrolysis separated.
On passing electricity, these reactions occur,

$$NaCl \rightleftharpoons Na^+ + Cl^-$$

At anode,

$$Cl^- \longrightarrow Cl + e^-$$
$$Cl + Cl \longrightarrow Cl_2$$

At cathode,

$$Na^+ + e^- \longrightarrow Na$$

The net cell reaction is:

$$2NaCl \longrightarrow 2\,Na + Cl_2$$

The sodium metal liberated at the cathode rises through the molten sodium chloride because it is lighter. Chlorine gas liberated at the anode escapes. As the reaction progresses, the concentration of NaCl decreases, and more NaCl can be added to maintain the plant's operation. Calcium is not liberated instead of sodium because it requires a higher voltage.

Advantages:

1. Highly pure Sodium metal is obtained (99.8%).
2. Chlorine is formed as a byproduct, which is a very useful industrial chemical.
3. Impure salt can be directly used.

Exam question

2. Can sodium be extracted by the electrolysis of an aqueous solution of sodium chloride? If not, why?

Answer: No. In aqueous NaCl, hydrogen has a lower discharge potential than sodium, so hydrogen is liberated at the cathode instead of sodium. Even if sodium metal did form momentarily, it would instantly react with water to give sodium hydroxide and hydrogen.

$$Na + H_2O \longrightarrow NaOH + H_2$$

Physical properties

- Soft silvery white metal with metallic lustre; soft enough to slice with a knife.
- Less dense than water **(it actually floats — briefly — before reacting!).**
- M. pt. 97^0C, B pt. 883^0C.

Chemical properties - sodium is a busy reactor

Action with air

Exposed to moist air, sodium tarnishes rapidly through a three-step chain reaction:

$$4\,Na + O_2 \longrightarrow 2\,Na_2O$$
$$Na_2O + H_2O \longrightarrow 2\,NaOH$$
$$2\,NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

First, Sodium metal absorbs oxygen, forming sodium oxide, which absorbs the moisture, changing it into sodium hydroxide. The Sodium hydroxide further absorbs carbon dioxide, forming sodium carbonate.

Therefore, sodium metal is stored dipped under *kerosene*.

3. Write the reactions for the conversion of sodium into washing soda.

[Hint: after the above sequence of reaction,

$$Na_2CO_3 + 10\,H_2O \xrightarrow[\text{Crystallization point}]{\Delta} \underset{\text{Washing soda}}{Na_2CO_3.10H_2O}$$

Exam question

4. Why is sodium kept in kerosene?

Answer: Sodium reacts readily with moisture and carbon dioxide in air — first forming sodium oxide, then sodium hydroxide, and finally sodium carbonate. Storing it in kerosene keeps air away and prevents this reaction.

$4Na + O_2 \rightarrow 2Na_2O$
$Na_2O + H_2O \rightarrow 2NaOH$
$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

Action with water- ***dramatic and dangerous***

When a piece of sodium is dropped into water, it reacts violently with water, forming caustic soda and hydrogen gas. This is a highly exothermic reaction. If a large amount of sodium is used, an explosion occurs.

$$2\,Na + 2\,H_2O \longrightarrow 2\,NaOH + H_2 + \text{heat}$$

Even the hydrogen gas formed is highly inflammable, making the reaction more dangerous.

Therefore, sodium fire cannot be extinguished by water.

Burning in Oxygen

Sodium burns in oxygen, forming mainly sodium peroxide and a small amount of sodium oxide.

$$Na + O_2 \longrightarrow Na_2O_2 \quad \text{(Major Product)}$$
$$Na + O_2 \longrightarrow Na_2O \quad \text{(Minor Product)}$$

Action with acids

It reacts with mineral acids, forming salt and displacing hydrogen gas.

$$Na + HCl \longrightarrow NaCl + H_2$$

Can sodium metal be used in place of zinc to prepare hydrogen gas in the laboratory?

Action with Hydrogen

When sodium is heated with hydrogen gas, Sodium hydride is formed, which is an unstable compound.

$$2\ Na + H_2 \longrightarrow 2\ NaH$$

Metal hydrides are compounds where hydrogen has an oxidation number of -1.

Action with other non-metals

Sodium reacts with other nonmetals, forming generally binary compounds like

$$2\ Na + Cl_2 \longrightarrow 2\ NaCl$$

$$2\ Na + S \longrightarrow Na_2S$$

Action with ammonia

When sodium is heated with ammonia gas at about 300^0C, Sodamide (sodium amide) is formed.

$$2\ Na + 2\ NH_3(g) \longrightarrow 2\ NaNH_2 + H_2$$

Sodium metal dissolves in liquid ammonia, forming a deep blue solution. Here, at first, sodium ionises as

$$Na \longrightarrow Na^+ + e^-$$

Then both sodium ion and free electron are ammoniated as:

$$Na^+ + x\ NH_3 \longrightarrow Na^+(NH_3)_x$$

$$e^- + y\ NH_3 \longrightarrow e^-(NH_3)_y$$

Uses of Sodium

- Sodium vapour lamp, which illuminates streets with yellow light, is distinctly visible in foggy weather as well.
- To prepare useful compounds like Sodamide, Sodium cyanide, Sodium peroxide, etc.
- Sodium **amalgam** is used as a reducing agent.
- As a lab reagent, especially for foreign element detection, Wurtz reaction, etc.

Exam question

5. Mention the biological importance of sodium and potassium.

Answer: Sodium and potassium exist as ions in the human body, where they help maintain osmotic pressure, assist in the transmission of nerve impulses, and maintain electro-neutrality of body fluids.

Sodium Hydroxide

Physical properties

- White deliquescent solid, soapy in touch
- Highly soluble in water; the solution is highly corrosive to skin and vegetable matter, hence called "caustic soda"
- Strong alkali, turns litmus blue, phenolphthalein pink

Chemical properties

Reaction with salt solutions (precipitation reaction)

NaOH reacts with many soluble salts of metals, giving insoluble hydroxide.

$FeSO_4 + NaOH \longrightarrow Fe(OH)_2\downarrow + Na_2SO_4$

$FeCl_3 + NaOH \longrightarrow Fe(OH)_3\downarrow + NaCl$

Action with carbon monoxide

Concentrated sodium hydroxide, when heated with carbon monoxide gas at 50 atm pressure to 160^0C °C, sodium formate is produced.

$$NaOH + CO \xrightarrow{160^0C,\ 50\ atm} HCOONa$$

(sodium formate)

Sodium methanoate

Uses

- Very important industrial alkali, used in the production of a large number of important compounds
- In the manufacture of Soap

  Oil + NaOH ⟶ Soap + Glycerol
- In the refining of oil
- In the paper and pulp industries
- Manufacturing of Rayon
- A common laboratory reagent, and in cosmetics and pharmaceuticals

Sodium carbonate (Na_2CO_3)

Physical Properties

- *Crystallises with 10 molecules of water: $Na_2CO_3.10H_2O$ — commonly called washing soda.*
- **Efflorescent** substance - loses water of crystallisation when exposed to the open atmosphere.

Chemical properties

1. **Action with SO_2**

Sodium carbonate reacts with Sulphur dioxide in the presence of Sulphur to give sodium thiosulphate.

$Na_2CO_3 + SO_2 \longrightarrow Na_2SO_3 + CO_2$

$Na_2SO_3 + S \longrightarrow Na_2S_2O_3$

2. **Action with CO_2**

When CO_2 is passed into an aqueous solution of sodium carbonate, sodium bicarbonate is produced.

$Na_2CO_3 + H_2O + CO_2 \longrightarrow 2\ NaHCO_3$

Sodium bicarbonate is called Baking soda.

3. **Formation of insoluble carbonates (precipitation reactions)**

When sodium carbonate is treated with some soluble salts like $CaCl_2$, $BaCl_2$, $AgNO_3$, $MgCl_2$, etc., the carbonates of respective metals are precipitated out.

$CaCl_2(aq) + Na_2CO_3 \longrightarrow CaCO_3(s)\downarrow + 2\ NaCl$

$BaCl_2 + Na_2CO_3 \longrightarrow BaCO_3\downarrow + 2\ NaCl$

4. **The action of water (Hydrolysis)**

It is soluble in water due to hydrolysis into sodium hydroxide (strong base) and carbonic acid (weak acid). The solution is slightly basic (alkaline). This is an exothermic process.

$Na_2CO_3 + 2\ H_2O \longrightarrow 2\ NaOH + H_2CO_3$

Uses of Sodium carbonate (Washing soda)

1. Single largest use: manufacture of glass.
2. As washing soda in laundry
3. A water softening agent.
4. In making wood pulp, paper, etc.
5. In food processing, as a pH moderator.
6. A laboratory reagent.
7. As a component of the fire extinguisher along with H_2SO_4 and $NaHCO_3$.

Quick Recap

- Alkali metals (Group 1) each have one valence electron, giving them +1 valency, high reactivity and low ionisation energy.
- Sodium is extracted from molten NaCl (mixed with $CaCl_2$) by the Downs process — electrolysis at a lowered melting point of ~600 °C.
- Sodium reacts vigorously with air, water, acids, hydrogen, non-metals and ammonia — always store it under kerosene.
- Sodium hydroxide (caustic soda) is a strong alkali used in soap-making, paper, and countless industries.
- Sodium carbonate (washing soda) is used in glass-making, laundry and water softening.

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