Chapter 3: Metals and Non-metals

Comprehensive Study Notes

Introduction

Elements can be classified as metals or non-metals based on their physical and chemical properties. Understanding these properties helps us determine their uses in daily life, from cooking utensils to electrical wires, and industrial applications.

Key Question: How are the properties of metals and non-metals related to their uses?

3.1 Physical Properties

3.1.1 Properties of Metals

Metallic Lustre

- **Definition:** Shining surface of pure metals
- **Observation:** Metals become shiny when cleaned with sandpaper
- **Examples:** Iron, copper, aluminum, gold, silver

Malleability

- **Definition:** Ability to be beaten into thin sheets
- **Most malleable:** Gold and silver
- **Applications:** Making aluminum foil, gold leaf for decoration
- **Test:** Strike metal with hammer on iron block

Ductility

- **Definition:** Ability to be drawn into thin wires
- **Most ductile:** Gold (1 gram can make 2 km wire)
- **Applications:** Copper wires for electricity, gold wires in electronics
- **Test:** Observe wires used in daily life

Hardness

- **General property:** Most metals are hard
- **Variation:** Hardness varies between metals
- **Exception:** Sodium metal can be cut with knife
- **Applications:** Steel for construction, iron for tools

Thermal Conductivity

- **Property:** Metals conduct heat efficiently
- **Best conductors:** Silver and copper
- **Poor conductors:** Lead and mercury
- **Test:** Heat one end of metal wire, observe heat transfer
- **Applications:** Cooking vessels, heat exchangers

Electrical Conductivity

- **Property:** Metals conduct electricity
- **Reason:** Free movement of electrons
- **Test:** Use electrical circuit with bulb
- **Applications:** Electrical wires, circuits

Sonority

- **Definition:** Metals produce sound when struck
- **Applications:** School bells, musical instruments
- **Test:** Strike metal against hard surface

Physical State

- **General:** Solids at room temperature
- **Exception:** Mercury (liquid at room temperature)
- **High melting points:** Most metals

3.1.2 Properties of Non-metals

Physical characteristics of non-metals:

- **States:** Solids or gases (except bromine - liquid)
- **Lustre:** Generally dull (exception: iodine is lustrous)
- **Malleability/Ductility:** Brittle, break into pieces
- **Thermal conductivity:** Poor conductors (except graphite)
- **Electrical conductivity:** Poor conductors (exception: graphite)
- **Sonority:** Do not produce sound
- **Hardness:** Generally soft (exception: diamond - hardest)

3.1.3 Exceptions to General Properties

Property	General Rule	Exceptions
Melting Point	Metals - high	Gallium, Caesium - melt in palm
Physical State	Metals - solid	Mercury - liquid

Property	General Rule	Exceptions
Lustre	Non-metals - dull	Iodine - lustrous
Hardness	Non-metals - soft	Diamond - hardest substance
Conductivity	Non-metals - poor	Graphite - conducts electricity
Malleability	Metals - malleable	Alkali metals - very soft

3.2 Chemical Properties of Metals

3.2.1 Reaction with Oxygen

General Reaction: Metal + Oxygen → Metal oxide

Examples:

1. **Copper:** $2Cu + O_2 \rightarrow 2CuO$ (Black oxide)
2. **Aluminum:** $4Al + 3O_2 \rightarrow 2Al_2O_3$
3. **Magnesium:** $2Mg + O_2 \rightarrow 2MgO$ (Dazzling white flame)

Reactivity with Oxygen:

- **Most reactive:** K, Na (catch fire in open air, stored in kerosene)
- **Moderate:** Mg, Al, Zn, Pb (form protective oxide layer)
- **Less reactive:** Fe (iron filings burn vigorously, but bulk iron doesn't)
- **Least reactive:** Cu (forms black coating when heated)
- **No reaction:** Ag, Au (even at high temperatures)

Nature of Metal Oxides:

- **Generally basic:** React with acids to form salts and water

- **Amphoteric oxides:** Al_2O_3, ZnO (react with both acids and bases)

Amphoteric oxide reactions:

- $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ (with acid)
- $Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ (with base)

3.2.2 Reaction with Water

General Reaction: Metal + Water → Metal hydroxide + Hydrogen

Classification by Water Reactivity:

Very Reactive (violent reaction with cold water):

- $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$ + heat
- $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$ + heat
- **Observation:** Hydrogen catches fire due to heat evolved

Moderately Reactive (cold water, less violent):

- $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
- **Observation:** Calcium floats due to hydrogen bubbles

Less Reactive (hot water only):

- $Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(aq) + H_2(g)$
- **Observation:** Starts floating due to hydrogen bubbles

React with Steam only:

- $2Al(s) + 3H_2O(g) \rightarrow Al_2O_3(s) + 3H_2(g)$
- $3Fe(s) + 4H_2O(g) \rightarrow Fe_3O_4(s) + 4H_2(g)$

No reaction with water:

- Pb, Cu, Ag, Au

3.2.3 Reaction with Acids

General Reaction: Metal + Dilute acid → Salt + Hydrogen

Examples:

1. $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
2. $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
3. $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$
4. $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$

Reactivity Order with Acids:

Mg > Al > Zn > Fe > (No reaction: Cu, Ag, Au)

Special Case - Nitric Acid:

- HNO_3 is strong oxidizing agent
- Generally no H_2 evolution (H_2 oxidized to H_2O)
- Exceptions: Very dilute HNO_3 with Mg and Mn produces H_2

3.2.4 Displacement Reactions

Principle: More reactive metal displaces less reactive metal from its salt solution.

Example: $Fe(s) + CuSO_4(aq) \rightarrow FeSO_4(aq) + Cu(s)$

- Iron nail becomes brownish (copper coating)
- Blue solution becomes green

- Iron is more reactive than copper

3.3 Reactivity Series

3.3.1 Activity Series Table

Metal	Symbol	Reactivity Level
Potassium	K	Most Reactive
Sodium	Na	↑
Calcium	Ca	|
Magnesium	Mg	|
Aluminium	Al	|
Zinc	Zn	| Reactivity
Iron	Fe	| Decreases
Lead	Pb	|
[Hydrogen]	**[H]**	|
Copper	Cu	|
Mercury	Hg	|
Silver	Ag	↓
Gold	Au	Least Reactive

3.3.2 Applications of Reactivity Series

1. **Predicting displacement reactions**
2. **Determining extraction methods**
3. **Understanding corrosion patterns**
4. **Selecting metals for specific uses**

3.4 How Metals and Non-metals React

3.4.1 Electronic Configuration and Reactivity

Noble Gas Configuration Goal

- Noble gases have complete valence shells (stable)
- Other elements achieve stability by gaining/losing electrons

Metal Behavior (Electron Loss)

Example - Sodium:

- Electronic configuration: 2,8,1
- Loses 1 electron from outermost shell
- Forms Na^+ cation: 2,8 (stable octet)

Example - Magnesium:

- Electronic configuration: 2,8,2
- Loses 2 electrons from outermost shell
- Forms Mg^{2+} cation: 2,8 (stable octet)

Non-metal Behavior (Electron Gain)

Example - Chlorine:

- Electronic configuration: 2,8,7
- Gains 1 electron to complete octet
- Forms Cl^- anion: 2,8,8 (stable octet)

3.4.2 Ionic Compound Formation

Formation of NaCl: Na → Na^+ + e^- (electron loss) Cl + e^- → Cl^- (electron gain) Na^+ + Cl^- → NaCl (electrostatic attraction)

Formation of $MgCl_2$: Mg → Mg^{2+} + $2e^-$ 2Cl + $2e^-$ → $2Cl^-$ Mg^{2+} + $2Cl^-$ → $MgCl_2$

3.4.3 Properties of Ionic Compounds

Physical Properties:

1. **State:** Solids at room temperature
2. **Structure:** Hard but brittle
3. **Melting/Boiling points:** High (strong ionic bonds)
4. **Solubility:** Soluble in water, insoluble in organic solvents

Electrical Properties:

- **Solid state:** Do not conduct (ions fixed in position)
- **Molten state:** Conduct electricity (ions free to move)
- **Aqueous solution:** Conduct electricity (ions dissociated)

High Melting Point Examples:

Compound	Melting Point (K)	Boiling Point (K)
NaCl	1074	1686
$CaCl_2$	1045	1900
CaO	2850	3120
$MgCl_2$	981	1685

3.5 Occurrence and Extraction of Metals

3.5.1 Natural Occurrence

Definitions:

- **Minerals:** Elements/compounds occurring naturally in earth's crust
- **Ores:** Minerals with high metal content for profitable extraction
- **Gangue:** Unwanted impurities (soil, sand) in ores

Occurrence Patterns:

1. **Free State:** Least reactive metals (Au, Ag, Pt, Cu)
2. **Combined State:** More reactive metals as oxides, sulphides, carbonates

3.5.2 Extraction Methods Based on Reactivity

For Least Reactive Metals (Cu, Hg, Ag, Au)

Method: Simple heating of ores

Mercury extraction from Cinnabar (HgS):

- $2HgS(s) + 3O_2(g) \rightarrow 2HgO(s) + 2SO_2(g)$
- $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$

Copper extraction from Cu_2S:

- $2Cu_2S + 3O_2(g) \rightarrow 2Cu_2O(s) + 2SO_2(g)$
- $2Cu_2O + Cu_2S \rightarrow 6Cu(s) + SO_2(g)$

For Moderately Reactive Metals (Zn, Fe, Pb)

Step 1: Concentration - Remove gangue by various methods

Step 2: Convert to Oxides

- **Roasting:** Heating sulphides in excess air $2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$
- **Calcination:** Heating carbonates in limited air
  $ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$

Step 3: Reduction with Carbon $ZnO(s) + C(s) \rightarrow Zn(s) + CO(g)$

Alternative: Displacement Method $3MnO_2(s) + 4Al(s) \rightarrow 3Mn(l) + 2Al_2O_3(s) + \text{Heat}$

For Highly Reactive Metals (K, Na, Ca, Mg, Al)

Method: Electrolytic reduction

- Cannot use carbon (metals have higher affinity for oxygen)
- Electrolyze molten chlorides

Example - Sodium extraction:

- At cathode: $Na^+ + e^- \rightarrow Na$
- At anode: $2Cl^- \rightarrow Cl_2 + 2e^-$

3.5.3 Refining of Metals

Electrolytic Refining

Process: Purify impure metals using electrolysis

Setup:

- **Anode:** Impure metal
- **Cathode:** Pure metal strip
- **Electrolyte:** Metal salt solution

Example - Copper refining:

- Pure copper deposits on cathode
- Impurities settle as anode mud
- Used for: Cu, Zn, Ni, Ag, Au, Sn

3.6 Corrosion

3.6.1 Definition and Examples

Corrosion: Attack on metals by moisture, acids, and other environmental factors

Common Examples:

- **Iron rusting:** Brown flaky coating ($Fe_2O_3.xH_2O$)
- **Silver tarnishing:** Black coating (Ag_2S from air sulphur)
- **Copper corrosion:** Green coating (basic copper carbonate)

3.6.2 Conditions for Rusting

Essential Requirements: Both air (oxygen) and water needed

Experimental Evidence:

- **Test Tube A:** Air + Water = Rusting occurs
- **Test Tube B:** Water only (no dissolved air) = No rusting
- **Test Tube C:** Dry air only = No rusting

3.6.3 Prevention Methods

1. **Painting:** Prevents contact with air and moisture

2. **Oiling/Greasing:** Creates protective layer
3. **Galvanization:** Coating with zinc layer
4. **Chrome plating:** Decorative and protective coating
5. **Anodizing:** Thick aluminum oxide layer formation
6. **Alloying:** Mixing with other metals

Galvanization Process:

- Coat iron/steel with zinc layer
- Zinc is more reactive, corrodes first
- Protects iron even if coating is broken

3.7 Alloys

3.7.1 Definition and Formation

Alloy: Homogeneous mixture of two or more metals, or metal and non-metal

Preparation Process:

1. Melt primary metal
2. Dissolve other elements in definite proportions
3. Cool to room temperature

3.7.2 Properties of Alloys

- **Electrical conductivity:** Less than pure metals
- **Melting point:** Generally lower than pure metals
- **Strength:** Often stronger than constituent metals

- **Corrosion resistance:** Better than pure metals

3.7.3 Common Alloys and Uses

Alloy	Composition	Properties	Uses
Brass	Cu + Zn	Corrosion resistant	Decorative items, musical instruments
Bronze	Cu + Sn	Hard, corrosion resistant	Statues, medals
Stainless Steel	Fe + Ni + Cr	Hard, rust-resistant	Cutlery, surgical instruments
Solder	Pb + Sn	Low melting point	Welding electrical wires
Amalgam	Metal + Hg	Varies with metal	Dental fillings

3.7.4 Gold Alloys

- **24 carat gold:** Pure gold (too soft for jewelry)
- **22 carat gold:** 22 parts gold + 2 parts Cu/Ag (used in India)
- **18 carat gold:** 18 parts gold + 6 parts other metals

3.8 Chemical Properties of Non-metals

3.8.1 Reaction with Oxygen

General Reaction: Non-metal + Oxygen → Non-metallic oxide

Examples:

1. **Carbon:** $C + O_2 \rightarrow CO_2$
2. **Sulphur:** $S + O_2 \rightarrow SO_2$

Testing Oxide Nature:

- **Sulphur oxide test:** $SO_2 + H_2O \rightarrow H_2SO_3$ (acidic)
- **Test with litmus:** Non-metallic oxides turn blue litmus red

Nature: Non-metallic oxides are acidic or neutral

3.8.2 Reaction with Hydrogen

Non-metals react with hydrogen to form hydrides:

- $H_2 + Cl_2 \rightarrow 2HCl$
- $3H_2 + N_2 \rightarrow 2NH_3$

3.9 Special Topics

3.9.1 Anodizing Process

Purpose: Form thick protective oxide layer on aluminum

Process:

1. Clean aluminum article made anode
2. Electrolysis with dilute H_2SO_4
3. Oxygen at anode reacts with aluminum
4. Forms thick Al_2O_3 layer
5. Can be dyed for attractive finish

3.9.2 Aqua Regia

Composition: 3:1 mixture of concentrated HCl and HNO_3

Properties:

- Highly corrosive, fuming liquid
- Can dissolve gold and platinum
- Neither acid alone can dissolve gold

Use: Dissolving noble metals for analysis

3.9.3 Thermit Process

Reaction: $Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(l) + Al_2O_3(s) + Heat$

Applications:

- Joining railway tracks
- Welding cracked machine parts
- Emergency welding in remote locations

3.10 Historical and Cultural Significance

Iron Pillar of Delhi

- **Age:** Over 1600 years old
- **Specifications:** 8 m high, 6 tonnes weight
- **Special property:** Rust-resistant due to ancient Indian metallurgy
- **Scientific interest:** Studied worldwide for rust prevention techniques

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Practice Questions and Answers

Q1. Why are cooking utensils made of aluminum and copper but handles are made of wood or plastic?

Answer: Aluminum and copper are good conductors of heat, allowing efficient cooking and even heat distribution. However, handles are made of wood or plastic because these are poor conductors of heat (thermal insulators), preventing burns while handling hot utensils.

Q2. Explain why sodium and potassium are stored in kerosene oil.

Answer: Sodium and potassium are extremely reactive metals that react vigorously with oxygen and moisture in air, often catching fire. Kerosene oil prevents contact with air and water, thus preventing accidental fires and oxidation of these metals.

Q3. What are amphoteric oxides? Give two examples and write their reactions with acids and bases.

Answer: Amphoteric oxides react with both acids and bases to form salts and water.

Examples: Al_2O_3 and ZnO

Reactions:

- $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ (with acid)
- $Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$ (with base)
- $ZnO + 2HCl \rightarrow ZnCl_2 + H_2O$ (with acid)
- $ZnO + 2NaOH \rightarrow Na_2ZnO_2 + H_2O$ (with base)

Q4. Copper vessels are cleaned with lemon or tamarind juice. Explain why.

Answer: Copper vessels develop a green coating of basic copper carbonate due to corrosion. Lemon and tamarind contain citric acid and tartaric acid respectively. These acids react with the basic copper carbonate to form soluble copper salts, which are easily washed away, restoring the original shine of copper.

Q5. Why is aluminum used for making utensils despite being highly reactive?

Answer: Although aluminum is highly reactive, it forms a thin, protective oxide layer (Al_2O_3) when exposed to air. This oxide layer prevents further corrosion and makes aluminum suitable for utensils. The process can be enhanced by anodizing to form a thicker protective layer.

3.11 Important Chemical Equations Summary

Metal Reactions:

1. **With Oxygen:** $4Al + 3O_2 \rightarrow 2Al_2O_3$
2. **With Water:** $2Na + 2H_2O \rightarrow 2NaOH + H_2$
3. **With Acids:** $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$
4. **Displacement:** $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

Extraction Processes:

1. **Roasting:** $2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$
2. **Calcination:** $CaCO_3 \rightarrow CaO + CO_2$
3. **Reduction:** $ZnO + C \rightarrow Zn + CO$
4. **Thermit:** $Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$

Corrosion Examples:

1. **Iron rusting:** $4Fe + 3O_2 + 2xH_2O \rightarrow 2Fe_2O_3.xH_2O$
2. **Silver tarnishing:** $2Ag + H_2S \rightarrow Ag_2S + H_2$
3. **Copper corrosion:** Formation of basic copper carbonate

3.12 Comparative Summary

Metals vs Non-metals

Property	Metals	Non-metals
Physical State	Mostly solids (except Hg)	Solids or gases (except Br)
Lustre	Lustrous	Dull (except I_2)
Malleability	Malleable	Brittle
Ductility	Ductile	Non-ductile
Heat Conduction	Good conductors	Poor conductors (except graphite)
Electrical Conduction	Good conductors	Poor conductors (except graphite)
Sonority	Sonorous	Non-sonorous
Oxide Nature	Basic (mostly)	Acidic or neutral
Ion Formation	Lose electrons (cations)	Gain electrons (anions)
Reaction with Acids	Displace hydrogen	Do not displace hydrogen

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3.13 Memory Aids and Study Tips

Reactivity Series Memory:

"Please Send Charlie's Monkey And Zebra In Lead Container Having Silver And Gold" (K, Na, Ca, Mg, Al, Zn, Fe, Pb, Cu, Hg, Ag, Au)

Property Patterns:

- **Down reactivity series:** Reactivity decreases
- **Metal extraction:** More reactive = more difficult extraction
- **Displacement:** Higher in series displaces lower

- **Corrosion resistance:** Lower in series = more resistant

Key Concepts:

- **Electron transfer** explains chemical behavior
- **Ionic compounds** form when metals meet non-metals
- **Activity series** predicts reaction outcomes
- **Extraction method** depends on metal reactivity

Chapter Summary

Metals and non-metals have distinctly different physical and chemical properties. Metals are generally lustrous, malleable, ductile, and good conductors, while non-metals are typically brittle, dull, and poor conductors with notable exceptions.

Chemical reactivity of metals follows a predictable pattern shown in the activity series. This series helps predict displacement reactions, extraction methods, and corrosion behavior. Metals lose electrons to form cations, while non-metals gain electrons to form anions, creating ionic compounds with characteristic properties.

Metal extraction involves multiple steps from ore concentration to refining, with methods varying based on metal reactivity. Understanding these principles is crucial for industrial metallurgy and explaining everyday phenomena like rusting and the use of different metals for specific applications.

The formation of alloys demonstrates how mixing metals can create materials with enhanced properties, making them more suitable for specific applications than pure metals.

Study Strategy:

- Master the activity series and its applications
- Practice electron transfer diagrams for ionic compound formation
- Understand extraction methods for different reactivity levels
- Connect physical properties to practical uses
- Focus on corrosion prevention methods

Source: NCERT Science Textbook
Detailed notes for thorough exam preparation