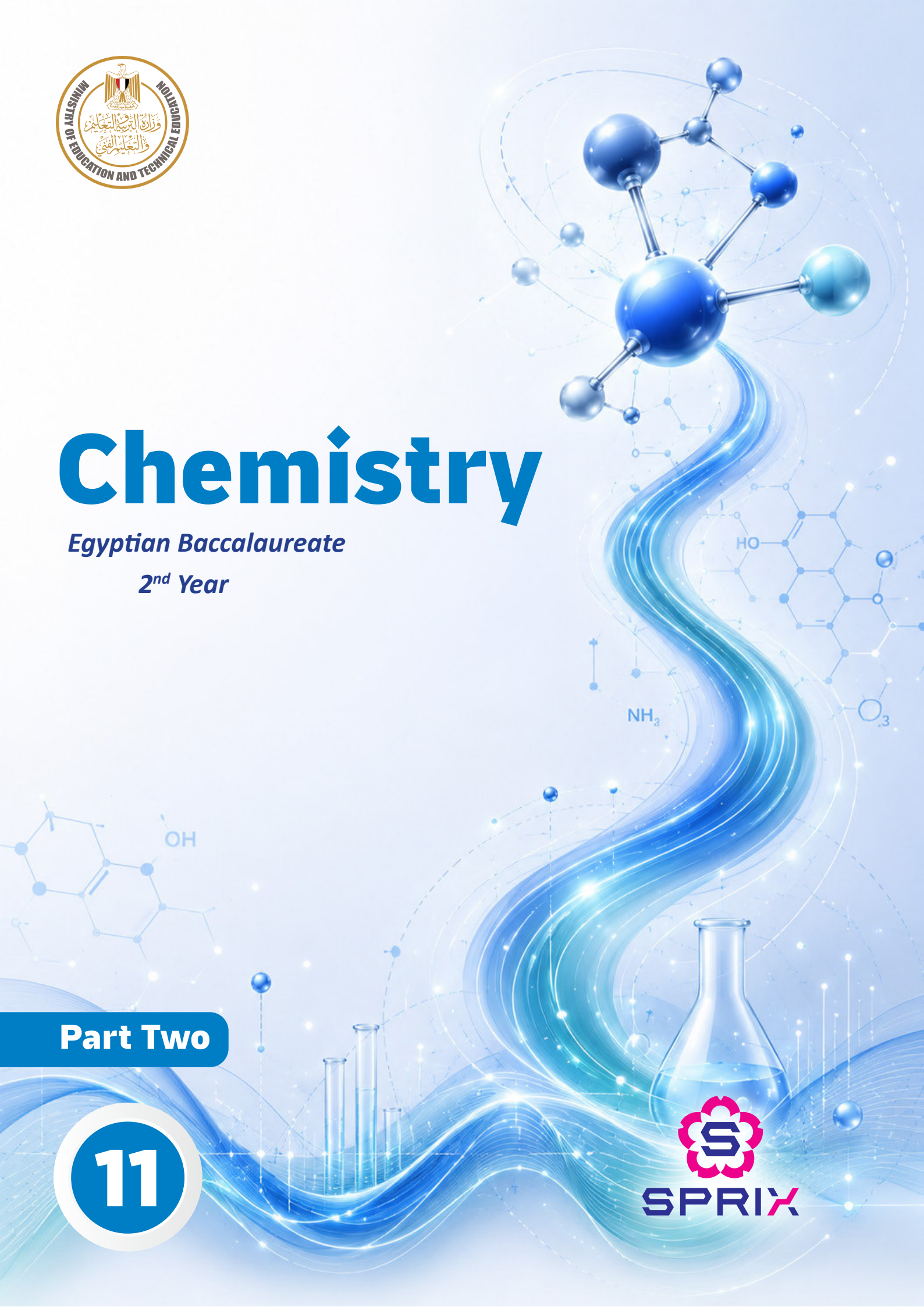
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Chemistry
Egyptian Baccalaureate
2nd Year
Part Two
11
SPRIX

Chemistry

Egyptian Baccalaureate

2nd Year

The International Baccalaureate™

has reviewed the pedagogical and assessment approaches underpinning this textbook.

Ministry of Education and Technical Education

New Administrative Capital

Cairo, Egypt

How to use this book

Every lesson follows a scientific learning journey:
Observe ▪ Question ▪ Investigate ▪ Explain ▪ Apply ▪ Evaluate

1 **Guiding Question**
Each lesson begins with a guiding question that focuses your thinking and helps you connect chemistry to real-world phenomena.

2 **Engaging Introduction**
A short scenario, phenomenon, or authentic context introduces the lesson and demonstrates why the topic matters in everyday life, technology, and society.

3 **Point!**
Key concepts, definitions, laws, principles, and scientific models are presented clearly and systematically.

4 **Exploration**
Investigate patterns, analyze evidence, identify relationships, and make predictions before formal explanations are introduced.

5 **Warm Up**
Questions and Examples that help you in applying knowledge and prepare for deeper learning.

6 **Explanation**
Step-by-step explanations demonstrate scientific reasoning, calculations, and problem-solving strategies.

7 **Think Like a Chemist**
Apply scientific thinking to justify conclusions, evaluate claims, and interpret experimental results.

8 **Think as an Engineer**
Use chemistry concepts to solve practical problems and make evidence-based decisions in technological and engineering contexts.

9 **Life Application**
Discover how chemistry influences sustainability, health, energy production, industry, transportation, and everyday life.

10 **Structure of Science**
Explore the scientific concepts, models, and principles that connect the lesson to broader scientific understanding.

11 **Nature of Science**
Examine how scientists collect evidence, design investigations, evaluate data, and build reliable explanations.

12 **Misconceptions Alert**
Identify frequent mistakes and misconceptions so that your understanding becomes more accurate and scientifically sound.

13 **Key equations at a glance**
Important formulas, symbols, and relationships are summarized for quick reference.

14 **Try**
Practice your learning
Apply new concepts through guided questions and structured exercises.

15 **Exercise**
Strengthen your understanding through increasingly challenging questions that require reasoning, calculations, and analysis.

16 **Challenge Your Thinking**
Tackle higher-order questions that require evaluation, synthesis, problem-solving, and scientific argumentation.

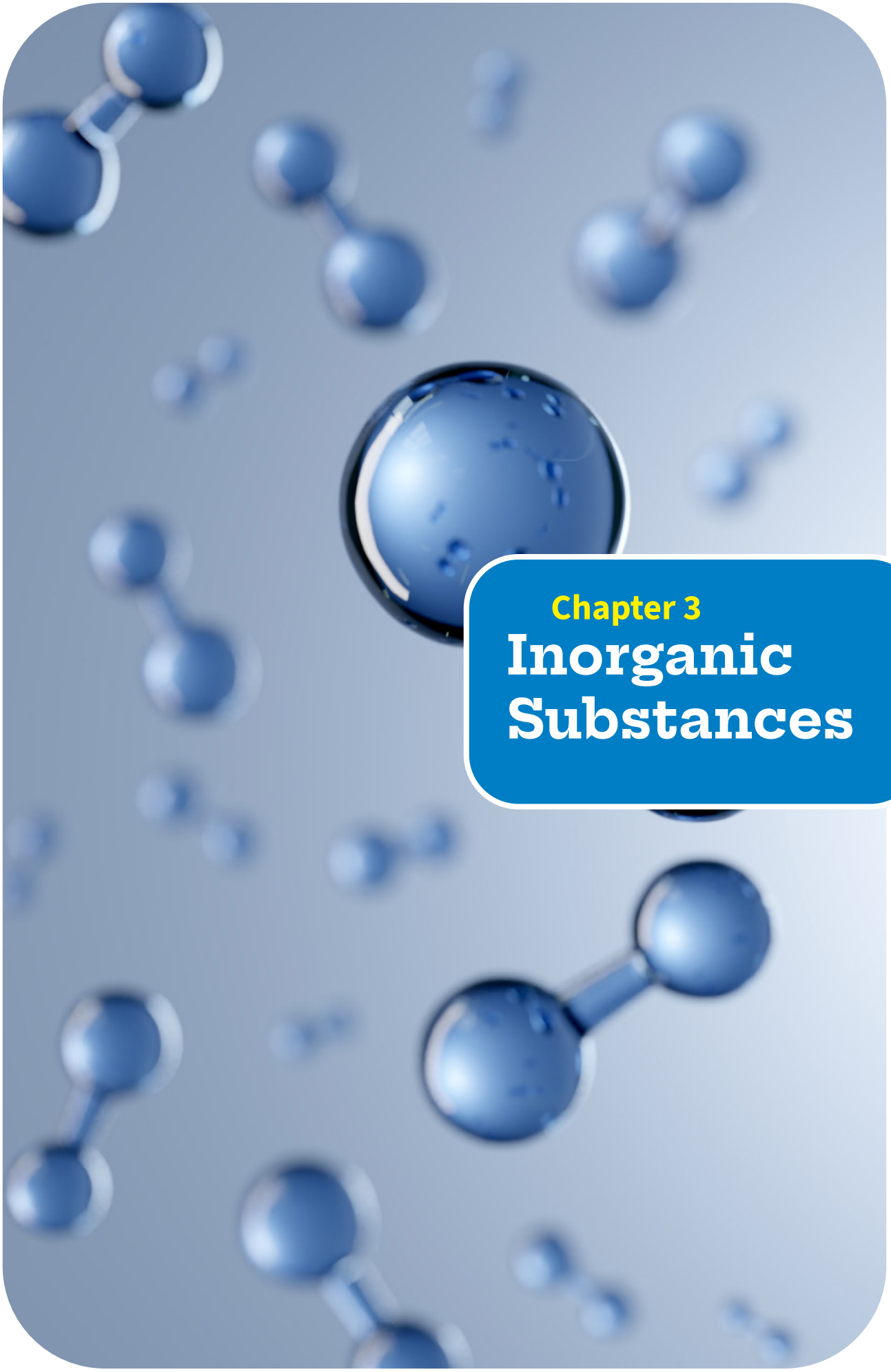
17 **Relect and grow**
Revisit key concepts from current and previous lessons to strengthen long-term understanding and exam readiness.

Your lessons and the EB syllabus

Second Part — every lesson mapped to its EB Chemistry topic

Chapter 3 -Inorganic Substances

Chapter 4 - Organic Compounds



Chapter 3

Inorganic Substances

Lesson 3-1 — Hydrogen and Noble Gases

Engaging Introduction

Hydrogen fuels spacecraft, powers fuel cells, and may become one of the world's cleanest energy sources. In contrast, noble gases such as helium and neon rarely react with other substances, yet they illuminate cities, preserve valuable materials, and enable advanced medical technologies.

In this lesson, you will investigate how the arrangement of electrons determines the chemical behavior of elements and why hydrogen and noble gases play such different—but equally important—roles in modern science and technology.

Guiding Question How does electron configuration determine whether an element is chemically reactive or chemically stable?

Exploration

A weather balloon filled with helium safely rises into the atmosphere.

Another balloon filled with hydrogen can produce a dramatic explosion when ignited.

Both gases are the lightest known substances.

Why do they behave so differently?

Without studying the lesson:

• Which gas would you choose for weather balloons? Why?…… ……

• Why is hydrogen widely used as a fuel while helium is not? ……

• What property makes noble gases almost completely unreactive?……

Point!

1.Hydrogen H_2

Properties of hydrogen

(i) A **colourless, odourless** gas, and the **lightest** of all gases.

(ii) **Poorly soluble** in water.

(iii) **Reduces** metal oxides at high temperatures.

$$CuO + H_2 \longrightarrow Cu + H_2O$$

figure 3.1.1 Reduction of Copper

Structure of Science

Key Fact :

• Hydrogen is the lightest element and acts as a reducing agent.

• Noble gases possess complete outer electron shells, making them highly stable.

• Electron arrangement explains many periodic trends and chemical properties.

Key Concepts:

• Hydrogen
• Reduction
• Oxidation
• Electron Configuration
• Valence Electrons
• Noble Gases
• Periodicity
• Chemical Stability
• Fuel Cells

(iv) Used in **fuel cells** .

(v) Generated when hydrochloric acid or dilute sulfuric acid is added to **metals** such as iron or aluminium.

$$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$$

Nature of Science

Observe

Hydrogen reacts with hot copper(II) oxide to produce copper metal.

$CuO + H_2 \rightarrow Cu + H_2O$

Infer

What role does hydrogen play in this reaction?

_____

Predict

Would hydrogen react similarly with other metal oxides?

Explain your reasoning.

_____

2. Noble Gases

(a) Noble gases

(i) He, Ne, Ar, Kr (Krypton), Xe (Xenon), Rn (Radon), and Og (Oganesson) in Group **18** of the periodic table.

(ii) The number of outermost shell electrons is **8** . Helium has **2** .

(iii) The number of valence electrons is **0** .

(b) Properties of noble gases

(i) The elements are **colourless, odourless** gases at room temperature.

(ii) Present in the air in trace amounts.

(iii) Melting points and boiling points are extremely **low** .

(iv) Hardly react with other atoms.

(v) Emit light when a voltage is applied.

Table 3-1-1 Properties of Noble Gas Elements

Element Name	Atomic Symbol	Atomic Electron Configuration (Shell) K	L	M	N	O	P	Boiling Point (°C)	Examples of Use
Helium	$_{2}He$	2						−269	Airships, Cryogenic Experiments
Neon	$_{10}Ne$	2	8					−246	Neon Signs
Argon	$_{18}Ar$	2	8	8				−186	Light Bulbs, Inert Gas for Welding
Krypton	$_{36}Kr$	2	8	18	8			−152	Light Bulbs, Inert Gas for Welding
Xenon	$_{54}Xe$	2	8	18	18	8		−107	Camera Strobes
Radon	$_{86}Rn$	2	8	18	32	18	8	−62	Medical Radiation Source

Chemistry in Everyday Life

Hydrogen: Fuel of the Future

Hydrogen-powered fuel cells produce electricity while releasing only water as a by-product.

Today, hydrogen technology is being developed for:

- Zero-emission vehicles
- Spacecraft propulsion
- Renewable energy storage
- Sustainable transportation

Misconception Alert

❌ Wrong idea:

„Noble gases never react under any circumstances."

✅ Correct:

Most noble gases are extremely unreactive, but heavier noble gases such as xenon can form compounds under special conditions.

Warm Up

Answer the following questions.

(a) Choose one incorrect statement from the following descriptions about hydrogen and answer with its letter.

A. Hydrogen is the lightest of all gases and is poorly soluble in water.

B. Hydrogen is generated when dilute sulfuric acid is added to zinc.

C. Hydrogen acts as an oxidising agent and reacts with heated copper to produce copper(II) oxide.

(b) Choose one incorrect statement from the following descriptions about noble gases and answer with its letter.

A. The melting and boiling points of noble gases are low.

B. Some noble gases have a number of valence electrons that is not 0.

C. All Group 18 elements are noble gases.

Explanation

(a) Hydrogen acts as a reducing agent at high temperatures. Therefore, C.

(b) All noble gases have 0 valence electrons. Therefore, B.

Data Interpretation Activity

Gas	Relative Reactivity	Common Application
Hydrogen	High	Fuel cells
Helium	Very Low	Weather balloons
Neon	Very Low	Neon signs
Argon	Very Low	Welding

Think Like a Chemist

Which gas is most chemically reactive?

.....

Which gases are suitable for protecting materials from oxidation?

.....

What evidence supports your conclusion?

.....

How does electron configuration explain these differences?

.....

Try

1. Indicate whether the following statements are True or False.

(a) Hydrogen is the lightest of all gases and is highly soluble in water.

(b) Hydrogen acts as an oxidising agent and reacts with heated copper(II) oxide to produce copper.

(c) Hydrogen is used in fuel cells together with oxygen.

2. Indicate whether the following statements are True or False.

(a) Many noble gases are highly combustible.

Be Global Citizen

Noble gases contribute to sustainable technologies by:

- Improving energy-efficient lighting
- Supporting medical imaging and radiation therapy
- Advancing space exploration

Understanding the chemistry of inert gases helps scientists develop safer industrial processes and more sustainable technologies.

(b) Elemental noble gases include both liquids and gases at room temperature and normal atmospheric pressure.

(c) All noble gas atoms have 8 electrons in their outermost shell.

(d) All noble gas atoms have 0 valence electrons.

Think Critically

A company wants to replace helium with hydrogen in commercial balloons because hydrogen is less expensive.

Evaluate this proposal.

• What are the scientific advantages?

……

• What are the potential safety risks?

……

• Which gas would you recommend?

……

Support your answer with scientific evidence.

……

Exercise

Choose the Correct Answer:

1. Which property makes helium suitable for filling weather balloons?

A. High density

B. High chemical reactivity

C. Low density and chemical stability

D. High solubility in water

……

2. Why can hydrogen reduce copper(II) oxide?

A. Hydrogen gains oxygen.

B. Hydrogen removes oxygen from copper oxide.

C. Copper loses electrons to hydrogen.

D. Hydrogen acts as an oxidizing agent.

……

3. Choose one incorrect statement from the following descriptions.

A. Hydrogen is the lightest of all gases and is highly soluble in water.

B. Hydrogen acts as a reducing agent and reacts with heated copper(II) oxide to produce copper.

C. Hydrogen is used in fuel cells together with oxygen.

D. Hydrogen is generated when dilute sulfuric acid is added to zinc.

4. Choose one correct statement from the following descriptions.

A. Noble gases are abundant in the air as compounds.

B. All noble gas atoms have 8 electrons in their outermost shell.

C. All elemental noble gases are gases at room temperature and normal atmospheric pressure.

D. Many noble gases are highly combustible.

E. When a noble gas is kept at low pressure, it emits a light of a characteristic colour.

Challenge Your Thinking

A scientist claims:

"Since hydrogen is the lightest element, it should always be the safest gas for lifting balloons."

Evaluate the claim.

• Is the reasoning scientifically valid?

_____

• Which properties should be considered besides density?

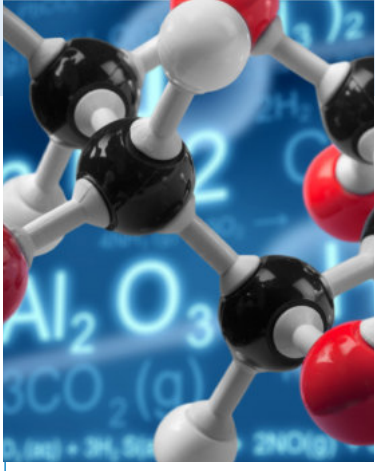
_____

• Why is helium preferred in many real-world applications?

_____

Use scientific evidence to justify your answer.

_____



Lesson 3-2 — Halogens and Their Compounds

Engaging Introduction

Imagine swimming in a pool on a hot summer day. The water looks clean and safe because it has been disinfected with chlorine compounds. In another laboratory, a forensic scientist adds a few drops of silver nitrate to an unknown solution and immediately identifies which halogen is present from the color of the precipitate.

Although halogens are among the most reactive non-metals, they play essential roles in public health, chemical analysis, medicine, and industry. Their behavior is governed by periodic trends, oxidation–reduction reactions, and electron transfer.

In this lesson, you will investigate why halogens differ in oxidising power, how chemists identify halide ions, and why chlorine compounds have become indispensable in modern society.

Guiding Question Why do halogens show different chemical reactivities even though they belong to the same group in the periodic table?

Exploration

Two swimming pools receive the same amount of disinfectant.

One remains crystal clear.

The other quickly becomes cloudy and contaminated.

Without studying the lesson:

• What chemical properties make chlorine an effective disinfectant?

……

• Why are chlorine compounds used instead of pure chlorine gas in many applications?

……

• How might chemists verify whether chloride ions are present in the pool water?

……

Point!

1. Halogens

(a) Halogens: F, Cl, Br, I, and At (Astatine) in Group 17 of the periodic table.

(b) Elemental halogens

All elemental halogens are diatomic molecules and act as oxidising agents.

The strength of the oxidising power is $F_2 > Cl_2 > Br_2 > I_2$.

Structure of Science

Key Fact :

• All halogens exist as diatomic molecules.

• Halogens are strong oxidising agents.

• Oxidising power decreases down Group 17.

• Chlorine compounds are widely used as disinfectants because of their oxidising ability.

Key Concepts:

Halogens

• Oxidation

• Reduction

• Oxidising Agent

• Hydrogen Halides

• Electronegativity

• Hydrogen Bonding

• Halide Ions

• Precipitation

• Oxoacids

⟨Properties of chlorine Cl_2⟩

- Has a **pungent odour** .
- A toxic, **yellow-green** gas at room temperature.
- **Heavier** than air, and **soluble** in water.

Capture by downward delivery.

- Generated by adding concentrated hydrochloric acid to manganese(IV) oxide MnO_2 and heating. The chemical equation is:

$$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$$

(Figure 3-2-1 on the right)

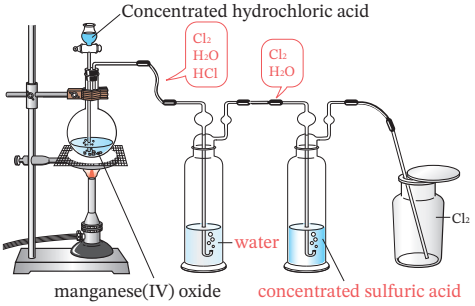


Figure 3-2-1 Generating of Chlorine

The generated gas is mixed with substances other than chlorine.

1. **Hydrogen chloride** is removed by **water** .
2. **Water** is removed by **concentrated sulfuric acid** .

Nature of Science

Observe

Chlorine gas has a yellow-green color and a pungent odor.
It is denser than air and dissolves in water.

Explain

Why is chlorine collected by downward delivery instead of over water?

.....

Predict

What would happen if chlorine were collected over water?

.....

2. Compounds of Halogens

(a) Hydrogen Halides

Hydrogen halides are compounds formed between halogen elements and hydrogen. They are all colourless, toxic gases with a pungent odour.

(i) Hydrogen Fluoride (HF)

Its aqueous solution is called **Hydrofluoric Acid** and is the only **weak acid** among the hydrogen halides.

[Explanation for being a weak acid]

Fluorine (F) has a very high **electronegativity** (tendency to strongly attract electrons). As a result, HF molecules **associate** through **hydrogen bonding**. This association makes it difficult for the molecule to release hydrogen ions (H^+) in water, resulting in weak acidity.

(ii) Hydrogen Chloride (HCl)

Its aqueous solution is known as **Hydrochloric Acid** and is a **strong acid** . When it reacts with ammonia (NH_3), it produces a **white smoke** consisting of fine crystals of ammonium chloride (NH_4Cl).

$$HCl + NH_3 \longrightarrow NH_4Cl$$

Scientific Investigation

A scientist receives three unknown solutions that may contain chloride, bromide, or iodide ions.

Plan an investigation using silver nitrate solution.

Students should identify:

Independent variable

……

Dependent variable

……

Controlled variables

……

Evidence to collect

……

(b) Identification of Halide Ions

When aqueous silver nitrate solution ($AgNO_3$) is added to an unknown aqueous solution, precipitates of different colours are formed depending on the halogen present. This reaction can be used to identify the type of halide ion.

Table 3-2-1: Solubility of Silver Halides in Water

Precipitate	Colour	Solubility in Water
AgF	Soluble (No precipitate formed)	Soluble
AgCl	White	Insoluble (Precipitate)
AgBr	Pale Yellow	Insoluble (Precipitate)
AgI	Yellow	Insoluble (Precipitate)

(c)Oxoacids of Halogens and Their Salts

Acids in which an oxygen atom is bonded to a halogen atom are called **oxoacids**. A salt of a chlorine oxoacid, known as "bleaching powder," is widely used in everyday life.

(i) **Formation of Bleaching Powder**

When chlorine gas (Cl_2) is absorbed by calcium hydroxide (**slaked lime**), **bleaching powder** (**$CaCl(ClO)\cdot H_2O$**) is produced.

$$Ca(OH)_2 + Cl_2 \longrightarrow CaCl(ClO)\cdot H_2O$$

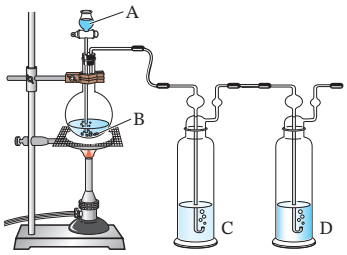
(ii) **[Mechanism] Principle of Bleaching and Disinfection**

The hypochlorite ion (ClO^-), a component of bleaching powder, possesses extremely strong **oxidising power**. This oxidising power is used to destroy the molecular structure of pigments to remove colour (**bleaching**) and to destroy and kill bacterial cells (**disinfection**).

Note: In recent years, "high-test hypochlorite" ($Ca(ClO)_2\cdot 2H_2O$), which has a higher concentration of active ingredients, is also widely used for disinfecting swimming pools and other applications.

Warm Up

Chlorine was generated using the apparatus shown in the figure on the right. Answer the following questions.



(a) Choose the substances A to D in the figure from the following respectively.
(i) Concentrated sulfuric acid (ii) Concentrated hydrochloric acid
(iii) Water (iv) Manganese(IV) oxide

(b) Choose the substances removed at C and D from the following respectively.
(i) Water (ii) Oxygen (iii) Hydrogen chloride

(c) Choose the appropriate collection method for chlorine from the following.
(i) Upward delivery (ii) Downward delivery (iii) Collection over water

Chemistry and Society
Understanding halogen chemistry allows scientists to:
- Produce safe drinking water
- Develop effective disinfectants
- Manufacture pharmaceuticals
- Improve forensic chemical analysis
- Monitor environmental water quality

Explanation

(a) Add concentrated hydrochloric acid to solid manganese(IV) oxide. For the generated gas, first, hydrogen chloride is removed by water, and then water is removed by concentrated sulfuric acid.

If water is placed after, water vapour will be mixed into the gas again after the water is removed by concentrated sulfuric acid.

A: (ii) B: (iv) C: (iii) D: (i)

(b) C: (iii) D: (i)

(c) Because chlorine is soluble in water and heavier than air, it is collected by downward delivery. (ii)

Try

Choose the correct answer.

1. Which hydrogen halide is classified as a weak acid?

A. HCl
B. HBr
C. HI
D. HF

.....

2. Why is chlorine collected by downward delivery?

A. It is lighter than air.
B. It reacts with oxygen.
C. It is denser than air and soluble in water.
D. It is insoluble in water.

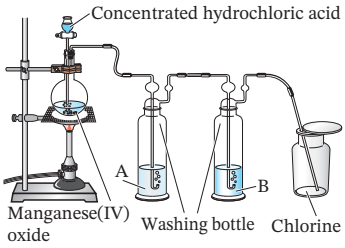
.....

3. Choose the two statements from A to D below that contain errors, and answer with their letters.

A All elemental halogens are diatomic molecules.
B The strength of the oxidising power of halogens is in the order of I2>Br2>Cl2>F2.
C Hydrogen fluoride is a strong acid and has the property of dissolving glass.

D Chlorine is a yellow-green gas and has a pungent odour.

4- The figure on the right is an apparatus for obtaining dry chlorine. Fill in the blanks ( ) in the following text with the appropriate words. Answer (vi) with a chemical formula.



In this experiment, chlorine is generated by the reaction:

$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$.

After that, (i) is placed in washing bottle A to absorb (ii) in the gas. (iii) is placed in washing bottle B to absorb (iv) in the gas. This yields dry chlorine gas.

Chlorine has strong oxidising power, and when chlorine is passed through an aqueous potassium iodide solution, (v) is liberated in the aqueous solution. Expressing this with a reaction equation:

$2KI + Cl_2 \longrightarrow 2KCl +$ (vi)

Evaluate the Evidence

A newspaper article states:

"Because chlorine kills bacteria, increasing the chlorine concentration always makes water safer."

Evaluate this statement.

• Is the claim scientifically accurate?

……

• What evidence should be considered?

……

• Can excessive chlorine create health or environmental problems?

……

Use scientific reasoning to justify your answer.

……

Exercise

1. Answer the following questions.

(a) For elemental halogens, does the oxidising power increase or decrease as the atomic number decreases?

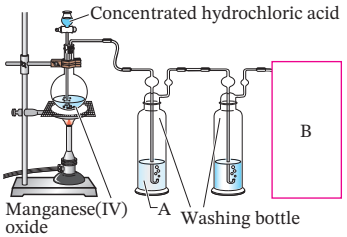
(b) Among the following hydrogen halides, choose all strong acids and answer with their letters.

(A) HF **(B)** HCl **(C)** HBr **(D)** HI

(c) Among the following hydrogen halides, choose the one that dissolves glass and answer with its letter.

(A) HF **(B)** HCl **(C)** HBr **(D)** HI

2. The figure below is an apparatus for obtaining dry chlorine, where chlorine was generated using concentrated hydrochloric acid and manganese(IV) oxide. Answer the following questions regarding this.



(a) Write a chemical equation for the generation of chlorine in this experiment.

(b) Write the name of the substance placed in washing bottle A and the name of the substance removed by it, respectively.

(c) State the collection method at the gas collection part B.

(d) State the colour and odour of the generated chlorine.

Lesson 3-3 — Oxygen, Sulfur and Their Compounds

Engaging Introduction

Every day, oxygen keeps us alive, purifies drinking water, and supports countless industrial processes. Meanwhile, sulfur compounds are found in car batteries, fertilizers, food preservation, and even the acid rain that affects our environment. Although these substances all contain oxygen or sulfur, they behave very differently because of their molecular structures and chemical properties.

In this lesson, you will investigate how differences in molecular structure lead to very different chemical behaviors and how these properties are applied to solve real-world challenges.

Guiding Question How does the structure of oxygen and sulfur compounds determine their chemical properties and their applications in everyday life?

Exploration

Think about these everyday situations:

You breathe oxygen every second to stay alive.

A candle keeps burning only when oxygen is present.

Some bottled drinking water is purified using ozone before it reaches your home.

Without studying this lesson, discuss the following questions.

Observation: What do all three situations have in common?.....

Prediction: Do you think oxygen (O_2) and ozone (O_3) behave in exactly the same way? Why? .....

Inquiry: Why is ordinary oxygen safe to breathe, while ozone is used only in small amounts for sterilizing water? .....

Point!

1. Oxygen O_2

(a) Properties of oxygen

- A colourless, odourless gas.
- Poorly soluble in water.

Collected by collection over water.

(b) Generation method of oxygen

Hydrogen peroxide is decomposed using manganese(IV) oxide MnO_2 as a catalyst.

Chemical equation: $2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$

(c) Ozone O_3: An allotrope of oxygen.

(i) Properties

- A toxic gas with a pale blue colour and a characteristic odour.
- Acts as a strong oxidising agent and is used for sterilising drinking water and bleaching fabrics.

Structure of Science

Key fact :

Oxygen and ozone are allotropes with different molecular structures.

- Ozone is a stronger oxidising agent than oxygen.
- Sulfuric acid exhibits different chemical properties depending on its concentration.

Key concepts:

Allotropy
- Catalyst
- Oxidation
- Reduction
- Sulfuric Acid
- Dehydration
- Oxidising Agent
- Hygroscopic Substance

- Atmospheric pressure
- Gas pressure

(ii) Generation method

• Subject oxygen to silent electrical discharge.

$$3O_2 \longrightarrow 2O_3$$

• Expose oxygen to **ultraviolet rays** .

Think Like a Scientist

Oxygen and ozone are made from the same element.
Yet one supports life while the other can damage lung tissue.
Explain.
• Why do these substances have different properties?.....
• What evidence supports your explanation?.....

2. Compounds of Sulfur S

(a) Hydrogen sulfide **H_2S**

• Generated by adding dilute sulfuric acid or dilute hydrochloric acid to iron(II) sulfide.

• Acts as a strong **reducing agent** .

(b) Sulfur dioxide **SO_2**

• Obtained by burning **sulfur** .

• Acts as a reducing agent, but acts as an oxidising agent against strong reducing agents such as hydrogen sulfide.

Evidence-Based Reasoning

A student spills concentrated sulfuric acid on a piece of paper.
After a few minutes the paper becomes black.
Claim: Sulfuric acid removed water from the paper.
Evidence.....
Reasoning .....

(c) Concentrated sulfuric acid and dilute sulfuric acid **H_2SO_4**

(i) Manufacturing process of sulfuric acid: Produced by the **Contact process** .

〈Contact process〉

❶ Sulfur dioxide SO_2 is oxidised using vanadium(V) oxide V_2O_5 as a catalyst to produce **sulfur trioxide SO_3** .

❷ SO_3 is absorbed into concentrated sulfuric acid and reacted with the water in it.

❶ $S + O_2 \longrightarrow SO_2$
$2SO_2 + O_2 \xrightarrow{V_2O_5} 2SO_3$
❷ $SO_3 + H_2O \longrightarrow H_2SO_4$

(ii) Properties of concentrated sulfuric acid

• It is **non-volatile** , and when reacted with a salt of a volatile acid, the volatile acid is liberated.

Example: $NaCl + H_2SO_4 \longrightarrow NaHSO_4 + HCl$
(Salt of a volatile acid → Volatile acid)

• Highly **hygroscopic** , and is used as a desiccant.

• Has a **dehydrating** effect.

It removes hydrogen atoms and oxygen atoms from organic compounds in the same proportion as water (H_2O).

Example: When concentrated sulfuric acid is added to formic acid HCOOH, carbon monoxide CO is generated.

• Hot concentrated sulfuric acid acts as a strong **oxidising agent** and dissolves

Misconception Alert

❌ Wrong idea:

„Oxygen and ozone have identical chemical properties because they are both made of oxygen atoms."

✅ Correct:

Oxygen and ozone are allotropes with different molecular structures, giving them different physical and chemical properties.

Chemistry in Industry

Sulfur compounds are essential in manufacturing Fertilizers, Car batteries, Industrial chemicals, Paper, and pharmaceuticals

Among them, sulfuric acid is often called the world's most important industrial chemical because the amount produced by a country is often used as an indicator of industrial development.

metals such as copper and silver.

$$Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$$

(iii) Properties of dilute sulfuric acid

- It is a **strong acid** .
- Reacts with metals that are more reactive than hydrogen, such as zinc and iron, to generate hydrogen.

$$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$$

Warm Up

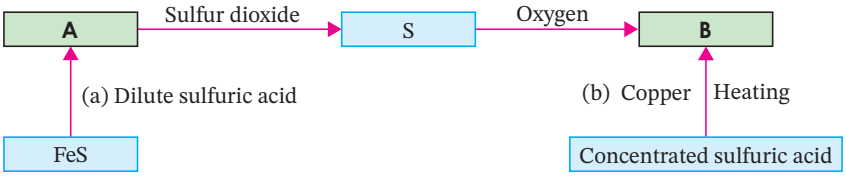
Answer the following questions.

(a) Answer the following questions about the generation of oxygen.

(i) Write the balanced chemical equation for the decomposition of hydrogen peroxide catalyzed by manganese(IV) oxide.

(ii) State the most appropriate collection method for oxygen.

(b) The following diagram shows sulfur and its compounds. Answer the questions below.



(i) Write the balanced chemical equation for the reaction occurring in step (b).

(ii) What properties of dilute sulfuric acid or concentrated sulfuric acid are utilized in the changes (a) and (b)? Choose from the following.

A. Non-volatile B. Dehydrating effect C. Strong acidity D. Oxidising property

(iii) When 1.0 kg of sulfur is completely converted into sulfuric acid, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced. Express your answer to two significant figures. (H = 1.0, O = 16, S = 32)

Explanation

(a) (i) $2H_2O_2 \longrightarrow 2H_2O + O_2$

(ii)Oxygen is poorly soluble in water. Gases that are poorly soluble in water are collected by collection over water. Answer: Collection over water.

(b)(i)First, substance B is formed by the reaction of sulfur and oxygen, so it must be sulfur dioxide (SO_2).
Therefore, the change in (b) is the reaction where sulfuric acid H_2SO_4 and copper react to produce SO_2.
The chemical equation is: $Cu + 2H_2SO_4 \longrightarrow CuSO_4 + 2H_2O + SO_2$

(ii) (a) When dilute sulfuric acid is added to iron(II) sulfide FeS, hydrogen sulfide H_2S is generated.
This is a reaction in which the weak acid H_2S is liberated due to the reaction of the strong acid H_2SO_4 with the salt of a weak acid FeS.

Sustainability Connection

Chemistry for a Sustainable Planet

Many technologies that improve our quality of life depend on oxygen and sulfur chemistry.

- Fertilizers that improve crop production.
- Batteries that store renewable energy.
- Cleaner factories that remove sulfur dioxide before it reaches the atmosphere.

Therefore, C.

Also, dilute sulfuric acid does not have non-volatile properties, dehydrating effects, or oxidising effects.

(b) Hot concentrated sulfuric acid acts as a strong oxidising agent and reacts with metals to dissolve them, as in (i). D

(iii) The reactions to produce sulfuric acid from sulfur are as follows:

$$S + O_2 \longrightarrow SO_2$$
$$2SO_2 + O_2 \longrightarrow 2SO_3$$
$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Therefore, 1 mol of sulfuric acid is produced from 1 mol of sulfur.

From sulfur S = 32, the amount of substance of 1.0 kg of sulfur is $\frac{1000}{32}$ mol, so the produced concentrated sulfuric acid is also $\frac{1000}{32}$ mol.

Letting the mass of 98% concentrated sulfuric acid H_2SO_4 be x [g], and since the molar mass of H_2SO_4 is 98:

$$\frac{1000}{32}\ \text{mol} = \frac{x\ [\text{g}] \times 0.98}{98\ \text{g/mol}}$$

$$x = 3.12 \times 10^3$$
$$\approx 3.1 \times 10^3\ \text{g}$$

Therefore, 3.1 kg.

Interpreting Experimental Data

Substance	Observation
Oxygen	Supports combustion
Ozone	Bleaches dyes
Concentrated H_2SO_4	Turns sugar black
Dilute H_2SO_4	Produces H_2 with Zn

Think Like a Chemist

Which substance acts mainly as a dehydrating agent?

.....

Which acts as the strongest oxidising agent?

.....

Which observations support your answer?

.....

Which chemical property explains each application?

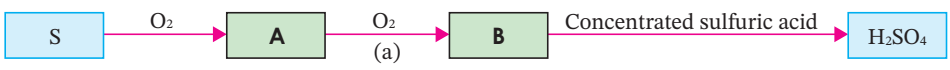
.....

Try

1. Identify the appropriate terms for (i) and (ii) in the following passage.

When oxygen is subjected to a silent electrical discharge, (i) is produced. To generate (i), another method is to expose oxygen to (ii). (i) has bleaching and sterilizing effects.

2. Answer the following questions based on the diagram showing the reactions of sulfur and its compounds. (H = 1.0, O = 16, S = 32)



(i) Identify the chemical formulas for substances A and B.

(ii) Write the name of the catalyst used in (a).

(iii) Name the industrial process used to manufacture concentrated sulfuric acid.

(iv) Assuming complete conversion, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced from 9.6 kg of sulfur. Express your answer to two significant figures.

3.Match each of the following reactions **(a)** through **(e)** with the corresponding property of sulfuric acid (A through E) that is utilized.

(a) When zinc was added to dilute sulfuric acid, hydrogen was generated.

(b) When sodium chloride was added to concentrated sulfuric acid and heated, hydrogen chloride was generated.

(c) When carbon dioxide containing water vapour was passed through concentrated sulfuric acid, dry carbon dioxide was obtained.

(d) When copper was added to concentrated sulfuric acid and heated, sulfur dioxide was generated.

(e) When concentrated sulfuric acid was added to formic acid and heated, carbon monoxide was generated.

A Non-volatile **B** Dehydrating property **C** Hygroscopic property **D** Oxidising property **E** Strong acidity

Think Critically

A company claims: "Ozone should completely replace chlorine in every water-treatment system because it is a stronger oxidising agent."
Evaluate this claim.
- What scientific evidence supports the claim? .....
- What limitations should also be considered? .....
- Would ozone always be the better choice?

Support your answer with evidence. .....

Exercise

1. Which statement correctly explains why ozone is a better disinfectant than oxygen?

   A. Ozone has a lower molecular mass.

   B. Ozone is a stronger oxidising agent.

   C. Ozone is more soluble in water.

   D. Ozone is less reactive.

   .....

2. Which property of concentrated sulfuric acid allows it to dry gases?

   A. Strong acidity

   B. Hygroscopic nature

   C. Non-volatility

   D. Weak oxidation

   .....

3. Answer the following questions.

(a) Write the balanced chemical equation for the decomposition of hydrogen peroxide catalyzed by manganese(IV) oxide.

(b) Identify the role of manganese(IV) oxide used in **(a)**.

(c) Identify the most appropriate collection method for oxygen gas.

(d) What is produced when oxygen is subjected to a silent electrical discharge?

4. Read the following text and answer the questions below.

Sulfur dioxide is synthesised by burning sulfur and serves as a raw material for sulfuric acid. Concentrated sulfuric acid is manufactured industrially by oxidising sulfur dioxide in the presence of a small amount of vanadium(V) oxide V_2O_5, and reacting the produced ( ) with water.

(a) Identify the substance that goes in the parentheses ( ).

(b) Name the industrial process described in the underlined part.

(c) Assuming complete conversion, calculate the mass (in kg) of 98% concentrated sulfuric acid that can be produced from 4.8 kg of sulfur. Express your answer to two significant figures. (H = 1.0, O = 16, S = 32)

5. Match each of the following reactions (i) through (iv) with the corresponding property of sulfuric acid (A through D) that is utilized.

(i) When concentrated sulfuric acid is added to sodium chloride and heated, hydrogen chloride is generated.

(ii) When concentrated sulfuric acid is added to sucrose $C_{12}H_{22}O_{11}$, it turns black.

(iii) When dilute sulfuric acid is added to zinc, hydrogen is generated.

(iv) When concentrated sulfuric acid is added to copper and heated, sulfur dioxide is generated.

A Non-volatility	B Oxidising property	C Dehydrating property	D Strong acidity

Lesson 3-4 — Nitrogen, Phosphorus and Their Compounds

Engaging Introduction

Every day, billions of people depend on crops grown with fertilizers that contain nitrogen and phosphorus. Without these compounds, many plants would not grow fast enough to produce enough food for the world's population. Behind every bag of fertilizer is a remarkable achievement of chemistry: scientists learned how to convert nitrogen from the air into useful compounds that plants can absorb.

In this lesson, you will discover how chemists transform nitrogen from the atmosphere into ammonia and nitric acid, why phosphorus is essential for plant growth, and how these industrial processes have changed modern agriculture and society.

Guiding Question How do chemists convert abundant natural resources into compounds that support life, agriculture, and industry?

Exploration

Look at these everyday situations:

A farmer spreads fertilizer on crops.

Plants become greener and grow faster.

Although almost 78% of the air is nitrogen, plants cannot use most of it directly.

Observation: What do you notice about the relationship between air and plant growth?

……

Inference: Why do farmers still need fertilizers if the atmosphere already contains large amounts of nitrogen?

……

Prediction: How might chemists convert nitrogen gas into a form that plants can use?

……

Point!

1. Nitrogen N_2

(a) Nitrogen compounds

(i) Ammonia **NH_3**

- A **colourless** gas with a **pungent** odour. **Lighter** than air.
- **Easily soluble** in water, and the aqueous solution is **basic** (alkaline).

(ii) Nitric acid **HNO_3**

- Both concentrated and dilute nitric acid have strong **oxidising** power and dissolve metals such as copper and silver.

Structure of Science

Key fact :

- Nitrogen gas is abundant but chemically unreactive.
- Ammonia is the starting material for producing nitric acid and many fertilizers.
- Different allotropes of phosphorus have different physical and chemical properties.

Key concepts:

Nitrogen Fixation
- Catalyst
- Haber–Bosch Process
- Ostwald Process
- Fertilizers

• Because it is easily decomposed by light or heat, it is stored in an amber bottle in a cool, dark place.

(iii) Nitric oxide (Nitrogen monoxide) **NO**

• Produced when dilute nitric acid reacts with copper.

$$3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 4H_2O + 2NO$$

(iv) Nitrogen dioxide **NO_2**

• Produced when concentrated nitric acid reacts with copper.

$$Cu + 4HNO_3 \longrightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2$$

(b) Industrial manufacturing processes of nitrogen compounds

(i) **Haber-Bosch process** : A method for manufacturing ammonia.

• Produced from nitrogen and hydrogen using **iron(II,III) oxide (triiron tetraoxide), Fe_3O_4** and others as a catalyst.

$$N_2 + 3H_2 \overset{Fe_3O_4}{\rightleftharpoons} 2NH_3$$

(ii) **Ostwald process** : A method for manufacturing nitric acid.

❶ Oxidise ammonia using **platinum Pt** and others as a catalyst to produce nitric oxide.

$$4NH_3 + 5O_2 \xrightarrow{Pt} 4NO + 6H_2O$$

❷ Oxidise nitric oxide to make nitrogen dioxide. $2NO + O_2 \longrightarrow 2NO_2$

❸ Absorb nitrogen dioxide in warm water to make nitric acid.

$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$

⇒ Expressing the overall reaction of ❶ to ❸ with a chemical equation:

$$NH_3 + 2O_2 \longrightarrow HNO_3 + H_2O$$

Think as an Engineer

Scientists wanted to produce ammonia efficiently on a large scale.
Instead of simply mixing nitrogen and hydrogen, they designed conditions that maximize production.
Investigation Question
Why are high pressure, suitable temperature, and catalysts used together during the Haber–Bosch process? ……
How might changing one of these conditions affect ammonia production?
……

2. Phosphorus P

(a) Allotropes of phosphorus

(i) White phosphorus (Yellow phosphorus)

• A **pale yellow** , highly toxic **solid** .

• Because it **spontaneously ignites** in air, it is stored in water.

(ii) Red phosphorus

• A **reddish-brown** powder with weak toxicity.

• Produced by heating white phosphorus in the absence of air.

(b) Phosphorus compounds

(i) Tetraphosphorus decaoxide P_4O_{10}

- A **white** powder produced by burning white or red phosphorus.
- It is highly **deliquescent** (absorbs moisture from the air and dissolves).

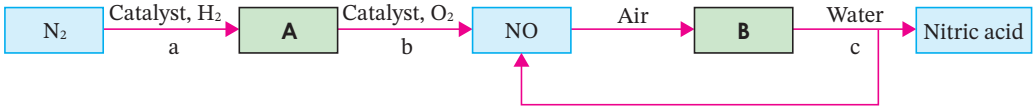
(ii) Phosphoric acid H_3PO_4

- Colourless crystals produced by dissolving tetraphosphorus decaoxide in water and heating.
- Its salts are used in fertilizers.

Warm Up

Answer the following questions.

(a) The following figure shows the process of industrial manufacturing of nitric acid. Answer the questions below.



(i) Identify the chemical formulas for substances A and B.

(ii) Write the names of the catalysts used in reactions a and b, respectively.

(iii) Write the balanced chemical equations for reactions b and c.

(b) Which of the following statements (A to D) about phosphorus is incorrect?

A. Phosphorus is an element belonging to the same group as nitrogen.

B. Elemental phosphorus burns in the air to become tetraphosphorus decaoxide.

C. Tetraphosphorus decaoxide is a white solid at room temperature.

D. Red phosphorus spontaneously ignites in the air.

Explanation

(a) (i) A: When nitrogen and hydrogen react, ammonia is produced.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

B: Nitric oxide is quickly oxidised in the air to become nitrogen dioxide.

$$2NO + O_2 \longrightarrow 2NO_2$$

(ii)a: Iron(II, III) oxide

b: From part (i), A is NH_3. When producing nitric oxide from ammonia, platinum Pt or similar is used as a catalyst. Answer: Platinum.

(iii)b: $4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$

c: From part (i), B is $3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$

(b) Red phosphorus is a stable substance, and white phosphorus spontaneously ignites in the air. Therefore, D.

Data Interpretation

Analyze Industrial Production

Compound	Main Use
NH_3	Fertilizers
HNO_3	Fertilizers, explosives
H_3PO_4	Fertilizers
P_4O_{10}	Drying agent

Think Like a Chemist

Which compound is produced directly from nitrogen gas?

……

Which compound is produced from ammonia?

……

Which compounds contribute directly to agriculture?

……

Why are catalysts essential in these industrial processes?

……

Try

Choose the correct answer:

1. Why is ammonia considered one of the world's most important industrial chemicals?

A. It is the main source of nitrogen for producing fertilizers.

B. It is the strongest acid.

C. It reacts with every metal.

D. It is the main component of air.

……

2. Which catalyst is used in the Haber–Bosch process?

A. Platinum

B. Iron(II,III) oxide (Fe_3O_4)

C. Manganese dioxide

D. Vanadium(V) oxide

3.Answer the following questions.

(a)Write the balanced chemical equation for the industrial production of ammonia.

(b)Write the three balanced chemical equations for the industrial production of nitric acid from ammonia. Also, name the catalyst required for each stage, if any.

(c)Write the overall balanced chemical equation for the process described in (b).

(d)Name the industrial process described in (a).

(e)Name the industrial process described in (b).

Be Global Citizen

Nitrogen and phosphorus compounds improve crop production, but excessive use can pollute rivers, lakes, and oceans by causing eutrophication, where excess nutrients lead to rapid algal growth and reduced oxygen levels for aquatic life.

4.Identify each of the following statements as True or False.

(a)White phosphorus spontaneously ignites in the air.

(b)Tetraphosphorus decaoxide is an ionic crystal and is highly hygroscopic.

(c) When red phosphorus is burned, tetraphosphorus decaoxide is produced.

Think Critically

A country wants to increase food production by using much larger amounts of nitrogen and phosphorus fertilizers. A scientist warns that excessive fertilizer use may damage nearby rivers and lakes.

Evaluate the Situation

• What benefits could increased fertilizer use provide?

……

• What environmental problems could occur?

……

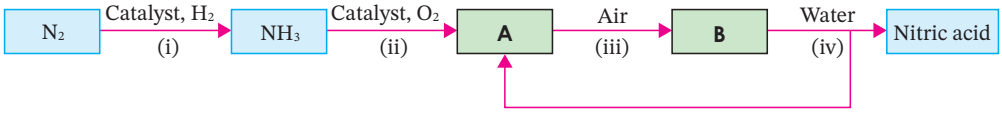
• How can chemistry help balance food production with environmental sustainability?

……

Use scientific evidence to justify your answers.

Exercise

1. The following figure shows the process of industrial manufacturing of nitric acid. Answer the following questions.



.Write the catalysts used in reactions (i) and (ii), respectively, with their chemical formulas **(a)**

(b) Identify the chemical formulas for substances A and B.

(c) Write balanced chemical equations for reactions (i) through (iv).

(d) Write the names of the industrial manufacturing processes for reaction (i) and reactions (ii) to (iv), respectively.

2. Among the following descriptions from (i) to (iv), choose two correct ones and answer with their numbers.

(i) White phosphorus is highly toxic and spontaneously ignites, so it is stored in water.

(ii) When red phosphorus is burned, white phosphorus is produced.

(iii) Tetraphosphorus decaoxide is an ionic crystal and is highly hygroscopic.

(iv) Some salts of phosphoric acid are used as fertilizers.

Challenge Your Thinking

A scientist says:

"Without the Haber–Bosch process, nearly half of the world's food production would not be possible."

Evaluate this statement.

• What scientific evidence supports this claim?

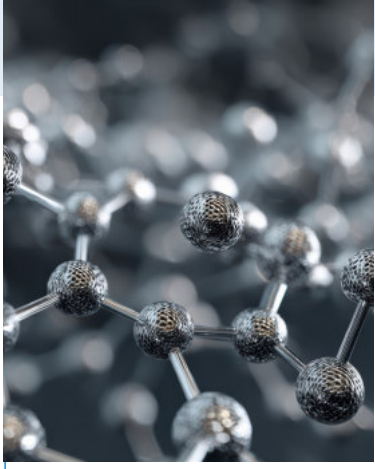
……

• What challenges result from relying heavily on synthetic fertilizers?

……

• How could future chemical technologies make fertilizer production more sustainable?

……



Lesson 3-5 — Carbon, Silicon and Their Compounds

Engaging Introduction

Every day, carbon compounds affect our lives in ways we often do not notice. Carbon dioxide helps plants grow and is found in soft drinks, while carbon monoxide is an invisible poisonous gas that can be produced by faulty heaters or poorly ventilated kitchens. At the same time, silicon compounds are found in smartphones, computer chips, glass, building materials, and even the small packets labeled "Do Not Eat" inside new shoes and electronic devices.

Although carbon and silicon belong to the same group in the periodic table, their compounds have very different properties and applications. Understanding these differences helps scientists design safer materials, protect human health, and develop modern technologies.

Guiding Question How do the properties of carbon and silicon compounds determine their uses in daily life and their impact on human health and the environment?

Exploration

Consider these familiar situations:

- A family opens the windows while using a gas heater.
- A plant grows by absorbing carbon dioxide from the air.
- Small packets inside shoe boxes keep products dry.

Observation: What do these situations have in common?

……

Inference: Why is one carbon compound essential for life while another can be deadly?

……

Prediction: Why do manufacturers place silica gel packets inside many packaged products?

……

Structure of Science

Key fact :

- Carbon monoxide is a toxic gas
- Carbon dioxide is essential for photosynthesis and the carbon cycle.
- Silicon is one of the most abundant elements in Earth's crust.

Key concepts:

Incomplete Combustion
- Reducing Agent
- Silica Gel
- Semiconductor
- Adsorptionpressure

- Gas pressure
-

Point!

1. Carbon C

(a) Allotropes of carbon

Carbon has allotropes such as diamond, graphite, and fullerene.

(b) Carbon compounds

(i) Carbon monoxide **CO**

- A colourless, odourless, **toxic** gas.
- It is **poorly soluble** in water.

- Has a **reducing** property, and reduces other substances by removing their oxygen, becoming carbon dioxide in the process.
- Burns with a pale blue flame in the air.
- Obtained by dehydrating **formic acid** HCOOH with concentrated sulfuric acid.

$$HCOOH \longrightarrow CO + H_2O$$

(ii) Carbon dioxide **CO_2**

- A colourless, odourless gas.
- **Sparingly soluble** in water. The aqueous solution is **weakly** acidic.
- Generated when **hydrochloric acid** is added to limestone (main component $CaCO_3$).

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

- The solution **turns milky white** when the gas is passed through an aqueous calcium hydroxide solution (limewater).
- The solid is called **dry ice** .

Think Critically

A family installs a carbon monoxide detector in their home but believes opening a window is unnecessary when using a charcoal heater indoors.

Evaluate the Situation

Is the family's reasoning scientifically correct?

……

Why can carbon monoxide accumulate indoors?

……

What evidence supports the use of both ventilation and carbon monoxide detectors?

……

Use scientific evidence to justify your answers.

……

2. Silicon Si

(a) Elemental silicon

- A covalent crystal with the same structure as diamond.
- Does not exist in nature.
- Obtained by melting silicon dioxide SiO_2 and reducing it with carbon.
- Exhibits the properties of a **semiconductor** .

Has electrical conductivity intermediate between "conductors" like metals and "insulators" like rubber.

(b) Silicon compounds

(i) Silicon dioxide **SiO_2**

- Exists in nature as quartz and rock crystal.
- Exhibits electrical insulation properties.

(ii) Sodium silicate Na_2SiO_3

- Produced by reacting silicon dioxide with sodium hydroxide or sodium carbonate.
- When water is added and heated, it forms a viscous liquid known as a **sodium silicate solution** .

(iii) Silica gel

• A porous solid used as an adsorbent and desiccant.
Has many small holes and a large surface area.

• Produced by heating and drying **silicic acid** H_2SiO_3, which is generated when hydrochloric acid is added to sodium silicate solution.

Life Application

The Toxicity of Carbon Monoxide

Carbon monoxide (CO) is a colourless and odourless gas, making it extremely difficult to detect when generated. Hemoglobin, found in red blood cells, normally plays the role of binding to oxygen and transporting it throughout the body. However, CO binds to hemoglobin much more strongly—over 200 times stronger—than oxygen does.
Once CO binds, hemoglobin can no longer bind to oxygen, and oxygen transport is severely inhibited. As a result, the entire body falls into a state of severe oxygen deprivation (carbon monoxide poisoning). Because CO is produced by the incomplete combustion of fuels in poorly ventilated environments with an insufficient oxygen supply, it is essential to always ensure adequate ventilation when using combustible fuels.

Warm Up

Answer the following questions.

(a) Identify the appropriate words or substance names for A to C in the following passage.

Carbon dioxide is usually generated in the laboratory by adding (A) to limestone. On the other hand, carbon monoxide is usually produced in the laboratory by adding concentrated sulfuric acid to (B) and heating. When carbon dioxide is passed through (C) , it turns milky white.

(b) In the reaction underlined in **(a)**, what is the role of concentrated sulfuric acid? Briefly explain by referring to the specific property of concentrated sulfuric acid.

(c) Which of the following statements (A to D) is incorrect?

A. Elemental silicon is obtained by reducing silicon dioxide.

B. Silica gel is used as a desiccant and adsorbent.

C. When water is added to sodium silicate and heated, it forms a sodium silicate solution.

D. Silicon dioxide exhibits the properties of a semiconductor.

Explanation

(a) A: hydrochloric acid.

B: formic acid.

When concentrated sulfuric acid is added to formic acid, the formic acid is dehydrated to produce carbon monoxide.

C: aqueous calcium hydroxide solution (limewater).

(b) It acts as a dehydrating agent. Concentrated sulfuric acid has a strong dehydrating property, which removes hydrogen and oxygen atoms from formic acid (HCOOH) in the form of water (H_2O), resulting in the formation of carbon monoxide (CO).

(c) D. Elemental silicon exhibits semiconductor properties, whereas silicon dioxide is an electrical insulator.

Data Interpretation Activity

Analyze the Properties

Substance	Observation
Carbon monoxide	Toxic, colorless gas
Carbon dioxide	Turns limewater milky
Silica gel	Absorbs moisture
Silicon	Semiconductor

Think Like a Chemist

Which substance is used to detect carbon dioxide? .....

Which substance removes moisture from the air? .....

Which compound presents the greatest health risk? .....

What evidence supports your answers?

Try

Choose the correct answer:

1. Why is silica gel placed inside product packaging?

A. To add fragrance

B. To absorb moisture

C. To cool the product

D. To produce oxygen

.....

2 . Which reagent is commonly used to identify carbon dioxide gas?

A. Hydrochloric acid

B. Limewater

C. Sodium hydroxide

D. Silver nitrate

.....

3. Identify the appropriate words or substance names for the blank spaces in the following passage.

Carbon monoxide is (i) soluble in water, and is a colourless, odourless, (ii) gas. High-temperature carbon monoxide has a strong (iii) property and brings about the (iii) of metal oxides. Carbon monoxide is obtained by adding (iv) to (v) and heating. Carbon dioxide is sparingly soluble in water and ionizes to become (vi). Therefore, the aqueous solution is weakly (vii). Calcium hydroxide $Ca(OH)_2$ is used for the detection of carbon dioxide. When put into limewater, calcium carbonate $CaCO_3$ is produced, turning the limewater (viii).

4. Identify each of the following statements as True or False.

(i) Silicon is abundant in the earth's crust and occurs naturally as a free element.

(ii) Elemental silicon has the same crystal structure as graphite.

(iii) When silicic acid is heated and dried, porous silica gel is obtained.

Exercise

1. Identify the appropriate words or substance names for the blank spaces in the following passage.

Carbon oxides include carbon monoxide and carbon dioxide. Carbon monoxide is produced by the incomplete combustion of carbon, and can also be obtained by adding concentrated sulfuric acid to (i) and heating. Carbon monoxide is highly toxic and is (ii) soluble in water. It also has a strong reducing property at high temperatures.

Carbon dioxide is obtained by adding (iii) to calcium carbonate. Carbon dioxide is sparingly soluble in water and exhibits weak acidity. Also, when carbon dioxide is passed through limewater, it turns (iv). Solid carbon dioxide is called (v), and when left at room temperature, it changes directly from a solid to a gas.

2. For each of the following statements, indicate whether the underlined part is True or False. If False, provide the correct term.

(i) When silicic acid is heated and dried, silica gel is obtained.

(ii) When hydrochloric acid is added to a sodium silicate solution, silicic acid is produced.

(iii) When silicon dioxide and sodium chloride are melted, sodium silicate is produced.

Engineering Challenge

You are designing packaging for electronic devices that will be shipped to a humid country.

Which material would you include to protect the electronics? Explain your decision using scientific evidence.

.....

.....

.....

Sustainability Connection

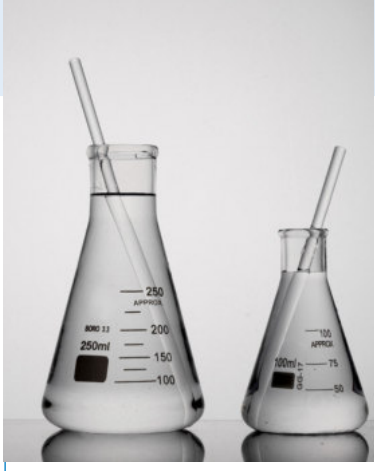
The Solvay Process demonstrates several principles of sustainable chemistry.

✓ Carbon dioxide is recycled.

✓ Ammonia is regenerated and reused.

✓ Raw material consumption is reduced.

✓ Less industrial waste is released.



Lesson 3-6 — Alkali Metals and Their Compounds

Engaging Introduction

Imagine baking a cake at home. As the mixture heats, tiny bubbles form, making the cake soft and fluffy. The secret ingredient is baking soda (sodium hydrogen carbonate), which releases carbon dioxide when heated.

Now imagine a water treatment plant producing millions of kilograms of sodium compounds every year for making glass, detergents, medicines, and clean drinking water. Chemists must carefully design manufacturing processes that recycle chemicals and reduce waste to make these products sustainably.

In this lesson, you will explore why alkali metals are among the most reactive elements on Earth and discover how chemistry transforms common salt into some of the world's most useful materials.

Guiding Question How can one highly reactive element—sodium—be transformed into many useful compounds that support everyday life and sustainable industry?

Exploration

Think about these familiar situations:

Bread becomes soft after baking.

Antacid tablets fizz when dropped into water.

Table salt looks harmless, but metallic sodium reacts violently with water.

Without studying the lesson:

• Why is metallic sodium dangerous while table salt is safe?

.....

• Why does baking soda produce bubbles during baking?

.....

• Why do industries recycle carbon dioxide during the manufacture of sodium carbonate?

.....

Point!

1. Alkali Metals

(a) Alkali metals: Li, Na, K, Rb (rubidium), Cs (caesium), and Fr (francium) in Group 1 of the periodic table, excluding H.

(b) Properties of alkali metals

(i) All are **silvery-white** metals with **low** density.

Structure of Science

Key fact :

• Alkali metals are highly reactive because they lose one valence electron easily.

• Sodium forms many important compounds with different chemical properties.

Key Concepts:

• Alkali Metals
• Reactivity
• Electrolysis
• Sodium Hydroxide
• Sodium Hydrogen Carbonate
• Sodium Carbonate
• Thermal Decomposition
• Industrial Recycling
• Solvay Process

(ii) Melting points are **low** .

(iii) The elements are obtained by molten salt electrolysis of their compounds

(iv) They impart characteristic colours to a flame during a **flame test** .

(v) React violently with water at room temperature to generate **hydrogen** .

(vi) Because they react immediately with water and oxygen in the air, they are stored under **kerosene** .

life application

Chemistry in Your Kitchen

Many household products contain sodium compounds.

Product	Sodium Compound	Why it is Used
Baking powder	Sodium hydrogen carbonate	Releases CO_2 to make cakes rise
Soap	Sodium hydroxide	Produces strong cleaning agents
Laundry detergent	Sodium carbonate	Softens hard water
Antacid tablets	Sodium hydrogen carbonate	Neutralizes excess stomach acid

2. Compounds of Sodium Na

(a) Sodium hydroxide **NaOH**

- Produced when sodium reacts with water. $2Na + 2H_2O \longrightarrow 2NaOH + H_2$
- A **white** solid.
- Highly soluble in water, and the aqueous solution is **strongly basic** .
- It is highly deliquescent (absorbs moisture from the air and dissolves).

(b) Sodium hydrogen carbonate **$NaHCO_3$**

- A **white** powder, also called **baking soda** (sodium bicarbonate).
- Sparingly soluble in water, and the aqueous solution is **basic** .
- Used in baking powder, gastrointestinal medicine, etc.

(c) Sodium carbonate **Na_2CO_3**

- A **white** solid.
- Highly soluble in water, and the aqueous solution is **basic** .
- Industrially manufactured by the **Solvay process** .

⟨Solvay Process⟩

❶ When ammonia is dissolved in a saturated aqueous solution of sodium chloride and carbon dioxide is passed through, sodium hydrogen carbonate precipitates.

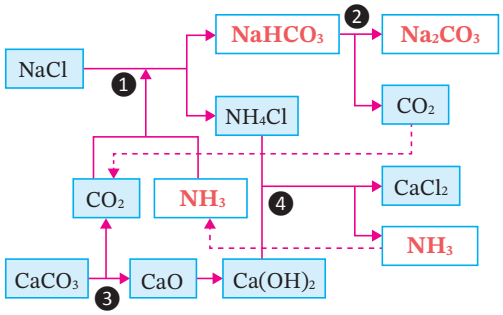
$$NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$$

❷ When this precipitate is thermally decomposed, sodium carbonate is obtained.

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

❸ The carbon dioxide generated in reaction ❷ is reused in reaction ❶. Furthermore, limestone CaCO3 is decomposed to obtain carbon dioxide.

$$CaCO_3 \longrightarrow CaO + CO_2$$



Sustainability Connection

The Solvay Process demonstrates several principles of sustainable chemistry.

✓ Carbon dioxide is recycled.

✓ Ammonia is regenerated and reused.

✓ Raw material consumption is reduced.

✓ Less industrial waste is released.

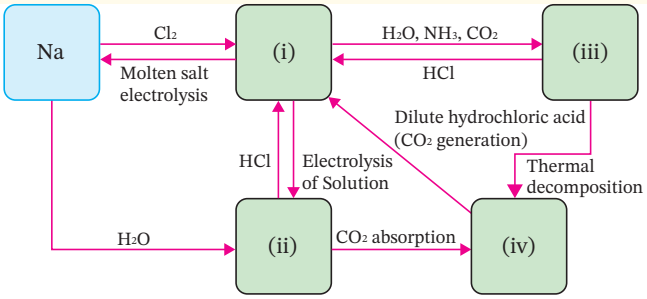
❹ Ammonia is regenerated by reacting ammonium chloride (produced in step ❶) with calcium hydroxide. The calcium hydroxide is obtained by reacting calcium oxide (from step ❸) with water. The regenerated ammonia is then reused in step ❶.

$$Ca(OH)_2 + 2NH_4Cl \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

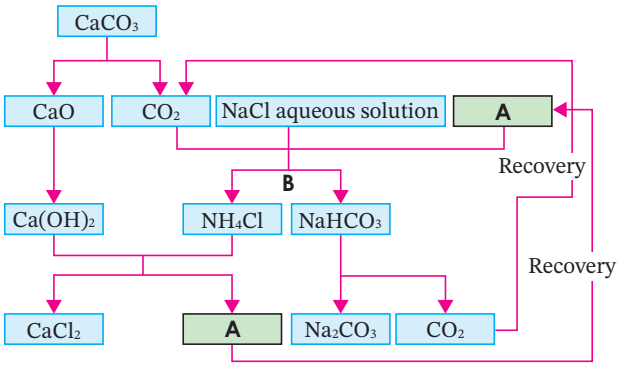
Warm Up

Answer the following questions.

(a) The figure on the right shows the relationship between sodium and its compounds. Identify the chemical formulas for the substances (i) through (iv).



(b) The figure on the right outlines the industrial manufacturing process of sodium carbonate. However, water is omitted from the figure. Answer the following questions regarding this.



(i) What is this manufacturing process called?

(ii) Identify the chemical formula for the substance A.

(iii) Write the balanced chemical equation for the reaction occurring in step B.

Explanation

(a) State the compound of sodium Na produced in each reaction.

(i) Sodium reacts with chlorine according to the following equation:

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

(ii) Sodium reacts with water according to the following equation:

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

(iii) Sodium chloride reacts with water, ammonia, and carbon dioxide according to the following equation:

$$NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$$

Answer: $NaHCO_3$

(iv) Sodium hydrogen carbonate undergoes thermal decomposition according to the following equation:

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

(b) (i) Solvay process

(ii) As shown in the figure, calcium hydroxide reacts with ammonium chloride according to the following equation:

$$Ca(OH)_2 + 2NH_4Cl \longrightarrow CaCl_2 + 2H_2O + 2NH_3$$

Therefore, NH_3.

(iii) $NaCl + H_2O + NH_3 + CO_2 \longrightarrow NaHCO_3 + NH_4Cl$

NOS: Identifying Variables

A chemical engineer wants to increase the sustainability of a sodium carbonate factory.

Challenge

How can the factory reduce waste while maintaining production?

Investigation

Predict which substances can be recovered and reused.

What is the independent variable?

.....

What is the dependent variable?

.....

Which variables should be controlled to ensure a fair test?

.....

Data Interpretation

A factory records the following information:

Process Step	CO_2 Used (kg)	CO_2 Recovered (kg)
Initial reaction	100	—
Thermal decomposition	—	42
Limestone heating	—	51

Think Like a Chemist

Why is CO_2 recovered instead of discarded? .....

Which reaction supplies additional CO_2? .....

How does recycling improve industrial efficiency? .....

Try

1. Which of the following statements about alkali metals are correct?

A. Alkali metal compounds impart characteristic colours to a flame during a flame test.

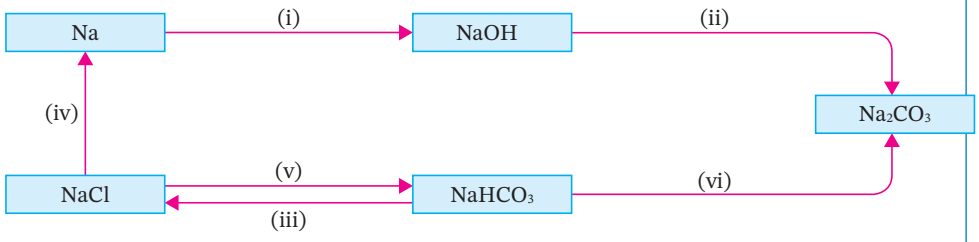
B. Many of the elements have high melting points and low densities.

C. The elements hardly react with water at room temperature, but react with hot water.

D. Elemental sodium is stored under kerosene.

E. Sodium hydroxide and sodium carbonate, which are compounds of sodium, are both white solids.

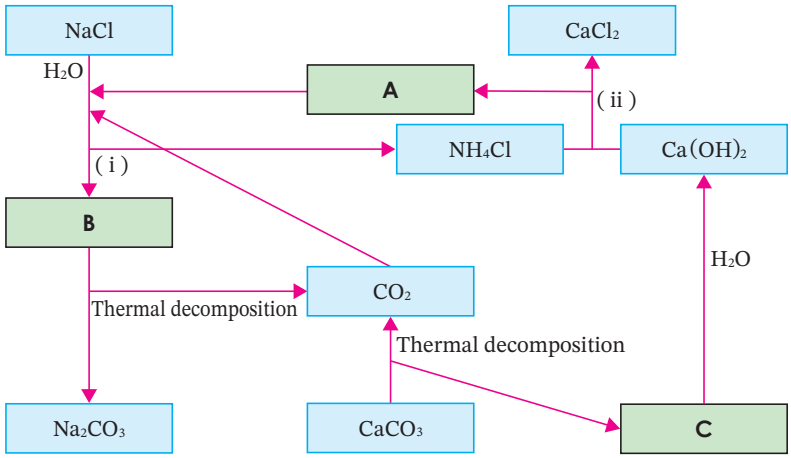
2.The following figure shows compounds obtained from sodium. Select the appropriate operations for (i) through (vi) from A to F below.



(A) Absorb CO_2 **(B)** Add HCl **(C)** Molten salt electrolysis

(D) Heat the solid **(E)** Add NH_3, H_2O, and CO_2 **(F)** Add water

3. Sodium carbonate is industrially manufactured as shown in the following figure. Answer the questions below regarding this.



(a) Name the industrial process used to manufacture sodium carbonate.

(b) Write the chemical formulas of the substances that correspond to A, B, and C in the figure.

(c) Write the chemical equations for (i) and (ii) in the figure.

Grand Challenge

A company plans to build a new sodium carbonate factory.
Two proposals are suggested.
Factory A
Releases all carbon dioxide into the atmosphere.
Factory B
Recovers and recycles carbon dioxide and ammonia.
Evaluate the designs.
Which factory is more sustainable? .....
Which factory would produce less waste? .....

Use scientific evidence to justify your conclusions. .....

Exercise

Choose the correct answer.

1. Why is metallic sodium stored under kerosene?

A. To increase its melting point.

B. To prevent reaction with air and moisture.

C. To improve electrical conductivity.

D. To reduce its density.

.....

2. During the Solvay Process, which substance is regenerated and reused?

A. Sodium chloride

B. Carbon dioxide

C. Calcium chloride

D. Hydrogen

.....

3. Which of the following statements about alkali metals are correct?

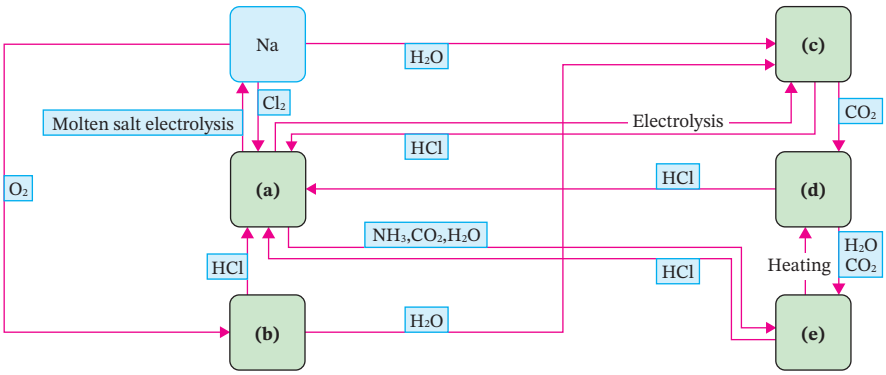
A. Many elemental alkali metals have high melting points and high densities.

B. Because elemental alkali metals react immediately with oxygen in the air, they are stored in water.

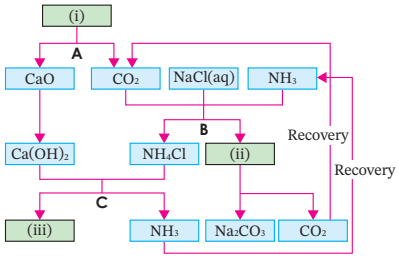
C. Sodium hydroxide is strongly basic and highly deliquescent.

D. The hydrogen carbonate salt of sodium is called baking soda and is used in baking powder, etc.

4. The figure below shows the relationship between sodium and its compounds. Identify the chemical formulas for the substances **(a)** through **(e)**.



4. The Figure on the right outlines the flow of the industrial manufacturing process of sodium carbonate. However, water is omitted from the figure. Answer the following questions.



(a) Name this industrial process.

(b) Identify the chemical formulas for substances (i) through (iii).

(c) Write the balanced chemical equations for the reactions occurring in steps A, B, and C.

Lesson 3-7 — Alkaline Earth Metals and Their Compounds

Engaging Introduction

Imagine walking into a magnificent limestone cave filled with towering stalactites and stalagmites that have taken thousands of years to form. Now imagine workers at a construction site mixing quicklime with water to prepare building materials. Although these situations seem completely different, they are connected by the chemistry of calcium compounds.

From caves and seashells to cement, drinking water, agriculture, and environmental protection, calcium compounds play an essential role in both nature and modern society.

In this lesson, you will discover how simple chemical reactions create remarkable natural landscapes and support many technologies that improve our daily lives.

Guiding Question How can the chemistry of calcium explain both the formation of natural limestone caves and the production of materials used in modern construction?

Exploration

Materials

- Limewater (calcium hydroxide solution)
- Straw (or CO_2 generator)
- Two test tubes
- Stopwatch

Procedure

1. Pour equal amounts of limewater into two test tubes.
2. Bubble air through the first tube for 30 seconds.
3. Bubble exhaled air (rich in CO_2) through the second tube.
4. Continue bubbling for another minute.
5. Compare the appearance of both solutions.

What is your observation?.....

What is your conclusion?.....

Point!

1. Alkaline Earth Metals

(a) Alkaline earth metals: Be, Mg, Ca, Sr (Strontium), Ba (Barium), and Ra (Radium) in Group 2 of the periodic table.

(b) Properties of alkaline earth metals

(i) Silvery-white metals.

Structure of Science

Key fact :

- Magnesium and calcium belong to Group 2 and usually form +2 ions.
- Calcium compounds continuously transform between solid and dissolved forms.

Key concepts:

- Alkaline Earth Metals
- Divalent Ions
- Calcium Cycle
- Limewater
- Quicklime
- Slaked Lime
- Carbonate
- Hydrogen Carbonate
- Solubility
- Hard Water Vacuum.

(ii) Compared to alkali metals in the same period, their metallic bonds are **stronger**, their melting points are **higher**, and their densities are **higher**.

(iii) Properties of magnesium Mg

- **Barely reacts** with water at room temperature. Reacts with hot water to form a **weakly basic** hydroxide.
- Magnesium carbonate is **poorly soluble** in water and **dissolves** in hydrochloric acid.
- **Does not impart** a characteristic colour in a flame test.

(iv)Properties of calcium Ca

- Reacts with water at room temperature to generate hydrogen and forms a **strongly basic** hydroxide.
- Calcium carbonate is **poorly soluble** in water and **dissolves** in hydrochloric acid.
- **Imparts** a characteristic colour in a flame test.

2. Compounds of Calcium

(a) Calcium oxide **CaO**

Oxides of calcium

$2Ca + O_2 \longrightarrow 2CaO$

- A white solid also called **quicklime**.
- Obtained by strongly heating limestone (main component $CaCO_3$).

(b) Calcium hydroxide **$Ca(OH)_2$**

- A white powder also called **slaked lime**.
- Produced when calcium oxide reacts with water.

$CaO + H_2O \longrightarrow Ca(OH)_2$

- Sparingly soluble in water, and its aqueous solution is **strongly basic**.
- The saturated aqueous solution is called **limewater**.

(c) Calcium carbonate **$CaCO_3$**

- Abundantly exists in nature as the main component of limestone, marble, shells, etc.
- Produced as a white precipitate when carbon dioxide is passed through limewater.

$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$

- If carbon dioxide is continuously passed through a cloudy white suspension of $CaCO_3$, **calcium hydrogen carbonate $Ca(HCO_3)_2$** is produced, and the suspension clears.
  In nature, water containing carbon dioxide dissolves $CaCO_3$ such as limestone, sometimes forming limestone caves.
  Conversely, when carbon dioxide is released from an aqueous solution containing **$Ca(HCO_3)_2$**, **$CaCO_3$** precipitates. By repeating this, stalactites and stalagmites form in limestone caves.

(d) Calcium sulfate **$CaSO_4$**

- Occurs in nature as calcium sulfate dihydrate $CaSO_4 \cdot 2H_2O$ (gypsum).

Misconception Alert

✗ Wrong idea:

„Limewater and limestone are the same substance."

✓ Correct:

Limewater is a solution of calcium hydroxide.

Limestone is solid calcium carbonate.

Sustainability Connection

Calcium compounds contribute to sustainable development by:

- Purifying drinking water.
- Neutralizing acidic soils.
- Supporting environmentally friendly construction materials.

(e) Bleaching powder $CaCl(ClO) \cdot H_2O$

• Obtained by reacting solid calcium hydroxide ($Ca(OH)_2$) with chlorine gas (Cl_2).

• Acts as an oxidising agent.

life application

Calcium All Around Us

Calcium compounds are found in many everyday products.

Compound	Everyday Use
Calcium oxide	Air Pollution Control
Calcium hydroxide	Water treatment
Calcium carbonate	Building stones, Cement Manufacturing
Gypsum	Medical casts and drywall
Bleaching powder	Swimming pool disinfection

Warm Up

Answer the following questions.

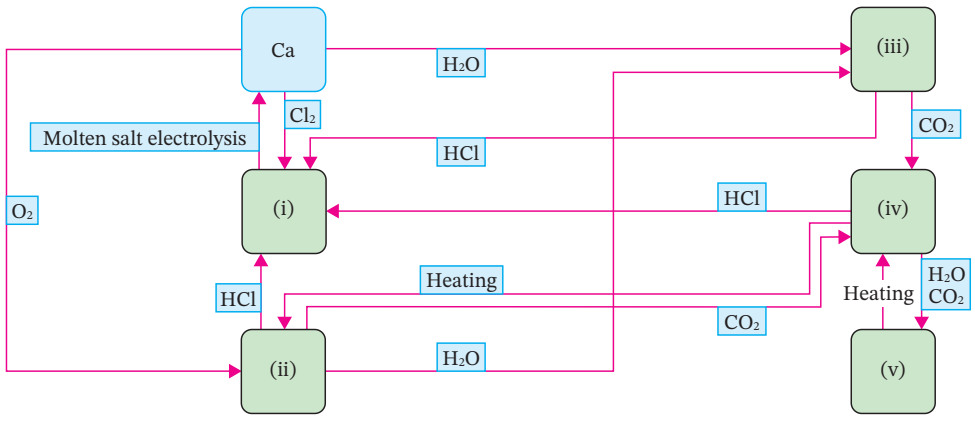
(a) For each of the following properties, indicate whether it applies only to calcium (A), only to magnesium (B), or to both (C).

(i) The aqueous solution of its hydroxide is strongly basic.

(ii) Its carbonate dissolves in hydrochloric acid.

(iii) Easily forms divalent cations.

(b) Identify the chemical formulas for substances (i) through (v) shown in the following figure.



Explanation

(a) (i) Magnesium reacts with hot water to form a weakly basic hydroxide. (A)

(ii) Both calcium carbonate $CaCO_3$ and magnesium carbonate $MgCO_3$ react with strong acids like hydrochloric acid to dissolve and generate carbon dioxide. (C)

(iii) Both calcium and magnesium are alkaline earth metals. Alkaline earth metals are in Group 2 of the periodic table, have 2 valence electrons, and easily form divalent cations. (C)

(b) State the compound of calcium Ca produced in each reaction.

(i) Calcium reacts with chlorine according to the following equation:

$$Ca + Cl_2 \longrightarrow CaCl_2$$ Answer: $CaCl_2$

(ii) Calcium reacts with oxygen according to the following equation:

$$2Ca + O_2 \longrightarrow 2CaO$$ Answer: CaO

(iii) Calcium oxide reacts with water according to the following equation:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$ Answer: $Ca(OH)_2$

(iv) Calcium hydroxide reacts with carbon dioxide according to the following equation:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$ Answer: $CaCO_3$

(v) Calcium carbonate reacts with water and carbon dioxide according to the following equation:

$$CaCO_3 + H_2O + CO_2 \rightleftharpoons Ca(HCO_3)_2$$ Answer: $Ca(HCO_3)_2$

Data Interpretation

Analyze Experimental Results

Experiment	Observation
Bubble CO_2 into limewater	White precipitate forms
Continue bubbling CO_2	Solution becomes clear

Think Like a Chemist

Why did the white precipitate first appear?

.....

Why did it disappear later?

.....

Which compound became soluble?

.....

Try

Choose the correct answer:

1. Which calcium compound is commonly called quicklime?

A. $CaCO_3$

B. CaO

C. $Ca(OH)_2$

D. $Ca(HCO_3)_2$

.....

2. Which calcium compound is responsible for turning limewater milky?

A. $Ca(HCO_3)_2$

B. $CaSO_4$

C. $CaCO_3$

D. $CaCl_2$

.....

3. Which of the following statements (A to D) applies to magnesium but not to calcium?

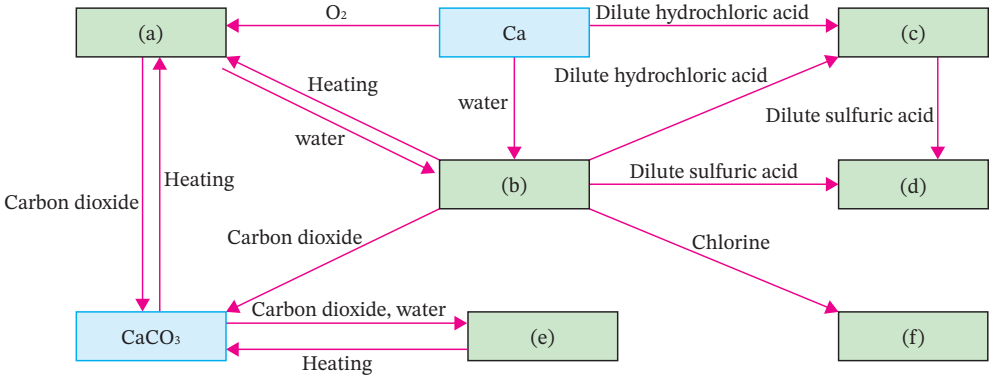
A. Its carbonate is soluble in water.

B. Does not impart a characteristic colour in a flame test.

C. The element reacts easily with water at room temperature.

D. Its hydroxide is highly soluble in water.

4. The following diagram shows elemental calcium and its compounds. Answer the questions below.



(A) Identify the chemical formulas and names for compounds (a) through (f).

(B) Which two of the following statements (i to vi) regarding compounds (a) through (f) are incorrect?

(i) (a) is a white solid called quicklime.

(ii) (b) is called slaked lime, and its aqueous solution is weakly basic.

(iii) (c) is the salt produced when the aqueous solution of (b) and hydrochloric acid are neutralized.

(iv) The dihydrate of (d) exists naturally as gypsum.

(v) An aqueous solution of (e) is formed in the process of a limestone cave forming.

(vi) (f) acts as a reducing agent.

Grand Challenge

A city plans to restore an old limestone monument damaged by acid rain.
As a materials scientist:
Explain why limestone is damaged by acid rain.
.....
Suggest a calcium compound that could help repair or protect the structure.
.....

Why is understanding calcium chemistry important for protecting cultural heritage?
.....
Support your answers using scientific evidence.
.....

Exercise

1. For each of the following properties, indicate whether it applies only to Mg (A), only to Ca (B), or to both (C).

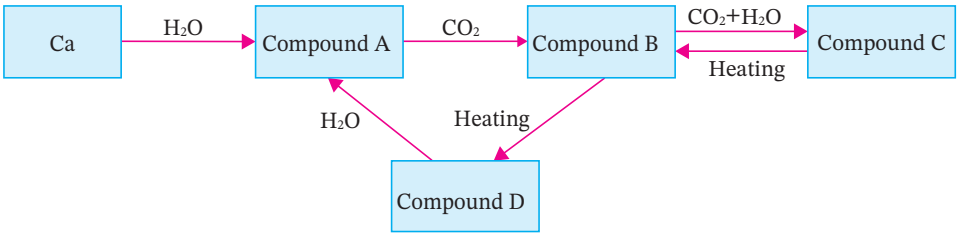
(a) Easily forms divalent cations.

(b) Does not react with water at room temperature, but reacts with hot water.

(c) Its carbonate is poorly soluble in water.

(d) Its hydroxide dissolves in water and its aqueous solution is strongly basic.

2. The following diagram shows elemental calcium and its compounds. Answer the questions below.



(a) Identify the chemical formulas and names for compounds A through D.

(b) Which of the following statements (i) to (iv) regarding compounds A through D is incorrect?

(i) Compound A is sparingly soluble in water, and its aqueous solution is weakly basic.

(ii) Compound B exists widely in nature as the main component of limestone and marble.

(iii) In a limestone cave, compound B precipitates from the aqueous solution of compound C, and limestone formations grow.

(iv) Compound D is called quicklime, and because it generates heat when reacting with water, it is used as a heating agent.

Lesson 3-8 — Representative Metals other than Groups 1 and 2

Engaging Introduction

Imagine drinking a soft drink from an aluminium can. Later, you use zinc-coated steel to protect a bicycle from rust, while a rechargeable lead-acid battery starts a car.

These metals look ordinary, but they behave in surprising ways. Unlike most metals, some can react with both acids and alkalis, while others form colourful chemical species called complex ions that chemists use in laboratories and industry.

In this lesson, you will discover why some metals have "double personalities" and how chemists use these unusual reactions to solve real-world problems.

Guiding Question Why can some metals react with both acids and bases while most metals cannot?

Structure of Science

Key fact :

The chemical behaviour of many metals depends on their electron configuration and their ability to form coordinate bonds and complex ions.

Key concepts:

Complex ion
- Coordinate bond
- Amphoteric metal
- Amphoteric oxide
- Ligands
- Precipitation reactions

Exploration

A student performs the following experiment:

Aluminium chloride solution is mixed with sodium hydroxide.

→ A white gel-like precipitate appears.

Then the student keeps adding more sodium hydroxide.

Suddenly...

The white precipitate disappears!

The same phenomenon happens with zinc ions.

Think before studying

- Why did the precipitate first appear?.....
- Why did it disappear after adding more sodium hydroxide?.....
- Where did the solid go?.....

Point!

1. Complex Ions

Complex ion : An ion formed by molecules or anions (Ligands) forming coordinate bonds with a metal ion.
The chemical formula is expressed using [ ].

Example: $[Fe(CN)_6]^{4-}$ Hexacyanidoferrate (II) ion
→A complex ion formed from an iron (II) ion Fe^{2+} and cyanide ions CN^-.

2. Aluminium Al

(a) Elemental aluminium

- Belongs to Group **13** of the periodic table and has **3** valence electrons.
- Industrially, it is produced by **molten salt electrolysis** of aluminium oxide purified

from **bauxite** .

• Reacts with aqueous solutions of acids and strong bases to generate **hydrogen** .

Example: • Reaction with hydrochloric acid: $2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$

• Reaction with sodium hydroxide:

$$2Al + 2NaOH + 6H_2O \longrightarrow 2Na[Al(OH)_4] + 3H_2$$

Sodium tetrahydroxidoaluminate

Note: A metal that reacts with both acidic and strongly basic aqueous solutions is called an **amphoteric metal** .

(b) Compounds of aluminium

(i) Aluminium oxide Al_2O_3

• A white powder produced when aluminium is heated in oxygen.

• Soluble in aqueous solutions of acids and strong bases.

Note: An oxide that is soluble in both acidic and strongly basic aqueous solutions is called an **amphoteric oxide** .

(ii) Aluminium hydroxide $Al(OH)_3$

• Produced as a white gel-like precipitate when a base is added to an aqueous solution containing aluminium ions Al^{3+}.

• Soluble in aqueous solutions of acids and strong bases.

Example: • Reaction with hydrochloric acid:

$Al(OH)_3 + 3HCl \longrightarrow AlCl_3 + 3H_2O$

• Reaction with sodium hydroxide: $Al(OH)_3 + NaOH \longrightarrow Na[Al(OH)_4]$

→ When an excess of sodium hydroxide aqueous solution is added, tetrahydroxidoaluminate ions $[Al(OH)_4]^-$ are produced.

Note: A hydroxide that is soluble in both acidic and strongly basic aqueous solutions is called an **amphoteric hydroxide** .

3. Zinc Zn

(a) Reactions of zinc

• Belongs to group (12), Has to Valence electrons

• Reacts with aqueous solutions of acids and strong bases to generate **hydrogen** . •

Zinc is an amphoteric metal.

• When burned, it produces white powdered zinc oxide **ZnO** .

(b) Reactions of zinc ion Zn^{2+}

• Adding a small amount of aqueous sodium hydroxide or aqueous ammonia: Precipitate of zinc hydroxide $Zn(OH)_2$ forms.

• Adding excess aqueous sodium hydroxide: Tetrahydroxidozincate(II) ions $[Zn(NH_3)_4]^{2+}$ form, resulting in a colourless aqueous solution.

Misconception Alert

Misconception 1

Aluminium behaves like all other metals.

Aluminium is amphoteric and reacts with both acids and strong bases.

Misconception 2

Complex ions are mixtures.

Complex ions are new chemical species formed through coordinate bonding.

$$Zn(OH)_2 + 2OH^- \longrightarrow [Zn(OH)_4]^{2-}$$

- Adding excess aqueous ammonia:
  Tetraamminezinc(II) ions **$[Zn(NH_3)_4]^{2+}$** form, a colourless aqueous solution.

$$Zn(OH)_2 + 4NH_3 \longrightarrow [Zn(NH_3)_4]^{2+} + 2OH^-$$

- Passing hydrogen sulfide through:
  A **white** precipitate of zinc sulfide **ZnS** forms.

4. Tin Sn and Lead Pb

(a) Elemental tin and lead

- Belong to Group **14** of the periodic table and have **4** valence electrons.
- **Soluble** in aqueous solutions of acids and strong bases.

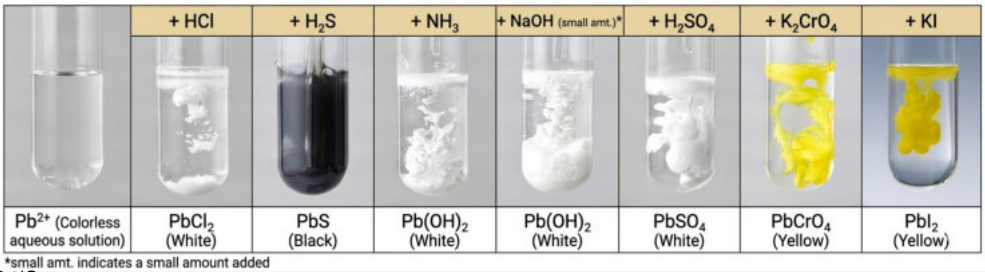
(b) Compounds of tin and lead

- Tin(II) chloride $SnCl_2$ is a strong **reducing** agent.
- Lead(IV) oxide PbO_2 is used as an **oxidising** agent in the positive electrode of a lead-acid battery, etc.
- Lead is poorly soluble in hydrochloric acid and dilute sulfuric acid because it forms an insoluble coating of
  lead(II) chloride ($PbCl_2$) and **lead(II) sulfate ($PbSO_4$)**, respectively.

(c) Reactions of Lead(II) Ions

Lead(II) ions (Pb^{2+}) react with various anions to form precipitates. While many lead compounds are insoluble in water, Lead(II) nitrate ($Pb(NO_3)_2$) and Lead(II) acetate ($(CH_3COO)_2Pb$) are soluble. Additionally, although Lead(II) chloride ($PbCl_2$) is insoluble in cold water, it dissolves in hot Water

Precipitation Reactions and Colors of Lead(II) Ions (Pb^{2+})



*small amt. indicates a small amount added

life application

Why Are Aluminium Cooking Pots Safe?

Aluminium reacts easily with acids and alkalis.

So why doesn't your cooking pot disappear?

Because aluminium instantly forms a thin layer of aluminium oxide (Al_2O_3) that protects the metal underneath.

This protective oxide layer is responsible for

✓ corrosion resistance

✓ lightweight aircraft

✓ food containers

✓ smartphones

Warm Up

Answer the following questions.

(a) Identify the appropriate numbers or words for the parentheses (A and F), and the chemical formulas for the brackets [B, C, D, and E] in the following passage.

Aluminium is a main group element belonging to Group (A) of the periodic table, and the element reacts with hydrochloric acid, generating hydrogen and dissolving to form [B]. When aqueous ammonia is added to the solution of [B], a precipitate of [C] is formed. When hydrochloric acid is added to [C], it dissolves to become [D]. Also, when an aqueous sodium hydroxide solution is added to [C], it dissolves to become [E]. A hydroxide that dissolves in both acids and strong bases, like [C], is called an (F).

(b) Identify the chemical formulas for (A), (B), and (C) in the following passage.

Elemental zinc Zn reacts with both acids and strong bases to generate (A). When a small amount of aqueous ammonia is added to an aqueous solution containing zinc ions Zn^{2+}, a white precipitate of (B) is produced. Furthermore, when aqueous ammonia is added, a complex ion represented by (C) is produced.

(c) Identify the appropriate numbers or terms for (A) through (E) in the following passage. Provide specific substance names for (D) and (E).

Tin and lead are both elements belonging to Group (A) of the periodic table, and have (B) valence electrons. The elements (C) in aqueous solutions of acids and strong bases, but in the case of lead, it is difficult to dissolve because it forms poorly soluble salts of (D) in hydrochloric acid and (E) in dilute sulfuric acid.

Explanation

(a) A: 13

B: Write the chemical equation for the reaction of aluminium with hydrochloric acid.

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$$ Answer: $AlCl_3$ (Al^{3+})

C: When ammonia is added to an aqueous solution containing aluminium ions (such as $AlCl_3$), a white precipitate of aluminium hydroxide forms. Answer: $Al(OH)_3$

D: Write the chemical equation for the reaction of aluminium hydroxide with hydrochloric acid.

$$Al(OH)_3 + 3HCl \longrightarrow AlCl_3 + 3H_2O$$ Answer: $AlCl_3$ (Al^{3+})

E: Write the chemical equation for the reaction of aluminium hydroxide with sodium hydroxide.

$$Al(OH)_3 + NaOH \longrightarrow Na[Al(OH)_4]$$ Answer: $Na[Al(OH)_4]$ ($[Al(OH)_4]^-$)

F: Amphoteric hydroxide

(b) A: H_2 B: $Zn(OH)_2$ C: $[Zn(NH_3)_4]^{2+}$

(c) A: 14 B: 4 C: dissolve D: lead(II) chloride E: lead(II) sulfate

Think Like a Chemist

A wastewater treatment plant contains aluminium ions.
A technician accidentally adds too much sodium hydroxide.
Initially, a white precipitate forms.
After additional sodium hydroxide is added, the solution becomes clear again.
Explain:
Why did the precipitate disappear? .....
Which complex ion was produced? .....
Why is understanding this reaction important in water treatment? .....

Try

1. Read the following text and answer the questions below.

When pure (A) obtained by chemically treating (B), an ore of aluminium, is subjected to molten salt electrolysis, elemental aluminium is obtained. When aluminium reacts with hydrochloric acid, it dissolves while generating (C) to become an aqueous solution of (D). Also, when an aqueous sodium hydroxide solution is gradually added to an aqueous solution containing Al^{3+}, a white gelatinous precipitate of (E) is first formed, but upon the addition of excess aqueous sodium hydroxide, this precipitate dissolves to form (F), resulting in a colourless and transparent aqueous solution.

(a) Identify the appropriate terms for A through D, and the chemical formulas for E and F.

(b) Write the balanced chemical equation for the reaction described in the underlined part.

(c) Write the balanced chemical equation for the reaction between (E) and hydrochloric acid.

(d) Write the balanced chemical equation for the reaction between (E) and sodium hydroxide.

2. Identify the appropriate term for (A) and the chemical formulas for [B] and [C] in the following passage.

When a small amount of aqueous sodium hydroxide is added to an aqueous solution containing zinc ions Zn^{2+}, a (A)-coloured precipitate of $Zn(OH)_2$ is produced, but when added in excess, it dissolves to form the complex ion [B]. Also, when aqueous ammonia is added to $Zn(OH)_2$, it dissolves to form the complex ion [C].

3. Identify the appropriate term for (A) and the chemical formulas for [B] and [C] to complete the following passage.

Lead is an (A) metal that dissolves in aqueous solutions of acids and strong bases, but the solid metal is poorly soluble in dilute sulfuric acid and dilute hydrochloric acid. This is because poorly soluble substances represented by [B] in dilute sulfuric acid and [C] in dilute hydrochloric acid are formed on the surface of the element.

Grand Challenge

Electronic waste contains aluminium, zinc, copper, gold and other valuable metals.
Your challenge: Design a chemical process that separates aluminium from other metals using its amphoteric behaviour.
Consider:
- Which reagent would you use?.....
- Why would aluminium dissolve while another metal remains?.....
- How could this improve recycling?.....

Be Global Citizen

Electrochemical cells play a major role in sustainable development. Where it uses in Electric vehicles, Renewable energy storage, Portable medical devices, Emergency power systems, Satellite technologies

Advances in battery technology can reduce fossil fuel dependence and support global sustainability goals.

Exercise

1.Aluminium hydroxide is treated with excess sodium hydroxide.

Which ion is produced?

A. Al^{3+}

B. Al_2O_3

C. $[Al(OH)_4]^-$

D. $AlCl_3$

.....

2.A white precipitate disappears after excess ammonia is added to a zinc ion solution.

Which complex ion is formed?

A. $[Zn(OH)_4]^{2-}$

B. $[Zn(NH_3)_4]^{2+}$

C. $ZnCl_2$

D. ZnO

.....

3. Read the following text and answer the questions below.

Aluminium is manufactured by (A) electrolysis of the oxide obtained from the ore (B), and is an (C) metal that dissolves in aqueous solutions of both acids and strong bases, generating hydrogen. When a small amount of aqueous sodium hydroxide solution is added to an aqueous solution containing Al^{3+}, (I) a white precipitate is formed, but when added in excess, this precipitate dissolves to form a (II) colourless solution.

(a) Identify the appropriate terms for (A) through (C).

(b) Write the chemical equations for the following reactions:

(i) Reaction of aluminium with dilute hydrochloric acid

(ii) Reaction of aluminium with aqueous sodium hydroxide solution

(c) Write the chemical formula of the substance in the underlined part (I).

(d) Write the chemical formula of the anion contained in the solution of the underlined part (II).

4. Identify the appropriate terms or numbers for (i) and (iii), and the chemical formulas for (ii), (iv), and (v) to complete the following passage.

Zinc is an element belonging to Group (i) of the periodic table. When zinc is burned in the air, it produces (ii).

The element is an (iii) metal, and dissolves in both hydrochloric acid and aqueous sodium hydroxide to generate hydrogen. When aqueous ammonia is added to an aqueous solution containing zinc ions, a white precipitate of (iv) is produced. Furthermore, when aqueous ammonia is added, the precipitate dissolves, and a complex ion (v) is produced.

5. Which two of the following statements (A to D) about tin and lead are incorrect?

A. Tin(II) chloride acts as a reducing agent.

B. Lead(II) sulfate is easily soluble in dilute sulfuric acid.

C. Lead(IV) oxide is used as an oxidising agent.

D. Tin and lead are both transition elements.

Lesson 3-9 — Transition Elements and Their Compounds (1) (Iron, Copper, Silver)

Engaging Introduction

Imagine you accidentally leave a bicycle outside for several weeks. The shiny metal slowly turns reddish-brown as rust forms. In another place, a laboratory technician adds a few drops of different solutions into an unknown sample. Within seconds, the solution changes colour, allowing the technician to identify which metal ion is present.

Although iron, copper, and silver are all metals, each behaves differently because of its electron arrangement and chemical properties.

In this lesson, you will explore how chemists use colour changes, precipitates, and complex ions to identify transition metals and explain why these metals are important in engineering, medicine, and environmental science.

Guiding Question Why do different transition metal ions produce different colours and reactions?

Exploration

Look at these everyday observations.

• An old iron gate develops reddish-brown rust.

• Copper roofs slowly become green after many years.

• Old silver jewelry sometimes becomes black.

Without studying the lesson,

Why do different metals change into different colours?

.....

Why doesn't every metal rust in the same way?

.....

How could a chemist identify these metals if they were dissolved in water?

.....

Point!

1. Iron Fe

(a) Iron ions: Iron ions include the iron(II) ion Fe^{2+} and the iron(III) ion Fe^{3+}.

• When Fe^{2+} is oxidised, it becomes Fe^{3+} .

(b) Reactions of iron ions in aqueous solutions: Reactions differ between Fe^{2+} and Fe^{3+}.

Structure of Science

Key fact :

Transition metals can often be identified because they form distinctive coloured ions, precipitates, and complex ions during chemical reactions.

Key Concepts

• Transition elements

• Oxidation and reduction Coordination bonding

• Qualitative analysis

⟨Aqueous solution added and colour change⟩

Aqueous solution added	$NaOH$, NH_3	H_2S	$K_4[Fe(CN)_6]$	$K_3[Fe(CN)_6]$	KSCN
Aqueous solution containing Fe^{2+}	**Greenish-white** precipitate	Black precipitate	Bluish-white precipitate	**Dark blue** precipitate	No change
Aqueous solution containing Fe^{3+}	**Reddish-brown** precipitate	Black precipitate	**Dark blue** precipitate	Brown solution	**Blood-red** solution

• When aqueous sodium hydroxide NaOH or aqueous ammonia NH_3 is added:

In an aqueous solution containing Fe^{2+}, a precipitate of **iron(II) hydroxide $Fe(OH)_2$** is produced.

$$Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_2$$

In an aqueous solution containing **iron(III) hydroxide** is produced.

Iron(III) hydroxide cannot be represented by a single chemical formula.

Predict

Without performing the experiment, predict what will happen.

A chemist adds sodium hydroxide solution separately to:

• Fe^{2+} solution

• Fe^{3+} solution

• Cu^{2+} solution

• Ag^+ solution

Complete the table.

Metal ion	Prediction
Fe^{2+}	_____
Fe^{3+}	_____
Cu^{2+}	_____
Ag^+	_____

2. Copper Cu

(a) Reactions of copper Cu

• Heating copper in air produces black **copper(II) oxide (CuO)** .

• Dissolving copper in hot concentrated sulfuric acid produces **copper(II) sulfate ($CuSO_4$)** .

(b) Reactions of copper(II) ion Cu^{2+}

• Addition of an aqueous base produces a bluish-white precipitate of **copper(II) hydroxide ($Cu(OH)_2$)** .

$$Cu^{2+} + 2OH^- \longrightarrow Cu(OH)_2$$

• Passing hydrogen sulfide through the solution produces a **black** precipitate of **copper(II) sulfide (CuS)** .

(c) Reactions of copper(II) hydroxide $Cu(OH)_2$

• Adding excess aqueous ammonia: tetraamminecopper(II) ions **$[Cu(NH_3)_4]^{2+}$** form, resulting in a **deep blue** aqueous solution.

$$Cu(OH)_2 + 4NH_3 \longrightarrow [Cu(NH_3)_4]^{2+} + 2OH^-$$

• Heating: $Cu(OH)_2$ decomposes to produce black **copper(II) oxide (CuO)** .

• Dissolving in dilute sulfuric acid or hydrochloric acid: Copper(II) ions Cu^{2+} form.

Think as an Engineer

Engineers designing water distribution systems must choose pipe materials carefully. Copper pipes are commonly used because they resist corrosion better than iron.

Question

Why would copper be a better material than iron for drinking-water pipes?

Consider:

• corrosion
• durability
• water quality
• maintenance costs

.....

3. Silver Ag

(a) Reactions of silver ion Ag^+

• Adding an aqueous base solution: A **brown** precipitate of **silver oxide Ag_2O** forms.

$$2Ag^+ + 2OH^- \longrightarrow Ag_2O + H_2O$$

• Further adding aqueous ammonia: diamminesilver(I) ions **$[Ag(NH_3)_2]^+$** form, resulting in a colourless aqueous solution.

$$Ag_2O + 4NH_3 + H_2O \longrightarrow 2[Ag(NH_3)_2]^+ + 2OH^-$$

• Passing hydrogen sulfide through: A **black** precipitate of **silver sulfide (Ag_2S)** forms.

$$2Ag^+ + S^{2-} \longrightarrow Ag_2S$$

(b) Silver halides: Compounds of silver and halogens (Cl, Br, I). Formed by the reaction of silver ions and halide ions. (Table 3-9-1 on the right)

Table 3-9-1 <Colours of Silver Halides>

Name	Chemical formula	Colour
Silver chloride	AgCl	White
Silver bromide	AgBr	Light yellow
Silver iodide	AgI	Yellow

• When silver halides are exposed to light, they decompose to yield silver metal.

Example: $2AgBr \xrightarrow{Light} 2Ag + Br_2$

Life application

Silver compounds have been used for over a century in photography.
When silver bromide is exposed to light, it decomposes to produce metallic silver.
Although digital cameras have largely replaced photographic film, this light-sensitive reaction remains an important example of photochemistry and is still used in specialized imaging technologies.

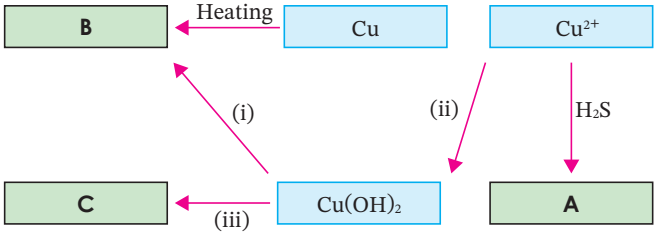
Warm Up

Answer the following questions.

(a) Identify the appropriate chemical formulas for (A), (B), and (C) in the following passage.

When dilute sulfuric acid is added to iron, it dissolves while generating hydrogen, producing a cation represented by
(A). This ion is oxidised by hydrogen peroxide to become an ion represented by (B). The formation of (B) can be confirmed by the fact that the aqueous solution turns blood-red when an aqueous solution of (C) is added to it.

(b) Answer the following questions based on the figure showing the reactions of copper and its compounds.



(I) Identify the chemical formulas for substances A, B, and C. Note that C is a complex ion.

(II) Select the most appropriate reagent or procedure for (i) through (iii) from the options below. Each option can be used only once.

a. Heating b. O_2 c. H_2 d. NH_3 e. NaOH

Explanation

(a) A: Fe^{2+} B: Fe^{3+} C: KSCN

(b) (I) A: When hydrogen sulfide is passed through an aqueous solution containing copper(II) ions, a precipitate of copper(II) sulfide is produced. Answer: CuS

B: Heating copper produces copper(II) oxide. Answer: CuO

C: The complex ion produced by the reaction with copper(II) hydroxide is the tetraamminecopper(II) ion. Answer: $[Cu(NH_3)_4]^{2+}$

(II) (i): Heating copper(II) hydroxide produces copper(II) oxide.

(ii): Adding an aqueous base solution to an aqueous solution containing copper(II) ions produces a precipitate of copper(II) hydroxide.

(iii): Adding excess aqueous ammonia to copper(II) hydroxide produces tetraamminecopper(II) ions.

Therefore, since aqueous ammonia NH_3 corresponds to (iii), NaOH, which is the remaining aqueous base solution, corresponds to (ii).

From the above, (i): a (ii): e (iii): d

Try

Choose the correct answer:

1-A pale green solution is suspected to contain Fe^{2+} ions. A student adds sodium hydroxide solution. Which observation is most likely?

A. A greenish-white precipitate

B . A deep blue solution

C. A brown solution

D. No visible change

.....

2. A solution gives a blood-red colour after adding potassium thiocyanate (KSCN).

Which ion is present?

A. Fe^{2+}

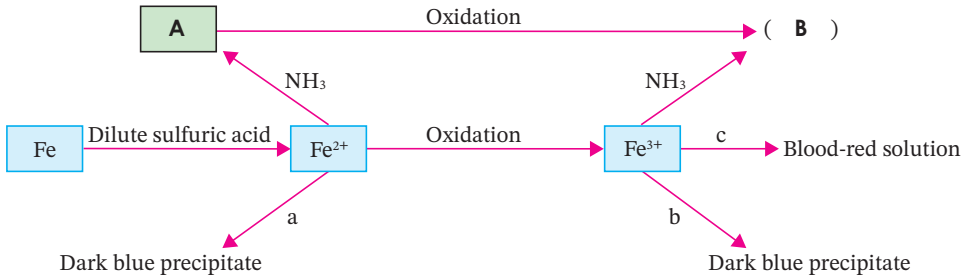
B. Fe^{3+}

C. Cu^{2+}

D. Ag^{+}

.....

3. Answer the following questions based on the diagram showing the reactions of iron and its compounds.



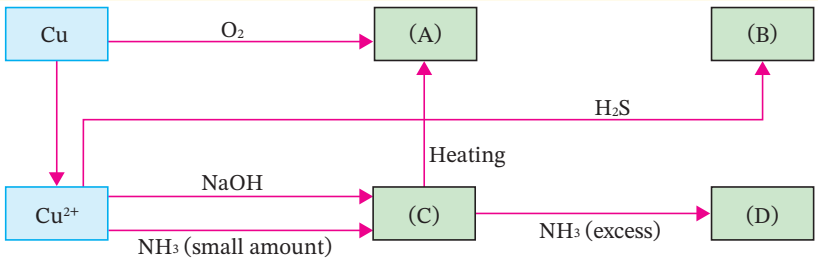
(a) Identify the chemical formula and colour for substance A.

(b) Identify the colour for substance B.

(c) Select the appropriate reagent for steps a, b, and c from the list (i) through (v).

(i) KCl (ii) KSCN (iii) NaOH (iv) $K_3[Fe(CN)_6]$ (v) $K_4[Fe(CN)_6]$

4.Answer the questions below regarding the following diagram.



(a) Identify the chemical formulas for compounds (A) through (C).

(bIdentify the name and chemical formula for the complex ion present in solution (D).

3. Identify the chemical formulas and colours for substances A, B, and C based on the following experiments.

Experiment I: When an aqueous sodium chloride solution was added to an aqueous

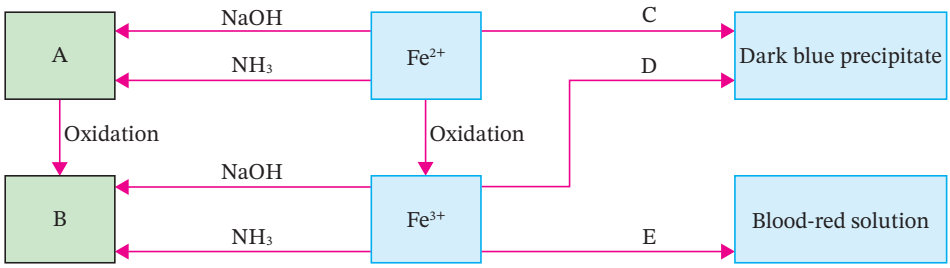
silver nitrate solution, precipitate A was produced.

Experiment II: When precipitate A was exposed to light, it decomposed to produce fine particles of B.

Experiment III: When excess aqueous ammonia was added to precipitate A, complex ion C was produced.

Exercise

1. Answer the following questions based on the diagram showing the reactions of iron and its compounds.



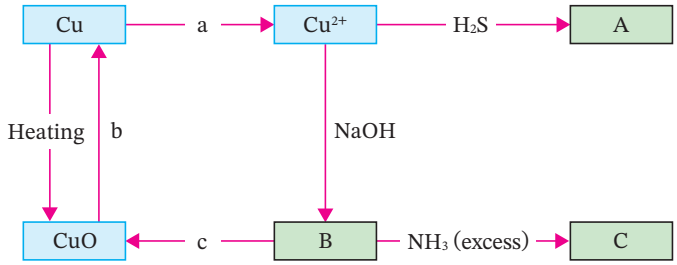
(a) Provide the chemical formula and colour for precipitate A.

(b) Provide the name and colour for precipitate B.

(c) Select the appropriate reagent for steps C, D, and E from the following options (i) to (iv).

(i) KSCN (ii) $K_4[Fe(CN)_6]$ (iii) KCl (iv) $K_3[Fe(CN)_6]$

2. The reactions of copper and its compounds are shown in the following diagram. Answer the questions below.



(a) Identify the chemical formulas for substances A, B, and C. Note that C is a complex ion

(b) Select the appropriate reagent or operation for steps a, b, and c from the following options (i) to (v).

(i) H_2 (ii) O_2 (iii) HCl (iv) HNO_3 (v) Heating

3. When aqueous sodium hydroxide, dilute hydrochloric acid, aqueous potassium bromide, and aqueous hydrogen sulfide were added to an aqueous silver nitrate solution, precipitates A, B, C, and D were produced, respectively. Identify the chemical formulas and colours for precipitates A, B, C, and D.

Challenge Your Thinking

A forensic scientist finds a colourless solution that may contain chloride ions.
After adding silver nitrate, a white precipitate appears.
Later, the precipitate darkens after being exposed to sunlight.
Questions
Which silver compound was probably formed? .....
Why did its colour change after exposure to light? .....
What property of silver halides makes them useful in photography? .....

Lesson 3-10 — Transition Elements and Their Compounds (2) (Gold, Chromium, Manganese)

Engaging Introduction

Gold has fascinated people for thousands of years. From the treasures of ancient Egypt, including Tutankhamun's golden mask, to the tiny electrical connectors inside today's smartphones and computers, gold remains one of the world's most valuable materials. Meanwhile, brightly coloured chromium and manganese compounds are widely used in laboratories, environmental testing, and water treatment because their colour changes reveal important chemical reactions.

Let's explore how the unique properties of gold, chromium, and manganese make them essential in modern technology, chemical analysis, and everyday life.

Guiding Question How do chemists use colour changes and chemical reactions to identify substances and explain their behaviour?

Structure of Science

Key fact :

Many transition-metal compounds undergo predictable colour changes because their oxidation states change during chemical reactions.

Key concepts:

Noble metals – Oxidation- Chemical equilibrium - Oxidising agents Transition elements

Exploration

Before studying the lesson,

Why doesn't gold rust like iron?

.....

Why are chromium compounds used in the bright yellow pigments of traffic signs?

.....

Point!

Egypt, where you live, has a deep connection with gold dating back to ancient times. Beginning with Tutankhamun's golden mask, which retains its brilliance after thousands of years, what special properties does gold possess?

1. Gold (Au)

Discovery and Physical Properties

Gold (Au) is found in its **elemental state**, uncombined with other elements, such as in alluvial gold (gold dust).

- **Malleability and Ductility**: It possesses the highest **malleability** (the property of being spread into thin sheets) and **ductility** (the property of being drawn into fine wires) among all metals. Due to this extremely high workability, it is widely utilized, from ancient ornaments to modern nanotechnology.
- **Conductivity**: It is an excellent **conductor** of electricity and heat.
- **Luster and Applications**: It has a beautiful golden **luster** and is highly resistant to oxidation (i.e., it does not rust), **making it extremely useful**. Because of these superior properties, gold is an indispensable metal for accessories and ornaments,

as well as a material for precise electronic devices such as mobile phones and computers.

Chemical Stability (Noble Metal)

- Gold has very low **reactivity**, making it chemically stable. For this reason, it does not dissolve in very strong acids like **nitric acid** or hot **concentrated sulfuric acid**.
- However, it dissolves in a special mixture of concentrated nitric acid and concentrated hydrochloric acid called Aqua Regia . In Aqua Regia, gold is oxidised and forms a stable complex ion, which allows this mixture to dissolve gold, despite gold being one of the most stable metals.

2. Chromium Cr

(a) Chromium compounds

(i) Potassium chromate K_2CrO_4

- When dissolved in water, yellow chromate ions CrO_4^{2-} form.

(ii) Potassium dichromate $K_2Cr_2O_7$

- When dissolved in water, red-orange dichromate ions $Cr_2O_7^{2-}$ form.

NOS: Prediction

A yellow chromate solution is treated with dilute sulfuric acid.
Predict what will happen.
□ The colour remains yellow.
□ The solution turns orange.
□ A precipitate forms.
Explain your prediction.
……

(b) Chromate ion CrO_4^{2-} and Dichromate ion $Cr_2O_7^{2-}$

- Chromate ions react with silver ions Ag^+, lead(II) ions Pb^{2+}, and barium ions Ba^{2+} to produce coloured precipitates in all cases. (Table 3-10-1 on the right)

Table 3-10-1 ⟨Precipitates by chromate ions⟩

Name of precipitate	Colour of precipitate
Silver chromate Ag_2CrO_4	Reddish-brown
Lead(II) chromate $PbCrO_4$	Yellow
Barium chromate $BaCrO_4$	Yellow

- When an aqueous solution containing chromate ions is acidified, dichromate ions are produced. When the solution is made basic, they revert to chromate ions.

$$\underset{\text{(Yellow)}}{CrO_4^{2-}} \underset{OH^-}{\overset{H^+}{\rightleftharpoons}} \underset{\text{(Red-orange)}}{Cr_2O_7^{2-}}$$

- Dichromate ions act as a strong oxidising agent in acidic aqueous solutions, producing dark green chromium(III) ions Cr^{3+}.

Inquiry Investigation

Investigating Colour Changes in Chemical Equilibrium

Materials

- Potassium chromate solution
- Dilute sulfuric acid
- Sodium hydroxide solution
- Two test tubes
- Dropper

Procedure

1. Pour potassium chromate solution into a test tube.

2. Add a few drops of dilute sulfuric acid.
3. Observe the colour.
4. Add sodium hydroxide solution.
5. Observe the colour again.

Observation ……

Conclusion……

3. Manganese Mn Compounds

(a) Manganese(IV) oxide MnO_2 ● Also called manganese dioxide.

- A black powder.
- Acts as an oxidising agent in acidic aqueous solutions, producing **pale pink** manganese(II) ions Mn^{2+}.

(b) Potassium permanganate $KMnO_4$

- Black-purple crystals.
- When dissolved in water, **red-purple** permanganate ions MnO_4^- form.
- Acts as a strong **oxidising** agent in acidic aqueous solutions, producing manganese(II) ions Mn^{2+}.

Warm Up

Choose one incorrect statement from the following descriptions.

A . When aqueous silver nitrate is added to an aqueous potassium chromate solution, a reddish-brown precipitate is produced.

B. When aqueous lead(II) acetate is added to an aqueous potassium chromate solution, a yellow precipitate is produced.

C. When a small amount of dilute sulfuric acid is added to an aqueous potassium chromate solution, the aqueous solution turns red-orange.

D. Manganese(IV) oxide is a black powder and reacts with concentrated hydrochloric acid to generate chlorine.

E Potassium permanganate dissolves in water to form a red-purple aqueous solution, and acts as a strong reducing agent in acidic aqueous solutions.

Explanation

A: Chromate ions CrO_4^{2-} are contained in the aqueous potassium chromate solution, and silver ions Ag^+ are contained in the aqueous silver nitrate solution. These ions react to produce a reddish-brown precipitate of silver chromate.

B: Lead(II) ions Pb^{2+} are contained in the aqueous lead(II) acetate solution. Chromate ions and lead(II) ions react to produce a yellow precipitate of lead(II) chromate $PbCrO_4$.

C: When dilute sulfuric acid is added to an aqueous potassium chromate solution, the aqueous solution becomes acidic. As a result, dichromate ions are produced, so the aqueous solution turns red-orange.

D: Manganese(IV) oxide, which is a black powder, acts as an oxidising agent in acidic aqueous solutions, so it produces chlorine Cl_2 as shown in the following chemical equation:

Be Global Citizen

Gold, chromium, and manganese are critical materials used worldwide.

Using these resources responsibly requires balancing technological development with environmental protection and recycling. Responsible use of Earth's mineral resources helps support a sustainable future.

$MnO_2 + 4HCl \longrightarrow MnCl_2 + 2H_2O + Cl_2$

E: Potassium permanganate acts as a strong oxidising agent in acidic aqueous solutions.

Therefore, E.

Think as an Environmental Chemist

Industrial wastewater sometimes contains chromium compounds.

Why is monitoring chromium compounds important before releasing wastewater into rivers?

Think about:

- human health,
- ecosystems,
- drinking water.

……

Try

Which of the following statements (i to iv) about chromium and manganese are incorrect?

(i) Both chromium and manganese are transition elements.

(ii) When chromate ions and lead(II) ions react, a reddish-brown precipitate is produced.

(iii) Permanganate ions show a red-purple colour in aqueous solutions.

(iv) Permanganate ions are reduced by hydrogen peroxide in acidic aqueous solutions.

……

……

……

Challenge Your Thinking

Two colourless solutions are tested.

Solution A changes orange dichromate solution to green.

Solution B does not.

Which solution is more likely to contain a reducing agent? Explain.

……

Exercise

Choose the correct answer:

1. A laboratory technician observes a purple solution becoming colourless during an experiment.

Which compound is most likely being used?

A. Potassium chromate

B. Potassium dichromate

C. Potassium permanganate

D. Silver nitrate

.....

2. During a redox reaction, orange dichromate ions become green chromium(III) ions.

This colour change indicates that dichromate ions have:

A. gained electrons.

B. lost electrons.

C. evaporated.

D. become gases.

.....

3. Read the following text and answer the questions below.

In acidic aqueous solutions, both potassium dichromate ($K_2Cr_2O_7$, a chromium compound) and potassium permanganate ($KMnO_4$, a manganese compound) act as strong (I) agents. When $\underset{(A)}{\text{aqueous sodium hydroxide was added to an aqueous potassium dichromate solution}}$, and then $\underset{(B)}{\text{aqueous barium nitrate was added, a precipitate was produced.}}$

(a) Identify the appropriate term for blank (I).

(b) Describe the colour change of the aqueous solution that occurs in step (A).

(c) Write the net ionic equation for the reaction occurring in step (A).

(d) Identify the chemical formula and colour of the precipitate formed in step (B).

Lesson 3-11 — Precipitation Reactions and Separation of Metal Ions

Engaging Introduction

A drinking water laboratory receives a water sample that may contain several dissolved metal ions. Although the solution looks perfectly clear, chemists can identify and separate each metal ion by adding carefully selected reagents. Suddenly, white, black, yellow, and reddish-brown precipitates appear one after another.

In this lesson, you will discover how chemists use precipitation reactions as a scientific tool to identify unknown substances and separate metal ions in environmental, industrial, and medical laboratories.

Guiding Question How can invisible dissolved metal ions be identified and separated using observable chemical reactions?

Exploration

Imagine two clear solutions are mixed together.

Within seconds, a bright yellow solid appears.

Without studying the lesson yet:

Why did a solid suddenly form although both solutions were transparent?

.....

What information might the colour of the precipitate provide?

.....

Point!

Precipitation reactions and separation of metal ions

(a) Precipitation reactions

Chemical formulas and colours of precipitates formed by various metal ions and anions (× indicates no precipitate is formed).

Anion / Metal ion	Cl^-	S^{2-} [Acidic]	S^{2-} [Basic]	OH^-
Ag^+	AgCl White	Ag_2S Black	Ag_2S (Black)	Ag_2O Brown
Pb^{2+}	$PbCl_2$ White	PbS Black	PbS (Black)	$Pb(OH)_2$ White
Cu^{2+}	×	CuS Black	CuS (Black)	$Cu(OH)_2$ Bluish-white
Fe^{2+}	×	×	FeS (Black)	$Fe(OH)_2$ Greenish-white
Fe^{3+}	×	×	FeS (Black)	Iron(III) hydroxide Reddish-brown

Structure of Science

Key fact :

- Different metal ions produce precipitates with characteristic colours when they react with specific anions.
- Chloride ions form white precipitates with Ag^+ and Pb^{2+}.
- Sulfide ions form black precipitates with Cu^{2+}, Fe^{2+}, and Fe^{3+}, and white precipitates with Zn^{2+}.

Key Concepts:

Selective Precipitation-Complex Ion Formation-Solubility -Complex IonsCondensation

Al^{3+}	×	×	$Al(OH)_3$ (White)	$Al(OH)_3$ White
Zn^{2+}	×	×	ZnS White	$Zn(OH)_2$ White

(b) Precipitation reactions with other anions

(i) Reaction with chromate ion CrO_4^{2-}

• Ag^+ produces a reddish-brown precipitate of silver chromate Ag_2CrO_4 .

• Pb^{2+} produces a yellow precipitate of lead(II) chromate $PbCrO_4$.

(ii) Reaction with hexacyanidoferrate(II) ion $[Fe(CN)_6]^{4-}$

• Reacts with Fe^{3+} to produce a dark blue precipitate.

NOS: Prediction

Predict what will happen when:

• Silver nitrate is added to a chloride solution.

Prediction: .....

What evidence would confirm your prediction? .....

(c) Properties of precipitates

(i) Chloride precipitates

Between AgCl and $PbCl_2$,

• $PbCl_2$ is soluble in hot water.

• AgCl dissolves in excess aqueous ammonia, producing diamminesilver(I) ions $[Ag(NH_3)_2]^+$.

(ii) Hydroxide precipitates

Among Ag_2O, $Pb(OH)_2$, $Cu(OH)_2$, $Fe(OH)_2$, iron(III) hydroxide, $Al(OH)_3$, and $Zn(OH)_2$:

• Soluble in excess aqueous sodium hydroxide: $Pb(OH)_2$, $Al(OH)_3$, $Zn(OH)_2$

• Soluble in excess aqueous ammonia: Ag_2O, $Cu(OH)_2$, $Zn(OH)_2$

(d) Separation of metal ions: By utilizing precipitation reactions of metal ions, specific metal ions can be separated from an aqueous solution containing multiple metal ions.

Table 3-11-1 ⟨Procedures and precipitates for separation of metal ions⟩

Operation	Precipitating metal ions	Precipitate (Colour)
❶ Add dilute hydrochloric acid	Ag^+ , Pb^{2+}	AgCl (White), $PbCl_2$ (White)
❷ Pass hydrogen sulfide gas through the solution	Cu^{2+} , Cd^{2+}	CuS (Black), CdS (Yellow)
❸ Add excess aqueous ammonia	Fe^{3+} , Al^{3+}	Iron(III) hydroxide (Reddish-brown), $Al(OH)_3$ (White)
❹ Pass hydrogen sulfide gas through the solution	Zn^{2+} , Mn^{2+}	ZnS (White), MnS (Pale-pink)
❺ Add aqueous ammonium carbonate	Ca^{2+} , Ba^{2+}	$CaCO_3$ (White), $BaCO_3$ (White)

Think Critically

Claim

A white precipitate alone is not enough to identify a metal ion.

Evidence

$AgCl$, $PbCl_2$, $Al(OH)_3$ and $Zn(OH)_2$ can all appear white.

Reasoning

Use information from this lesson to explain why additional chemical tests are necessary before identifying an unknown ion.

.....

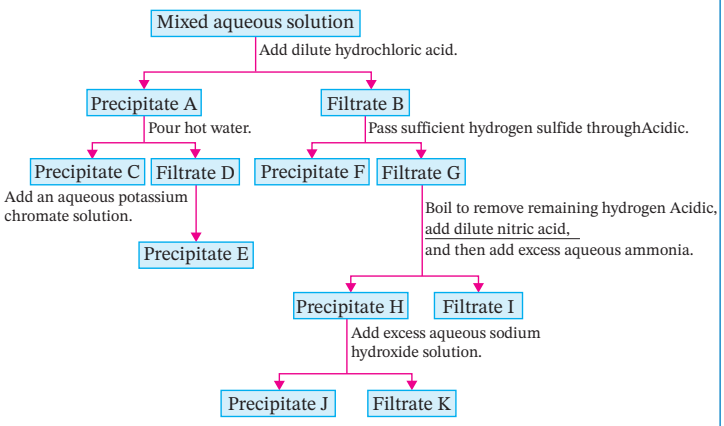
.....

Warm Up

Based on the flowchart showing the separation of six metal ions (Ag^+, Al^{3+}, Cu^{2+}, Fe^{3+}, Pb^{2+}, and Zn^{2+}) from a mixed aqueous solution, answer the following questions.

(a) Identify the chemical formulas and colours for precipitates C, E, and F. Identify the name and colour for precipitate J.

(b) Identify the chemical formulas for the complex ions formed when the metal ions in precipitate C and filtrate I react with ammonia.



(c) Explain the purpose of the underlined operation in the flowchart.

(d) Explain the problem that would occur if hydrogen sulfide (H_2S) gas were mistakenly passed through the mixed aqueous solution before the addition of dilute hydrochloric acid (HCl).

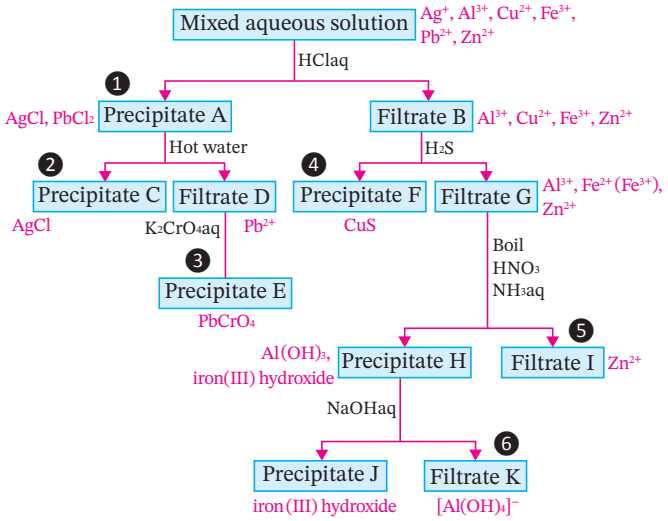
Explanation

Confirm the reactions one by one.

❶ When dilute hydrochloric acid is added, the ions that produce precipitates are Ag^+ and Pb^{2+}, and the chemical formulas of the precipitates are AgCl and $PbCl_2$.

❷ Of ❶, the one that does not dissolve in hot water is AgCl.

❸ When an aqueous potassium chromate solution is added to the aqueous solution in which $PbCl_2$ is dissolved in hot water, Pb^{2+} and chromate ions CrO_4^{2-} in the aqueous solution react to



Sustainability Connection

Many electronic devices contain valuable metals such as silver and copper.

Instead of mining new metals, industries can recover these metals from electronic waste using precipitation reactions.

Recovering metals helps to:

- reduce mining waste
- conserve natural resources
- decrease environmental pollution
- support a circular economy

produce a yellow precipitate of lead(II) chromate $PbCrO_4$.

❹ The ions contained in filtrate B are Al^{3+}, Cu^{2+}, Fe^{3+}, and Zn^{2+}. Also, because dilute hydrochloric acid was added in ⓧ, the aqueous solution is acidic. At this time, when hydrogen sulfide is passed through, it is Cu^{2+} that produces a precipitate, and the chemical formula of the precipitate is CuS.

❺ The ions contained in filtrate G are Al^{3+}, Fe^{2+} (Fe^{3+}), and Zn^{2+}. When an aqueous base solution is added to these, they produce precipitates of $Al(OH)_3$, iron(III) hydroxide, and $Zn(OH)_2$, respectively. Of these, the one that dissolves in excess aqueous ammonia is $Zn(OH)_2$.

❻ $Al(OH)_3$ dissolves in excess aqueous sodium hydroxide, whereas iron(III) hydroxide does not.

(a) C Chemical formula: AgCl, Colour: White E Chemical formula: $PbCrO_4$, Colour: Yellow F Chemical formula: CuS, Colour: Black J Substance name: Iron(III) hydroxide, Colour: Reddish-brown

(b) C: Since the ion contained in precipitate C is Ag^+, the complex ion formed with ammonia is $[Ag(NH_3)_2]^+$.
I: Since the ion contained in filtrate I is Zn^{2+}, the complex ion formed with ammonia is $[Zn(NH_3)_4]^{2+}$.

(c) By the hydrogen sulfide added in ❹, Fe^{3+} has been reduced to Fe^{2+}. To oxidise it back to Fe^{3+}, dilute nitric acid is added. **Example:** To oxidise Fe^{2+} back to Fe^{3+}.

(d) Ag^+ and Pb^{2+} would precipitate prematurely as sulfides, preventing their separation from metal ions such as Cu^{2+}. Consequently, subsequent analytical procedures—such as the dissolution of Pb^{2+} in hot water and its detection using chromate (CrO_4^{2-})—would be rendered impossible.

Think as an Engineer

Chemical engineers often design automated systems that continuously separate dissolved metal ions during water treatment and mining.
Which property of precipitates would be most important when designing such a system? Explain your answer.
……

Try

Choose the correct answer:

1. Which property makes Zn^{2+} different from Fe^{3+} during separation?

A. $Zn(OH)_2$ dissolves in excess ammonia

B. Zn^{2+} forms a red precipitate.

C. Fe^{3+} dissolves in ammonia.

D. Fe^{3+} forms no precipitate.

……

……

2. A white precipitate forms after adding dilute hydrochloric acid. Why is hot water added next?

A. To dissolve AgCl.

B. To dissolve $PbCl_2$.

C. To dissolve CuS.

D. To remove Zn^{2+}.

.....

3. For each of the following questions, identify the appropriate metal ions from the given list (A to G).

(A) Ag^+ (B) Cu^{2+} (C) Fe^{3+} (D) Fe^{2+}

(E) Al^{3+} (F) Pb^{2+} (G) Zn^{2+}

(a) Which of the metal ions produce a precipitate when dilute hydrochloric acid is added? (Select all that apply.)

(b) Choose all metal ions that produce a precipitate when a small amount of aqueous sodium hydroxide is added, and answer with their letters.

(c) From the precipitates formed in **(b)**, choose all that dissolve when an excess of aqueous sodium hydroxide is added, and answer with their letters.

(d) From the precipitates formed in **(b)**, choose all that dissolve when an excess of aqueous ammonia is added, and answer with their letters.

4. Which of the following ions (A to G) exhibits the reactions described in **(a)** through **(e)**?

(a) When aqueous ammonia is added, a bluish-white precipitate is produced, but when aqueous ammonia is further added, the precipitate dissolves to form a deep blue aqueous solution.

(b) When dilute hydrochloric acid is added, a white precipitate is produced. When this precipitate is exposed to light, it turns black.

(c) When aqueous ammonia is added, a white precipitate is produced, but when aqueous ammonia is further added, the precipitate dissolves to form a colourless aqueous solution.

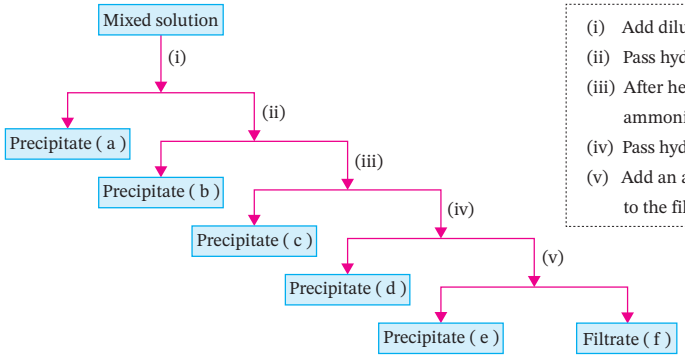
(d) When an aqueous potassium hexacyanidoferrate(II) solution is added, a dark blue precipitate is produced.

(e) When hydrochloric acid is added, a white precipitate is produced, and when an aqueous potassium chromate solution is added, a yellow precipitate is produced.

(A) Ag^+ **(B)** Al^{3+} **(C)** Cu^{2+} **(D)** Fe^{2+} **(E)** Fe^{3+} **(F)** Pb^{2+} **(G)** Zn^{2+}

5. The operations (i) to (v) in the following figure were performed on a mixed solution containing six metal ions: K^+, Ag^+, Ca^{2+}, Zn^{2+}, Cu^{2+}, and Al^{3+}.

Write the chemical formulas for the precipitates formed at each step (a) to (e) and for the ions present in the final filtrate (f).



(i) Add dilute hydrochloric acid
(ii) Pass hydrogen sulfide gas through the Acidic
(iii) After heating the filtrate, add excess aqueous ammonia to make it basic
(iv) Pass hydrogen sulfide gas through Basic
(v) Add an aqueous ammonium carbonate solution to the filtrate

Exercise

1. Complete the following table by identifying the chemical formula and colour of the precipitate formed when each metal ion reacts with the specified reagent. If no precipitate forms, write ×.

	Ag^+	Pb^{2+}	Cu^{2+}	Al^{3+}	Zn^{2+}
Hydrochloric acid	AgCl, White	A	B	C	×
Hydrogen sulfide (Acidic)	D	E	F	×	G
Aqueous ammonia (small amount)	H	I	$Cu(OH)_2$, Bluish-white	$Al(OH)_3$, White	J
NaOH aqueous solution (small amount)	K	$Pb(OH)_2$, White	L	M	N

2. Identify the cation (from A to H) that corresponds to each of the following observations **(a)** through **(e)**.

(a) When a small amount of aqueous ammonia is added, a bluish-white precipitate is produced, and when an excess of aqueous ammonia is added, the precipitate dissolves to form a deep blue aqueous solution.

(b) When hydrochloric acid is added, a white precipitate is obtained, and when an aqueous potassium chromate solution is added, a reddish-brown precipitate is obtained.

(c) When an aqueous potassium hexacyanidoferrate(II) solution is added, a dark blue precipitate is produced.

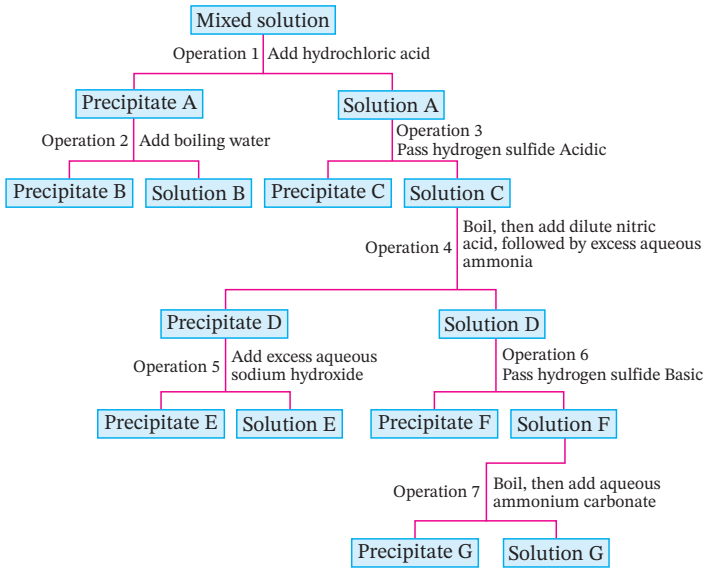
(d) When a small amount of aqueous ammonia is added, a white precipitate is produced. Even if excess aqueous ammonia is added to this precipitate, it does not dissolve, but if excess aqueous sodium hydroxide is added, the precipitate dissolves.

(e) Produces a red-purple flame in a flame test.

(A) Ag^+ **(B)** Cu^{2+} **(C)** Fe^{3+} **(D)** Al^{3+}

(E) Zn^{2+} **(F)** Ba^{2+} **(G)** Na^+ **(H)** K^+

3. A solution contains eight metal ions: Pb^{2+}, Cu^{2+}, Fe^{3+}, Zn^{2+}, Ba^{2+}, K^+, Ag^+, and Al^{3+}. A series of operations shown in the diagram were performed to separate and identify each ion. Answer the following questions.



(a) Identify the name and chemical formula of precipitate B.

(b) Explain why dilute nitric acid is added in operation 4.

(c) Write the chemical formula of the complex ion present in solution E.

(d) From the initial eight metal ions, identify which ions are present in solution G. Write their chemical formula.

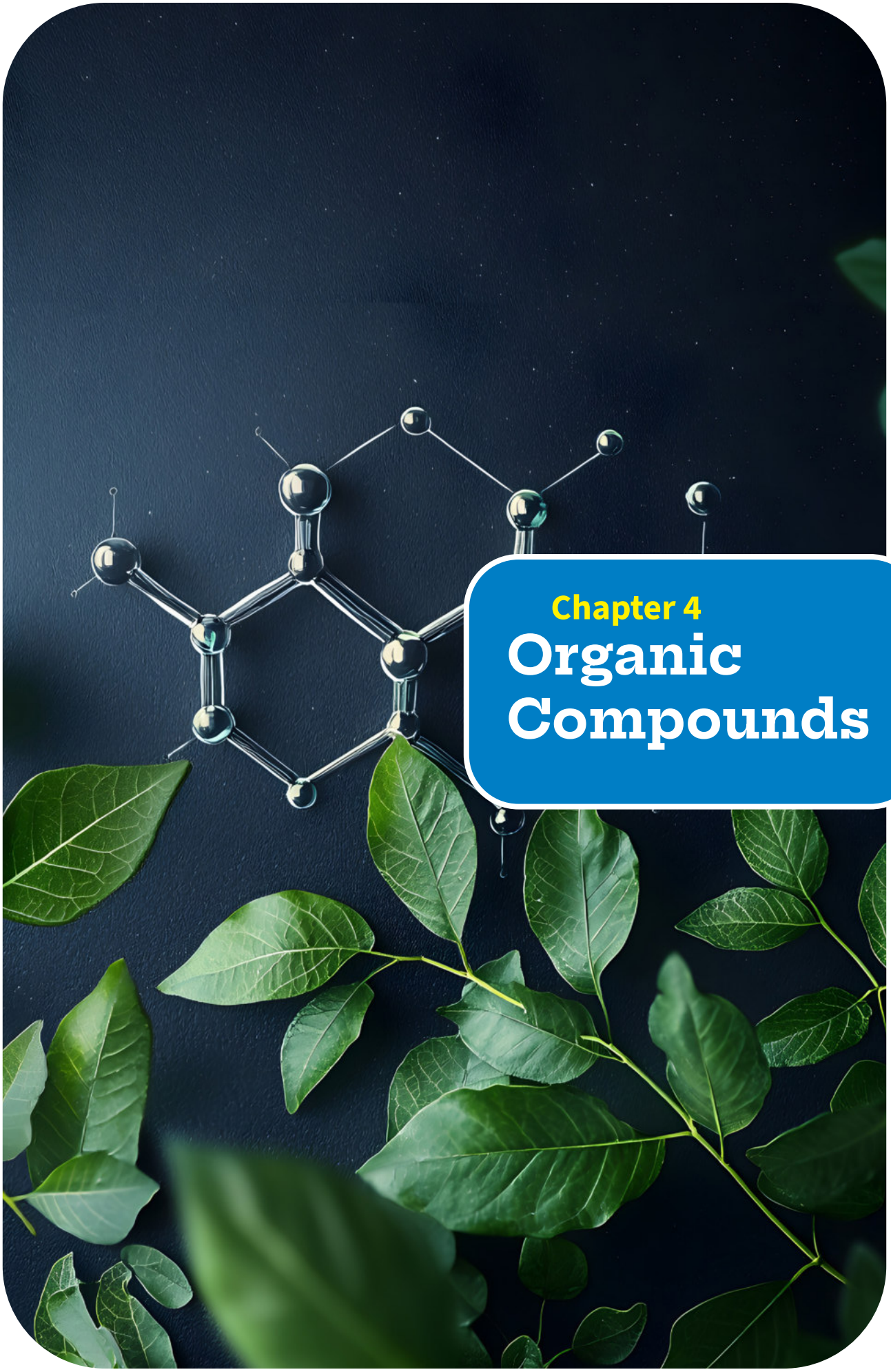
Challenge Your Thinking

A solution contains the following ions:

- Ag^{+}
- Pb^{2+}
- Cu^{2+}
- Zn^{2+}

Design the shortest possible sequence of reagents that separates all four ions.
Justify every step using the chemistry you learned.

.....



Chapter 4

Organic Compounds

Lesson 4-1 — Covalent Bonds

Engaging Introduction

Imagine watching two invisible gases—hydrogen and oxygen. Individually, hydrogen is highly flammable, while oxygen supports combustion. Yet when they react together, they form water, a liquid that can extinguish fire.

Every breath you take, every drop of water you drink, every molecule in your body exists because atoms share electrons in a remarkable way.

Today, you will discover how chemists explain the invisible connections that hold matter together.

Guiding Question How does the sharing of electrons allow atoms to form stable molecules with properties that are completely different from the individual atoms?

Exploration

A chemistry student builds four molecular models.

Hydrogen forms one bond.

Oxygen forms two bonds.

Nitrogen forms three bonds.

Carbon forms four bonds.

Observation

Describe the relationship between the number of unpaired electrons and the number of bonds formed.

……

Inference

Why do different elements form different numbers of covalent bonds?

Use electron arrangements to justify your answer.

……

Point!

1. Covalent Bonds

(a) **Covalent bond**: A bond formed by the sharing of valence electrons between atoms.

(b) **Molecule**: A It consists from Two or more atoms joined by covalent bond or more atoms joined by covalent bonds.

2. Lewis Structures (Electron Dot Diagrams)

(a) **Lewis symbol of atoms** : A notation in which dots are placed around an element's symbol to represent its valence electrons.

- Among the valence electrons, two electrons that are paired together are called a lone pair (**electron pair**), and a single electron that is not paired with another electron is called an **unpaired electron**.

Structure of Science

Key Fact :

- Covalent bonds form by sharing electrons.
- Molecules consist of atoms joined by covalent bonds.
- Shared electron pairs form covalent bonds.
- Lone pairs do not participate in bonding. where complex ions form via coordinate bonds donated from ligand lone pairs.

Key Concepts:

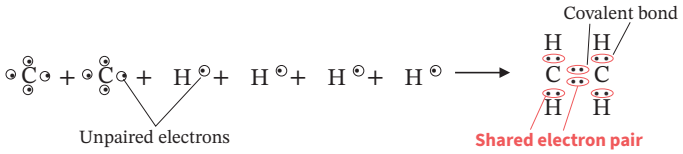
covalent bond- lone pairs - bonding pairs- structural formulas

Group	1	2	13	14	15	16	17	18
Lewis symbol	Li ·	· Be ·	· $\dot{B}$ ·	· $\dot{C}$ ·	· $\ddot{N}$ ·	: $\ddot{O}$ ·	: $\ddot{F}$ ·	: $\ddot{Ne}$:
Number of unpaired electrons	1	2	3	4	3	2	1	0

(b) Lewis structures of molecules

- A covalent bond is formed when an unpaired electron of an atom pairs with an unpaired electron of another atom. An electron pair shared between atoms in this way to form a covalent bond is called a **shared electron pair** (bonding pair). An electron pair not shared between atoms is called a lone pair of electrons (lone pair).

Example: C_2H_4 (Ethylene) molecule



- A covalent bond formed by sharing one electron pair is called a **single bond**. Covalent bonds formed by sharing two or three electron pairs are called **double bonds** and **triple bonds**, respectively.

2. Structural Formulas

(a) **Structural formula**: A chemical formula representing covalent bonds within a molecule using lines (bonds).

(b) Lewis structures and structural formulas of major molecules

Name and molecular formula	Lewis structure	Structural formula
Hydrogen H_2	H : H	H — H
Water H_2O	H : $\ddot{O}$: H	H — O — H
Ammonia NH_3	H : $\ddot{N}$: H H	H — N — H | H
Methane CH_4	H H : $\dot{C}$: H H	H | H — C — H | H

A structural formula can be drawn by replacing one pair of shared electrons in Lewis structure with one line.

Life Application

DNA Structure

Every DNA molecule is held together by millions of covalent bonds linking atoms into long chains. Without covalent bonds, genetic information could not be stored.

Food Chemistry

Proteins, carbohydrates, and fats all consist of atoms connected through covalent bonds. Breaking and forming these bonds releases energy during metabolism.

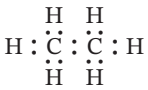
Warm Up

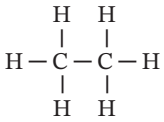
Write the Lewis structure and structural formula for each of the following molecules.

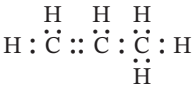
(i) C_2H_6 (ii) C_3H_6 (iii) HCl

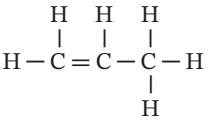
Explanation

Remember to include the lone pairs of electrons in the Lewis structures.

(i) Lewis structure: 

Structural formula: 

(ii) Lewis structure: 

Structural formula: 

(iii) Lewis structure: 

Structural formula: 

Think Critically

Scenario

A pharmaceutical company is developing a new medicine.

The research team discovers that one carbon atom has accidentally been drawn with five covalent bonds.

As the chemist responsible for quality control,

• Identify the error. .....

• Explain why the structure is chemically impossible.

.....

• Draw the corrected Lewis structure.

.....

Try

1. Which pair of electrons forms a covalent bond?

A. Lone pair B. Shared electron pair

C. Inner-shell electrons D. Core electrons

2. Which molecule contains a triple covalent bond?

A. H_2O B. NH_3

C. C_2H_2 D. CH_4

3. Write the Lewis structure and structural formula for each of the following molecules.

(i) HCN

.....

(ii) C_3H_8

.....

(iii) C_2H_4

.....

(iv) C_2H_2

.....

Chemistry Shapes Materials

Diamond vs Graphite:

Both consist entirely of carbon atoms.

Different covalent bonding arrangements give them completely different properties.

- Diamond ⟶ hardest natural material .
- Graphite ⟶ soft and conducts electricity.

Be Global Citizen

Modern society depends on synthetic materials made from covalent compounds. These materials improve healthcare, transportation, and communication. However, many plastics made from covalent polymers persist in the environment for centuries.

Challenge Your Thinking

Scientists can now design entirely new molecules that have never existed in nature.
If you could design a new covalent molecule, what problem would it solve?
Examples:

- biodegradable plastic
- better medicine
- carbon dioxide capture
- clean energy storage

Justify your design scientifically.

.....

Exercise

Write the Lewis structure and structural formula for each of the following molecules:

(i) CCl_4

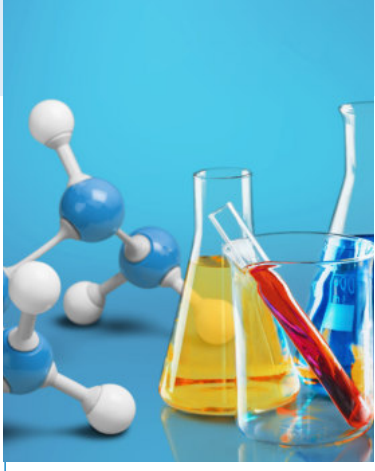
(ii) CH_4

(iii) HCN

(iv) C_2H_2

(v) C_2H_4

Lesson 4-2 — Characteristics and Structures of Organic Compounds



Engaging Introduction

Imagine walking into a supermarket where you see hundreds of products that look completely different: plastic water bottles, medicines, perfumes, cooking oil, chocolate, synthetic fabrics, gasoline, and even vitamins.

At first glance, these materials seem to have nothing in common. Yet scientists know that they are all built from the same remarkable element—carbon.

In this lesson, you will investigate how carbon›s unique bonding ability creates the diversity of molecules that support life, modern technology, medicine, agriculture, and industry.

Guiding Question How can changing the arrangement of carbon atoms create substances with completely different properties and uses?

Exploration

Which of these substances do you think have the most similar chemical structures? Explain your reasoning.

- Glucose (sugar)
- Plastic bottle
- Gasoline
- Aspirin
- Candle wax

Point!

1. Organic Compounds

(a) Organic compounds: Compounds with a skeleton of **carbon** atoms.

(b) Characteristics of organic compounds

(i) The number of constituent element types is **small**, but the number of compound types is **large**.

(ii) Many are combustible, and when completely burned, they mainly produce carbon dioxide and water.

(iii) They consist of **molecules** and have **low** melting and boiling points than ionic compounds

(iv) Many are **poorly soluble** in water, but **soluble** in organic solvents such as alcohols.

Liquid organic compounds that act as solvents.

Structure of Science

Key Fact :

- Organic compounds are built around a carbon skeleton.
- Most organic compounds contain carbon and hydrogen, and many also contain oxygen or nitrogen.
- Functional groups determine the chemical properties of organic compounds.

Key Concepts:

- Organic Compounds
- Hydrocarbons
- Functional Groups
- Molecular Structure

2. Classification of Organic Compounds

(a) Hydrocarbons: Organic compounds consisting only of carbon and hydrogen.

(i) Open-chain hydrocarbons (Aliphatic hydrocarbons): Hydrocarbons in which carbon atoms are bonded in a chain.

- **Alkane**: An open-chain hydrocarbon in which carbon atoms are bonded only by single bonds. The general formula is C_nH_{2n+2}.
- **Alkene**: An open-chain hydrocarbon having one double bond. The general formula is C_nH_{2n}.
- **Alkyne**: An open-chain hydrocarbon having one triple bond. The general formula is C_nH_{2n-2}.

(ii) Cyclic hydrocarbons: Hydrocarbons in which carbon atoms are bonded in a ring.

- **Cycloalkane**: A cyclic hydrocarbon in which carbon atoms are bonded only by single bonds. The general formula is C_nH_{2n}.
- **Cycloalkene**: A cyclic hydrocarbon having one double bond. The general formula is C_nH_{2n-2}.

(b) **Functional group**: A group of atoms that determines the characteristics of a compound.

Table 4-2-1 ⟨Classification of organic compounds by functional groups⟩

Name of functional group	Structure	Name of compound	Name of functional group	Structure	Name of compound
Hydroxyl group	$-OH$	Alcohol	Carboxyl group	$-\overset{\overset{O}{\|\|}}{C}-OH$	Carboxylic acid
Ether linkage	$-O-$	Ether	Ester linkage	$-\overset{\overset{O}{\|\|}}{C}-O-$	Ester
Carbonyl group (Ketone group)	$-\overset{\overset{O}{\|\|}}{C}-$	Ketone	Nitro group	$-NO_2$	Nitro compound
Formyl group (Aldehyde group)	$-\overset{\overset{O}{\|\|}}{C}-H$	Aldehyde	Amino group	$-NH_2$	Amine
			Sulfo group	$-SO_3H$	Sulfonic acid

(c) **Hydrocarbon group:** A part consisting only of carbon and hydrogen other than the functional group. Represented by the symbol R −.

Example: Alcohols are represented as R − OH.

(d) **Condensed structural formula:** A semi-structural formula in which the functional group is shown explicitly while the remaining atoms are written in a condensed (grouped) form.

Example: Ethanol is written as C_2H_5OH rather than the molecular formula C_2H_6O.

The molecular formula is C_2H_6O.

Think Critically

Claim

Organic compounds usually have lower melting and boiling points than many inorganic compounds.

Evidence

Most organic compounds consist of molecules held together by relatively weak intermolecular forces.

Reasoning

Use evidence from the lesson to explain why weaker intermolecular forces lead to lower melting and boiling points.

……

3. Isomers

Isomers: Compounds with the same molecular formula but different structures.

(i) **Structural isomers**: Isomers with different bonding orders of atoms.

(ii) **Stereoisomers**: Isomers with the same bonding order of atoms but different three-dimensional structures. (3D)

- **Cis-trans isomers**: Stereoisomers that arise because they have a double bond between carbons.
- **Enantiomers**: Stereoisomers that arise because they contain a carbon atom bonded to four different atoms or groups (a chiral carbon atom).

Life Application

Cosmetics

Perfumes, soaps, shampoos and skin-care products depend on organic molecules containing alcohols, esters and aromatic compounds.

Agriculture

Fertilizers, pesticides and herbicides are carefully designed organic compounds that increase crop production.

Warm Up

Answer the following questions.

(a) Among the following descriptions about organic compounds, choose all correct ones.

(i) Organic compounds consist of molecules, and many are soluble in water but poorly soluble in organic solvents.

(ii) For some, even if the molecular formula is the same, there are substances with different ways of bonding atoms and structures.

(iii) Because they are composed of many types of elements, there are many types of organic compounds.

(iv) They have low melting and boiling points.

(v) Carbon dioxide and sodium hydrogen carbonate are organic compounds.

(b) Name the underlined functional groups of the following organic compounds.

(i) H<u>CHO</u> (ii) H<u>COOH</u>

(c) Fill in the blanks with the appropriate words in the following text.

Isomers include (A) isomers, in which the bonding order of atoms is different, and stereoisomers, in which the three-dimensional arrangement of atoms or groups of atoms in a molecule is different. Stereoisomers further include (B) isomers, which are based on double bonds between carbon atoms, and (C), which arise because of the presence of a chiral carbon atom.

Be Global Citizen

Sustainable Organic Chemistry

Organic chemistry is essential for developing:

- Biodegradable plastics
- Renewable biofuels
- Green solvents
- Sustainable fertilizers
- Eco-friendly pharmaceuticals impacts.

Explanation

(a) (i) Many organic compounds are poorly soluble in water and soluble in organic solvents.

(ii) Compounds with the same molecular formula but different structures are called

isomers.

(iii) There are many types of organic compounds, but the types of constituent elements are few.

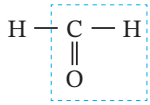
(iv) Because organic compounds consist of molecules, their melting and boiling points are lower than those of inorganic compounds.

This is because the intermolecular forces between organic molecules are weak.

(v) Carbon dioxide CO_2 and sodium hydrogen carbonate $NaHCO_3$ contain carbon atoms but are treated as inorganic substances. Therefore, (ii), (iv) .

(b) (i) The functional group consisting of C, H, O is the formyl group (aldehyde group).

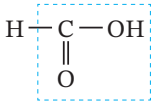
It has a structure like the one on the right.



Formyl group (Aldehyde group)

(ii) The functional group consisting of C, O, O, H is the carboxyl group.

It has a structure like the one on the right.



Carboxyl group

(c) A: Structural B: Cis-trans C: Enantiomer

Think as an Engineer

Scenario

Engineers often need materials that are strong, flexible, lightweight, or biodegradable. Understanding molecular structure and functional groups allows engineers to design plastics, synthetic fibers, adhesives, and medical materials with specific properties.

Which property would be most important when designing a biodegradable food package? Explain your answer.

……

Try

1. Read the following text and answer the questions below.

The types of elements constituting organic compounds are (A), but the types of compounds are extremely (B), and they have (C) structures or cyclic structures.

Also, a group of atoms that determines the characteristics of an organic compound is called a (D). There are also isomers, which are divided into structural isomers and (E). (E) includes (F), which arises because of a double bond, and (G), which arises because of a chiral carbon atom.

(a) Fill in the appropriate words for A to G.

(b) Name the following hydrocarbons (i) to (iii).

(i) A hydrocarbon represented by the general formula C_nH_{2n} and having one double bond between carbon atoms.

(ii) A hydrocarbon represented by the general formula C_nH_{2n}, having no double bonds, and having a cyclic structure.

(iii) A hydrocarbon represented by the general formula C_nH_{2n-2} and having one triple bond between carbon atoms.

(c) Choose all descriptions that correctly describe properties of organic compounds, and write the corresponding letters.

A. Many are poorly soluble in water but soluble in organic solvents.

B. Many consist of covalent bonds and are electrolytes.

C. Many consist of molecules and have relatively high melting and boiling points.

D. Many are combustible compounds, and often produce water and carbon dioxide upon combustion.

2. Answer the following questions about the compounds below.

(a) $CH_3\underline{CHO}$ **(b)** $CH_3\underline{CO}CH_3$ **(c)** $C_2H_5\underline{COOH}$

(d) $C_2H_5\underline{OH}$ **(e)** $C_6H_5\underline{NO_2}$ **(f)** $CH_3\underline{NH_2}$

(i) For the underlined functional groups in each compound, write their respective names.

(ii) What type of organic compound is each, based on its functional group? Write the name of the class. However, *d* is not a phenol.

3. Which of the following descriptions about a pair of enantiomers is incorrect?

(a) Properties such as melting and boiling points are the same.

(b) Their molecular formulas are the same.

(c) Their three-dimensional structures are different.

(d) They have a double bond between carbons within the molecule.

Challenge Your Thinking

Two compounds have the molecular formula C_3H_6O.
One smells pleasant and is used in perfumes.
The other is an important industrial solvent.
Challenge
Without changing the molecular formula, explain how changing only the arrangement of atoms could produce completely different substances.

.....

Exercise

Choose the correct Answer

1. Chemist wants to produce a compound that mixes well with water:

Which functional group would most likely help?

A. Hydrocarbon chain B. Hydroxyl group (–OH)

C. Carbon chain only D. Carbon-carbon triple bond

2. Which property is mainly determined by a functional group?

A. Number of neutrons B. Chemical reactivity

C. Number of protons D. Atomic mass

3. Fill in the blanks with the appropriate words or formulas. Note: Use *n* to represent the number of carbon atoms when writing general formulas.

Organic compounds are compounds with a skeleton of (i) atoms. The types of constituent elements are (ii), and the types of compounds are (iii).

Generally, they consist of (iv) , and their melting and boiling points are (v). Many organic compounds are (vi) in water, but (vii) in organic solvents.

Open-chain hydrocarbons containing one double bond between carbon atoms

are called (viii) , and their general formula is represented by (ix) ($n \geq 2$). Open-chain hydrocarbons represented by the general formula C_nH_{2n-2} ($n \geq 2$) and having one (x) bond between carbon atoms are called (xi).

4. Answer the following questions about the functional groups below.

(a) Hydroxyl group

(b) Formyl group (Aldehyde group)

(c) Carboxyl group

(d) Ether linkage

(e) Ester linkage

(f) Nitro group

(g) Sulfo group

(h) Amino group

(i) Write the functional groups (a) to (h) as in the example.

(**Example:** Carbonyl group $-\overset{\overset{O}{\|}}{C}-$)

(ii) What are the compounds having the functional groups (a) to (h) called?

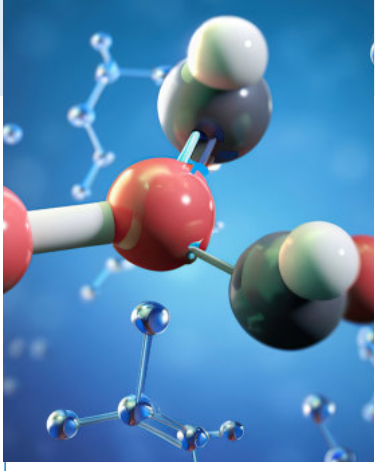
5. For the following sentences **(a)** to **(c)**, write *A* if it applies when the two compounds are cis-trans isomers, *B* if it applies when they are enantiomers, *C* if it applies in both cases, and *D* if it applies in neither case.

(a) The molecular formulas are different.

(b) The three-dimensional structures of the molecules are different.

(c) There is a double bond between carbons.

Lesson 4-3 — Determination of Structural Formulas of Organic Compounds



Engaging Introduction

A forensic laboratory discovers an unknown organic compound. Although scientists know it contains carbon, hydrogen, and oxygen, they do not know its identity. By burning a small sample and carefully measuring the products formed, they can gradually reveal the compound›s molecular structure.

In this lesson, you›ll discover how chemists identify unknown compounds using scientific evidence and logical reasoning.

Guiding Question How do particle motion and intermolecular forces determine whether a liquid evaporates, condenses, or boils?

Point!

1. Determination of Structural Formulas

(a) Elemental analysis: A procedure used to determine the proportion of each element present in a compound.

(b) Procedure for determining the structural formula

The structural formula of an organic compound is determined by the following procedure.

Extract a pure sample → Investigate constituent elements → Perform **elemental analysis** → Determine **empirical formula** → Determine **molecular formula** → Determine **structural formula**

(c) Empirical formula: A chemical formula that shows the number of atoms constituting a substance in the simplest integer ratio.

〈How to find the empirical formula〉

The ratio of atom numbers equals the ratio of each element's mass divided by its relative atomic mass. Therefore, for a compound with empirical formula $C_xH_yO_z$,

$$x : y : z = \frac{\text{Mass of C}}{\text{Relative atomic mass of C}} : \frac{\text{Mass of H}}{\text{Relative atomic mass of H}} : \frac{\text{Mass of O}}{\text{Relative atomic mass of O}}$$

Data Detective

A compound contains carbon, hydrogen, and oxygen.
Its elemental analysis gives the following masses:
• Carbon = 24 g
• Hydrogen = 4 g
• Oxygen = 32 g
Without solving completely, predict:
• Which element has the greatest number of atoms?
……
• What information do you need next to determine the molecular formula?
……

Structure of Science

Key fact :

• Elemental analysis determines the elements present in a compound.

• The empirical formula shows the simplest ratio of atoms.

• The molecular formula shows the actual number of atoms.

Key concepts:

Empirical formula-Molecular formula-Structural formula

(d) Molecular formula: A formula representing the types of constituent elements and the number of atoms of each element constituting a molecule.

⟨Empirical formula and molecular formula⟩

The molecular formula is the empirical formula multiplied by n (n: integer). The relational expression is: Molecular formula = Empirical formula × n. The value of n is obtained from the relative molecular mass of the compound.

$$n = \frac{\text{Relative molecular mass of Substance}}{\text{Formula weight of empirical formula}}$$

(e) Determination of structural formula: Identify the correct structure by distinguishing among possible isomers on the basis of their functional groups and physical properties, such as melting and boiling points.

Think Critically

Claim

The molecular formula of an organic compound cannot be determined using elemental percentages alone.

Evidence

What evidence supports this claim?

……

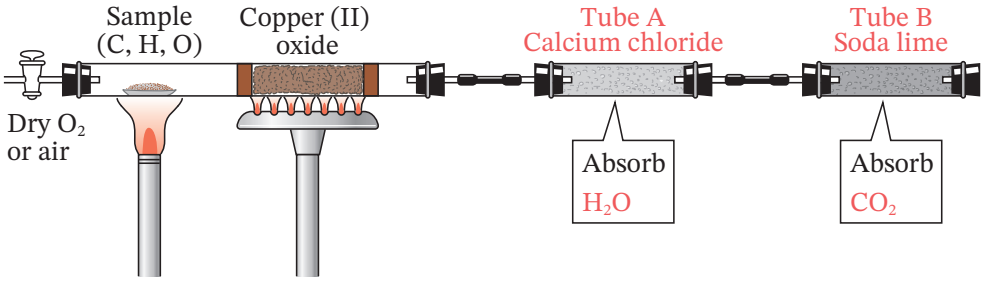
Reasoning

Explain why the relative molecular mass is also required.

……

2. Mass Measurement of Carbon, Hydrogen, and Oxygen

⟨Procedure for elemental analysis of a compound consisting of carbon, hydrogen, and oxygen⟩



❶ Heat and burn the Weighed sample.

- Add copper(II) oxide. Reason: To ensure **the sample is completely burned** .
- Carbon C becomes **CO_2**, and hydrogen H becomes **H_2O**.

❷ Absorb the generated substances.

- First, absorb **H_2O** in the **calcium chloride** tube.
- Next, absorb **CO_2** in the **soda lime** tube.

Note: The order of the tubes cannot be reversed.

Reason: **Soda lime absorbs both water and carbon dioxide, making it impossible to determine the masses of carbon and hydrogen separately** .

❸ Calculate the masses of carbon and hydrogen from the amount of increase in mass of each tube. (A and B)

❹ Find the mass of oxygen O.

Mass of Oxygen = Mass of Sample − (Mass of Carbon + Mass of Hydrogen)

Life Application

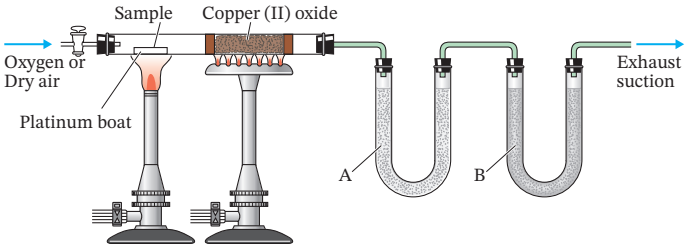
Food Quality Testing

Food scientists determine the carbon, hydrogen, oxygen, and nitrogen contents of foods to measure nutritional value and verify product quality.

Warm Up

Answer the following questions.

When 30.8 mg of organic compound X, consisting of carbon, hydrogen, and oxygen, was completely burned using the apparatus in the figure, the mass increase of tube A was 25.2 mg, and the mass increase of tube B was 61.6 mg. Also, when the relative molecular mass of this compound was measured, it was 88. Answer the following questions. (H = 1.0, C = 12, O = 16)



(a) Regarding the apparatus in the figure, what role does copper(II) oxide play? Answer briefly.

(b) What substances should be packed in tube A and tube B, respectively?

(c) Find the mass of C, the mass of H, and the mass of O contained in organic compound X, with their respective units.

(d) Write the molecular formula of organic compound X.

(e) Write two possible structural formulas of carboxylic acids for organic compound X.

Explanation

(a) To completely burn the sample.

(b) A: Unhydrous Calcium chloride B: Soda lime

(c) Mass of C: CO_2 is absorbed in tube B. Since the mass of tube B increased by 61.6 mg:

$$61.6\ \text{mg} \times \frac{12}{44} = 16.8\ \text{mg}$$

$$\text{Mass of C} = \text{Mass of } CO_2 \times \frac{\text{Relative atomic mass of C}}{\text{Relative molecular massof } CO_2}$$

Mass of H: H_2O is absorbed in tube A. From the mass increase of tube A being 25.2 mg,

$$25.2\ \text{mg} \times \frac{2.0}{18} = 2.80\ \text{mg}$$

$$\text{Mass of H} = \text{Mass of } H_2O \times \frac{\text{Relative atomic mass of H}}{\text{Relative molecular mass of } H_2O}$$

Mass of O: Using Mass of oxygen = Mass of sample − (Mass of carbon + Mass of hydrogen),

30.8 − (16.8 + 2.80) = 11.2 mg.

From the above, Mass of C: 16.8 mg Mass of H: 2.80 mg Mass of O: 11.2 mg.

(d) First, find the empirical formula of the compound. Assuming the empirical formula is $C_xH_yO_z$, from (c),

$x : y : z = \frac{16.8}{12} : \frac{2.8}{1.0} : \frac{11.2}{16}$

$= 1.4 : 2.8 : 0.7$

$= 2 : 4 : 1$

Therefore, the empirical formula of this compound is C_2H_4O.

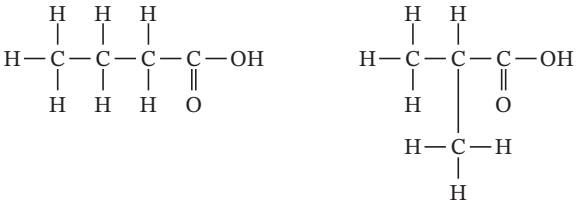
Next, using Molecular formula = Empirical formula × n: since the formula weight of C_2H_4O is 44 and the relative molecular mass is 88,

$n = \frac{\text{Relative molecular mass}}{\text{Formula weight of empirical formula}}$

$n = \frac{88}{44} = 2$

Therefore, the desired molecular formula is twice C_2H_4O, which is $C_4H_8O_2$.

(e) Since carboxylic acids possess a carboxyl group —C(=O)—OH, Two possible structural formulas for $C_4H_8O_2$ are:



For the three carbon atoms excluding the carboxyl group, it is conceivable that they are unbranched.

Think as an Engineer

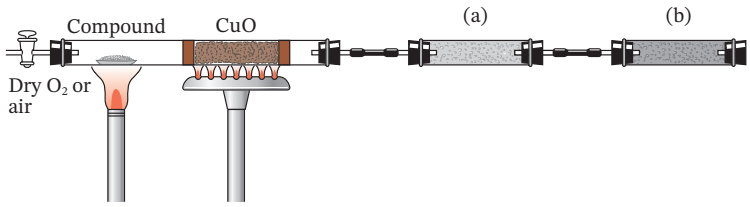
Chemical engineers use combustion analysis to verify the identity and purity of substances used in medicines, foods, and industrial chemicals.

How does accurate chemical analysis improve product quality and public safety?

.....

Try

1. Using the apparatus shown on the right, determine the structural formula of an unknown organic compound. When 1.02 g of an organic compound composed of carbon, hydrogen, and oxygen was completely combusted, 2.2 g of carbon dioxide and 0.90 g of water were obtained. Answer the following questions. (H = 1.0, C = 12, O = 16)



(i) What is the role of CuO? Select the best answer from A to D.

A To prevent incomplete combustion of the sample.

B To increase heat retention in the glass tube.

C To make the reaction proceed faster.

D To keep the inside of the glass tube dry.

(ii) To determine the mass of carbon dioxide produced, which tube — (a) or (b) — should you compare before and after the reaction?

(iii) What should be put in (a) and (b), respectively? Choose one each from A to F below

and select the appropriate letters.

(A) Silicon dioxide
BCalcium hydroxide
(C) Limestone
(D) Sodium hydrogen carbonate
(E) Calcium chloride
(F) Soda lime

(iv) Can this experiment be performed if the order of (a) and (b) is reversed? Explain your reasoning based on the properties of the substances in the tubes.

(v) Find the empirical formula of this organic compound.

(vi) Assuming the relative molecular mass of this organic compound is 102, find its molecular formula.

(vii) Among the structural isomers of this organic compound, write one that has a carboxyl group.

.....

2. When 30.0 g of compound A consisting only of carbon, hydrogen, and oxygen was completely burned, 66.0 g of carbon dioxide and 36.0 g of water were produced. Answer the following questions. (H = 1.0, C = 12, O = 16)

(a) What is the mass of carbon contained in 30.0 g of compound A? Report your answer to two significant figures.

(b) What is the mass of hydrogen contained in 30.0 g of compound A? Report your answer to two significant figures.

(c) What is the mass of oxygen contained in 30.0 g of compound A? Report your answer to two significant figures.

(d) Write the empirical formula of compound A.

(e) Find the molecular formula of compound A. Assume the relative molecular mass of compound A is 180..

.....

Exercise

Choose the Correct Answer

1.During combustion analysis, why is copper(II) oxide added?

A. To absorb carbon dioxide
B. To absorb water vapor
C. To ensure complete combustion
D. To cool the gases

.....

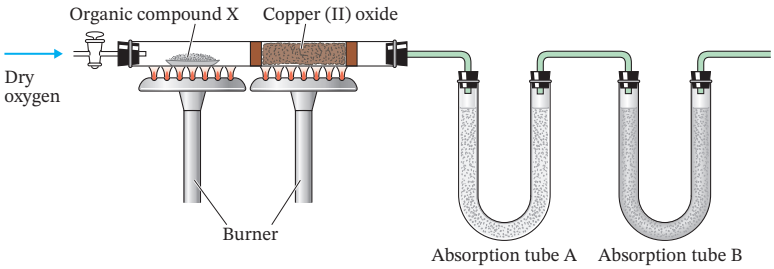
2.Which instrument collects water produced during combustion?

A. Soda lime
B. Calcium chloride
C. Copper oxide
D. Platinum catalyst

.....

Answer the following questions

3. Consider an organic compound X consisting only of carbon, hydrogen, and oxygen. An elemental analysis of organic compound X was performed using the apparatus shown in the figure below. Answer the questions below. (H = 1.0, C = 12, O = 16)



(i) What is the role of copper (II) oxide? Select the best answer from the following.

a A reducing agent to completely reduce X

b An oxidising agent to completely oxidise X

(ii) Which substance should be placed in absorption tube A? Select the appropriate letter from the following.

a Soda lime

b Sodium chloride

c Calcium chloride

d Calcium carbonate

(iii) Which substance is absorbed by absorption tube B? Select the appropriate letter from the following.

(a) Carbon dioxide

(b) Ammonia

(c) Water vapour (Water)

(d) Oxygen

(iv) When 72 mg of compound X was completely burned, the mass of absorption tube A increased by 72 mg and the mass of (d)rption tube B increased by 176 mg. Which is the empirical formula of X? Choose one from the following and select the appropriate letter.

(a) C_4H_8O

(b) $C_8H_{16}O_2$

(c) $C_4H_8O_2$

(d) C_6H_2O

(e) $C_{12}H_4O_2$

.....

4. Based on the results of (I) and (II) below, answer the questions below. (H = 1.0, C = 12, O = 16)

(I) When 6.0 mg of organic compound A consisting of carbon, hydrogen, and oxygen was completely burned, 13.2 mg of carbon dioxide and 7.2 mg of water were produced.

(II) When 6.0 mg of organic compound A was heated in a 300 mL container at 27°C and 8.3×10^5 Pa until it became a gas, the relative molecular mass was calculated from the ideal gas law to be 60.

(a) Find the empirical formula of organic compound A.

(b) Find the molecular formula of organic compound A.

(c) Write one possible structural formula of an alcohol for organic compound A.

.....

Challenge Your Thinking

Suppose another unknown compound produced:

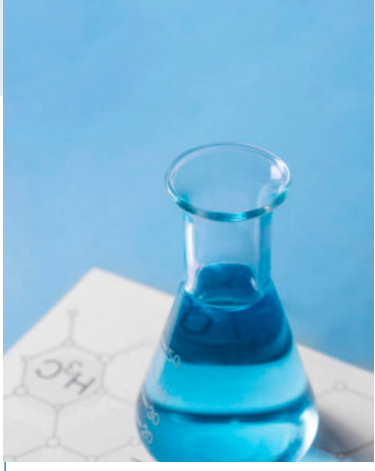
• 44 mg CO_2 • 18 mg H_2O

Without completing every calculation: Predict whether this compound contains more carbon or more oxygen than the previous sample.

.....

Justify your prediction.

.....



Lesson 4-4 — Saturated Hydrocarbons

Engaging Introduction

Imagine two camping trips.

On one trip, a camper lights a portable gas stove, and the fuel burns with a clean blue flame, heating water within minutes.

On another trip, someone accidentally spills gasoline onto the ground. The fuel evaporates quickly, creating a dangerous fire hazard.

Although both fuels are made mainly of alkanes, they behave differently depending on their molecular structures.

Guiding Question How can the structure of an alkane explain its physical properties, chemical reactions, and practical uses in everyday life?

Exploration

Observe the following two compounds.

Compound A:

A hydrocarbon with five carbon atoms arranged in a straight chain, where each carbon atom is connected in a continuous sequence.

Compound B:

A hydrocarbon with the same molecular formula (C_5H_{12}), but with the carbon atoms arranged in a branched chain, forming a different structural pattern.

Based on your observations,Think about the following questions:

1.What similarities do you observe between Compounds A and B?.....

2.How does the arrangement of the carbon atoms differ in each compound?.....

Point!

Alkane

(a) Saturated hydrocarbons: Hydrocarbons in which carbon atoms are bonded only by single bonds.

Table 4-4-1 〈Straight-chain alkanes〉

Number of carbons	Name	Molecular formula
1	Methane	CH_4
2	Ethane	C_2H_6
3	Propane	C_3H_8
4	Butane	C_4H_{10}
5	Pentane	C_5H_{12}
6	Hexane	C_6H_{14}

(b) Alkane: Open-chain saturated hydrocarbons.

The general formula is C_nH_{2n+2}. (Table 4-4-1 on the right)

(c) Alkyl group: A hydrocarbon group formed by removing one hydrogen atom from an alkane molecule. (Table below)

Structure of Science

Key fact :

- Alkanes are saturated hydrocarbons.
- They contain only single covalent bonds.
- They undergo substitution reactions with halogens.

Key Concepts:

Alkane- Saturated hydrocarbons- Alkyl group- Cycloalkane- a substitution reaction- substituent

Table 4-4-2 ⟨Examples of alkyl groups⟩

Name	Structure
Methyl group	CH_3-
Ethyl group	CH_3CH_2-
Propyl group	$CH_3CH_2CH_2-$
Isopropyl group	$CH_3CH(-)CH_3$

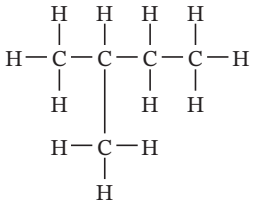
- In branched alkanes, the longest continuous chain of carbon atoms is called the main chain, and the branches are called side chains.

(d) Nomenclature of alkanes

Table 4-4-2

- The name of a branched alkane is constructed as: **Position number** of the side chain + Name of the **side chain** + Name of the **main chain** .

Example: Regarding the alkane on the right,



- The position of the side chain is **2** .
- The side chain is a **methyl** group.
- The main chain is **butane** .

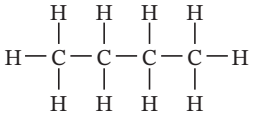
→ The name is **2-methylbutane**.

> - Number the chain so that the position number of the side chain is as small as possible.
> - When there are multiple identical side chains, use the prefixes di- (2), tri- (3), or tetra- (4) before the side-chain name.

(e) Structure of alkanes

- Alkanes with **4** or more carbon atoms have structural isomers.

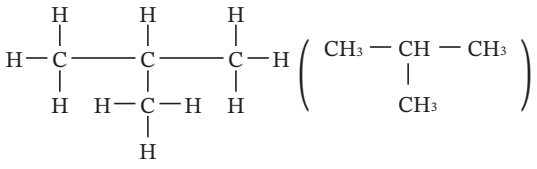
Example: There are two structural isomers with 4 carbon atoms.



Butane

Structural formulas are sometimes written in a simplified way as follows.

$CH_3-CH_2-CH_2-CH_3$

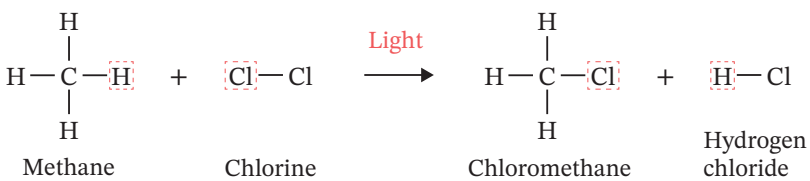


2-Methylpropane

(f) Reactions of alkanes

- When completely burned, they produce **carbon dioxide** and **water**.
- When a mixture of an alkane and a halogen is **exposed to light**, the hydrogen atoms in the alkane molecule are replaced by halogen atoms.

Example: Reaction of methane and chlorine

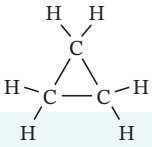


Note: A reaction in which an atom or group of atoms in a molecule is replaced by another atom or group of atoms in this way is called a **substitution reaction**, and the atom or group of atoms that takes the place of the original atom or group is called a **substituent**. (The replaced atom or group is referred to as the leaving group.)

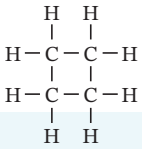
(g) Cycloalkane: Cyclic saturated hydrocarbons.
The general formula is C_nH_{2n} $(n \geq 3)$.

⟨Examples of cycloalkanes⟩

Cyclopropane



Cyclobutane



Life Application

Different fuels contain different alkanes.
- Natural gas (Methane) Methane is used in homes as Fuel because it burns cleanly.
- Propane fuels portable stoves and camping equipment.
- Gasoline powers cars.
- Diesel contains longer-chain hydrocarbons for heavy vehicles.

Warm Up

Answer the following questions.

(a) Name the substance represented by the following structural formula.

$$CH_3 - CH_2 - CH_2 - CH_3$$

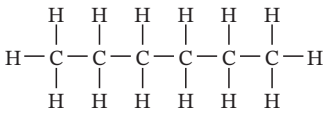
(b) Write all structural formulas and names for the structural isomers of the alkane with the molecular formula C_6H_{14}.

Explanation

(a) Because it is a straight-chain alkane with 4 carbon atoms, it is butane.

(b) There are 5 isomers of the alkane with 6 carbon atoms.

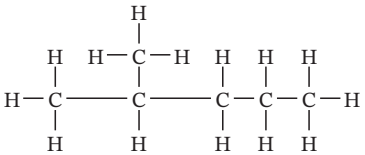
Structural formula:



Straight chain

Name: Hexane

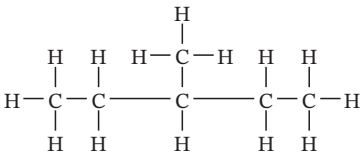
Structural formula:



The main chain has 5 carbon atoms, and the side chain is connected to the 2nd carbon atom.

Name: 2-Methylpentane

Structural formula:



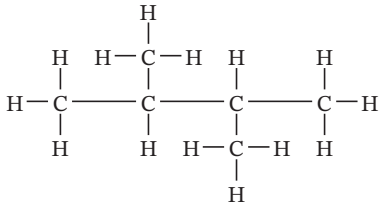
The main chain has 5 carbon atoms, and the side chain is connected to the 3rd carbon atom.

Name: 3-Methylpentane

Structural formula:

Be Global Citizen

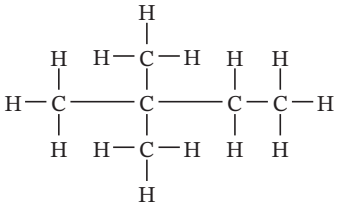
Burning fossil fuels releases carbon dioxide that contributes to climate change.
Scientists and engineers are developing cleaner fuels such as biofuels, green hydrogen, and synthetic hydrocarbons to reduce environmental impacts.



The main chain has 4 carbon atoms, and the side chains are connected to different carbon atoms.

Name: 2,3-Dimethylbutane

Structural formula:



The main chain has 4 carbon atoms, and the side chains are connected to the same carbon atom.

Name: 2,2-Dimethylbutane

Prediction

Methane reacts very slowly with chlorine in darkness.
Predict what will happen if the mixture is exposed to ultraviolet light.
Explain your reasoning before reading the reaction

Try

1. Answer the following questions.

(a) Fill in the blanks with the appropriate words in the following text.

In straight-chain hydrocarbons, they are named according to the number of carbon atoms, such as CH_4 is methane, C_2H_6 is (i) , C_3H_8 is propane, and C_4H_{10} is (ii) , which is the basis for the nomenclature of organic compounds.

(b) For each blank in the following sentences, select one from A to D.

(i) When an alkane is mixed with chlorine or bromine and ( ), a substitution reaction occurs.

A Warmed slowly　　B Irradiated with light

C Heated at high temperature　　D Left in the shade

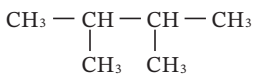
(ii) For the alkane represented by C_5H_{12}, there are ( ) types of structural isomers.

A 2　　B 3　　C 4　　D 5

2. Answer the following questions about organic compounds.

(a) Name the substance represented by the following structural formula.

(i) $CH_3-CH_2-CH_2-CH_2-CH_3$

(ii) 

(b) Write the structural formulas for the following substances. If there is more than one possibility, draw all of them.

(i) Cyclopentane　　(ii) Alkane represented by C_4H_{10}

Exercise

Choose the correct answer:

1. A hydrocarbon has the molecular formula C_5H_{12}.

What explains why it has three different structures?

A. Different molecular masses

B. Different functional groups

C. Different arrangements of carbon atoms

D. Different numbers of hydrogen atoms

2. A chemist exposes methane and chlorine to sunlight.

Which type of reaction occurs?

A. Addition

B. Combustion

C. Substitution

D. Neutralization

3. Fill in the blanks with the appropriate words, chemical formulas, or numbers. For the general formula, use n to represent the number of carbon atoms.

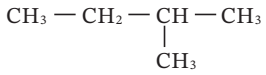
Acyclic hydrocarbons with no unsaturated bonds (double or triple bonds) are collectively called (i), and are represented by the general formula (ii). When straight-chain (i)s are listed in increasing order of their carbon atoms, they are (iii), ethane, (iv), butane, (v), and so on. Structural isomers exist for (i)s with (vi) or more carbon atoms; for example, butane has 2 isomers and (v) has (vii). These compounds are highly flammable, and their complete combustion produces (viii) and (ix) (in either order).

4. Answer the following questions about organic compounds.

(a) Name the substance represented by the following structural formula.

(i) $CH_3 — CH_2 — CH_2 — CH_2 — CH_2 — CH_3$

(ii)



(b) Write the structural formulas for the following substances. If there is more than one possibility, write all of them.

(i) Cyclopropane

(ii) Alkane represented by C_5H_{12}

Challenge Your Thinking

Cycloalkanes and straight-chain alkanes can have the same molecular formula.

For example,

Cyclobutane → C_4H_8 Butene → C_4H_8

Why does one belong to saturated hydrocarbons while the other is unsaturated?

.....

Explain using bonding and molecular structure.

.....

Chemistry Across Disciplines

Engineers study alkanes when designing efficient fuels. Environmental scientists monitor hydrocarbon emissions. Geologists investigate hydrocarbons during petroleum exploration.

Lesson 4-5 — Unsaturated Hydrocarbons (1) (Alkenes)

Engaging Introduction

Every day, millions of plastic bags, bottles, pipes, and food containers are manufactured from a simple gas called ethylene. At the same time, the very same molecule helps fruits ripen naturally on trees and in storage facilities. How can one small molecule play such different roles?

In this lesson, we will explore how the presence of a carbon–carbon double bond gives alkenes distinctive properties, explains their chemical reactions, and makes them valuable in both biological systems and industrial applications.

Guiding Question How does the presence of a carbon–carbon double bond change the properties, reactions, and applications of organic compounds?

Exploration

Look at the following everyday objects:

- A green banana
- A ripe banana
- A plastic shopping bag
- A plastic bottle

Although they appear completely different, they are connected by the same simple molecule: ethene (ethylene).

Think about

- What changes as a banana ripens?

……

- Why are many everyday plastics made from ethene?

……

- What properties of this molecule make it useful in both living organisms and industry?

……

Point!

1. Alkenes

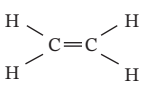
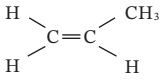
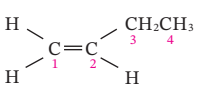
(a) **Unsaturated hydrocarbons:** Hydrocarbons having double bonds between carbon atoms.

(b) **Alkene:** An open-chain unsaturated hydrocarbon having one double bond. The general formula is C_nH_{2n} .

(c) **Nomenclature of alkenes** (Table on the right)

- The name of an alkene is formed by changing the suffix "-ane" of the alkane with the same number of carbons to "-ene".

Table 4-5-1 〈Examples of alkenes〉

Number of carbons	Name	Structural formula
2	Ethene (Ethylene)	
3	Propene (Propylene)	
4	1-Butene	

structure of science

Key fact :

The carbon–carbon double bond is one of the most reactive features in organic chemistry because it contains a region of high electron density that can easily participate in chemical reactions.

Key concepts:

Unsaturated hydrocarbons- Cis-trans isomers- Cycloalkene- Addition reaction- Addition polymerization.

• For alkenes with four or more carbon atoms, the position of the carbon atom forming the double bond is indicated by the lowest chain number.

(d) Properties of alkenes

• The carbon atoms forming the double bond C=C and the four atoms directly bonded to them are on the **same plane** (coplanar).

(e) Cis-trans isomers (Geometric isomers)

(i) Cis isomer: Isomers in which identical atoms or groups are on **the same side** of the double bond.

(ii) Trans isomer: Isomers in which identical atoms or groups are on **opposite sides** of the double bond.

Example: Cis-trans isomers of 2-butene

(i) Cis isomer (Cis-2-butene) (ii) Trans isomer (Trans-2-butene)

(f) Cycloalkene: A cyclic unsaturated hydrocarbon having one double bond. The general formula is C_nH_{2n-2} ($n \geq 3$).

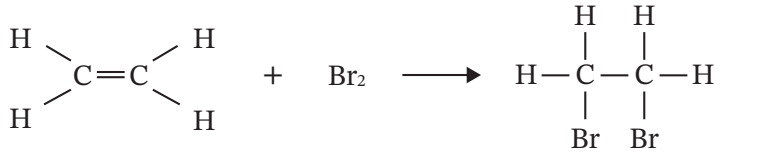
2. Reactions of Ethylene C_2H_4

(a) Manufacturing process of ethylene: Ethylene is produced by heating a mixture of ethanol and **concentrated sulfuric acid** to **160–170** °C.

Ethanol C_2H_5OH is dehydrated.

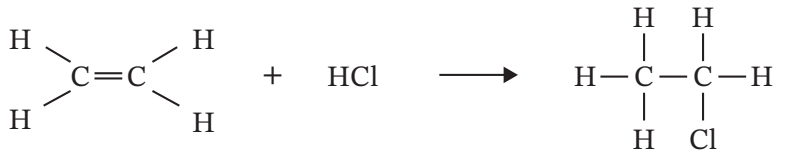
(b) **Addition reaction**: A reaction in which other atoms or groups of atoms bond to an unsaturated bond such as a double bond. By addition reaction, a double bond becomes a single bond.

• Addition reaction of bromine



Ethylene Bromine **1, 2-Dibromoethane**

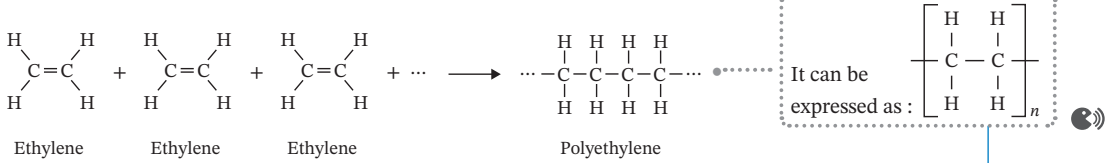
• Addition reaction of hydrogen chloride



Ethylene Hydrogen chloride **Chloroethane**

(c) **Addition polymerization**: A reaction in which many molecules of Alkene undergo successive addition reactions to form a long-chain polymer.

• Production of polyethylene



Ethylene Ethylene Ethylene Polyethylene

It can be expressed as :

Life Application

Fruits such as bananas, apples, and tomatoes release ethylene gas as they ripen. Commercial fruit storage facilities carefully control ethylene concentration to delay ripening during transport or accelerate ripening before products reach supermarkets.

Warm Up

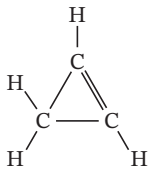
Answer the following questions.

(a) Answer the following questions (i) and (ii) .

(i) Name the substances represented by the following structural formulas.

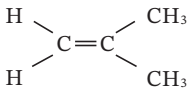
(A) $CH_2=CH-CH_2-CH_2-CH_3$

(B)

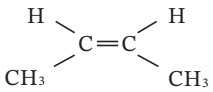


(ii) Among the following, select the structural formula of the substance that has cis-trans isomers (choose from A to C)

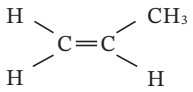
A



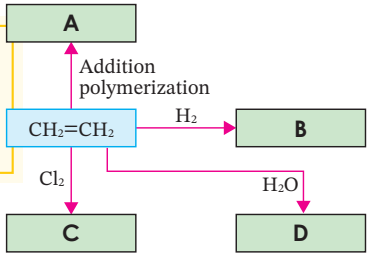
B



C



(b) Answer the following questions about the figure on the right showing the reactions of ethylene.



(i) Write the structural formulas of the substances A to C.

(ii) Name the substances A to D.

Explanation

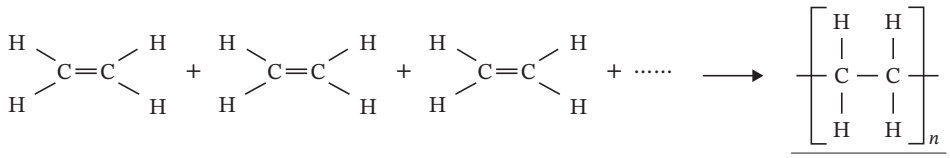
(a) (i) A: Change the suffix "-ane" of pentane, an alkane with 5 carbon atoms, to "-ene" to get pentene. Furthermore, since the double bond is at the first carbon atom, it is 1-pentene.

The position of the double bond is counted from the direction that gives the smaller number.

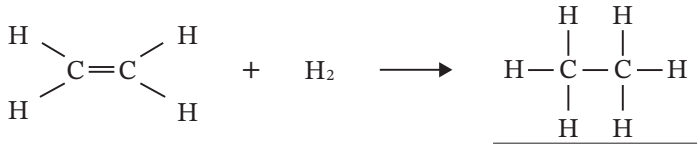
B: Since it is a cycloalkene with 3 carbon atoms, it is cyclopropene.

(ii) If the same atoms or groups of atoms are bonded to the carbon atoms forming the double bond C=C, cis-trans isomers do not exist. In A, the same atoms or groups of atoms are bonded to both carbon atoms, and in C, the atoms bonded to one carbon atom are the same, so cis-trans isomers do not exist. Therefore, B.

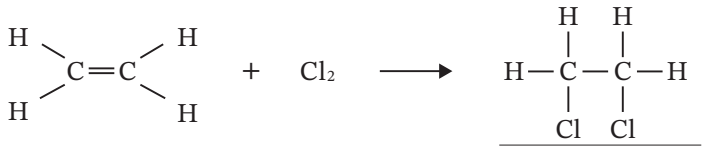
(b) (i) A: When ethylene is subjected to addition polymerization, it reacts as follows.



B: When ethylene and hydrogen H_2 react, the following addition reaction occurs.

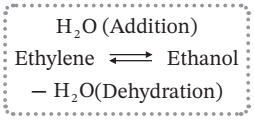


C: When ethylene and chlorine Cl_2 react, the following addition reaction occurs.



(ii) A: Polyethylene B: Ethane C: 1, 2-Dichloroethane

D: When ethanol is dehydrated, ethylene is obtained. Conversely, when water H_2O is added to ethylene, ethanol is produced. Ethanol



Think Critically

Scenario

Scientists discover two hydrocarbons with the same molecular formula C_4H_8.
One reacts rapidly with bromine water.
The other reacts much more slowly.
Without performing any additional tests, what might you infer about their molecular structures?
Explain your reasoning.

.....

Try

1. Answer the following questions about unsaturated hydrocarbons.

(a) What is the name of a reaction in which atoms or groups of atoms add across an unsaturated bond such as a double or triple bond?

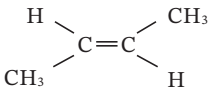
(b) What is the name of the reaction in which many molecules undergo the reaction in **(a)** successively to form a long-chain polymer?

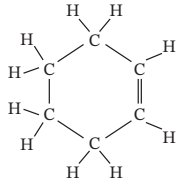
(c) Write the structural formula and name of the substance obtained by subjecting $CH_2 = CH_2$ to the reaction in **(b)**.

2. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH_2 = CH - CH_2 - CH_3$

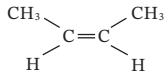
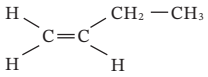
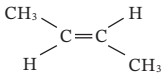
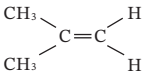
(ii) 

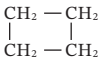
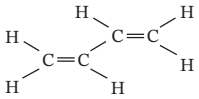
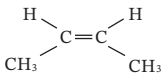
(iii) 

Be Global Citizen

Every year, millions of tons of polyethylene are produced from ethylene.
Although plastics improve modern life, improper disposal contributes to global pollution.
Scientists worldwide are developing biodegradable plastics and advanced recycling technologies to create a more sustainable future.

(b) Answer the following questions about the structural formulas (A) to (G).

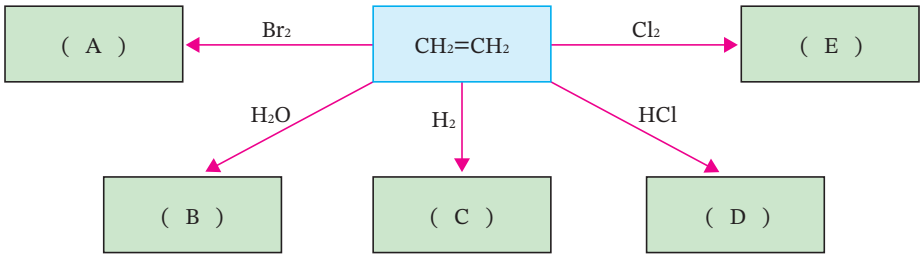
(A)  (B)  (C)  (D) 

(E)  (F)  (G) 

(i) Choose all substances that are structural isomers of (A) from (B) to (G).

(ii) Choose all substances that are cis-trans isomers of (A) from (B) to (G).

3. Answer the following questions about the figure below showing the reactions of $CH_2 = CH_2$.



(a) Name the substances (A) to (E).

(b) Write the structural formulas of the substances (A) to (E).

Exercise

Choose the correct answer:

1- A chemist wants to produce polyethylene.

Which reaction should be used?

A. Combustion
B. Substitution
C. Condensation
D. Addition polymerization

2. Which experimental observation provides evidence that an unknown compound is unsaturated?

A. It dissolves in water.
B. It has a low boiling point.
C. It burns with a blue flame.
D. It decolorizes bromine water.

3. Choose the appropriate words or chemical formulas for the blanks in the following sentences from A to D, one by one, and select the appropriate letters.

(a) Alkenes have the same general formula as ( ) with the same number of carbons.

(A) Alkanes
(B) Alkynes
(C) Cycloalkanes
(D) Carboxylic acids

(b) ( ) has cis-trans isomers.

(A) $CH_2 = CH_2$
(B) $CH_3CH = CH_2$
(C) $CH_2 = CHCH_3$
(D) $CH_3CH = CHCH_3$

Chemistry Across Disciplines

- Engineers design stronger plastics using polymer chemistry.
- Agricultural scientists use ethylene to control fruit ripening.
- Environmental scientists investigate biodegradable polymers.
- Biomedical engineers develop polymer-based artificial joints and prosthetic materials.

(c) In ( ), all atoms are on the same plane.

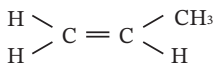
(A) Methane **(B)** Ethane

(C) Ethylene **(D)** Cyclopropane

4. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH_3-CH=\underset{\displaystyle CH_3}{\overset{\displaystyle |}{C}}-CH_3$

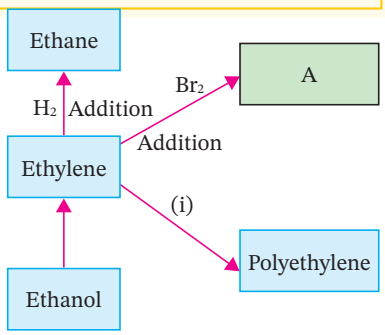
(ii) 

(b) Write the structural formulas for (i) to (iv) to meet the following conditions.

[Conditions]

- (i) to (iv) are all alkenes represented by the molecular formula C_4H_8.
- The name of the substance having the structural formula (i) is 1-butene.
- (i), (ii), and (iii) are structural isomers of each other.
- (iii) and (iv) are cis-trans isomers of each other, and (iii) is the cis isomer.

5. The figure on the right shows the interrelationship of the reactions of organic compounds. Answer the following questions.



(a) Ethylene is produced by the intramolecular dehydration of ethanol. Choose the correct operation for this from the following select the appropriate letter.

(A) Add concentrated hydrochloric acid to ethanol and heat at about 130–140°C.

(B) Add concentrated sulfuric acid to ethanol and heat at about 130–140°C.

(C) Add concentrated hydrochloric acid to ethanol and heat at about 160–170°C.

(D) Add concentrated sulfuric acid to ethanol and heat at about 160–170°C.

(b) Name compound A.

(c) What is reaction (i) called? Select one answer from A to E.

(A) Neutralization **(B)** Integration

(C) Dehydration **(D)** Polymerization

(E) Reduction

Challenge Your Thinking

Polyethylene is made entirely from carbon and hydrogen.

Why doesn't it behave like ethylene?.....

Explain how changing molecular size changes material properties.

.....

Lesson 4-6 — Unsaturated Hydrocarbons (2) (Alkynes)

Engaging Introduction

Imagine watching a welder repair a bridge using an extremely hot flame that can melt steel within seconds. Surprisingly, the fuel responsible for this intense flame is a simple hydrocarbon called acetylene. The same molecule is also used to manufacture plastics, synthetic fibers, and many important industrial chemicals.

In this lesson, we will explore how the unique carbon–carbon triple bond gives alkynes their distinctive structure, high reactivity, and wide range of industrial applications.

Guiding Question How does replacing a double bond with a triple bond change the properties and chemical behavior of a hydrocarbon?

structure of science

Key fact :

A carbon–carbon triple bond consists of one sigma (σ) bond and two pi (π) bonds, making alkynes more reactive than alkanes and suitable for many addition reactions

Exploration

Acetylene is used in welding because its flame can reach temperatures above 3000°C, making it hot enough to cut and join metals.

At the same time, chemists use acetylene as a starting material for producing plastics, synthetic rubber, pharmaceuticals, and other valuable chemicals.

Think about

• Why can one small molecule release so much energy?

.....

• What feature of its structure makes it more reactive than many other hydrocarbons?

.....

Point!

1. Alkynes

(a) Alkyne: An open-chain unsaturated hydrocarbon having one **triple bond** . The general formula is C_nH_{2n-2} .

(b) Nomenclature of alkynes: The suffix "-ane" of the alkane with the same number of carbon atoms is changed to "-yne".

(c) Structure of alkynes: The carbon atoms forming the triple bond C≡C and the two atoms directly bonded to them are in a **straight line** (linear). Alkynes do not have cis-trans isomers.

NOS: Prediction

Acetylene reacts with bromine much faster than methane.

Predict:

Why would one hydrocarbon react immediately while another shows almost no reaction under the same conditions?

.....

2. Reactions of Acetylene C_2H_2

The structural formula of acetylene is CH ≡ CH.

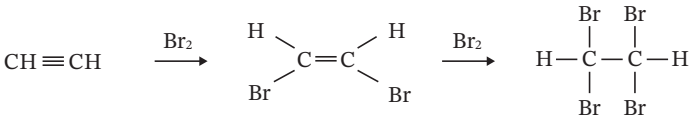
(a) Preparation process of acetylene: Acetylene is produced by adding water to _ **calcium carbide** (CaC_2).

$$CaC_2 + 2H_2O \longrightarrow C_2H_2 + Ca(OH)_2$$

(b) Addition reactions

(i) Addition of hydrogen molecules: Adding 1 molecule of hydrogen produces _ **ethylene** .
Adding 2 molecules produces **ethane** .

(ii) Addition of halogens: 2 molecules of halogen add to 1 molecule of acetylene.



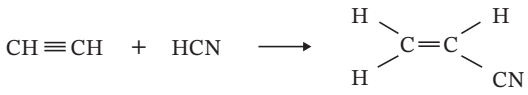
1,2-Dibromoethylene **1, 1, 2, 2-Tetrabromoethane**

(iii) Addition of other substances

- Addition of hydrogen chloride HCl: Produces **vinyl chloride** CH_2 = CHCl.

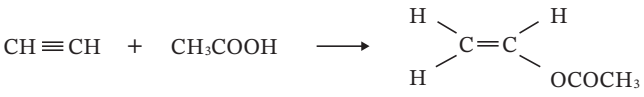
Vinyl chloride (Chloro ethene)

- Addition of hydrogen cyanide HCN: Produces **acrylonitrile** CH_2 = CHCN.



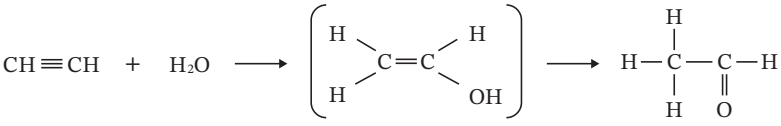
Acrylonitrile

- Addition of acetic acid CH_3COOH: Produces **vinyl acetate** CH_2 = $CHOCOCH_3$.



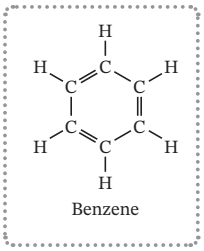
Vinyl acetate

- Addition of water H_2O: Produces **acetaldehyde** CH_3CHO via unstable vinyl alcohol.



Vinyl alcohol (Unstable) **Acetaldehyde**

(iv) Trimerization (Polymerization of 3 molecules): 3 molecules of acetylene cyclotrimerize to form **benzene** C_6H_6.


Benzene

Life Application

Acrylonitrile is used to manufacture:

- Carbon fibers for aircraft
- Sports equipment
- Automotive components.
- Protective helmets
- Synthetic textiles

Warm Up

Answer the following questions:

(a) Name the following substances (i) and (ii).

(i) $CH \equiv C - CH_3$ (ii) $CH_3 - C \equiv C - CH_3$

(b) Write the structural formula and name of the substance produced when the following substances (i) to (iv) are added to 1 molecule of acetylene.

(i) 1 molecule of hydrogen

(ii) 2 molecules of hydrogen

(iii) 2 molecules of bromine

(iv) 1 molecule of water

Explanation

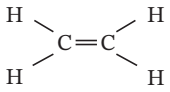
(a) (i) Change the suffix "-ane" of propane, an alkane with 3 carbon atoms, to "-yne". Propyne

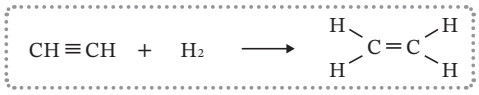
The position of the Triple bond is counted from the direction that gives the smaller number.

(ii) Change the suffix "-ane" of butane, an alkane with 4 carbon atoms, to "-yne" to get butyne. Also, since the triple bond is at the second carbon atom, it is 2-butyne.

(b) (i) Structural formula:

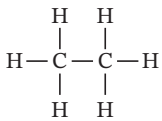
Name : Ethylene(Ethene)

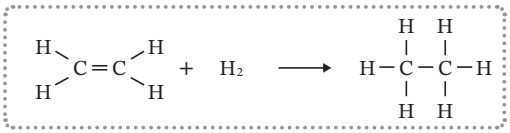




(ii)Structural formula:

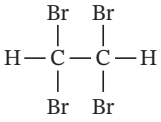
Name : Ethane





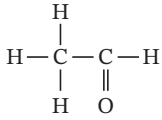
(iii) Structural formula:

Name : 1, 1, 2, 2- Tetrabromoethane



(iv) Structural formula:

Name : Acetaldehyde



When 1 molecule of water is added, it first becomes vinyl alcohol $CH_2 = CHOH$, but because this is unstable, it becomes acetaldehyde.

Be Global Citizen

Vinyl chloride is the starting material for PVC (polyvinyl chloride), one of the world's most widely used plastics.

PVC is used in:

- Drinking water pipes
- Electrical insulation
- Medical tubing
- Window frames.

Try

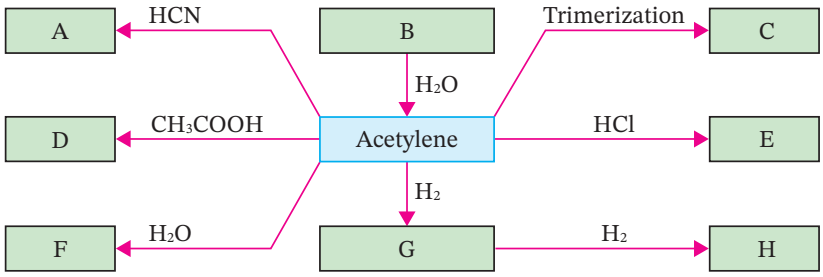
1. Answer the following questions about organic compounds.

(a) Name the substances represented by the following structural formulas.

(i) $CH \equiv CH$ (ii) $CHBr_2 - CHBr_2$

(b) Write the structural formulas of 1-butyne and 2-butyne, which are structural isomers of each other.

2. The figure on the right shows the synthetic pathway of organic compounds related to acetylene.



2- Answer the following questions.

(a) Name the substances corresponding to A to H.

(b) Which statement about substance G is correct? Select one from I to IV.

(i) The bond between carbon atoms can rotate.

(ii) When 1 molecule of chlorine Cl_2 is added, 1, 1-dichloroethane is produced.

(iii) All constituent atoms exist on the same plane.

(iv) Substitution reactions occur easily.

(c) Write the structural formula of the substance produced when 2 molecules of bromine Br_2 are added to 1 molecule of acetylene.

Exercise

Choose the correct answer:

1. Which industrial application depends directly on acetylene's high combustion temperature?

A. Water purification B. Food preservation

C. Metal welding D. Fertilizer production

2. Which product is obtained when three acetylene molecules react together?

A. Ethane B. Cyclohexane

C. Polyethylene D. Benzene

Answer the following question:

3. Answer the following questions about organic compounds.

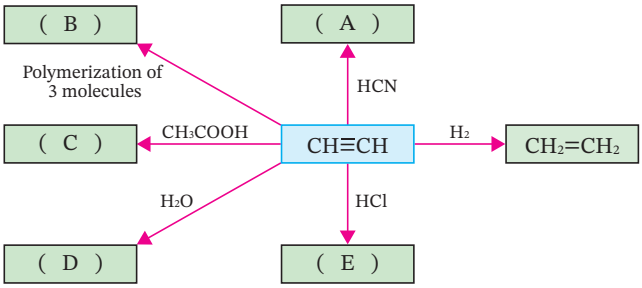
(a) Name the substances represented by the following structural formulas.

(i) $CH \equiv C - CH_3$ (ii) $CH \equiv C - CH_2 - CH_3$

(b) Write the structural formulas of the following substances.

(i) 2-Butyne (ii) 1, 1, 2, 2-Tetrabromoethane

4. Answer the following questions about the figure on the right showing the reactions of CH ≡ CH.



(a) Write the structural formulas and names of (A) to (E).

(b) Choose the laboratory manufacturing process of CH ≡ CH in the figure from I to IV below.

I Add ethanol C_2H_5OH while heating concentrated sulfuric acid to 160–170°C.

II Add ethanol C_2H_5OH while heating concentrated sulfuric acid to about 130°C.

III Add calcium carbide CaC_2 to water.

IV Mix sodium acetate CH_3COONa and sodium hydroxide and heat.

Challenge Your Thinking

Three molecules of acetylene combine to form benzene.

How can several small molecules join together to produce a completely different compound with new properties?

.....

What advantages might this transformation provide in chemical manufacturing?

.....

Lesson 4-7 — Alcohols and Ethers

Engaging Introduction

Imagine walking into a hospital and noticing the strong smell of hand sanitizer. Later, you see a racing car fueled with bioethanol, and at home someone uses rubbing alcohol to disinfect a wound.

These very different products all belong to the same family of organic compounds—alcohols— and Ethers yet they behave differently because of small differences in their molecular structures.

In this lesson, we will explore how the structure of alcohols and ethers determines their physical properties, chemical reactions, and their many applications in medicine, industry, transportation, and everyday life.

Guiding Question How does changing the structure of an alcohol or ether change its physical properties, chemical behavior, and practical applications?

Exploration

Consider:

- Hand sanitizer
- Perfume
- Engine biofuel
- Medical disinfectant
- Laboratory solvent

Discuss with a partner:

- Which products might contain alcohol? .....
- Why do some liquids mix easily with water while others do not?.....

Point!

1. Alcohols

(a) Alcohols: Compounds in which a hydrogen atom of a hydrocarbon is substituted with a hydroxyl group − OH. The general formula is R − OH Where are as an alkyle group.

(b) Nomenclature of alcohols: The suffix "-e" of the alkane with the same number of carbon atoms is changed to "-ol" . (Table 4-7-2 the right)

Table 4-7-1 ⟨Examples of alcohols⟩

Name	Condensed structural formula
Methanol	CH_3OH
Ethanol	C_2H_5OH
1-Propanol	$CH_3CH_2CH_2OH$
1-Butanol	$CH_3CH_2CH_2CH_2OH$

structure of science

Key fact :

Alcohols contain a hydroxyl group (−OH), while ethers contain an oxygen atom between two hydrocarbon groups (R−O−R′).

Primary, secondary, and tertiary alcohols undergo different oxidation reactions.

Key concepts:

Functional groups
Alcohol classification
Hydrogen bonding a
Oxidation pattern
Dehydration of ethanol
Alcohol

(c) Classification of alcohols

(i) An alcohol with 1 hydroxyl group − OH is called a **monohydric alcohol**, one with 2 is called a **dihydric alcohol**, and one with 3 is called a **trihydric alcohol**.

Table 4-7-2 ⟨Classification of alcohols and substance examples⟩

Classification	Substance example	Structure
Monohydric	Methanol	CH_3-OH
	Ethanol	CH_3-CH_2-OH
Dihydric	Ethylene glycol	$CH_2(OH)-CH_2(OH)$
Trihydric	Glycerin (Glycerol)	$CH_2(OH)-CH(OH)-CH_2(OH)$

(ii) A **primary alcohol** has one other hydrocarbon group attached to the carbon bearing the − OH group; a **secondary alcohol** has two; and a **tertiary alcohol** has three.

Table 4.7.3. solubility of alcohol in water

Primary alcohol	Secondary alcohol	Tertiary alcohol
$R^1-CH(H)-OH$	$R^1-CH(R^2)-OH$	$R^1-C(R^2)(R^3)-OH$

(d) Reactions of alcohols

(i) Solubility in water: Because the hydroxyl group easily bonds with water molecules, alcohols with a small number of carbon atoms are highly soluble in water.

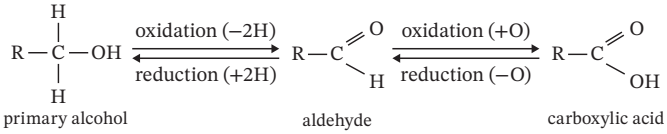
(ii) Reaction with sodium: When sodium is added to an alcohol, **hydrogen** is generated.

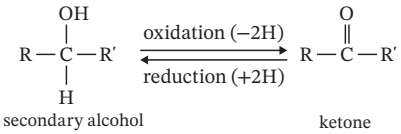
Example: Reaction with Ethanol $2C_2H_5OH + 2Na \longrightarrow \underset{\text{sodium ethanolate}}{2C_2H_5ONa} + H_2$

(iii) Oxidation by oxidising agents: Primary alcohols: Are oxidised to **aldehydes**; further oxidation gives **carboxylic acids**.

Secondary alcohols: Are oxidised to **ketones**.

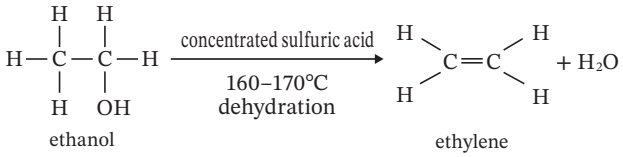
Tertiary alcohols: Resistant to oxidation.



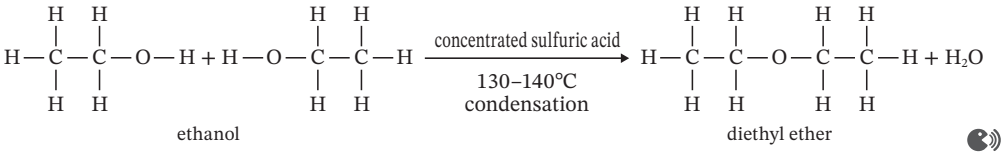


(iv) Dehydration reactions:

- When a mixture of ethanol and concentrated sulfuric acid is heated to 160–170°C, **ethylene** is produced.



• When heated to 130–140°C, **diethyl ether** is produced.



Nature of Science

Observation

Three alcohol samples are treated with the same oxidizing agent.

• Sample A forms an aldehyde.

• Sample B forms a ketone.

• Sample C shows almost no reaction.

Inference

What type of alcohol is each sample?.....

Prediction

What products would form if oxidation continued?

.....

2. Ethers

(a) Ethers: Compounds in which the hydrogen atom of the hydroxyl group − OH of an alcohol is substituted with a hydrocarbon group. The general formula is $R^1 - O - R^2$.

(b) Properties of ethers

• There are alcohols that are **structural isomers** of them.

• Their boiling points are **lower** compared to their isomeric alcohols.

• **Poorly soluble** in water, and **do not react** with sodium.

(c) Diethyl ether **$C_2H_5OC_2H_5$**

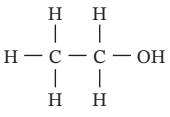
• A colourless, volatile liquid with an **anaesthetic** effect.

• **Dissolves** many organic compounds.

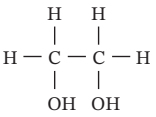
Warm Up

(a) Answer the following questions about substances **A** to **D** below.

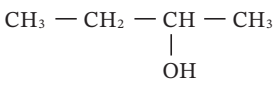
A



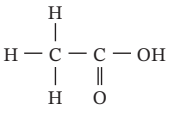
B



C



D



(i) Which of A to D is a secondary alcohol? Select the appropriate letter.

(ii) Which of A to D is a dihydric alcohol? Select the appropriate letter.

(b) The following statements (i) to (iii) describe either ethanol or diethyl ether. Select all statements that describe diethyl ether.

(i) Generates hydrogen when sodium is added.

(ii) Because it can dissolve many organic compounds, it is used as an organic solvent.

(iii) Poorly soluble in water.

(c) Two test tubes contain ethanol and dimethyl ether, which are represented by the molecular formula C_2H_6O. To distinguish between them, elemental sodium was added to each test tube.

(i) State what change is observed in each test tube.

(ii) Explain why such a difference occurs.

Explanation

(a) (i) Classified into primary alcohols, secondary alcohols, and tertiary alcohols based on the number of other hydrocarbon groups bonded to the carbon atom to which the hydroxyl group − OH is bonded.

In A and B, there is 1 other hydrocarbon group bonded to the carbon to which the hydroxyl group is bonded, so they are primary alcohols. In C, there are 2, so it is a secondary alcohol. D is not an alcohol but a carboxylic acid having a carboxyl group − COOH. Therefore, C.

(ii) Classified into monohydric alcohols, dihydric alcohols, trihydric alcohols, ... based on the number of hydroxyl groups − OH.

A and C have 1 hydroxyl group, so they are monohydric alcohols. B has 2 hydroxyl groups, so it is a dihydric alcohol. Therefore, B.

(b) Ethanol is an alcohol, and diethyl ether is an ether.

(i) It is ethanol, an alcohol, that reacts with sodium.

(ii) Diethyl ether dissolves many organic compounds and is used as an organic solvent.

(iii) Ethanol is highly soluble in water, but diethyl ether is poorly soluble in water.

Therefore, (ii) , (iii) .

(c) (i) Ethanol: Effervescence (hydrogen gas) is observed as the sodium dissolves.

Dimethyl ether: No reaction occurs.

(ii) **Example:** Ethanol contains a hydroxyl group, whereas dimethyl ether has an ether linkage and lacks a hydroxyl group.

Think as an Engineer

Chemical engineers can produce either

• Ethylene • Diethyl ether

from ethanol simply by changing the reaction temperature.

Challenge

Design a process to maximize ethylene production while minimizing ether formation. Which operating temperature would you choose?

Explain your decision.

Try

1. Choose a dihydric alcohol and a tertiary alcohol from the following alcohols A to E, and select the appropriate letters.

(A) $CH_3 - CH_2 - CH_2 - OH$

(B) $HO - CH_2 - CH_2 - CH_2 - OH$

(C) $HO - CH_2 - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_2 - OH$

(D) $CH_3 - CH_2 - \underset{\displaystyle OH}{\underset{|}{CH}} - CH_3$

(E) $CH_3 - \underset{\displaystyle OH}{\underset{|}{\overset{\displaystyle CH_3}{\overset{|}{C}}}} - CH_3$

2. Fill in the blanks with the appropriate words or numbers in the following text.

Alcohols are classified by the number of (a) atoms bonded to the carbon atom that bears the − OH group. When an alcohol is (b) using potassium dichromate acidified with sulfuric acid, primary alcohols are first converted to (d) and then further to (c), and secondary alcohols produce (e), but tertiary alcohols are not (b). Also, alcohols are classified by the number of (f) groups in the molecule. Methanol is a monohydric alcohol, ethylene glycol is a dihydric alcohol, and glycerin is a trihydric alcohol.

3. Which of the following statements (i) to (iv) describe ethanol? Select all that apply.

(i) Poorly soluble in water.

(ii) Reacts with elemental sodium and generates hydrogen.

(iii) A colourless, volatile liquid with an anaesthetic effect.

(iv) It is a primary alcohol.

Interpreting Data

Questions

- At which temperature is ether production greatest?

.....

- At which temperature is alkene production favored?

.....

- Explain using collision theory and reaction pathways.

.....

Temperature (°C)	Main Product
130	Diethyl ether
140	Mostly diethyl ether
150	Mixture
160	Mostly ethylene
170	Ethylene

Exercise

Choose the correct answer:

1.Which alcohol would most likely produce a ketone when oxidized?

A. Methanol

B. Ethanol

C. Propan-2-ol

D. tert-Butanol

2. An engineer wants to maximize ethylene production from ethanol. Which condition is most appropriate?

A. 120°C

B. 135°C

C. 165°C

D. Room temperature

Answer the following question:

3. Classify the following alcohols into primary alcohols, secondary alcohols, and tertiary alcohols.

(A) CH_3-CH_2-OH **(B)** $CH_3-CH_2-CH_2-OH$ **(C)** $CH_3-\underset{\displaystyle OH}{\underset{|}{CH}}-CH_3$

(D) $CH_3-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-OH$ **(E)** $CH_3-CH_2-\underset{\displaystyle CH_3}{\underset{|}{CH}}-OH$ **(F)** $CH_3-\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}-OH$

4. Fill in the blanks with the appropriate words, compound names, or chemical formulas in the following text.

Compounds with a structure in which hydrogen atoms of a hydrocarbon are replaced by hydroxyl groups are collectively called alcohols. The name of the alcohol with the simplest structure is methanol, its molecular formula is (a), and its condensed structural formula is (b). The name of the alcohol with 2 carbon atoms is (c), and industrially it is synthesized by the addition of water to (d) using phosphoric acid or the like as a catalyst.

There are two types of structures in which a hydrogen atom of propane is substituted with a hydroxyl group: the primary alcohol (e) and the secondary alcohol (f). When a primary alcohol is oxidised with an oxidising agent, it first changes to (g), and upon further oxidation, produces (h).

5. For the following statements I to V, write A if it applies to ethanol, B if it applies to diethyl ether, C if it applies to both, and D if it applies to neither.

I Highly soluble in water.

II A highly flammable, volatile liquid with an anaesthetic effect.

III Acts as an oxidising agent.

IV A colourless liquid at room temperature.

V Does not react with elemental sodium.

Challenge Your Thinking

An unknown compound has the molecular formula C_2H_6O.

Experimental observations:

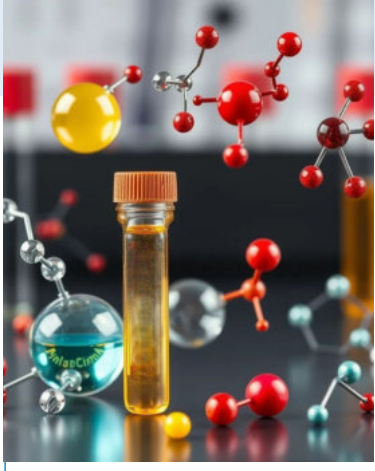
- It mixes completely with water.
- It reacts with sodium, producing bubbles.
- It does not behave as an ether.

Identify the compound.

Support your answer using structural evidence.

.....

Lesson 4-8 — Aldehydes and Ketones



Engaging Introduction

Imagine a chemist working in a quality-control laboratory receives two identical bottles containing colorless liquids. One is used to preserve biological specimens, while the other is commonly found in nail polish remover. Although they look almost identical, simple chemical tests reveal that they behave very differently. One forms a brilliant silver mirror inside a test tube, while the other does not react at all.

How can chemists distinguish between compounds that appear so similar? What does their molecular structure reveal about their chemical behavior?

Let's explore how the structures of aldehydes and ketones determine their properties, reactions, laboratory identification, and real-world applications.

Guiding Question How do chemists distinguish between aldehydes and ketones using their chemical reactions?

structure of science

Key fact :

Although aldehydes and ketones both contain a carbonyl group (C=O), the position of this group determines their chemical behavior.

Key concepts:

Aldehydes-Fehling's solution- Ketones-Iodoform Reaction

Exploration

A laboratory receives two unlabeled bottles containing colorless liquids.

Bottle A forms a silver mirror when heated with Tollens' reagent Ammoniacal Silver Nitate aquaus solution.

Bottle B shows no visible change.

Discuss:

- Are the two liquids the same compound? ……
- What evidence would help identify each substance? ……
- Why might one react while the other does not?……

Point!

1. Aldehydes

(a) Aldehydes: Compounds having a formyl group (aldehyde group) . The general formula is R − CHO.

(b) Properties of aldehydes

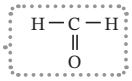
- Obtained by oxidising **primary alcohols** , and upon further oxidation, become **carboxylic acids** .
- Aldehydes are easily oxidised and exhibit **reducing** properties.

(i) **Silver mirror test**: When an aldehyde is added to an ammoniacal silver nitrate aqueous solution and heated, silver ions Ag^{+} are reduced and silver precipitates.

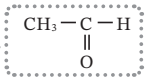
(ii) Reduction of Fehling's solution: When an aldehyde is added to Fehling's solution and heated, copper(II) ions Cu^{2+} are reduced, producing a red precipitate of copper(I) oxide Cu_2O.

Fehling's solution contains Cu^{2+}.

(c) **Various aldehydes**

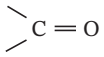
(i) **Formaldehyde** HCHO 

- A colourless, toxic gas with a pungent odour.
- **Highly soluble** in water.
- Obtained by oxidising **methanol** in the air.
- An aqueous solution containing about 37% formaldehyde is called **formalin**, and is used as a preservative solution for animal specimens, etc.

(ii) **Acetaldehyde** CH_3CHO 

- A colourless, toxic liquid with a pungent odour.
- Obtained by oxidising **ethanol** with an acidic sulfuric acid aqueous solution of potassium dichromate.

2. Ketones

(a) Ketones: Compounds in which two hydrocarbon groups are bonded to a carbonyl group  . The general formula is $R^1 - CO - R^2$.

(b) Properties of ketones

- Obtained by oxidising **secondary alcohols** .
- Not easily oxidised and do not exhibit reducing properties.
- There are aldehydes that are structural isomers of them.

(c) Acetone CH_3COCH_3

- A colourless liquid with a pleasant odour.
- Miscible with water in any proportion.
- In the laboratory, it is obtained by the oxidation of 2-propanol or the thermal decomposition of calcium acetate.

(d) Iodoform Reaction

The iodoform reaction occurs when an organic compound with a specific structural unit is heated with iodine (I_2) in an alkaline aqueous solution, producing a yellow precipitate of **iodoform** (CHI_3) with a characteristic color.

Think as an Engineer

Quality-control engineers in a pharmaceutical company must verify whether an alcohol has been completely oxidized during production.

Which laboratory test would you recommend?

- Silver mirror test
- Fehling's test
- Iodoform test

Justify your recommendation using chemical evidence.

……

Structural Requirements

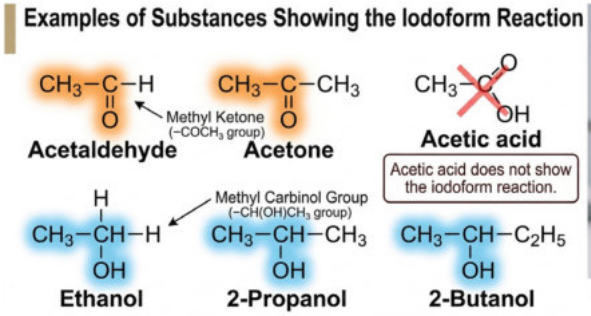
This reaction is given by compounds that contain **one of the following structural units** in their molecule (where R is a hydrogen atom (H) or a hydrocarbon group):

(i) Compounds with the structure $CH_3 - CO -$ (e.g., Acetaldehyde, Acetone, etc.)

(ii) Compounds with the structure $CH_3 - CH(OH) -$ (e.g., Ethanol, Propan-2-ol, etc.)

Note: Compounds with structure (ii) are oxidized (Oxidation) by iodine during the reaction, converting them into structure (i). Consequently, they give the

iodoform reaction.



Yellow Precipitate from the Iodoform Reaction

Think Critically

Claim

Aldehydes are reducing agents, while ketones are not.

Evidence

Use results from both laboratory tests.

……

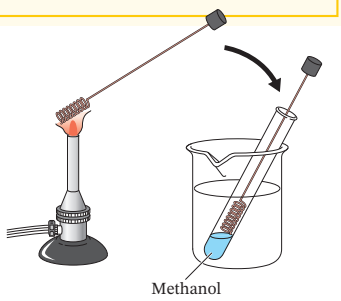
Reasoning

Explain how oxidation state and molecular structure account for the observed differences.

……

Warm Up

(a) Answer the following questions about the experimental procedures and results (I to III) regarding methanol.



(i) Put about 7 mL of methanol into a test tube and warm it in a water bath.

(ii) When a copper wire heated to become copper(II) oxide was brought close to the liquid surface of the methanol, the blackened copper wire part turned red.

III To confirm the product in Experiment II, when an ammoniacal silver nitrate aqueous solution was added, the inner wall of the test tube was covered with a silvery-white substance.

(i) In Experiment II, what did copper(II) oxide change into?

(ii) In Experiment II, what did methanol change into? Name the substance and write its structural formula.

(iii) What characteristics of organic compounds can the operation performed in Experiment III detect?

(b) Answer the following questions about the compounds represented by the molecular formula C_3H_8O.

(i) Among these compounds, name the substance that becomes an aldehyde upon gentle oxidation, and becomes a carboxylic acid upon further oxidation.

(ii) Write the structural formulas of the aldehyde and carboxylic acid produced in (i).

(iii) Among these compounds, name the substance that becomes a ketone upon oxidation.

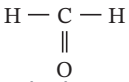
(iv) Does the compound in (iii) show an iodoform test?

Explanation

(a) (i) Since copper(II) oxide changed to red, it is understood that it changed to copper.
Answer: Copper.

(ii) From (i), since copper(II) oxide was reduced and changed to copper, it is understood that methanol was oxidised. What is obtained by oxidising methanol is formaldehyde.

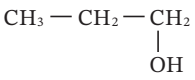
Therefore, Name: Formaldehyde, Structural formula:



(iii) The reaction that occurred in Experiment III is the silver mirror test, in which Ag^+ in the aqueous solution is reduced and silver Ag precipitates. The silver mirror test is a reaction caused by the reducing property of aldehydes, and organic compounds having a formyl group are called aldehydes.

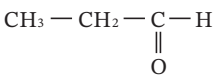
Thus, the silver mirror test detects: organic compounds containing a formyl group (an aldehyde group).

(b) (i) What becomes a carboxylic acid via an aldehyde upon gentle oxidation is a primary alcohol. In a primary alcohol, the hydroxyl group is bonded to the terminal carbon atom, giving the structure shown on the right.

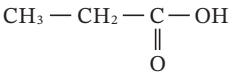


Therefore, the substance is: 1-propanol.

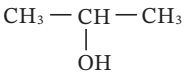
(ii) Aldehyde:



Carboxylic acid:



(iii) What becomes a ketone upon oxidation is a secondary alcohol. In a secondary alcohol, the hydroxyl group is bonded to the central carbon atom, giving the structure shown on the right.



Therefore, the substance is: 2-propanol.

(iv) It shows the reaction.

Interpreting Data

Students analyze the following results

Compound	Silver Mirror	Fehling's	Oxidation Product
Methanal	Yes	Yes	Methanoic acid
Ethanal	Yes	Yes	Ethanoic acid
Propanone	No	No	No reaction

Questions

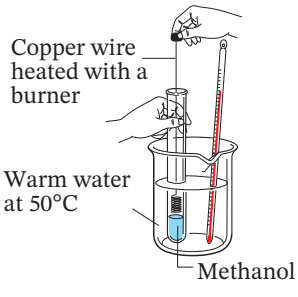
- Which compounds are aldehydes? .....
- Which compound is a ketone? .....
- Which compound is easiest to oxidize? .....
- Explain the pattern.....

Be Global Citizen

Formaldehyde is useful for preserving biological materials, but prolonged exposure may affect human health. Scientists and governments regulate its use in schools, hospitals, and workplaces.

Try

1. Place about 5.0 mL of methanol in a test tube and warm it in 50°C water. After warming, a spiral copper wire heated in the air using a gas burner was brought close to the liquid surface of the methanol while it



was hot, as shown in the figure, and this operation was repeated 5 to 6 times. Answer the following questions.

(a) What did methanol change into as a result of this procedure? Write the condensed structural formula and name the product.

(b) To confirm the product of **(a)**, an ammoniacal silver nitrate aqueous solution was added. What kind of change occurred? Also, answer the name of the test.

(c) An approximately 37% aqueous solution of the substance produced in the experiment is used for preserving biological specimens. What is this aqueous solution called?

2. Answer the following questions:

(a) Fill in the blanks with the appropriate words in the following text.

Aldehydes are compounds having a (i) group − CHO, and (ii) are compounds having a carbonyl group.

As an experiment to confirm the properties of an aldehyde, there is one where an ammoniacal silver nitrate aqueous solution is added to an aldehyde and heated. This is called the (iii) test. One of the representative aldehydes is (iv), which is obtained by oxidising ethanol with an acidic sulfuric acid aqueous solution of potassium dichromate.

Ketones have representative substances such as acetone. When iodine is added to a basic aqueous solution in which acetone is dissolved and reacted, a yellow precipitate with a characteristic odour is produced. This reaction is called the (v) test.

(b) For the following descriptions, write A if it applies to acetaldehyde, and B if it applies to acetone.

I Produced by the oxidation of a primary alcohol.

II Produced by the oxidation of a secondary alcohol.

III Becomes a carboxylic acid when oxidised.

IV Has reducing properties.

3. Consider compounds A, B, and C represented by the molecular formula C_3H_8O. A and B react with sodium to generate a gas, but C does not. Also, when A and B were gently oxidised, compound D was obtained from A, and compound E was obtained from B. When an ammoniacal silver nitrate aqueous solution was added to D and E, only E showed a test. Answer the following questions.

(a) Write the structural formulas of A to E.

(b) Among A to E, which ones produce a yellow precipitate when iodine and aqueous sodium hydroxide are added and reacted? Select all appropriate letters.

(c) Among A to E, which ones produce a red precipitate when Fehling's solution is added and heated? Select all appropriate letters.

Exercise

Choose the correct answer:

1- A chemist wants to distinguish an aldehyde from a ketone using a simple laboratory test. Which reagent should be used?

A. Bromine water
B. Ammoniacal silver nitrate solution
C. Dilute hydrochloric acid
D. Sodium chloride solution

2.A primary alcohol is gently oxidised. What is the first organic product formed?

A. Ketone B. Alkene

C. Aldehyde D. Carboxylic acid

Answer the following question:

3. After strongly heating a copper wire with a gas burner, it was immediately brought close to the liquid surface of methanol placed in a test tube, and the copper wire returned to its original colour. By repeating this operation, compound A with a pungent odour was produced. A has ((i) oxidising property / reducing property), and when an aqueous solution containing A is added to Fehling's solution and heated, a ((ii) red / yellow) precipitate of (iii) (Cu_2O / CHI_3) is formed. Also, when added to an ammoniacal silver nitrate aqueous solution and warmed, the (iv) test is observed. Answer the following questions.

(a) Choose the appropriate words or chemical formulas for the blanks (i) to (iii) in the text from the options in parentheses.

(b) Provide the word corresponding to (iv).

(c) In the underlined part, why did the copper wire return to its original colour? Explain using all the following words. [Word group: Reduction, Copper(II) oxide, Copper, Methanol]

4. Answer the following questions.

(a) Fill in the blanks with the appropriate words or compound names in the following text.

When a primary alcohol is oxidised with an oxidising agent, it first changes to a (i), and upon further oxidation, produces a (ii). Also, when a secondary alcohol is oxidised, it changes to a (iii). For example, by oxidising 2-propanol with an oxidising agent, it becomes (iv), which is a kind of (iii).

(b) For formaldehyde and acetone, write A if the following properties (i) to (v) apply only to formaldehyde, B if they apply only to acetone, and C if they apply to both in common.

(i) Has the structure − CO −. (ii) Reduces Fehling's solution.

(iii) Shows the iodoform test. (iv) Becomes a carboxylic acid when oxidised.

(v) Becomes a secondary alcohol when reduced.

5. Consider 3 types of compounds, A to C, represented by the molecular formula C_3H_8O. A and B are alcohols, and C is an isomer of A and B. D is obtained by the oxidation of A, or by the thermal decomposition of calcium acetate without air. E shows a reducing property and is obtained by the oxidation of B, but when E is further oxidised, it becomes F, which is a weak acid. Answer the following questions.

(a) Name compounds A, B, and D.

(b) Write the structural formulas of compounds C and E.

(c) Among compounds A to F, how many show the iodoform test?

Challenge Your Thinking

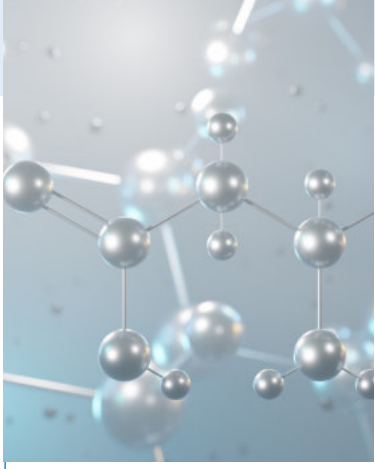
A chemist performs the following tests on an unknown compound.

- Positive Tollens' test
- Positive Fehling's test
- Negative Iodoform test

Predict:

- Which functional group is present? .....
- Suggest one possible compound. .....
- Explain your reasoning using evidence .....

Lesson 4-9 — Carboxylic Acids



Engaging Introduction

Think about the sharp smell of vinegar in your kitchen. Why does it taste sour, while alcohol has a completely different taste and behavior, even though both contain carbon, hydrogen, and oxygen?

Now imagine that two medicines contain the same atoms arranged in almost the same way, yet one works effectively in the human body while the other has a completely different biological effect.

In this lesson, let's explore how the structure of carboxylic acids and the three-dimensional arrangement of molecules determine their chemical reactions and their importance in biology, medicine, and everyday life.

Guiding Question How does molecular structure determine the chemical properties, biological activity, and practical applications of carboxylic acids and their isomers?

Point!

1. Carboxylic Acids

(a) Carboxylic acids: Compounds having a carboxyl group − COOH. The general formula is R − COOH.

(b) Classification of carboxylic acids

A carboxylic acid with 1 carboxyl group − COOH is called a **monocarboxylic acid**, and one with 2 is called a **dicarboxylic acid**.

(c) **Fatty acids**: Long-chain monocarboxylic acids.

- **Higher fatty acids**: Fatty acids with a large number of carbon atoms.
- **Lower fatty acids**: Fatty acids with a small number of carbon atoms.

(d) Properties of carboxylic acids

- Obtained by the oxidation of **primary alcohols** and **aldehydes**.
- Aqueous solutions are **weakly acidic**.
- Their acid strength is **stronger** than carbonic acid, and they react with sodium hydrogen carbonate to generate **carbon dioxide**.

Example: $CH_3COOH + NaHCO_3 \longrightarrow CH_3COONa + H_2O + CO_2$

Inquiry-Based Learning

A student has two colorless liquids:

- Vinegar
- Ethanol

Both look identical.

How could you identify which one is the carboxylic acid using only sodium hydrogen carbonate?

.....

Predict your observations before reading the explanation?

.....

Structure of Science

Key fact :

Carboxylic acids are organic compounds that contain the carboxyl functional group (–COOH).

Enantiomers are stereoisomers that are non-superimposable mirror images of each other.

Fatty acids are open-chain monocarboxylic acids..

Key Concepts

- Fatty acids

Functional groups

Carboxylic acids

Hydroxy acids

Geometric (cis–trans) isomerism

Stereoisomerism

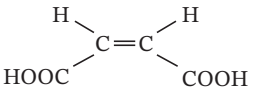
(e) Various carboxylic acids

(i) Formic acid **HCOOH**: A colourless, toxic liquid with a pungent odour. Has the structure of a formyl group.

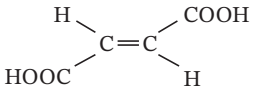
(ii) Acetic acid **CH_3COOH**: A colourless liquid with a pungent odour. Contained in vinegar at 4–5%.

(iii) Maleic acid, Fumaric acid: Dicarboxylic acids that are cis-trans isomers of each other.

- **Maleic acid** dehydrates when heated. **Fumaric acid** is difficult to dehydrate.



Maleic acid (cis isomer)



Fumaric acid (trans isomer)

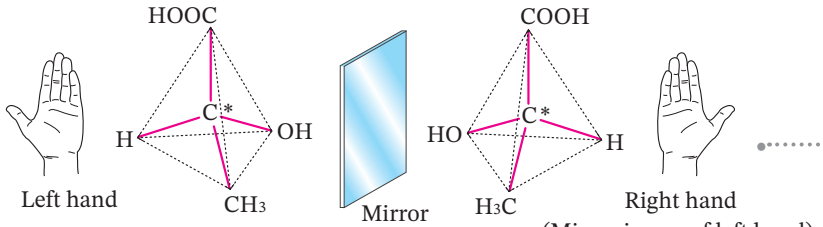
(iv) **Hydroxy acids**: Carboxylic acids having a hydroxyl group − OH. Show properties of both alcohols and carboxylic acids. **Example:** Lactic acid CH_3CH (OH) COOH

2. Enantiomers (Optical Isomers)

(a) **Chiral carbon atom**: A carbon atom to which 4 different types of atoms or groups of atoms are bonded.

(b) **Enantiomers**: Stereoisomers that arise due to having a chiral carbon atom. They have a relationship of a real image and a mirror image, like left and right hands.

⟨Enantiomers of lactic acid⟩



Chiral carbon atoms are often represented with an asterisk (*).

Think Critically

Claim

Enantiomers can have identical physical properties but different biological effects.

Evidence

- Same melting point
- Same density
- Different optical activity
- Different physiological responses

Reasoning

Biological receptors are three-dimensional and recognize molecular shape rather than molecular formula.

(c) Properties of enantiomers

- Properties such as melting point and density are the same.
- They differ in optical activity (rotation of plane-polarised light) and in physiological effects such as taste.

Life Application

Why Does Vinegar Remove Lime scale?

Vinegar contains acetic acid, a weak acid that reacts with calcium carbonate deposits (limescale), producing carbon dioxide gas and soluble salts.

Warm Up

Answer the following questions.

(a) Select the letter of the most appropriate word for each blank.

(i) ( ) reacts with sodium hydrogen carbonate to generate carbon dioxide.

(A) Formic acid **(B)** Acetone **(C)** Ethanol **(D)** Ethyl methyl ether

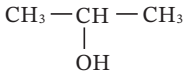
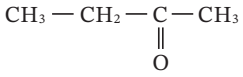
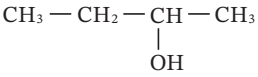
(ii) Carboxylic acids are produced by the oxidation of ( ).

(A) Secondary alcohol **(B)** Ketone **(C)** Aldehyde **(D)** Ester

(iii) The dicarboxylic acid that dehydrates when heated is ( ).

(A) Acetic acid **(B)** Maleic acid **(C)** Lactic acid **(D)** Fumaric acid

(b) From A to C, select the structure that has a chiral carbon atom (and therefore exists as enantiomers).

(A)  **(B)**  **(C)** 

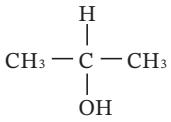
Explanation

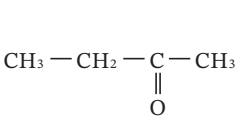
(a) (i) It is carboxylic acids that react with sodium hydrogen carbonate to generate carbon dioxide. Among the choices, only formic acid is a carboxylic acid. Answer: A.

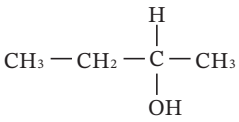
(ii) C (iii) B

(b) For a chiral carbon atom, the ends of the 4 bonds extending from C are all different atoms or groups of atoms.

If the structural formulas of A to C are rewritten so that the bonds of C are easy to understand, they become as follows:

A 

B 

C 

In A , two $-CH_3$ groups are bonded.

B has a double bond, so 4 different types are not bonded.

In C, 4 different groups ($-C_2H_5$, $-CH_3$, $-H$, $-OH$) are bonded.

Therefore, C.

Interpreting Data

Suppose the following experimental observations were recorded.

Compound	Dehydrates when Heated?
Maleic acid	Yes
Fumaric acid	No

Questions

- What conclusion can you draw about the effect of molecular arrangement on chemical reactions?

.....

Try

1. Read the following text and answer the questions below.

(i) is the main component of vinegar, and is obtained by oxidising (ii) which has a formyl group. (i) is a colourless liquid with a pungent odour, its aqueous solution is (iii), and its strength is (iv) than carbonic acid.

(a) Fill in the blanks with the appropriate substance names and words in the text.

(b) Under which of the following conditions is a chemical change observed? Select the appropriate letter, and name the gas generated.

A Mix sodium acetate and carbonated water.

B Add acetic acid to an aqueous sodium hydrogen carbonate solution.

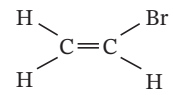
2. Fill in the blanks (i) to (vi) with the appropriate words in the following text. Also, choose the compounds A to E from the word bank below and write their structural formulas.

A, B, and C are open-chain (i) monocarboxylic acids. A shows a silver mirror reaction, but B and C do not. Also, C has a carboxyl group and a (ii) group in its molecule, and is a (iii) acid contained in yogurt, etc. Furthermore, C has one chiral carbon atom in its molecule, and (iv) isomers exist. On the other hand, D and E are open-chain (v) dicarboxylic acids. D and E are (vi) isomers of each other, and when D is heated, it undergoes dehydration to produce an acid anhydride, but such a change does not occur in E.

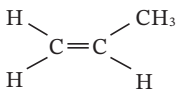
[Word group] Formic acid Maleic acid Acetic acid Fumaric acid Lactic acid

3. Which of the compounds **A** to **D** below yield a product with two chiral carbon atoms when iodine I_2 is added? Select all that apply.

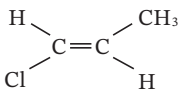
A



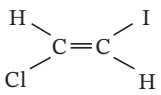
B



C



D



Exercise

Choose the correct answer:

1. A student adds sodium hydrogen carbonate to an unknown liquid. Gas bubbles are produced immediately. Which functional group is most likely present?

A. Hydroxyl group

B. Carboxyl group

C. Carbonyl group

D. Ether linkage

2. A bottle of vinegar is tested in the laboratory. Which carboxylic acid is mainly responsible for its acidic properties?

A. Formic acid

B. Acetic acid

C. Lactic acid

D. Fumaric acid

Answer the following question:

Chemistry in Society

Carboxylic acids and chiral molecules are essential in:

- Food preservation
- Medicine
- Biotechnology
- Agriculture
- Polymer production
- Sustainable chemical manufacturing

Understanding molecular structure allows scientists to design safer medicines, improve food quality, and develop environmentally friendly materials.

3. Choose the appropriate words corresponding to the blanks (i) to (v) in the text.

A compound having ((i) − CHO / − COOH) in the molecule is called a carboxylic acid. Acetic acid is a kind of carboxylic acid, its aqueous solution shows ((ii) basicity / acidity), and its strength is ((iii) stronger / weaker) than an aqueous solution of carbon dioxide (carbonic acid). Therefore, when ((iv) sodium hydrogen carbonate / sodium) is added to acetic acid, ((v) oxygen / carbon dioxide) is generated.

4. Read the following text and answer the questions below.

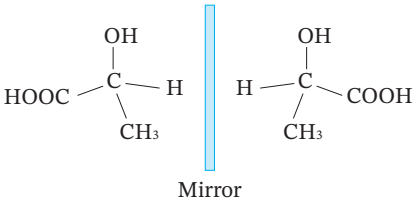
Because A contains a (i) group as well as a carboxyl group, it shows a (ii) property. This is why when A is added to an ammoniacal silver nitrate aqueous solution, (iii) precipitates.

Also, among unsaturated dicarboxylic acids with 4 carbon atoms, there are (iv) in the cis form and (v) in the trans form, which are cis-trans isomers of each other.

(a) Fill in the blanks with the appropriate words.

(b) Write the structural formulas of compounds A, (iv), and (v).

5. The figure on the right shows the isomers of lactic acid. Read the following text about lactic acid and answer the questions below.

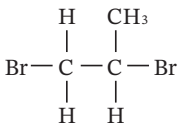


When a carbon atom is attached to four different atoms or groups of atoms, as seen in lactic acid, it is called an (i), and a pair of (ii) isomers exist. These (ii) isomers share almost identical melting points, densities, and general chemical properties, but they differ in their optical activity.

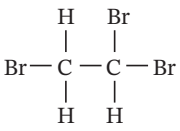
(a) Fill in the blanks with the appropriate words.

(b) Among the following A to D, identify which molecules have zero, one, and two chiral carbon atoms.

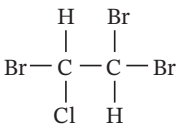
A



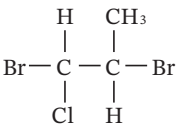
B



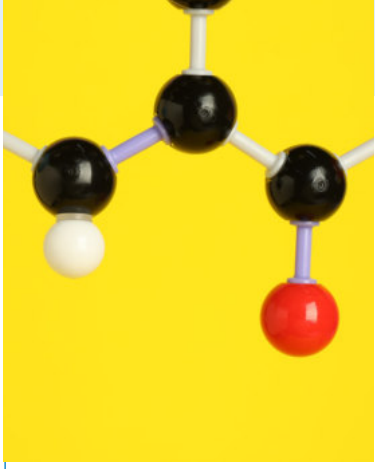
C



D



Lesson 4-10 — Esters



Engaging Introduction

Imagine walking into a bakery and noticing the pleasant smell of fresh pastries. Later that day, you peel an orange and enjoy its refreshing aroma. Surprisingly, many of these familiar scents come from the same family of compounds—esters.

These compounds are not only responsible for the fragrances of fruits and flowers but are also used in perfumes, paints, medicines, and even food flavorings.

In this lesson, we will explore how esters are formed, why they have unique properties, and how chemists use them in everyday life and industry.

Guiding Question How can one type of chemical reaction create substances that are useful in food, medicine, fragrances, and manufacturing?

Exploration

Observe the following products:

- Perfume
- Banana flavoring
- Nail polish remover
- Paint thinner

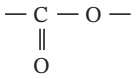
Discuss with a partner:

- What do these products have in common? .....
- Why do many pleasant smells come from similar types of molecules? .....
- How might chemists design compounds with different fragrances? .....

Point!

Esters

(a) **Ester**: A compound having an ester linkage.

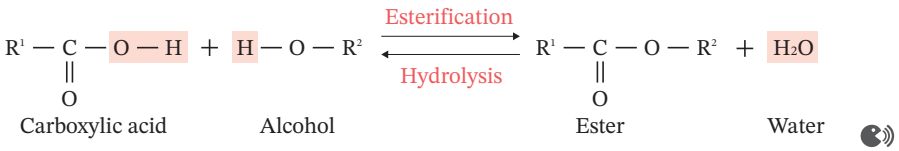


(b) Properties of esters

- Generally, **poorly soluble** in water and **soluble** in organic solvents.
- Esters with small molecular weights have a **fruity** fragrance.
- Used as fragrances and solvents.

(c) **Esterification**: A reaction in which a water molecule is removed from a carboxylic acid and an alcohol to produce an ester.

(d) **Hydrolysis**: The reverse reaction of esterification. When an ester is heated with dilute hydrochloric acid or dilute sulfuric acid, a carboxylic acid and an alcohol are produced.



structure of science

Key fact :

- Esters are responsible for many natural fruit aromas.
- Most esters are poorly soluble in water.
- Esterification is reversible.

Key concepts:

- Ester linkage
- Condensation reaction
- Hydrolysis
- Saponification
- Organic synthesis

Think Like a Chemist

Predict what will happen if:

- excess water is added
- concentrated sulfuric acid is removed
- the mixture is heated for a longer time

Explain your reasoning

……

(e) Mechanism of Esterification

Esterification was carried out using a carboxylic acid ($R^1 - COOH$) and an alcohol ($R^2 - {}^{18}OH$) enriched with the oxygen isotope ^{18}O (mass number 18). It was determined that the ^{18}O was incorporated into the resulting ester. This result indicates that the OH group is eliminated from the carboxylic acid and the H atom is eliminated from the alcohol to form water (H_2O). In this manner, the reaction mechanism was elucidated using an oxygen isotope.

(f) Various esters

(i) **Methyl acetate** CH_3COOCH_3

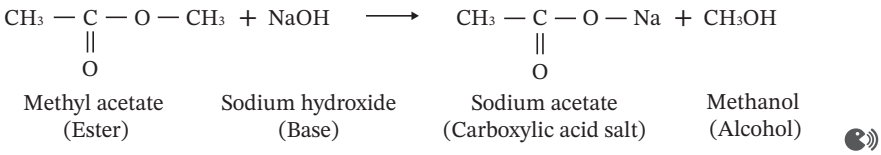
- Produced by the esterification of acetic acid and **methanol** .
- A colourless liquid, **poorly soluble** in water.

(ii) **Ethyl acetate** $CH_3COOC_2H_5$

- Produced by the esterification of acetic acid and **ethanol** .
- A colourless liquid, **poorly soluble** in water.
- Used as a solvent for paints and as a fragrance.

(g) **Saponification**: Hydrolysis of an ester by a base. Produces a carboxylic acid salt and an alcohol.

Example: When an aqueous sodium hydroxide solution is added to methyl acetate and heated, sodium acetate and methanol are produced.



Life Application

Chemists design synthetic esters with different molecular structures to control:

- fragrance intensity
- evaporation rate
- stability
- cost

This is why perfumes, cosmetics, shampoos, and air fresheners often contain specially designed esters.

Warm Up

Answer the following questions about the esters A, B, and C represented by the molecular formula $C_4H_8O_2$.

(a) When ester A was hydrolysed, an alcohol with a boiling point of 78°C and acetic acid were obtained. Write the structural formula and name of ester A.

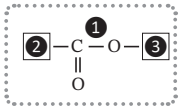
(b) When the carboxylic acid obtained by hydrolysing ester B was added to a test tube containing an ammoniacal silver nitrate aqueous solution, silver precipitated on the inner wall of the test tube. Also, when the alcohol obtained from B was oxidised, a

ketone was produced. Write the structural formula of ester B.

(c) When the alcohol obtained by hydrolysing ester C was oxidised, formaldehyde was produced. Also, when the obtained carboxylic acid was added to a test tube containing an ammoniacal silver nitrate aqueous solution, silver did not precipitate. Write the structural formula of ester C.

Explanation

(a) ❶ Write the ester bond.



❷ Since the carboxylic acid is acetic acid CH_3COOH, the structure excluding the carboxyl group is CH_3.

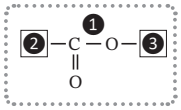
❸ The alcohol with a boiling point of 78°C is ethanol. For ethanol C_2H_5OH, the structure excluding the hydroxyl group is C_2H_5. Also, what produces ethanol and acetic acid upon hydrolysis is ethyl acetate.

$$CH_3 - \underset{\underset{O}{\|}}{C} - O - C_2H_5$$

Ethyl acetate is produced by the esterification of ethanol and acetic acid.

Name: Ethyl acetate.

(b) ❶ Write the ester bond.



❷ Since the carboxylic acid obtained by hydrolysis showed a silver mirror reaction, it is understood that it has a formyl group. Therefore, since the structural formula of the carboxylic

$$- \underset{\underset{O}{\|}}{C} - H$$

acid is understood to be , the structure excluding the carboxyl group is H.

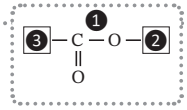
❸ Since the molecular formula is $C_4H_8O_2$, what connects to the oxygen atom is C_3H_7.

Since the alcohol obtained from B produced a ketone when oxidised, it is understood to be a secondary alcohol. Therefore, the hydroxyl group is originally bonded to the central carbon atom among the three.

Therefore, the desired structural formula is .

$$H - \underset{\underset{O}{\|}}{C} - O - \underset{\underset{CH_3}{|}}{CH} - CH_3$$

(c) ❶ Write the ester bond.



❷ Since the structure of the carboxylic acid is not determined, consider from the alcohol.

Since oxidising the alcohol obtained by hydrolysis produced formaldehyde, it is understood to be methanol CH_3OH. Therefore, the structure excluding the hydroxyl group is CH_3.

❸ Since the molecular formula is $C_4H_8O_2$, what connects to the carbon atom is C_2H_5.

$$H - \underset{\underset{O}{\|}}{C} - OH$$

This structure also applies to the fact that it does not show a silver mirror reaction.

$$C_2H_5 - \underset{\underset{O}{\|}}{C} - O - CH_3$$

Therefore, the desired structural formula is .

Interpreting Data

Compound	Water Solubility	Fruity Odor	Reacts with NaOH
Ethanol	High	No	No
Ethyl acetate	Low	Yes	Yes
Acetic acid	High	No	Yes

Questions

- Which compound is most likely the ester? .....
- Explain your answer using the data? .....

Sustainability Connection

Soap production illustrates one of chemistry's most important industrial reactions.

Modern industries aim to:

- reduce waste
- recycle raw materials
- replace hazardous solvents
- improve energy efficiency.

Try

1. Read the following text and answer the questions below.

A compound produced by removing a (a) molecule from a (b) group of a carboxylic acid and a (c) group of an alcohol is called an (d). For example, when a small amount of concentrated sulfuric acid is added to a mixture of acetic acid and ethanol and warmed, an (d) called (e) is produced. Such a reaction is called (f). Low molecular weight (d) compounds are volatile liquids with a (g)-like fragrance, and are highly soluble in { h water · organic solvents }.

(i) Fill in the blanks with the appropriate words or substance names in the text. Also, choose the correct one for { }.

(ii) Write a chemical equation for the reaction in the underlined part.

(iii) Write a chemical equation for the reaction that occurs when an aqueous sodium hydroxide solution is added to (e) and heated.

2. When an aqueous sodium hydroxide solution was added to ester A represented by the molecular formula $C_5H_{10}O_2$ and heated, and an acid was added to neutralize it, carboxylic acid B and alcohol C were obtained. Alcohol C is not easily oxidised. Carboxylic acid B is a colourless liquid and showed a reaction with an ammoniacal silver nitrate aqueous solution. Write the structural formula for A, and the structural formulas and names for B and C.

Think Critically

Claim

The oxygen atom in the ester originates from the alcohol

Evidence

The oxygen-18 isotope was detected in the ester product.

Reasoning

Your Reasoning is .....

Exercise

Choose the correct answer:

1- Why is esterification considered a condensation reaction?

A. It produces oxygen.
B. It removes water.
C. It forms carbon dioxide.
D. It breaks double bonds.

2. Which reaction is the reverse of esterification?

A. Combustion
B. Oxidation
C. Hydrolysis
D. Polymerization

Read the following text and answer the questions below.

3. When a small amount of concentrated sulfuric acid is added to a mixture of acetic acid and methanol and warmed, (a) is produced. This reaction is called (b) , and the oxygen atom of the water produced in the reaction is from acetic acid. (a) is lighter than water, is a liquid that is (c) in water, and has a fragrance.

(i) Fill in the blanks a to c with the appropriate words in the text.

(ii) Write a chemical equation for the reaction in the underlined part.

(iii) Name all substances produced when hydrochloric acid is added to (a) and heated. Also, name this reaction.

(iv) Write a chemical equation for the reaction that occurs when an aqueous sodium hydroxide solution is added to (a) and heated. Also, name this reaction.

……

4. Consider esters A to C represented by the molecular formula $C_5H_{10}O_2$. When they were hydrolysed, A became propionic acid and ethanol, and B became acetic acid and alcohol D. When an aqueous potassium dichromate solution was added to alcohol D, a ketone was produced. C became 2-butanol and carboxylic acid E, and E reacted with an ammoniacal silver nitrate aqueous solution. Answer the following questions.

(a) Write the structural formulas of the compounds A to E.

(b) Which of the compounds A to D show reducing properties? Select all appropriate letters.

(c) Which of the compounds A to E contain a chiral carbon atom? Select all appropriate letters.

……

Lesson 4-11 — Fats and Oils / Soap

Engaging Introduction

Imagine washing greasy dishes with only water. No matter how much you rinse, the grease remains stuck to the surface. However, the moment you add a small amount of dish soap, the grease suddenly disappears.

Now think about another everyday observation. Why is olive oil liquid at room temperature while butter remains solid, even though both are made from fats?

In this lesson, we will explore the chemistry of fats, oils, and soap, and discover how molecular structure determines their properties, uses, and importance in everyday life.

Guiding Question How does the molecular structure of fats, oils, and soaps determine their physical properties, biological roles, and industrial applications?

Exploration

Place a drop of cooking oil into a glass of water. No matter how long you wait, the oil forms a separate layer. Now add a few drops of liquid soap and gently stir. The oil breaks into tiny droplets and spreads throughout the water.

- Why does soap succeed where water fails? .....
- What is happening at the molecular level? .....

Point!

1. Fats and Oils

(a) **Fats and oils**: Esters of long-chain fatty acids and glycerin.

(b) **Classification of fats and oils**:

(i) Fat: Fats and oils that are solid at room temperature.

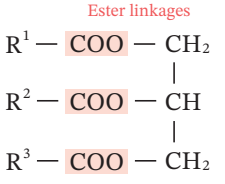
(ii) Fatty oil: Fats and oils that are liquid at room temperature.

- Drying oil: Fatty oils that are easily oxidised and solidify in the air.
- Hardened oil (Hydrogenated oil): Fatty oils made solid by adding hydrogen.

(c) **Structure and molecular weight of fats and oils**:

- One molecule of fat or oil contains 3 ester linkages. (Figure on the right).
- Molecular weight of fat/oil = **Sum of the molecular weights of 3 long-chain fatty acids + 38 Where 38 represents molecular weight of Gyserol -3H2O molecules**

⟨Structure of fats and oils⟩



Think as an Engineer

Food manufacturers often hydrogenate vegetable oils to improve shelf life.

What engineering advantages does hydrogenation provide? .....

What health trade-offs should engineers consider? .....

(d) **Saponification value and Iodine value**:

(i) Saponification value: The numerical value of the mass [mg] of potassium hydroxide

Structure of Science

Key Fact :

- Every fat molecule contains **three ester bonds**.
- Saturated fats contain **no C=C bonds**.
- Unsaturated fats contain **one or more C=C bonds**.

Key Concepts:

- Triglyceride
- Ester linkage
- Saturated fatty acid
- Unsaturated fatty acid
- Hydrogenation
- Saponification value
- Iodine value

KOH (formula weight 56) required to saponify 1 g of fat or oil.

The amount of potassium hydroxide KOH required to saponify 1 mol of fat or oil is **3** mol.

One KOH is required per one ester bond.

Therefore, if the average molecular weight of the fat or oil is M, Saponification value = $\frac{1}{M} \times 3 \times 56 \times 10^3$

(ii) **Iodine value:** The numerical value of the mass [g] of iodine I2 (molecular weight 254) that can be added to 100 g of fat or oil.

Iodine I_2 can be added as much as the number of **double bonds** between carbon atoms.

If the average molecular weight of the fat or oil is M and the number of double bonds between carbon atoms in one molecule is n, $\frac{1}{M} \times n \times 254$

Investigation

Investigate different cooking oils available at home.

Research:

- Which contain mostly saturated fats?.....
- Which contain unsaturated fats? .....
- Which are hydrogenated? .....

Predict which would have the highest iodine value.

Table 4-11-1: Fatty Acid Composition of Fats and Oils (wt%, per 100g edible portion)

fatty acid composition		Saturated Fatty Acids		Unsaturated Fatty Acids		
		Palmitic Acid	Stearic Acid	Oleic Acid	Linoleic Acid	Linolenic Acid
Chemical Formula		$C_{15}H_{31}-COOH$	$C_{17}H_{35}-COOH$	$C_{17}H_{33}-COOH$	$C_{17}H_{31}-COOH$	$C_{17}H_{29}-COOH$
Melting Point		63°C	71°C	13°C	−5°C	−11°C
Number of C = C Bonds		0	0	1	2	3
Fatty Oil	Sunflower Oil	6.2	4.2	20.2	66.9	0.3
	Soybean Oil	9.9	4	22	50	6.1
Fat	Beef Tallow	23	14	41	3.3	0.2

Data Interpretation Activity

Study the fatty acid composition table.

Which oil would you predict has:

- the highest iodine value?
- the lowest melting point?
- the greatest resistance to oxidation?

Support your conclusions using the data.

.....

2. Soap

(a) **Soap**: A sodium salt of a long-chain fatty acid, RCOONa, obtained by saponifying fats and oils with an aqueous sodium hydroxide solution.

(b) **Structure of soap**: Consists of a hydrophobic group (lipophilic group), which is a hydrocarbon group R −, and a hydrophilic group, − COO−. (Figure 4-11-1 on the right).

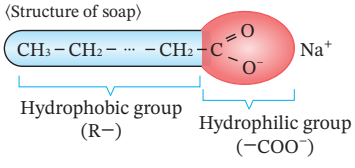


figure 4-11-1- ⟨Structure of soap

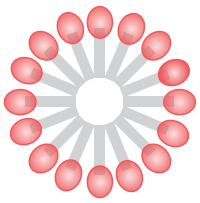
(c) **Surfactant**: A substance that has both a hydrophobic group and a hydrophilic group, like soap. They line up on the surface of water and lower its surface tension.

(d) **Emulsifying action**: The action in which the hydrophobic part of soap surrounds oil and disperses it in water.

(e) **Properties of soap**:

- Its aqueous solution is **weakly basic** .
- When the concentration in an aqueous solution exceeds a certain level, ions gather to form colloidal particles. These colloidal particles are called **micelles** . Figure 4-11-2 on the right
- In **hard water** containing a lot of Ca^{2} + and Mg^{2+}, it forms slightly soluble salts and loses its cleaning power.

〈Micelle〉



They line up with the hydrophobic group on the **inside** and the hydrophilic group on the **outside** .

Figure 4-11-2 〈Micelle〉

(f) **Synthetic detergent**: An artificially synthesized surfactant. Its aqueous solution is neutral, and it maintains its cleaning power even in hard water.

Life application

Warm water reduces the viscosity of oils and fats, making them easier for soap molecules to surround and remove. This is why greasy dishes are usually easier to clean with warm water than with cold water.

Warm Up

Answer the following questions.

(a) Answer the following questions about a fat/oil consisting of 2 molecules of oleic acid $C_{17}H_{33}COOH$ (relative molecular mass 282) and 1 molecule of palmitic acid $C_{15}H_{31}COOH$ (relative molecular mass 256) per molecule of fat/oil. (I_2 = 254, KOH = 56)

(i) Calculate the saponification value to the nearest integer.

(ii) Calculate the iodine value to three significant figures.

(b) Fill in the blanks with the appropriate words in the following text. When an aqueous sodium hydroxide solution is added to fat/oil and heated, it is (**A**), producing (**B**) and a sodium salt of a long-chain fatty acid. This sodium salt is called (**C**). (**C**) consists of a hydrophobic hydrocarbon group and a hydrophilic group of atoms. When (**C**) is dissolved in water, it forms colloidal particles with the hydrophobic part on the (**D**) side and the hydrophilic part on the (**E**) side. This is called a (**F**). When oil and (**C**) water are added and shaken well, the oil becomes fine droplets and disperses in water, forming an emulsion. Such an action of (**C**) is called an (**G**) action, and this is why oil stains are removed. Because (**C**) is a salt of a weak acid and a strong base, it partially hydrolyses in an aqueous solution, and the aqueous solution is (**H**).

(c) When soap is used in hard water, it does not lather well and its cleaning effectiveness decreases. Briefly explain the reason for this.

Explanation

(a) (i) Since Relative molecular mass of fat/oil = Sum of relative molecular masses of 3 long-chain fatty acids +38, the relative molecular mass is:

$282 \times 2 + 256 + 38 = 858$

Since Saponification value = $\frac{1}{M} \times 3 \times 56 \times 10^{3}$ (*M:* average molecular mass), the

saponification value is:

$\frac{1}{858} \times 3 \times 56 \times 10^3 = 195.8 \approx 196.$ Answer: 196

(ii) Iodine value = $\frac{100}{M} \times n \times 254$ (*M:* average molecular mass, *n*: number of double bonds)

When R of a long-chain fatty acid R − COOH has only single bonds, it is represented as $C_nH_{2n+1}COOH$.

For 15 carbon atoms, it is $C_{15}H_{31}COOH$, so palmitic acid has no double bonds. For 17 carbon atoms, it is $C_{17}H_{35}COOH$, so oleic acid has 2 fewer H atoms, meaning it has 1 double bond. Therefore, there are 2 double bonds per molecule of the fat/oil.

Therefore, the iodine value is:

$\frac{100}{858} \times 2 \times 254 = 59.20 \approx 59.2.$ Answer: 59.2

(b) **(A)** Saponification **(B)** Glycerin **(C)** Soap **(D)** Inside **(E)** Outside **(F)** Micelle **(G)** Emulsifying **(H)** Weakly basic

(c) Soap reacts with calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) present in hard water to form an insoluble precipitate called "scum" (metallic soap). Because the soap molecules are consumed to form this precipitate, they cannot function to lower the surface tension and remove dirt, resulting in poor lathering and reduced cleaning power.

Try

1. The mass [mg] of potassium hydroxide required to saponify 1 g of fat/oil is called the saponification value, and the mass [g] of iodine that adds to 100 g of fat/oil is called the iodine value. Answer the following questions.
(C = 12, H = 1.0, O = 16, K = 39, I = 127)

(a) A certain fat/oil has a structure in which 1 molecule each of stearic acid $C_{17}H_{35}COOH$, linoleic acid $C_{17}H_{31}COOH$, and linolenic acid $C_{17}H_{29}COOH$ are esterified to 1 molecule of glycerin. Find the molecular weight of this fat/oil.

(b) Calculate the saponification value of this fat/oil to the nearest integer.

(c) Calculate the iodine value of this fat/oil to three significant figures.

(d) Write one possible structure for this fat/oil using a structural formula.

2. Fill in the blanks with the appropriate words in the following text.

When fat/oil is saponified with an aqueous sodium hydroxide solution, a sodium salt of a long-chain fatty acid is obtained. This is (**A**), and its aqueous solution is weakly (B) due to hydrolysis. (**A**) has a (**C**) hydrocarbon group and a hydrophilic $-COO^-$, and gathers in an aqueous solution with the hydrocarbon groups on the (**D**) side. Oil attached to fibers is taken into this (**D**) side and becomes easier to disperse in water. This is called an (**E**) action. However, in (**F**) water with a lot of Ca^{2+} or Mg^{2+}, slightly soluble salts are produced, and the cleaning power decreases. Therefore, in synthetic detergents, salts consisting of strong acids and strong bases, such as sodium alkylbenzenesulfonate, are used.
Also, this aqueous solution is (**G**).

⚠ Misconception Alert

Common Misconception:

More soap does not always produce better cleaning.

In hard water, much of the soap reacts with calcium and magnesium ions before it can remove grease.

Be Global Citizen

Modern detergent manufacturers develop biodegradable surfactants that break down more easily in the environment, reducing water pollution and protecting aquatic ecosystems.
Green chemistry aims to design cleaning products that are both effective and environmentally friendly.

Exercise

Choose the Correct Answer

1. Which fat would most likely have the highest iodine value?
   (a) A fat containing only saturated fatty acids
   (b) A fat containing one double bond
   (c) A fat containing several double bonds
   (d) A hydrogenated fat

2. Which statement about saponification value is correct?
   (a) It increases as molecular mass increases.
   (b) It depends only on the number of double bonds.
   (c) It is higher for fats with lower molecular mass.
   (d) It measures the acidity of fats.

3. Answer the following questions about a fat/oil whose constituent fatty acid is only oleic acid $C_{17}H_{33}COOH$ (relative molecular mass 282) (I_2 = 254, KOH = 56)
   (a) Calculate the saponification value to the nearest integer.....
   (b) Calculate the iodine value to three significant figures.....
   (c) Write a possible structure for this fat/oil using a structural formula.....

4. Read the following text, choose the appropriate words for the blanks (i) to (viii) in the text from the options A to L below, and select the appropriate letters.

Fats and oils are important as food components, and together with carbohydrates and proteins, they are called the three major nutrients. Among fats and oils, those that are solid at room temperature are called (i), and those that are liquid at room temperature are called fatty oils. Among fatty oils, those containing many unsaturated fatty acids that easily solidify when left in the air are called (ii). Also, fatty oils made solid by adding hydrogen under a nickel catalyst are called (iii), and they serve as raw materials for margarine, etc. When an aqueous sodium hydroxide solution is added to fats and oils and heated, they are saponified to produce (iv) and sodium salts of fatty acids. The sodium salt of a fatty acid is called soap. Because soap has both hydrophilicity and hydrophobicity within its molecule, it has the property of lowering the surface tension of water. A substance that acts like this is called a (v). In water, soap particles arrange their hydrophobic parts on the inside and their hydrophilic parts on the outside to form spherical colloidal particles. Such particles are called (vi). When a small amount of oil is mixed into soapy water and stirred vigorously, the oil is surrounded by soap and disperses into the water. Such an action of soap is called (vii). However, in (viii) with a lot of Ca^{2+} or Mg^{2+}, slightly soluble salts are produced, and the cleaning power decreases.

A. Micelle	B. Hardened oil	C. Drying oil	D. Emulsifying action
E. Surfactant	F. Dispersion	G. Fat	H. Glycerin
I. Ethylene glycol	J. Soft water	K. Hard water	L. Pure water

Challenge Your Thinking

Two oils have the same molecular mass.
Oil A has three C=C bonds.
Oil B has one C=C bond.
Without calculation,
Which has the higher iodine value? .....
Explain .....

Lesson 4-12 — Aromatic Hydrocarbons

Engaging Introduction

Walk through a city street and you will encounter substances that all have something in common. The fuel used in cars, the plastic parts of electronic devices, the dyes in clothing, many medicines, perfumes, and even aspirin all contain compounds built around the same remarkable molecular structure: the benzene ring.

In this lesson, we will explore how the unique structure of aromatic hydrocarbons gives rise to their remarkable stability, reactions, and countless applications in science, technology, and industry.

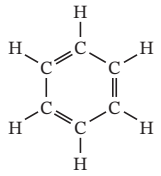
Guiding Question Why is the benzene ring exceptionally stable, and how does this stability influence its reactions and industrial importance?

Point!

1. Aromatic Hydrocarbons

(a) **Benzene**: A substance with a structure in which 6 carbon atoms are located at the vertices of a regular hexagon, and one hydrogen atom is bonded to each. The molecular formula is C_6H_6 .

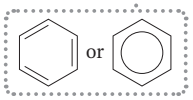
⟨Structure of benzene⟩



Note: All bonds between carbon atoms are in an intermediate state between a single bond and a double bond.

- The regular hexagonal carbon skeleton of benzene is called a **benzene ring** .
- The structural formula of benzene is often shown in an abbreviated form.

(b) Aromatic hydrocarbons: Hydrocarbons having a benzene ring.



Nature Phenomenon

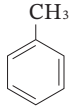
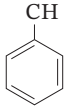
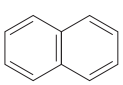
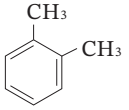
Many plants naturally produce aromatic compounds responsible for their characteristic scents. Examples include:

- Vanilla
- Cinnamon
- Cloves
- Wintergreen

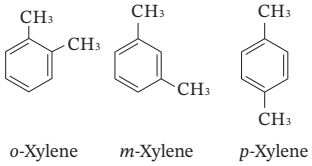
These natural aromatic compounds help plants attract pollinators or defend against insects.

(c) Examples of aromatic hydrocarbons other than benzene

Table 4-12-1 Examples of aromatic hydrocarbons other than benzene

Name	Toluene	Styrene	Naphthalene	o-Xylene
Structural formula				

- When there are 2 substituents on the benzene ring, such as in xylene, there are 3 types of structural isomers: *o*- (ortho-), *m*- (meta-), and *p*- (para-) depending on the positions of the substituents. (Figure 4-12-1 on the right)



o-Xylene *m*-Xylene *p*-Xylene

Figure 4-12-1 Isomers of xylene

Structure of Science

Key Fact :

- Every carbon atom in benzene is sp^2 hybridized.
- All C–C bonds have identical lengths.
- Benzene contains delocalized π electrons.
- Aromatic compounds prefer substitution rather than addition.

Key Concepts:

- Aromatic hydrocarbon
- Benzene ring
- Delocalized electrons
- Aromatic stability
- Substitution reaction
- Addition reaction
- Catalyst

2. Reactions of Benzene

(a) Substitution reactions • Because the benzene ring is stable, substitution reactions in which hydrogen atoms are replaced by other atoms or groups of atoms readily occur.

(i) Halogenation

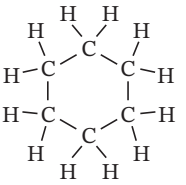
- Chlorination: When chlorine Cl_2 reacts with benzene using iron powder as a catalyst, **chlorobenzene** C_6H_5Cl is produced.
- Bromination: When bromine Br_2 reacts with benzene using iron powder as a catalyst, **bromobenzene** C_6H_5Br is produced.

(ii) Sulfonation: When concentrated sulfuric acid is added to benzene and heated, **benzenesulfonic acid** $C_6H_5SO_3H$ is produced.

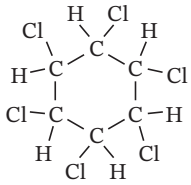
(iii) Nitration: When a mixture of concentrated sulfuric acid and concentrated nitric acid is added to benzene and heated, **nitrobenzene** $C_6H_5NO_2$ is produced.

(b) Addition reactions

- At high-pressure hydrogen H_2 reacts with benzene using nickel or platinum as a catalyst, **cyclohexane** C_6H_{12} is produced.
- When a mixture of benzene and chlorine is irradiated with ultraviolet rays, **1, 2, 3, 4, 5, 6-hexachlorocyclohexane** $C_6H_6Cl_6$ is produced.



Cyclohexane



1, 2, 3, 4, 5, 6-Hexachlorocyclohexane

(c) Oxidation reaction: When benzene is heated to a high temperature and reacted using vanadium(V) oxide V_2O_5 as a catalyst, maleic anhydride is produced.

Life Application

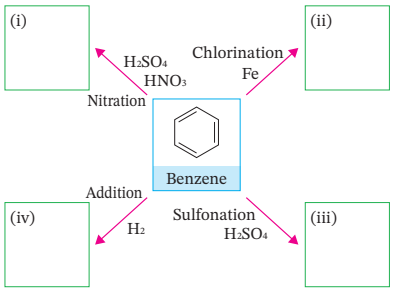
Many medicines—including aspirin, and some antibiotics—contain aromatic rings because their stable structures allow them to interact effectively with biological molecules.

Warm Up

Answer the following questions.

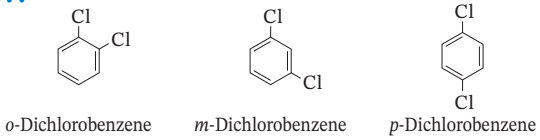
(a) Determine the number of isomers for the aromatic compounds represented by the following molecular formulas. (i) $C_6H_4Cl_2$ (ii) C_8H_{10}

(b) Provide the names and structural formulas corresponding to (i) to (iv) in the following figure.



Explanation

(a) (i)



o-Dichlorobenzene *m*-Dichlorobenzene *p*-Dichlorobenzene

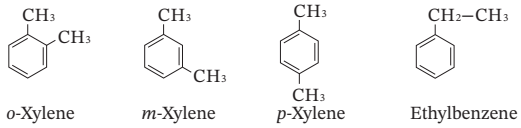
Therefore, there are 3 isomers.

(ii) In addition to the ortho (*o*-), meta (*m*-), and para (*p*-) positions, an isomer having

Be Global Citizen

Aromatic compounds contribute to advances in medicine and technology, but some, such as benzene, are hazardous pollutants. Responsible production and safe handling are essential for protecting both human health and the environment.

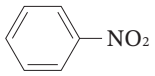
an ethyl group CH_3CH_2- also exists.



Therefore, there are 4 isomers.

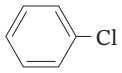
(b) (i) Name: Nitrobenzene

Structural formula:



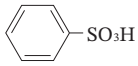
(ii) Name: Chlorobenzene

Structural formula:



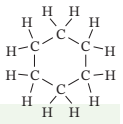
(iii) Name: Benzenesulfonic acid

Structural formula:



(iv) Name: Cyclohexane

Structural formula:



Think Critically

A student says:

"Ortho-, meta-, and para-xylene are different compounds.."

Evaluate the Claim

- Is this explanation fully accurate?

  .....

- What evidence supports or challenges it?

  .....

- What is the reasoning that support the evidence?

  .....

Try

Choose the correct answer:

1. Which pair represents positional isomers?

   (a) Benzene and cyclohexane **(b)** Ethane and ethene

   (c) Ortho-xylene and para-xylene **(d)** Benzene and toluene

2. Which statement best explains the stability of benzene?

   (a) It contains only single bonds.

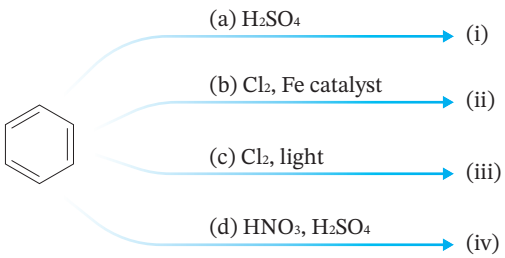
   (b) Its π electrons are delocalized around the ring

   (c) It contains triple bonds.

   (d) It has six separate double bonds.

3. Write all the structural formulas of the aromatic compounds represented by the molecular formula $C_6H_4Br_2$.

4. Answer the following questions about the figure below.



(a) Write the structural formulas and names of the compounds corresponding to (i) to (iv) in the figure.

(b) Name the reactions (a) to (d) in the figure.

Sustainability Connection

Modern chemical industries are developing greener catalytic processes that reduce energy consumption and waste during aromatic compound production.

Exercise

1. Write all the structural formulas of the isomers of the aromatic hydrocarbon represented by the molecular formula C_8H_{10}.

.....

2. Write the names and structural formulas for the organic compounds produced when the following operations **(a)** to **(d)** are performed on benzene. Also, choose the name of the reaction from A to E below and select the appropriate letter.

   (a) React benzene with chlorine using iron powder as a catalyst.

   (b) Add a mixture of concentrated nitric acid and concentrated sulfuric acid and warm.

   (c) React benzene with excess hydrogen using a nickel catalyst.

   (d) Add concentrated sulfuric acid and heat.

.....

.....

A. Halogenation	B. Nitration	C. Sulfonation
D. Oxidation	E. Addition reaction	

Challenge Your Thinking

Investigate common products at home that contain aromatic compounds.
Examples may include:

- perfumes
- detergents
- medicines
- plastics
- food flavorings

Classify each product according to its aromatic compound, if possible.

.....

Lesson 4-13 — Phenols and Aromatic Carboxylic Acids

Engaging Introduction

Every day, millions of people take medicines to relieve pain, reduce fever, or treat inflammation. One of the most widely used medicines in the world—aspirin—begins its story with a simple aromatic compound called phenol.

Surprisingly, a small change in the structure of phenol transforms it from a corrosive substance into compounds that improve human health and are used in medicine, cosmetics, and industry.

In this lesson, we will explore how phenols and aromatic carboxylic acids demonstrate the powerful relationship between molecular structure, chemical reactions, and real-world applications.

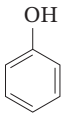
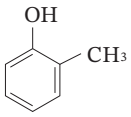
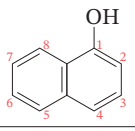
Guiding Question Why do phenols behave differently from alcohols even though both contain a hydroxyl (-OH) group?

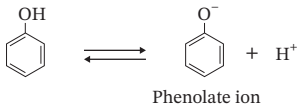
Point!

1. Phenols

(a) Phenols: Compounds in which a hydroxyl group − OH is directly bonded to a carbon atom of a benzene ring. (Table 4-13-1 on the right)

⟨Examples of phenols⟩

Name	Phenol	*o*-Cresol	1-Naphthol
Structure			



Phenolate ion

(b) Phenol and alcohols Phenol has a hydroxyl group, but it also shows different properties from alcohols.

(i) Similarities to alcohols

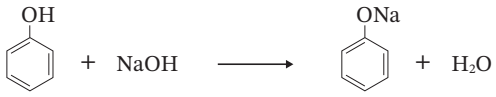
- Reacts with sodium to generate hydrogen .
- Reacts with acetic anhydride to produce an ester .

Nature Phenomenon

The bark of willow trees naturally contains compounds related to salicylic acid. For centuries, people used willow bark to relieve pain long before scientists understood its chemistry.

(ii) Differences from alcohols

- Partially ionises in an aqueous solution to produce H+, and the aqueous solution shows weak acidity .
- Neutralises with an aqueous sodium hydroxide solution to become sodium phenoxide .

Example: 

- Shows a purple colour reaction when an aqueous iron(III) chloride $FeCl_3$ solution is added.

Structure of Science

Key fact :

- Phenols contain an –OH group directly attached to a benzene ring.
- Phenols are more acidic than alcohols.
- Phenols react with NaOH but alcohols do not.
- Ferric chloride solution identifies phenolic compounds.

Key concepts:

- Phenol
- Aromatic alcohol
- Ferric chloride test
- Aromatic carboxylic acid
- Functional group

Think Critically

Claim

Phenols are chemically different from alcohols, even though both contain a hydroxyl group.

Evidence

Use at least two observations from the lesson.

1. …… 2. ……

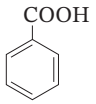
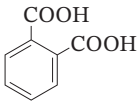
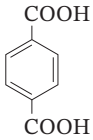
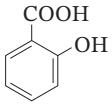
Reasoning

Explain how the presence of the benzene ring changes the behavior of phenols compared with alcohols. ……

2. Aromatic Carboxylic Acids

(a) **Aromatic carboxylic acids**: Compounds in which a carboxyl group − COOH is bonded to a carbon atom of a benzene ring. The aqueous solution shows **weak acidity**.

(b) **Various aromatic carboxylic acids**

Name	Benzoic acid	Phthalic acid	Terephthalic acid	Salicylic acid
Structure				
Manufacturing process	Oxidise **toluene** with an aqueous potassium permanganate solution.	Oxidise ***o*-xylene**.	Oxidise ***p*-xylene**.	Treat **sodium salicylate**, obtained by reacting sodium phenoxide with carbon dioxide, with dilute sulfuric acid.

Think as an Engineer

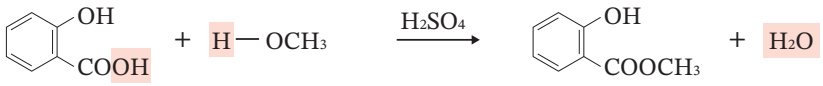
Engineers selecting materials for hospitals or laboratories must consider both chemical effectiveness and safety.

Why is understanding the acidity and reactivity of phenols important when designing disinfectants or antiseptic products?

……

(c) **Reactions of salicylic acid**

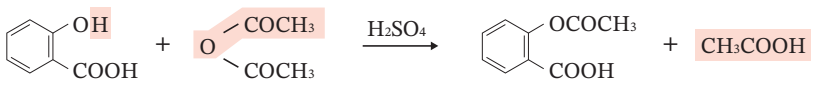
(i) **Methyl salicylate**: Produced when methanol react with salicylic acid in presence of Sulfric acid.



Salicylic acid Methanol Methyl salicylate Water

- Used as an anti-inflammatory analgesic.
- **Shows** a colour reaction with an aqueous iron(III) chloride solution. • Has a phenolic − OH.

(ii) **Acetylsalicylic acid**: Produced when acetic anhydride and concentrated sulfuric acid react with salicylic acid in presence of Sulfric acid.



Salicylic acid Acetic anhydride Acetylsalicylic acid Acetic acid

Note: A reaction introducing an acetyl group CH_3CO- in this way is called **acetylation**.

Misconception Alert

Common Misconception: Because phenol contains a hydroxyl (–OH) group, it behaves exactly like an alcohol.

Reality The benzene ring changes the electronic environment of the hydroxyl group, making phenol weakly acidic and giving it unique reactions, such as reacting with sodium hydroxide and producing a purple color with iron(III) chloride solution.

• Used as an antipyretic **analgesic**.

• **Does not show** a colour reaction with an aqueous iron(III) chloride solution.

Does not have a phenolic – OH group.

Appreciate Scientists

Scientists transformed the naturally occurring salicylic acid into acetylsalicylic acid (aspirin), reducing stomach irritation while preserving its pain-relieving properties. This discovery became one of the greatest achievements in medicinal chemistry.

Warm Up

Answer the following questions.

(a) For phenol and ethanol, choose all applicable descriptions from A to D below and select the appropriate letters.
(**A**) Reacts with an aqueous sodium hydroxide solution.
(**B**)The aqueous solution is neutral.
(**C**)Shows a colour reaction with an aqueous iron (III) chloride solution.
(**D**) Produces an aldehyde when oxidised.

(b) Write the name and structural formula of the carboxylic acid produced when toluene is oxidised.

(c) Answer the following questions about salicylic acid.
(i) Fill in the blanks (**A**) to (**C**) with the appropriate words in the following text.
Phenol is a substance with (**A**) properties, and dissolves in an aqueous sodium hydroxide solution to form (**B**).
When this reacts with (**C**) under heating and pressure, sodium salicylate is produced, and when it reacts with dilute sulfuric acid, salicylic acid is liberated.

(ii) Write the names and structural formulas of compounds A and B obtained by the following reactions.

$$\text{A} \xleftarrow[\text{Concentrated sulfuric acid}]{\text{Methanol}} \text{Salicylic acid} \xrightarrow[\text{Concentrated sulfuric acid}]{\text{Acetic anhydride}} \text{B}$$

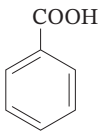
(iii) Which of Compound, A or B, gives a colour reaction with an aqueous iron(III) chloride solution? State the name of the substance and explain the reason for your choice.

Explanation

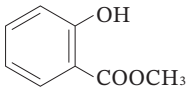
(a) Phenol: Phenol is neutralised by an aqueous solution of a base such as sodium hydroxide to form a salt. Also, when an aqueous iron (III) chloride solution is added, it shows a purple colour reaction. Therefore, A, C.

Ethanol: Ethanol is a primary alcohol, dissolves in water to show neutrality, and becomes an aldehyde when oxidised. Therefore, B, D.

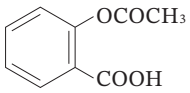
(b) Name: Benzoic acid Structural formula:



(c) (i) A: Weak acid B: Sodium phenoxide C: Carbon dioxide
(ii) A Name: Methyl salicylate Structural formula:



B Name: Acetylsalicylic acid Structural formula:



(iii) The colour reaction with an aqueous iron(III) chloride solution is a test used to detect phenolic compounds (structures in which a hydroxyl group is directly bonded to a benzene ring). Methyl salicylate shows a colour reaction because it

retains a phenolic hydroxyl group. Acetylsalicylic acid, on the other hand, does not show a colour reaction because the phenolic hydroxyl group of salicylic acid has been acetylated by acetic anhydride, changing it into an ester linkage (– $OCOCH_3$).

Interpreting Data

Study the table comparing phenol and ethanol.

Property	Phenol	Ethanol
Reacts with NaOH	✓	✗
$FeCl_3$ Test	Purple	No colour
Weak acidity	✓	✗

Questions

1. Which compound behaves as a weak acid?
   .....
2. Which observation confirms the presence of a phenolic group?
   .....
3. Explain why both compounds contain –OH but show different chemical behavior.
   .....

Try

1. For the following statements **(a)** to **(f)**, write A if it applies to phenol, B if it applies to ethanol, and C if it applies to both.

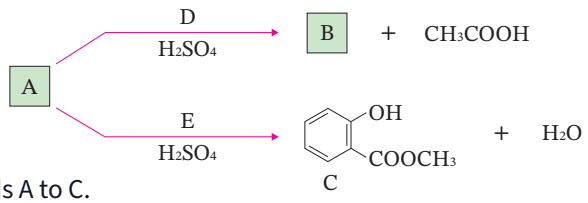
   (a) An aldehyde is produced upon gentle oxidation.
   (b) The aqueous solution shows weak acidity.
   (c) Reacts with an aqueous sodium hydroxide solution to form a salt.
   (d) Shows a purple colour with an aqueous iron (III) chloride solution.
   (e) Highly soluble in water.
   (f) Reacts with sodium to generate hydrogen.

2. Write the name and structural formula of the aromatic carboxylic acid produced when *p*-xylene is oxidised.

3. Read the following text and answer the questions below.

It has been known since ancient times that willow bark has an antipyretic effect, but in the mid-19th century, its active ingredient was found to be compound A. Later, compound B, in which the hydrogen atom of the hydroxyl group of A was substituted with an acetyl group, was synthesised and became the first synthetic drug with antipyretic and analgesic effects. On the other hand, compound C, in which the carboxyl group of A is esterified, is widely used in poultices for muscle pain, etc.

(a) The following figure shows the reaction pathway when synthesising B and C from A. D and E are reagents necessary for the reaction. Write the structural formulas of A and B, referring to the structural formula of C. Also, write the condensed structural formula of E.



(b) Name compounds A to C.

(c) Which of the compounds A to C show a colour reaction when added to an aqueous iron (III) chloride solution? Select all appropriate letters.

Exercise

Choose the Correct Answer

1.Which compound is used to manufacture aspirin?

(a) Ethanol **(b)** Methanol

(c) Salicylic acid **(d)** Phenol

2. Which reagent is commonly used to identify phenols?

(a) Bromine water **(b)** Sodium chloride

(c) Iron(III) chloride solution **(d)** Hydrochloric acid

3. For the sentences (a) to (c) below, choose all that apply from options A to H, and select the appropriate letters.

(a) Applies to ethanol, but does not apply to phenol.

(b) Applies to phenol, but does not apply to ethanol.

(c) Applies to both ethanol and phenol.

A. Highly soluble in water. B. Produces an aldehyde when oxidised.

C. Has − OH. D. The aqueous solution is basic.

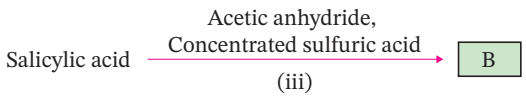
E. The aqueous solution is acidic. F. Reacts with a base to form a salt.

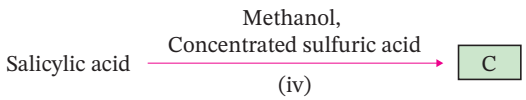
G. Forms an ester. H. Shows a colour reaction with an aqueous iron (III) chloride solution.

4. Read the following text and answer the questions below.

Salicylic acid is synthesised as follows.

Salicylic acid was actively used as a medicine, but because side effects when taken internally became a problem, compound B was developed. Also, compound C, which is used for topical applications, can be obtained from salicylic acid.





(a) Provide the chemical formulas for the substances in (i) and (ii), and name the reactions for (iii) and (iv).

(b) Name the compounds corresponding to A to C.

(c) Write the structural formulas of the compounds suitable for B and C.

Global Challenge

Modern medicine requires effective drugs with minimal side effects. If you were a pharmaceutical chemist, how could you modify the structure of salicylic acid to develop an improved medicine while maintaining its therapeutic effect?

Sketch or describe your idea.

Lesson 4-14 — Aromatic Amines and Azo Compounds

Engaging Introduction

Imagine wearing a brightly colored shirt, printing with vivid inks, or using a rapid medical test strip. Many of these technologies rely on compounds that were first developed from aniline, a simple aromatic amine.

More than 150 years ago, the accidental discovery of an aniline-based dye revolutionized the textile industry and launched the modern chemical industry. Today, related compounds are used in medicines, plastics, food analysis, medical diagnostics, and advanced materials.

Let's explore how aromatic amines transform into some of the most important compounds in modern chemistry.

Guiding Question

How can one simple molecule lead to colorful dyes, life-saving medicines, and advanced technologies?

Exploration

Look carefully at the following products:

- Colored fabrics
- Permanent markers
- Hair dye
- Printer ink
- Medical test strips
- Laboratory pH indicators

Think:

1. Which of these products depend on organic chemistry? .....
2. Why do some molecules appear brightly colored while others are colorless? .....
3. How might chemists intentionally design molecules with specific colors? .....

Point!

1. Aromatic Amines

(a) Aromatic amines: Compounds in which an amino group $-NH_2$ is directly bonded to a benzene ring.

(b) Aniline $C_6H_5NH_2$

(i) Manufacturing process of aniline: Produced when the nitro group of nitrobenzene is reduced to an amino group.

(ii) Properties of aniline

- A weakly basic liquid.
- Shows a red-purple colour when oxidised with an aqueous bleaching powder solution.
- Poorly soluble in water, but becomes soluble in water when neutralised with

Structure of Science

Key fact :

- Aromatic amines contain an $-NH_2$ group directly attached to a benzene ring.
- The simplest aromatic amine is aniline.
- Aromatic amines behave as weak bases.

Key concepts:

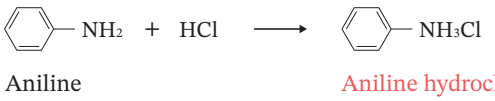
Aromatic amines
amino group

Azo compounds
Diazonium salts
Diazotization
Diazocoupling

an acid to form a salt.

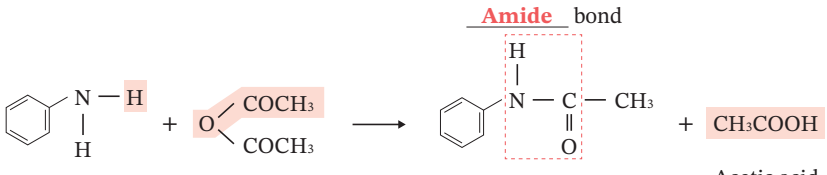
(iii) Reactions of aniline

- When added to hydrochloric acid, it produces **aniline hydrochloride** and dissolves well.



Aniline — Aniline hydrochloride

- When it reacts with acetic anhydride, **acetylation** occurs, and **acetanilide** is produced.



Aniline — Acetic anhydride — Acetanilide — Acetic acid

Inquiry-Based Learning

A chemist wants to manufacture a bright orange textile dye.
Which sequence of reactions would most likely be required?
A. Benzene → Cyclohexane → Ethanol
B. Nitrobenzene → Aniline → Diazonium salt → Azo dye
C. Methane → Ethanol → Acetic acid
Explain your reasoning
……

2. Azo Compounds

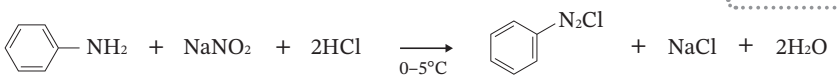
(a) Azo compounds: Compounds having an **azo group** – N = N – in the molecule.

(b) Diazonium salts: Salts having the structure R – $N^+ \equiv N$.

(c) **Diazotization**: A reaction that produces a diazonium salt.

- When aniline is dissolved in hydrochloric acid and mixed with an aqueous sodium nitrite $NaNO_2$ solution, **benzenediazonium chloride** is produced.

Benzenediazonium chloride is a diazonium salt.



Benzenediazonium chloride

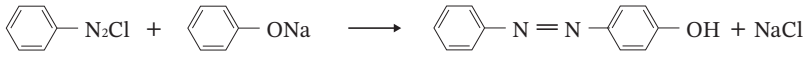
Note: This reaction is carried out under cooling.

〈**Reason**〉 **Because benzenediazonium chloride easily decomposes when the temperature rises.**

(d) **Diazocoupling**: A reaction that produces an azo compound from a diazonium salt.

- When an aqueous sodium phenoxide solution is added to an aqueous benzenediazonium chloride solution, an orange-red ***p*-hydroxyazobenzene** (***p*-phenylazophenol**) is produced.

p-Hydroxyazobenzene is an azo compound.



Benzenediazonium chloride — Sodium phenoxide — *p*-Hydroxyazobenzene (*is an azo compound*)

Think as an Engineer

An industrial company wants to manufacture aniline safely on a large scale.
As a chemical engineer, suggest:

- methods to control temperature,
- safe storage procedures,
- waste treatment,
- worker protection,
- environmental monitoring.

How would your design reduce industrial risks?

……

Life Application

Aromatic amines are widely used in:

- pharmaceutical manufacturing
- rubber production
- plastics
- antioxidants
- photographic chemicals
- dyes
- agricultural chemicals

Warm Up

Answer the following questions.

(a) When acetic anhydride reacts with aniline, acetanilide is produced. Acetanilide was obtained by reacting aniline with an excess amount of acetic anhydride. Answer the following questions.

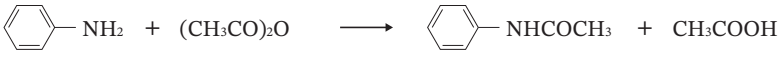
(i) Write a chemical equation for the reaction between aniline and acetic anhydride.

(ii) Acetanilide has an − NH − CO − bond. Name this bond.

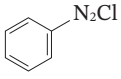
(b) Name the substance produced when an aqueous sodium nitrite $NaNO_2$ solution is added to a dilute hydrochloric acid solution of aniline while cooling with ice, and write its structural formula.

(c) Name the substance produced when benzenediazonium chloride reacts with a mixed aqueous solution of phenol and sodium hydroxide, and write its structural formula.

Explanation

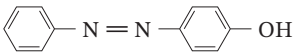
(a) (i) 

(ii) Amide bond

(b) 

(n) When phenol is added to an aqueous sodium hydroxide solution, sodium phenoxide is formed, so it reacts with benzenediazonium chloride.

Name: *p*-Hydroxyazobenzene (*p*-Phenylazophenol)

Structural formula: 

Interpreting Data

A student measures the stability of benzenediazonium chloride at different temperatures.

Questions

1. Describe the trend? .....
2. Why must diazotization be performed under cooling? .....
3. Predict what would happen if the reaction were performed at 40°C.

.....

Temperature (°C)	Stability
0	Very stable
5	Stable
15	Slowly decomposes
25	Rapid decomposition

Try

Answer the following questions about aniline.

Aniline is obtained when the (A) group of nitrobenzene is (B) to an (C) group using tin and hydrochloric acid. Aniline is a (D) compound and is (E) in water. (i)When hydrochloric acid is added to aniline, it is neutralized to form (F), which is (G) in water. Also, (ii)when aniline reacts with acetic anhydride, it undergoes (H) to produce (I), which contains an (J) bond.

(a) Fill in the blanks with the appropriate words or compound names in the text.

(b) Write a chemical equation for the reaction in the underlined part (i).

(c) Write a chemical equation for the reaction in the underlined part (ii).

(d) Name the compound produced when an aqueous sodium nitrite solution is added to the aqueous solution of underlined part (i) while cooling.

(e) What is the reaction in **(d)** called?

(f) Write the structural formula for the compound produced when an aqueous sodium phenoxide solution is added to the product of **(d)**.

Challenge Your Thinking

Why are azo compounds usually brightly colored while benzene itself is colorless?

Use your understanding of:

- conjugated systems,
- electron delocalization,
- absorption of visible light

Exercise

Choose the correct answer:

1- Which reaction converts aniline into a diazonium salt?

A. Hydrogenation
B. Diazotization
C. Esterification
D. Hydrolysis

2. The bright color of azo compounds mainly results from

A. ionic bonding
B. conjugated π-electron systems
C. hydrogen bonding
D. saturated carbon chains

Read the following text and answer the questions below:

3. Aniline reacts with acetic anhydride to produce (A), which has an antipyretic effect. This reaction is called the (I) of aniline. Also, after aniline is dissolved in hydrochloric acid, (ii) when an aqueous sodium nitrite solution is added while cooling with ice, (B) is produced. This reaction is called (II). When phenol is dissolved in an aqueous sodium hydroxide solution and added to the aqueous solution of (B), (III) occurs, and an orange-red compound, (C), is produced.

(a) Name the reactions corresponding to the blanks (I) to (III) in the text.

(b) Write the structural formulas for the compounds corresponding to the blanks A to C in the text.

(c) In the molecule of the compound corresponding to blank C, − N = N − exists. Name this functional group.

(d) Write a chemical equation for the reaction in the underlined part (i).

(e) Explain why the reaction in the underlined part (ii) is carried out under cooling.

Grand Challenge

Scientists are trying to replace traditional azo dyes with environmentally friendly alternatives.

Design a new dye that:

- is brightly colored,
- is biodegradable,
- does not release toxic aromatic amines,
- is inexpensive to manufacture.

What chemical properties would your molecule require?

……

Lesson 4-15 — Separation of Aromatic Compounds

Engaging Introduction

Imagine you are a forensic chemist investigating a suspicious liquid recovered from a laboratory. Analysis shows that it contains four different aromatic compounds mixed together. Before identifying each compound, you must first separate them without changing their chemical structures.

In this lesson, we will explore how chemists use differences in solubility and acid–base properties to separate aromatic compounds efficiently and accurately.

Guiding Question How can chemists separate compounds that look similar but have different chemical properties?

Exploration

A mixture contains:

• Aniline • Phenol • Salicylic acid • Nitrobenzene

Without using chromatography or distillation:

• Which compound would dissolve in dilute hydrochloric acid?.....

• Which would react with sodium hydrogen carbonate?.....

• Which would remain unchanged?.....

• Write your predictions before studying the separation procedure?.....

Point!

Separation of Aromatic Compounds

(a) **Separation experiment**: By using a separating funnel and dividing into an aqueous layer and an organic solvent layer such as diethyl ether (ether layer), compounds can be separated. (Figure 4-15-1 on the right)

- Substances highly soluble in water move to the **aqueous layer** .
- Substances highly soluble in organic solvents move to the **ether layer** .

(b) **Properties of aromatic compounds**:

Between water and organic solvents, they are highly soluble in **organic solvents** .

(c) **Separation by neutralisation reaction**:

When they become salts through a neutralisation reaction, they become highly soluble in **water** .

- Acids react with a **base** to form a salt.
- Bases react with an **acid** to form a salt.
- Neutral substances do not react with either acids or bases.

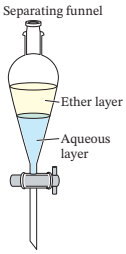


Figure 4-15-1
seperation experiment

Investigation

Research Question.

How does changing the pH affect the solubility of aromatic compounds?

Investigate:

• Which compounds become salts? .....

• Which remain neutral? .....

• Which layer (aqueous or ether) each compound occupies after each treatment?

.....

Construct a separation flowchart based on your observations.

Structure of Science

Key Fact :

- Aromatic compounds generally dissolve better in organic solvents than in water.
- Acid–base reactions can convert neutral molecules into water-soluble salts.
- Separating funnels allow efficient liquid–liquid extraction.

Key Concepts:

- Organic solvents
- Hydrochloric acid
- Neutral substances

(d) Separation by liberation of weak acids and weak bases:

• A salt of a weak acid reacts with an acid **stronger** than it to liberate the weak acid.

⟨Acid strength⟩

Hydrochloric acid , Sulfuric acid > Sulfonic acids > **Carboxylic acids** > **Carbonic acid** > **Phenols**

• A salt of a weak base reacts with a base **stronger** than it to liberate the weak base.

Aqueous sodium hydroxide solution > **Aniline**

⟨Base strength⟩

Think as an Engineer

A pharmaceutical company must separate valuable organic compounds from industrial waste with minimal environmental impact.

Design a separation process that:

- minimizes solvent use,
- allows solvent recycling,
- reduces chemical waste,
- maximizes product recovery.

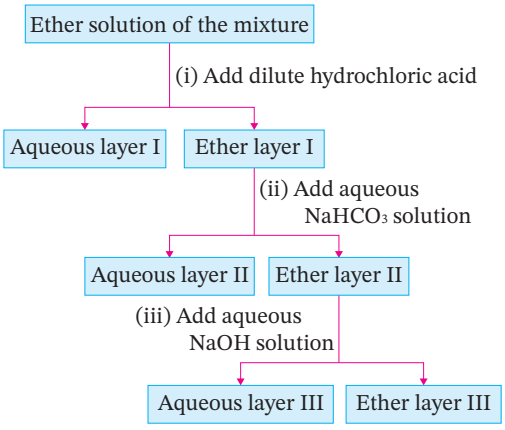
How would your design improve industrial sustainability?

Warm Up

The figure shows the procedure for separating each compound from an ether solution containing a mixture of aniline, salicylic acid, nitrobenzene, and phenol. Answer the following questions.

(a) Write the structural formulas of the aromatic compounds contained in aqueous layers I to III.

(b) Briefly describe the change that occurs when an aqueous sodium hydroxide solution is added to aqueous layer I.

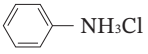


Explanation

(a) Since all 4 substances are aromatic compounds, they are dissolved in the ether solution. Also, their respective properties are: aniline is weakly basic, salicylic acid is weakly acidic, nitrobenzene is neutral, and phenol is weakly acidic.
Verify the reactions in order.

Aqueous layer I: Since the dilute hydrochloric acid added in (i) is strongly acidic, the basic aniline is neutralised to form a salt, which dissolves in water and moves to the aqueous layer. Therefore, aqueous layer I contains aniline hydrochloride.

The structural formula is:



Chemistry in Everyday Life

Extraction techniques similar to those in this lesson are used to:

- isolate caffeine from tea,
- purify medicines,
- remove pollutants from wastewater,
- analyze forensic evidence,
- produce fragrances,
- recover natural products from plants.

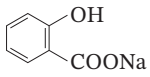
Be Global Citizen

Many organic solvents used in extraction are hazardous to human health and the environment. Modern chemistry promotes:

- greener solvents,
- solvent recycling,
- waste reduction,
- safer laboratory practices

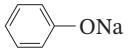
Aqueous layer II: Since the $NaHCO_3$ added in (ii) is a salt of carbonic acid, it reacts with stronger acids. Of salicylic acid and phenol, the acid stronger than carbonic acid is salicylic acid, which is an aromatic carboxylic acid, so salicylic acid becomes a salt and moves to the aqueous layer. Therefore, aqueous layer II contains sodium salicylate.

The structural formula is:



Aqueous layer III: Since the aqueous sodium hydroxide NaOH solution added in (iii) is strongly basic, it neutralises the acidic phenol from the nitrobenzene and phenol remaining in the ether layer to produce a salt. Therefore, aqueous layer III contains sodium phenoxide.

The structural formula is:



(b) When sodium hydroxide, a strong base, is added to aniline hydrochloride, a salt of a weak base, aniline is liberated. Liberation of a weak base

Aniline is liberated.

Interpreting Data

Step	Reagent Added	Compound Removed
I	Dilute HCl	Aniline
II	$NaHCO_3$	Salicylic acid
III	NaOH	Phenol
Remaining	Ether layer	Nitrobenzene

Think Like a Chemist

Questions

1. Why is hydrochloric acid added first?

……

2. Why doesn't sodium hydrogen carbonate remove phenol?

……

3. Why is nitrobenzene left in the ether layer?

……

4. Predict what would happen if NaOH were added first.

……

Try

Read the following text and answer the questions below.

1. Consider a diethyl ether solution containing dissolved phenol, aniline, salicylic acid, and nitrobenzene.

Operation I: Add 5% aqueous sodium hydrogen carbonate solution and shake well to obtain aqueous layer I and ether layer I.

Operation II: After separating aqueous layer I and ether layer I, add 2 mol/L aqueous sodium hydroxide solution to ether layer I and shake well to obtain aqueous layer II and ether layer II.

Operation III: After separating aqueous layer II and ether layer II, add A to ether layer II and shake well to obtain aqueous layer III and ether layer III.

(a) Choose one suitable reagent for A from options a to d below.

a. 10% aqueous sodium chloride solution

b. 2 mol/L hydrochloric acid

c. 2 mol/L aqueous sodium hydrogen carbonate solution

d. 0.1 mol/L aqueous sodium hydroxide solution

(b) Write the structural formulas of the organic compound salts dissolved in aqueous layers I to III.

(c) Fill in the blanks (i) to (iv) with the appropriate structural formulas in the following text.

When enough dilute hydrochloric acid was added to aqueous layer I, a white solid (i) precipitated. When enough carbon dioxide was passed through aqueous layer II, (ii) was obtained. When enough an aqueous sodium hydroxide solution was added to aqueous layer III, (iii) was obtained. When ether layer III was evaporated, an oily liquid, (iv), remained.

Exercise

Choose the correct answer:

1. Which compound remains in the ether layer after sodium hydrogen carbonate is added?

(a) Salicylic acid **(b)** Aniline hydrochloride

(c) Nitrobenzene **(d)** Sodium salicylate

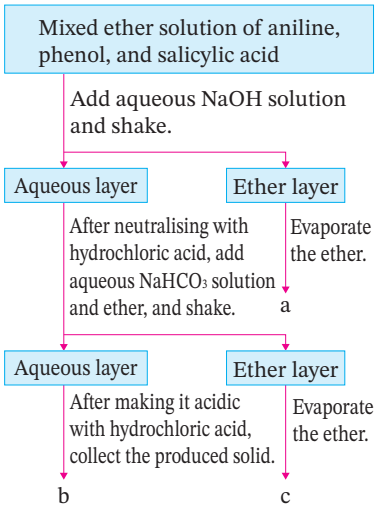
2. Why is sodium hydroxide added after sodium hydrogen carbonate?

(a) It is a stronger oxidizing agent. **(b)** It converts phenol into a soluble salt.

(c) It evaporates the solvent. **(d)** It neutralizes nitrobenzene.

Answer the Following Questions

3. Consider a solution containing aniline, phenol, and salicylic acid dissolved in diethyl ether. Each component of this mixed solution was separated by the operations as shown in the figure on the right. Answer the following questions.



(a) Write the structural formulas for the compounds a to c in the figure.

(b) Choose the reagent that reacts with only one of the compounds a to c from options A to D below, and select the appropriate letter.

A. Fehling's solution

B. Bleaching powder

C. Aqueous iron(III) chloride solution

D .Iodine and aqueous sodium hydroxide solution

(c) If toluene was also contained in the initial mixed solution, where among a to c in the figure would toluene be separated? Select the appropriate letter.

Challenge Your Thinking

Suppose the mixture also contained benzoic acid.

Would the same separation sequence still work?

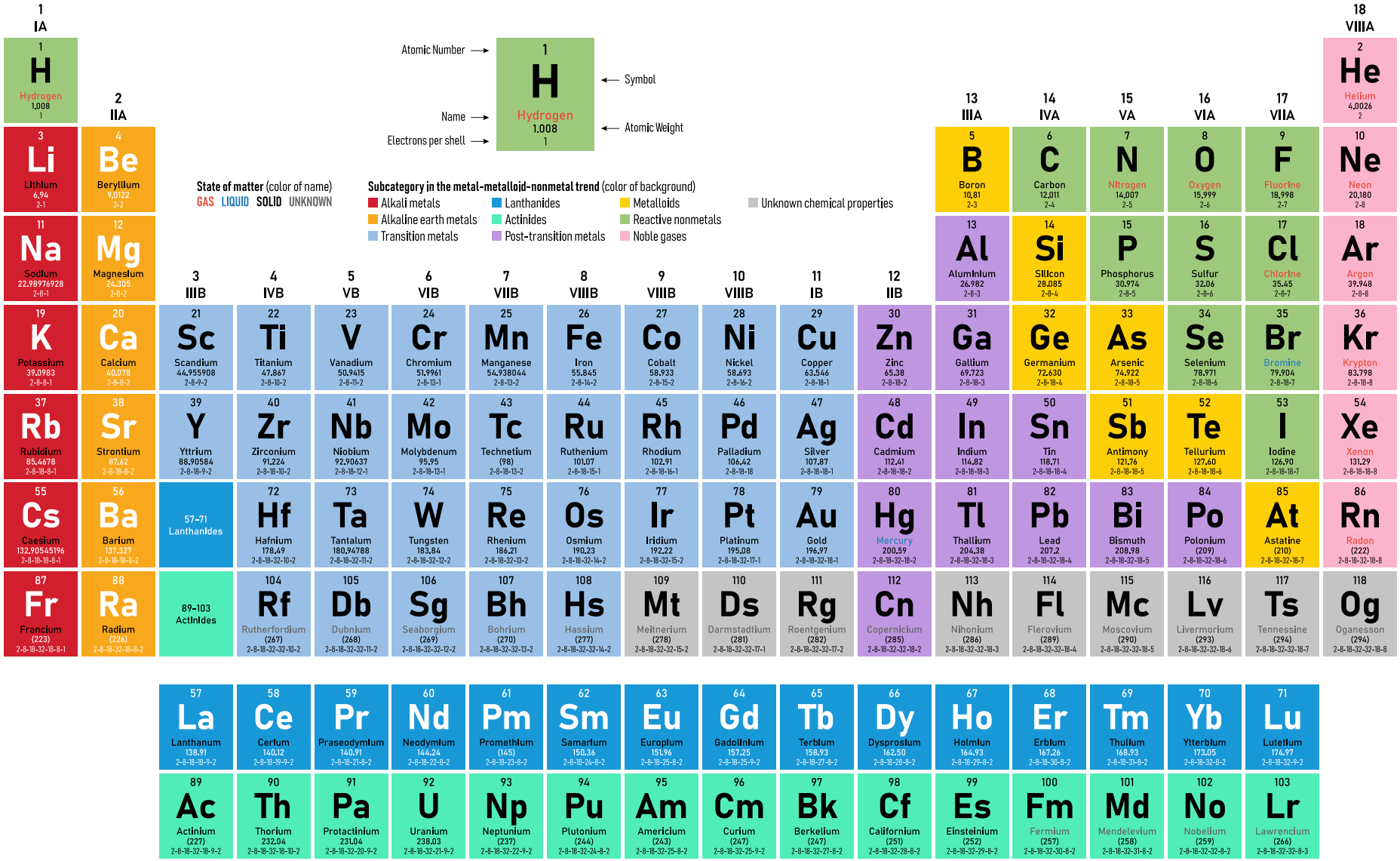
If not,

Examples may include:

• what would change? • which reagent should be added first?

• why? .....

Periodic Table of the Elements



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