2.2 LAWS OF STOICHIOMETRY

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Learning outcomes

By the end of this chapter, Students should be able to:

State and explain the laws of stoichiometry, viz:

- law of conservation of mass,
- law of constant proportion,
- law of multiple proportions,
- law of reciprocal proportions, and
- the law of gaseous volume.

Apply these laws in simple numerical problems

Introduction

Have you ever wondered:

- Why does a glass of water from any source – river, rain, or tap – always contain hydrogen and oxygen in the **same mass ratio**?
- Why do chemical reactions produce predictable amounts of products every time?

These questions puzzled early chemists for centuries. The answers lie in the **laws of stoichiometry**

Stoichiometry is the branch of chemistry that deals with the **mass (weight) relationship that prevails in chemical compounds and chemical reactions**.

The laws of stoichiometry were established through careful experiments carried out by scientists in the 18th and 19th centuries. These laws laid the foundation for modern chemical calculations and the atomic theory.

There are five laws of stoichiometry.

1. Law of conservation of mass

Proposed by M.V. Lomonosov (1756); established experimentally by Antoine Lavoisier (1774)

Statement:

It may be stated as "in a chemical reaction, the total mass of reactant consumed is equal to the total mass of the products."

In simple words:

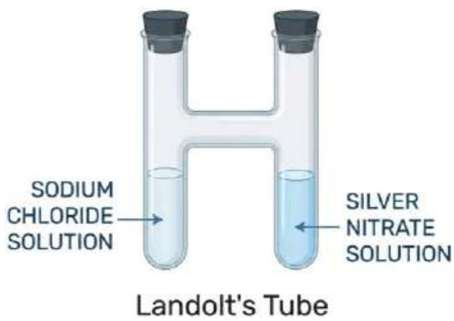
- Mass remains constant during a chemical reaction.
- Atoms only rearrange themselves.
- No atoms are lost or newly created.

Experimental Illustration:

The law was demonstrated experimentally using an **H-shaped tube**, known as **Landolt's tube**.

Experiment

- One limb of the tube contains sodium chloride solution (NaCl).
- The other limb contains silver nitrate solution ($AgNO_3$).



- The tube is sealed and weighed carefully.

The solutions are then mixed by inverting the tube.
A white precipitate of silver chloride is formed.
The reaction is:

$$AgNO_3(aq.) + NaCl\ (aq.) \longrightarrow \underset{\textit{White ppt.}}{AgCl\ (aq.)}\downarrow + NaNO_3\ (aq.)$$

- Mass before reaction = Mass after reaction

This proves that mass is conserved during the reaction.
Explanation: In a chemical reaction:

- atoms are neither created nor destroyed,
- They only rearrange to form new substances.

Therefore, the total mass remains unchanged.

The law of conservation of mass can also be called **the law of indestructibility of matter.** As mass remains unchanged after the reaction, though matter may change its form, it cannot be destroyed during the chemical reaction.
Importance of the Law: The law of conservation of mass is important because it:

- forms the basis of chemical equations,
- helps in stoichiometric calculations,
- supports the atomic theory,
- is used in industrial chemical processes.

2. Law of constant proportions

(also called Definite proportions/ constant composition) Louis Prout (1799)

Statement:

The same chemical compound always contains the same elements combined in the definite proportion by mass, irrespective of its source or method of preparation."

This means:

- *every sample of a compound has the same composition,*
- *the ratio of elements by mass is always constant.*

Illustration:

Copper oxide can be prepared by heating copper nitrate, copper carbonate, or copper hydroxide.

A fixed mass of copper oxides produced from the different compounds is heated in a current of hydrogen.

$CuO+H_2 \rightarrow Cu+H_2O$

Copper and water thus produced can easily be separated and weighed. The mass of oxygen is determined.

The ratio of Cu to O by mass in all samples will be nearly equal to 4:1. This illustrates the law of constant composition.
Importance of the Law: *This law:*

- *distinguishes compounds from mixtures,*
- *supports Dalton's atomic theory,*
- *helps determine chemical formulas,*

3. Law of multiple proportions

(John Dalton, 1803)

Statement:

When two elements combine to form more than one compound, the ratio by mass of one of the elements that combines with a fixed (constant) weight of another is a simple whole number ratio.

Illustration:

Phosphorus reacts with oxygen to produce phosphorus trioxide and phosphorous pentoxide.

In phosphorous trioxide (P_2O_3),

31x2 parts by weight of P combine with 16x3 parts by weight of oxygen.

In phosphorous pentoxide (P_2O_5),

31x2 parts by weight of P combine with 16x5 parts by weight of oxygen.

Therefore, the ratio by wt. of oxygen that combines with fixed (31x2 parts) wt. of phosphorous is,

16x3:16x5 = 3:5

This is a simple ratio in whole numbers.

4. Law of Reciprocal Proportions/Equivalent Proportions

J. B. Reichter 1792

Statement:

When two elements combine separately with the same mass of a third element, the ratio of their masses is the same as or a simple multiple of the ratio in which they combine with each other.

Illustration:

Oxygen and hydrogen react separately with carbon to give CO_2 and CH_4, respectively. Oxygen combines with hydrogen to give water.

In CO_2, 12 parts by wt. of C combine with 32 parts by wt. of O.

In CH_4, 12 parts by wt. of C combine with 4 parts by wt. of H.

The ratio by wt. of O to H that combine with a constant (12 parts) wt. of C is

32:4 = 8:1

In H_2O, 16 parts by wt. of O combine with 2 parts by wt. of H.

The ratio by wt. of O to H that combine with each other is 16:2 = 8:1

The two ratios are the same; this illustrates the law of equivalent proportions.

5. Gay-Lussac's Law of Gaseous Volume

(J.L. Gay Lussac, 1805)

📜 **Statement:**

Whenever gases react, their volumes bear a simple ratio to one another and the volumes of products if they are also gases under similar temperature and pressure conditions.

🧪 **Illustration: Formation of Ammonia**

$N_2 (g) + 3 H_2 (g) \rightarrow 2 NH_3 (g)$

Volume ratio: 1:3:2

Thus: 1 volume of nitrogen reacts with

- 3 volumes of hydrogen to form
- 2 volumes of ammonia gas.

Importance of the Law: *This law:*

- *supports Avogadro's hypothesis,*
- *helps determine molecular formulas of gases,*
- *is useful in industrial gas reactions.*

These laws form the foundation of:

- chemical equations,
- mole concept,
- atomic theory,
- quantitative chemistry.

Understanding these laws is essential for mastering stoichiometry and further chemistry topics.

Key Takeaways

- Stoichiometry = mass relationships in chemistry.
- Five laws govern how elements combine and react.
- These laws laid the groundwork for the atomic theory and the mole concept.
- They are still used today in chemical calculations, industrial processes, and analytical chemistry.

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***** This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material. *****