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Law of Multiple Proportions

The law of multiple proportions states that when two elements combine to form more than one compound, the masses of one element that combine with a fixed mass of the other are in ratios of small whole numbers.

Example:

Consider carbon monoxide (CO) and carbon dioxide (CO₂). Both compounds consist of carbon and oxygen. In carbon monoxide, 12 grams of carbon combine with 16 grams of oxygen. In carbon dioxide, 12 grams of carbon combine with 32 grams of oxygen. The ratio of the masses of oxygen that combine with a fixed mass of carbon (12 grams) is 16:32, which simplifies to 1:2, a small whole number ratio.

Numerical Problem:

If 20 grams of element A combine with 40 grams of element B to form compound AB, and 20 grams of element A combine with 80 grams of element B to form compound AB₂, show that this follows the law of multiple proportions.

Solution:

For AB: 20 grams A : 40 grams B = 1 : 2

For AB₂: 20 grams A : 80 grams B = 1 : 4

The ratio of the masses of element B combining with a fixed mass of element A (20 grams) is 2:4, which simplifies to 1:2, a small whole number ratio.

Law of Definite Proportions

The law of definite proportions states that a chemical compound always contains the same elements in exactly the same proportions by weight or mass.

Example:

Water (H₂O) always consists of 2 parts hydrogen and 16 parts oxygen by mass. Regardless of the source or the amount of water, the ratio of hydrogen to oxygen by mass is always 1:8.

Numerical Problem:

Calculate the mass of hydrogen in 90 grams of water.

Solution:

The molar mass of water (H₂O) = 2 * (1) + 16 = 18 g/mol

Mass ratio of H

$$= 2:16 = 1:8$$

In 18 grams of water, there are 2 grams of hydrogen.

Therefore, in 90 grams of water:

$$\text{Mass of hydrogen} = \left(\frac{2}{18} \times 90 \right) = 10 \text{ grams}$$

Law of Reciprocal Proportions

The law of reciprocal proportions states that if two elements, A and B, combine separately with a fixed mass of a third element, C, the ratio of the masses in which they do so will be the same or a simple multiple of the ratio in which A and B combine with each other.

Example:

Hydrogen (H) combines with sulfur (S) to form H_2S and with oxygen (O) to form H_2O . Sulfur and oxygen combine to form SO_2 .

- Mass ratio in H_2S : H
= 2:32 = 1:16
- Mass ratio in H_2O : H
= 2:16 = 1:8
- Mass ratio in SO_2 : S
= 32:32 = 1:1

Since H combines with S and O, and S and O combine with each other, the ratios of the masses of S and O that combine with a fixed mass of H are $16:8 = 2:1$, and S and O combine in the ratio of 1:1.

Numerical Problem:

Given that 10 grams of element X combine with 40 grams of element Y and 10 grams of element X combine with 20 grams of element Z, and 40 grams of element Y combine with 20 grams of element Z, show that this follows the law of reciprocal proportions.

Solution:

Mass ratio of X
= 10:40 = 1:4

Mass ratio of X
= 10:20 = 1:2

Mass ratio of Y
= 40:20 = 2:1

The ratio of the masses of Y and Z that combine with a fixed mass of X is $4:2 = 2:1$, which is the same as the ratio in which Y and Z combine with each other.

These laws are fundamental to understanding the stoichiometry of chemical reactions and the composition of compounds. They demonstrate the predictable and proportional nature of chemical combinations.