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TEACHING SPECIFICATION OF ELEMENTARY ENTITIES IN AMOUNT OF SUBSTANCE AND THE MOLE

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Summary. Students often understand the mole (a physical quantity) as either a number counting unit or mass. It seems that one of the origins of this problem can be attributed to chemistry teachers who often do not pay sufficient attention to the specification of elementary entities in chemical substance. This contribution shows how specification can be introduced to chemistry beginners.

Introduction

The mole, a fundamental unit of SI (the International System of Units), is stated in two ways [1]: The first is to define the mole in terms of carbon-12, and the second is to specify elementary entities in a given chemical substance. The mole is a physical quantity [2-5]; however, science/chemistry educators [6-7], and hence students [8] often understand the mole as either a number counting unit or mass. It appears that the failure in teaching the mole can be attributed to two origins. One is that educators do not show students the principle of comparison of a given ‘amount of substance’ with the mole, i.e., the principle of measurement of amount of substance, based on the SI mole definition; this principle in stoichiometry is one-to-one correspondence [9]. The other is that the mole teaching does not stress adequately the specification of elementary entities in chemical substance. This contribution shows how to introduce chemistry beginners to specification.

The specification of SI for the mole [1] is written as "When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles or specified groups of such particles." This specification is essential for students' understanding of not only the mole but also 'amount of substance' (chemical amount) because, as shown below, the choice of elementary entities determines the quantity of 'amount of substance'. It should be noted in chemistry education that incomplete expressions peculiar to the chemistry community are used in specifying elementary entities.

Chemists' Expression for Specification

It is ambiguous to say that when the name of a chemical substance is S, the amount of substance of S is n(S); because there is no specification of elementary entities in the statement. The correct expression is as follows; let n(B) be the amount of substance for a chemical substance S whose elementary entity is B. This is just the specification of elementary entities, which is also a notice to use the mole.

Chemists often divert the chemical symbol B of an elementary entity to the name of a chemical substance in brief form such that "n(B) is the amount of substance for a chemical substance B" or in more shortened form "n(B) is the amount of substance B." The Green Book [1, p. 46], for example, says that n(Cl) is amount of Cl or amount of chlorine atoms; this symbol n(Cl) means the amount of the chemical substance that is an assembly of chlorine atoms. On the other hand, the atomic mass (relative atomic mass) A_r(Cl) is that for only one atom. The present note uses the chemists' expression such as "let n(B) be the amount of substance of B," where B is the chemical symbol of an elementary entity.

Specification in Stoichiometry

Let us consider the problem of specification of elementary entities in the stoichiometric equation:

$$2H_2 + O_2 = 2H_2O$$

Two molecules of hydrogen react with one molecule of oxygen, producing two molecules of water. Chemists regard this equation as representing the reaction of hydrogen gas with oxygen gas to yield liquid water. One can then expand the three chemical substances as an entity sheet [9]:

$$\begin{array}{l} \{\ 2H_2 \quad 2H_2 \quad \ldots \quad 2H_2\ \} \\ \{\ O_2 \quad O_2 \quad \ldots \quad O_2\ \} \\ \{\ 2H_2O \quad 2H_2O \quad \ldots \quad 2H_2O\ \} \end{array}$$

Here a pair of curl brackets denotes a chemical substance. Note that all chemical symbols such as $2H_2$ and O_2 stand for elementary entities. In each column three elementary entities, $2H_2$, O_2 and $2H_2O$, have one-to-one correspondence to one another. One can hence get the amount balance

$$n(2H_2) = n(O_2) = n(2H_2O)$$

Expanding chemical substance $2H_2$ leads to another chemical substance H_2; then the row of H_2 is double the row of $2H_2$. The amount balance is then expressed as

$$n(2H_2) = n(H_2)/2 = n(O_2) = n(2H_2O) = n(H_2O)/2$$

This equality well illustrates the importance of specification of elementary entities in writing amount of substance.

It is easy to follow one-to-one correspondence in a given chemical substance. Let n(CH_3OH) be the amount of substance for methanol CH_3OH. The elementary entity CH_3OH includes, i.e., corresponds to, other elementary entities such as CH_3, OH and 4H. The amount balance in methanol is therefore given by

$$n(CH_3OH) = n(CH_3) = n(OH) = n(4H)$$

The last equality implies that one can choose an imaginary particle 4H which is not a molecule as an elementary entity.

The Mole and Specification

Now expand 0.012 kg of carbon-12 as an entity sheet

$$\{\ ^{12}C\ \ ^{12}C\ \ \ldots\ \ ^{12}C\ \}$$

which is just a realization of the SI mole. Let us measure a given amount of substance $n(H_2O)$ in terms of this measure ruler. Suppose that one elementary entity H_2O in the entity sheet of H_2O has one-to-one correspondence to double the measure ruler; in other words, $n(H_2O)/\text{mol} = 2$, i.e., $n(H_2O) = 2$ mol. The mass of this chemical amount is 36 g. This example is also expressed as $n(2H_2O) = 1$ mol, because $n(2H_2O) =$ $= n(H_2O)/2$.

The word 'molar' in molar quantities is defined [1] as 'divided by mol.' The molar mass of water H_2O is well-known as $M(H_2O) = 18$ g/mol. Hence, one has $M(2H_2O) = 36$ g/mol for water $2H_2O$, because $n(2H_2O) = 1$ mol is 36 g. Similarly, the molar volumes (25 degrees, 1 atm) for water H_2O and $2H_2O$, respectively, are given by $V_m(H_2O) = 18$ cm^3/mol and $V_m(2H_2O) = 36$ cm^3/mol.

The above-mentioned examples clearly show the importance of specification of elementary entities in the mole.

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МОЛ И НЕОБХОДИМОСТТА ОТ ОПРЕДЕЛЯНЕ НА ЧАСТИЦИТЕ В КОЛИЧЕСТВОТО ВЕЩЕСТВО

Учениците под мол като физична величина разбират най-често или брой частици, или маса на веществото. Една от причините за възникването на концептуални трудности при усвояването на тази материя е недостатъчното внимание от страна на учителите за определяне на вида частици, които изграждат веществото. Тази работа предлага път, по който тези трудности могат да бъдат преодолени.

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