

- *Нови подходи* •
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## ‘AMOUNT OF SUBSTANCE’ AND A SINGLE ELEMENTARY ENTITY

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**Abstract.** The definition of the mole in SI can be expressed as: 1 mol is equal to the product of  $N$  and  $n_a(\mathbf{B})$ , where  $N$  is the number of atoms in 0.012 kg of carbon-12, and  $n_a(\mathbf{B})$  is ‘chemical amount’ (or ‘amount of substance’) for a single elementary entity  $\mathbf{B}$ . This paper suggests that  $n_a(\mathbf{B})$  is a key concept for understanding the mole:  $n_a(\mathbf{B})$  for all chemical substances remains the same; the amount of a chemical substance becomes smaller if the elementary entities are grouped; the inverse of  $n_a(\mathbf{B})$  is the Avogadro constant. The suggested procedure could help to reduce students’ confusion about the mole being a number counting unit.

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### Introduction

Thoughtful students taking introductory chemistry courses may ask their teachers the following question with regard to the mole in SI.

Q 1: Is there ‘amount of substance’ for a single elementary entity?

The definition [1] of the mole in SI is as follows: “The mole is the amount of substance of a system which contains as many elementary entities as there

are atoms in 0.012 kg of carbon-12. 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.” The number in strong relation to the expression “. . . as many elementary entities as” has been measured [1] as  $6.02 \dots \times 10^{23}$ ; let the said number be  $N$  hereafter. One mole of any chemical substance is composed of  $N$  elementary entities, and ‘chemical amount’ has the extensive (additive) property [2]. Thus, Q 1 inquires as to the minimal value of chemical amount.

The second part of the above-mentioned SI definition specifies elementary entities in a given chemical substance, and may lead students to ask another question relating to the mole as ‘chemical amount’.

Q 2: Does the mole itself need specification?

This contribution provides some answers for students.

### The Mole in Mathematical Form

Let  $m_a(^{12}\text{C})$  be the mass of a single elementary entity carbon-12, and let  $m(^{12}\text{C})$  be the total mass of a chemical substance that is made up of carbon-12. Counting elementary entities in the substance, as one, two, three, . . . , leads to the expression:

$$m(^{12}\text{C}) = x \times m_a(^{12}\text{C}) \quad (1)$$

where  $x$  is the number of elementary entities. The counting procedure also gives the amount  $n(^{12}\text{C})$  of chemical substance:

$$n(^{12}\text{C}) = x \times n_a(^{12}\text{C}) \quad (2)$$

Here  $n_a(^{12}\text{C})$ , which is discussed below in detail, stands for ‘chemical amount’ for a single atomic carbon-12. Equations (1) and (2) are both in the form of a legitimate physical quantity [3]; i.e., a physical quantity is equal to the product of a numerical value and a unit. This paper deals with Eqs. (1) and (2) as keys for understanding the concepts of ‘chemical amount’ and the mole.

Let us express mathematically the definition of the mole in SI using Eqs. (1) and (2). Firstly, the left-hand side of Eq. (1) is set as 0.012 kg, and then the numerical value is denoted as  $N$ . Secondly,  $x$  in Eq. (2) is set as  $N$ , and then the left-hand side is replaced with mol.

$$0.012 \text{ kg} = N \times m_a(^{12}\text{C}) \quad (3)$$

$$\text{mol} = N \times n_a(^{12}\text{C}) \quad (4)$$

Both 0.012 kg and  $m_a(^{12}\text{C})$  are, of course, physical quantities. Equation (4) means that the mole can be measured in terms of the ‘unit’  $n_a(^{12}\text{C})$  to get the

numerical value  $N$ . One can say by means of Eq. (4) that if the mole is a number or a number counting unit, then  $n_a(^{12}\text{C})$  is a number, and vice versa. McGlashan [4,5], however, noted that the mole in SI is not a number counting unit, and that ‘amount of substance’ (or ‘chemical amount’) is a physical quantity.

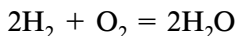
### The Kind-Independence of and Grouping of Elementary Entities

Several laws [6] in classical physical chemistry are based on a property, called colligative, of chemical substance. For example, the depression of freezing point in dilute solution is proportional to the number of solute entities, i.e., to the total amount of elementary entities. This implies that ‘chemical amount’ for a solute is independent of the kind of chemical substance.

$$n_a(\mathbf{B}) = n_a(^{12}\text{C}) = n_a \quad (5)$$

Here  $\mathbf{B}$  indicates any elementary entity, so that  $n_a$  is independent of  $\mathbf{B}$ ; then the second equality in Eq. (5) holds. Reading again carefully the definition of the mole in SI shows that Eq. (4) is not correct;  $n_a(^{12}\text{C})$  in Eq. (4) should be read as  $n_a(\mathbf{B})$  or as  $n_a$ . In other words, the mole in SI needs no specification of elementary entities.

Let us consider, for example, a stoichiometric equation:



Using Eq. (5), one has Eq. (6). When a stoichiometric equation occurs once, it may also occur any number of times; this gives Eq. (7). Similarly, Eq. (5) leads to Eq. (8).

$$n_a(2\text{H}_2) = n_a(\text{O}_2) = n_a(2\text{H}_2\text{O}) \quad (6)$$

$$n(2\text{H}_2) = n(\text{O}_2) = n(2\text{H}_2\text{O}) \quad (7)$$

$$n(\text{H}_2)/2 = n(\text{O}_2)/1 = n(\text{H}_2\text{O})/2 \quad (8)$$

In general, for a chemical substance whose elementary entity is  $\mathbf{B}$ , the choice of a new elementary entity  $y \times \mathbf{B}$  gives the amount balance [7] as

$$n(\mathbf{B})/y = n(y \times \mathbf{B}) \quad (9)$$

### New Definition of ‘Amount of Substance’

Chemistry teachers can now choose Eq. (5) as the starting point in teaching ‘chemical amount’ and the mole. A new definition of ‘chemical amount’ for school chemistry is as follows [8]: ‘chemical amount’ for a single elementary entity is the same for every elementary entity, even if they are different in kind; and ‘chemical amount’ of a system which contains elementary entities is equal to the summation of the amounts of the elementary entities. Here  $x(\mathbf{B})$  is the number of elementary entities.

$$n(\text{B}) = n_a + n_a + \dots + n_a = x(\text{B}) \times n_a \quad (10)$$

### ‘Chemical Amount’ and a Single Elementary Entity

Equation (9) implies that the amount of a chemical substance becomes smaller if the elementary entities are grouped, and hence that ‘chemical amount’ for a single elementary entity is minimal in a given chemical substance. Equation (5) says that ‘chemical amount’ for all the elementary entities remains the same. Combining Eqs. (5) and (9), one can state that  $n_a$  is minimal in the dimension of ‘chemical amount’. This physical quantity has been measured [1] in terms of the mole as

$$n_a = 1 \text{ mol}/N = 1/N_A = (1/6.02 \dots) \times 10^{-23} \text{ mol} \quad (11)$$

Equation (11) indicates that if the Avogadro constant  $N_A$  is a physical quantity, then both  $n_a$  and mol are physical quantities. McGlashan [4] has stated that “There are good reasons why the chemist needs the mole as a dimensionally independent unit; Avogadro’s constant has an accepted value which has frequently been changed and can never be known exactly”.

### Conclusion

The procedure suggested for answering students’ questions clarifies and underlines the importance of  $n_a$ , ‘chemical amount’ or ‘amount of substance’ for a single elementary entity, which is the inverse of the Avogadro constant.

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## КОЛИЧЕСТВО ВЕЩЕСТВО И МОЛ

**Резюме.** На критика е подложена препоръчаната от ИЮПАК дефиниция на мол. Тази работа предлага нова гледна точка по въпроса за определянето на мол и количество вещество. Предложената процедура ще минимизира трудностите на учениците в усвояването на тази сложна материя.

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