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The SI 2019 approach to redefine units does not apply to the mole

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Summary:

The SI (2019) claims that the Avogadro constant N_A may be used to redefine the mole. In particular, the expression $N_A = 6.022\ 140\ 76 \times 10^{23} \times \text{mol}^{-1}$ is a defining relation whose inversion provides the algebraic definition of the mole. This paper shows that the SI (2019) approach based on the defining relations that is used to redefine the other six base units does not apply to the mole.

Keywords: Avogadro constant, Avogadro number, Chemical measurements, Molar mass constant, Relative atomic mass

1. Introduction

This paper shows that the SI (2019) approach based on the defining relations that is used to redefine the other six base units (second, meter, kilogram, ampere, kelvin, and candela) does not apply to the mole. Let X denote a specified elementary entity of a stated substance, and N(X) denote the number of entities of type X in a sample. The SI (2006 and 2019) define *amount of substance* n(X) in that sample as $n(X) = N(X)/N_A$, where $(1/N_A)$ is a proportionality constant whose reciprocal N_A is called the *Avogadro constant*. The SI (2019 § 2.3.1) calls the numerical value of N_A the *Avogadro number*, conventional symbol $\{N_A\}$. Then the SI (2019 § 2.3.1) declares that $\{N_A\}$ is equal to the fixed number of entities in one mole. This declaration implies that one can substitute "1 mol" for n(X) and $\{N_A\}$ for N(X) in the SI definition $N_A = N(X)/n(X)$. Then $N_A = \{N_A\} \times \text{mol}^{-1}$. Thus, the Avogadro number $\{N_A\}$ and the Avogadro constant N_A represent the same quantity; namely, the fixed number of entities in one mole. The Avogadro number $\{N_A\}$ is dimensionless. The Avogadro constant N_A has the dimension mol^{-1}.

The unit mole has had only two SI definitions. The SI (1970) definition of the unit mole (with a clarification added in 1980) is stated in the SI (2006 § 2.1.1.6) as follows. "…The mole … contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12…." The SI (1970) Avogadro number is "as many entities as the ratio of the mass 0.012 kg to the mass of one atom of carbon-12 (unbound, at rest and in ground state)". The SI (1970) Avogadro number $\{N_A\}$ defines the SI (1970) mole.

The SI (2019 § 2.3.1) redefined the unit mole as follows. "… One mole contains exactly 6.022 140 76 × 10^{23} elementary entities. …." The SI (2019) Avogadro number is "exactly 6.022 140 76 × 10^{23} elementary entities". The SI (2019) definition of the mole consists of five sentences. The sentences 1, 2, and 5 define the mole completely. The SI (2019) Avogadro number $\{N_A\}$ defines the SI (2019) mole (sentences 1, 2, and 5) without referring to the Avogadro constant N_A.

2. The SI 2019 approach to redefine units does not apply to the mole

The magnitude of a quantity and a value assigned to that magnitude are different concepts. In the SI, a value is expressed as the product of a number and a unit. In nature, the magnitude of a quantity is unvalued. Usually, a value is assigned to the magnitude of a quantity by measurement. An unvalued magnitude is the input, and the assigned value is the output of measurement. A value assigned to the magnitude of a quantity by measurement is a quantitative description of that magnitude, and it carries uncertainty.

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The SI (2019) uses the magnitudes of the defining constants and their established values, expressed in terms of the previous units, to redefine the units. A defining relation is an equation of the form: “magnitude of a defining constant = established numerical value × unit”. The SI (2019) inverts the defining relations to redefine (the magnitudes of) the units of the defining constants as proportional to the magnitudes of the defining constants as follows: “unit of a defining constant = magnitude of a defining constant / established numerical value”. The algebraic definitions of the units of the defining constants so obtained are solved to define the other SI units. The units second, candela, and meter were redefined based on the defining constants $\Delta\nu_{Cs}$, K_{cd}, and c in 1967, 1979, and 1983, respectively. The SI (2019) redefines the other base units.

Example: The defining relation corresponding to the transition frequency of the cesium-133 atom $\Delta\nu_{Cs}$ is

$$\Delta\nu_{Cs} = 9\,192\,631\,770 \times \mathrm{s}^{-1} \,. (2.1)$$

Here, $\Delta\nu_{Cs}$ is the constant magnitude of a property of the cesium-133 atom. The product 9 192 631 770 × s^{-1} is the established SI value of $\Delta\nu_{Cs}$. The time-duration ($1/\Delta\nu_{Cs}$) of one cycle of frequency $\Delta\nu_{Cs}$ is a constant that exists independently of the magnitude of the unit of time, one second s, that is used to express its value. Therefore, the SI could logically use the defining relation (2.1) to redefine the unit s^{-1}. By inverting (2.1), the SI redefined the unit s^{-1} of $\Delta\nu_{Cs}$ as

$$\mathrm{s}^{-1} = \Delta\nu_{Cs} / 9\,192\,631\,770 \,. (2.2)$$

By rearranging (2.2), the algebraic definition of one second is

$$1\,\mathrm{s} = 9\,192\,631\,770 \times (1/\Delta\nu_{Cs}) \,. (2.3)$$

Similarly, the SI (2019) units based on the six defining constants $\Delta\nu_{Cs}$, c, h, e, k, and K_{cd} are redefined by solving the algebraic definitions of the corresponding units s^{-1}, $m\ s^{-1}$, $kg\ m^2\ s^{-1}$, A s, $kg\ m^2\ s^{-2}\ K^{-1}$, and $cd\ sr\ kg^{-1}\ m^{-2}\ s^3$.

An essential requirement to redefine the units via the defining relations is that each defining constant must have an intrinsic magnitude that exists independently of the magnitude of the unit which that constant is used to redefine (to avoid circular reasoning). The magnitudes of the six defining constants $\Delta\nu_{Cs}$, c, h, e, k, and K_{cd} exist independently of the magnitudes of their units. Therefore, the SI could logically use the corresponding defining relations to redefine their units.

The SI (2019 § 2.3.1) claims that the expression

$$N_A = 6.022\,140\,76 \times 10^{23} \times \mathrm{mol}^{-1} \,, (2.4)$$

is the defining relation corresponding to the Avogadro constant N_A, and the expression

$$1\,\mathrm{mol} = 6.022\,140\,76 \times 10^{23} / N_A \,, (2.5)$$

is the algebraic definition of the unit mole.

The Avogadro constant N_A expresses the fixed number of entities in one mole as the SI value $N_A = \{N_A\} \times \mathrm{mol}^{-1}$ with the unit mol^{-1}. The description of the Avogadro number $\{N_A\}$ completely defines both the mole and the Avogadro constant $N_A = \{N_A\} \times \mathrm{mol}^{-1}$. So, the Avogadro constant N_A does not have an intrinsic magnitude that exists independently of its unit mol^{-1}. Therefore, the Avogadro constant N_A does not satisfy an essential requirement of defining relations. Consequently, the Avogadro constant N_A is not a defining constant, and the SI (2019) approach to redefine SI units based on defining relations does not apply to the mole. In particular, the expression (2.4) is not a defining relation, and the expression (2.5) does not define the mole.

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