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Commentary

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What's in a Name? Amount of Substance, Chemical Amount, and Stoichiometric Amount

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ABSTRACT: The term *stoichiometric amount* is proposed as a substitute or a synonym for the problematic SI-base quantity *amount of substance*. The word *stoichiometric* not only makes the term highly specific in modifying the word *amount*, but also signals that the expression is a technical term rather than a phrase of common English words. The term can be usefully employed in explaining the mole (i.e., as a unit of stoichiometric amount) regardless of the official name of the quantity of which the mole is a unit. It can be used alongside the phrase *chemical amount*, which has previously been proposed as an alternative to *amount of substance*.

KEYWORDS: *First-Year Undergraduate/General, High School/Introductory Chemistry, Nomenclature/Units/Symbols, Stoichiometry*

■ INTRODUCTION

The General Conference on Weights and Measures (CGPM) has proposed to revise the International System of units (SI) so that all of its base units will be defined by "explicit-constant" formulations.[1] Draft definitions for the "new SI"[2] of two units in particular have received scrutiny from chemists, namely the mole and the kilogram. In the course of discussing the definition of the unit mole, an IUPAC project task group[3] focusing on the new SI sought the opinions of its national adhering organizations (NAOs) on the definition and name of *amount of substance* (*AoS*, the quantity of which the mole is a unit[4]) as well. Although there was no consensus on the topic, dissatisfaction with the name *amount of substance* was expressed by many of the respondents.[5] The terminology used by practicing chemists in their technical writing can also be used to infer that *amount of substance* does not meet with their favor: they employ *number of moles* considerably more frequently.[6] Several terms have been proposed as alternatives, the most prominent of which appears to be *chemical amount*. This commentary proposes another term, *stoichiometric amount*, and examines the pedagogical utility and this and other terms.

Some of the problems with the name *amount of substance* have been raised previously: the term *amount of substance* lacks a rigorous official definition and it is widely ignored by practicing chemists.[6] In addition, the word *amount* is a common English word that refers to many quantities, including mass and volume. The modifier "*of substance*" is neither sufficiently clear to rule out mass or volume, nor sufficiently unusual or specialized to signal that *amount of substance* is meant to be a technical term with a specific meaning. The desirability of changing the name *amount of substance* has been recognized by IUPAC since 2009, and several of IUPAC's NAOs expressed dissatisfaction with the term in response to the IUPAC questionnaire already mentioned.[5]

The alternative term employed by most practicing chemists, *number of moles*, is not really a suitable substitute. The principle of distinguishing quantities from units is a sound one—even if there is only one unit in common use. Clear handling of quantities and units, known as quantity calculus,[7] expresses physical quantities as a product of a numerical value and a unit

$$\text{physical quantity} = \text{numerical value} \times \text{unit}$$

AoS deserves a better name than *number of moles*. In current chemical education, the mole is taught as a core concept in chemistry; it has been the subject of numerous articles in this *Journal* and it has a prominent presence in every textbook of introductory chemistry. Logically, the mole concept includes *AoS*, whether or not that quantity is named: if one expresses a quantity in moles, one is expressing an *AoS*. One might expect the concept of the quantity to be prior to the concept of the unit, but in this case, the quantity, to the extent that it is taught at all, is secondary to the unit, the mole.

B. P. Leonard has argued for the term *chemical amount*,[8] and the IUPAC project task group critically evaluating proposals on chemical quantities in the new SI endorses that name.[5] Recognizing that the quantity in question is an amount of some sort, but noting that the word *amount* is very general, Leonard and the task group propose modifying it with another word describing the kind of amount. They offer *electrical current* as an analogous example of an official term made from a common word modified by a technical limiter. They also conceive of the modifier being dropped if the context permits. *Chemical amount* is a term that IUPAC has recognized as an alternative to *amount of substance* for over 20 years.[9]

In my opinion, *chemical amount* is an improvement over both the official *amount of substance* and the term most commonly used by chemists, *number of moles*. In the context of teaching introductory chemistry, however, it shares some of the drawbacks of *amount of substance*. After all, within a chemistry class, the term *chemical* is not really a narrowing term. Furthermore, chemists and chemistry students measure mass and volume directly in the laboratory; surely these are *amounts* suitable for measurements of *chemicals* or by chemists.

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Besides *chemical amount*, terms such as *number of entities*, *numerousness*, or *numerosity* have been proposed. Indeed, terms of this sort, which take the quantity to be a number of atoms, molecules, photons, ions, or chemical events, were the alternatives most frequently suggested by NAOs responding to the IUPAC task group.[5] That task group proposes a definition of the mole explicitly as a set number of entities:[10]

> *The mole, symbol mol, is the SI unit of chemical amount. One mole contains exactly 6.022 140 86 × 10[23] elementary entities.*

IUPAC publications have long made a distinction between *amount of substance* and *number of entities*. See, for example, Table 2.10 in the *Green Book*.[9] The *Gold Book* comes closer to suggesting that *number of entities* is synonymous with *amount of substance*. The entry for *amount of substance* includes:[11]

> *Since it is proportional to the number of entities, the proportionality constant being the reciprocal Avogadro constant and the same for all substances, it has to be treated* ***almost identically*** *[emphasis added] with the number of entities.*

Pedagogically, it is common to treat the mole as a numerical package, like a dozen or a gross. Because the most straightforward way to define the unit mole is to state how many elementary entities constitute a mole, it is, perhaps, natural to think of *AoS* as primarily, if not exclusively, a number.

To think of the mole as a unit of *number of entities* is attractive in many ways. In my opinion, the obstacles to adopting *number of entities* as substitute for *amount of substance* are primarily formal and philosophical rather than pedagogical. Both the current[1] and draft[2] versions of the SI regard quantities that have the nature of a count as dimensionless quantities whose dimension is one and unit one (1), and SI permits only one SI unit per quantity. Leaving that issue aside, is it accurate to say that, for example, 2.0×10^{-9} mol of carbon atoms *is* 1.2×10^{15} carbon atoms? Certainly it is true that 2.0×10^{-9} mol of carbon atoms *contains* 1.2×10^{15} carbon atoms. By the same token, *are* 6 dozen doughnuts 72 doughnuts? *Are* 4.2 million mousetraps 4,200,000 mousetraps? Clearly "million" *is* a number. Is dozen anything other than another way of writing 12? Maybe, maybe not. Is mole anything more than another way of writing 6.022×10^{23}? I believe it is, as will be explained below. But for the moment, I close this paragraph not recommending against teaching the mole as a measure of number of entities, but recommending against teaching the mole as *only* a measure of number of entities.

■ STOICHIOMETRIC AMOUNT

Historically, the mole is closely associated with stoichiometry. Today, in the teaching of introductory chemistry, the mole concept is usually introduced in the context of stoichiometry or preparatory to it. I propose the term *stoichiometric amount* as an alternative to *amount of substance*. By this terminology, *stoichiometric amount* means, in effect, the measure of amount required for stoichiometry.

By stoichiometry, I mean, "The relative proportions in which elements form compounds or in which substances react."[12] (It is necessary to clarify the boundaries of stoichiometry as I understand it and as I see it commonly presented in introductory chemistry texts. Some sources define stoichiometry much more broadly, as[13]

> *The field of chemistry that includes all chemical measurements, such as the measurements of atomic and molecular weights and sizes, gas volumes, vapor densities, deviation from the gas laws, and the structure of molecules.*

Others restrict it to ratios in chemical reactions.[11]) Topics in an introductory chemistry course that fall under this heading include empirical formulas, molecular formulas, balancing equations, limiting reagent, theoretical yield, and titration. Most textbooks introduce the mole and molar mass at the start of such topics or as a preliminary to them.[14]

In a typical stoichiometry problem, amounts of materials are given as masses of pure substances or volumes of solutions of known concentration. After all, mass and volume are easy to measure in the laboratory. Invariably in the course of a stoichiometry problem, these amounts must be expressed in units appropriate for stoichiometry, namely moles. I suggest juxtaposing mass and volume, quantities directly measurable in the laboratory, with *stoichiometric amount*, the quantity appropriate for stoichiometric analysis. Grams and milliliters are common examples of units for mass and volume, respectively; the mole (occasionally modified by an SI prefix) is practically the only unit used for *stoichiometric amount*. Thus, one can treat the mole as a unit distinct from its quantity and parallel to other units without resorting to statements that fly in the face of common usage. An instructor can say, "We are given the mass of sodium chloride, but we need its *stoichiometric amount*, so we must convert grams to moles." Contrast that to the formally correct, "We are given the mass of sodium chloride, but we need its *amount of substance*," to which a student might well wonder, "Isn't the mass its amount?" No wonder instructors (myself included) frequently short-circuit such statements, using constructions like, "We are given the mass of sodium chloride, but we need to express that quantity in moles," which juxtaposes a quantity with a unit.

It is hoped that by using the term *stoichiometric amount* in conjunction with stoichiometry problems, one reinforces the fact that moles are a unit of a quantity that expresses amount in a sense different from mass and volume and appropriate for stoichiometry. Of course, chemists have understood for more than a century that what makes the mole the right unit for stoichiometry is that a mole of any pure substance contains the same number of elementary entities. What that number happens to be is rarely relevant to the stoichiometric operation in question, though, and for that reason, I think that teaching the mole *only* as a number of entities is inadequate. A mole certainly is a definite number of entities, and the definition of mole as an Avogadro's number of entities makes that clear. We know what that definite number is to about eight significant figures, and we make that number part of the definition of the unit. Emphasizing number exclusively, though, is overemphasis: the absolute number of elementary entities in a chemical sample is almost never of interest. The mole is, then, a unit for a quantity that is clearly an amount, a different kind of amount from mass or volume, one that is relevant particularly to stoichiometry, from which one *can* compute number of entities (but rarely does).

■ OBJECTIONS TO *STOICHIOMETRIC AMOUNT*

I am aware of three objections to the proposed name *stoichiometric amount* for the quantity discussed here. One is the existence of a different meaning already attached to the phrase. Another is that the term is too narrow, because *AoS* is

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J. Chem. Educ. XXXX, XXX, XXX−XXX

not limited to stoichiometry. Finally, the phrase is cumbersome and inelegant.

A *stoichiometric amount* of one reactant can mean the amount that will react completely with a given amount of another reactant, leaving no excess of either one. In this usage, the amount may be a mass, a volume, or an *AoS*, and the adjective *stoichiometric* refers not to stoichiometry in general but to stoichiometric equivalence in particular. Thus, this sense is synonymous with *equivalent amount*. In my opinion, the prior existence of this other sense is a surmountable obstacle, at least for pedagogical use of *stoichiometric amount* in the sense proposed in this article. Students who are learning about moles and stoichiometry in the first place are not likely to have encountered the phrase before, in either sense. So the phrase in the sense of *equivalent amount* is unlikely to prevent them from understanding the phrase in the sense of *AoS*. The group for whom the pre-existing sense is most likely to interfere with the sense proposed here consists of established chemists. Even for them, however, there exists a sufficiently well-established synonym, namely *equivalent amount*, so that there is no gap left by appropriating the phrase *stoichiometric amount* for *AoS*. *Equivalent amount* is easy to associate with the conceptually similar *equivalence point*. And there is room for even more specific and descriptive phrases such as *stoichiometric equivalent*.

As for the second objection, the concept *AoS* is undoubtedly larger than stoichiometry as defined above; *AoS* is relevant to gas laws, kinetics, and thermodynamics, among other topics. In such contexts, *chemical amount* may be a more appropriate term, particularly if that term is adopted as a new official name for *AoS*. Indeed, this commentary is not intended to advocate exclusive use of *stoichiometric amount* as a term for *AoS*. But even in applications beyond stoichiometry, the phrase *stoichiometric amount* can be useful. It is a reminder that stoichiometry is the context in which *AoS* and the mole arose in chemistry and the context in which they are introduced in the chemistry curriculum. Furthermore, chemists routinely use terms beyond the contexts in which they arose and those immediately suggested by the words themselves. The terms *oxidation* and *gas constant* come to mind.

Finally, the phrase is unquestionably cumbersome: *stoichiometric* is polysyllabic, unfamiliar to nonchemists, and difficult to spell. The term may not be appropriate for younger students encountering notions of atoms, molecules, chemical formulas, and chemical reactions for the first time. In science classes before high school, terms such as *chemical amount* and introduction of the mole as a "chemist's dozen" are perfectly appropriate. Introduction of the term *stoichiometric amount* before students are about to be introduced to stoichiometry would be premature and pedagogically inappropriate. In my opinion, the awkwardness of the term is also a surmountable obstacle to its profitable use in education. The solution is simply to reserve the term for classes for which it is pedagogically appropriate, namely in courses that include quantitative stoichiometry and later courses. Furthermore, the formidable appearance of the term makes it clear that it is not a phrase of common English, and would therefore preclude the confusion that can accompany *amount of substance*.

OF OFFICIAL DEFINITIONS AND PEDAGOGY

Thus far, although I have mentioned the status of official terms such as *amount of substance*, I have tried to make it clear that my proposal of the term *stoichiometric amount* is a pedagogical proposal. I would like to add, however, that I believe the term would also make a suitable official name. It follows the approach taken by the IUPAC project task group mentioned above of retaining *amount* and modifying it to explain what kind of amount. And it does so with a term even more specific and less likely to be confused for a common term than the modifier *chemical*.

Regardless of whether CGPM retains or changes *amount of substance* or whether IUPAC adopts the advice of the project task group in recommending *chemical amount* as a new name for that quantity, *stoichiometric amount* can be used as an explanatory term, as a supplement to, if not a substitute for, the official name.

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Notes

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(4) This article is largely concerned with this quantity and what to call it. To avoid using the cumbersome circumlocution "the quantity of which the mole is a unit", the abbreviation *AoS*, based on its current official name, is employed when referring to the quantity as a concept regardless of its name.

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J. Chem. Educ. XXXX, XXX, XXX−XXX

(10) Note, by the way, that the task group's text is an explicit-unit formulation in terms of Avogadro's number rather than an explicit-constant formulation in terms of the Avogadro constant. It is logically identical to the definition in the draft new SI, but not identical in form.
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