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Reply to "Comment on 'Unpacking the Meaning of the Mole Concept for Secondary School Teachers and Students'"

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ABSTRACT: This letter is in response to a letter, "Comment on 'Unpacking the Meaning of the Mole Concept for Secondary School Teachers and Students'", discussing a recent article we wrote on the mole concept.

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

Thank you to Andrzej Barański for his comments on the article "Unpacking the Meaning of the Mole Concept for Secondary School Teachers and Students".[1] It has always been our hope that the discussion stimulated by the article would contribute to teachers' teaching and students' understanding of the mole.

The letter by Barański[2] pointed out that, in our article, the section What Does the SI Definition Tell Us? lacks a definition of Avogadro's number. Barański used eq 1 to define Avogadro's number as the conversion coefficient for expressing grams as unified atomic mass units. He further argued that eq 1 not only allows us to calculate the mass of one mole of substance *Y* but also helps to explain "*counting by weighing*" (by eq 2 in which the role of Avogadro's number as a conversion coefficient is explicit). We find the clarity of Barański's commentary extremely helpful.

We have two comments in response to Barański's letter.

First, eq 1 cannot be understood unless one explains the definition of "u" (unified atomic mass unit). Explanation of "u" in terms of its relationship with gram constructs Avogadro's number as a ***number*** with the dimensions gram/u, concealing its status as a dimensionless ***ratio*** of mass to mass (that is, to think of u as $1/6.022 \times 10^{23}$ gram). At its most simplistic level, the value of Avogadro's number is an artifact of our choice of the gram as the microscopic unit of mass. However, as our article attempts to make clear, the actual value of Avogadro's number is of trivial importance compared with the conceptual significance of the existence of a numerical connection between the microscopic world of particle-counting and macroscopic world of object-weighing. The conceptual leap embodied in Avogadro's number lies in this capacity to connect the microscopic and the macroscopic.

$$\frac{\text{mass of carbon-12 mole}}{\text{mass of carbon-12 atom}} = \frac{12\text{ grams}}{12\text{ u}} = \frac{\text{gram}}{\text{u}} = N_A \qquad (1)$$

There is an inevitable circularity in all attempts to define, and this is evident here. In fact, to make sense of the definition of "u" depends on an understanding of the mole concept.

The information conveyed by eq 1 is implicit in our concept map. We used both the number aspect and the mass aspect to interpret the idea of eq 1 because secondary students are often confused about whether they are dealing with "a number of entities" or "mass". According to Barański, the mole can be defined as **a collection of Avogadro's number of entities, where Avogadro's number is the ratio gram/unified atomic mass unit.** We think this is one way to explain the mole. However, when defining the mole like this, it is still crucial to explain why the mole is defined in terms of *this* specific number of entities (i.e., why Avogadro's constant has the value $6.022 \times 10^{23}\ \text{mol}^{-1}$ and not some other value), and how the mole and the ratio (gram/unified atomic mass unit) are related. To answer these questions, one still needs to go back to the meaning of the mole and to stress *not* the absolute value of Avogadro's number but the conceptual necessity for such a number to connect microscopic particle counting with macroscopic weighing actions.

Second, we agree that eq 2 is useful when calculating the mass of one mole of one particular isotope of an element. However, it is problematic when the concepts of relative atomic or molecular mass are brought in.

$$\begin{aligned} m_{1\text{ mol }Y} &= N_A \times (M_Y \times \text{u}) = M_Y \times (N_A \times \text{u}) \\ &= M_Y \times \text{gram} \end{aligned} \qquad (2)$$

More specifically, according to Barański, M_Y is the *relative* atomic or molecular mass. Because relative atomic or molecular masses are ratios without a unit, we question the utility of adding the additional unit (u) to relative atomic/molecular mass; in other words, it is unclear what $(\boldsymbol{M_Y \times u})$ means in this equation.

Finally, we agree with Barański that more discussion is needed regarding the issue of whether we educators think the definition of the mole should emphasize consistency with the SI definition. The SI definition can conceal the arbitrariness of the actual value of Avogadro's number. The relationship between the SI definition of the mole and Avogadro's number is one of mutual definition. Each interprets "amount of substance" in a distinctive way, while making the connection between these two conceptions explicit. In fact, for understanding the mole more meaningfully, the scientific domain might need to further clarify and explain what "amount of substance" actually means.

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Notes

The authors declare no competing financial interest.

REFERENCES

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(2) Barański, A. Comment on "Unpacking the Meaning of the Mole Concept for Secondary School Teachers and Students". *J. Chem. Educ.* **2014**, *91*; DOI: 10.1021/ed5002398.