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Relative Atomic Mass Scale

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A Teaching Aid

Erwin Baumgartner[1]
Comisión Nacional de Energía Atómica, Departamento Química de Reactores, Av. Libertador 8250, Buenos Aires (1429), Argentina

Carlos Benítez, Alicia Fernández Cirelli and Luz Lastres Flores
Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Argentina

Many years of teaching general chemistry at the high school and introductory university level have shown us that one of the seemingly most abstruse and difficult concepts for students is the relative atomic mass (RAM) concept. The difficulty lies apparently in the word relative, and confusions go sometimes so far as students believing that one hydrogen atom weighs 1 g. Naturally, it may be very frustrating for a teacher to get this as an answer, after having spent hours in explaining one of the major achievements in chemistry, which is the establishment of the RAM scale.

In order to avoid these confusions and to clarify the significance of the value 1 assigned to hydrogen, we try to stimulate the students' imagination by creating perplexities about this point. We achieve this objective quite successfully by telling them to use any other value instead of 1, let us say 2, for instance. Here, we usually observe the first shaking of their beliefs, as it is not quite obvious to them that this could be allowed. It is, of course, carefully stressed that this is perfectly valid, as we are talking about *relative* atomic masses, and that the value 1 was chosen exclusively for reasons of convenience. It is necessary to point out at this stage that the value 1 constitutes the *arbitrary unit* in the scale of RAM. We also stress that *all* selections of units—for masses, distances, times, etc.—are completely arbitrary. For instance, it is shown that the definition of the meter as the distance between the two marks on a Pt–Ir rod, deposited in Sèvres, France, or its definition as 1650763.73 times the wavelength in vacuum of an emission line of krypton-86 seems much more scientific than the definition of a foot as the foot length of a certain king, but that they are all equally arbitrary.

After choosing the value 2 as the base unit of the RAM scale, it follows immediately that the RAM of each element is now twice as large as in the previous scale. At this point we ask the students to perform a stoichiometric calculation, involving masses, moles, and volumes, using this new scale, and to see how the results compare with those obtained through the normal procedure. For the calculation of masses, obviously the same answers are obtained. As far as the produced volume is concerned, we always expect the students to give the immediate answer that it is the same, irrespective of what choice of unit one makes, as it cannot depend on this choice. Practically without exceptions, they do not follow this line of reasoning and instead, calculate the number of moles of produced gas, getting the "correct" answer of half the value as with the regular calculation, as the relative molar mass of the gas is now twice as large. Then they calculate the volume by the general ideal gas equation, and here comes the surprise, not only for students, but to be honest also for teachers: if the equation $PV = nRT$ is applied without giving any thought about it, the volume one gets is half of the real one. How can this contradiction be explained? A closer look at the equation tells us that the answer must be found in R, the gas constant and that its value should be twice as large as the normal one. On the other hand, the first reaction is to say that R is a universal physical constant and that its value cannot be dependent on the choice of the unit of the RAM scale. Some students calculate the gas volume through the value of the molar volume at standard conditions, 22.4 L, and of course obtain the same incorrect answer. Again, the conclusion, not easily accepted at first, is that the molar volume must be 44.8 L, if a value of 2 is assigned to hydrogen in the RAM scale. This means in turn that Avogadro's constant (N_A) must be doubled as well, a conclusion which again is somehow against our intuitive idea of universal physical constants. The perplexity thus created must now be resolved. This is done by explaining that the unit of the RAM scale, in this case the value assigned to hydrogen, has exactly the same meaning as the unit meter for distances, second for time, etc., and that, although any measurable quantity has a certain intrinsic value, the number we associate to its measure depends on the choice of the unit. Therefore, as an example, as everybody knows, 1 meter = 100 centimeters = 39.37 inches = 3.281 feet = 1.094 yards. In the same way, it can be shown that all physical constants that contain the mole in their definition, such as N_A, R, Faraday's constant, etc., change their values if the unit in the scale of RAM is changed.

Comparison of the Value of Avogadro's Constant for Different Choices of the Unit for the Relative Atomic Mass Scale

Scale	Characteristic	N_A
In use	$^{12}C = 12.0000$ (exactly)	$(6.0225 \pm 0.0004) \times 10^{23}$
Physical	$^{16}O = 16.0000$ (exactly)	6.0244×10^{23}
Chemical	$O = 16.0000$ (exactly)	6.0227×10^{23}
Historical	$H = 1.0000$ (exactly)	5.975×10^{23}

It is interesting to note that all these physical constants had to be modified when the scale of RAM was changed from H = 1.0000 to O = 16.0000 and finally to $^{12}C = 12.0000$. This is, in our opinion, a very important conclusion, and it has not been recognized as widely as it deserves. In the table, we show the value of Avogadro's constant for the different unit choices. Although the observed changes are small, they are not negligible, as in some cases they lie outside the accepted experimental error.

In summary, we propose the preceding idea of suggesting the use of a RAM scale in which hydrogen is assigned a value quite different from 1 as a teaching aid for better understanding the concept of RAM. In this way, some perplexities are created that, after being resolved and explained thoroughly, help to clarify the ideas and concepts one wants to transmit about this topic.

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[1] Author to whom correspondence should be addressed.

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