Textbooks and the SI Base Units. A Challenge for Authors and Editors.

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Abstract

The vast number of chemistry textbooks and their many revisions provide opportunity for advancing the fundamentals of chemistry. Among those fundamentals are the SI (*Système International*) Base Units for: time; length; mass; thermodynamic temperature; electrical current; intensity of light; and amount of substance. All of these are significant in the practice of chemistry.

Presently, an international effort is underway to redefine each of the SI Base Units. Led by the International Committee on Weights and measures (CIPM), there is a growing consensus on the new definitions with the prospect of their formal adoption by the next General Conference on Weights and Measures (CGPM) in 2018. Originally, the SI Base units were based on physical observations of terrestrial phenomenon to which anybody could relate. The revised definitions are all based on physical constants considered to be invariants of nature.

How these new definitions will be represented in chemistry textbooks is an open question with few authors and editors aware of the forthcoming changes.

Paper

The present system of physical units has developed over the last two centuries. Originally, the important units for science and commerce were weights and measures. Indeed, those remain in the names of the relevant organizations that are responsible for units.

Prior to the French Revolution, there were thousands of different weights and measures in what we know as Western Europe. Never mind those in other parts of the world most of which were unknown to the French revolutionists. As a part of that great upheaval, it was decreed that there would be a single system of weights and measures in the new republic. Science was highly developed in France and the scientists were charged with the development of this “universal” system. From these beginnings came the present and widely-accepted SI (*Système International*).

For measures, the meter was defined as 10^{-7} (or one ten-millionth) of a quadrant of the Earth’s circumference. Happily, such a quadrant (one-fourth of a great circle of the Earth) ran through France from Dunkirk on the north coast to Barcelona just outside southern France. Measuring this distance and calculating that fraction of the measured quadrant was left to the surveyors who had at their disposal a highly accurate method of measuring angles. Starting with a single linear measurement of the base of a single triangle two teams set out to measure hundreds of triangles across France on the way between Dunkirk and Barcelona. They met near the town of Rodez. All that remained was to calculate the linear distance using simple trigonometry. Thus, the meter (or metre) was based on the dimension of the Earth and was easily understood.

For weight the kilogram was defined as a cubic decimeter of water at 4°C that was known to be the temperature of greatest density of water. Interestingly, the kilogram depended on the meter as it was necessary to have that linear measurement to determine the volume of water. How could this be done as the meter itself was not yet known? Each of the units, meter and kilogram, were determined as “provisional” until the calculation of the meter was completed. Thus, the kilogram was based on a terrestrial phenomenon that was easily understood.

We now recognize the seven SI Base Units shown in figure 1.

SI Base Unit	Symbol
second	S
meter (metre)	M
kilogram	Kg
ampere	A
Kelvin	K
Mole	Mol
candela	Cd

Figure 1. SI (*Système International*) Base Units

In the late 1700's prototypes of the meter and kilogram were rendered as a durable objects made of metal. They were deposited in the archives of the French Republic in December 1799. In May 1875, seventeen countries signed the Metre Convention that established the International Bureau of Weights and Measures (BIPM)[1]. In 1921 the convention was extended to all physical measurements. The United States of America was one of the original signers of the Metre Convention. Now, more than fifty countries are members of this convention.

Later, forty standard kilograms were produced using a platinum-iridium allow and each measuring 39 mm in diameter and 39 mm in height. They were cast in London by George Matthey and were "hammered, polished and adjusted" to match the kilogram in the French archive. In 1889, 34 of these "witnesses" were distributed while six remained in France. In 1890, K4 and K20 arrived in the US where K20 was designated the primary standard kilogram for the US.

Following the distribution of the standard kilograms it was decided to return them periodically to France for comparison to **the** standard kilogram referred to as "le Grand K." Results of these comparisons are shown in Figure 2.

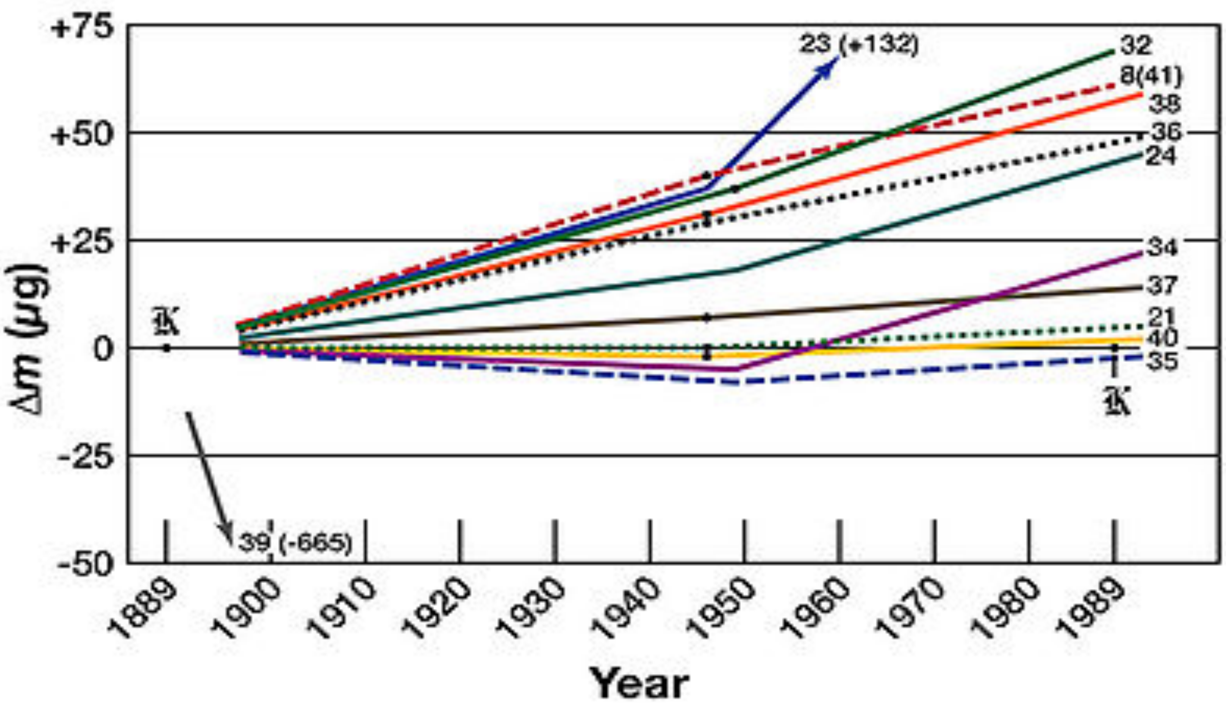

Figure 2. Comparison of standard kilograms to le Grand K.

Because le Grand K is **the** standard, it is always used as the reference; le Grand K is at the top of the hierarchy of standard kilograms. The results clearly show that the mass of the witnesses is changing relative to le Grand K. There is the possibility that le Grand K itself is changing mass but it cannot

[1] "BIPM is an intergovernmental organization under the authority of the General Conference of Weights and Measures (CGPM) and the supervision of the International Committee for Weights and Measures (CIPM)" www.bipm.org

be compared to any other mass as it is **the** standard. It is this consistent drift over time that has led to the proposal to eliminate the "artefact" know as le Grand *K*.

Redefining the kilogram by eliminating le Grand *K* requires some other basis for the definition of the kilogram. Since 1968 the definition of the *second* has been based on the radiation of the ^{133}Cs atom. Since 1983, the *meter* has been defined on the speed of light. In each case, the definition is a physical constant believed to be an invariant of nature. Prompted by the need to redefine the kilogram, all SI Base Units will be defined on invariants of nature. Consensus values for the constants will be adopted as exact values with uncertainty.

While all seven SI Base Units are of importance in the practice of chemistry, the new definitions of the *kilogram, kelvin* and *mol* required particular attention as they are more complicated to understand and teach.

Unit of amount of substance (mole)

In 1971 the following definition was adopted:

1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol."
2. 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.

This is the current definition of the mole that will be replaced. The definition is based on the agreement that the mass of an atom of carbon-12 is exactly 12 and that agreement is enshrined in the definition. All atomic and molecular weight measurements are referenced to this exact number by definition.

It's a well-known chemistry fact that Avogadro's number (or the Avogadro constant) is related to this definition. Accordingly, the proposed redefinition uses the Avogadro constant as an invariant of nature:

- *The mole is the unit of amount of substance of a specified elementary entity which may be an atom, molecule, ion, electron, other particle or specified groups of such particles; its magnitude is set by fixing the numerical value of the Avogadro constant to be equal to exactly 6.022 141…x 10^{23} when it is expressed in the unit mol^{-1}.*

This might be an easier way to introduce the Avogadro constant as it will be the basis of the definition of the mole. What is lost is the fundamental concept of the mass of an atom of carbon-12 is exactly. Most likely the agreement on the mass of carbon-12 will remain fundamental in chemistry even though it is lost in the proposed definition of the mole.

Much discussion has led to the belief that "amount of substance" is an ambiguous and inappropriate term for the mole concept. Most likely the term "chemical amount" or "amount of chemical substance" will gain favor. This, too, may be clarifying and pedagogically more pleasing.

Unit of thermodynamic temperature (kelvin)

Presently, the definition is:

> The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

Once again there is a terrestrial phenomenon used to define the SI Base Unit. It is easily understood and realized. For consistency however, there is a problem: Exactly what is water? It is known that for most elements the distribution of the stable isotopes is not consistent throughout the world. Accordingly, in 2005 the definition was enriched:

> This definition refers to water having the isotopic composition defined exactly by the following amount of substance ratios: 0.000 155 76 mole of ^{2}H per mole of ^{1}H, 0.000 379 9 mole of ^{17}O per mole of ^{16}O, and 0.002 005 2 mole of ^{18}O per mole of ^{16}O.

The proposed definition is:

> *The kelvin, K, is the unit of thermodynamic temperature its magnitude is set by fixing the numerical value of the Boltzmann constant to be equal to exactly 1.380 65… 10^{-23} when it is expressed in the unit s^{-2} m^2 kg K^{-1}, which is equal to J K^{-1}.*

The proposed definition has the advantage of not requiring a further definition of water. It has the disadvantage of explaining the Boltzmann constant and visualizing just how that defines thermodynamic temperature.

Comparison of the present and proposed definitions of thermodynamic temperature provides an opportunity to illustrate the concept of "*mise en practique"* so important to the SI Base Units. Roughly translated it means put into practice. It is imperative that we convey the notion that *mise en practique* is entirely separate from the definition.

Note that the present definition provides the *mise en practique;* obtain the correct, isotopically balanced water and lower the temperature until ice appears. Under normal atmospheric pressure that's the triple point of water.

With the proposed definition, there is no such guidance. What is the experiment or procedure that will relate in a practical way the Boltzmann constant to thermodynamic temperature?

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