Subject: Re: Redefinition of kilogram
Date: 2/18/07 7:40:42 PM
From: "Barry Taylor"
To: ron.fox@physics.gatech.edu, "Ted Hill" , i.m.mills@reading.ac.uk, mohr@nist.gov, terry.quinn@physics.org, edwin.williams@nist.gov

Dear Ron and Ted,

Permit me to attempt to answer your questions via the text in red interspersed in your email. I do hope that you find these remarks helpful. My colleagues may also wish to add to what I have said.

Regards,

Barry Taylor

At 07:50 PM 2/18/2007, Ted Hill wrote:
Dear Colleagues,

In your 2006 Metrologia article (Vol 43, p 227-246), do any of the three proposed new definitions of the kilogram (kg-1a, kg-1, kg-2) imply or assume that the number of atoms in 12 grams of carbon-12 is an integer? (We asked Prof Mills, but have not received a response.)
No. None of the definitions that we propose for any of the four units, kilogram, ampere, kelvin and mole, have anything to do with carbon 12.

In that paper you list the benefits of your proposed redefinitions of the kilogram, ampere, Kelvin and mole to both the metrology and scientific communities, and stress the critical importance of intelligible communication between practical metrology and quantum physics. It is in that same spirit that we (a mathematician and a physicist) are writing to ask for clarification of several points in that article that are confusing to us.

Although you emphasize (in the abstract, in section 2.1 etc) that your new definition of the kilogram is linked to an exact value for the Avogadro constant NA, it is our understanding that your proposal:

May I respectfully suggest that you look at the abstract and the beginning of section 2.1 a bit more carefully? In particular, the opening sentence of 2.1 reads "In this section, we propose possible wordings for new definitions of the kilogram, ampere, kelvin and mole that link these units to exact values of h, e, k, and N_A, respectively." The key word here is "respectively." Thus the sentence means that the new definition of the kilogram links the kilogram to an exact value of the Planck constant h; the new definition of the ampere links the ampere to an exact value of the elementary charge e; the new definition of the kelvin links the kelvin to an exact value of the Boltzmann constant k; and the new definition of the mole links the mole to an exact value of the Avogadro constant

N_A.

(1) leaves unchanged the official definition of NA (as the number of atoms in 0.12 kg of carbon-12 in its rest energy state);

No. The current definition of the Avogadro constant in terms of carbon 12 will be abrogated. Of course, to ensure continuity in the size of the mole, the value of N_A chosen to define the "new mole" will be as close as possible to its current value. This means that the value chosen will be approximately equal to the number of carbon 12 atoms in 12 g of carbon 12. Nevertheless, the formal definition has nothing to do with carbon 12 and the product (N_A mol) should be viewed simply as a number.

(2) leaves unchanged the current methods (e.g., silicon lattice and watt-balance methods) for estimating NA; and
In general, no matter what the definition of a unit happens to be, any method consistent with the laws of physics can be used to realize it, which means to bring into existence a concrete representation of the unit that can be used in measurements. But note that when the mole is defined in terms of an exactly known value of N_A, one will never have to estimate the value of N_A; it is known for evermore. The uncertainty of interest is that associated with the practical realization of the unit "mole" in terms of this exact value of N_A.

(3) leaves unchanged the CODATA recommended value of NA, which has non-zero uncertainty and which is also changing in time since it is based on the results of experiments (i.e., not mathematical identities).

No. The values of h, e, k, and N_A to be chosen to define the kilogram, ampere, kelvin, and mole, respectively, will be based on the 2010 CODATA recommended values, but will be adopted as exact values (i.e., with no uncertainty). They will never change no matter what new experimental results are obtained. Note that what is being proposed is analogous to the current definition of the meter in terms of an exact value of the speed of light in vacuum c. The value of c chosen in 1983 to define the meter, namely, c=299792458 m/s exactly, will never change.

Is that correct?

The proposal introduces a "correction factor" k via (1+ k) = (6.0221415× 10^(23))/NA whose value, by (3) above, is not known exactly (you list its current uncertainty as 0.2 × 10^(-8)) and is also changing in time. This implies that the formulas for your proposed calculations for u, M_u, A_r, M(X) and M(c-12) in Table 2 are not known exactly and are changing in time.

Is that correct?

Yes and no. First, the molar mass constant M_u is simply a symbol that represents the unit g/mol = 10^-3 kg/mol. Thus, "it is what it is," i.e., it does not change. Second, the relative atomic mass of an entity X, A_r(X), remains unchanged because it is still defined as m(X)/(m(12^C)/12). It is determined, for example, by measuring cyclotron frequency ratios and the actual mass of m(12^C) in kilograms is not required.

Third, the definition of u remains unchanged -- it is still 1 u = m(12^C)/12. however, the expression one must use to relate u to the kilogram is changed and changes with time; see column 3, line 1, of Table 2 of our 2006 Metrologia paper.

Fourth, The definition of the molar mass M(X) of an entity X (including 12^C) in terms of the mass of X, m(X), and N_A remains unchanged, but its calculation from the relative atomic mass of X, A_r(X), is changed and changes with time; see column 3, next to last line of Table 2.

With regard to the factor (1 + kappa), it is given by the expression after the second equals sign in Eq. (17) of our paper. Thus, it will change with time. However, The value of N_A chosen to define the mole will initially be taken equal to the expression on the right-hand-side of Eq. (16), hence (1 + kappa) will initially be equal to zero and with a relative uncertainty equal to that of this expression, which will be about 1.5 parts in 10^9.

You also stress that the definitions of units should preferably be "comprehensible to students in all disciplines", yet they seem to be difficult even for established scientists to understand, either intuitively or exactly. Could you please explain your three proposed new definitions of the kilogram in terms that are understandable to, say, mathematics and physics undergraduate students - for example, as the definitions might appear in chemistry and in physics texts?

I would sum up the kilogram definitions this way. The purpose of the three definitions of the kilogram in column 1 of Table 1 is simply to fix the value of the Planck constant h. Since the second, s, is defined in terms of the cesium 133 hyperfine splitting transition frequency, and the meter, m, is defined in terms of the speed of light in vacuum, by fixing h, the unit of which is m^2 kg s^-1, one defines the kilogram. That is, 1 kg = h m^-2 s/(6.626.... x 10^-34) [see column 2, p. 235, of our article]. Thus, since h is exactly known, any experiment that would allow one in principle to measure h, is in fact an experiment that allows one to realize the kilogram. The moving coil watt balance is just such an experiment, as is the XRCD method of measuring N_A. However, the watt balance does not require the determination of any other fundamental constant (the local value of the acceleration due to gravity is not really a fundamental constant), while the determination of h via N_A does (i.e., it requires alpha, A_r(e), and R_inf).

We applaud your attempt to streamline and modernize the SI units, especially in a way that will benefit and will encourage communication between the metrology and scientific communities, and look forward to your response to our questions.

Thank you for your time!

Regards

Ron Fox ron.fox@physics.gatech.edu

Ted Hill hill@math.gatech.edu

****
Barry N. Taylor
NIST, Bldg. 221, Rm. A255
100 Bureau Drive, Stop 8420
Gaithersburg, MD 20899-8420
USA
Tel.: 301-975-4220
Fax: 301-990-1350
Web: <http://physics.nist.gov/cuu>
<http://physics.nist.gov/cuu>
http://physics.nist.gov/cuu <http://physics.nist.gov/cuu>
****