Key features of the currently proposed revisions to the SI

In 1983 the definition of the metre was changed to give an exactly defined value of the speed of light *c*. In a similar way the recent paper in *Metrologia* by Mills et al.[1] is proposing that the kilogram, ampere, kelvin and mole should now be redefined so that they are linked to exactly defined values of the Planck constant *h*, elementary charge *e*, Boltzmann constant *k*, and Avogadro constant N_A respectively. The values could be based on the CODATA least-squares adjustment of the fundamental constants scheduled for 2010, thereby ensuring continuity in the magnitudes of the SI units, and the new definitions could then be adopted by the 24th CGPM in 2011. *Mises en pratiques* for the new definitions would be prepared by the appropriate consultative committees (CCs) of the CIPM, and the exact wordings of the new definitions would be developed by the CIPM through its CCs, other international bodies, and the national metrology institutes.

These redefinitions should proceed only if the data on which the values of *h*, *e*, *k* and N_A are based have sufficiently small uncertainties and are in acceptable agreement.

If these new definitions were to be implemented then all the base units of the SI except the candela would be defined in terms of the values of fundamental constants, which are the true invariants of nature. The benefits of these new definitions include:

(i) the guaranteed future ability of the SI to serve as the common measurement language in all fields of scientific and technical endeavour;

(ii) the new units, and particularly the base unit of mass, the kilogram, could be realised at any time, at any place, by anyone;

(iii) the Josephson and quantum Hall effects could be used to realise directly the SI electrical units, so that the current system of conventional electrical units could be abandoned;

(iv) a large number of the fundamental constants of physics would become exactly known, and the uncertainties of most other constants would be significantly reduced;

(v) a number of "energy conversion factors" would become exactly known, so that the mass of a particle would have the same relative standard uncertainty whether its value was expressed in kg, J, cm^{-1} (or m^{-1}), Hz, or eV;

(vi) the variation in the values of the remaining fundamental constants from one CODATA adjustment to the next would be significantly reduced.

These definitions would have the following further consequences.

(i) The mass of the international prototype of the kilogram would no longer be exactly 1 kg by definition, but would have to be measured experimentally and would have an uncertainty. The new definition would be chosen so that the mass of the prototype was 1.0 kg but with a relative standard uncertainty of about 2×10^{-8} (i.e. a standard uncertainty of about 20 μg), arising from the uncertainty in the mass of the prototype in relation to any true invariant such as the Planck constant.

[1] I M Mills, P J Mohr, T J Quinn, B N Taylor and E R Williams, *Metrologia* 2006, **43**, 227-246.

(ii) The magnetic constant (permeability of a vacuum) μ_0 would no longer be exactly $4\pi \times 10^{-7}$ N/A^2 by definition, but would have to be measured experimentally and would have an uncertainty. The new definition would be chosen so that μ_0 would have the same value but with a relative standard uncertainty of about 7×10^{-10} (see the paragraphs below for the calculation of this uncertainty).

(iii) The temperature of the triple point of water T_{tpw} would no longer be exactly 273.16 K by definition, but would have to be measured experimentally and would have an uncertainty. The new definition would be chosen so that T_{tpw} would have the same value but with a standard uncertainty of about 0.5 mK, corresponding to a relative standard uncertainty of about 1.8×10^{-6}.

(iv) The molar mass of carbon 12, $M(^{12}\text{C})$, would no longer be exactly 12 g/mol (= 0.012 kg/mol) by definition, but would have to be determined by experiment and would have an uncertainty. The new definition would be chosen so that $M(^{12}\text{C})$ would have the same value but with a relative standard uncertainty of about 1.5×10^{-9} (i.e. a standard uncertainty of about 18 ng/mol).

These uncertainties, which are the price one has to pay for the advantages of the new definitions outlined above, are in each case so small that they are of no real practical significance.

Aspects of the new definitions that are of particular relevance to electrical measurements

The present definition of the ampere is referenced to the force between wires carrying an electric current. This leads to the exactly defined value of the magnetic constant μ_0 (permeability of free space), and hence also of the electrical constant ε_0 (permittivity of free space) and the impedance of a vacuum Z_0 (since the speed of light c is an exactly defined constant and $\mu_0\varepsilon_0 = 1/c^2$, and $Z_0 = \mu_0 c$). This definition also links the ampere to the kilogram, so that suspected instability in the kilogram reappears in the ampere.

However this definition is somewhat artificial in the sense that it implies an experimental realisation of the ampere, using a current balance, which is actually a difficult experiment to realise and in consequence is never now performed. This definition was chosen sixty years ago, before the Josephson effect and the quantum Hall effect had been discovered. Defining the ampere in terms of a specified flow rate of elementary charges, as is now proposed, is also a more natural way of defining the unit in terms of our present day knowledge.

However the important point is that today all precise electrical measurements are made using Josephson and quantum Hall devices, which give highly reproducible results for electrical potential difference and electrical resistance. These experiments at present give results in terms of the 1990 conventional values for the Josephson constant $K_{\text{J-90}}$ and the von Klitzing constant $R_{\text{K-90}}$ that are assumed to be close to the true SI values $2e/h$ and h/e^2 respectively. Because the SI values of K_J and R_K are only known in terms of the present SI units with an uncertainty of a few parts in 10^7, i.e. a much greater uncertainty than the repeatability of the experimental measurements, this has led to the use of the conventional values $K_{\text{J-90}}$ and $R_{\text{K-90}}$ based on the best experimental data that was available in 1990.

The new definitions of the kilogram and the ampere that are now proposed would result in exactly known values for both h and e, and hence for both K_J and R_K, in terms of the new SI units, on the assumption that K_J can be taken to equal $2e/h$ and R_K to be equal to h/e^2. These are assumptions that for the purposes of a *mise-en-pratique* of the definition of the ampere are acceptable. They would thus lead to a significant simplification in all electrical measurements, and the elimination of uncertainties arising from uncertainties in the values of K_J and R_K. The conventional values K_{J-90} and R_{K-90} would no longer be required. This would be a big advance in the field of electrical metrology.

The new value of the fine-structure constant α from the improved measurement of, and theoretical expression for, the electron magnetic moment anomaly a_e has a relative standard uncertainty u_r of only 7×10^{-10} (see Odom et al., Phys Rev Letters **97**, 30801 (2006), and Gabrielse et al., Phys Rev Letters **97**, 30802 (2006)).

Since $\mu_0 = 2\alpha h / c_0 e^2$, it follows that μ_0, ε_0, Z_0 and Y_0 will be exactly equal to their current SI values with a relative standard uncertainty u_r of only 7×10^{-10} after redefining the kilogram and the ampere, and they will be unlikely ever to deviate from these values by more than say 2×10^{-9} (nearly 3 sigma). This will be true even if no further reductions in the uncertainty of α occur at the proposed time of adoption of the new units by the CGPM in 2011. Such an uncertainty and deviation have no practical significance.

It is also an important point that the Josephson and quantum Hall effects can be used to realize the SI base unit ampere, A, as well as the SI derived units volt, V, ohm, Ω, watt, W, farad, F, henry, H, and coulomb, C. All electric measurements are at present made in terms of conventional electric units, not SI units, i.e. in terms of A-90, V-90, Ω-90, F-90, H-90 and C-90, based on the conventional values of K_{J-90} and R_{K-90}. By fixing the value of e we completely eliminate the conventional electric unit system and replace it with the SI. We would thus be establishing electrical metrology on a true SI basis, which is not the case with the system used at present.

IMM and TJQ 4 October 2006