Letter to the Editor of *Metrologia*
(Rejected Mar 7, 2013; see excepts of Referees' reports below)

The Urgency in Redefining the Kilogram and Mole

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Abstract

This letter provides three compelling reasons for postponing the major overhaul of the SI called for in the CGPM's Resolution 1. First, in the time since the introduction of the proposed redefinitions, there have been significant advances in basic science that relate to the SI. Second, basic scientific criticisms of the New SI published by international experts have gone unanswered by either the architects of the New SI or the BIPM/CIPM. Third, the pending redefinitions contain fundamental flaws and confusing constructs, and require the introduction of an artificial new fundamental constant.

1. Introduction

There appears to be fairly general consensus that the SI needs modernizing [1], especially with regard to the definition of the kilogram (and, consequently, the mole). In sharp contrast to that consensus, however, there is strong disagreement on exactly how pressing it is to totally revamp the SI during the next few years.

Professor Ian Mills, President of the CCU and lead architect of the New SI insists that "the time is not only ripe, but urgent" [2, p 46]. Professor Richard Davis, on the other hand, former head of mass division at BIPM, counters that "It's not yet urgent…It's not causing aeroplanes to drop out of the sky. People have been living with this for years" [2, p 49].

The BIPM (and the CCQM in particular) has reiterated its commitment to encourage communication, awareness and debate on the possible revision of the SI as outlined in Resolution 1[1], and it is the goal of this letter to contribute to that debate. We will show that numerous critical issues remain unresolved and even unaddressed in this journal, and argue that caution warrants restraint in racing to adopt the New SI.

2. New advances in theory

After the proposed redefinitions of the SI base units were introduced by Mills, Mohr, Quinn, Taylor and Williams in 2005 [3] and 2006 [4], several key advances in physics and statistics have appeared that directly affect the underlying tenets of the proposed New SI.

First, additional evidence has appeared that the fine-structure constant, and hence also Planck's constant, may vary in time and location [5] – in fact, this research led to the Eureka Science

Award in 2012. The current proposal to base the kilogram on a fixed value of Planck's constant should be further examined in light of this new evidence.

Second, theoretical advances in statistics have led to a new mathematical method to combine data from different experiments [6]. The new method, "conflation", is easy to compute and is the unique method that minimizes the loss in Shannon information when combining data from fundamentally different experiments. As such, this new statistical technique may help resolve the current discrepancies in results from the watt-balance and silicon-sphere experiments used to detemine the Planck and Avogadro constants, and thus may affect the decisions regarding the choice of redefinition of several of the base units.

Third, and perhaps most relevant to the SI and proposed New SI, are two recent discoveries in physics. Researchers at the University of California and Lawrence Berkeley National Laboratories used momentum-spectroscopy on a recoiling atom to stabilize an oscillator, thereby providing a direct link between time and mass. Unlike the watt-balance's "auxiliary measurements and/or intricate theory", this method is "based on simple physical principles", and is reported to be "over 10 times more accurate than in the present SI" [7]. Researchers at NIST, in the meantime, have constructed an optical clock based on quantum logic spectroscopy of an Al+ ion that may be more than 100 times as accurate as the cesium clock [8]. Each of these discoveries warrants an in-depth analysis by BIPM/CIPM before a final decision is made with regard to redefinitions of the kilogram and second.

3. Unanswered criticisms of the New SI

Allegations of serious shortcomings of the proposed New SI have appeared recently in the scientific literature (e.g. articles [9, 10, 11], the summary [12], the BIPM website [13], and the entire issue of [14]). Among the most important of these unanswered criticisms are: the discovery by Russian metrologists that the proposed redefinition of the kilogram requires the introduction of a new quantum-mechanical current standard [9]; the physically-unrealistic order of magnitude 10^{41} of the constant inherent in the proposed redefinition of the kilogram [10]; and inconsistencies and/or circular arguments in the proposed redefinitions [11, 12, 15] (e.g., the proposed definition of the second specifies the temperature in kelvin of a cesium atom, and the definition of the kelvin specifies the value of the Boltzmann constant when expressed in units involving the second [1]).

4. Explaining the kilogram

The President of the CCU and other architects of the New SI have declared that "since it is important that the basis of our measurement system be taught in schools and universities, it is preferable, as far as modern science permits, that the definitions of base units be comprehensible to students in all disciplines" [4, p 228]. But seven years after proposing the New SI, they still have failed to produce a definition of the proposed Planck kilogram that is suitable for an introductory university textbook, let alone a textbook for beginning science students. When asked for such a definition, they responded that they are "not in the business of writing

introductory textbooks…[and] will leave that to others" [16]. After continued requests, the President of the CCU finally provided a 300-word "textbook definition" [17].

The importance of the comprehensibility of the New SI was reconfirmed by one of the NIST architects of the New SI in a recent lecture entitled "Proposed changes to the SI, their impact on fundamental constants, and other SI units" [18]. The presentation emphasized that "What is needed to implement the new system…[is to] Educate your community". In "Explaining the Kilogram", however, the definition provided was "The kilogram is the mass of 6.0221415×10^26 idealized atoms, each of these atoms having a mass such that the Planck constant, the most important constant in quantum mechanics, has the specified value of 6.6260693×10^(–34) joule second." There has been no answer to email queries about what an "idealized atom" is, and how it differs from the standard carbon-12 atom appearing in the formal SI definition of the dalton.

5. Hidden new fundamental constant

The issues surrounding the redefinition of the mole are even thornier than those surrounding the kilogram. The "new molar mass" constant M_u [1] in the proposed New SI is related to the quantity 12 g mol^{-1} in that the difference between them "carries the same information that is carried by the factor (1 + κ)" [19, p L19], where the term κ was introduced in [4]. The architects of the New SI confirmed that in fact one could call κ a "new fundamental constant"[16], so their New SI hinges on the introduction of an equivalent *new fundamental constant* M_u = (1 + κ) g mol^{-1}.

Leonard, too, noted the "confusing *ad hoc* inexact correction factors such as (1+ κ) or the proposed 'modified molar-mass' constant" [15], which remain unexplained. One of the NIST architects declared that κ (and hence M_u) "will change with time" [20]. Eight months later, another of the NIST architects declared that κ is *not* changing in time, but his colleague had instead "meant that our knowledge of kappa would be changing...I did not discuss it with him, but that is all it could possibly mean"[21], and noted that κ was "simply introduced for convenience and should not be allowed to cloud ones[sic] thinking" [22].

A year and a half later, the President of the CCU and lead author of the New SI conceded that "the (1+ κ) factor ... is confusing to many people and ... we now regret introducing" it [23]. Their solution, however, has been to simply conceal κ inside the modified mass constant M_u by setting M_u = (1 + κ) g mol^{-1}[3, 4; see also 15]. Thus, the proposed New SI is predicated on introduction of *ad hoc* new fundamental constant M_u , which some of its designers apparently maintain is changing in time, and which other of its designers maintain is constant but only our knowledge of it is changing.

6. Conclusions

The designers of the New SI themselves concede that key aspects of the proposed New SI are confusing. Coupled with the unanswered published scientific criticisms of the New SI, and the fundamental new scientific discoveries directly related to the SI, this certainly calls into question the wisdom of pressing for a complete restructuring of the SI at this time.

The pending Resolution 1 should be returned to the CCU, who should abolish its own Rule C that "The CCU has no observers" [24, 25]. The CCU should then reopen the debate on revising the SI, and welcome input and observers into its deliberations.

There is absolutely no harm in exercising patience in revising the SI. But rushing to install a New SI that requires the introduction of an artificial new fundamental constant, that is rife with defective and confusing definitions, and that will possibly soon be superseded by recent discoveries directly linking time, mass, and optics – *that* will cause future scientists incalculable waste of time and energy.

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POSTSCRIPT

After an earlier Letter to the Editor of *Metrologia* was rejected, I rewrote it completely and resubmitted. The revised version above was also swiftly rejected based on THREE negative referees' reports, including:

Ref report #1

"the author is at odds with the general body of expert opinion in the field...
the proposed changes; well, they have been under discussion for the last 20
years...I wonder if he has himself attended any of the several Varenna conferences on metrology held over the last fifteen years"

Ref report #2

"Unanswered criticisms, per se, are not valid motivations to reject the proposed redefinition...Before claiming that the pending redefinition is flawed, it is necessary to demonstrate an inconsistency or a contradiction in the new system...circularity is not an issue"

Ref report #3

"It is a Resolution adopted unanimously by the Member States of the Metre Convention and is the result of a great deal of prior discussion...this Resolution stems from meetings of expert Committees of the International Committee for Weights and Measures and that its Consultative Committee for Units, which includes the international scientific unions as well as the international standardizing bodies, also adopted the draft unanimously...One makes the best one can of science as it is today, otherwise we would be waiting for ever before any change was made. The contrast is, or at least should be, between science as it is today and science as it was in the late 19th century when the present kilogram was defined"

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TPH