Letter to the Editor of *Metrologia*
(Rejected June 21, 2012; see excerpt of Referee report below)

Confusion within the "New SI"

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Abstract
This letter pinpoints basic confusion about the proposed New SI, even among its own architects. The pending proposal for redefinition of the SI base units should be withdrawn, and the open debate continued until the CCU and CIPM eliminate the confusion.

1. Introduction

At its 24th meeting (October 2011), the CGPM adopted a Resolution on the possible future revision of the base units of the International System of Units (SI) that is used worldwide both in everyday commerce and in science. The BIPM has reinforced its commitment "to encourage communication, awareness and debate on the possible revision of the SI" as outlined in the Resolution [1]. In the proposed New SI, four of the base units would hinge on the reference constants, h, e, k and N_A, different from the ones currently used. Serious shortcomings of the proposed New SI definitions have recently appeared in the scientific literature (e.g. articles [2, 3, 4], the summary [5], the BIPM website [6], and the entire issue of [7]).

Additionally, in a new article in *Metrologia*, Leonard [8] identifies explicit problems with the proposed redefinitions of the kilogram and mole if the current definition of the dalton were to be retained. He provides a compelling argument for why the dalton should be redefined exactly in terms of the kilogram, and in doing so, exposes the "confusing *ad hoc* inexact correction factors such as (1+kappa) or the proposed 'modified molar-mass' constant" [8] appearing in the proposed New SI. Confusing to whom? Confusing to other scientists and metrologists, certainly, but they even appear to be confusing to the architects of the New SI.

2. Three basic questions

After the proposed redefinitions of the SI base units were introduced by Mills, Mohr, Quinn, Taylor and Williams in 2005 [9] and 2006 [10], we wrote the authors asking several questions related to their proposal: 1) Is kappa changing in time? 2) Is kappa a new "fundamental constant"? 3) What is their proposed introductory-level textbook definition of the fixed-Planck-constant kilogram?

3. Responses to questions

Responding to the first question, one of the NIST authors of the New SI stated that "the factor (1+ kappa)...will change with time" [11]. He copied this message to his four coauthors,

explicitly inviting them to add to what he had said. When none did so for more than two months, the same NIST author responded to the second and third questions, writing, "one could call (1 + kappa) a new fundamental constant", and "I am not in the business of writing introductory textbooks – I will leave that to others" [12].

That message, too, was copied to his four coauthors, and five months later one of them responded that kappa 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"[13]. Incredibly, the coauthor with whom he did not even bother to discuss it for five months was at his same institute! Again no comments or disclaimers or textbook definition of the kilogram materialized from the rest of the New SI authors. Apparently realizing that the answers to the basic questions regarding kappa were still confusing, this second NIST author wrote us that kappa was "simply introduced for convenience and should not be allowed to cloud ones[sic] thinking" [14].

A year and a half later, the lead author of the New SI proposal in [9, 10] finally weighed in and conceded that "the (1 + kappa) factor ... is confusing to many people and ... we now regret introducing" it [15]. What was their solution to this problem? Not to modify any of the underlying theory of their proposed New SI, but simply to conceal kappa inside a "modified mass constant" Mu by setting Mu = (1 + kappa) g/mol [16, 17; see also 8]. Thus, in lieu of any clarification from the authors of the New SI, Mu must *a fortiori* also be considered a new fundamental constant...one which some of its designers apparently think is changing in time, and one which other designers of the New SI think is constant but only our knowledge of it is changing.

4. Bigger picture

The intrinsic problems with the dalton, the mole, and kappa (including its camouflaged form Mu) are only the tip of the iceberg. One of the coauthors of the New SI recently wrote that "it would be an egregious and unjustifiable error to abandon the beauty and many benefits of the New SI just because a 12 year old student might not be able to understand it" [18]. Forget 12-year-olds. The architects themselves are not able to provide consistent answers to simple questions about their proposal, including the question whether or not the Avogadro constant is a fundamental constant of nature.

And at the very heart of the New SI, the redefinition of the kilogram, the proposed fixed-Planck-constant kilogram is so convoluted that even after five years of prodding, its expert authors cannot provide a textbook definition that is understandable to mainline university science students. As far as meeting the CIPM goal of providing definitions that are understandable to students in all disciplines, the New SI fails miserably. Any possible "beauty" that the New SI is supposed to provide evaporates instantly if the most basic definitions are opaque even to university science students and teachers.

5. **Conclusion**

Scientists and metrologists have raised serious unanswered criticisms about many aspects of the New SI, and the fixed-Planck-constant kilogram in particular. The BIPM explicitly and actively encourages communication, awareness and debate on the possible revision of the SI, and there is absolutely no necessity to replace the current SI in the next year or two. As the previous head of the Mass Section at BIPM stated, a complete overhaul of the current SI is "not yet urgent … people have been living with this for years". And there is certainly no pressing need to adopt a New SI that its own architects, including the Chair of the CCU himself, admit is "confusing to many people".

The proposed New SI is poorly conceived, and should be withdrawn immediately.

Acknowledgement. The author is grateful to two anonymous colleagues for valuable suggestions.

References (all emails referenced will be provided upon request)

[1] BIPM Resolution 1 of the 24th CGPM 2011 *On the possible future revision of the International System of Units, the SI* http://www.bipm.org/en/si/new_si/

[2] Khruschov A 2010 Fundamental problems in metrology; possible definition of the unit of mass and fixed values of the fundamental physical constants, *Meas. Tech.* **53** 583–91.

[3] Hill T P, Miller J, and Censullo AP 2011Towards a Better Definition of the Kilogram, *Metrologia* 48, 83-86 .

[4] Chyla W T 2102 On the proposed redefinition of the mole *Metrologia* 49 L11–L13.

[5] Hill T P 2011 Criticisms of the proposed "New SI", *Accreditation and Quality Assurance* 16 (8-9), 471-472.

[6] BIPM "New SI": *Discussion in the Scientific Literature*, http://www.bipm.org/en/si/new_si/

[7] De Bièvre P (Ed.) 2011 *Accreditation and Quality Assurance* 16(3) March.

[8] Leonard B P 2012 Why the Dalton should be redefined exactly in terms of the kilogram, *Metrologia* XXX, XXX.

[9] Mills I M, Mohr P J, Quinn T J, Taylor B N and Williams E R 2005 Redefinition of the kilogram: a decision whose time has come *Metrologia* **42** 71–80.

[10] Mills I M, Mohr P J, Quinn T J, Taylor B N, and Williams E R 2006 Redefinition of the kilogram, ampere, Kelvin, and mole: a proposed approach to implementing CIPM recommendation 1 (CI-2005), *Metrologia* 43, 227-246.

[11] Taylor B N 2007 Personal communication via NIST email February 18.

[12] Taylor B N 2007 Personal communication via NIST email May 4.

[13] Mohr P J 2007 Personal communication via NIST email October 25.

[14] Mohr P J 2007 Personal communication via NIST email November 5.

[15] Mills I M 2009 Personal communication via University of Reading email May 1.

[16] Taylor B N 2009 Molar mass and related quantities in the New SI *Metrologia* **46** L16–L19.

[17] Milton M J T and Mills I M 2009 Amount of substance and the proposed redefinition of the mole *Metrologia* **46** 332–338.

[18] Taylor B N 2011 Personal communication via NIST email June 30.

Excerpts from Referenced Emails

[11] Taylor B N 2007 Personal communication via NIST email February 18.

> Subject: Re: Redefinition of kilogram
> Date: 2/18/07 7:40:42 PM
> From: "Barry Taylor"<barry.taylor@nist.gov>
> 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
>
> [part deleted]
>
> 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.
>
> [part deleted]

[12] Taylor B N 2007 Personal communication via NIST email May 4.

> Subject: Re: Redefinition of kilogram
> Date: 5/4/07 8:54:54 PM
> From: "Barry Taylor" <barry.taylor@nist.gov>
> To: "Ted Hill" , i.m.mills@reading.ac.uk, mohr@nist.gov, terry.quinn@physics.org, edwin.williams@nist.gov
> Cc: ron.fox@physics.gatech.edu

[part deleted]

>3. Isn't kappa essentially a new fundamental constant?
> (it seems to be the crucial link between your new proposed numerical definitions of
> fundamental constants and the physical world of real atoms - e.g.via amu/carbon-12)

I suppose one could call (1 +kappa) a new fundamental constant if
one wishes to do so, but one should keep in mind that it is really
just a combination of well known constants and writing the combination
as (1 + kappa) is for convenience. Note that in the new SI we have

(1 + kappa) = (2R_inf N_A h/)[c alpha^2 A_r(e) M_u], (2)

where N_A is the Avogadro constant and M_u is the molar mass constant,
equal to 10^-3 kg/mol exactly.

[part deleted]

>4. What is your proposed introductory-level textbook definition of a
>kilogram (cf your Table 1)? (including all the necessary pre-definitions, such as de
>Broglie, Planck, photon frequency etc)

I am not in the business of writing introductory textbooks -- I
will leave that to others. All I will say is that we do not believe
any of the proposed new definitions are any more complex than the
current definitions of some of the SI base units.

[part deleted]

[13] Mohr P J 2007 Personal communication via NIST email October 25.

Subject: Re: N_A questions
Date: 10/25/07 2:20:02 PM
From: "Peter J. Mohr" <mohr@nist.gov>
To: hilltp66@charter.net
Cc: rf17@mail.gatech.edu

[part deleted]

>Thank you again for your time on the phone last week, and your patience.
>You said that if I had any concrete questions, that you would try to answer them.
>After rereading your 2006 Metrologia paper, I still am confused about k (kappa).

>In equations (14) and (17), what are N_A and N~_A exactly?

In either case, N_A is the number of entities in a mole. The difference is that N_A is the number of entities in the mole as currently defined, and ~N_A is the number of entities in the new redefined mole. They are not the same number, because the definition of the mole is different in each case. Barry and I do not disagree. He meant that our knowledge of k would be changing as I did. I did not discuss it with him, but that is all it could possibly mean, since the definition is of k is not changing.

[part deleted]

[14] Mohr P J 2007 Personal communication via NIST email November 5.

Subject: Re: Questions
Date: 11/5/07 10:44:07 AM
From: "Peter J. Mohr" <mohr@nist.gov>
To: rf17@mail.gatech.edu
Cc: barry.taylor@nist.gov, hilltp66@charter.net

[part deleted]

After the redefinition, N~_A will never change, because by definition, it is the number of entities in the newly defined mole which is now just a certain number. However, N_A, which is the number of particles in the mole as previously defined will reflect any changes in our knowledge. In particular, the number of entities in 0.012 kg of carbon may become better known than it is at the time of the redefinition, since with the old definition, it is a number that depends on the results of experiments. It may even eventually disagree with the value at the time of the redefinition. The main point is that the old definition does not tell us the actual number of particles in a mole, but only gives us a way to find the number experimentally.

You can work out for yourself the consequences for kappa, which was simply introduced for convenience and should not be allowed to cloud ones thinking.

[15] Mills I M 2009 Personal communication via University of Reading email May 1.

From: Ian Mills <i.m.mills@reading.ac.uk>
Date: May 1, 2009 10:57:03 AM EDT

To: "Leonard,Brian P" <bpleona@uakron.edu>, IAN MILLS <ian704mills@btinternet.com>
Cc: 'Claudine Thomas' <cthomas@bipm.org>
Subject: Re: Upcoming CCU Meeting Comments

Dear Dr Leonard,

Thank you for your message and attachment. I have read and follow your ideas.

I think a major problem with your suggestion that would make it difficult for many people is that your proposal would mean that the atomic mass of the carbon 12 atom would no longer be exactly 12 Da. (At present the unified atomic mass unit, symbol u, is simply an alternative name for the dalton, symbol Da. I am not sure what you propose for the u.) I think that chemists would not like this change. That is what has lead us to prefer to redefine M_u as (1/12) of the molar mass of carbon 12, accepting that this would no longer be exactly 1 g/mol. We prefer to describe it this way, without introducing the (1+kappa) factor, which is confusing to many people and which we now regret introducing. We feel that chemists will not wish to change the so-called "atomic weights" which everyone is used to, which are actually relative atomic masses relative to carbon 12 as exactly 12. We shall see what the CCU decides to do.

[part deleted]

[18] Taylor B N 2011 Personal communication via NIST email June 30.

Date: Thu, 30 Jun 2011 14:12:18 -0400
From: "Taylor, Barry N." <barry.taylor@nist.gov>
Subject: RE: The new SI
To: 'Anders J Thor' <athor@mech.kth.se>
Cc: 'Ian Mills' <ian704mills@btinternet.com>, "tjqfrs@gmail.com"

[part deleted]

(1) I am in complete agreement with Terry's email. Simply put, it would be an egregious and unjustifiable error to abandon the beauty and many benefits of the new SI just because a 12 year old student might not fully understand it.

[part deleted]

Excerpts from Referee's Report (June 21 2012)

…The paper only expresses a viewpoint, among the many based on matter of preferences and convenience. I don't see scientific or technical results of such a significance to deserve a publication. In addition, a scientific journal like Metrologia is not a forum where to find an agreement about the conventional aspects of the choice of the measurement units or where to

discuss teaching issues. As regards a discussion of the didactical aspect implied in the proposed SI changes, the American Journal of Physics and the European Journal of Physics are more appropriate. For these reasons, I am afraid to suggest that this paper is rejected.