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LETTER TO THE EDITOR

Some simple principles for basic measurement system construction

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Dear Sirs:

The problems created for chemical measurement by the 1971 inclusion of the thermodynamic 'mole' in the Système International (SI) measurement units are a salutary lesson to all other measurement disciplines seeking inclusion in the SI. Do not do it! By all means make units useable with the SI but do not surrender basic principles.

Chemical measurement has a serious semantic problem. Most analysts, not unreasonably, regard the SI as fundamentally irrelevant as far as the thermodynamic 'mole' is concerned and continue to use the earlier chemical mole, understood as an Avogadro *number of specified things*. However, the users of their measurements do not have this understanding. They examine the SI Brochure [1] to find to their surprise that a 'mole' is something quite different, having to do with a thermodynamic quantity puzzlingly named 'amount of substance'. The next edition of the brochure [2] will make the difference even starker and more inexplicable. The longstanding ambiguity of two 'moles' cannot continue into the twenty-first century. Analysts need to consider their options. The term 'mole' is unsuitable for clear communication; it has two incompatible meanings. Chemists themselves need to clear up this confusion for it is clear that the SI will not. The solution is simple for metrology in chemistry. All we need is a new name for an Avogadro *number of things* that cannot be confused with the thermodynamic 'mole' and to make it crystal clear that the quantity we measure is a *number of things* and not the inexplicable thermodynamic construct termed 'amount of substance'.

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The new name is obvious. It is an Avogadro *number of things*, although the obvious common abbreviation will be the avo. It's equally obvious symbol is Av, following well-accepted conventions for honouring appropriate scientists, in this case Amedeo Avogadro (1776–1856). The avo is a unit that can be used with the SI but it is not of the SI. It is SI compatible. It is not a base unit. The base unit for its corresponding quantity is one specified thing. Leonard calls it the entity (symbol ent) [3]. As Leonard shows, there are many ways in practice to construct a system of measurement units, with a variety of advantages, disadvantages, and risks.

There are a few essential requirements of any practical system of measurement units. The first and highest priorities are that it be simple, concise, clear, and most essential of all, comprehensible to all users. This includes especially the audience to which the measurement results are communicated. A *number of things* is the simplest and most comprehensible quantity there is. That cannot be said of 'amount of substance'.

The next priority is that it be well anchored. Anchoring chemical measurements in an Avogadro *number of things* is simple in concept and straightforward, dependent vitally on the specific measurement problem at hand. Its ultimate anchor is the notion of one thing. After four decades, we still do not know how to anchor an 'amount of substance' for we still do not know in clear and concise terms what it is.

The next priority, and one implied by the previous, is to strive for maximum independence of the base units and quantities. This may be a counsel of perfection, but it is something to strive for. However, there is at least one measurement unit that is independent of all others. It is one thing (or entity). One thing is what it is, quite irrespective of what other measurement units one may choose. If one

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thing is not some kind of base unit, and a *number of things* is not a base measurement quantity, then you cannot have a credible measurement system. They are required by simple logic. If counting and numeration are not genuine measurement, then why not and exactly what is?

Again following from the previous priorities, there is the principle of direct reference: define base units as directly as possible by reference to a stable, natural, accessible example of the specific quantity. This is a trivial exercise for one thing and indeed, for an Avogadro *number of things*. A direct referent for an 'amount of substance' is not a possibility. It must be inferred. Intrinsically, it can be neither independent nor direct.

Finally and not to be ever forgotten is flexibility. A system of measurement units must be able to evolve to include new kinds of quantities and units as the demands of measurement in our world require. It must be open to change as our understanding grows. Timeless principles are out. It must be robust. A system of measurement units is a working tool for getting on with the essential job of ensuring for all users that measurements are in fact, what they are purported to be. It is always a work in progress, slowly rebuilt and renewed by actual measurement practice even as it goes about its work.

In addition to the essential requirement of facilitating communication among humans, a very desirable attribute of a modern measurement system is also of course to facilitate communication of humans with machines and of machines with machines [4]. The most notable features of twenty-first century measurement are databases, sensors, instruments, and informatics generally. This is especially the case for chemical measurement.

On none of these criteria is the SI a credible or useable means to concisely and accurately communicate chemical measurement results.

So let us explain the idea of a *number of things* to our clients, get into the habit of reporting our results in avos and get on with the proper task of making chemical measurements as clearly communicated, as accurate and as well anchored as we can make them.

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