to be presented at the 33rd IUPAC General Assembly
in Lyon, France – 30 August–7 September, 1985.

BNL–NCS–36952

The Atomic Weight Versus Atomic Mass Controversy. *

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I. Introduction.

A nagging problem for the Atomic Weights Commission for the past decade has been the controversial battle over the names 'atomic weight' and 'atomic mass'. The Commission has considered the arguments on both sides over the years and it appears that this meeting will see more of the same discussion taking place. In this paper, I will review the situation and hopefully offer some reasonable alternatives. There is already an additional suggestion, which differs from past options, that has come from our chairman[1]. I will discuss this new proposal along with some other ideas on the subject. A serious effort should be made to consider what if any of these various proposals might provide an acceptable way out of what has become an unending dilemna.

The present term used to express the data, which we have been compiling and evaluating since the turn of the century, 'atomic weight', has had a history which was closely allied with the development of modern chemistry[2]. As I have stated on previous occasions[3], I do not think that the term 'atomic weight' should be replaced unless the alternative, which is introduced is, in fact, an improvement. In other words, I do not hold with change for the sake of change. While hoping not to repeat everything that our chairman has stated in his excellent paper, let us quickly review the major arguments and suggestions that have been made in a short history of the present problem and then see if any of these proposals or even combinations of proposals might allow us room to produce an acceptable compromise. We should keep in mind the true meaning of compromise, i.e. a solution which makes everyone somewhat unhappy and upset.

II. History of the Problem.

The term 'atomic weight' was not used by Dalton in his early papers[4]. He tabulated the relative weights of ultimate particles, which included both weights for elements as well as compounds. The use of the term 'relative weight' was due to the use of gravimetry by Dalton. It was not imagined that one would someday be able to determine the mass of an atom. Kolb[5] quotes the verse:

They laughed when they heard Aston say
He would weigh tiny atoms one day
But he had the last laugh – with his mass spectrograph
He 'weighed' them a different way.

The major problem during the last century dealt with whether or not 'atoms' really existed. As late as the beginning of this century, Ostwald opposed the atom on the principle that its existence was undemonstrated. Radioactivity, Brownian motion and cathode rays indisputably established the particulate nature of matter and the opposition of a century faded.

With the invention of the mass spectrograph, scientists were able to determine mass ratios by physical means. The previous chemical determinations were always given relative to some standard. Since the weighings of the sample and the standard had been performed in a common gravitational field, the relative atomic weights and the relative atomic masses would be numerically identical.

The discovery of the isotopes of oxygen[6] led to a situation in which physicists used a scale with $^{16}O = 16$, while chemists used an elemental oxygen = 16 scale. When the isotopic composition of oxygen was found to be variable in nature[7], a variable difference in scales was introduced. After agreement by physicists and chemists, a new scale with $^{12}C = 12$ was adopted and a new table of atomic weights was prepared in 1961[8].

With the new standard, the International Commission on Atomic Weights, (ICAW), proposed to change tha name 'atomic weight' to 'relative atomic mass'. However, the Commission on the Nomenclature of Inorganic Chemistry of the International Union of Pure and Applied Chemistry, (IUPAC), reported to the Inorganic Chemistry Division that 'atomic weight' should be retained with the argument "from dimensional considerations it is quite irrelevant whether the term 'atomic weight' is retained or whether it is replaced by the term 'relative atomic mass'. Since the former is a well-established term with a definite meaning which has been used by chemists for a long time without giving rise to any confusion, the Commission on Nomenclature recommends that 'atomic weight' be retained inasmuch as the other alternative might be confused with the atomic mass of a single isotopic species. If it is felt, however, that the term 'atomic weight' should be abandoned for some reason, then it should be replaced by a term which indicates that it is actually a pure number".

As an interesting side note to this change, some members of the ICAW had proposed that the Commission should be disbanded and its work done by the IUPAP Commission on Atomic Masses. As noted above, this proposed name change failed to gain IUPAC approval. As a result, this other suggestion was also discarded.

After this decision by the Inorganic Division, the ICAW reaccepted the term 'atomic weight', until it was informed by the Commission on Symbols, Terminology, and Units, (Commission I.1), of IUPAC after its' 1969 meeting that the continued use of 'atomic weight' by the ICAW was causing IUPAC to break its' agreement with IUPAP not to recommend conflicting names. This situation resulted from Commission I.1 recommending 'relative atomic mass of an element' as a replacement for 'atomic weight' in the Terminology Manual

for Physicochemical Quantities[9]. A series of joint meetings with other Commissions and interested parties at IUPAC General Assemblies during the mid and latter part of the 1970's lead to a new definiton of 'atomic weight (mean relative atomic mass)'[10].

Having settled on a better definition, a series of papers with proposals for changing the name 'atomic weight' or with arguments for retaining the continued use of the expression, 'atomic weight', provided a background for recent discussions.

III. Proposals for Change.

Behind the various proposals for changing the name 'atomic weight' lies the author's conclusion that there are problems with continued use of the term. Rigg[11] has ennumerated some of these difficulties as follows:

1. a problem with the term 'weight' itself,
2. a problem with the factor of 1000 or 0.001 between g/mol and the coherent unit kg/mol when calculations are done,
3. a problem with the reference system from H = 1, to O = 16, to ^{12}C = 12,
4. a problem with the concept of atomic weight, since Dalton would have applied the term to any sort of component that could be counted, and
5. a problem with the atomic mass unit for biochemists, who prefer to replace the unified atomic mass unit (u) with the dalton (Da).

The first problem is an obvious one with the physicist's distinction between mass and gravity force (weight) possibly leading to confusion when a mass ratio is expressed as 'atomic weight'. The second problem, which will be touched on later in this paper, deals with the fact that the SI unit for mass is not grams but kilograms and a factor of 0.001 or 1000 is often left out of calculations. The only problem with the reference system in the third problem would be the factor of 1.00024 between the values for colloidal particles and viruses determined when the O = 16 scale was used and those determinations done on the ^{12}C = 12 scale after 1961. The fourth problem mentioned that Dalton actually included compounds as well as elements in his work is certainly true. The final problem indicates that for some biochemists, the unified atomic mass unit, u, is confused with an old enzyme unit, U, (1 μmol/min). The proposed solution, according to Rigg, is to express the 'atomic weight' in mass units with the designation dalton.

In a similar manner, Freeman[12] indicated that although the term 'atomic weight' is not wrong, it has two major difficulties. The definition of 'atomic weight' in terms of the mass of an atom causes difficulties for students taught the distinction between 'weight' and 'mass' in physics class. The definition of atomic weight as a dimensionless ratio is a more difficult concept for students than is the idea of expressing (average) atomic masses in atomic mass units. To solve these two difficulties, Freeman proposes to make the quantity have dimensions of mass and call it (average) atomic mass of the element.

Cohen[13] pointed out the distinction between the molecular mass and the molar mass is in the (fictitious) reference standard (10^{-3}kg/mol). He discusses the desirability of assigning a symbol to the quantity, '10^{-3}kg/mol'. He is concerned that the numerical equivalence will tend to obscure the dimensional differences and that the distinction between mass, molecular mass and molar mass will be ignored.

Martin[1] has reviewed these same arguments and comes to the conclusion that the term 'atomic weight' should be changed to 'atomic weight ratio' or 'atomic mass ratio'. This would obviously eliminate some of the above objections. He also proposes the name dalton (Da) for the quantity defined as one-twelfth of the mass of an atom of the nuclide ^{12}C in its nuclear and electronic ground state, i.e. Cohen's fictitious reference standard. He would change the name of the Commission and the name of the tables which it provides to be consistent with the new name.

IV. Discussion of Proposals.

On previous occasions, I have discussed the various objections to the term 'atomic weight'[14]. The major arguments have been that if the term is not in error, or if a change is not a definite improvement to the existing terminology, then it is not necessary to make a change at this time. I will address only new considerations at this point to eliminate duplication.

The proposal of atomic weight ratio by Martin would eliminate part of the problem referred to above. Students could no longer be confused by a quantity which is defined as a ratio if it is also called a ratio. However, a more fundamental question should be addressed. Although the atomic weight has historically always been a ratio and therefore dimensionless quantity, this is probably due to the impossibility of determining absolute values of masses or weights at the atomic level at the beginning of the nineteenth century. Is there still a reason, other than historical precedence, for not expressing the atomic weight as a dimensional quantity, i.e. in mass units? If the answer to this question is in the negative, then the problem resolves itself into finding an appropriate name for an elemental mass. Since the atomic masses of the nuclides, which are used to calculate the atomic weights, are themselves determined relative to the ^{12}C standard and yet are expressed in mass units, it becomes rather hard to justify the failure to follow suit with the abundance weighted average of these masses. Once the Commission can make a determination on this point, the decision on a name should merely be a matter of finding a suitable adjective to modify the term mass.

Martin's other suggestion, i.e. to give Cohen's fictitious reference standard the name dalton (Da), is rather interesting. This would enable the biochemists to use this symbol to express their rather large masses for viruses and colloidal particles in convenient units.

On this whole problem, it is important to keep in mind the role of the teacher and the influence on the next generation of scientists. It has often been stated that revolutions in science do not occur with a new or unusual idea convincing the 'old guard' scientists, but with resistence to the new idea dying out with the death or retirement of the old guard. We should convince ourselves that by resisting a new concept, e.g. redefining atomic weight as an mass rather than a mass ratio, we are not merely attempting to delay the inevitable acceptance of the concept. Personally, I do not see the next generation of scientists continuing to resist the change. However, it is up to the Commission, as a whole, to decide what should be done in this matter. Perhaps a two year interval until the next General Assembly will allow the members to give this matter the necessary time to adjust their thinking and if the move to a mass rather than a mass ratio concept is acceptable, also provide the time to come up with a suitable name to replace the time honored 'atomic weight'.

V. Acknowledgements

The author acknowledges helpful correspondence over the years with J. C. Rigg (Div. VII), R. D. Freeman (Comm. I.2), E. R. Cohen (Comm. I.1) and H. S. Peiser (Comm. II.1), which aided in the preparation of this paper.

VI. References.

1. R.L.Martin, priv. comm. 'Atomic Weight Ratio, Molar Mass and the Dalton' attachment to CAWIA Memorandum 1/85, (Jan. 17, 1985).
2. N.E.Holden, Chemistry International (1), 5 (1984).
3. N.E.Holden, Chemistry in Australia 49, 135 (1982).
4. J.Dalton, Mem. Proc. Manchr. lit. phil. Soc. 1, 271 (1805).
5. D.Kolb, J. Chem. Ed. 54, 543 (1977).
6. W.F.Giauque and H.L.Johnson, J. Am. Chem. Soc. 51, 3528 (1929) and Nature 123, 831 (1929).
7. M.Dole, J. Am. Chem. Soc. 57, 2731 (1935).
8. A.E.Cameron and E.Wichers, J. Am. Chem. Soc. 84, 4175 (1962).
9. Commission on Symbols, Terminology and Units, Pure Appl. Chem. 21, 1 (1970).
10. Commission on Atomic Weights and Isotopic Abundances, Pure Appl. Chem. 52, 2349 (1980).
11. J.C.Rigg, Clin. Chem. Newsletter 3, 29 (1983), and Chemistry International (5), 2 (1982).
12. R.D.Freeman, Chemistry International (2), 8 (1982). See also, priv. comm. (Jan. 26, 1982).
13. E.R.Cohen, priv. comm. (July 8, 1981, Aug. 6, 1981 and Nov. 22, 1982).
14. N.E.Holden, Brookhaven Report, BNL-NCS-31694 (1982).

*Research carried out under the auspices of the U.S.Department of Energy under Contract No. DE-AC02-76CH00016.