New Reference Nuclide

The use of ^{12}C as the basis for a unified scale of nuclidic masses and atomic weights is proposed.

T. P. Kohman, J. H. E. Mattauch, A. H. Wapstra

There exist at present three scales of atomic masses or weights: (i) the absolute scale based on the gram, (ii) that defined by taking the mass of one atom of the nuclide ^{16}O equal to 16 units (the "physical scale" of "atomic masses" or "nuclidic masses"), and (iii) that taking the average atomic mass of the isotope mixture of "natural" oxygen as 16 units (the "chemical scale" of "atomic weights"). Of these, only the last two are in common and extensive use. The chemical scale is indefinite to the extent of the variation in the average atomic mass of oxygen from various natural sources (some 15 parts per million) resulting from variations in the relative proportions of ^{16}O, ^{17}O, and ^{18}O.

Recently, proposals for improving this situation have been made and discussed. These discussions concern (i) how the definition of the chemical scale can best be made more precise, (ii) whether or not the physical and chemical scales ought to be unified, and (iii) whether the definition of the physical scale could perhaps be improved as well.

The most extensive recent discussion of the problem of the mass scales is that of Wichers (*1*), who invites consideration and expressions of opinion by interested persons. Accordingly, we wish to bring into the light of public discussion a proposal which has received considerable consideration in private and which seems to have merit with respect to all three of the afore-mentioned points.

The existence of two sets of mass values differing slightly but significantly, even were the present uncertainty of the chemical scale to be eliminated by a more precise definition, in itself causes some confusion, which is often reflected in pedagogic difficulties. But more serious is the necessity of having two values, one for each scale, of the universal molar "constants," in particular the Avogadro number, the Faraday constant, and the gas-law constant. The necessity of matching the proper value of the Avogadro number with the mass values employed arises especially often in the domain of nuclear chemistry.

Proposals to unify the scales by adopting the physical scale for chemical atomic weights have been regarded with disfavor by many chemists because of the relatively large change, about 275 parts per million, which would have to be made in all of the quantities whose values depend on the size of the mole. There are many physicochemical data whose precision is greater than that and whose values would therefore have to be changed. On the other hand, the serious consideration which has been given by chemists (*1, 2*) to the proposal of a new unified scale based on $^{19}F = 19$, which would result in a change of 41 parts per million, indicates that many chemists would be willing to accept a unified scale if the atomic weights would not be changed by more than about this amount. There are relatively few chemical data bearing such high precision.

12-Carbon

Fortunately, there is a possible scale definition which, as the basis of a unified scale, would suit chemists and by which, moreover, physicists would benefit greatly. In order to see this we may start by asking why physicists use a relative mass scale and do not give atomic masses in grams. The reasons are twofold: (i) By making a suitable definition of the atomic mass unit, every nuclidic mass can be made very nearly equal to the number *A* of nucleons in the nucleus, which has obvious advantages. (ii) Masses can be expressed much more accurately in relative than in absolute units (precision of about one part in 10^7 instead of three parts in 10^5). The determination of nuclidic masses to six, seven, or even eight significant figures is more than just an exercise in precision. Slight variations in mass represent relatively large changes in the binding energy of nucleons and may give important information on the nature of nuclear forces. Thus, nuclear physicists will continuously strive to improve the precision because an additional decimal place may reveal hitherto obscure effects of fundamental importance.

Evidently, that definition is to be preferred which allows most nuclidic masses to be expressed with the smallest errors, not only now but also in the foreseeable future. As is shown below, this purpose is fulfilled by taking ^{12}C as the reference nuclide. The best definition of the atomic mass unit is, accordingly,

Mass of ^{12}C equals exactly 12 atomic mass units.

The unit defined in this way is 318 parts per million larger than the present physical mass unit and 43 parts per million larger than the present chemical one.

Physics

To our knowledge, this proposal was first made independently by the physicist A. O. Nier and by the chemist A. Olander (*3*). Although the proposal was not discussed at the 1957 meeting of the Commission on Atomic Weights of the International Union of Pure and Applied Chemistry, a note pointing out the advantages to physicists of ^{12}C as a reference nuclide was appended to the report of the commission (*4*). Briefly, these advantages are the following.

In the mass-spectroscopic determination of nuclidic masses, the most important substandard is ^{12}C. Not only do the doubly, triply, and quadruply charged atomic ions of ^{12}C occur at integral mass numbers so that they can be paired in doublets with nuclides having mass numbers 6, 4, and 3, respectively, but—much more important—no other element besides carbon can be found which forms molecular ions containing as many atoms of but one kind (up to 10 and more). Therefore, the scale $^{12}C = 12$ would allow many more direct doublet comparisons of masses, especially of heavy nuclides, with the reference nuclide than any other scale. 12-Carbon has the ad-

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Dr. Kohman is professor of chemistry at Carnegie Institute of Technology, Pittsburgh, Pa. He is on leave for 1957–58 at the Max-Planck-Institut für Chemie, Mainz, Germany, as a National Science Foundation senior postdoctoral fellow. Dr. Mattauch is director of the Max-Planck-Institut für Chemie. Dr. Wapstra is on the staff of the Instituut voor Kernphysisch Onderzoek, Amsterdam, Netherlands.

ditional advantage that carbon forms many more hydrides than any other element, so that an easy reference line for doublets can be produced at almost every mass number up to $A \sim 120$. Many stable nuclides in the mass region $120 < A < 240$ can also be measured in reference to ^{12}C by pairing in doublets their doubly charged ions with singly charged ions of $^{12}C_n$ or of $^{12}C_nH_m$ fragments. Use can then be made of nuclear disintegration data to obtain accurate masses of many other, especially unstable, nuclides.

With ^{16}O as the official reference nuclide, mass spectroscopists have been forced to spend much time and effort in measurements of the ^{12}C to ^{16}O mass ratio, which is needed in order to use their other results. This state of affairs is the more disagreeable since for some reason or other this mass ratio appears to be rather elusive. The proposed definition would put an end to this unfortunate situation.

Chemistry

From a chemical point of view, the opinion has been expressed that the most suitable reference substances for atomic weights are those elements which in nature are anisotopic. However, this seems to be based on an assumption that the only alternatives are natural polyisotopic elements, whose isotopic composition may be variable. If individual nuclides can be accepted, the argument loses its force. The most accurate chemical atomic weights are at present derived from physical data, and for those cases where a chemical determination might still be more precise (for example, Cl, Br, Ag), the physical determination of the atomic weight of a natural carbon isotope mixture in terms of the ^{12}C mass can be made with more than adequate precision; if necessary, the preparation of separated ^{12}C in adequate purity and quantity would be quite feasible.

Conclusion

The adoption of the proposed redefinition of the atomic weight scale should cause very little difficulty for chemists, because the changes would be small in relation to the precision of most chemical data. The present chemical atomic weights can be converted to the new scale by dividing by 1.000043; changes of more than one unit in the last figure of the official 1957 values would be required for only five elements (Cl, Ar, K, Br, and Ag—the latter changing from 107.880 to 107.875). Quantities whose magnitudes are proportional to the size of the mole must similarly be divided by the same factor; in most cases the changes will be insignificant.

For physicists, however, the changes in the mass values would be enormous in relation to the uncertainties in the data, and the new definition would be generally useful for them only if tables of nuclidic masses in the new scale were available. Two of us are considering the compilation of such tables. These data being available, we are inclined to think that neither chemists nor physicists should have objections to the new definition (5).

References and Notes

1. E. Wichers, *J. Am. Chem. Soc.* 78, 3235 (1956).
2. V. Caglioti, *Nuovo Cimento* 6, 280 (1957); A. F. Scott and W. R. Ware, *J. Am. Chem. Soc.* 79, 4253 (1957).
3. A. O. Nier, University of Minnesota, private communication; A. Olander, Stockholm, private communication.
4. J. Mattauch, Addendum No. 2, Report for 1957, Commission on Atomic Weights, International Union of Pure and Applied Chemistry, *Comptes Rendus de la Dix-Neuvième Conférence, Paris 16–25 Juillet 1957,* p. 153.
5. A more detailed discussion of the problem of the scales of atomic weights and nuclidic masses is being prepared by one of us (J.H.E.M.).

George Malcolm Stratton, Social Psychologist

George M. Stratton, who died 8 Oct. 1957, was the last of a pioneer group of students of the renowned German psychologist Wilhelm Wundt who were credited with having introduced experimental psychology into the United States. True to the experimental emphasis of the Leipzig School, Stratton established and equipped at the University of California one of the first laboratories of experimental psychology in America. Throughout his long and productive career he applied the experimental method to a variety of areas in human behavior, with particular efforts to study the intangible determinants of social behavior.

It was in 1896 that he published his first experimental study. This research was concerned with "vision without inversion of the retinal image" and was the starting point of an extended and significant series of studies in visual space. The original study is today considered a classic in the field. Stratton is credited in this experiment with having "settled both Kepler's problem of erect vision with an inverted image and Lotze's problem of the role of experience in space perception." Although Stratton's studies on binocular vision and depth perception have had the greatest single impact on the thinking and research of his colleagues in psychology, he himself probably considered of greater importance his studies in the fields of emotions, social values, and international conduct. He staunchly believed that the understanding of the impulses, instincts, and motives of man merited the same careful scientific analysis as did sensation and perception, intellect and ability, and learning and memory. It was in these latter fields that most of the early experimental psychologists had directed their energies.

Very early in his career Stratton became interested in studying volitional behavior as it is manifested in drives, impulses, and emotional reactions. Here he found it possible to apply experimental and laboratory techniques to many of the problems, but in studying volitional behavior in social contexts he was confronted with the need of proceeding from the behavior of the individual to the behavior of the group, and group behavior did not readily yield to experimental attack. To these problems of group behavior Stratton brought the objective, factual approach that had characterized his laboratory studies. His theory of group behavior was an extension of the theories he had derived to explain