ATOMIC DEFINITION OF PRIMARY STANDARDS

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As matters stand to-day, the primary references for all physical measurements are the standard metre and the standard kilogram, preserved at Sèvres, France, and the mean solar day, determined by astronomical observations of the earth's rotation. The standards of length and mass are arbitrary and not independently reproducible. The standard of time is at the mercy of irregularities in the rotation of the earth. Furthermore, there are limits to the accuracy with which one can compare any physical quantity with the primary standards, and these limits are now being felt.

In view of these disadvantages, it is interesting to consider the possibility of selecting other quantities to serve in the place of the present primary standards. In particular, one might select as standards certain immutable properties of atoms or molecules with which other physical quantities can be readily and accurately compared. Any laboratory can rather easily procure samples of the appropriate atoms or molecules. According to present knowledge, such samples would be universally identical.

Recent advances in physical techniques make the use of atomic standards more than an idle speculation, for it is now becoming possible to compare certain physical quantities with atomic or molecular properties more accurately than they can be compared with the present arbitrary standards.

For example, the most precise measurements of length now made in the laboratory rely on interferometric techniques in which the unknown length is compared with the characteristic wave-length of the radiation emitted by certain atoms (such as mercury-198). The resulting uncertainty in the absolute measurement of length now lies primarily in the step where this wave-length is compared with the prototype metre. We can increase the accuracy of absolute measurement of length by adopting the characteristic wave-length as the primary standard and thus omitting metre-bar comparisons. (The prototype metre was not designed, of course, with wave-length comparisons in view.) In fact, work with optical spectra—first with the red line of cadmium and now with the green line of mercury-198—has progressed to the point where the international prototype metre is provisionally defined in terms of the cadmium red line. The International Conference of Weights and Measures held in 1948 [1] endorsed, in principle, the idea of defining the ultimate standard of length in terms of the radiation from an atom such as mercury-198 with an 'even-even' nucleus.

Similar advances have been made in the field of time standards. Recent studies in microwave spectroscopy have led to the development of an atomic clock based on a constant natural frequency associated with the vibrations of the atoms in the ammonia molecule[2].

The recent absolute determination of the gyromagnetic ratio of the proton[3] suggests the possible use of this ratio as a third basic standard. Other physical quantities could then be derived from the three atomic standards by application of suitable electrical techniques.

Thus, we are now in a position to consider the possibility of a complete set of primary atomic standards. Their adoption would remove the need for preserving arbitrary standards and for making whatever corrections are required by irregularities in the motion of the earth. The use of atomic properties as standards offers the additional advantage that they can be measured with increasingly refined techniques, and a growing variety of methods.

The establishment of primary standards based on atomic properties can proceed along the line already suggested by Michelson and Morley[4] for establishing the standard of length in terms of the wave-length of a selected spectral line. Preliminary measurements reported by the National Bureau of Standards, by the National Physical Laboratory, and by the International Bureau of Weights and Measures[5] permit present definition of the metre as 1,831,249·2 wave-lengths of the green radiation characteristic of mercury-198 in standard air. To make it independent of possible variations in air density, the atomic metre should eventually be defined as a number of waves *in vacuo*.

Similarly, the unit of time—the standard second—can be defined as the duration of a certain number of oscillations of an electromagnetic field the frequency of which lies at the centre of some well-defined microwave absorption line. The ammonia molecule has already been used for this purpose in the atomic clock, and work on the use of atomic beam techniques in the microwave range may lead to an even better standard.

The third independent unit could then be based upon the absolute measurement of the gyromagnetic ratio of the proton, making use of these previous definitions of length and time. One might, for example, proceed by defining a unit field-strength of magnetic induction as that field in which protons would precess at the rate of 4,257·84 cycles per second[3].

In principle, all other physical quantities would follow from these three. Actual definitions for the derived quantities would involve a chain of experimental measurements. In the design of the definitive measurements, one may want to exploit the accuracy of length- and time-measurements by means of interference effects. A good example of such an indirect measurement is found in a recent measurement of the velocity of light in terms of the physical dimensions and characteristic frequency of a cavity resonator[6].

It would be rash to claim that the gyromagnetic ratio of the proton, the wave-length of mercury-198, and the absorption frequency of ammonia constitute an immediately satisfactory set of atomic standards. Nevertheless, a large variety of physical quantities may be related to these fundamental standards through workable, moderately accurate procedures.

For example, unit current may be defined by the following procedure. Construct a precision solenoid the dimensions of which are known accurately in terms of the proposed standard metre. Observe proton resonance in the magnetic field of the solenoid while it is carrying direct current. The current is adjusted until the frequency of proton resonance is a certain fraction of the frequency defined by the new standard second. The current flowing under these conditions will then be the new unit of current. To avoid confusion, the dimensions of the coil and the frequency of resonance could be selected to give the present accepted value for the ampere. The charge transported by the new standard current in unit time would then be the new unit of charge.

Similarly, a unit of force could then be defined through the use of a current balance the dimensions of which were referred to the atomic metre, so that the new unit would be the force of attraction between parallel wires when they were carrying unit current. The geometry should be selected to yield the force in terms of the present dyne or newton.

The general procedure which has been discussed here establishes as primary units the 'atomic metre, second, and gauss', or indirectly, the 'atomic metre, coulomb, second, dyne'. (The present four-standard M.K.Q.S. system follows in essence from the three-standard one by taking the permeability of free space as $4\pi \times 10^{-7}$ henry/metre.)

Mass can be derived, of course, from measurements of force and acceleration. Probably the most convenient method at the present time would be a determination of g at the location of the current balance used for force measurements. Other more accurate methods of relating mass to force might be devised.

We thus have in principle a method for deriving all physical quantities from the three suggested atomic standards; but the accuracy with which this process could be carried out is not everywhere satisfactory. Only in the case of the standard of length can present atomic measurements surpass in precision the methods based on conventional standards. The accuracy of atomic time measurements is not yet as good as the accuracy of crystal oscillators corrected by astronomical observations, but the gap is rapidly closing. The accuracy of electric measurements derived from the proton gyromagnetic ratio is still far from adequate, but there is good evidence that this accuracy will improve greatly as time goes on.

It should be pointed out that present-day measurement of atomic constants in terms of currently accepted standards constitutes, in effect, an atomic definition of these standards. Any new standard can be related to the old by a series of measurements on atomic systems. However, when it becomes possible to establish intercomparisons with atomic standards more accurately than with the accepted arbitrary standards, it will be desirable to change from the accepted standards to the new atomic standards. In length measurements, this point has now been reached, and in time measurements it is being rapidly approached. There is good promise that new techniques for the absolute measurement of nuclear gyromagnetic ratios or charge-to-mass ratios will soon put us in this position with regard to the measurement of charge and current.

The present article is intended primarily to direct attention to the possibility of adopting a complete set of atomic standards and to the various questions related to this problem. We hope that further discussion will produce better and more detailed suggestions for achieving these aims.

Even now, one may suggest that the present units be given alternate provisional definitions in terms of atomic systems and that these definitions be revised as experimental techniques improve. When measurements referred to atomic systems become more accurate than those referred to existing arbitrary standards, then the atomic definitions should supersede the arbitrary ones. In the meantime, should some unforeseen circumstance destroy our arbitrary standards, the atomic definitions would provide us with reasonably good substitutes.

For the purposes of discussion, a set of working definitions consistent with the latest values of the atomic constants, subject to further improvement, can be given:

(1) *Atomic Metre:* The length equal to 1,831,249·2 wave-lengths from the '5460·7532 A.' line of mercury-198 in standard air.

(2) *Atomic Second:* The time required for 238,701 $\times 10^5$ oscillations of the 23,870 Mc. or 3,3 line of NH_3.

(3) *Atomic Ampere:* The current flowing in an infinite solenoid of 1,000 turns per atomic metre which gives proton nuclear resonance at a frequency of 53,505·6 cycles per atomic second in a sample located at the centre of the solenoid.

(4) *Atomic Newton:* 5 million times the force exerted on each atomic metre length of either of two infinite parallel wires separated by one atomic metre and carrying one atomic ampere.

(5) *Atomic Coulomb:* The charge transported by one atomic ampere in one atomic second.

(6) *Atomic Kilogram:* The mass which experiences an acceleration of one atomic metre per atomic second squared, when acted upon by a force of one atomic newton.

[1] 9th General Conference of Weights and Measures, 1948, Sèvres, France.

[2] Lyons, H., "Microwave Spectroscopic Frequency and Time Standards", *Elec. Eng.*, **68**, 251 (1949). "The Atomic Clock, An Atomic Standard of Frequency and Time", *N.B.S. Tech. News Bull.*, **33**, 17 (1949).

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[4] Michelson, A. A., and Morley, E. W., *Amer. J. Sci.*, **38**, 181 (1889).

[5] Perard, A., and Terrien, J., *C.R. Acad. Sci., Paris*, **228**, 964 (1949).

[6] Essen, L., *Nature*, **159**, 611 (1947). Essen, L., and Gordon Smith, A. C., *Proc. Roy. Soc.*, A, **194**, 348 (1948).

RICE PRODUCTION AND UTILIZATION

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RICE is the staff of life for more than half the world's population—about 1,000 million people—but, since the War, supplies have fallen perilously low. Pre-war consumption of rice averaged 16–18 ounces per person per day; but until recently barely enough rice has been available to provide 5 ounces per person per day in most of the urban rationed areas of the Far East.

World production of rice in 1949–50 has virtually recovered the pre-war level; but the increase was due largely to expanded production in the minor producing areas, while Asia's rate of recovery still lagged behind the rate of population increase. This gap has been only partially filled by the substitution of wheat and other grains.

The accompanying table shows the production of paddy in 1949–50 by the major producing countries, compared with pre-war and 1946–47.