The Need for a New Type of Frequency and Time Standard*

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The measurement of a physical quantity requires first, a unit in terms of which to make the measurement, and second, an operation by means of which the standard and the unknown may be compared. Although the details of defining both the standard and the operation vary widely for measurements of different types, the two factors can always be observed in any physical measuring process. For example, the determination of a length consists first of defining a unit of length which may be a light year or a kilometer or a yard or an x-unit and then comparing the length of the standard with that of the unknown by direct comparison, triangulation, or some other method.

The establishment of a standard having all the possible desirable characteristics is not a simple matter. The ideal standard should be indestructible, simple, invariable, independent of any and all external influences, reproducible, and readily accessible. No known standard meets all of these conditions. It is also desirable to distinguish between operational standards and defining standards since few, if any, standards meet the requirements for both. An operational standard is one which is used in making measurements: for example, a liter measure. A defining standard is one used in setting forth the definition of a unit: for example, the wavelength of the light of a certain spectral line. In some cases a defining standard may also be an operational standard, as the spectral definition of length.

The measurement of time, time-interval and frequency is no exception. It is first necessary to have a standard in terms of which to define the unit of time, and second it is necessary to have an operation by means of which time intervals can be compared with this standard. For immediate use without prolonged waiting the standard of time is a provisional standard defined as a certain fraction of the average period of the rotation of the earth. Another and more uniform standard is defined with reference to long-term observations of celestial bodies and their motions. Unfortunately, the period of rotation of the earth is not constant over long periods of time and it is erratic over short periods of time and no adequate and satisfactory means exists for interpolating the standard for comparison with the periods of high frequency oscillations.

Years ago it was realized that the wave-length of the light in a spectral line of an atom is an excellent length standard. The fact that even this is not an ideal standard because of the effect of the uncertainty principle need not be discussed here. Such a standard does satisfy the requirements of permanence, invariance, and reproducibility. It is not, however, convenient, and it is, therefore, used as a defining standard, rarely as an operating standard.

There is at present no perfect time standard. The second, which is defined as 1/86,400 part of a mean solar day, is not invariant over periods of the order of a century, nor is it constant over periods of the order of a day. Astronomers have defined a more nearly uniform time as the sidereal year at 1,900.0 and designated it ephemeris time. No satisfactory operational means for employing this definition is known.

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Despite the fact that time is inseparably involved in most of the other physical constants and relationships and in many engineering and scientific principles, the common unit of time is far from being readily available with high accuracy at the time it is needed.

An immediate problem is that of providing time (frequency) standards of adequate accuracy for use in communication and navigation devices and scientific work. Precisions approaching one part in 10^9 over long intervals (days) are now being approached and will soon be achieved. In order to produce and calibrate such devices and monitor them it is essential that the unit of time be quickly available with an accuracy of one part in 10^9 and that transfer standards be devised with which to compare the defined standard with the operating device.

The above statement may be clarified by consideration of the process by means of which the standard meter is defined. The unit of length is that of the wave-length of the red line of cadmium (the work of Meggers and others shows that better standards could now be chosen). By means of an interferometer, the distance between two indicating marks on a suitable bar is compared with the wavelength of the chosen light. The bar then becomes the operational standard. If lost or damaged, a new one, as good as or better than the original can be made quickly to replace it. It can be quicly recalibrated at intervals in case of suspicion of variance. The length of the meter is defined as being equal to a certain number multiplied by the wavelength of the light in the selected spectral line. This is the defining standard even though it is inconvenient or even impractical to use it as an operational standard.

The present state of physical knowledge suggests only one source of a satisfactory time standard, namely the period of molecular, atomic, or nuclear vibrations. Such a time standard would meet the requirements of permanence, reproducibility, invariance and ready access without prolonged waiting and expense.

It is possible today to define the unit of time in terms of the period of vibration of a chosen molecular resonance. A reproducibility to one part in 10^7 has been obtained using molecular and atomic clocks. A number of atomic clocks of the most promising type should be built and observed. Effort should be concentrated on obtaining agreement and reproducibility to one part in 10^9 or better between independent units.

To put such an atomic time standard into operation requires the following steps: (1) Investigation of the most nearly ideal molecular, atomic or nuclear vibration to be used as the defining standard; (2) Development of suitable apparatus reproducible to one part in 10^9 or better for correlation of an operating standard to the defining standard; (3) Legislation and/or agreement designed to implement the new standard in practice.

Of course, formidable difficulties lie in the way of each of these steps, but the importance of the measurement of time, time-interval, and frequency in both applied and pure research make it imperative that this work be started at once and actively carried to completion.