letters

The speed of light and the new meter

In the January 1974 issue of PHYSICS TODAY a note entitled "New standards for light velocity and wavelength" (page 112) listed values recommended by the Comité International des Poids et Mesures for two stabilized laser wavelengths and the speed of light. The concluding sentence of the note was: "Still to be decided is whether to redefine the meter in terms of one of the stabilized laser transitions or to designate the meter as the distance traveled by electromagnetic waves in a vacuum during a specified fraction of a second."

The key to that decision is the answer to the following question: In order to define the two units, the second and the meter, is there a need for *two* transitions (two standard devices) or is it feasible to establish a unified system for the measurement of time and length based on *only one* atomic transition (one standard device) and on a defined value of *c*, the speed of light? The recognition in recent times that *c* is independent of frequency to a prodigious accuracy and the ability, acquired also in recent times, to measure optical frequencies are two factors that in our opinion tip the balance in favor of the unified system. A brief outline of our arguments follows. A more detailed discussion with citations of the relevant literature, is being published elsewhere.[1]

In the unified system the second is defined by a frequency standard. The meter is defined such that the distance traveled by light waves in 1 second (the "lightsecond") is $|c|$ meters where $|c|$ is an agreed-upon dimensionless number. (Equivalent expressions are that the numerical value of the speed of light in m/sec is $|c|$, or that the meter is the distance traveled by light in $|c|^{-1}$ sec.) Thus the basic standards in this system are the standard frequency (chosen always to be of the highest frequency uniformity attainable) and the speed of light. The novel feature is the use of a fundamental constant of nature for a standard.

There is hardly any need to debate the inherent appeal of such a unified system. However, this system can only be introduced after two questions can be answered in the affirmative.

The first question is, how large is the inherent uncertainty of the lightsecond? The speed of light (notwithstanding theory) may change (a) in time, (b) it may be affected by the orbital motion of the Earth, (c) it may have directional dependence in space, and (d) it may depend on frequency. Phenomena (a), (b), and (c) are irrelevant for a choice between wavelength standards or the unified system.[2] (These phenomena could be relevant to the consistency of measurements based on the propagation of light and on rigid rods respectively. It may be noted that there is no evidence for the existence of such effects in excess of the limits of observational accuracy of approximately 5×10^{-12}.[2] Thus, they can be ignored with the anticipation that if ever they will be known to exist, they can be corrected for.) Only (d), the dependence on frequency, would discriminate against the unified system, and therefore it was treated by us in a separate article.[3] An analysis of the most recent experimental data led to the conclusion that in the entire spectrum from microwaves to ultraviolet, *c* is independent of frequency to approximately 10^{-20}.

Thus the uncertainty of the lightsecond is limited to that of the present second, which is about 3×10^{-13}, as defined by the Cs^{133} clock. The lightsecond, about ¾ the distance to the Moon, is thus accurate to ±0.1 mm. One of the beauties of the unified system is that the meter is defined in it with the same accuracy as the second, which is by far the most accurate unit of experimental physics. In contrast, if one of the recommended laser wavelengths is accepted, while in frequency uniformity (10^{-11}–10^{-10}) they are much superior to the present Kr^{86} standard ($\approx 4 \times 10^{-9}$), neither of them could provide for a meter as accurate as the second. Presumably, they would also be shortlived. In the event of new technical developments, only one unit needs to be redefined in the unified system; the meter automatically acquires the accuracy of the second.

The other, practical, question is: How precisely can the lightsecond (or the meter) be subdivided? Relatively large fractions and multiples of the lightsecond can be determined by the accurate measurement of the time of light propagation (radar, geodimeter, mekometer, and so on). For small fractions of the meter (refined determination of small lengths, wavelengths in spectroscopy) the measurement of optical frequencies is required. In this respect we are in the favorable position of having two schemes in course of development. Both have already achieved spectacular results and both promise the capability of fully utilizing the accuracy afforded by frequency standards. It must be stressed that the condition of competitiveness with wavelength standards is a less stringent one, namely that the accuracy capabilities of frequency measurements should not be inferior to those of wavelength measurements. This condition is already fulfilled.

The "direct" method or "frequency synthesis" links the optical to microwave frequencies via a multiplying and heterodyning chain (as in radio techniques) using specially constructed fast diodes. Started by a group led by A. Javan in 1967 in the far infrared, this technique is extended now to the 88 THz of the methane stabilized laser in the near infrared by K. M. Evenson et al (*Phys. Rev. Lett.* **29**, 1346, 1972).

In the other method, that of "frequency transfer," the optical carrier frequency is split into sidebands by

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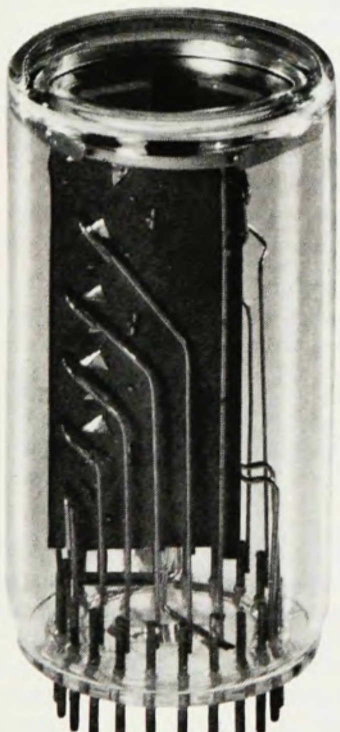

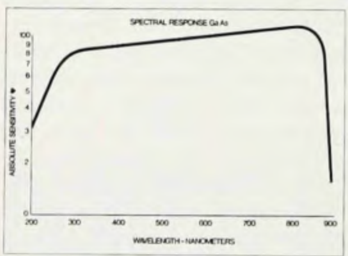

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modulation at a microwave or infrared frequency. The lower frequency is transferred thereby into the optical domain as a known frequency difference. Simultaneous interferometric determination of the ratio of the sideband frequencies yields the carrier frequency. Started and pursued by Z. Bay and coworkers, this technique was used to measure the 473 THz of the 633-nm red laser line in a recent prototype experiment, connecting the 10-GHz microwave frequency to the optical in one step (Z. Bay et al, *Phys. Rev. Lett.* **29**, 189, 1972). Extension of the modulation frequency into the infrared, notably up to 88 THz in one experiment, has been demonstrated by K. M. Baird et al (*Opt. Com.* **7**, 107, 1973). The method is applicable to any laser light with predictable improvements in accuracy to the limit of frequency standards. It uses relatively simple equipment. Thus the practical requirements for the introduction of the unified system are fulfilled.

The idea of using fundamental constants of nature for the definition of the units of measurements in general was suggested by M. Planck as early as 1906. Owing to the large uncertainties in the constants at that time, the idea remained dormant. After the advent of lasers, C. H. Townes in 1961 directed attention to the future possibility of measuring optical frequencies and then connecting the units of time and length through the speed of light. An explicit proposal to measure optical frequencies and to introduce a time–length measurement system unified by a defined value of *c*, was made in the National Bureau of Standards by Z. Bay in 1965. Detailed studies of the problems involved[1-3] and the successful experiments mentioned above fully justify in our opinion a decision in favor of the unified system.

References

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2. Z. Bay, *Atomic Masses and Fundamental Constants 4,* (J. H. Sanders, A. H. Wapstra, eds.) Plenum, London (1972), page 323.
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Disagreement with Wigner

Recently Eugene Wigner addressed a large group of physicists and physics students at the Southeastern Sectional meeting of the American Physical Society in Winston-Salem, North Carolina, on the subject "On Some of Physics Problem." In view of the fact that he is perhaps one of the greatest minds of the twentieth century (Nobel prize in 1963 for application of symmetry principles to quantum mechanics, inventing parity and isospin, among other things) what he says can not be taken lightly. He says first of all that physics has perhaps grown too fast and become too complicated, so that even he can not follow all of the review articles in the latest "Annual Reviews of Nuclear Science." Second he says that because of the enormous success of physics it is physically possible for everyone to have a materially carefree life, at least in countries where it is fully operative. Hence new developments in physics and technology are less needed; society problems become of a social and human nature. He said that he knew many people in the audience would disagree with him and would not like what he said.

I would like to take up the cudgel for those who disagree. Let me begin by saying that at that same meeting I had lunch with three black students who were physics majors, and they were saying more or less the same thing, with the additional point that they resented the fact that the West was so much trying to say that its civilization was better than the African civilization and trying to impose its way of life on the Africans. Their point was, if the Africans have a happy, carefree life why not let them stay that way unencumbered by physics and technology? But then I reminded them of the millions who are going to starve to death next year because the Sahara desert is gradually moving south.

Let me now turn to the happy carefree life in the US, the most technologically advanced country in the world. Do we have enough physics and technology? Now that the oil from the Arab world has actually stopped flowing into our country we are confronted with a major disruption of our society. Millions of people may be thrown out of work, food and heat shortages may develop and a state of near chaos may prevail. Is this the carefree life? I think it has never been more clear that we need more technology and even more physics. Of course that is not all that we need. Also and terribly important we must learn to live with the fact that each new development in science and technology can be turned into a wonderful means of enriching our lives or a monster that may kill us