Letters

High Accuracy in Physics

Philip H. Abelson (Editorial, 9 May, p. 693) applauds the work of those physicists who, with high devotion, produced the report *Physics Through the 1990's* (*1*). I agree with Abelson, except for one point. He reviews accomplishments in atomic physics and says, "Of all of the quantities in physics, time is by far the most accurately measured." Research not discussed in the report suggests otherwise.

Josephson junctions, when suitably biased by direct current and by microwave radiation, have ranges of current in their current-voltage characteristics over which the voltage is not a function of current, but is simply constant. Josephson predicted that this time-averaged voltage on these "constant voltage steps" would be proportional to the applied radiation frequency, and many experiments confirm that idea to various degrees of accuracy. Nearly two decades ago John Clarke (*2*) devised an elegant experimental method for testing the proportionality between frequency and voltage. Recently, Jaw-Shen Tsai, A. K. Jain, and J. E. Lukens (*3*) used the same basic experimental method, but much higher junction voltages. As a result they showed that the voltages across each of two Josephson junctions, exposed to microwaves from a common source, were the same within two parts in 10^{16} for a measuring time of 5 hours. This is an extraordinary result because the precision of experimental measurements is rarely advanced by many orders of magnitude, about seven in this case, in one giant leap. Add to that the fact that the results of the comparison were obtained with quite different styles of Josephson junctions: one was an indium microbridge, and the other was an SNS (superconducting-normal-superconducting) junction. We now have direct evidence that the dynamics of the superconducting state are independent of the material producing that state, to unprecedented precision, and we move closer to the conclusion that the proportionality constant relating voltage and frequency requires no correction; the constant is just $2e/h$, where e is the charge of the electron and h is Planck's constant.

It is said that the time (interval) standard has an accuracy of one part in 10^{13}. For clarity of interpretation, one can define accuracy to be a joint measure of how reproducible a measurement (or comparison) of a quantity is and how well one can theoretically describe the measuring process for the quantity. A thermistor, for example, can give very reproducible experimental results for temperature, but, because its response is not well understood and is variable from device to device, it would not be said to be as accurate as a gas thermometer. With this understanding, we have a well-defined prescription for producing voltage (namely, use the Josephson effect), and from that prescription we can obtain a voltage with an uncertainty that is just the uncertainty of the time (frequency) standard. Because of the results of Tsai *et al.*, we have good reason to believe that another experimentalist, working independently, can produce the same voltage within the accuracy with which the applied radiation frequency can be reproduced, if the apparatus is competently constructed. Thus, quite unexpectedly, we now find in this instance that the accuracy of solid state physics is on a par with that of atomic physics.

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REFERENCES

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2. J. Clarke, *Phys. Rev. Lett.* **21**, 1566 (1968).
3. J.-S. Tsai, A. K. Jain, J. E. Lukens, *ibid.* **51**, 316 (1983).

U.S. Intellectual Resources

Perhaps because I am a university teacher, my diagnosis of the primary disorder dealt with in Daniel E. Koshland, Jr.'s editorial "Global economic competition" (28 Mar., p. 1489) is different, at least in emphasis, from his. Our elementary education is bad, but even more relevant is that, unlike our creditors, we fail to provide free university education to those applicants intelligent enough to pass their entrance exams and stay in good grace.

We have adequate intellectual resources, but we waste them at elementary and university levels. At the former we devote enormous resources to the underachievers, all to the good; but we virtually ignore the above average, who also are hard to teach if we are to retain their interest in schooling. At the latter, as fees rise and federal restraints are felt, the loss to the nation of those with intelligence but without funds (shameful as it is now) is becoming commoner. We cannot afford any of this.

Koshland is optimistic in feeling that continuing decline is not inevitable, but I am not. Decline could be stopped if the United States were willing (I believe it is not) to abandon some ingrained dogmas, such as, that school systems should be local matters under locally elected school boards and that anything other than private initiative and free enterprise produces parasites. Our adverse trade balance makes it obvious that there is plenty of initiative left in countries with social services far more extensive than ours. By comparison with our successful competitors, this country in matters of higher education, health, and social security does not treat any of its citizens well; in addition, it shows a special neglect for its gifted children.

It does not seem to me that the need for radical change in order to compete effectively has much chance of moving the very conservative and parochial U.S. political and social philosophy to the point of endorsing free university education in this country.

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Methylene Geometry

Recent letters (13 June, p. 1319) have discussed the theoretical (*1*) and experimental (*2*) determinations of the structure of the ground state of methylene that were made in 1970. The agreement of these independent approaches provided additional support for each, clarifying the uncertain situation that then existed.

The experimental study was based on electron paramagnetic resonance (*2*). The analysis included a calculated function relating the bond angle and a parameter E that arises from the magnetic interaction of the unpaired electrons in the triplet ground state. E is a measure of the deviation from cylindrical symmetry and thus from a linear geometry. Other relations may be used, and four alternatives were subsequently provided by Harrison and Liedtke (*3*). These alternatives lead to angles of from 134° to 140° as compared with the original determination of 136° ± 7° (*2*). Near these angles E is a rather rapidly varying function of bending. Substantial differences in the calculated functions lead to only small variations in the angles deduced. The method retains its validity within the stated uncertainties.

For most of the intervening years theory has provided the best determination of the methylene geometry (*4*), clearly surpassing experiment. Now, with the elegant studies of Bunker and co-workers, experiment has an even higher accuracy (*5*).

In the future we expect to find an increasing number of situations in which theory will be the preferred source of information