important as it ever was. Second, one thing we can do is improve our communication with the public. We can do something about what Kadanoff calls "a huge amount of self-serving noise on every subject from global warming to 'the face of God.'"

We can, and I am convinced we must, act to reduce the noise by holding scientists as accountable for their statements to the public as they are when speaking to a scientific audience that includes their best competitors—when, in the words of Philip Handler, they are engaged in "the more conventional, time-honored, self-policing scientific endeavor."[1] Today the standard method of communication to the public is via committees whose credibility is based on the elite credentials of their members. This is not a self-policing system, and its output has frequently been challenged, creating the noise Kadanoff (and Handler) found so objectionable.

If in communicating with the public we can carry over the self-policing methodology we use internally, the scientific community can provide information needed for policy-making in a way that draws strength from the historic achievements of the scientific method. In pursuit of that end I have proposed[2] that the scientific community enforce a new norm, namely: *Any scientist who addresses the public or lay officials on scientific facts bearing on public policy matters should stand ready to publicly answer questions not only from the public but from expert adversaries in the scientific community.*

The media called procedures based on this norm "Science Courts." Efforts to begin the development of more credible procedures started with an attempt to persuade the Federal government to sponsor experimental procedures. It was not hard to persuade Presidential campaigns (Ford and Carter in 1976 and Reagan in 1980) to promise such developments. However, it was not found possible to get elected officials interested in developing an institution *intended* to limit their flexibility to state the scientific facts as they wanted them stated.

Such efforts have been much more welcome on university campuses, where they have a number of advantages. "Scientific Adversary Experiments" intended to begin the development of effective procedures have been conducted at the University of California, Berkeley (using Love Canal as a test case), and at Dartmouth (using the Strategic Defense Initiative).[3] This experience confirmed the expectation that we could reduce the "self-serving noise" by enforcing the norm.

Science retains the enormous promise it has had for centuries as part of a grand strategy for widening humanity's horizons, for doing its work and healing its sick. The institutions of science are making a valiant effort to increase the budget for research. In this competition with the other interest groups we are addressing the symptom rather than the cause of the disease. We should not resign ourselves to a declining role without first improving our communication with society. Then we can use the clear channels to inform people of our capabilities to help them achieve whatever world they want.

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Kilogram Definition Should Be Immaterial

The kilogram is the only basic SI unit still defined by a material artifact. The international prototype kilogram, made of platinum–iridium alloy, is kept in a vault at the Bureau International des Poids et Mesures, at Sèvres, near Paris. Physicists accustomed to seeing particle masses listed with accuracies of fractional parts per million[1] may be surprised to know[2] that macroscopic masses have not been determined to better than 8 ppm, and usually not better than about 100 ppm. Actually, comparisons with the international prototype kilogram are always made in air, while particle masses are usually referred to the unified atomic mass unit, defined as $^1/_{12}$ of the mass of a ^{12}C atom at rest in a vacuum.

Macroscopic masses are determined from a chain of comparisons of the international prototype with a number of copies and multiples. The prototype is infrequently compared with several prototype copies at BIPM. At intervals of about ten years, after a special cleaning procedure, the 75 *national* prototype copies from various countries are compared with the BIPM prototype copies, with typical standard deviations on the

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order of 10 μg (that is, 0.01 ppm). Even after cleaning, the national prototypes have exhibited continual increases in mass on the order of about 1 μg/year that are presumably the result of surface contamination. In the various national bureaus, the national prototypes are compared with the *primary standards*, which are made of steel or brass. The primary standards are then used to calibrate the *reference standards*, also made of steel and used for checking scientific and industrial mass standards. That all of these mass comparisons are made in air introduces errors from surface contamination and, most importantly, from buoyancy corrections, since platinum–iridium differs from steel and brass in density, leading to errors of about 30 μg (0.03 ppm) resulting from air temperature and density uncertainties. For determinations of large masses, a number of multiples of 1 kilogram must be constructed, usually of steel, to bootstrap the comparison masses to large values.[2]

It is exceedingly unlikely that the international prototype kilogram has the same mass as when it was first adopted as the unit in 1889, or even from one comparison to the next. That the mass comparisons are all made in air effectively limits the accuracy of macroscopic mass determinations to about 10 ppm; more commonly the masses are determined to about 100 ppm. These accuracies are adequate for most commercial purposes and also for determination of Newton's gravitational constant, G, which is known only to about 128 ppm.[1] However, all of the other constants of nature and fundamental units are known or defined to much greater accuracy, and Alvin J. Sanders and I have recently proposed an experiment[3] to determine G to about 1 ppm, with the greatest uncertainty arising from the comparison of the interacting masses (essentially *in vacuo*) with the mass of the international prototype kilogram (measured in air).

Since scientific metrology has made great progress since 1889, and all other constants of nature have now been defined in terms of more reproducible and presumably more invariant atomic quantities, it seems reasonable to redefine the kilogram, probably in terms of the mass of some reasonably fundamental particle, such as the proton or some other stable nucleus, *in vacuo*. Doing so would not make any change necessary in everyday determinations of macroscopic commercial masses, but it would put the measurement of scientific quantities, which can and should be measured with much greater accuracy, on a much more secure basis. It would also facilitate reference to primary standards in various scientific laboratories, which are the only places where the additional precision is possible and needed. Measurement of macroscopic masses could continue as at present, at least until the technology to compare them with the atomic standards becomes widely available.

The choice of which "atomic" mass is to be used to define the kilogram should be decided by international consensus, perhaps using such criteria as permanence, convenience and adaptability. The present state of our knowledge of the kilogram has recently been described by T. J. Quinn.[4] The simplest possibility would be to define the kilogram as a certain number of unified atomic mass units, simply inverting the present best value of the conversion ratio. To get a more up-to-date figure there could be considerable research on redetermining Avogadro's constant, counting atoms in pure single crystals (such as diamonds or silicon), measuring the mass of a counted number of large molecules such as $^{12}C_{60}$ "buckyballs" or fullerenes, measuring the electron charge–mass ratio and evaluating various electromagnetic devices used for making "mass" measurements. There have also been suggestions[5] that the kilogram and ampere should both become secondary units, derived from the volt (defined using Josephson junctions) and the ohm (defined using the quantum Hall effect) via the joule and newton. Perhaps it is time to reconsider the dimensionally attractive system of units based on length, time, electric charge and magnetic flux, in which all physical quantities have very simple dimensions. From the standpoint of fundamentality, the obvious physical bases seem to be c, e, $\hbar$ and one other quantity, such as magnetic flux.

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The Truth about Feynman's Father

Freeman Dyson's review of James Gleick's book *Genius: The Life and Science of Richard Feynman* appeared in the November 1992 issue of PHYSICS TODAY (page 87). Richard Feynman was my brother, and I would like to comment on the review.

Dyson says that he found the book enlightening in that it gave him a deeper understanding of some aspects of Feynman's character. In particular he says he discovered that our father did not, as my brother had written, impart a philosophy of science to my brother. Instead, our father was "a harassed and unsuccessful businessman who was forced to travel to earn a living and had little time left over for his children." Dyson remarks that "the fact that Feynman could create a legend of the philosopher–father out of such a meager reality is an important clue to understanding his character."

Dyson is in error. Our father was as my brother described him. It is particularly ironic that this debunking of the legend should appear under the headline "Doubt as the Essence of Knowing: The Genius of Richard Feynman." The importance of doubt as the first step to knowledge was one of the principles our father taught us both. It was due to his love and appreciation of nature that we both became scientists.

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Dyson replies: I am grateful to Joan Feynman for correcting my mistake. I should have consulted her before publishing an unwarranted speculation about her father. As she says in her letter, the mistake was mine. James Gleick is not responsible for it.

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Solar Cycle's Effect on How High Hubble Flies

A letter by John G. Kepros in your October 1992 issue (page 142) appears to be confused about the effect of the solar cycle on the orbit of the Hubble Space Telescope and NASA's plan for accommodating this natural orbital phenomenon.

Solar activity cycles between peaks every 11 years. During peak activity, the temperature of the atmosphere rises, and thus the density of the