continued from page 15
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 atmosphere at a given altitude also increases. The effect of this increased atmospheric density can be profound even on a satellite in low Earth orbit. The increased aerodynamic drag from the 1978–79 solar cycle slowed Skylab, lowering its altitude and thereby exposing it to even denser atmosphere. Ultimately this effect led to Skylab's unanticipated reentry in July 1979.

HST was deployed at an altitude of 611 kilometers, and over the first two and a half years since its launch, during the current solar cycle peak, the orbit has decayed to 590 km. NASA planning has always provided for the space shuttle to reboost HST to a higher orbit as needed to counter orbital decay. Currently reboost is planned for every servicing mission if there is residual fuel for the shuttle after rendezvous. (Servicing missions are to take place at roughly three-year intervals.) During the period of minimum solar activity over the next five years or so, orbital decay will be relatively minor, but particular efforts will be made to reboost HST as high as possible prior to the next solar cycle in 1999.

Kepros refers to NASA's announcing that HST's lifetime would be truncated from 15 years to 5 because "the atmosphere had expanded" and then mysteriously withdrawing that announcement. NASA policy has always been that HST is intended to be a permanent space observatory with a planned 15-year mission lifetime. While it remains an exceptionally challenging goal to maintain and regularly upgrade a complex space observatory over that period of time, the effect of the solar cycle on orbital decay is only a small part of the challenge HST faces.

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Gibbons's Doctoral Adviser Amended

Irwin Goodwin's news story about the new science adviser to the President and head of the Office of Science and Technology Policy, John Gibbons (March, page 73), implies that I was Gibbons's thesis adviser at Duke University, where he received his PhD in 1954. Although he was a student in a course I taught at Duke during the academic year 1951–52, I was *not* his adviser. Rather, Gibbons worked in the experimental nuclear physics program at Duke under the direction of the late Henry W. Newson. There he was the first student to receive a PhD in the laboratory that later grew into Triangle Nuclear Physics Laboratory.

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A Shortcut to Sending FSU Scientists Journals

From reports such as the one on page 90 of the February 1992 issue, readers of PHYSICS TODAY know about the grave situation in the former Soviet Union with respect to subscriptions to foreign scientific periodicals. I would like to suggest a form of relief for this problem that is not burdened by bureaucratic barriers: Let each Western scientist put on his or her mailing list several libraries of leading institutes (or just persons) in the FSU that are working in the same area and regularly send to those addresses copies of his or her latest papers, without receiving any request for them. (Remember that we are completely isolated from periodicals and hence cannot request specific papers.) To cut postal expenses copies could be accumulated in a special box at your institute and posted monthly or quarterly.

Of course this is not a solution to the problem, but at least it is something.

My colleagues and I will be very grateful for copies of papers dedicated to solid Earth physics, atmospheric and hydrospheric physics, and solar–terrestrial connections.

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Defense Research Defended

Glenn Cooper's letter (July 1992, page 13) repeats the often heard argument that the secrecy of defense research robs science of access to the products of creative work. Cooper further maintains that scientists should shun defense work in favor of other activities. In support of the first point, he asserts that keeping the results of militarily useful adaptive optics research classified for a period of time has delayed progress in astronomy. In support of the second point, he maintains that development of high-speed trains and better climate models are more worthwhile uses of scientific talent than improving missile accuracy and developing better command-and-control software.

I suggest that these absolutist positions are shortsighted and dangerous. To be sure, the defense of our country is not free, and it is proper to measure its cost against that of alternative uses for money, talent and knowledge (that is, what economists call opportunity costs). However, having no defense or neglecting to constantly improve our defense is appropriate only in a mythical world that has no threats. In the dangerous world that we actually live in, threats to our nation are both real and ever changing. Though the Soviet Union may have fallen, the continuing conflict with Iraq over that nation's nuclear weapons program (see Jay C. Davis and David A. Kay's article on page 24 of the same issue of PHYSICS TODAY) is illustrative of the reality that we face significant hostile powers that are determined to acquire and exploit the most advanced military technology. Likewise, only in a mythical world of unlimited resources can the cost of defense be ignored. Rational analysis of alternatives, not absolutist stances, is needed if we are to progress economically while retaining our freedom.

I propose that adequately protecting our nation and the free world is of importance to scientists in general and to physicists in particular. As a reader of PHYSICS TODAY, I know from numerous articles just how bad life is for scientists who live under undemocratic regimes of the sort that would quickly replace our constitutional republic if we neglected our defenses. The technical contribution of physics to defense remains as critical today as it was during World War II. For these reasons, I believe that in addressing public policy issues related to defense, PHYSICS TODAY, AIP and its member societies have an obligation to make an informed and reasoned contribution that prudently balances the needs of defense and other uses of science. Likewise, the professional organizations of physics ought to treat defense as no less worthy an occupation than other applied areas.

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8/92

Correction

August 1992, page 59—Senator Dale Bumpers is from Arkansas. ■