letters

Perspectives and contributions over the past 75 years

For his insightful review of the changes in physics during the first 75 years of the American Institute of Physics (PHYSICS TODAY, June 2006, page 32), Spencer Weart began with a hypothetical physicist who, at age 100 now, surveys what has happened since his graduate student days in 1931. But it was not necessary to be hypothetical. There is a real example of a living physicist, John Archibald Wheeler, who was a 19-year-old physics graduate student in June 1931, two years before receiving his PhD from Johns Hopkins University. Wheeler detailed most of the changes in his 1998 autobiography, *Geons, Black Holes, and Quantum Foam: A Life in Physics*, with Kenneth Ford (Norton, 1998), and has been actively engaged in physics for the entire history of the American Institute of Physics, including a year (1966) as president of the American Physical Society.

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The physics community expends significant effort encouraging students to pursue physics as a career. Promoting physics to a broader audience was a major goal in commemorating the year 2005 as the World Year of Physics. But what are the misperceptions that discourage an enthusiastic person from joining "the club"?

One misperception comes from publications that overemphasize the fact that discoveries and innovations made by physicists often occurred early in their careers. This gives the impression that the essential factor for success in physics is to be gifted.

Take, for example, Spencer Weart's article about the advancements of physics in the past century. Weart frequently stresses the age of the physicist: "Dirac was a year short of his 30th birthday. Younger still, at 26, was Caltech student Carl Anderson." Weart says of Ernest Lawrence, "He had just turned 30; so had Robert Van de Graaff." To assure readers that physics is indeed the realm of geniuses, Weart writes, "Frederick Seitz, 20 years old in 1931 but only three years from his PhD," and "Hans Bethe, a student who turned 25 that year, found a solution of the Ising model for a one-dimensional lattice." The message that any of these phrases has for me is simple: If you turn 30 and have not yet made a significant discovery, you are in the wrong field.

True, many ideas that revolutionized the way we look at the world came from masterminds early in their careers. Nevertheless, that is not the whole story; the essential requisite for accomplishment is not how gifted you are but how passionate and hard working you are. For example, a knowledge of Albert Einstein's approach toward nature could be illuminating for students who look to him as their role model. Someone who knew Einstein during his years at the Institute for Advanced Study said of him, "What motivated him was his intense curiosity about nature."[1] In my opinion, that is what should be emphasized to the public and to students who are undecided about their future. We must infuse a passion for the beauty of nature, emphasizing its accessibility to everyone willing to put forth the effort. It is not only some genius-born elite that finds physics joyful and rewarding. Understanding natural phenomena is blissful and pleasant for any enthusiastic person at any level.

Reference

1. C. N. Yang, *AAPPS Bulletin* **15**(1), 4 (February 2005).

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Letters and opinions are encouraged and should be sent to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842 or by e-mail to ptletters@aip.org (using your surname as "Subject"). Please include your affiliation, mailing address, and daytime phone number. We reserve the right to edit submissions.

Dark energy and field equations without λ

An intensive search for a presumed "dark energy" driving the acceleration of the cosmic expansion has taken place during the past decade. Adjunct to the search is the determination of the acceleration's "equation of state" if the driver is other than λ, Einstein's cosmological constant. What is remarkable and long since forgotten is that Erwin Schrödinger, shortly after Albert Einstein introduced the cosmological constant, discussed the field equations without λ but with a stress-energy tensor containing the term $p\delta^{\mu}{}_{\nu}$. Einstein objected to this as a trivial variation of his field equations. It happened as follows.

Einstein introduced λ in 1917.[1] In November of that year, Schrödinger submitted a paper[2] in which Einstein's original equations, without λ, were provided with a stress-energy tensor consisting of a uniform distribution of dust and a negative pressure term. Shortly thereafter, in a note submitted to the same journal in March 1918, Einstein responded with some acerbity:[3]

> When I wrote my description of the cosmic gravitational field I naturally noticed, as the obvious possibility, the variant Herr Schrödinger had discussed. But I must confess that I did not consider this interpretation worthy of mention.
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> . . . . A spatially closed world is only thinkable if the lines of force of gravitation, which end in ponderable bodies (stars), begin in empty space. Therefore, a modification of the theory is required such that "empty space" takes the role of gravitating, negative masses which are distributed all over the interstellar space. Herr Schrödinger now assumes the existence of matter with negative [scalar] mass density [*negativen skalaren Massendichte*] and represents it by the scalar p. This scalar

> p has nothing to do with the internal pressure of "really" ponderable masses, i.e., the noticeable pressure within stars of condensed matter of density ρ; ρ vanishes in the interstellar spaces, p does not.
>
> The author [Schrödinger] is silent about the law according to which p should be determined as a function of the coordinates. We will consider only two possibilities:
>
> 1. p is a universal constant. In this case Herr Schrödinger's model completely agrees with mine. In order to see this, one merely needs to exchange the letter p with the letter λ and bring the corresponding term over to the left-hand side of the field equations. Therefore, this is not the case the author could have had in mind.
>
> 2. p is a variable. Then a differential equation is required which determines p as a function of x1 . . . x4. This means, one not only has to start out from the hypothesis of the existence of a nonobservable negative density in interstellar spaces but also has to postulate a hypothetical law about the space-time distribution of this mass density.

Of course, this occurred long before the advent of quantum-field theoretic concerns about zero-point energy and the later discovery of the type 1a supernovae with its implications, so the discussion vanished into the archives.

References

1. A. Einstein, in *The Principle of Relativity*, W. Perrett, G. B. Jeffery, trans., Dover, New York (1923), p. 177.
2. E. Schrödinger, *Phys. Z.* **19**, 20 (1918).
3. A. Einstein, *Phys. Z.* **19**, 165 (1918); also in *The Collected Papers of Albert Einstein, Volume 7: The Berlin Years: Writings, 1918–1921*, A. Engel, trans., Princeton U. Press, Princeton, NJ (2002), doc. 3, p. 31.

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A microscopic definition of mass

The story in the April 2006 issue of PHYSICS TODAY (page 32) on the redefinition of the kilogram leads me to draw attention to an alternative way of defining mass, which I think deserves further consideration.

First of all, the measurement of relative masses can be done much more precisely at the microscopic level than at the macroscopic; the combination of measurements via precision mass spectrometers, magnetic traps, and nuclear-reaction Q values already yields mass ratios for several elementary particles and atoms with a precision of 1 part per billion or better. The actual masses in kilogram units of various microscopic systems—for example, electron, proton, or a monoisotopic atom—that might be chosen for a mass standard are also accurately known, but with a somewhat larger uncertainty, around the 50-ppb mark. The present aim of mass metrology is to reduce that uncertainty to a few parts per billion. But, since atomic-scale measurements are so accurate, why not define the kilogram here and now as a prescribed multiple of the mass of the chosen microscopic standard? We would then have a mass standard with the desired properties of permanence, stability, universal availability, and the embodiment of the concept of mass with a precision that is in principle indefinitely high. Moreover, the standard would be located in the experimental domain where accurate masses are most directly accessible and most important. The standard kilogram artifact and its various copies would then revert to calibrated comparison objects for carrying out macroscopic mass measurements, in which a precision of 50 ppb is far better than needed by commerce, industry, physics experiments, or everyday life.

I have another comment, which concerns the choice of microscopic standard and indeed whether one can define mass without having to choose such a standard. Analysis of the systematic change in spacetime orientation of the equal-phase hypersurfaces in an accelerated charged-particle wavepacket shows that a particle's inertia is proportional to the value of its de Broglie angular frequency when the particle is free and in its rest frame. This fact strongly suggests that this frequency be used as an absolute definition[1] of inertial mass m, in contrast to the usual mass M, which is relative to the kilogram or some agreed standard atomic object. Such absolute masses can be, and already are being, measured with very high precision. Since $m = Mc^2/\hbar$ and c is a defined number, values of absolute mass can be calculated immediately from the measurements of $\hbar/M$ obtained by several recent methods. Those methods combine interference or diffraction with determination of velocities of particles or of atomic recoils associated with photon emission or absorption, with uncertainties now approaching the few-ppb level.

Following the microscopic-first approach mentioned earlier, the kilogram could then be defined once and for all as the mass of an object consisting of atoms whose summed absolute masses (subtracting $1/c^2$ times interatomic binding energy) amount to exactly $8.522\,467\,2 \times 10^{50}\ \mathrm{s}^{-1}$. This awkwardly large number would rarely enter calculations. In the microscopic world, it is measured frequencies that are important; macroscopic measurements would use comparison objects calibrated to the new kilogram via direct or indirect determinations of the numbers of atoms they contain, calibrations that would employ a number of modern mass-metrology techniques.

An added bonus of the microscopic mass definition is that it eliminates the need for a separate unit—and dimension—not only for mass, but also for electric charge. For an inverse-square force law, charge turns out to be dimensionless; classical and quantum physics can then be expressed entirely in terms of just two kinds of basic units—those of time and length.

Reference

1. J. W. G. Wignall, *Meas. Sci. Technol.* **16**, 682 (2005).

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Correction

February 2007, page 25—The configuration of warheads shown in the photograph is for a Peacekeeper missile, not a Minuteman as stated in the caption. ■