> *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

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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

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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. ■