The maximon and minimon in light of a possible formulation of the concept of an "elementary particle"

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A possible definition of the concept of an "elementary particle" which would include the entire list of particles which, on occasion, are still referred to in the literature as "elementary" (nucleons, baryon, etc.) is discussed. There is a version of the theory in which a "maximon" (the particle with the maximum mass in the mass spectrum of "elementary particles") determines the numerical value of the "minimon" (the particle with the smallest nonzero mass).

History shows that the effort to achieve a scientific classification of entities which are combined in corresponding families is, in a sense, a thankless task. As a rule, the terminology which has been suggested has turned out to run into contradictions with the objects of the classification even in a linguistic sense. The "indivisible"—in terms of its linguistic meaning—"atom" became "divisible" a long time ago. The term introduced not long ago for the family of "leptons" (light particles) to emphasize the contrast with the term "baryons" (heavy particles) continues to survive after its linguistic meaning has been contradicted by the appearance of the τ meson, which is heavier than certain baryons. With the appearance of the concepts of partons, quarks, subquarks, etc., in light of which it became linguistically unnatural to call the particles which we are discussing here "elementary," the latter term has disappeared entirely from a booklet published by CERN.[1] One wonders whether it would be possible to find in the list of particles given in the CERN booklets any general characteristics which would make it physically meaningful to attempt to classify this list of particles with a common term, even if, for example, the general name "elementary particle" is retained.

For any particle of mass m, regardless of whether it is *macroscopic* or *microscopic, and regardless of its internal structure,* there are two characteristic lengths which are related in a fundamental way to the value of the mass of the particle, m. These lengths are constructed from universal constants: c, the velocity of light; κ, the gravitational constant; and h (or $h/2\pi$), Planck's constant. One of these lengths is the gravitational radius of the "particle":

$$l_{gr} = 2m\kappa/c^2 \, . \tag{1}$$

The other fundamental length associated with the mass of the particle is a length of the nature of the Compton length:

$$l_c = \alpha \frac{\hbar}{mc} \, , \tag{2}$$

where α is a constant which is arbitrary at this point. The imposition of the condition

$$l_c \geqslant l_{gr} \tag{3}$$

on these lengths substantially limits the mass spectrum of the particles which are considered; specifically,

$$\alpha \frac{\hbar}{mc} \geqslant \frac{2m\kappa}{c^2} \, . \tag{4}$$

This condition imposes a restriction, specifically, a maximum upper value of the mass, on the list of particles. The particles with the maximum mass in the list of elementary particles could naturally be called a "maximon"[2]:

$$m_{max} = \sqrt{(\alpha/2)(\hbar c/\kappa)} \sim 10^{-5} \text{ g if } \alpha \sim 1. \tag{5}$$

The list of particles limited by conditions (3) and (5), however, would include particles not found in the CERN booklet. For example, dust particles with a mass $m \sim 10^{-5}$ g, consisting of 10^{19} nucleons, would have appeared in the list of particles in the CERN booklet if the list of particles had been restricted exclusively by condition (5) with $\alpha \sim 1$. However, all particles can be characterized physically be certain geometric dimensions. These structural dimensions of the particles (l_r) are not expressed directly in terms of universal constants, but they are ultimately determined by the fundamental interactions of the particles which make up the given particle (i.e., nucleons, quarks, partons, and so forth). In principle, in a systematic theory of fields these structural dimensions of the particles should be calculated theoretically in all cases. The point which we wish to discuss here is this: Would the one additional condition

$$l_c > l_r \tag{6}$$

limit the list of particles to precisely those in the CERN booklets. For these particles we could then retain the now conventional term "elementary particles." Conditions of the type in (4) and (6) can indeed exclude particles made up of nucleons. The simplest of these particles is the deuteron.

Deuteron. The mass of the deuteron is $m_D \sim 1876$ MeV. The radius of the deuteron is

$$R_D \sim 4.8 \times 10^{-13}\,\text{cm}; \qquad l_c = (\alpha \hbar / M_D c) \sim \alpha \times 10^{-14}\,\text{cm}.$$

According to (3) and (6), therefore, the deuteron drops off the list of "elementary particles" if our constant α is less than 48; e.g., if it is 1 or 2π.

So far, we have essentially no information on the structural lengths of the other particles in the CERN booklet.

Leptons. The leptons—e, μ, τ—may be point particles or may in some sense have dimensions

$$l_r^L = e^2/m_L c^2 \; .$$

In this case the ratio of l_c to l_r would satisfy condition (6):

$$l_c / l_r \sim 137. \tag{7}$$

Proton. The mass of the proton is $m_p \sim 938$ MeV. The literature yields an experimental value for the "dimensions" of the proton:

$$l_r^p \sim 0.8 \times 10^{-13} \; .$$

If we call this value the "structural dimension" of the proton, then the value of α in (2) would increase to about $\alpha = 2\pi$.

It is not clear whether the as yet unknown structural dimensions of the hyperons and a large number of mesons in the CERN table of particles will be consistent with $\alpha \leqslant 2\pi$. Probably the entire systematic list of particles in the CERN booklet will be consistent with the interval of α values allowed by the deuteron ($\alpha \leqslant 48$). At these values of α (i.e., $\alpha \gg 2\pi$), however, we find the systematics to be somewhat inelegant. Although it is true that Einstein recommended that we leave elegance to tailors and shoemakers, there may be other opinions on this matter. All particles having an intrinsic mass of zero, such as the photon and the graviton, clearly fit into this classification, since for them we have

$$l_c = (\hbar / mc) \underset{m \to 0}{\rightarrow} \infty .$$

According to this classification, an upper limit on the mass spectrum of the particles follows from the relation

$$\alpha \frac{\hbar}{m_{max} c} = \frac{2\kappa m_{max}}{c^2};$$

if $\alpha \sim 1$, then

$$m_{max} \sim \sqrt{\hbar c/\kappa} \sim 10^{-5}\ \mathrm{g}.$$

The physical reality of such a particle is at least as certain as the existence of a decaying black hole. If black holes do exist, and if they do decay as a result of Hawking radiation, then after it reaches a mass $\sim 10^{-5}$ g in the course of its decay a black hole would acquire the properties of a "maximon."[2]

In the mass spectrum of the particles which we are discussing here there must unavoidably also be a particle with a minimum nonzero mass, which would naturally be called a "minimon." The value of the minimum mass of this particle should also have a special theoretical foundation. For example, in the mechanism of Gell-Mann, Ramond, Slanskiĭ, and Yanagida,[3] the smallness of the mass of the neutrino which participates in weak interactions is determined by the mass of the first Majorana neutrino. In a grand unified theory this mass can reach the scale of the masses of maximons: $V \sim 10^{19}$ GeV. In other words, if the mass of the Majorana (ν_R) heavy neutrino satisfies

$$m_D = m_R \sim 10^{19}\mathrm{GeV},$$

then the mass of the other neutrino, m_l, is given by the expression[3]

$$m_1 \sim m_D \frac{m_D}{m_R},$$

where m_D is the mass of the Dirac neutrino.

The mass of the particle with the minimum mass (the minimon) may in principle be determined by the mass of the maximon.

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[1] Particle Properties. Data Booklet, April 1986.

[2] M. A. Markov, Progr. Theor. Phys. Supl. Commemoration Issue for 30th Anniversary of the Mason Theory, by Dr. H. Yukawa, 1965; M. A. Markov, Zh. Eksp. Teor. Fiz. **51**, 878 (1966) [Sov. Phys. JETP **24**, 584 (1967)]

[3] G. T. Zatsepin and A. Yu. Smirnov, Neĭtrino i neĭtrinnaya astrofizika. Chast'. I. Neĭtrino (Neutrinos and Neutrino Astrophysics. Part I. Neutrinos), Izd. MGY, 1984.

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