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The Electromagnetic-Mass Paradox.

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The assumption of a finite electron leads to the question: Is its structure entirely electromagnetic or not? The affirmative answer to this question gives rise to the so-called « electromagnetic-mass paradox ». Almost all text books in electrodynamics analyse this problem. Jammer [1] has discussed the philosophical aspects of this question. Recently Zink [2] has also analysed this classical controversy. This paradox has been object of many discussions in the past fifty years but, up to the present time, there is no satisfactory solution of this controversy. In the present note we want to make a discussion in order to remove this paradox.

Let us suppose that the electron is a charged sphere moving with constant velocity v in empty space. If the velocity is very low we can use the quasi-static approximation. We shall consider that the body has a spherically symmetric charge distribution. It is well known that the total linear momentum of the field is given by

$$p = (4S/3c^2)v = m'v \,, \tag{1}$$

where S is the electrostatic energy of the body and m' is the « electromagnetic-mass ».

The total momentum of the field (1) is a consequence of the motion of the electron and thus the interaction between field and particle opposes the motion of the body. The experimental mass of the electron should be the superposition of the mass of the particle and the electromagnetic mass. Thus the effective mass of the body is given by

$$m_{\text{eff}} = m + m', \tag{2}$$

where m is the mass of the body.

If the electron is assumed to be a particle of purely electromagnetic mass we must set $m = 0$ in relation (2). If m' is the entire mass of the electron we must have by the special theory of relativity

$$m' = m_0/(1 - v^2/c^2)^{\frac{1}{2}} \tag{3}$$

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(1) M. Jammer: *Concepts of Mass*, Chap. 5 (Harvard, 1961).
(2) J. W. Zink: *Am. Journ. Phys.*, **34**, 211 (1966).

and

$$E_0 = m_0 c^2, \quad (4)$$

where E_0 is the rest energy and m_0 is the rest mass of the particle.

By relation (3), we have for low velocities $m' = m_0$ and so the electromagnetic mass m' should obey relation (4), namely

$$m' = m_0 = S/c^2. \quad (5)$$

By comparing relations (1) and (5) we can see that the assumption of an entirely electromagnetic electron leads to a paradox. This contradiction may be called the « electromagnetic-mass paradox ». This paradox has been object of many interesting controversies. FEYNMAN (3) has resumed some of these discussions. A more complete exposition of this problem has been made by ROHRLICH (4). However, all the attempts in order to reconcile (1) and (5) are insatisfactory.

As we have shown a purely electromagnetic electron is in full contradiction with the special theory of relativity. However relativity has been confirmed experimentally over the past fifty years. On the other hand an entire electromagnetic electron should be unstable due to the repulsive forces of its constituent parts. So that the hypothesis of a purely electromagnetic electron must be abandoned because it leads to absurd consequences. Thus the electromagnetic-mass paradox may be solved by the renunciation of this assumption.

It must be stressed that the electromagnetic mass is due to the interaction between the charge and the field. This situation is analogous to the motion of a sphere in an ideal fluid. As a consequence of the motion of the sphere the fluid acquires kinetic energy and thus there is an « induced mass » of the field which interacts with the body. A recent discussion of this problem has been given by LUIZ (5). In this case we can measure the rest mass of the body and we can calculate the « induced mass » of the fluid. The principal difference between the two situations is that it is impossible to measure the rest mass of the electron. On the other hand the electromagnetic mass of the electron cannot be calculated because we do not know either the geometrical shape of the electron or its exact charge distribution.

Finally we should emphasize that the electromagnetic mass is only a part of the experimental mass of the electron, but, actually we do not know if this term is negligible or if it is the dominant one. It seems impossible to separate the electromagnetic mass from the other component of the effective mass of the electron. Up to the present time there is no theoretical nor experimental determination of the electromagnetic mass of the electron.

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(3) R. P. FEYNMAN, R. B. LEIGHTON and M. SANDS: *The Feynman Lectures on Physics*, vol. **2**, chap. 28 (Reading, Mass., 1964).

(4) F. ROHRLICH: *Classical Charged Particles*, chap. 6 (Reading, Mass., 1965).

(5) A. M. LUIZ: *Chem. Engn. Sci.*, **22**, 1083 (1967).