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ON THE SELF-CONFINEMENT OF ELECTROMAGNETIC RADIATION

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ABSTRACT

A theoretical approach is outlined which attempts to explain elementary particles with a rest mass as eigenmodes of self-confined electromagnetic radiation. For this purpose an extended interpretation of Maxwell's equations is being suggested

The theory is illustrated by a simple special case where the particle interior contains a unipolar-like electric field having a non-vanishing divergence and being coupled to a poloidal dipole-like magnetic field having a non-vanishing curl. At large distances from the particle centre these fields approach their classical vacuum solutions. Numerical order-of-magnitude estimations being based on this model are at least consistent with the experimental data of the electron and the proton. (author)

1. Introduction

Ever since the discoveries of the first elementary particles, a number of attempts have been made by various investigators to explain the internal structure and features of these particles. This applies in particular to the magnititudes of and relations between such properties as charge, mass, magnetic moment, spin, and particle size. Accordingly the relation between energy and matter, and the corresponding processes of annihilation and pair production, have attracted special interest.

The present paper summarizes some unpublished ideas being developed on this subject by the author since the early 1960's, in attempts to explain particles with a rest mass as various eigenmodes of self-confined electromagnetic radiation. The reason for a rather crude and incomplete theoretical approach to be presented here, is that the author has just been informed of the existence of a theory on oscillating cavity modes by Jennison and collaborators [1-3] which has several features in common with that to be presented in the following sections.

2. Main Physical Features of Present Approach

The present approach is based on ideas the physical features of which can be summarized as follows:

(i) Electromagnetic radiation in free space consists of moving wave packets (photons) being characterized by coupled electric and magnetic fields. Particles of finite rest mass are suggested to arise from a self-confinement (self-trapping) of such radiation within discrete volumes of space. Thus, annihilation should be regarded as a process by which this closed field pattern is broken up, i.e. from a self-confined into a freely moving wave packet structure. Pair production should represent the inverse process.

(ii) For a charged particle at rest, such as an electron or a positron, space can be divided into two main parts, the "boundary" between which is defined by a particle radius r_o. In the outer region ($r \gtrsim r_o$) there is mainly an electrostatic field originating from the total electric charge q_o of the particle, as well as a magnetic dipole field originating from its magnetic moment M_o. In the inner region ($r \lesssim r_o$) both the electric and magnetic fields remain finite and form a more complex but axisymmetric (or possibly nearly axisymmetric) pattern where the electric field has to vanish at the centre $r = 0$ from symmetry reasons, and the magnetic field remains finite at the axis of symmetry.

(iii) For a particle at rest a steady, self-consistent and stable balance of forces is required. It should be somewhat analogous to the toroidal confinement of a plasma in a magnetic field, in the sense that the radiation pressure gradient of the electromagnetic field within the region $r \lesssim r_o$ is mainly being balanced by the electric current pattern and the magnetic field in this region. In other words, the equilibrium should have the form of a self-confinement of electromagnetic radiation within the inner region $r \lesssim r_o$. This self-confinement could be characterized as one in which the radiation "bends" its own paths of propagation into closed orbits, i.e. the energy flux and the corresponding Poynting vector should then circulate in closed paths. In a more general case the equilibrium state may include both poloidal (in planes through the symmetry axis) and toroidal (in circles around the symmetry axis) field components, as well as effects from self-gravity and centrifugal forces due to the circulating energy. Here we shall only treat a simple model which can be considered as a special case of a larger class of equilibria.

(iv) Whether the self-confined field pattern within $r \lesssim r_o$ could consist of sets of eigen-modes being strictly static or having the form of standing waves [1-3] is not clear at this stage. In any case, this does not affect the order of magnitude of the average field strengths. On the other hand, this question may have an influence on the general physical picture, in a way which cannot be penetrated here in detail. It is in any case obvious that the electric and magnetic field patterns $\underline{E}$ and $\underline{B}$ in the inner and outer regions have to be matched in the "boundary region" around $r = r_o$. In the remote region $r \gg r_o$ the fields $\underline{E}$ and $\underline{B}$ further have to become static at every point in space. These conditions, as well as those of a stable equilibrium of forces, have to be included in a selfconsistent theory.

(v) The present approach is expected to yield values of and relations between the particle charge q_o, mass m_o, magnetic moment M_o, spin (angular momentum) S_o, and particle radius r_o. These relations should contain a set of universal constants as represented by the velocity of light $c=3\times10^8$ m/s, by the magnetic permeability in vacuo $\mu_o = 4\pi \times 10^{-7}$ Vs/Am or the dielectric constant $\epsilon_o = 1/\mu_o c^2 = (1/36\pi)\times10^{-9}$ As/Vm, and by Planck's constant $h = 6.625 \times 10^{-34}$ VA s^2, here being expressed in SI units. The various possible eigenmodes for self-confinement should then give rise to sets of particle solutions of both electric polarities, which can also be combined to electrically neutral particles. At this stage we shall only present one example being obtained from a crude order-of-magnitude estimation in terms of a simple model of the field geometry.

(vi) An additional question concerns gravitation and its possible relation to an electromagnetic description of matter. The average interaction force between two pieces of matter, which both contain a large electrically neutral assembly of positively and negatively charged self-confined systems of the present type, would certainly become zero in first order. However, the self-field of one single system (particle) should interfere with the fields originating from surrounding systems. In higher order this should lead to an additional interaction force. To be more specific, the attractive force between two parallel magnetic dipoles (ring-currents) being situated on a common axis, has the same modulus as the repulsive force between a corresponding pair of two antiparallel dipoles, but only in first order. From symmetry reasons the cases of parallel and antiparallel dipoles do not become equivalent to each other. Thus, the change in total energy of the superimposed internal and external fields, as being caused by a change in axial distance between the dipoles, should not have exactly the same magnitude for a parallel as for an antiparallel pair of dipoles. In other words, a small "rest force" is expected to arise when forming the average force between two dipoles over all possible spatial orientations of their axes. The question then arises whether this rest force could be associated with gravity, but further discussions on this matter are out of the scope of this paper.

3. Basic Concepts and Assumptions

The first starting-point of this theory is Maxwell's equations

$$\mathrm{curl}\,\underline{B}/\mu_o = \underline{j} + \varepsilon_o \partial \underline{E}/\partial t \tag{1}$$

$$\mathrm{curl}\,\underline{E} = - \partial \underline{B}/\partial t \tag{2}$$

where $\underline{j}$ is the electric current density,

$$\mathrm{div}\,\underline{E} = \sigma/\varepsilon_o \tag{3}$$

is obtained from Eq. (1) with σ representing the charge density, and the condition $\mathrm{div}\,\underline{B} = 0$ is derived from Eq. (2).

We further adopt Einstein's relation

$$W_m = mc^2 \tag{4}$$

between a mass m and its corresponding energy W_m, as well as the Planck relation

$$W_\nu = nh\nu \tag{5}$$

between the energy W_ν and the frequency ν of the n-th state of an electromagnetic oscillator. Here h denotes Planck's constant and n an integer.

4. An Extended Interpretation of Maxwell's Equations

We now have to relate Maxwell's equations to the problems of self-confined electromagnetic radiation. In classical electromagnetic field theory the current density $\underline{j}$ is defined as a convection current due to the motion of discrete charged particles. For the special case of "empty" space with $\underline{j} = 0$, it is thus seen from Eq. (1) that the magnetic field $\underline{B}$ becomes related to $\partial\underline{E}/\partial t$ only. With this interpretation, the equilibria of electromagnetic fields in vacuo would only become possible in the form of such states as standing wave patterns. In this context we shall, however, also consider the possibility of extending the interpretation of Maxwell's equations in such a way that static equilibria of forces in an electromagnetic field can be realized.

4.1. Particle being at Rest

We first consider a particle being at rest, in the sense that the centre of the corresponding self-confined field configuration does not move in space. Then, the interpretation of $\underline{j}$ also has to be extended in a corresponding manner. Thus, the electric charge density σ has no longer to be associated with discrete charged particles only, but is instead interpreted as an intrinsic property of the electric field itself. We therefore use Eq. (3) in the form $\sigma = \epsilon_o \mathrm{div}\underline{E}$ as a definition of the charge density in terms of the electric field $\underline{E}$. The corresponding current density should then be expressed by the modified form

$$\underline{j}^{*} = \epsilon_o(\mathrm{div}\underline{E})\underline{w}^{*} \tag{6}$$

where $\underline{w}^{*}$ is a corresponding equivalent velocity. The question now arises how to define the velocity $\underline{w}^{*}$. For this purpose we turn to Eqs. (1) and (2), the vector products with $\underline{E}$ and $\underline{B}$ of which can be combined to

$$\varepsilon_o(\mathrm{curl}\,\underline{E}) \times \underline{E} + (1/\mu_o)(\mathrm{curl}\,\underline{B}) \times \underline{B} = \underline{j} \times \underline{B} + \varepsilon_o \frac{\partial}{\partial t}(\underline{E} \times \underline{B}) \tag{7}$$

The obtained relation is usually interpreted as a momentum balance of the electromagnetic field, with the equivalent momentum of radiation per unit volume being given by

$$\underline{P} = \varepsilon_o \underline{E} \times \underline{B} \tag{8}$$

On the other hand, it should become possible to express the same momentum in terms of the velocity $\underline{w}^*$ and the equivalent mass density ρ^* of the electromagnetic field, i.e.

$$\underline{P} = \rho^* \underline{w}^* \tag{9}$$

According to Eq. (4) and for reasons being put forward in Section 4,2, we now make the Ansatz

$$\rho^* = \varepsilon_o B^2 \tag{10}$$

Combination of Eqs. (8)-(10) then yields the modified current density

$$\underline{j}^* = \varepsilon_o(\mathrm{div}\,\underline{E})\underline{E} \times \underline{B}/B^2 \tag{11}$$

Consequently for a particle being at rest, and possibly containing oscillating field components $\underline{E}$ and $\underline{B}$, Maxwell's equation (1) can be rewritten in the modified form

$$c^2 \mathrm{curl}\underline{B} = (\mathrm{div}\underline{E})\underline{E} \times \underline{B}/B^2 + \partial\underline{E}/\partial t \tag{12}$$

whereas Eq. (2) remains unchanged. The set of Eqs. (12) and (2) leads to the following asymptotic cases:

(i) For a time-dependent field with $\partial/\partial t \neq 0$ and when considering the space $r \gg r_o$ far outside of the self-confined particle region, i.e. where $\mathrm{div}\underline{E}$ vanishes, the equations of an electromagnetic wave in vacuo are recovered.

(ii) For a static case with $\partial/\partial t = 0$, we obtain $\underline{E} = -\underline{\nabla}\phi$ from Eq. (2), and Eq. (12) reduces to

$$c^2 \mathrm{curl}\underline{B} = (\mathrm{div}\underline{E})\underline{E} \times \underline{B}/B^2 \tag{13}$$

In the external region $r \gg r_o$ the resulting static fields obey the conditions $\mathrm{div}\underline{E} = 0$ and $\mathrm{curl}\underline{B} = 0$, as expected. On the other hand, application of Eq. (13) to the internal region $r \lesssim r_o$ leads to a relation between $\underline{E}$ and $\underline{B}$ by which the space charge represented by $\mathrm{div}\underline{E} \neq 0$ becomes coupled to the electric current density being represented by $\mathrm{curl}\underline{B} \neq 0$. Further, in a static case the balance of forces in the internal region should be expressed by

$$(\mathrm{curl}\underline{B}) \times \underline{B}/\mu_o = \underline{j}^* \times \underline{B} \tag{14}$$

which then becomes an extended version of Eq. (7) for this region. In Eq. (14) the left hand member plays the role of a pressure gradient being balanced by the volume force

$\underline{j}^*$ x $\underline{B}$ of the right hand member. We also observe that this equilibrium condition does not lead to any additional and independent balance equation, but is merely a consequence of the original Eqs. (1) and (12) expressing the magnetic field in terms of its sources. Needless to say, it also has to be found out under what conditions stable equilibria can be found which satisfy Eq. (13) for fields $\underline{E}$ and $\underline{B}$ under the conditions curl$\underline{E}$ = 0 and div$\underline{B}$ = 0 of a static state, but this question is out of the scope of this context.

4.2. Particle Performing a Slow Translatory Motion

The adopted Eqs. (6), (9), (10), and (11) should be considered as a first Ansatz in attempts to satisfy the conditions of equilibrium for a self-confined field structure. To obtain further support for this approach, we consider a frame of reference moving at a small translatory velocity $-\underline{v}$ = const., with respect to the particle centre. Indicating the field quantities in this frame by a dash ('), we then have

$$\underline{E}' \simeq \underline{E} - \underline{v} \times \underline{B} \qquad \underline{B}' \simeq \underline{B} \tag{15}$$

when $v^2 \ll c^2$. The modified current density of Eq. (11) thus has the form

$$\underline{j}^{*\prime} \simeq \underline{j}^* + \varepsilon_0(\mathrm{div}\underline{E})\underline{v} - \varepsilon_0(\mathrm{div}\underline{E})\underline{B}(\underline{B} \cdot \underline{v})/B^2 +$$

$$+ \varepsilon_0(\underline{v} \cdot \mathrm{curl}\underline{B})\underline{E} \times \underline{B}/B^2 \tag{16}$$

In all parts of vacuum space being outside of the self-confinement volume we then have $\underline{j}^{*\prime} = \underline{j}^* = 0$, as being expected. We now choose a surface S which is perpendicular to $\underline{v}$ and cuts through the internal particle region at a certain time t.

Within this region all terms of Eq. (16) then become different from zero. We further assume that the internal field of the particle is axially symmetric and consists of a monopole-like electric field and a dipole-like magnetic field. When integrating the current density over the surface S, these symmetry conditions and the constancy of the vector field $\underline{v}$ yield zero net contributions from the first, third, and fourth terms of the right hand member of Eq. (16). Thus the resulting current through S becomes

$$\underline{J}^{*'} = \int_S \sigma \underline{v} \, dS \tag{17}$$

Expression (17) has the form of a convection current produced by the motion of the charge density σ at the velocity $\underline{v}$, as expected from conventional theory.

The obtained result supports the Ansatz of Eq. (10). If we would instead have chosen an equivalent mass density of the form $\varepsilon_0(E^2 + c^2B^2)/2c^2$, the deductions would still have ended up with Eq. (17), provided that $\underline{E}^2 = c^2\underline{B}^2$. In this connection has to be stressed that definitions of a local energy density of an electromagnetic field in terms of $\varepsilon_0\underline{E}^2/2$ and $\underline{B}^2/2\mu_0$ are merely to be considered as formal, and cannot in a strict physical sense be associated with a corresponding localized mass density. Only when integrating these energy densities over the entire volume of the system, they will become equal to its total energy. Therefore it is not unlikely that one could put $\langle\underline{E}^2\rangle = \langle c^2\underline{B}^2\rangle$, with $\langle\ \rangle$ henceforth denoting average values being formed over the particle volume.

5. A First Simplified Approach to a Self-Confined System

We now turn to a crude order-of-magnitude estimation of the field quantities of a self-confined system as outlined in the previous Sections 2 and 4. A simple special model is being treated, but it has also to be kept in mind that other field configurations and self-confined modes of similar systems could become possible.

5.1. The Internal Field Distributions

The model to be applied has largely been outlined in Section 2 under (ii)-(v). In a first approach the various field quantities and their derivatives are expressed in terms of corresponding characteristic amplitudes and lengths. Quantities in the inner ($r \lesssim r_o$) and outer ($r \gtrsim r_o$) regions are here denoted by subscripts ($_1$) and ($_2$), and r indicates the radial distance from the particle centre in a frame of spherical coordinates. Consequently, the electric field is assumed to become monopolar far away from the particle. It should have the moduli

$$\langle E_1 \rangle \equiv E_o = c_E q_o / \varepsilon_o r_o^2 \tag{18}$$

and

$$E_2 = q_o / 4\pi\varepsilon_o r^2 \tag{19}$$

in the inner and outer regions, respectively. The factor c_E in Eq. (18) is a dimensionless constant of order unity being dependent of the detailed distribution of $\underline{E}$ across the inner region. We return later to the question about the magnitude of this factor. In the present simplified field configuration we further assume a main poloidal magnetic field, being given by the moduli

$$\langle B_1 \rangle \equiv B_o \simeq c_B \mu_o M_o / r_o^3 \tag{20}$$

and

$$\langle B_2 \rangle \simeq \mu_o M_o / 4\pi r^3 \tag{21}$$

in the inner and outer regions. The factor c_B in Eq. (20) is a dimensionless constant of order unity, being dependent of the detailed distribution of $\underline{B}$ in the inner region.

The adopted model has now to be related to the balance condition being expressed by Eq. (13). Here it should first be observed that the latter equation is invariant to reversals in direction of either of the field quantities $\underline{E}$ and $\underline{B}$. Second, we have $\underline{E} \cdot \mathrm{curl}\underline{B} = 0$ and $\underline{B} \cdot \mathrm{curl}\underline{B} = 0$ from Eq. (13) which is consistent with the assumed field geometry of the model. Third, the modified current density of Eq. (11) and the form of the momentum vector become consistent with an electric current and an energy flux circulating in closed paths within the particle volume. Fourth, with characteristic lengths of the order of r_o for the spatial field variations in the inner region, we have $|\mathrm{curl}\underline{B}| \simeq B_o/r_o$ and $|\mathrm{div}\underline{E}| \simeq E_o/r_o$ from which Eq. (13) yields

$$E_o \simeq cB_o \tag{22}$$

in a first approximation. This result is consistent with the picture of trapped electromagnetic radiation circulating inside the particle around its axis, at the velocity c of light. It also supports the adopted Ansatz associated with Eq. (10) and being discussed in connection with Eq. (17) at the end of Section 4.2.

Further, it has to be stressed that the field distributions in the particle interior which satisfy Eq. (13) may require the strengths $|\underline{E}_1|$ and $|\underline{B}_1|$ to become greater than those corresponding to the external asymptotic fields $\underline{E}_2$ and $\underline{B}_2$ of Eqs. (19) and (21) at $r = r_o$. Also div$\underline{E}_1$ may have to change sign in certain regions within the volume $r < r_o$, even if the total charge q_o has a definite sign. These circumstances could lead to values of c_E and c_B in Eqs. (18) and (20) being greater than unity.

From Eqs. (28), (20), and (22) we obtain an expression for the modulus of the magnetic moment, i.e.

$$M_o = (c_E/c_B)cq_or_o \tag{23}$$

Finally, it should be observed that Eq. (13) includes space derivatives of $\underline{B}$ and $\underline{E}$ both being of first order. Therefore, the possible solutions of this equation with its appropriate boundary conditions cannot give information about the length scale of the particle geometry. Only mutual relations between the fields $\underline{E}$ and $\underline{B}$ are given by Eq. (13). To determine the absolute length scale, or particle mass, additional conditions have to be included in the theory, in a way not being clear at this stage.

5.2. The Associated Particle Mass and Angular Momentum

Starting from Eqs. (4), (18), and (22) we now express the mass of the particle as

$$m_o = 4\pi r_o^3 \langle (\varepsilon_o E_1^2/2) + (B_1^2/2\mu_o) \rangle /3c^2 = c_m \mu_o q_o^2/r_o \tag{24}$$

where c_m is a dimensionless constant of order unity. The first and last members of Eq. (24) lead to an expression for r_o being equivalent to that of the classical electron radius [4]. Further, the azimuthally circulating energy flux should correspond to an angular momentum (spin) having the modulus

$$S_o \simeq m_o r_o E_o / B_o \simeq c_m \mu_o q_o^2 c \qquad (25)$$

5.3. Azimuthal Periodicity Condition

In the case of an azimuthally circulating wave pattern, a periodicity condition must be imposed which in the present simplified model can be written as

$$c_\nu r_o = n(c/\nu) \qquad (26)$$

where $1/\nu$ is the average time of revolution of the radiation around the symmetry axis, n denotes an integer, and c_ν is a dimensionless constant of order unity being associated with the detailed internal geometry of the particle and the corresponding effective path length of the azimuthally circulating energy flux. The constant c_ν is likely to be somewhat larger than unity.

We now make the assumption that the present special case of steady fields can be represented by $n = 1$ in Eqs. (26) and (5), and that the total energy of the particle is given by $W_o = W_m = W_\nu$ as expressed by Eqs. (4) and (5). This results in the relation

$$r_o = h/c_\nu m_o c \qquad [m] \qquad (27)$$

between the particle radius and mass.

5.4. Numerical Results

The difficulties in making an exact definition of the particle radius and uncertainties in its experimental data for the electron, suggest that the obtained results are rearranged in a way being independent of r_o. For this purpose Eqs. (23)-(25), and (27) are combined and rewritten into the expressions

$$q_o \simeq (h/\mu_o c c_\nu c_m)^{1/2} \qquad [A \cdot s] \qquad (28)$$

$$M_o \simeq (c_E h q_o / c_B c_\nu m_o) \simeq (c_E^2 h^3 / c_B^2 c_\nu^3 c_m \mu_o c m_o^2)^{1/2} \qquad [A \cdot m^2] \qquad (29)$$

$$s_o \simeq h/c_\nu \qquad [kg \cdot m^2/s] \qquad (30)$$

These formulae as well as Eq. (27) lead to the following numerical results as given in SI units:

(i) For the charge of Eq. (28) we obtain $q_o \simeq 13 \times 10^{-19}/(c_\nu c_m)^{1/2}$. As compared to the modulus of the experimentally determined electron and proton charge we thus have $q_o/e \simeq 8/(c_\nu c_m)^{1/2}$.

(ii) Concerning the magnetic moment the second member of Eq. (29) yields $M_o \simeq 1.2 \times 10^{-22} c_E/c_B c_\nu$ for $q_o = e$ and $m_o = m_e$ in the case of the electron, as well as $M_o \simeq 6.4 \times 10^{-26} c_E/c_B c_\nu$ for $q_o = e$ and $m_o = m_p$ in the case of the proton. According to the third member of Eq. (29) we have instead $M_o \simeq 9.6 \times 10^{-22} (c_E^2/c_B^2 c_\nu^3 c_m)^{1/2}$ for the electron, and $M_o \simeq 53 \times 10^{-26} (c_E^2/c_B^2 c_\nu^3 c_m)^{1/2}$ for the proton. The measured data |4| are $M_e = 0.926 \times 10^{-23}$ and $M_p = 1.405 \times 10^{-26}$ for the electron and the proton, respectively.

(iii) With the coefficient c_ν being somewhat larger than unity, the angular momentum S_o of Eq. (30) becomes somewhat smaller than h. The correct value according to current literature [5] is $h(3/16\pi^2)^{1/2}$ for the electron and the proton.

(iv) We finally turn to Eq. (27) which yields the radius $r_o \simeq 2.4 \times 10^{-12}/c_\nu$ for the electron and $r_o \simeq 1.3 \times 10^{-15}/c_\nu$ for the proton. The experimental data on the electron radius are so far uncertain [6]. For the proton radius the value $r_p = 1.5 \times 10^{-15}$ has been given in the literature [4].

6. Conclusions

From the present results and considerations the following conclusions can be drawn:

(i) The theory of this paper yields relations between the particle charge q_o, mass m_o, radius r_o, magnetic moment M_o, and spin S_o in terms of the three universal constants c, $\mu_o = 1/\varepsilon_o c^2$, and h. At least for the electron and the proton these relations lead to numerical results which appear to be of correct orders of magnitude as compared to experimentally determined data. This agreement is as good as can be expected from the present crude theoretical approach.

(ii) The previously described deductions concern one simple type of mode and its field structures. Other more complex modes, both including static solutions and standing wave patterns [1-3], may also have to be considered. The existence of equilibrium solutions also has to be verified by a rigorous mathematical treatment. Provided that the present approach is correct in its principles, one should expect these modes to lead to a spectrum of various types of elementary particles. The possible eigenmodes could also become related to quarks.

(iii) The particle charge q_o and spin S_o should be independent of both mass m_o and radius r_o according to Eqs. (27), (28), and (30). This is consistent with experimental facts.

(iv) Concerning the magnetic momentum M_o there is a dependence on the mass m_o according to Eq. (29) which is at least in qualitative agreement with experimental observations. Further, the equivalent current density j^* of Eq. (11) suggests that the azimuthally circulating electric current and momentum should become antiparallel in the case of negatively charged particles. This is at least in agreement with the properties of the electron.

(v) Equilibria may also exist for which the electric and magnetic fields have both poloidal and toroidal components. The total strengths of the fields $\underline{E}_1$ and $\underline{B}_1$ within the particle "interior" would then become much greater than those of the fields $\underline{E}_2$ and $\underline{B}_2$ which "leak" through the particle boundary $r = r_o$ and reach the external region being "outside" of the particle.

(vi) The stability of the various modes of equilibrium has to be analysed, among other things with respect to perturbations of the particle radius r_o.

(vii) In this context conditions are missing for a determination of the absolute value of the particle radius r_o (or mass m_o). This question has to be further analysed, as well as that of the number and types of universal constants which have to be included in the theory. Further investigations are also required on the problem whether a matching of the inner ($\underline{E}_1$, $\underline{B}_1$) and outer ($\underline{E}_2$, $\underline{B}_2$) fields at the boundary $r = r_o$ might become possible only for certain sets of discrete parameter values or not.

(viii) It also has to be found out, in which way the deflection of light by a force field or by photon-photon scattering may become related to the ideas of self-confined radiation.

(ix) The present theoretical approach has not taken the problems of invariance into account which are commonly discussed in field theory. This point requires further clarification.

(x) Further analysis is also required on the problem how gravitation could become related to the concept of self-confined radiation and its corresponding field structure.

7. Acknowledgement

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Stocksund, July 15, 1979

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Key words: Elementary particles, electromagnetic fields.