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Abstract

Full Text

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Physics

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TOWARD A UNIFIED THEORY OF ELEMENTARY PARTICLES

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Considerations and estimates will be set forth which indicate the possibility of constructing a logically simple and general theory of physical phenomena. The initial propositions are formulated in Sections 1-3; the remaining sections contain conclusions.

1. **Basic concepts:** the space-time of the special theory of relativity and primary particles—world lines having no thickness.
2. **Law of motion:** all trajectories are equally probable. More precisely, some simple measure (“probability of a trajectory”) is chosen in which the correlation between successive positions of a particle is minimal. One may take, for example, the Wiener measure—the particular form of the measure is immaterial.
3. **Model of the Universe:** a tangle of world lines of $N = 10^{80}$ particles, uniformly distributed over a sphere of radius $R = 10^{28}$ cm. Topological characteristics (of the type of the number of knots) are invariants that specify the degree of entanglement; they are specified and do not change under summation over paths (the lines do not break). For what follows it is sufficient to specify the value of the simplest invariant described by Edwards ⁽¹⁾ for an analogous problem.
4. **Conclusion of the basic interaction.** As Edwards showed ⁽¹⁾ using the example of long polymer chains, summation over noninteracting chains with the simplest topological restrictions is equivalent to the inclusion of an electromagnetic interaction between the chains. An analogous situation may occur for world lines.
5. **Mass of particles.** The aim of Sections 1-4 is to adduce arguments in favor of the fundamental character and irreducibility of the electromagnetic interaction. For what follows it is sufficient to postulate such an interaction (or a nuclear one—in the approximate estimates of the following sections they do not differ; only the magnitude of the coupling constant is important).

Electrodynamics (and mesodynamics, see below) differs from the generally accepted one: for the field produced by a charge, the solution is taken to be symmetric with respect to the direction of time (Schwarzschild, Fokker, see ⁽³⁾), and not retarded, as is done at present. Grounds for introducing an advanced potential were indicated by Dirac ⁽²⁾. Radiation arises only in the presence of an absorber (the possibility of such a situation was first noted by Tetrode (see ⁽³⁾). Wheeler and Feynman ⁽³⁾ constructed a consistent theory containing both these ideas. In experiment we observe only the retarded potential. According to Wheeler and Feynman ⁽³⁾, this is explained by the interaction of an individual electron with the rest of the Universe. The direction of time is connected with statistics. Hogarth ⁽⁴⁾ and Hoyle and Narlikar ⁽⁵⁾ proposed another variant of the theory, in which the singled-out character of time is a result of the expansion of the Universe. The theory has not been carried through to completion because of difficulties with the introduction of spin (see in this connection ⁽¹²⁾). In their recent work Hoyle and Narlikar ⁽⁵⁾ noted that the interaction of the field with the matter of the Universe at high frequencies may become weakened. This will change the electromagnetic interaction at high frequencies—the mass of the electron may become finite.

These arguments may be refined and continued as follows. Let the field mass, as a result of the interaction of a particle with the Universe

finite and equal to m . The interaction of electromagnetic waves with matter is specified by the value of the scattering cross section on a free charge

$$\sigma = \frac{8\pi}{3} \left(\frac{q^2}{mc^2} \right)^2$$

(at high frequencies $\sigma = \pi \left(\frac{q^2}{mc^2} \right)^2 \frac{m}{\omega}$, q —charge, ω —frequency). As a cosmological model let us take an open model, in which R is the maximum interaction radius, N is the number of particles inside a sphere of radius R . The weakening of the interaction with the Universe at high frequencies means, according to Wheeler and Feynman ⁽³⁾, the absence of radiation and, consequently, the absence of a contribution to the mass from transverse electromagnetic waves at these frequencies. A specification of this mechanism for the estimates (1)–(3) is not necessary. If the mass is finite, then each charge must be substantially screened by the other particles, i.e. the total cross section of all particles σN must be close to R^2 . The effect will be connected mainly with distant particles at distances of order R . Therefore

$$\sigma N \simeq R^2, \tag{1}$$

and since $\sigma = \frac{8\pi}{3} \left(\frac{q^2}{mc^2} \right)^2$, then

$$m = \left(\frac{8\pi}{3}\right)^{1/2} \frac{q^2 \sqrt{N}}{c^2 R} = \begin{cases} 10^{-27} & \text{for the electron } (q\text{--electron charge}) \\ 10^{-24} & \text{for the proton } (q\text{--charge of strong interactions}) \end{cases} \quad (2)$$

The validity of substituting the baryon charge into (1)–(2) requires special justification, but the possibility of constructing a variant of mesodynamics symmetric with respect to the direction of time seems natural.

Relation (2) was obtained by Hayakawa ⁽⁸⁾ from other considerations.

6. Gravitational constant. The energy of a system of N particles will be $Nmc^2 = q^2 N^{3/2}/R$. The nonadditivity of this expression may be interpreted as the result of an interaction with potential

$$\frac{\varkappa m^2}{R} N$$

(gravitation). Comparing the constants at $1/R$, we obtain (m –proton mass, q –charge of strong interactions)

$$\varkappa = q^2/2m^2\sqrt{N} \simeq 10^{-8}. \quad (3)$$

7. Quantum mechanics. In the initial picture of the motion of one particle (without taking account of the influence of the Universe) we knew nothing about the character of the motion, and therefore must admit any paths, in particular paths with kinks in time (a particle without mass). After taking account of the interaction and the appearance of mass, kinks are impossible; however, the creation and annihilation of a pair on scales of order r_0 ($r_0^2 = \sigma$, where σ is specified by relation (1)) will not create a field at large distances if the charges move with a velocity close to the speed of light. Therefore the path of a particle, smooth on large scales, on small scales may be a sequence of a large number of creations and annihilations ⁽⁶⁾. As shown in ⁽⁷⁾, under these conditions oscillations with frequency $1/\tau$ arise in the system, where τ is the free-flight time, and the motion of the particle obeys the Dirac equation with $mc^2/h = 1/\tau$. In the present case $\tau \sim r_0/c$ and

$$h = mc r_0 = 1 \cdot 10^{-26} \quad (m\text{--proton mass}) \quad (4)$$

According to ⁽⁷⁾, the Dirac equation—the kinetic equation for motion with two signs of time—is valid only for frequencies greater than the reciprocal time of the collision that produces a kink of the world line. Following Hayakawa ⁽⁸⁾, we shall regard fluctuations of the gravitational field as the cause of the quantum-mechanical chaos. Since the energy mc^2 is the result of the action of all particles of the Universe, and the contribution of an individual particle may turn to zero

when screened by other particles (i.e. is a random quantity), the energy (and mass) will experience fluctuations of order mc^2/\sqrt{N} . These fluctuations can separate two charged balls to a distance l , which is determined by comparing the energy $kl^2/2$ (k -constan-

then is determined from the condition $kr_0^2 = 2mc^2$ with mc^2/\sqrt{N} . Taking r_0 from (1), we obtain:

$$l = r_0/N^{1/4} = 10^{-32}. \quad (5)$$

8. Proton and electron. Since quantum mechanics has been obtained, the conclusions of quantum electrodynamics are also valid. If one takes the expression of L. D. Landau, A. A. Abrikosov, and I. M. Khalatnikov⁽⁹⁾ for the renormalization of the electric charge and substitutes the cutoff radius calculated above, then we obtain (ν is the number of particle types, Λ is the cutoff momentum)

$$e^2/hc = 3\pi/2\nu \ln(\Lambda/mc^2) = 6\pi/\nu \ln N \simeq 1/12\nu. \quad (6)$$

It follows from this expression that the renormalized charge can exist independently of the bare one. Following L. D. Landau⁽¹⁰⁾, the electron can be interpreted as a collective excitation of the vacuum with charge determined by relation (6). The electron mass is specified by the magnitude of the charge according to (2).

9. Neutrino and weak interactions. It is usually considered that a hard sphere cannot possess half-integer spin, and that in a system of charged particles there cannot arise excitations without charge and with half-integer spin. This follows from the requirement of single-valuedness of the wave function (the double-valued representations of the rotation group associated with half-integer angular momentum are discarded).

This requirement does not lead to any contradictions with experiment and, nevertheless, is doubtful. According to the views set forth in⁽¹¹⁾, physical requirements may be imposed only on probability. If one adheres to this principle, then the existence of a sphere with half-integer angular momentum becomes possible; only transitions between states with integer and half-integer angular momentum are forbidden. A particle can absorb a photon, but cannot absorb a neutrino. This assertion may, generally speaking, become incorrect while the pair has not separated to the distance l calculated in Section 7—this region is not described by quantum mechanics; here the particle interacts intensely (and chaotically) with the Universe. One may expect that only during this time, constituting a fraction l/r_0 of the total time (r_0 is the mean free path), does interaction with a neutrino become possible. Therefore the cross section calculated in Section 4 for the neutrino will decrease by a factor l/r_0 and become equal to

$$\sigma = r_0 l \simeq 10^{-44}. \quad (7)$$

This is the usual value of the scattering cross section for weak interactions.

10. Strong interactions. According to the picture described in Section 7, the spread of the particle coordinates will consist of two parts: $|\xi_1|^2$ —the spread due to the change in the direction of time (pair creation), and $|\xi_2|^2$ —the spread along segments of the path with a constant direction of time. Random forces determine the value of the sum $|\xi_1|^2 + |\xi_2|^2$. It is possible that precisely this circumstance leads to $SU(3)$ -symmetry (in the space $\xi_1 + i\xi_2$).

The principal difference between the present work and other unified theories lies in the treatment of quantum mechanics. Quantum mechanics here is a consequence of the changing direction of time in the microworld and a result of the interaction of the particle with the Universe.

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