Theoretical Errors in Contemporary Physics

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Errors pertaining to the following physical theories are discussed: the Dirac magnetic monopole theory; the Klein-Gordon equation; the Yukawa theory of nuclear force; the idea of Vector Meson Dominance; the Aharonov-Bohm effects; the idea of diffraction-free electromagnetic beams and Quantum Chromodynamics. Implications of the theoretical errors are discussed briefly. In particular, relations between the Dirac monopole theory, the idea of Vector Meson Dominance and Quantum Chromodynamics cast doubt on the current interpretation of strong interactions.

Keywords: Monopoles, Klein-Gordon, QCD, Yukawa Theory, VMD, Aharonov-Bohm, Diffraction-free beams.

1. Introduction

The purpose of the present work is to discuss several theoretical errors existing in contemporary physics. Before addressing specific cases, let us examine the structure of a physical theory and the meaning of errors that can be found in it.

A physical theory resembles a mathematical theory. Both rely on a set of axioms and employ a deductive procedure for yielding theorems, corollaries, etc. The set of axioms and their results are regarded as elements of the structure of the theory. However, unlike a mathematical theory, a physical theory is required to explain existing experimental data and predict results of new experiments.

This distinction between a mathematical theory and a physical theory has several aspects. First, experiments generally do not yield precise values but contain estimates of the associated errors. (Some quantum mechanical data, like spin, are the exception.) It follows that in many cases, a certain numerical difference between theoretical predictions and experimental data is quite acceptable.

Next, one does not expect that a physical theory should explain every phenomenon. For example, it is well known that physical theories yield very good predictions for the motion of planets around the sun. On the other hand, nobody expects that a physical theory be able to predict the specific motion of an eagle flying in the sky. This simple example proves that the validity of a physical theory should be evaluated only with respect to a limited set of experiments. The set of experiments which are relevant to a physical theory is called its domain of validity. (A good discussion of this issue can be found in [1], pp.

1-6.)

Relations between two physical theories can be deduced from an examination of their domain of validity. In particular, let D_A and D_B denote the domains of validity of theories A and B, respectively. Now, if $D_A \subset D_B$ and $D_A \neq D_B$ then one finds that theory B takes a higher hierarchical rank than theory A (see [1], pp. 3-6). Here theory B is regarded as a theory having a more profound status. However, theory A is not "wrong", because it yields good predictions for experiments belonging to its own (smaller) domain of validity. Generally, theory A takes a simpler mathematical form. Hence, wherever possible, it is used in actual calculations. Moreover, since theory A is good in its validity domain D_A and $D_A \subset D_B$, then one finds that *theory A imposes constraints on theory B in spite of the fact that B's rank is higher than A's rank.* This self-evident relation between lower rank and higher rank theory is called below "restrictions imposed by a lower rank theory." It is used here more than once. Thus, for example, although Newtonian mechanics is good only for cases where the velocity v satisfies $v \ll c$, relativistic mechanics should yield formulas which agree with corresponding formulas of Newtonian mechanics, provided v is small enough.

Having these ideas in mind, a theoretical error is regarded here as a mathematical part of a theory that yields predictions which are clearly inconsistent with experimental results, where the latter are carried out within the theory's validity domain. The direct meaning of this definition is obvious. It has, however, an indirect aspect too. Assume that a given theory has a certain part, P, which is regarded as well established. Thus, let Q denote another set of axioms and formulas which yield predictions that are inconsistent with P. In such a case, Q is regarded as a theoretical error. (Note that, as explained above, P may belong to a lower rank theory.) An error in the latter sense is analogous to an error in mathematics, where two elements of a theory are inconsistent with each other.

There are other aspects of a physical theory which have a certain value but are not well defined. These may be described as neatness, simplicity and physical acceptability of the theory. A general rule considers theory C as simpler (or neater) than theory D if theory C relies on a smaller number of axioms. These properties of a physical theory are relevant to a theory whose status is still undetermined because there is a lack of experimental data required for its acceptance or rejection.

The notions of neatness, simplicity and physical acceptability have a subjective nature and so it is unclear how disagreements based on these criteria can be settled. In particular, one should note that ideas concerning physical acceptability changed dramatically during the 20th century. Thus, a 19th century physicist would have regarded many well established elements of contemporary physics as unphysical. An incomplete list of such elements contains the relativity of length and time intervals, the non-Euclidean structure of space-time, the corpuscular-wave nature of pointlike particles, parity violation and the nonlocal nature of quantum mechanics (which is manifested by the EPR effect).

For these reasons neatness, simplicity and physical acceptability of a theory have a secondary value. Thus, if there is no further evidence, then these aspects should not be used for taking a *final decision* concerning the acceptability of a physical theory. In this work properties of a physical theory pertaining to a lack of neatness, simplicity and physical acceptability are mentioned. However, this aspect of the problems may be helpful for the reader but they should not be regarded as decisive arguments. In the text there is no distinction between neatness and simplicity. Thus, the term neatness is not used.

Before concluding these introductory remarks, it should be stated that the erroneous nature of a physical theory E cannot be established merely by showing the existence of a different (or even a contradictory) theory F. This point is obvious. Indeed, if such a situation exists then one may conclude that (at least) theory E *or* theory F is wrong. However, assuming that neither E nor F rely on a mathematical error, then one cannot decide on the issue without having an adequate amount of experimental data.

Another issue is the usage of models and phenomenological formulas. This approach is very common in cases where there is no established theory or where theoretical formulas are too complicated. This approach is evaluated by its usefulness and not by its theoretical correctness. Hence, it is not discussed in the present work.

The following discussions rely on the ideas described above and are devoted to theoretical aspects of the following topics: the Dirac magnetic monopole (called just monopole) theory, the Klein-Gordon (KG) equation, the Yukawa interaction, the idea of Vector Meson Dominance (VMD), the Aharonov-Bohm (AB) effects and the idea of creating diffraction-free electromagnetic beams. Experimental data pertaining to Quantum Chromodynamics that have no adequate explanation are presented in the penultimate Section. The paper contains new material that has not been published before and other topics that have already been published. The latter cases are included here in order to help the reader see the full picture. However, the corresponding presentation takes a concise form and references to detailed articles are given.

In this work units where $\hbar = c = 1$ are used. The Lorentz metric is diagonal and its entries are $(1, -1, -1, -1)$. Greek indices run from 0 to 3. The symbol $W_{,\mu}$ denotes the partial derivative of W with respect to x^μ.

2. The Dirac Monopole Theory

Monopoles are defined by the following duality transformation (called also duality rotation by $\pi/2$)

$$\mathbf{E} \to \mathbf{B}, \quad \mathbf{B} \to -\mathbf{E} \tag{1}$$

and

$$e \to g, \quad g \to -e, \tag{2}$$

where g denotes the magnetic charge of monopoles.

A theory of monopoles was published by Dirac in the first half of the previous century[2,3]. At present, there is no established experimental evidence of these monopoles[4]. This experimental status of monopoles led Dirac later in his life to state: "I am inclined now to believe that monopoles do not exist. So many years have gone by without any encouragement from the experimental side"[5].

Here the following question arises: Does the failure of the monopole quest stem from the fact that they do not exist in Nature or from erroneous elements in Dirac's monopole theory? It is shown in this Section that the second possibility holds.

Let us examine the established part of electrodynamics. Here the system consists of electric charges carried by matter particles and electromagnetic fields. The equations of motion of the fields are Maxwell equations

$$F^{\mu\nu}_{(e)\ ,\nu} = -4\pi j^{\mu}_{(e)} \tag{3}$$

and

$$F^{*\mu\nu}_{(e)\ ,\nu} = 0, \tag{4}$$

and the 4-force exerted on charged matter is given by the Lorentz law

$$ma^{\mu}_{(e)} = eF^{\mu\nu}_{(e)}v_{\nu}. \tag{5}$$

Here $F^{\mu\nu}$ is the antisymmetric tensor of the electromagnetic fields, $F^{*\mu\nu} = \frac{1}{2}\varepsilon^{\mu\nu\alpha\beta}F_{\alpha\beta}$, $\varepsilon^{\mu\nu\alpha\beta}$ is the completely antisymmetric unit tensor of the fourth rank and j^{μ} is the electric 4-current. Subscripts $_{(e)}$, $_{(m)}$ denote quantities related to charges and monopoles respectively. The duality transformation of fields (1) can be written in a tensorial form $F^{\mu\nu} \rightarrow F^{*\mu\nu}$.

An important quantity is the electromagnetic 4-potential A_{μ}. This quantity is used in the Lagrangian density of the system. The fields' part of the Lagrangian density is (see [6], p. 71; [7], p. 596)

$$L_{fields} = -\frac{1}{16\pi}F^{\mu\nu}_{(e)}F_{(e)\mu\nu} - j^{\mu}_{(e)}A_{(e)\mu}. \tag{6}$$

Using the duality transformation (1), (2) and Maxwellian electrodynamics (3)-(6), one derives a dual Maxwellian theory for a system of monopoles and electromagnetic fields (namely, a system without charges)

$$F^{*\mu\nu}_{(m)\ ,\nu} = -4\pi j^{\mu}_{(m)}, \tag{7}$$

$$-F^{\mu\nu}_{(m)\ ,\nu} = 0, \tag{8}$$

$$ma^{\mu}_{(m)} = gF^{*\mu\nu}_{(m)} v_{\nu} \tag{9}$$

and

$$L_{fields} = -\frac{1}{16\pi} F^{*\mu\nu}_{(m)} F^{*}_{(m)\mu\nu} - j^{\mu}_{(m)} A_{(m)\mu} \tag{10}$$

At this point we have two theories: the ordinary Maxwellian electrodynamics whose domain of validity does not contain magnetic monopoles and a monopole related Maxwellian theory which does not contain electric charges. The problem is to determine the form of a covering theory of a system of charges, monopoles and their fields.

As explained in the first Section, the two subtheories mentioned above impose constraints on the required charge-monopole theory:

1. It should conform to Maxwellian electrodynamics (3)-(6) in the limit where monopoles do not exist.

2. It should conform to the dual Maxwellian electrodynamics (7)-(10) in the limit where charges do not exist.

It turns out that Dirac's monopole theory is inconsistent with requirement 2. Therefore, it is inconsistent with a restriction imposed by a lower rank theory.

As a matter of fact, Dirac also uses implicitly a new axiom which has no experimental support. Thus, his theory assumes that:

A. Electromagnetic fields of charges and electromagnetic fields of monopoles have identical dynamical properties.

This approach forces him to use just one kind of 4-potential A_μ and to confront a new kind of singularity. Indeed, if the 3-vector $\mathbf{A}$ is regular then

$$\nabla \cdot \mathbf{B} = \nabla \cdot (\nabla \times \mathbf{A}) = \mathbf{0} \tag{11}$$

and monopoles do not exist. Dirac uses the term 'string' for this kind of singularity. The utilization of the new axiom A, and the introduction of a new kind of singularity into electrodynamics indicate a departure from simplicity.

Several additional errors of the Dirac monopole theory have been pointed out a long time ago. Thus, it was claimed that the Dirac monopole theory is inconsistent with the S-matrix theory (see [8,9]). A third article [10] claims that the inclusion of the Dirac monopole in electrodynamics is inconsistent with relativistic covariance. Another kind of error of the Dirac monopole theory was published recently [11]. It is shown there that a hypothetical quantum mechanical system that contains a charge and a Dirac monopole violates energy conservation (see [11] pp. 98-99).

Another problem is the definition of the interaction part of the angular momentum in a system containing an electric charge and a Dirac monopole. Here one finds that the interaction part of the fields' angular momentum *does not vanish for cases where the distance between the two particles tends to infinity* (see [7] p. 256; [11], pp. 97-98; [12] p. 1366). Such an interaction as this is unknown in classical electrodynamics and is regarded as unphysical.

The discussion carried out in this Section shows several theoretical errors and a deviation from simplicity by using an additional axiom and unphysical properties of the Dirac monopole theory. These difficulties are completely consistent with the failure of the experimental efforts aiming to detect Dirac monopoles. It is interesting to note that a regular and self-consistent charge-monopole theory can be constructed without using axiom A [11,13,14]. This theory derives a different set of equations of motion. The failure of the attempts to detect the Dirac monopoles is predicted in [8] and it is derived from the equations of motion of the regular monopole theory [15] as well.

3. The Klein-Gordon Equation

The KG equation

$$(\Box + m^2)\phi = 0 \tag{12}$$

was derived in the very early days of quantum mechanics (see [16], bottom of p. 25). It can be regarded as a quantize form of the relativistic relation $E^2 - \mathbf{p}^2 = m^2$, where $i\partial/\partial t,\ -i\nabla$ replace E and $\mathbf{p}$, respectively. Hence, there is no doubt concerning its correctness *as a formula*. Indeed, as is well known, components of a solution of the Dirac equation satisfy the KG equation.

The problem discussed in this Section is the status of the KG equation (12) *as a fundamental quantum mechanical equation derived from a Lagrangian density*. Here the Lagrangian density of an electrically charged KG particle is

$$\mathcal{L} = (\phi^*_{,0} - ieV\phi^*)(\phi_{,0} + ieV\phi) - \sum_{k=1}^{3}(\phi^*_{,k} + ieA_k\phi^*)(\phi_{,k} - ieA_k\phi) - m^2\phi^*\phi \tag{13}$$

(See [17,18], eq. (37). Note that here units where $\hbar = c = 1$ are introduced.) This aspect of the KG equation had a controversial status for a very long time. Dirac's negative opinion on this equation (see [19] and [20], pp. 3-8) directed him to construct his famous equation which is now regarded as the relativistic quantum mechanical Hamiltonian of spin-1/2 particles.

Other researchers disagree with Dirac (see [18], pp. 70-72, 105, 188-205; [16], second column of p. 24). In particular, Pauli and Weisskopf constructed the second order Lagrangian density (13). Unlike the case of the Dirac equation, this Lagrangian density does not yield an expression for the particle density but for its charge density.

Before examining the experimental side, let us state a fundamental property of particles described by a wave function $\psi(x^\mu)$. Due to the fact that $\psi(x^\mu)$ depends on a *single* set of space-time coordinates x^μ, one concludes that a particle *truly described* by $\psi(x^\mu)$ must be elementary, namely a pointlike structureless particle.

The experimental data of elementary massive spin 1/2 (Dirac) particles, like the electron, the muon and the u, d quarks is consistent with the pointlike requirement. This is not true for the old candidates for the KG particles, namely the three 0^- π mesons. Indeed, it is now known that a π meson contains a quark and an antiquark. The charge radius of the $\pi^\pm$ is 0.672 ± 0.008 fm (see [4], p.499). Hence, π mesons are definitely not pointlike objects. For this reason, they cannot be regarded as Klein-Gordon particles.

A recent analysis of the KG Lagrangian density proves that it is also not free of theoretical difficulties [21]. Thus, it is proved that the theory derived from the KG Lagrangian density (13) has the following difficulties:

1. There is no expression for the particle's density. The expression for the charge density depends on coordinates of *external particles*.

2. The Hamiltonian density depends on the time derivative of ϕ. Hence, if a Hamiltonian of the KG particle exists, then the Hamiltonian density depends on the Hamiltonian.

3. There is no *covariant differential operator* that serves as a Hamiltonian [21]. Furthermore, the Hamiltonian matrix of a charged KG particle destroys the inner product of the Hilbert space [21]. There is no Hilbert space for an uncharged KG particle because in this case density is undefined [17].

4. The *second order* KG equation (12), which is derived from the KG Lagrangian density (13), is not identical to the *first order* fundamental quantum mechanical equation $i\partial\phi/\partial t = H\phi$.

5. One cannot construct a self-consistent electromagnetic interaction of a charged KG particle. The linear interaction $eA_\mu j^\mu$ entails an equation imbalance [22] and the quadratic term $(p^\mu - eA^\mu)(p_\mu - eA_\mu)$ destroys the inner product of the Hilbert space [21].

6. There is no explanation why the energy-momentum operators $(i\partial/\partial t, -i\nabla)$ are used for the *different* task of representing charge density and current.

7. The nonrelativistic limit of the KG equation disagrees with the Schroedinger equation. Indeed, in the case of the

Schroedinger equation, $\Psi^*\Psi$ represents probability density [23] whereas the KG equation has no expression for probability density. Hence, the KG equation is inconsistent with a restriction imposed by a lower rank theory.

8. Another aspect of the previous point is the dimension of the corresponding wave functions. Examining the Schroedinger equation, one finds that $\Psi^*\Psi$ represents probability density. It follows that the dimension of Ψ is $[L^{-3/2}]$. On the other hand $m^2\phi^*\phi$ is a term of the Lagrangian density of the KG field [17]. Hence, in units where $\hbar = c = 1$, the dimension of $m^2\phi^*\phi$ is $[L^{-4}]$ and that of ϕ is $[L^{-1}]$. Therefore, due to the difference in dimension, the nonrelativistic limit of the KG equation disagrees with the Schroedinger equation.

(By contrast, it is proved in [21] that an analogous analysis of the Dirac equation yields completely acceptable relations.)

These theoretical difficulties, together with the lack of support from the experimental side (there is no candidate for a *pointlike* KG particle) indicate that, unlike the case of the Dirac equation, the existence of a genuine KG particle is not very likely.

4. The Yukawa Interaction

The Yukawa interaction is derived from a Lagrangian density containing an interaction term of a Dirac spinor with a KG particle (see [24], p.79 and [25], p. 135)

$$L_{Yukawa} = L_{Dirac} + L_{KG} - g\bar{\psi}\psi\phi. \tag{14}$$

Here the KG particle plays a role which is analogous to that of the photon in electrodynamics. The dependence of (14) on the KG Lagrangian density indicates that it suffers from all the difficulties of the KG theory which are pointed out in the previous Section. Furthermore, note that, due to the fact that all terms of the Lagrangian density are Lorentz scalars, the interaction term of (14) depends on the Dirac particle's *scalar density* $\bar{\psi}\psi$ which is *not* its actual density $\psi^\dagger\psi$. This situation is very strange because one expects that the intensity of the interaction of a Dirac particle should depend on its actual density $\psi^\dagger\psi$ which is a component of the Dirac 4-current and *not* on the scalar density $\bar{\psi}\psi$. Moreover, it is explained below that (14) is not free of covariance problems.

An analysis of the nonrelativistic limit of two Dirac particles interacting by means of a Yukawa field, yields the following expression for the interaction term (see [26], p. 211)

$$V(r) = -g^2 \frac{e^{-\mu r}}{r}, \tag{15}$$

where μ denotes the mass of the KG particle. The Yukawa theory was suggested as a theoretical interpretation of the nucleon-nucleon interaction. This idea was proposed in the early days of nuclear theory when nucleons were regarded as elementary Dirac particles. Now it is known that nucleons are composite particles containing quarks and therefore this application of (14) is deprived of its theoretical basis. Furthermore, a recent discussion proves that the classical limit of the interaction (15) is inconsistent with special relativity (see [22], p. 13). This argument relies on the relativistic relation between the 4-velocity and the 4-acceleration

$$a^{\mu}v_{\mu} = 0. \tag{16}$$

Examining an elementary classical particle, one finds that relation (16) yields the following relation for the 4-force $f^{\mu}v_{\mu} = 0$. It is explained below why this relation is inconsistent with the Yukawa interaction (15).

Let an elementary classical particle W move in a field of force. The field quantities are independent of the 4-velocity v^{μ} of W but the associated 4-force must be orthogonal to v^{μ}. In electrodynamics this goal is attained by means of the Lorentz force (5). In this case, one finds

$$a^{\mu}v_{\mu} = \frac{e}{m}F^{\mu\nu}v_{\nu}v_{\mu} = 0, \tag{17}$$

where the null result is obtained from the antisymmetry of $F^{\mu\nu}$ and the symmetry of the product $v_{\mu}v_{\nu}$. In electrodynamics, the antisymmetric field tensor $F^{\mu\nu}$ is constructed as the 4-curl of the 4-potential A_{μ}. Such a field of force cannot be obtained from the *scalar* KG field. Hence, the classical limit of the Yukawa interaction is inconsistent with special relativity.

Considering the experimental side, the application of the Yukawa theory to nuclear interactions cannot be regarded as a success. The nuclear force is characterized by a very hard (repulsive) core and a rapidly decreasing attractive force outside this core. Therefore, at a certain point of r, the nuclear potential *changes sign* (see [27], p. 97). The Yukawa formula (15) does not change sign. Hence, it is inconsistent with this property. The nuclear force also has a tensorial component as well as a spin-orbit dependence (see [27], pp. 68-78). Today people use phenomenological formulas for a description of the nucleon-nucleon interaction data (see [27], pp. 97-99).

5. The Idea of Vector Meson Dominance

The idea of VMD has been suggested as an explanation for interaction properties of high energy photons with hadrons. Here the data show that the cross section of the interaction of such photons with a proton target is very similar to that of a neutron target [28]. Since the electric charge of proton constituents differ from those of a neutron, one concludes that the interaction of these photons with the *electric charge* of constituents of nucleons *cannot* explain this similarity.

At first the VMD idea was not accepted by all physicists. The humoristic- sarcastic poster published on page 267 of [28] provides an illustration for this claim. Moreover, contemporary classifications of physical subjects (like PACS and arXiv.org) regard VMD as a *phenomenological* idea. Now if VMD is just a phenomenological idea or a model then the current approach of the physical community to strong and electromagnetic interactions (namely, the Standard Model) *has no theoretical explanation for the photon-hadron interaction.*

The main idea of VMD is that the wave function of an energetic photon takes the form

$$\mid \gamma > = c_0 \mid \gamma_0 > + c_h \mid h >, \tag{18}$$

where $\mid \gamma >$ denotes the wave function of a physical photon, $\mid \gamma_0 >$ denotes the pure electromagnetic component of a physical photon and $\mid h >$ denotes its hypothetical hadronic component. c_0 and c_h are appropriate numerical coefficients. The values of

c_0 and c_h depend on the photon's energy. Thus, for soft photons $c_h = 0$ whereas it begins to take a nonvanishing value for photons whose energy is not much less then the ρ meson's mass (see [28] and [29]).

Theoretical aspects of VMD were discussed recently [30]. This analysis proves that VMD is inconsistent with well established physical theories and with experimental data as well. In particular, it is proved in [30] that VMD is inconsistent with Wigner's analysis of the Poincare group [31,32] and with the scattering data of linearly polarized photons impinging on an unpolarized target of protons [30].

The following simple thought experiment disproves the VMD's idea stating that the size of the hadronic components of a photon depend on its energy [29]. Consider two intersecting rays of optical photons (see fig. 1). In the laboratory frame Σ, the optical photons of the rays do not interact. Thus, neither energy nor momentum are exchanged between the rays. Therefore, after passing through O, the photons travel in their original direction. Let us examine the situation in a frame Σ'. In Σ, frame Σ' is seen moving very fast in the negative direction of the Y axis. Thus, in Σ', photons of the two rays are very energetic. Hence, if VMD holds, then photons of both rays contain hadrons and should exchange energy and momentum at point O. This is a contradiction because if the rays do not exchange energy and momentum in frame Σ, then they obviously do not do that in any other frame of reference. This argument proves that VMD is a theoretical error.

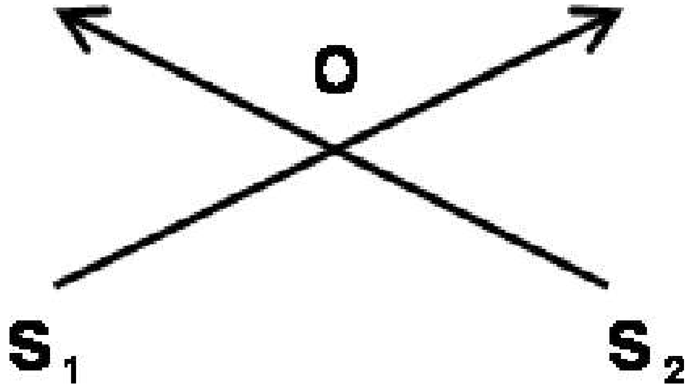

Figure 1: Two rays of light are emitted from sources S_1 and S_2 which are located at $x = \pm 1$, respectively. The rays intersect at point O which is embedded in the (x, y) plane. (This figure is published in [30] and is used here with permission.)

6. The Aharonov-Bohm Effects

The AB effects refer to the phase difference between two sub-beams of an electron that travels in a non-simply connected field-free region [33]. The phase difference is manifested by the interference pattern of the sub-beams (see fig. 2). Hereafter, an electron of the beam is called "the traveling electron." The authors of [33] claim that there are two kinds of realization of this idea. In the electric AB effect, the region R contains a *time-dependent* electric field whereas in the magnetic AB effect the region R contains a magnetic field.

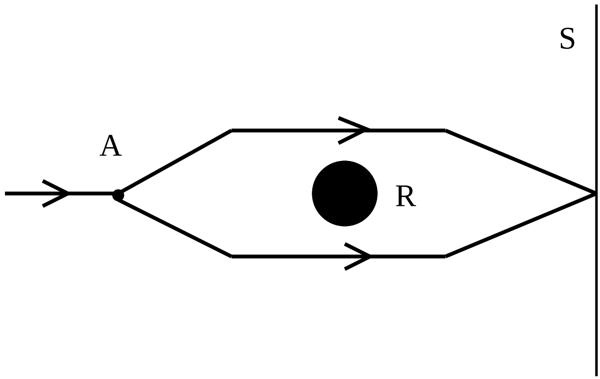

Figure 2: A beam consists of electrons that travel from left to right. They are split into two sub-beams at point A. The sub-beams travel in a field-free region and interfere on the screen S. The field is nonzero in a region R denoted by the black circle.

The AB effects certainly belong to quantum mechanics, because the sub-beams move in a field-free region. Hence, no force is exerted on the traveling electron and its inertial motion is not affected by the field at R. However, quantum mechanical equations of motion depend on the 4-potential A_μ. Hence, a quantum mechanical effect may take place. The effect emerges from the different phase associated with the sub-beams and is detected by the interference pattern on the screen S. Hence, both the origin and the detection of the effects belong to the realm of quantum mechanics.

The original approach of the authors of [33] treat the phase as a single particle property of the traveling electron. This approach certainly does not hold in many cases. Indeed, the quantum mechanical system consists of the traveling electron *and* of the charges associated with the field at R. Let r_e and r_s denote the coordinates of the traveling electron and of the charges at the source of the field, respectively. Thus, since the traveling electron interacts with the 4-potential A_μ associated with r_s, one finds that the Hamiltonian of the system takes the form

$$H = H(r_s, r_e) \tag{19}$$

and the Schroedinger equation is

$$i\hbar \frac{\partial}{\partial t} \Psi(r_s, r_e) = H(r_s, r_e)\Psi(r_s, r_e) \tag{20}$$

Now, in the experiment, the beam of the traveling electron is split into two sub-beams. Hence, the system's wave function can be written as a sum of two terms

$$\Psi(r_s, r_e) = \phi_1(r_s)\psi_1(r_e) + \phi_2(r_s)\psi_2(r_e). \tag{21}$$

Here $\psi_i(r_e)$ is the traveling electron's wave function of the ith sub-beam and $\phi_i(r_s)$ is the corresponding wave function of the source. Now, the traveling electron interacts with the charge at r_s and *vice versa*. For this reason ϕ_2 may differ from ϕ_1. This analysis proves that *the phase is a property of a term and not of a single particle*. It is shown below how this result can help one to discern between correct and incorrect claims of [33].

Let us examine the magnetic AB effect. Here the source of the magnetic field is a ring which is a single domain of a ferromagnetic material [34]. Thus, the source of the magnetic field is a quantum mechanical system. An analysis of the interaction of a ferromagnetic atom with the field of the traveling electron indicates that this interaction cannot induce a quantum jump of an atom's state in the crystal [35,36]. Hence, in the case of the magnetic AB effect, the source can be treated as an inert object whose state does not vary during the process.

On the basis of this conclusion, one may cast the wave function (21) into the following form

$$\Psi(r_s, r_e) = \phi(r_s)[\psi_1(r_e) + \psi_2(r_e)], \tag{22}$$

where $\phi(r_s) = \phi_1(r_s) = \phi_2(r_s)$ denotes the inert state of the ferromagnetic source. This outcome proves that, in the case of the magnetic AB effect, $\phi(r_s)$ is factored out in (22) and the phase of each term of the wave function (21) can be regarded as a single particle property. For this reason, the magnetic AB's prediction is correct theoretically and was detected in experiment [34].

It was proved recently [35,36] that if the magnetic source is replaced by a classical device made of rotating charged material then the magnetic AB effect disappears. The reason for this result is that the contribution of the state of the traveling electron to the phase difference is canceled by that of the (non-inert) source.

The physics of the electric AB effect differs from that of the magnetic one. Here the state of the source *varies* during the process. A close examination of the process proves that it is analogous to the case of the classical magnet mentioned above. Thus, the contributions of the traveling electron and that of the source to the phase difference cancel each other and the effect disappears [37,38]. Moreover, if one adheres to the AB's single particle approach [33,39], then energy conservation is violated [37,38]. This outcome proves that the prediction of the electric AB effect is wrong.

The AB effects have a general (or philosophical) aspect too. Indeed, in the AB processes, the traveling electron moves in a nonsimply connected field-free region. Thus, the single particle approach to the AB effects leads to the claim that topology is an inherent element of quantum mechanics [33]. However, it can be proved that this claim of AB has no profound meaning (see a detailed discussion in [36], Section V). This conclusion can also be established on the basis of the linearity of electrodynamics. Thus, the interaction V is a sum of 2-body interactions

$$V(r_s, r_e) = \sum_i V(r_{s_i}, r_e), \tag{23}$$

where r_{s_i} denotes the coordinates of the ith ferromagnetic atom. Here no field-free region exists because *the magnetic field of a single ferromagnetic atom does not vanish at* r_e and the magnetic field associated with the motion of the traveling electron does not vanish at r_{s_i}. This analysis proves that the fundamental 2-body interaction is *not* field-free. Hence, the fundamental 2-body interaction (23) disproves ABs' claim stating that the topological structure of field-free regions is an inherent property of quantum mechanics.

7. Diffraction-Free Beams

The idea that diffraction-free beams (also called propagation invariant beams) exist has been published in the literature [40].

The spatial part of such a beam is assumed to take the form (see [40], eq. (2))

$$\phi = e^{i\beta z} J_0(a\rho), \tag{24}$$

where ρ denotes the radius in cylindrical coordinates, J_0 is the zeroth order Bessel function of the first kind and a is a factor having the dimension $[L^{-1}]$. Article [40] has inspired a lot of activity and it has been cited more than 400 times. Following [40], a family of diffraction-free solutions of Maxwell equations has been published [41].

Taking the diffraction-free idea literally, one obviously realizes that it is an error, because it is inconsistent with the uncertainty principle. Indeed, the notion of a beam describes a set of physical objects moving in a specific direction and the linear dimension of the relevant cross section containing these objects is much smaller than the beam's length (see [40], p. 1499, near the bottom of the left column).

The ratio between the length and the diameter of the beam indicates that it may be evaluated at the wave zone. It is easy to realize that a Bessel beam like (24) cannot exist [42]. Indeed, let us examine a circle C at the wave zone having a diameter which equals that of the assumed beam (see fig. 3). At the source, the beam's amplitude is a Bessel function, which means that it changes sign alternately. It follows that it interferes *destructively* at C. Hence, since energy is conserved in the process, one concludes that a part of the beam does not pass through C. This conclusion means that the beam is *not* diffraction-free. Moreover, a Bessel beam spreads *faster* than a uniform beam because, at circle C, interference of the latter is constructive.

Using this result, one infers that the family of diffraction-

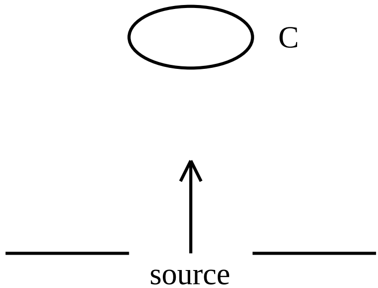

Figure 3: A beam of electromagnetic wave is emitted from a circular source S. The beam's intensity is calculated at a circle C whose radius is the same as that of the source. (This figure was published in [41]).

free solutions of Maxwell equations [41] describe solutions of electromagnetic waves inside a perfect cylindrical wave guide.

Moreover, most (if not all) experiments that follow [40] use a φ-invariant setup and show a strong peak at the center. Now, the φ-invariant solutions of Maxwell equations [41] are derived from the following vector potential

$$\mathbf{A} = -iJ_1(ar)e^{i(bz-\omega t)}\mathbf{u}_\varphi. \tag{25}$$

The fields are

$$\mathbf{E} = -\partial\mathbf{A}/\partial t = \omega J_1(ar)e^{i(bz-\omega t)}\mathbf{u}_\varphi \tag{26}$$

and

$$\mathbf{B} = curl\mathbf{A} = -bJ_1(ar)e^{i(bz-\omega t)}\mathbf{u}_r - iaJ_0(ar)e^{i(bz-\omega t)}\mathbf{u}_z. \quad (27)$$

There is a dual solution where $\mathbf{E} \rightarrow \mathbf{B}$, $\mathbf{B} \rightarrow -\mathbf{E}$. Now, the Bessel function $J_1(0) = 0$, which means that at the beam's center, the energy current $\mathbf{E} \times \mathbf{B}/4\pi$ of these solutions has a *minimum*. This prediction contradicts the data and provides another proof of the claim that the experiments should not be described as a superposition of diffraction-free beams. A more detailed discussion of these topics can be found in [42].

8. Unexplained Quantum Chromodynamics Data

The discussions presented in the previous Sections contain theoretical arguments showing contradictions pertaining to several parts of contemporary physics. This approach is analogous to an analysis of errors in a mathematical theory. In addition it is pointed out in the Introduction that a physical theory should satisfy a second level of tests where compatibility of its predictions with experimental data is required. Now, QCD has been investigated for more than 30 years. Hence, one expects that its main properties are already included in textbooks. This Section contains a list of several experimental QCD data that have no adequate explanation in textbooks.

A. The Higgs Mesons.

QCD is an element of a broader theory called the Standard Model. Here it is assumed that particles called Higgs mesons exist. In spite of a prolonged search, no evidence of these particles has been detected (see [4], p. 32).

B. The Photon-Hadron Interaction

The data show that a hard photon (having energy greater than 1000MeV) interacts with a proton in a form which is very similar to that of a neutron [28]. Due to the difference between the electric charge of the proton's constituents and those of the neutron, this similarity cannot be explained as interactions of the photon with an electric charge. It turns out that VMD (see Section 5) has been suggested in order to provide an explanation for this effect. Now, it is proved in [30] that VMD contains serious theoretical errors. Moreover, in the PACS classification it is regarded as just a model and in the xxx arXiv, VMD is relegated to the phenomenological category. Hence, QCD has no *theoretical* explanation for the interaction of a hard photon with hadrons.

C. Properties of Anti-Quarks in Hadrons

The structure functions of proton constituents show that the width of x values of antiquarks is much smaller than that of quarks (see [43], p. 281). (x is a dimensionless Lorentz scalar used in the analysis.) Henceforth, quarks and anti-quarks are denoted by q and $\bar{q}$, respectively. The width values indicate that, in the nucleon, the uncertainty of momentum of $\bar{q}$ is smaller than the corresponding value of q (see [43], pp. 270, 271). Therefore, due to the uncertainty principle, one concludes that in a nucleon, $\bar{q}$ occupies a volume which is *larger* than that of q. This property of nucleons lacks an adequate explanation.

In the literature, the $\bar{q}$ region is called "the $q - \bar{q}$ sea" (see [43] p. 281). This terminology does not aim to be a theoretical explanation and cannot be regarded as such. Indeed, a π meson is a bound state of $q\bar{q}$, both of which came from the Dirac sea of negative energy states. Now, in a π meson, the $\bar{q}$ is attracted just by one q. In spite of that, this force is strong enough for binding the system in a volume which is even smaller than the nucleon's volume (see [4], pp. 499, 854). Hence, it is not clear why 4 quarks (the 3 valence quarks and the $\bar{q}$'s companion) cannot do that. It is concluded that QCD has no explanation for the rather large volume of $\bar{q}$ in nucleons.

D. The Lack of Strongly Bound States of $qqqq\bar{q}$ (pentaquarks)

Consider the $qqqq\bar{q}$ system (a nucleon-meson system called pentaquark). The following properties of hadrons are relevant to an evaluation of this object. Data of strongly interacting systems show that gaps between energy states are measured by hundreds of MeV. On the other hand, the binding energy of a nucleon in a typical nucleus is about 8 MeV. These values can be used for making a clear distinction between true strong interactions and the nuclear force, which is regarded as a residual force.

Another property of hadrons can be learned from the data. The mass of a π meson is about 140MeV whereas the mass of a nucleon is about 940MeV. Therefore, one concludes that if QCD holds, then the $q\bar{q}$ binding energy is much larger then that of a qq pair (in a nucleon there are 3 such pairs of interactions).

Let us turn to the case of pentaquarks and examine a particle called Θ^+ having a mass of 1540MeV. Evidence of this object has been found in several experiments (see e.g. [4], p. 916). This object can be regarded as a union of a neutron and a K^+ meson. The sum of the masses of these particles is about 1435MeV. Therefore, the Θ^+ is an *unbound* state of the nK^+ system. On the other hand, a strongly bound state of nK^+ should have a mass which is smaller than 1400MeV. Hence, QCD still does not provide an explanation for the absence of *strongly* bound states of pentaquarks. Moreover, it does not explain why the deuteron (a 6-quark system) is a bound state whereas the nK^+ (which contain an antiquark) has no bound state.

E. The Uniform Density of Nuclear Matter

Consider nuclei that contain more than a very small number of nucleons. The data show that for these nuclei, the nucleon density is (very nearly) the same. QCD does not provide an explanation for these data. Another aspect of this issue is that QCD does not provide an explanation for the striking similarity between the form of the van der Waals force and that of the nuclear force.

F. The EMC Effect

An examination of the mean volume occupied by quarks in nuclei shows that it increases with the increase of the number of nucleons of the nucleus [44,45]. This effect is analogous to the screening effect of electrons in molecules. QCD has not predicted this effect and provides no explanation for it.

In principle, one established experimental result which is inconsistent with a theory, casts doubt on the theory's validity. In this Section one can find several examples of experimental data which are not explained by QCD.

9. Concluding Remarks

Two different aspects of the issues presented above are discussed in this Section: implications of specific problems presented above and the general treatment of theoretical errors by the community. These aspects are treated below in this order.

The issues discussed above can be put in two different categories: issues having implications on other parts of theoretical physics and stand-alone topics. It turns out that problems of the Dirac monopole theory (see Section 2), those of the VMD attempting to provide an explanation for the hard photon-nucleon interaction (see Section 5) and the experimental inconsistencies of QCD as described in Section 8 are related. Indeed, instead of the Dirac monopole theory, one can construct a regular monopole theory [13,14]. It can be shown that this monopole theory can explain experimental results which are unexplained by QCD [11]. Thus, the relations between the topics discussed in Sections 2, 5 and 8 are probably the most significant part of this work.

It is clear that there is a connection between the problems of the KG equation and those of the Yukawa theory, because these theories examine the same kind of particle. The KG equation is supposed to be the fundamental equation of motion of a spin-0 particle whereas the Yukawa theory examines this particle as an object that carries interaction between two spin-1/2 particles.

Hence, the difficulties of these theories, which are presented in Sections 3 and 4, respectively, have an underlying basis.

On the other hand, the AB effect and the Diffraction-Free idea can be regarded as stand-alone issues. Thus, the electric AB effect does not exist and the magnetic effect has no inherent dependence on nonsimply connected field-free regions of space. Hence, one merely concludes that the AB effects do not prove that quantum mechanics has an inherent topological structure.

The Diffraction-Free idea is clearly inconsistent with the uncertainty principle. Examining this idea literally, one concludes that it is just wrong. Hence, fundamental physical theories are not affected by its removal.

The general approach of a typical journal of physics to a free critical debate of existing physical theories is very far from being satisfactory. Indeed, the publication of articles presenting pros and cons concerning existing physical theories practically does not exist in many journals. One may wonder why the modern community of physicists has adopted such a practice. After all, the history of scientific theories teaches us that not all theories survive the test of time. Another aspect of this matter is that the status of a truly correct theory can only be improved if it is tested critically every once in a while. Hence, people who genuinely believe in a specific physical theory should support such a debate.

As a matter of fact, every topic presented in Sections 2-8 above cries out for a clarifying debate. The suppression of such a debate certainly does not make a positive contribution to the progress of science. Referring to this issue, it is interesting to cite S. D. Drell's final speech as president of the American Physical Society (APS). In his description of referees of APS's Journals, he uses the following quotation: "We have met the enemy and he is us" (see [46], p.61 second column). In my personal experience, I have seen reports of many excellent referees. However, there are too many referees belonging to a different category. Considering them, I must say that I cannot deny Drell's description.

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