A Critical Study of Quantum Chromodynamics and the Regular Charge-Monopole Theory

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Abstract

The compatibility of the strong interaction theory called Quantum Chromodynamics (QCD) with relevant experimental data is critically examined. The clear advantage of the Regular Charge-Monopole Theory over QCD is explained. An analysis of new data provides further support for this claim. The paper points out several specific effects that illustrate this conclusion: the hard photon-nucleon interaction, the striking difference between the high energy electron-proton and proton-proton cross section, the peripheral location of the proton's antiquark, the strong CP problem, the quite large amount of the $\bar{s}s$ pair in the proton, the excess of the proton's $\bar{d}$ antiquarks over its $\bar{u}$ antiquarks, and the spin-dependence of high energy polarized proton-proton scattering. These problematic issues are in accordance with M. Gell-Mann's recently published qualms about the QCD merits.

Keywords: Structure of quantum theories, Strong interactions, Quantum chromodynamics, Regular charge-monopole theory

1 Introduction

The acceptability of a physical theory relies on its consistency with two kinds of requirements – it must have a coherent mathematical structure, and it must provide an adequate explanation for data that belong to its domain of validity. There is now a common agreement about the general structure of a quantum field theory (QFT) of an elementary particle: It should be derived from a Lagrangian density by means of the variational principle. Eqs. (1) - (4) are primary expressions that can be found in standard textbooks. Here the variational principle applies to an action whose general form is

$$I(\psi) = \int d^4x \mathcal{L}(\psi(x), \psi(x)_{,\mu}), \tag{1}$$

where x denotes the four space-time coordinates, $\mathcal{L}(\psi(x), \psi(x)_{,\mu})$ denotes the Lagrangian density, and the ordinary notation of a relativistic expression is used. For example, a well-known textbook supports this approach and states: "all field theories used in current theories of elementary particles have Lagrangians of this form" (see [1], p. 300).

Several arguments provide strong support for this approach. Thus, if a Lagrangian density is a Lorentz scalar then also the action (1) is a Lorentz scalar. In this case, the theory takes a relativistic covariant form. Furthermore, the Noether theorem says that if the Lagrangian density does not explicitly depend on x then the theory conserves energy, momentum, and angular momentum (see [2], pp. 17-22).

The Noether theorem also shows that if the Lagrangian density is invariant under a global phase transformation of the quantum function $\psi(x)$

$$\psi(x) \rightarrow \exp(i\alpha)\psi(x), \tag{2}$$

where α is a mathematically real variable then one obtains

$$0 = i\alpha\left[\frac{\partial\mathcal{L}}{\partial\psi} - \partial_\mu\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu\psi)}\right)\right]\psi + i\alpha\partial_\mu\left(\frac{\partial\mathcal{L}}{\partial(\partial_\mu\psi)}\psi\right) \tag{3}$$

(see [3], p. 314). The Euler-Lagrange equation proves that the quantity enclosed inside the square brackets of (3) vanishes. Since the variation parameter α does not vanish identically, one finds that the expression that is written inside the last bracket of (3) is a conserved 4-current

$$j^\mu = \frac{\partial\mathcal{L}}{\partial(\partial_\mu\psi)}\psi, \quad j^\mu_{,\mu} = 0. \tag{4}$$

As stated above, this procedure is regarded as the predominant way for obtaining a relativistic covariant QFT that abides by well-established conservation laws.

Fig. 1 describes the structure of a given QFT of a particular elementary quantum particle. Its left-hand side represents the theory's general structure that is shown above, and its right-hand side stands for specific attributes of the theory's description of the given quantum particle and its interactions. Here the Euler-Lagrange equations are the partial differential equations whose solutions describe the particle's time-evolution. It means that distinct QFTs differ in the form of specific terms of their Lagrangian density. Hence, the mathematical coherence of a given QFT pertains to the upper rectangle of Fig. 1 and the middle rectangle on the right-hand side of this figure. The right-hand side of the figure refers to the fit of the theory to its relevant data. Here one makes a comparison between elements of the middle rectangle and their corresponding quantities of the lowest rectangle.

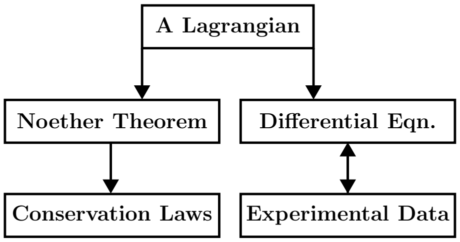

Figure 1: *Elements of the structure of a quantum field theory. (see text).*

The main objective of this work is to compare two strong interaction theories. At present, quantum chromodynamics (QCD) is regarded as the acceptable strong interaction theory (see e.g. chapter 18.7 of [4] or chapter 17 of [5]). QCD is the strong interaction sector of a general theory of elementary particles called the Standard Model (SM). The consistency of physical attributes of QCD with relevant experimental data is examined below. The same procedure is carried out for a strong interaction theory that is based on a regular charge-monopole theory (RCMT) [6–10]. Articles [8–10] demonstrate the clear advantage of the RCMT over QCD. It turns out that data of recent publications provide further support for this conclusion. The paper describes the new data, and in so doing, it helps readers acquire a wider basis of this issue.

M. Gell-Mann certainly was a key person of the QCD construction [11]. It is interesting to point out a recent publication of his doubtful opinion on QCD's merits. Thus, he has advised a colleague who worked on QCD and told him that he "should work on more worthwhile topics" [12]. This new information about Gell-Mann's qualms concerning QCD certainly provides another good reason for examining the new data that are relevant to this theory.

The second section outlines the main features of QCD and the RCMT. The third section presents known advantages of the RCMT over QCD. The significance of the new data is discussed in the fourth section. The last section summarizes this work.

2 An Outline of QCD and the RCMT

QCD states that a baryon comprises three valence quarks, additional quark-antiquark pairs, and gluons that bind the system. It is derived from a Lagrangian density that depends on physical variables that have an internal symmetry of the SU(3) group. QCD adds three internal degrees of freedom (called colors) to each quark.

On the other hand, the RCMT is a regular extension of Maxwellian electrodynamics that comprises electric charges and magnetic monopoles. Here the duality transformation connects charges to monopoles (see [13], p. 1363). The theory is derived from a regular Lagrangian density [6–9]. Therefore, its structure follows well established physical principles. The primary results of this theory are:

RCMT.A Charges do not interact with bound fields of monopoles.

RCMT.B Monopoles do not interact with bound fields of charges.

RCMT.C Radiation fields of the system are identical and charges as well as monopoles interact with them.

RCMT.D Unlike the Dirac monopole theory, the size of the elementary monopole unit is a free parameter.

RCMT.E Unlike the Dirac monopole theory, the RCMT is free of irregular strings and of the artificial limitation that forbids an electric charge to be on the string's space-time points (see [14], pp. 251-260).

RCMT.F RCMT is compatible with the systematic failure of experimental attempts to detect a Dirac-like monopole. Many documents report this failure (see e.g. [15] and references therein). Furthermore, a quite long time ago the RCMT *predicted this failure* [16]. This successful prediction is another example of the RCMT merits.

The RCMT regards quarks as quantum particles that obey the Dirac equation. Each quark carries a (negative) monopole unit. Hence, strong interactions are analogous to electromagnetic interactions. It follows that a baryon is analogous to a neutral atom: A baryon has a core whose overall monopole charge is +3, and each of its three valence quarks carries a negative unit of a monopole charge. A baryon is neutral with respect to monopole like an unionized atom is electrically neutral. A meson is a quark-antiquark bound state which is analogous to an electron-positron state of the positronium. The latter analogy can be found in the literature (see [17], pp. 169-174). The high energy of hadronic interactions indicates that the elementary monopole unit is much larger than the electron's electric charge unit, where $e^2 \simeq 1/137$.

It is interesting to note that several very well known authors have already put forward the idea that monopoles are constituents of hadrons (see e.g. [18–21]). An important advantage of the RCMT is its automatic explanation of the null electric dipole moment of the neutron [22]. Thus, experimental devices that measure this dipole moment use electrons which carry no monopole. Hence, result RCMT.A proves that these measurements cannot detect the bound fields of the axial electric dipole moment that is expected to stem from the monopole components of a spinning neutron.

3 Examples of the RCMT's Advantages over QCD

Articles [8–10] describe many experimental data that support the RCMT and cast serious doubts on the QCD's veracity. A brief description of three cases illustrates this issue.

1. Experiments that have been carried out many years ago prove that "the limiting photon total cross sections on neutrons and protons are nearly the same, indicating that the photon interaction does not depend primarily on the charge of the target" (see [23], p. 269). The SM has no explanation for these data and SM textbooks do not discuss this issue.

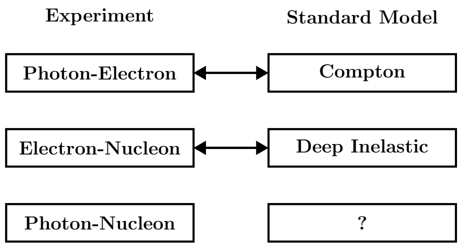

Figure 2: *Several kinds of scattering data and its SM interpretation (see text).*

Fig. 2 describes the present unfortunate status of this effect. The electron, photon, and nucleons are well-known particles, and this figure shows scattering experiments have been carried out for every pair of these particles. The photon-electron scattering (called Compton scattering) is discussed in relevant textbooks on quantum electrodynamics (QED) (see e.g. [3], pp. 141-144; [5], pp. 158-167). The same is true with the electron-nucleon deep inelastic scattering (see e.g. [3], chapter 8; [5], pp. 475-480, 555-563 and 621-647). By contrast, SM textbooks refrain from a discussion of the case of a hard photon scattered on a nucleon. Here experimental data do exist, but textbooks ignore the effect.

Conclusion: SM has no explanation for the hard photon-nucleon interaction.

As a matter of fact, the above mentioned RCMT.C property provides a straightforward interpretation for this effect: Quarks are monopoles whose unit charge is much greater than that of the electron. Hence, property RCMT.C means that the intensity of the hard photon interaction with the proton is about the same as that of the neutron.

2. The total electron-proton cross section is well documented in textbooks. At high energy, an inelastic process stems from an elastic scattering of an electron that hits an individual quark of the proton (see [24], p. 185). General QED formulas show that the cross section decreases monotonically with the increase of the collision energy (see [24], chapter 8.2).

   Moreover, "because of the finite size of the proton, the cross section for electron-proton elastic scattering decreases rapidly with energy. Consequently, high-energy e-p interactions are dominated by inelastic scattering processes where the proton breaks up" (see [24], p. 178).

   The corresponding data of high energy proton-proton scattering is shown on p. 11 of [25]. Fig. 3 depicts the main features of these data. The proton-proton high energy data differ dramatically from the corresponding electron-proton data: In the electron-proton scattering, the total cross section decreases monotonically, and the relative portion of the elastic scattering becomes negligible. In contrast, at high energy scattering, the proton-proton total and elastic cross section begins to rise, and the relative portion of the elastic cross section takes a uniform value of about 1/6.

QCD has no explanation for this effect. For example, QCD says that a proton-proton collision is a superposition of individual quark-quark collisions. Hence, it is not clear why a heavy blow of an electron on a quark yields an inelastic process where the proton breaks up, while in the case of a quark-quark heavy blow, the relative portion of elastic events is not negligible.

Another QCD inconsistency stems from its claim called asymptotic freedom of the quark-quark interaction. The QCD asymptotic freedom says that the strength of the quark-quark interaction parameter decreases with the decrease of the interparticle distance (see [24], section 10.5). It is well known that higher energy means a shorter distance: "To probe small distances you need high energies" (see [17], p. 6). Hence, QCD cannot explain the increase of the cross section of the high energy proton-proton data. The interpretation of this effect is ignored by QCD textbooks, and this negligence substantiates the previous assertion.

The RCMT provides a straightforward explanation for these data. Thus, in higher energy more details of the proton show up and its core gradually begins to participate in the scattering process. The core is a relatively rigid object due to its closed shells of quarks. Hence, a core-core collision is likely to yield an elastic event.

3. Measurements show the momentum distribution of the nucleon's quark and its

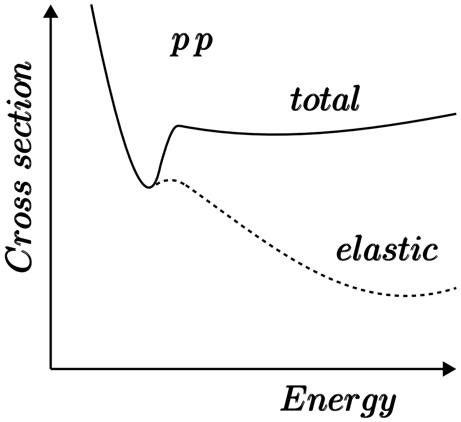

Figure 3: *Energy dependence of the total and the elastic proton-proton cross section. (see text).*

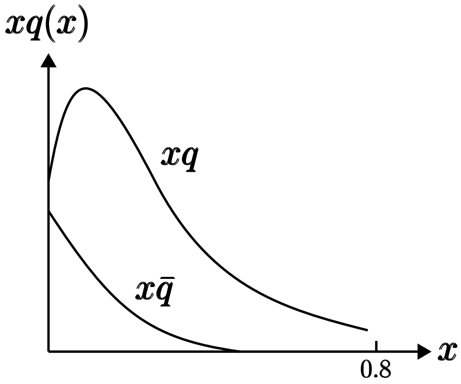

Figure 4: *The Bjorken x dependence of the momentum distribution of the nucleon's quarks and its antiquarks (see text).*

antiquarks as a function of Bjorken x ([26], p. 281). Fig. 4 depicts the main features of these data. The nucleon's quarks are confined inside its volume, and the Heisenberg uncertainty principle proves that they acquire a Fermi motion. This motion is the underlying reason for the width of the graphs of fig. 4 (see [26], pp. 266-271). In other words: the stronger is the Fermi motion of a given component of the nucleon – the wider is its graph on fig. 4.

The data depicted on fig. 4 show that the graph of the nucleon's quarks is much wider than that of its antiquarks. It means that the quarks' Fermi motion is considerably stronger than that of the antiquarks. Therefore, the Heisenberg uncertainty principle says that the nucleon's quarks are enclosed inside a much smaller volume than that of its antiquarks.

The charge radius of the proton is $<R_p>= 0.84$ fm and that of the π^+ is $< R_{\pi^+} >= 0.66$ fm [22]. These data are relevant to the following argument. The π^+ is a $u\bar{d}$ bound state and its radius is smaller than that of the proton. Now, QCD says that the proton comprises three valence quarks, a probability of quark-antiquark pairs, and gluons. Consider a state of one additional quark-antiquark pair. Here QCD cannot explain why the proton's four quarks (the three valence quarks and the antiquark's companion) cannot hold the antiquark inside their self-volume, while the single u quark of the π^+ holds firmly the antiquark inside a smaller volume.

The RCMT provides a straightforward explanation for the nucleon's larger spatial volume of antiquarks. The nucleon has a core whose monopole charge is +3. Quarks have a monopole charge of -1. Therefore, standard electromagnetic laws state that the core attracts quarks. Antiquarks have a monopole charge of +1. Hence, the core repels them to the nucleon's peripheral region.

4 The Significance of the New Data

This section examines scientific evidence that is not mentioned in the earlier publications [8, 9].

Data.1 Quantum textbooks discuss these transformations: The parity transformation (called P) of the space-time coordinates is $(t, \boldsymbol{x}) \rightarrow (t, -\boldsymbol{x})$. Charge conjugation (called C) is a transformation where a particle and its antiparticle are interchanged (see [5], p. 64). Experiments prove that strong and electromagnetic interactions conserve C and P (see [5], p. 64). Hence, these interactions conserve the combined transformation CP. These data should affect the structure of theories of these interactions.

It turns out that the theoretical structure of QCD allows a CP violation. This well-known QCD property is called *the strong CP problem* (see [5], p. 726). This problem is regarded as one of the unsettled QCD problems [27].

This problem does not arise in the RCMT. Indeed, the RCMT is a regular Maxwellian-like theory, which in the group theory parlance is called a U(1) theory. In the quantum domain, it uses the Dirac field for a description of a massive particle. This theory conserves C and P (see [5], pp. 65-71). Hence, it conserves CP as well.

Data.2 A recent publication of the CERN ATLAS collaboration shows that the proton's amount of the $\bar{s}s$ quark-antiquark pair is about the same as that of the $\bar{d}d$ quark-antiquark pair [28]. It is not clear how can QCD explain these new data. Indeed, a general rule of physics says that the probability of a higher energy state is smaller than that of a lower energy state. Here the s-quark is heavier than the d-quark, and strange hadrons are heavier than their corresponding hadrons that comprise only quarks of the u, d flavor. Furthermore, the QCD additional color degree of freedom indicates that the Pauli exclusion principle allows the addition of a $\bar{d}d$ pair to the proton's ground state.

The RCMT provides a direct explanation for these results. Indeed, the RCMT shows that in addition to the three valence quarks, the proton has a core that comprises an inner object *and* closed shells of u, d quarks. Furthermore, quarks are ordinary Dirac particles (see [9], p. 98). Hence, the u, d quarks of an additional quark-antiquark pair occupy a higher energy state. By contrast, energy considerations indicate that in the proton, the existence of closed shells of s quark is less likely. Hence, the Pauli principle allows the s quark of the additional $\bar{s}s$ pair to occupy a lower energy state. This effect increases the probability of the additional $\bar{s}s$ pairs. It can be concluded that two effects effectively cancel each other and yield a similar probability of the additional $\bar{s}s$ and $\bar{d}d$ pairs: The higher mass of the s quark reduces its probability, whereas the Pauli principle allows it to take a lower energy state and thereby increases its probability.

It is interesting to note that the existence of closed shells of u, d quarks in the proton's core, *and* the null (or much lower) probability of closed shells of s quarks were *predicted* by the RCMT: "The baryonic core contains closed shells of quarks of the u, d flavor" (see [9], p. 98). Moreover: "It follows that inner closed shells of s quarks either do not exist or that their number is smaller than those of the u, d quarks" (see [9], p. 110). This successful prediction provides another indication of the RCMT veracity.

Data.3 The excess of the proton's $\bar{d}$ antiquarks over its $\bar{u}$ antiquarks is already known for several decades [29]. Results of recent experiments that have been carried out at CERN and Fermilab support this effect [30]. Here is a simple argument that explains this conclusion. The figure on p. 281 of [26] (fig. 4 illustrates its general features) proves that the portion of antiquarks that have Bjorken x greater than 0.3, can be ignored. The new data are shown on the left-hand side of fig. 2 of [30]. It shows that at $x < 0.3$ the ratio $\bar{d}/\bar{u}$ varies between 1 and 1.75. Arguments similar to those of item Data.2 rely on the QCD additional color degree of freedom and point out why QCD cannot explain this effect. In contrast, the Pauli exclusion principle and the proton's *uud* valence quarks are the reason for the straightforward explanation that is provided by the RCMT (see also [9], p. 105). The QCD failure to describe the different amount of the $\bar{u}, \bar{d}$ components of the proton is also stated in the literature: "...but yet our understanding of the dynamics that form a physical proton from quarks and gluons is, at best, poor" [31].

Data.4 An article by A. D. Krisch reports data of polarized proton-proton scattering. The results show that at higher energy a difference arises between the parallel spin data and the antiparallel spin data [32].

Here is Krisch's description of the meaning of these results: "In particular, the theory that is now called QCD, has been unable to deal with this data: Glashow once called this experiment 'the thorn in the side of QCD.' In his summary talk at Blois 2005, Stan Brodsky called this result 'one of the unsolved mysteries of hadron physics.'"

Krisch continues and states that "some theorists seemed quite unhappy" with the results of polarized proton experiments, and that QCD experts have expected that "QCD might not work for elastic scattering". The biased and unscientific approach of mainstream people to this issue is inferred from Krisch's statement: "Thus, one result of our experiments was to make both elastic scattering experiments and spin experiments unpopular in some circles."

In principle, this phenomenon is expected by the RCMT. Indeed, the RCMT is an electromagnetic-like theory. Here an energy increase entails an increase of the relative portion of the spin-dependent (magnetic) interaction with respect to the spin-independent (electric) interaction (see [26], pp. 192-194). Hence, the charge-monopole duality relations mean that in a higher energy experiment, the proton-proton spin-dependent interactions are likely to arise.

5 Conclusions

M. Gell-Mann's doubtful opinion on the QCD merits has recently been reported [12]. This evidence encourages an examination of the validity of this theory, and this work undertakes this assignment. Earlier publications already show inconsistencies between QCD and many kinds of experimental data. Moreover, an examination of an alternative strong interaction theory called the RCMT shows the clear advantage of the RCMT over QCD [8–10]. It turns out that the progress of time provides new data that indicate other kinds of QCD discrepancies and support older ones. Like in the earlier cases, the RCMT provides consistent explanations also for the new data. Section 3 of this work describes three striking effects that refute QCD, which are discussed in [8, 9]. The new data that are examined in section 4 support this conclusion.

The RCMT has been derived from pure theoretical arguments aiming to answer this problem: How can one use the charge-monopole duality transformations and the variational principle for the construction of a regular charge-monopole theory that is an extension of Maxwellian electrodynamics? The specific experimental topics that are discussed in sections 3 and 4 certainly do not affect the derivation of this theoretical structure, beside finding an estimate for the size of free parameters, like that of the relatively large monopole unit. Its overall success is described herein and in [8–10]. This success indicates that the RCMT can be regarded as the right basis for a comprehensive strong interaction theory.

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