A Critical Examination of Quantum Electrodynamics and Quantum Chromodynamics

E. Comay

Charactell Ltd., Tel-Aviv, Israel
Email: elicomay@post.tau.ac.il

Abstract

Statements made by R. P. Feynman and M. Gell-Mann indicate that these persons have cast doubts on the veracity of Quantum Electrodynamics and Quantum Chromodynamics. An analysis of elements of these theories and an examination of well established experimental data substantiate their claims. The independent experimental examples that are discussed herein are known for decades. Unfortunately, these examples as well as their problematic aspects are ignored by the current mainstream literature

Subject Areas

Modern Physics

Keywords

Quantum Electrodynamics, Quantum Chromodynamics, Consistency Criteria, Consistency Tests

1. Introduction

A general agreement of contemporary physicists says that there are four kinds of fundamental interactions in Nature: Strong, electromagnetic, weak, and gravitational (see e.g. [1], p. 4; [2], p. 59). Experiments substantiate this distinction. An important attribute of a two-particle interaction is the spatial size that encloses the particles where the specific interaction is determined. Here one finds processes that take place within an atomic scale whose linear size is measured in units of 10^{-8} cm and processes that take place within a nuclear scale whose linear size is measured in units of 10^{-13} cm. Experiments prove that the gravitational interaction is extremely weak for particles that are enclosed inside a volume of such a size. For this reason, textbooks on particle physics and its general theory Quantum Field Theory (QFT) do not discuss details of gravitational interaction.

Therefore, particle physics textbooks focus on the other fundamental interactions. The presently accepted theory of strong interactions is called Quantum Chromodynamics (QCD) and that of electromagnetic interactions is called Quantum Electrodynamics (QED).

R. P. Feynman and M. Gell-Mann were two distinguished figures of the physical community and each of them has made a significant contribution to the development of physics during the second half of the 20th century. It is interesting to see their opinion on QED and QCD. A process called renormalization is an element of QED. Feynman referred to this process and stated that it is "a dippy process!" (see [3], p. 128). A few lines later he restates his opinion: "I suspect that renormalization is not mathematically legitimate." Referring to QCD, Gell-Mann has used a more delicate terminology. Thus, he advised a colleague who has worked on QCD and said that "you should work on more worthwhile topics" [4].

These quotations indicate that a critical examination of QED and QCD are quite interesting assignments. Evidently, such an examination can only make a positive scientific contribution. In the case of a correct theory, this work can only improve its validity, whereas in the case of an imperfect theory, this work can illuminate some of its problematic elements. The present work undertakes these assignments. It utilizes two general requirements that an acceptable physical theory should satisfy: The theory must have a coherent mathematical structure and it must provide a good description of experimental data that belong to its domain of validity.

Units where $\hbar = c = 1$ are used. Greek indices run from 0 to 3. Most formulas take the standard form of a relativistic covariant expression. The metric is diagonal and its entries are (1, -1, -1, -1). An upper dot denotes the time-derivative. The second section describes two theoretical elements that are used in the analysis. The third section critically examines QED, and the fourth section critically examines QCD. The last section summarized this work.

2. Principles Used in the Analysis

This section describes two theoretical elements that are used in this work.

The Lagrangian density is a primary element of a QFT. 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 [5], p. 300). The QED Lagrangian density is

$$\mathcal{L}_{QED} = \bar{\psi}(\gamma^\mu i \partial_\mu - m)\psi - e\bar{\psi}\gamma^\mu A_\mu \psi - \frac{1}{16\pi}F_{\mu\nu}F^{\mu\nu}. \qquad (1)$$

(see [6], p. 78; [7], p. 84). Here $\psi(x)$ is the quantum function of a charged Dirac particle and x denotes the four space-time coordinates. A_μ and $F^{\mu\nu}$ denote the electromagnetic 4-potential and the fields' tensor, respectively (see [8], pp. 48, 65; [9], pp. 549, 550). The compatibility of the last term of (1) with experiments is discussed in the next section.

Wigner's analysis of the unitary representations of the inhomogeneous Lorentz group (see [10] or [11], pp. 44-53) plays an important role in the discussion. His analysis proves that a physical particle has positive energy in every frame. Moreover, a massive quantum particle has a well-defined mass and spin, whereas a massless particle has two components of helicity. It means that two quantum states that do

not have the same mass or the same spin necessarily refer to different physical objects. These results are briefly denoted below by the term *Wigner's analysis*.

This work also uses experimental data. Scattering experiments are an important tool of particle physics. The following lines explain very briefly some elements of this issue. Here two incoming particles are prepared and the experimenters examine the outgoing particles. The total energy and momentum of the process are conserved. New particles may be produced in a scattering event, and in some cases an incoming particle does not come out. A scattering event is a case where the momentum of one of the incoming particles is not identical to that of the corresponding outgoing particle. The scattering cross section is related to the intensity of the two-particle interaction (see e.g. [1], pp. 69, 70; [2], pp. 199-203). The *total cross section* is proportional to the total number of scattering events. An elastic scattering event is a case where the outgoing particles are the same as the incoming particles, but the initial momentum changes. The *elastic cross section* is proportional to the total number of elastic events.

3. A Critical Examination of QED

Two kinds of electromagnetic fields are discussed in the literature - radiation fields and bound fields. In principle, bound fields are all fields that are not radiation fields. Radiation fields pertain to the quantum particle called photon, and bound fields pertain to a massive charged particle. For example, radiation fields travel at the speed of light in every inertial frame, whereas bound fields of a free motionless charged particle are time-independent. Furthermore, the literature uses the concepts of *real photon* and *virtual photon*. The different notation can be regarded as a strong hint stating that *Nature contains more than one kind of electromagnetic fields!* If this is true then there is no justification for summing all fields in the product of the $F^{\mu\nu}$ tensors of the last term of the QED Lagrangian density (1).

Considering this hint, let us compare physical attributes of radiation fields and bound fields. The following lines prove that these fields have different physical attributes. Therefore, radiation fields and bound fields are inherently different physical objects.

3.1. Fields of a Single Particle

Let us examine fields of two free particles, the radiation fields of a photon and the bound fields of an electron.

Electromagnetic fields have two Lorentz invariants (see [8], pp. 67, 68)

$$Inv_1 = \frac{1}{2} F_{\mu\nu} F^{\mu\nu} = B^2 - E^2 \tag{2}$$

and

$$Inv_2 = \frac{1}{2} \epsilon_{\mu\nu\alpha\beta} F^{\mu\nu} F^{\alpha\beta} = \boldsymbol{E} \cdot \boldsymbol{B}, \tag{3}$$

where $\epsilon_{\mu\nu\alpha\beta}$ is the completely antisymmetric unit tensor of the fourth rank.

In the units used herein, radiation fields have the following properties (see [8], p. 185)

$$|\boldsymbol{E}| = |\boldsymbol{B}|, \tag{4}$$

$$\boldsymbol{E} \perp \boldsymbol{B}. \tag{5}$$

A substitution of (4) into the first fields invariant (2) yields a null value and the same result is obtained from the substitution of (5) into the second fields invariant (3).

The photon pertains to radiation fields and in a given inertial frame, the 4-momentum of a photon moving in the x-direction has these properties

$$p^\mu = (E, E, 0, 0); \quad p^\mu p_\mu = 0, \tag{6}$$

where $E > 0$ denotes the photon's energy (see [2], pp. 240, 241).

Let us turn to the fields of a single charged particle. Relativistic invariants take the same value in every inertial frame. For a motionless charge at the origin of coordinates, one finds for all points outside the origin

$$|\boldsymbol{E}| > 0, \quad \boldsymbol{B} = 0. \tag{7}$$

These values prove that contrary to the photon case, a substitution of the charge's fields (7) into the first fields invariant (2) yields a negative value throughout the entire space-time points (except at the location of the point-charge).

This result means that:

A. *Radiation fields and bound fields are different physical objects.*

3.2. Photon's Fields vs Fields of a Scattered Charge

Consider a low energy elastic scattering event of two charged particles (Rutherford scattering). In the rest frame of the system, the two charges exchange momentum but each of them conserves its initial energy (see e.g. fig. 7.2 in [1], p. 162). In this approximation, the process is radiation-free and the bound fields of the two charges determine the process. The 4-momentum that is exchanged in the process is

$$p^\mu = p^\mu_{in} - p^\mu_{out} = (0, \boldsymbol{p}), \tag{8}$$

where $\boldsymbol{p}$ is the 3-momentum that is exchanged between the particles. The corresponding Lorentz scalar of (8)

$$p^\mu p_\mu = -|\boldsymbol{p}|^2 < 0 \tag{9}$$

is negative.

In the present terminology the process shows that the two particles exchange a *virtual photon* (see e.g. [1], pp. 160, 161; [2], p. 65). The different names *real photon* vs *virtual photon* indicate that they are not the same particle. Indeed, a real photon (6) has positive energy and it is a massless particle where the square of its 4-momentum vanishes. By contrast, in the rest frame of the system, the virtual photon of (8) has null energy and the square of its 4-momentum is negative. Hence, the Wigner's analysis proves that they are not the same physical objects and the virtual particle is not a genuine physical particle. This is another proof of statement A of subsection 3.1.

3.3. Interactions of the Hydrogen Atom with Fields

Let us take the hydrogen atom as an experimental device and use it for finding physical properties of radiation fields and bound fields. The Dirac equation (and the Schroedinger equation) provides a good description of states and processes of this atom. Hence, these equations are used here as a reliable description of experimental data.

H.1. Consider the 1s ground state of the hydrogen atom and an incoming photon whose energy equals the difference between the energy of the states 2p and 1s. This photon induces an allowed transition (see [12], p. 264), and this process proves that the spin/parity of the photon are $j^\pi = 1^-$ (see e.g. [2], p. 141, [13]).

H.2. Now let us examine the hydrogen atom energy levels. Here the state's angular momentum *is determined only by the electronic wave function* (see e.g. [12], pp. 141-149). The same is true with parity (see e.g. [12], pp. 73, 74). Here the proton's and the electron's electromagnetic fields make no contribution to the spin/parity of the system. Hence, if the fields of a bound state represent a particle, then the spin/parity of this particle are $j^\pi = 0^+$. In this case, due to the different spin of radiation fields and bound fields, the Wigner's analysis proves that they are different physical entities. This is yet another proof of statement A of subsection 3.1.

The different parity of the real photon and of the hydrogen atom bound fields means that the last term of the QED Lagrangian density (1) violates parity. By contrast, it is well known that electrodynamics conserves parity (see e.g. [1], p. 288; [2], p. 141).

Each of the examples of this section substantiates the claim stating that *there is no justification for summing all fields in the product of the $F^{\mu\nu}$ tensor of the last term of the QED Lagrangian density* (1). Therefore, each of these examples is an independent proof of Feynman's opinion that QED is not a flawless theory.

4. A Critical Examination of Quantum Chromodynamics

QCD is the Standard Model sector aiming to describe strong interactions of hadronic states and processes. Let us compare QCD with well established hadronic data.

4.1. The Hard Photon Interaction with a Nucleon

The cross section data of the interaction of a hard photon with a proton target is very similar to that of a neutron target [14]. Since the electric charge of the proton constituents differs from that of the neutron constituents, one concludes that the interaction of a hard photon with the *electric charge* of nucleon constituents *cannot* explain this similarity. The idea of Vector Meson Dominance (VMD) has been suggested as an explanation for this effect.

The primary claim of VMD says that the wave function of an energetic photon takes the form

$$| \gamma > = c_0 \, | \gamma_0 > + c_h \, | h >, \tag{10}$$

where $| \gamma >$ denotes the wave function of a physical photon, $| \gamma_0 >$ denotes the pure electromagnetic component of a physical photon, and $| h >$ denotes its hypothetical hadronic component. c_0 and c_h are appropriate numerical coefficients whose value depends on the photon's energy. Thus, for a soft photon $c_h \simeq 0$ whereas it begins to take a nonvanishing value for a photon whose energy is not much less than the ρ meson's mass (see [14] and [15]).

The VMD idea (10) combines a massless photon with a massive meson. It follows that it is an inherently erroneous theoretical idea because it is inconsistent with the Wigner's analysis. Claims about other VMD flaws can be found in the literature: "No direct translation between the Standard Model and VMD has yet been made" [16]. See also [17] and [18]. An examination of the modern mainstream literature shows that it ignores the VMD idea as well as the effect of the hard photon interaction with nucleon (see e.g. [1,2]).

It can be concluded that the Standard Model in general and QCD in particular provide no explanation for the hard photon-nucleon scattering data.

4.2. Scattering Properties of a Proton Target

Let us compare the energy dependence of the cross section of proton-proton scattering experiments with that of electron-proton scattering experiments. The de Broglie principle says that the wavelength of a projectile decreases with the increase of its momentum. This is the basis for the general law that says that in order "to probe *small distances* you need *high energies*" (see [2], p. 6). It means that as the collision energy increases the process is determined at a smaller spatial region around the target.

Figure 1 depicts the general features of the proton-proton total and elastic cross section plotted vs the collision energy. At low energy, there is no inelastic event and the two graphs coincide. The correct graphs are shown on p. 11 of [19]. The decreasing part of the graph at the low energy part of the figure describes the typical decrease of the Coulomb cross section as shown by the Rutherford and the Mott formulas.
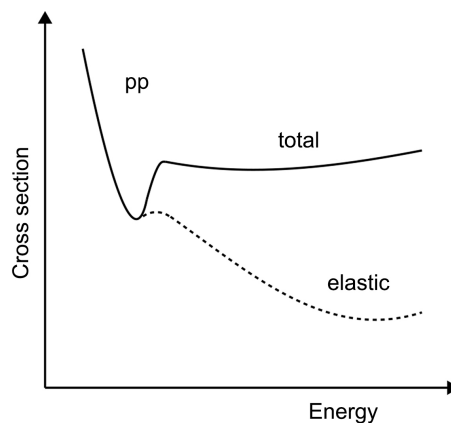

Figure 1. The proton-proton (pp) total and elastic cross section as a function of the collision energy. Axes are drawn in a logarithmic scale (see text).

An observation of Figure 1 shows that at higher energy the proton-proton scattering data have these properties:

CS-pp.1 The total cross section stops decreasing and begins to increase.

CS-pp.2 The elastic cross section stops decreasing and begins to increase.

CS-pp.3 The portion of the elastic cross section is nearly uniform and it takes about 1/6 of the total cross section.

6

Let us compare these features with those of the electron-proton cross section. Here the required data are described adequately by electromagnetic formulas which are documented in textbooks. The following items describe the dependence of the electron-proton cross section on the collision energy. They enable a comparison with the proton-proton items which are described above.

CS-ep.1 The total electron-proton cross section decreases strongly like the Mott cross section (see [1], chapter 8).

CS-ep.2 The elastic electron-proton cross section decreases very strongly as the collision energy increases (see [1], p. 178).

CS-ep.3 "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 [1], p. 178).

The striking differences between the high energy data of the two kinds of experiments stem from the fact that in the proton-proton case the effect depends on strong interactions between the quark constituents of the colliding particles, whereas in the electron-proton case the effect is electromagnetic. At higher energy, the results are completely different:

Diff.1 The total proton-proton cross section begins to increase. By contrast, the corresponding electron-proton data decrease monotonously.

Diff.2 The elastic proton-proton cross section begins to increase. By contrast, the corresponding electron-proton data decrease very strongly.

Diff.3 In the proton-proton case, elastic events take a uniform portion of the total number of events. By contrast, the relative portion of elastic events becomes negligible in the corresponding electron-proton case.

It can be concluded that experiments prove that the energy dependence of the quark-quark strong interaction is completely different from that of the electromagnetic electron-proton interaction.

The Standard Model says that QCD is the strong interaction theory. Asymptotic freedom is an inherent QCD property. This feature applies to the dependence of the strength of the QCD interaction on the quark-quark distance. Asymptotic freedom says that "QCD coupling decreases at short distances" (see [2], p. 70). Relying on this property, it can be stated that with the decrease of the distance between the interacting particles, QCD says that the relative increase of the electromagnetic force is not weaker than that of the strong force. The discussion on pp. 253-259 of [1] leads to the same conclusion.

As stated above, higher energy scattering is determined by a smaller distance between the colliding particles (see [2], p. 6). Hence, the QCD asymptotic freedom blatantly contradicts the experimental data on the energy dependence of the total and the elastic cross section of the proton-proton scattering that is shown in Figure 1. At present, the mainstream QCD literature does not discuss this discrepancy.

4.3. The Proton's Antiquark Spatial State

Figure 2 shows the quark and the antiquark x-values. The correct figure can be seen in [20], p. 281. A more detailed figure shows separately the graphs of quarks of a different flavor (see [1], p. 202). The data described by these graphs are obtained from deep inelastic lepton-nucleon scattering experiments.
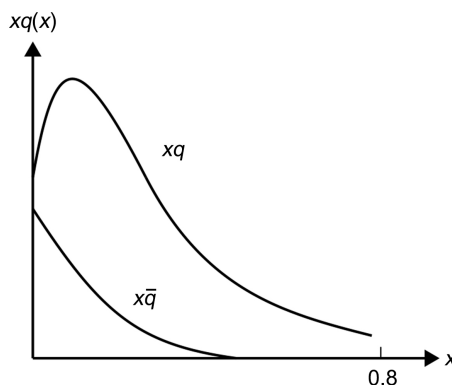

Figure 2. The proton's quark and antiquark x-values (see text)

It is recognized "that the underlying process in electron-proton inelastic scattering is the *elastic* scattering of electrons from pointlike spin-half constituent particles within the proton, namely the quarks" (see [1], p. 185). A restatement of this issue says "that inelastic lepton-nucleon scattering can be interpreted in terms of the elastic scattering of the lepton by pointlike parton constituents" of the nucleon (see [20], p. 271).

The Bjorken x

$$x = \frac{q^2}{2M\nu} \tag{11}$$

is an important variable of the analysis. Here q is the 4-momentum transferred in the scattering; M is the mass of the nucleon target; ν is the energy transferred in the target's rest frame (see [1], p. 181; [20], p. 266). In the case of an elastic scattering on a free target, a sharp $x = 1$ value is obtained (see [1], p. 180; [20], p. 267). The Fermi motion of quarks in the nucleon modifies the results and no sharp peak is seen. Instead, the graph is smeared and its width demonstrates the linear momentum of the Fermi motion of individual quarks' (see [20], p. 271).

An observation of Figure 1 shows that the *width* of the quarks' graph is larger than that of the antiquarks. It means that the quarks' Fermi motion is greater than that of antiquarks. Hence, the Heisenberg uncertainty principle proves that *the spatial volume of the proton's antiquarks is larger than that of quarks.*

QCD does not explain this effect. Indeed, the pion is a quark-antiquark bound state whose volume is smaller than that of the proton [13]. It means that a single quark attracts an antiquark so strongly that the quark-antiquark pair are enclosed inside a volume that is smaller than the proton's volume. Now, QCD says that the proton comprises quarks, antiquarks, and gluons (see [1], p. 178). Hence, it is not clear why the four proton's quarks (the three valence quarks and the antiquark's companion) do not hold the antiquark inside the proton's quarks volume?

The mainstream QCD literature does not discuss this problem.

QCD is nearly 50 years old. This quite a long period and the previous examples that demonstrate its failure to explain fundamental experimental data indicate that it suffers inherent contradictions. Other examples of QCD drawbacks are discussed elsewhere [21].

5. Conclusions

The theoretical structure of Quantum Electrodynamics and Quantum Chromodynamics is examined, and these theories are compared with relevant experimental data. Inconsistencies of these theories are substantiated.

For example, the literature distinguishes between two kinds of electromagnetic objects: *real photons* and *virtual photons.* The paper proves that the different notation is justified because real photons and virtual photons have different physical properties. In spite of this evidence, the QED Lagrangian density (1) does not distinguish between them. Indeed, the parity of a real photon is odd, whereas the parity of the bound fields of the hydrogen atom is even. Hence, the last term of the QED Lagrangian density (1) violates parity conservation. By contrast, electrodynamics conserves parity (see e.g. [1], p. 288; [2], p. 141).

An examination of well established experimental data of hadronic systems proves that QCD fails to explain them. Specific examples are the cross section experimental data of a hard photon scattered on nucleons; the high energy electron-proton and proton-proton cross section; the different features of the Bjorken-x dependence of the momentum distribution of quarks and antiquarks of the nucleon.

Unfortunately, the current mainstream literature ignores these problems.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Thomson, M. (2013) Modern Particle Physics. Cambridge University Press, Cambridge.
https://doi.org/10.1017/CBO9781139525367

[2] Griffiths, D. (2008) Introduction to Elementary Particles. 2nd Edition, Wiley-VCH, Weinheim.

[3] Feynman, R.P. (1990) QED: The Strange Theory of Light and Matter. Penguin, London.

[4] Wolfram, S. (2019) Remembering Murray Gell-Mann (1929-2019), Inventor of Quarks.
https://writings.stephenwolfram.com/2019/05/remembering-murray-gell-mann-1929-2019-inventor-of-quarks/

[5] Weinberg, S. (1995) The Quantum Theory of Fields. Vol. I, Cambridge University Press, Cambridge.
https://doi.org/10.1017/CBO9781139644167

[6] Peskin, M.E. and Schroeder, D.V. (1995) An Introduction to Quantum Field Theory. Addison-Wesley, Reading, MA.

[7] Bjorken, J.D. and Drell, S.D. (1965) Relativistic Quantum Fields. McGraw-Hill, New York.

[8] Landau, L.D. and Lifshitz, E.M. (2005) The Classical Theory of Fields. Elsevier, Amsterdam.

[9] Jackson, J.D. (1975) Classical Electrodynamics. John Wiley Sons, New York.

[10] Wigner, E. (1939) On Unitary Representations of the Inhomogeneous Lorentz Group. *Annals of Mathematics*, **40**, 149-204. https://doi.org/10.2307/1968551

[11] Schweber, S.S. (1964) An Introduction to Relativistic Quantum Field Theory. Harper & Row, New York.

[12] Schiff, L.I. (1955) Quantum Mechanics. McGraw-Hill, New York.

[13] Tanabashi, M., *et al.* (2018) Review of Particle Physics. *Physical Review D*, **98**, Article ID: 030001. https://pdg.lbl.gov/2018/reviews/contents_sports.html

[14] Bauer, T.H., Spital, R.D., Yennie, D.R. and Pipkin, F.M. (1978) The Hadronic Properties of the Photon in High-Energy Interactions. *Reviews of Modern Physics*, **50**, 261. https://doi.org/10.1103/RevModPhys.50.261

[15] Frauenfelder, H. and Henley, E.M. (1991) Subatomic Physics. Prentice Hall, Englewood Cliffs, 296-304.

[16] O'Connell, H.B., Pearce, B.C., Thomas, A.W. and Williams, A.G. (1997) Rho-Omega Mixing, Vector Meson Dominance and the Pion Form-Factor. *Progress in Particle and Nuclear Physics*, **39**, 201-252. https://doi.org/10.1016/S0146-6410(97)00044-6

[17] Friedman, J.I. (1991) Deep Inelastic Scattering: Comparisons with the Quark Model. *Reviews of Modern Physics*, **63**, 615. https://doi.org/10.1103/RevModPhys.63.615

[18] Comay, E. (2009) Physical Consequences of Mathematical Principles. *Progress in Physics*, **4**, 91-98.

[19] Plots of the Particle Data Group. http://pdg.lbl.gov/2012/reviews/rpp2012-rev-cross-section-plots.pdf

[20] Perkins, D.H. (1987) Introduction to High Energy Physics. Addison-Wesley, Menlo Park, CA.

[21] Comay, E. (2012) The Regular Charge-Monopole Theory and Strong Interactions. *Electronic Journal of Theoretical Physics*, **9**, 93-118. http://www.ejtp.com/articles/ejtpv9i26p93.pdf