

INTRICATE APPRAISAL OF QUANTUM CHROMODYNAMICS

N MUNEEER

*Bachelor of Technology in Mechanical Engineering,
A P J Abdul Kalam Technological University, Kerala, India.*

Abstract - There are four forces in Nature: "gravity" as seen in celestial motion and described by the general theory of relativity; the "electromagnetic force" as seen in the interaction between the nucleus and electrons; the "weak force" which describes the beta decay of a nucleus (the "electromagnetic force" and the "weak force" are unified in the electro weak theory); the force which acts between the quarks and gluons. The Strong Force is represented by theory known as quantum chromodynamics. This Strong Force has many very interesting characters; property called "asymptotic freedom" is that the force is relatively weak when quarks are close together, and becomes stronger and stronger when they are further and further apart.

Key Words: Quantum Chromodynamics, Quantum Mechanics, Gauge Theory, Lattice QCD.

1. INTRODUCTION

Quantum chromodynamics is the theory of the strong force existing quarks and gluons, the basic particles that form up composite hadrons like the nucleon, nucleon. QCD could be a variety of quantum theory known as a non-abelian gauge theory, with symmetry cluster SU(3). The QCD analogue of electrical charge could be a property known as color. Gluons are the force carrier of the idea, like photons are for the magnetic attraction force in quantum field theory. The theory is a crucial part of the quality Model of high-energy physics. A large body of experimental proof for QCD has been gathered over the years. QCD exhibits two main properties- Color confinement. This is a consequence of the constant force between two color charges as they are separated: In order to increase the separation between two quarks within a hadron, ever-increasing amounts of energy are required. Eventually this energy becomes so great as to spontaneously produce a quark-antiquark pair, turning the initial hadron into a pair of hadrons instead of producing an isolated color charge. Although analytically unproved, color confinement is well established from lattice QCD calculations and decades of experiments.[1] straight-line freedom, a reduction in the strength of interactions between quarks and gluons because the energy scale will increase and the length scale decreases. The asymptotic freedom of QCD was discovered in 1973 by David Gross and Frank Wilczek,[2] and independently by David Politzer in the same year.[3] For this work all

three shared the 2004 Nobel Prize in Physics. Physicist Murray Gell-Mann coined in his work. On June 27, 1978, Gell-Mann wrote a private letter to the editor of the Oxford English Dictionary, in which he related that he had been influenced by Joyce's words: "The mention to a few quarks appeared excellent." (Originally, only three quarks had been discovered.)[4] The three kinds of charge are referred to as "color charge" by loose analogy to the three colors (red, green and blue) observed by humans. Other than this terminology, the quantum parameter "color" is completely unrelated to the everyday, familiar phenomenon of color. Since the idea of electrical charge is dubbed "electrodynamics", the Greek word χρώμα chroma "color" is applied to the idea of color charge, "chromodynamics".

2. HISTORY OF QUANTUM MECHANICS AND QUANTUM FIELD THEORY

With the invention of bubble chambers and spark chambers within the Fifties, experimental high energy physics discovered an oversized and ever-growing range of particles referred to as hadrons. It appeared that such an oversized range of particles couldn't all be basic. First, the particles were classified by charge and isospin by Eugene Wigner and Werner Heisenberg; then, in 1953-56,[5][6] according to strangeness by Murray Gell-Mann and Kazuhiko Nishijima (see Gell-Mann-Nishijima formula). To gain bigger insight, the hadrons were sorted into groups having similar properties and masses using the eightfold way where invented in 1961 by Gell-Mann[7]. Perhaps the primary remark that quarks ought to possess an extra quantum range was made[8] as a brief footnote within the preprint of Boris Struminsky in reference to Ω^- hyperon composed of three strange quarks with parallel spins (this situation was peculiar, because since quarks are fermions, such combination is forbidden by the Pauli exclusion principle): Three identical quarks cannot form an antisymmetric S-state. In order to realize an antisymmetric orbital S-state, it is necessary for the quark to have an additional quantum number. The problem thought of during this preprint was recommended by Nikolay Bogolyubov who was advised by Boris Struminsky in this research.[9] In the beginning of 1965, Nikolay Bogolyubov, Boris Struminsky and Albert Tavkhelidze wrote a preprint with a lot of elaborate discussion of the extra quark quantum degree of freedom.[10] This work was

conjointly conferred by Albert Tavkhelidze while not getting consent of his collaborators for doing so at an international conference in Trieste (Italy), in May 1965.[11] A similar mysterious situation was with the Δ^{++} baryon; in the quark model, it is composed of three up quarks with parallel spins. In 1964–65, Greenberg[12] and Han–Nambu[13] independently resolved the problem by proposing that quarks possess an additional SU(3) gauge degree of freedom, later called color charge. Han and Nambu noted that quarks would possibly act via an octet of vector gauge bosons: the gluons. Since free quark searches consistently failed to turn up any evidence for the new particles, Gell-Mann said that quarks convenient mathematical constructs, not real particles. The meaning of this statement was usually clear in context: He meant quarks are confined, but he also was implying that the strong interactions could probably not be fully described by quantum field theory.

Richard Feynman argued that top energy experiments showed quarks are not real particles: he referred to as partons (since they were elements of hadrons). The difference between Feynman's and Gell-Mann's approaches reflected a deep split in the theoretical physics community. Although Gell-Mann believed that certain quark charges could be localized, he was open to the possibility that the quarks themselves could not be localized because space and time break down. This radical approach of S-matrix theory. James Bjorken proposed that point like partons would imply certain relations in deep inelastic scattering of electrons and protons, which were verified in experiments at SLAC in 1969. This junction rectified physicists to abandon the S-matrix approach for the robust interactions.

In 1973 the idea of color because the supply of a "strong field" was developed into the idea of QCD by physicists Harald Fritzsch and de:Heinrich Leutwyler, together with physicist Murray Gell-Mann.[19] In particular, they employed the general field theory developed in 1954 by Chen Ning Yang and Robert Mills[20] (see Yang–Mills theory), in which the carrier particles of a force can themselves radiate further carrier particles. (This is different from QED, where the photons that carry the electromagnetic force do not radiate further photons.) The discovery of asymptotic freedom in the strong interactions by David Gross, David Politzer and Frank Wilczek allowed physicists to form precise predictions of the results of the many high energy experiments victimisation the quantum theory technique of perturbation theory. These experiments became more and more precise, culminating in the verification of perturbative QCD at the level of a few percent at the LEP in CERN. The other side of asymptotic freedom is confinement. Since the force between color charges doesn't decrease with distance, it's believed that quarks

and gluons will never be liberated from hadrons. This aspect of the theory is verified within lattice QCD computations, but is not mathematically proven. One of the Millennium Prize Problems announced by the Clay Mathematics Institute requires a claimant to produce such a proof. Other aspects of non-perturbative QCD are the exploration of phases of quark matter, including the quark–gluon plasma.

3. STANFORD LINEAR ACCELERATOR CENTRE

An enormous version of Rutherford's scattering experiment accelerated intense beams of electrons up to 20GeV at liquid hydrogen and deuterium targets in end station A. Researchers observed electrons scattering at wide angles much more frequently than expected. Analysis of the distribution of the scattered electron measured in the magnetic spectrometer in the end station A revealed three scattering centres within the nucleon.



Fig-1: Block diagram for SLAC

4. GAUGE THEORY

A theory within which are unit diagrammatic by Dirac fields within the basic illustration three of the gauge cluster SU(3). They additionally carry electrical phenomenon (either $-1/3$ or $+2/3$) and participate in weak interactions as a part of weak isospin doublets. They carry world quantum numbers together with the number, that is $1/3$ for every quark, hypercharge and one in all the flavour quantum numbers. Gluons are spin-1 bosons which also carry color charges, since they lie in the adjoint representation 8 of SU(3). They have no electrical phenomenon, don't participate within the weak interactions, and don't have any flavor. They lie in the singlet representation 1 of all these symmetry groups. Every quark has its own antiquark. The charge of each antiquark is exactly the opposite of the corresponding quark.

5. LATTICE QCD

Among non-perturbative approaches to QCD, the most well established one is lattice QCD. This approach uses a discrete set of spacetime points (called the lattice) to reduce the analytically intractable path integrals of the continuum theory to a very difficult numerical

computation which is then carried out on supercomputers like the QCDOC which was constructed for precisely this purpose. While it is a slow and resource-intensive approach, it has wide applicability, giving insight into parts of the theory inaccessible by other means, in particular into the explicit forces acting between quarks and antiquarks in a meson. However, the numerical sign problem makes it difficult to use lattice methods to study QCD at high density and low temperature (e.g. nuclear matter or the interior of neutron stars).

6. COMPARISON BETWEEN QCD AND QED

There are 2 main difference between QCD from QED. The quarks interact more strongly, when they are further apart and no other force does this! Gluons interact with themselves because they also carry color charge while photons are not electrically charged. The photon do-not interact with each other. QED has two types of charges- Electric (Positive and Negative). QCD has three types of charges- Color (red, blue, green).

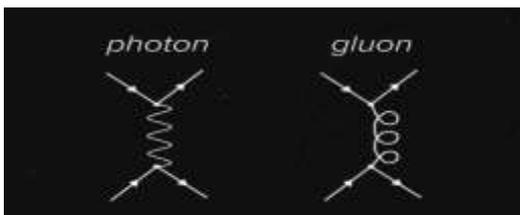


Fig-2: Diagrammatic representation of photon and gluon

7. CONCLUSION

We now stand at the precipice of a radical change in the way we build technology. Instead of starting from the top and working our way down, we are now looking to build technology from the bottom to up. Entanglement allows particles obeying the rules of quantum mechanics to be linked together over vast distances. So, manipulating one instantly affect its partner in ways we fundamentally have no idea. These things that were long relegated to the dustbin of mathematical curiosities but no longer! Our understanding about quantum dynamics is much less, but these are real and accessible. Now, we are learning to control and harness these phenomena as resources powering a new generation of technologies. All these efforts take time and once when it is done, our universe will no longer be mystery!

ACKNOWLEDGEMENT

I am grateful to Dr. Sreeraj P (Principal, Younus College of Engineering & Technology Kollam) for sharing his pearls of wisdom with me during the course of this work.

REFERENCES

1. J. Greensite (2011). An introduction to the confinement problem. Springer. ISBN 978-3-642-14381-6.
2. D.J. Gross; F. Wilczek (1973). "Ultraviolet behavior of non-abelian gauge theories". *Physical Review Letters*. 30 (26): 1343-1346.
3. H.D. Politzer (1973). "Reliable perturbative results for strong interactions". *Physical Review Letters*. 30 (26): 1346-1349.
4. Gell-Mann, Murray (1995). *The Quark and the Jaguar*. Owl Books. ISBN 978-0-8050-7253-2.
5. Nishijima, K (1955). "Charge Independence Theory of V Particles". *Progress of Theoretical Physics*. 13 (3): 285-304.
6. Nakano, T; Nishijima, N (1953). "Charge Independence for V-particles". *Progress of Theoretical Physics*. 10 (5): 581.
7. Gell-Mann, M. (1961). "The Eightfold Way: A Theory of strong interaction symmetry" (No. TID-12608; CTSL-20). California Inst. of Tech., Pasadena. Synchrotron Lab.
8. Fyodor Tkachov (2009). "A contribution to the history of quarks: Boris Struminsky's 1965 JINR publication".
9. B. V. Struminsky, Magnetic moments of barions in the quark model. JINR-Preprint P-1939, Dubna, Russia. Submitted on January 7, 1965.
10. N. Bogolubov, B. Struminsky, A. Tavkhelidze. On composite models in the theory of elementary particles. JINR Preprint D-1968, Dubna 1965.
11. A. Tavkhelidze. Proc. Seminar on High Energy Physics and Elementary Particles, Trieste, 1965, Vienna IAEA, 1965
12. O. W. Greenberg, "Spin and Unitary Spin Independence in a Paraquark Model of Baryons and Mesons." *Phys. Rev. Lett.* 13, 598-602 (1964).
13. M. Y. Han and Y. Nambu, "Three-Triplet Model with Double SU(3) Symmetry." *Phys. Rev.* 139, B1006-B1010 (1965)