On Some New Ideas in Hadron Physics

Florentin Smarandache* and Vic Christianto†
*Department of Mathematics, University of New Mexico, Gallup, NM 87301, USA
E-mail: smarand@unm.edu
†Sciprint.org — a Free Scientific Electronic Preprint Server, http://www.sciprint.org
E-mail: vxianto@yahoo.com, admin@sciprint.org

We shortly review a series of novel ideas on the physics of hadrons and nuclear matter. Despite being vastly different in scope and content, these models share a common attribute, in that they offer unconventional viewpoints on infrared QCD and nuclear phenomena. In a sense, they are reminiscent of the plethora of formulations that have been developed over the years on classical gravitation: many seemingly disparate approaches can be effectively used to describe and explore the same physics.

1 Introduction

Given the extent and complexity of hadron and nuclear phenomena, any attempt for an exhaustive review of new ideas is outright unpractical. We survey here only a limited number of models and guide the reader to appropriate references for further information. The paper is divided in several sections according to the following plan:

1. The first section discusses the Brightsen model and the Nuclear String hypothesis;
2. Models inspired by Kerr-Newman twistor model and the AdS/CFT conjecture are introduced in the second section;
3. The last section discusses CGLE model of hadron masses and non-equilibrium phase transitions in infrared QCD.

The selection of topics is clearly incomplete and subjective. As such, it may not necessarily reflect the prevalent opinion of theorists working in this field. Our intent is to simply stimulate a constructive exchange of ideas in this active area of research.

2 Brightsen mdodel and the nuclear string hypothesis

In this hadron model, developed by M.Pitkanen [1] based on his TGD theory, it is supposed that ^{4}He nuclei and $A < 4$ nuclei and possibly also nucleons appear as basic building blocks of nuclear strings. This seems like some kind of improvement of the Close Packed Spheron model of L. Pauling in 1960s, which asserts that nuclei is composite form of small numbers of interacting boson-fermion nucleon clusters, i.e. ^{3}He (PNP), triton (NPN) and deuteron (NP). Another extension of Pauling model is known as Brightsen's cluster nuclei model, which has been presented and discussed by F. Smarandache and D. Rabounski [2].

Interestingly, it can be shown that the Close Packed model of nuclei may explain naturally why all the upper quarks have fractional electric charge at the order of $Q = +\frac{2}{\sqrt{3}}$. So far this is one of the most mysterious enigma in the hadron physics. But as described by Thompson [4], in a closed-packed crystal sheet model, the displacement coefficients would be given by a matrix where the 1-1 component is:

$$c_{11} = \frac{2\rho}{\sqrt{3}} - 1\,, \qquad (1)$$

where the deformation can be described by the resolved distance between columns, written as ρd. Here d represents diameter of the nuclei entity. Now it seems interesting to point out here that if we supposed that $\rho = 1 + \frac{\sqrt{3}}{2}$, then c from equation (3) yields exactly the same value with the upper quark's electric charge mentioned above. In other words, this seems to suggest plausible deep link between QCD/quark charges and the close-packed nuclei picture [3].

Interestingly, the origin of such fractional quark charge can also be described by a geometric icosahedron model [4]. In this model, the concept of quark generation and electroweak charge values are connected with (and interpreted as) the discrete symmetries of icosahedron geometry at its 12 vertices. Theoretical basis of this analog came from the fact that the gauge model of electroweak interactions is based on SU(2)×U(1) symmetry group of internal space. Meanwhile, it is known that SU(2) group corresponds to the O(3) group of 3D space rotations, hence it appears quite natural to connect particle properties with the discrete symmetries of the icosahedron polygon.

It is worth to mention here that there are some recent articles discussing plausible theoretical links between icosahedron model and close-packed model of nuclei entities, for instance by the virtue of Baxter theory [5]. Furthermore, there are other articles mentioning theoretical link between the close-packed model and Ginzburg-Landau theory. There is also link between Yang-Baxter theory and Ginzburg-Landau theory [6]. In this regards, it is well known that cluster hydrogen or cluster helium exhibit superfluidity [7, 8], therefore it suggests deep link between cluster model of Pauling or Brightsen and condensed matter physics (Ginzburg-Landau theory).

The Brightsen model supports a hypothesis that antimatter nucleon clusters are present as a parton (*sensu* Feynman) superposition within the spatial confinement of the proton

($^1H_1$), the neutron, and the deuteron ($^1H_2$). If model predictions can be confirmed both mathematically and experimentally, a new physics is suggested. A proposed experiment is connected to orthopositronium annihilation anomalies, which, being related to one of known unmatter entity, orthopositronium (built on electron and positron), opens a way to expand the Standard Model.

Furthermore, the fact that the proposed Nuclear String hypothesis is derived from a theory which consists of many-sheeted spacetime framework called TGD seems to suggest a plausible link between this model and Kerr-Schild twistor model as described below.

3 Multiparticle Kerr-Schild twistor model and AdS/CFT Light-Front Holography model

Kerr's multiparticle solution can be obtained on the basis of the Kerr theorem, which yields a many-sheeted multi-twistorial spacetime over M^4 with some unusual properties. Gravitational and electromagnetic interaction of the particles occurs with a singular twistor line, which is common for twistorial structures of interacting particles [6].

In this regards the Kerr-Newman solution can be represented in the Kerr-Schild form [9]:

$$g_{\mu\nu} = \eta_{\mu\nu} + 2hk_\mu k_\nu \,, \tag{2}$$

where $\eta_{\mu\nu}$ is the metric of auxiliary Minkowski spacetime.

Then the Kerr theorem allows one to describe the Kerr geometry in twistor terms. And using the Kerr-Schild formalism, one can obtain exact asymptotically flat multiparticle solutions of the Einstein-Maxwell field equations. But how this model can yield a prediction of hadron masses remain to be seen. Nonetheless the axial stringy system corresponds to the Kerr-Schild null tetrad can be associated with superconducting strings. Interestingly one can find an interpretation of Dirac equation from this picture, and it is known that Dirac equation with an effective QCD potential can describe hadron masses.

What seems interesting from this Kerr-Schild twistor model, is that one can expect to give some visual interpretation of the electromagnetic string right from the solution of Einstein-Maxwell field equations. This would give an interesting clue toward making the string theory a somewhat testable result. Another approach to connect the superstring theory to hadron description will be discussed below, called Light-Front Holography model.

Brodsky et al. [10, 11] were able to prove that there are theoretical links, such that the Superstring theory reduces to AdS/CFT theory, and Ads/CFT theory reduces to the so-called Light Front Holography, which in turn this model can serve as first approximation to the Quantum Chromodynamics theory.

Starting from the equation of motion in QCD, they identify an invariant light front coordinate which allows separation of the dynamics of quark and gluon binding from the kinematics of constituent spin and internal orbital angular momentum. Of most interesting here is that this method gives results in the from of 1-parameter light-front Schrödinger equation for QCD which determines the eigenspectrum and the light-front wavefunctions of hadrons for general spin and orbital angular momentum.

The light-front wave equation can be written as [8]:

$$\left(-\frac{d^2}{d\zeta^2} - \frac{1-4L^2}{4\zeta^2} + U(\zeta)\right)\phi(\zeta) = M^2\phi(\zeta)\,, \tag{3}$$

which is an effective single-variable light-front Schrödinger equation which is relativistic, covariant, and analytically tractable; here M represents the mass spectra.

Nonetheless, whether this Light-Front Holography picture will yield some quantitative and testable predictions of hadron masses, remains to be seen.

4 Concluding note

We shortly review a series of novel ideas on the physics of hadrons and nuclear matter. Despite being vastly different in scope and content, these models share a common attribute, in that they offer unconventional viewpoints on hadron, nuclear phenomena, and infrared QCD. In a sense, they are reminiscent of the plethora of formulations that have been developed over the years on classical gravitation: many seemingly disparate approaches can be effectively used to describe and explore the same physics.

These very interesting new approaches, therefore, seem to suggest that there is a hitherto hidden theoretical links between different approaches.

In our opinion, these theoretical links worth to discuss further to prove whether they provide a consistent picture, in particular toward explanation of the hadron mass generation mechanism and spontaneous symmetry breaking process.

The present article is a first part of our series of review of hadron physics. Another part is under preparation.

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