# On Some Novel Ideas in Hadron Physics. Part II

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As a continuation of the preceding section, we shortly review a series of novel ideas on the physics of hadrons. In the present paper, emphasis is given on some different approaches to the hadron physics, which may be called as "programs" in the sense of Lakatos. For clarity, we only discuss geometrization program, symmetries/unification program, and phenomenology of inter-quark potential program.

## 1 Introduction

We begin the present paper by reiterating that given the extent and complexity of hadron and nuclear phenomena, any attempt for an exhaustive review of new ideas is outright unpractical. Therefore in this second part, we limit our short review on a number of scientific programs (in the sense of Lakatos). Others of course may choose different schemes or categorization. The main idea for this scheme of approaches was attributed to an article by Lipkin on hadron physics. accordingly, we describe the approaches as follows:

1. The geometrization approach, which was based on analogy between general relativity as strong field and the hadron physics;
2. Models inspired by (generalization of) symmetry principles;
3. Various composite hadron models;
4. The last section discusses phenomenological approach along with some kind of inter-quark QCD potential.

To reiterate again, the selection of topics is clearly incomplete, and as such it may not necessarily reflect the prevalent opinion of theorists working in this field (for more standard review the reader may wish to see [1]). Here the citation is far from being complete, because we only cite those references which appear to be accessible and also interesting to most readers.

Our intention here is to simply stimulate a healthy exchange of ideas in this active area of research, in particular in the context of discussions concerning possibilities to explore elementary particles beyond the Standard Model (as mentioned in a number of papers in recent years).

## 2 Geometrization approach

In the preceding section we have discussed a number of hadron or particle models which are essentially based on geometrical theories, for instance Kerr-Schild model or Topological Geometrical Dynamics [1].

However, we can view these models as part of more general approach which can be called "geometrization" program. The rationale of this approach can be summarized as follows (to quote Bruchholz): "The deeper reason is that the standard model is based on Special Relativity while gravitation is the principal item of General Relativity" [2].

Therefore, if we follow this logic, then it should be clear that the Standard Model which is essentially based on Quantum Electrodynamics and Dirac equation, is mostly special relativistic in nature, and it only explains the weak field phenomena (because of its linearity). And if one wishes to extend these theories to explain the physical phenomena corresponding to the strong field effects (like hadrons), then one should consider the nonlinear effects, and therefore one begins to introduce nonlinear Dirac-Hartree-Fock equation or nonlinear Klein-Gordon equation (we mentioned this approach in the preceding section).

Therefore, for instance, if one wishes to include a consistent general relativistic approach as a model of strong fields, then one should consider the general covariant generalization of Dirac equation [3]

$$\left(i\gamma^{k}(x)\,\overline{\nabla}_{k}-m\right)\psi(x)=0\,. \tag{1}$$

Where the gamma matrices are related to the 4-vector relative to General Coordinate Transformations (GCT). Then one can consider the interaction of the Dirac field with a scalar external field U which models a self-consistent quark system field (by virtue of changing $m \to m+U$) [3].

Another worth-mentioning approach in this context has been cited by Bruchholz [2], i.e. the Geilhaupt's theory which is based on some kind of Higgs field from GTR and Quantum Thermodynamics theory.

In this regards, although a book has been written discussing some aspects of the strong field (see Grib et al. [3]), actually this line of thought was recognized not so long ago, as cited in Jackson and Okun [4]: "The close mathematical relation between non-Abelian gauge fields and general relativity as connections in fiber bundles was not generally realized until much later".

Then began the plethora of gauge theories, both including or without gravitational field. The essential part of these GTR-like theories is to start with the group of General Coordinate Transformations (GCT). It is known then that the finite dimensional representations of GCT are characterized by the corresponding ones of the SL(4,R) which belongs to GL(4,R) [5]. In this regards, Ne'eman played the pioneering role in clarifying some aspects related to double covering of SL(n,R) by GL(n,R), see for instance [6]. It can also be mentioned here that spinor SL(2,C) representation of GTR has been discussed in standard textbooks on General Relativity, see for instance Wald (1983). The SL(2,C) gauge invariance of Weyl is the most well-known, although others may prefer SL(6,C), for instance Abdus Salam et al. [7].

Next we consider how in recent decades the progress of hadron physics was mostly driven by symmetries consideration.

## 3 Symmetries approach

Perhaps it is not quite an exaggeration to remark here that most subsequent developments in both elementary particle physics and also hadron physics were advanced by Yang-Mills' effort to generalize the gauge invariance [8]. And then Ne'eman and Gell-Mann also described hadrons into octets of SU(3) flavor group.

And therefore, it becomes apparent that there are numerous theories have been developed which intend to generalize further the Yang-Mills theories. We only cite a few of them as follows.

We can note here, for instance, that Yang-Mills field somehow can appear more or less quite naturally if one uses quaternion or hypercomplex numbers as basis. Therefore, it has been proved elsewhere that Yang-Mills field can be shown to appear naturally in Quaternion Space too [8].

Further generalization of Yang-Mills field has been discussed by many authors, therefore we do not wish to reiterate all of them here. Among other things, there are efforts to describe elementary particles (and hadrons) using the most generalized groups, such as E8 or E11, see for instance [9].

Nonetheless, it can be mentioned in this regards, that there are other symmetries which have been considered (beside the SL(6,C) mentioned above), for instance U(12) which has been considered by Ishida and Ishida, as generalizations of SU(6) of Sakata, Gursey et al. [10].

One can note here that Gursey's approach was essentially to extend Wigner's idea to elementary particle physics using SU(2) symmetry. Therefore one can consider that Wigner has played the pioneering role in the use of groups and symmetries in elementary particles physics, although the mathematical aspects have been presented by Weyl and others.

## 4 Composite model of hadrons

Beside the group and symmetrical approach in Standard Model, composite model of quarks and leptons appear as an equivalent approach, as this method can be traced back to Fermi-Yang in 1949, Sakata in 1956, and of course the Gell-Mann-Ne'eman [10]. Nonetheless, it is well known that at that time quark model was not favorite, compared to the geometrical-unification program, in particular for the reason that the quarks have not been observed.

With regards to quarks, Sakata has considered in 1956 three basic hadrons (proton, neutron, and alphaparticle) and three basic leptons (electron, muon, neutrino). This Nagoya School was quite influential and the Sakata model was essentially transformed into the quark model of Gell-Mann, though with more abstract interpretation. It is perhaps more interesting to remark here, that Pauling's closed-packed spheron model is also composed of three sub-particles.

The composite models include but not limited to superconductor models inspired by BCS theory and NJL (Nambu-Jona-Lasinio theory). In this context, we can note that there are hadron models as composite bosons, and other models as composite fermions. For instance, hadron models based on BCS theory are essentially composite fermions. In developing his own models of composite hadron, Nambu put forward a scheme for the theory of the strong interactions which was based on and has resemblance with the BCS theory of superconductivity, where free electrons in superconductivity becomes hypothetical fermions with small mass; and energy gap of superconductor becomes observed mass of the nucleon. And in this regards, gauge invariance of superconductivity becomes chiral invariance of the strong interaction. Nambu's theory is essentially non-relativistic.

It is interesting to remark here that although QCD is the correct theory for the strong interactions it cannot be used to compute at all energy and momentum scales. For many purposes, the original idea of Nambu-Jona-Lasinio works better.

Therefore, one may say that the most distinctive aspect between geometrization program to describe hadron models and the composite models (especially Nambu's BCS theory), is that the first approach emphasizes its theoretical correspondence to the General Relativity, metric tensors etc., while the latter emphasizes analogies between hadron physics and the strong field of superconductors [3].

In the preceding section we have mentioned another composite hadron models, for instance the nuclear string and Brightsen cluster model. The relativistic wave equation for the composite models is of course rather complicated (compared to the 1-entity model of particles) [10].

## 5 Phenomenology with Inter-Quark potential

While nowadays most physicists prefer not to rely on the phenomenology to build theories, it is itself that has has its own virtues, in particular in studying hadron physics. It is known that theories of electromagnetic fields and gravitation are mostly driven by some kind of geometrical principles. But to describe hadrons, one does not have much choices except to take a look at experiments data before begin to start theorizing, this is perhaps what Gell-Mann meant while emphasizing that physicists should sail between Scylla and Charybdis. Therefore one can observe that hadron physics are from the beginning affected by the plentitude of analogies with human senses, just to mention a few: strangeness, flavor and colour.

In other words one may say that hadron physics are more or less phenomenology-driven, and symmetries consideration comes next in order to explain the observed particles zoo.

The plethora of the aforementioned theories actually boiled down to either relativistic wave equation (Klein-Gordon) or non-relativistic wave equation, along with some kind of inter-quark potential. The standard picture of course will use the QCD linear potential, which can be derived from Maxwell equations.

But beside this QCD linear potential, there are other types of potentials which have been considered in the literature, to mention a few of them:

a. Trigononometric Rosen-Morse potential [11]

$$v_t(|z|) = -2b\cot|z| + a(a+1)^2\csc|z|, \qquad (2)$$

where $z = \frac{r}{d}$;

b. PT-Symmetric periodic potential [12];

c. An Interquark qq-potential from Yang-Mills theory has been considered in [13];

d. An alternative PT-Symmetric periodic potential has been derived from radial biquaternion Klein-Gordon equation [14]. Interestingly, we can note here that a recent report by Takahashi et al. indicates that periodic potential could explain better the cluster deuterium reaction in Pd/PdO/ZrO2 nanocomposite-samples in a joint research by Kobe University in 2008. This experiment in turn can be compared to a previous excellent result by Arata-Zhang in 2008 [15]. What is more interesting here is that their experiment also indicates a drastic mesoscopic effect of D(H) absorption by the Pd-nanocomposite-samples.

Of course, there is other type of interquark potentials which have not been mentioned here.

## 6 Concluding note

We extend a bit the preceding section by considering a number of approaches in the context of hadron theories. 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.

It can be expected that those different approaches of hadron physics will be advanced further, in particular in the context of possibility of going beyond Standard Model.

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