"Quark Confinement" and Evolution of Covariant Hadron-Classification Scheme

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The extension of Non-Relativistic Classification scheme for Composite Hadrons to Covariant one is one of the most important problem in the hadron spectroscopy. It seems us recently the Covar. Classif. scheme entering into an evolutionary stage, by taking seriously Quark-Confinement into account.

In section 1, firstly we give a brief history of our way of the extension on the kinematical framework, that is, from N.R. scheme one, $SU(2)_\sigma \otimes O(3)_L$ (aside from the flavor freedom), to Covar. scheme, $\widetilde{U}(4)_{DS,\mathfrak{m}} \otimes O(2)_{\boldsymbol{r}\perp\boldsymbol{v}}$ (the former is a tensor-space of Dirac-spinor embedded with a static spin-symmetry $SU(2)_\mathfrak{m}$, $\mathfrak{m}$ representing a new mass-reversal symmetry reflecting the physical situation of Q.C.; while the latter is a space of 2-dimensional internal spatial-vector $\boldsymbol{r}$, being orthogonal to the boost velocity $\boldsymbol{v}$, embedded in the Lorentz-space $O(3,1)_{\text{Lor.}}$). Secondly we describe a role of the chirality symmetry in Composite Hadrons, which is valid through light to heavy quark system. It is a symmetry of QCD/Standard Gauge Model, of which importance in hadron spectroscopy has been overlooked for many years.

In section 2, propertime τ quantum mechanics for multi-body confined quark system and quantization of Comp. Hadron field is developed. The similar to conventional procedures are performed, but all in Galilean inertial frame (with $\boldsymbol{v} = $ const); starting from an application of variational method to a classical action of the relevant confined system, where quarks have Pauli-type $SU(2)_\sigma$-intrinsic spin and also $SU(2)_\mathfrak{m}$-mass spin. A notable feature of the τ-Q.M. is, it is concerned only future-development : which induces application of the crossing rule for "Negative-Energy Problem". This rule is conventionally supposed ad hoc. The τ-Q.M. also induces Existence of the chiral-quark, with $J^P = (1/2)^-$ (, in addition to the normal quark with $J^P = (1/2)^+$) which is considered to be an origin of new exotics, mysterious from N.R. scheme.

In section 3, it is summarized somewhat new framework of hadron spectroscopy guided by τ-Q.M.: Especially, "Regge Trajectories", in $q\bar{q}$ meson system, are given by Mass-Squared vs. $\hat{N}(n,l)$; where $M^2 = M_0^2 + N\Omega$ ($N = 2n + l$), *Intrinsic spin of hadrons $\boldsymbol{J} = \boldsymbol{S}$ comes from only quark-spin*, and *Orbital $\boldsymbol{l}$ contributes only to N*.

In section 4, the evolved Cov. Class. scheme is applied to phenomenology of bottomonium, of which experiment obtained a great progress recently. As a result it has been shown the *several remarkable facts*, including the *seemingly-strange ones from N.R. framework, are possible to be clearly explained/interpreted*.

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1. Introduction

1.1 A Road of Non-Relativistic to Covariant Classification Scheme [2, 3, 4]

Most natural way[5, 6, 7, 8] of extension is to extend separately both of external and internal parts of the kinematical framework(, see Fig.1 in Ref. [1]; "No-Go" Theorems against Covariant Extension of Non-Relativistic Spectroscopy.). However, this way had been seen to be closed by two No-Go theorems.[9] The external one by the rigorous mathematical one; while the internal one as result of detailed investigation by Yukawa-School researchers.[10] The origin of internal No-Go theorem is considered to come from the close connection between the C.M. coordinate X_μ and the internal coordinate r_μ, as is seen from an ad hoc subsidiary "relative-time frozen" condition. Then we have chosen a semi-phenomenological means of pass-through(, see Fig. 2 in Ref.[1]; Phenomenological Means of Pass-Through Difficulties.). Concerning the intrinsic quark-spin, *a new freedom of SU(2)-mass spin* is supposed in addition to the $SU(2)$-σ spin, which makes possible to apply the crossing rule to confined quarks, in conformity with *color-singlet condition of parent hadrons*; while concerning the undesirable connection of internal r_μ to C.M. X_μ, it is separated by supposing r_μ to be space-like and $\boldsymbol{r}$ to be *orthogonal* [1] to the boost velocity $\boldsymbol{v}$.

1.2 Chirality: Overlooked Symmetry in Hadron Spectroscopy

Chirality is(, see Fig. 3 in Ref. [1]; Chirality Conservation in Standard Gauge Model, and Mass Reversal of Constituent Quarks.), an important symmetry conserved through all gauge-interaction with each-flavored quarks. This property of chirality seems us that it deserves to be an attribute of, somewhat *elementary entity,* Composite Hadrons, consisting of *confined quarks*.

Here (Fig. 3 in Ref. [1]) it may be worth to point out the two side-role of Dirac-spinor in the covariant classification $\widetilde{U}(4)_{DS,\mathrm{m}}$-scheme: the one, as urciton spinors, which concerns the chirality[11] structure $\chi^{(i)}(\pm)$'s of parent hadrons, while the other, as constituent-quark spinors concerns the mass-reversal[12] [2] structure $r^{(i)}(\pm)$'s of parent hadrons.

Further (Fig. 4 in Ref. [1]; New Attribute-χ·Structure of Composite Hadrons, and Two Representations of Urciton-Quark Spinor.) there are two Representations of Urciton spinors(, see Fig. 4 in Ref [1]); the B.W. Repr. with definite sign of Mass term and Chirality Repr. with definite sign of $\chi(\pm)$. The local meson wave-function $\Phi_\alpha^{(M)\beta}(X)$ is expanded by complete set of 8-Dirac Matrices, of which respective amplitudes, $\Phi^{(i)}$'s with *definite $J^{PC\chi}$* are to be 2nd-quantized, as "*elementary*" entity. [3]

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[1]This implies that constituent quarks have lost a role of carrier of *orbital angular momentum*, as $\boldsymbol{l} = \boldsymbol{r} \times \boldsymbol{p}(\boldsymbol{v}) \overset{\boldsymbol{v}=0}{=} 0$ in the observer frame ($\boldsymbol{v} = 0$). (See, section 2.2))

[2]Here it may be notable that the sign of mass, which had been meaningless for free Dirac particles, now plays an important role for *Confined Quarks*: and that Galilean Inertial Frame with definite Boost Velocity ($\boldsymbol{v} \neq \boldsymbol{0}$) for Isolated, multi-particle system seems to be well representing the physical situation of Quark Confinement. The frame with ($\boldsymbol{v} \neq \boldsymbol{0}$), to be called the Particle Frame, while the one with ($\boldsymbol{v} = \boldsymbol{0}$) is called the Observer Frame. The formulas obtained in the former (latter) becomes Lorentz invariant (covariant).

[3]It is to be noted that Urciton spinors in *B.W.* Repr. appear as spin W.F. of mixed-states of the quantized pure-states with definite χ(see, section 4.).

2. Propertime Quantum Mechanics for Multi-Body Confined-Quark System and Quantization of Composite-Hadron Fields

Before going into details, an overview for constructing a Quantum Field Theory of Composite Particle is shown in Fig. 5 of Ref. [1]; Overview Bound for Composite-Hadron Field.

2.1 Prototype Mechanics for Solitary Urciton-Quark Field

The concrete formulas, obtained from application of the plan (Fig. 5 in Ref. [1]), in the ideal case of Constituent-Quark/Urciton Field [4] is collected in Fig. 6 of Ref. [1]; Action Principle and τ-Gauge Condition, and in Fig. 7 of Ref. [1]; τ-Schrödinger Wave-Equation and Existence of *Chiralon* as *"Shadow"* of Paulon: From Fig. 6 in Ref. [1] we see that i) Einstein Formula on 4-momentum is included as Kinematics in our scheme; and ii) Mass-shell condition is deduced from the Invariance of action for τ-Gauge transformation, which reflects that the τ-scale of solitary/confined system is not observable. And from Fig. 7 in Ref. [1] we see that iii) the τ-gauge condition deduces on the one hand the $SU(2)_\mathrm{m}$-mass space with the basic vectors[5] chiralon ($J^P = \frac{1}{2}^-$) in addition to Paulon($J^P = \frac{1}{2}^+$); and on the other hand the Klein-Gordon Eq. as "Prime" one for Const. Quark Field, leading to the crossing rule[6] for Negative-Energy problem.

2.2 Prototype Mechanics for Multi-Urciton Quark Fields

The concrete formulas, result of application of the plan (Fig. 5 in Ref. [1]) in the relevant case are collected in Fig. 8 of Ref. [1]; Internal Coord., Propertime and Action Principle for Multi-Particle System and in Fig. 9 of Ref. [1]; Multi-Spectral Operator and $\widetilde{U}(4)_{DS,\mathrm{m}}$-Multiplet of Local Hadron WF: In Fig. 8 is also shown How to dissolve the undesirable connection between X_μ and r_μ, both in $O(3,1)_\mathrm{Lor.}$ (in section 1.1), making the direct product $\{X_\mu \text{ in } O(3,1)_\mathrm{Lor.}\} \otimes \{r \in O(2)_{r\perp v},$ embedded in $O(3,1)_\mathrm{Lor.}\}$. Here it may be worth to note that the choice of internal coordinate $r_\mu^{(i)}$'s with the Kinematical Constraint (which, might be queer from the conventional view of composite model,) is quite natural in the Particle F., as an inertial frame. It is remarkable that there is No *Relative-Time Problem* in our scheme.

In Fig. 9 is given, especially, (squared-)Mass Spectral Operator, which consists of independent sum of those, being respective Hooke-type oscillator on $r^{(i)}$'s; and derived an interesting formula on the relation that the constituent-quark mass is given by the average value of respective potential $\bar{U}^{(i)}(0)$. Here also is given a Prescription of How to derive the Local Hadron WF to be Second Quantized from the Non-Local Multi-Quark WF. Here it may be instructive to note that all the results given in section 2.1 are valid here (in section 2.2) as formulas concerning on C.M. coordinate X_μ. Needless to mention, this comes from the separation between X_μ and r_μ explained in Fig. 8 in Ref. [1].

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[4] Strictly this case is included as a part of General Formalism for multi Urciton-Quark system.

[5] As Elementary Entity only Paulon ($M > 0$; $\frac{1}{2}^+$) exits, while Chiralon($M < 0$; $\frac{1}{2}^-$) permitted to do, as its Shadow.

[6] The reason of this deduction originates from that the propertime mechanics is concerned only *Future development*.

3. Hadron Spectroscopy Guided by τ-Quantum Mechanics

In Fig. 10 of Ref. [1]; Physical Image for Composite-Hadron System and Eight-Trajectories of Quarkonium, is summarized Essence of Renewed Covariant Classif. Scheme. It might be notable that such as the concrete picture for Composite-Hadron becomes from the view-point of Particle F.. In connection to this we should like to point out that Urciton Quarks are c-number Simulator of Bound Quarks by Non-Pert. QCD-Force, carrying spinor-index, internal extension; and mass of quarks; and that our scheme be satisfied[13] with Cluster Property.

4. Phenomenology of Bottomonium-System in the Evolved Classification-Scheme

In Figure 11 of Ref. [1]; Experimental Features of New Observed Resonances and Its Interpretation in Evolved Classif. Scheme, in the former-half, Experimental Data[14, 15] and Properties on Two-h_b's and Two-$Z_b^{\pm}$'s are summarized with Problems -*three-experimental facts*(Exp. F-1, F-2, F-3)- to be clarified on the standpoint of conventional Non-Relativ. classification: while, in the latter-half, Identification and Theoretical Interpretation in Evolved Classif. Scheme are given. Furthermore, here is also given the extended *CPT*-theorem, to be applied for Quantized Comp. Hadrons, which becomes a theoretical basis to solve the above problems.

In Figure 12 of Ref. [1]; Chirality-Flow Chart in Respective χ-definite pair-states $\Upsilon(5S)^{(N/E)}$, we have shown the status of chirality conservation through all the relevant process in a rather concrete way. At the beginning it is to be stressed that the initial state $\Upsilon(5S)$ is produced through Electro-magnetic Process, ignorant of the chirality, and is the mixed-state of quantized definite-χ states, $\Upsilon(5S)^{(N)}$ and $\Upsilon(5S)^{(E)}$, with equal mixing-probability. Then[16] the status of χ_b conservation is described along the $\chi_b(+)$"Light"-chart and the $\chi_b(-)$"Shadow"-chart, respectively. On the basis of all above considerations the problems in the Non-Relativistic scheme seem to be dissolved in Evolved Classif. Scheme, as follows: Exp. Fact-1 and -2 on production rate are rather natural, and Exp. Fact-3 is predicted in $\widetilde{U}(4)_{DS,\text{m}}$-spin scheme. The problem on Spin-Flip Mech. disappears; since in our identification both of $\Upsilon^{(N)}(nS)$/ $(\Upsilon(nS))$ and $A^{(E)}(nS)/(h_b((1,2)P))$ is in the spin-triplet state.

5. Concluding Discussions

(Summary)

In this talk we have described essential logical basis of renewed covariant scheme of hadron-spectroscopy, developed recently, by applying propertime quantum mechanics to the multi-body confined quark system.

We have applied it to investigate the phenomenology on the bottomonium and its alike systems, of which experiment has obtained a great progress recently.

(Remarks)

The result of above application seems us to be successful, and suggesting us that the phenomenological knowledge thus far obtained, resorting on non-relativistic scheme, should be reexamined from the relativistic one seriously and vigorously!

Acknowledgement

I wish to express my deep gratitude to Prof. K. Yamada and Dr. T. Maeda for useful discussions and comments. This talk, without their kind cooperation, would not be realized. I am also grateful to Prof. T. Takamatsu, whose continual interests in Extension of Non-Relativistic to Covariant Spectroscopy, stimulating our collaboration in the σ-group.

References

[1] S. Ishida, arXiv:1401.2589 [hep-ph].

[2] S. Ishida, M. Ishida and T. Maeda, Prog. Theor. Phys. **104**, 785 (2000), S. Ishida and M. Ishida, Phys. Lett. B **539** (2002), 249.

[3] S. Ishida and σ-group members, Soryushiron Kenkyu (electronic edition) Vol. 12 (2012) No. 2.

[4] S. Ishida, K. Yamada, T. Maeda, T. Komada, K. Takamatsu, respectively in *Proceedings of the IHEP Seminar on Perspectives for Studies of Chiral Particles at BES*, KEK Proceedings 2006-8. (Editors, W. G. Li, S. Kurokawa, K. Takamatsu, K. Yamada, and T. Komada.)

[5] A. Salam, R. Delbourgo and J. Strathdee, Proc. Roy. Soc.(London) A **284** (1965), 146, B. Sakita and K. C. Wali, Phys. Rev. **139** (1965), B1355.

[6] H. Yukawa, Phys. Rev. **91** (1953), 415 and 416.

[7] S. Ishida, Prog. Theor. Phys. **46** (1971), 1570 and 1905.

[8] R. P. Feynman, M. Kislinger, and F. Ravndal, Phys. Rev. D **3** (1971), 2706, S. Ishida and K. Yamada, Phys. Rev. D **35** (1987), 265, T. Takabayasi, Nuovo Cimento **33** (1964), 668, K. Fujimura, T. Kobayashi, and M. Namiki, Prog. Theor. Phys. **43** (1970), 73, Y. S. Kim and M. E. Noz, Phys. Rev. D **8** (1973), 3521, S. Ishida, K. Takeuchi, S. Tsuruta, M. Watanabe and M. Oda, Phys. Rev. D **20** (1979), 2906.

[9] S. Colemann and J. Mandula, Phys. Rev. **159** (1967), 1251.

[10] H. Yukawa(p.2), C. Møller(p.13) and R. E. Peierls(p.24); the session Field Theory A Non-Local Theory in Proceedings of International Conf. of Theoretical Physics, Kyoto & Tokyo Sept.(1953).

[11] S. Watanabe, Phys. Rev. **106** (1957), 1306.

[12] J. J. Sakurai, Nuovo Cimento, **7** (1958), 649, J. Tiomono, Nuovo Cimento, **1** (1955), 226.

[13] A textbook on "Specific Q.M." by S. Kamefuchi and M. Omote (in Japanese), Asakura, (2003).

[14] Belle Collaboration, I. Adachi et al., Phys. Rev. Lett. **108**, 032001 (2012).

[15] Belle Collaboration, A. Bondar et al., Phys. Rev. Lett. **108**, 122001 (2012).

[16] A text book on "Basic Q. M." by S. Machida (in Japanese), Maruzen, (1990).