PROGRESS REPORT

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Theoretical Aspects of Electroweak and Other Interactions in Medium Energy Nuclear Physics – Interim Project Report

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Abstract

In the project period under review, progress has been made on the problem of dynamic symmetries exhibited by mesons as color strings. A novel property of the vibrational states of heavy mesons, that of an approximate saturation of a particular spectroscopic interval, has been found as a "fingerprint" for linear quark confinement potentials. Progress has been continued in the study of electroweak excitation of the baryon resonances, including the use of Compton scattering. Four graduate students and one undergraduate student are currently associated with this research program, the latter for the first time. A strong involvement with the Institute for Nuclear Theory (Seattle) research programs IV and V in the summer of 1991 has been exciting. An invitation to write a Physics Report article on Delta Excitation has been received and accepted. The principal investigator is a member of the International Advisory Committee for the Excited Baryon 1992 Conference, being organized by Yale University. The CEBAF association continues strongly through the N^* collaboration.

1. Introduction

The central focus of this research is to study hadron structure in a variety of ways motivated by QCD, and to continue our program of understanding electromagnetic excitations of baryon resonances, both strongly connected with the research program proposed at CEBAF and other emerging electron accelerators. Theoretical elucidation of "elementary" processes off nucleons would inspire corresponding work in complex nuclei.

Below we first give an outline of the research progress during the project year under review, April 1991 to March 1992, in Section 2. Section 3 contains a summary of progress of graduate students associated with the program. Section 4 gives a brief account of the research travel of the principal investigator. Section 5 summarizes current external collaborations. Section 6 gives other research news relevant to this grant not covered in the above items. Appendix A lists student collaborations. Appendix B itemizes institutions where the principal investigator has given invited presentations in the current academic year. Appendix C gives papers published or completed in the academic year 1991–92. Appendix D gives an example of recent CEBAF Letters of Intent, of which the principal investigator is a coauthor.

2. Research Progress

Seven major papers [1–7] have been completed or published during the year in review. These have been included in the Appendix C, either in entirety or in the abstract form. Two conference abstracts [8,9] have also been published.

(1) Property of color strings in the $q\bar{q}$ mesons and their spectrum generating algebra

One of the consequences of quantum chromodynamics (QCD) is the possible development of the color string structure [10] in hadrons. Such strings in the meson system may be described in terms of their dynamic symmetry, a subject of continuing investigation by Professor Franco Iachello (Yale), the RPI graduate student, Lie–Sheng Zhang, and the principal investigator. For the $q\bar{q}$ mesons with quarks of n flavors, we use the spectrum

generating algebra (SGA) [1,2]:

$$G = U(4) \otimes SU_s(2) \otimes SU_f(n) \otimes SU_c(3). \qquad (1)$$

where the subscripts s, f, and c stand for spin, flavor and color respectively. We show that 57 well–established mesons, appearing in the 1990 Particle Data Group meson summary table [11], can be described in the context of the above SGA, and derive suitable mass formula for these mesons. We account for the mass squared of these mesons within an average deviation of 5.7%, a level of accuracy comparable to that achieved in the best of the quark model calculations, such as those by Godfrey and Isgur [12]. We find good evidence for the dynamic symmetry $U(4) \supset SO(4)$ for the color string. Our derived mass formula allows us to recognize meson states that are unlikely to be $q\bar{q}$ type, such as $a_o(980)$ in the π–family, a characteristic which can be cross–checked by the study of their decay properties. These are thus good candidates for quark molecules, of the structural type $q\bar{q}\ q\bar{q}$.

(2) Vibrational trajectories for the heavy quarkonia

Graduate student L. Zhang, a research assistant associated with this program, and the principal investigator have studied the nature of the $q\bar{q}$ confinement potential, by examining the spectroscopic interval [3]

$$\Delta_v = M_v^2 - M_{v-1}^2 \qquad (2)$$

as a function of v, the vibrational quantum number of the states $vS(v \geq 0)$ of the heavy quarkonia, M_i being the mass of the meson state i. After initial bending, the quantity Δ_v approximately saturates only in the case of linear confinement, thus providing a spectral "fingerprint" for the quark confinement potential, in a manner analogous to the 't Hooft phenomenon in the 1+1 dimensional relativistic field theory [13] of mesons.

(3) Effective Lagrangian approach to the theory of pion photoproduction in the $\Delta(1232)$ region

Former graduate students Dr. R.M. Davidson and Dr. R. Wittman, now from University of Mainz (Germany), and Westinghouse Lab respectively, and the principal investigator have studied the pion photoproduction in the $\Delta(1232)$ region with a view to examine sensitivity of extraction of the resonant M1 and E2 amplitudes to the assumptions needed in this theoretical approach. The ratio EMR of E2 to M1 nucleon to delta amplitudes is extracted to be [4]

$$\text{EMR}\ (N \rightarrow \Delta) = (-1.57 \pm 0.72)\%, \qquad (3)$$

in comfortable agreement with the value of (−1.07 ± 0.37) %, obtained from a model–independent approach [14]. Extracted M1 and E2 resonant amplitudes show sizable deviations from the best quark model estimates of Isgur and Karl and their collaborators [15], posing an outstanding theoretical problem for the quark model.

(4) Effective Lagrangian approach to the theory of eta photoproduction in the $S_{11}(1535)$ region

Graduate student M. Benmerrouche, a research assistant with this research program, and the principal investigator have been studying the reaction $\gamma+p \rightarrow p+\eta$, which presents interesting similarities and differences, when compared with the reaction [16] $\gamma+p \rightarrow p+\pi^\circ$, from their respective threshold through the resonance region. In the contrast to the latter, both pseudoscalar and pseudovector meson–nucleon couplings can be accommodated in the former case; also, even at threshold, the former is dominated by the resonance excitation. We find that a parameter [5] characteristic of the resonance excitation and decay can be extracted from the existing data in a model–independent fashion. This is:

$$(\chi\,\Gamma_\eta)^{1/2}\,A_{1/2}\,/\,\Gamma_T = (0.22 \pm 0.02) \times 10^{-3}\ \mathrm{MeV}^{-1}. \qquad (4)$$

where χ is a kinematic parameter, Γ_η, Γ_T are the eta channel and total widths of the decay of $S_{11}(1535)$ resonance, and $A_{1/2}$ is the nucleon to $S_{11}(1535)$ electromagnetic excitation amplitude. With standard values for χ, Γ_η and Γ_T, this yields

$$A_{1/2} = (95 \pm 11) \times 10^{-3}\ \mathrm{GeV}^{-1/2}, \qquad (5)$$

which is in fair agreement with the pion photoproduction data [11], but in disagreement with the non–relativistic quark models [17]. In our present analysis, we also explore the implications of the recently obtained Bates data [18] on the photoproduction of eta mesons.

(5) Compton scattering in the $\Delta(1232)$ region

For the last fifteen years, a long–standing problem in the theory of Compton scattering of protons in the $\Delta(1232)$ region has been the apparent violation of the unitary lower bound for differential cross–section in the experiment by the Bonn group [19] for lab photon energy $E_\gamma = 320$ MeV and the cm scattering angle of 90°. The graduate assistant M. Benmerrouche and the principal investigator have examined this with a careful redoing of the order analysis, and a new approach of using the newer multipole data sets of Grushin et al. [20]. The latter have the unique advantage of not implicitly ignoring the Compton phase in the extraction of the real and imaginary parts of the pion photoproduction multipole amplitudes, as they extract them separately. The result of our analysis [6] is that no significant discrepancy between the theoretical bound and the experiment is found once the bound is derived using the newer multipole data set. We explore the opportunity of learning from future high–precision experiments, using photon polarization as a tool, the resonant M1 and E2 amplitudes in the nucleon to $\Delta(1232)$ transition. Also, the use of optical theorem allows us to aim for higher accuracies of magnetic Compton amplitude from the photohadron experiments. Our study poses useful experimental questions for new

or improved photon facilities such as Brookhaven LEGS.

(6) Perturbative QCD signatures for hybrid hadrons

Perturbative QCD provides a powerful calculus of hadron properties at high Q^2. One of the interesting questions in hadron structure is the possible existence of hybrid hadrons which contains valence gluons. Li et al. [21] have recently reopened the question as to whether the Roper resonance N(1440) is such a structure. Prof. Carl E. Carlson (College of William and Mary/CEBAF) and the principal investigator have taken advantage of their mutual overlap at the Institute for Nuclear Theory (INT), Seattle, in the last summer, and have begun an inverstigation on the general question of the perturbative QCD signatures of the hybrid hadrons. They have shown [7] that the hybrid baryons have a specific signature for deep inelastic electron scattering in that the resonance peak to background ratio is small for transverse structure function, but this ratio is of normal size for the longitudinal one. They have found a useful rule that a delta–like Roper is a hybrid, barring a wave function accident. This may be tested at CEBAF, though we do not know if the momentum transfer at CEBAF would be high enough to reach the perturbative domain of QCD.

3. Progress of students associated with the program

There are four graduate students currently associated with the program (Appendix A). Two of them, M. Benmerrouche and L. Zhang, are supported full time, the others enjoying teaching assistantships of the RPI Physics Department. One of them, M. Benmerrouche, will get his Ph.D. degree in the next academic year. For the first time in the history of this program, we have an undergraduate working with our program.

4. Outside travel by the principal investigator

A list of institutions hosting seminars and colloquia given by the principal investigator in the current research year is given in Appendix B. Main research travel this year, apart from attending American Physical Society meetings, has been to the Institute of Nuclear Theory (INT), Seattle. The principal investigator has been a Visiting Fellow at

the INT during Program IV from May to June '91, and again during Program V between July and August '91. During these programs, he has focused on the research on Compton scattering in the $\Delta(1232)$ region, and has collaborated with Professor C.E. Carlson on the perturbed QCD signal for hybrid baryons. Two papers from these efforts have already been completed – one [7] is due to appear in the Phys. Rev. Lett., and the other [6] has been submitted to the Phys. Rev. D. Graduate student L. Zhang has also spent the summer semester doing research at the INT as a Visiting Student Fellow.

Due to his strong commitment to the programs at INT, Seattle, the principal investigator has postponed his planned European visits to the next academic year. Only outside trip takes has been to TRIUMF, Vancouver, B.C. (Canada), for a sojourn of seminar and research consultations.

5. Current external collaborations

Collaboration with Professor F. Iachello (Yale) is continuing on the hadron structure and dynamic symmetry approach. There is also an on–going research collaboration with Professor C.E. Carlson (William and Mary) on perturbative QCD, and with Dr. P. Herczeg (LANL) on the possible T–violation in nuclear physics. Collaborative discussions are underway with Dr. Z. Li (Tennessee) on the problem with current conservation in quark models. A special note: Three former graduates of this program are currently maintaining research associations with this program from their respective postdoctoral positions. They are: Dr. R.M. Davidson (University of Mainz, Germany), Dr. B. Doyle (University of Montreal, Canada), and Dr. R. Wittman (Westinghouse Lab, S.C.). Their continuing interests are in the areas of excited baryons. Dr. Doyle is providing an important link with Prof. B.G. Goulard (Montreal, Canada) in the expertise on light nuclear structure.

6. Other research news

The principal investigator has been invited to be one of the International Advisors to the planned conference Excited Baryons, 1992, being organized at Yale University. He has also been asked by Professor G.E. Brown (SUNY, Stony Brook) to write a review on the $\Delta(1232)$ electroexcitation for the journal, Physics Reports. He has agreed to undertake this. The Institute of Nuclear Theory, Seattle, has invited the principal investigator to return as a Visiting Fellow in its Program VII on Symmetry. The collaboration with the Excited Baryon Group at CEBAF is continuing (Appendix D).

7. References cited

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[16] See, for example, R. Davidson and N.C. Mukhopadhyay, Phys. Rev. Lett. 60, 748 (1988); R. Beck et al., ibid. 65, 1841 (1990).

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Appendix A: Student collaborators with the program 1991–92

* M. Benmerrouche, Graduate Student

* L. Zhang, Graduate Student

† R. Dasgupta, Graduate Student

† K.C. Yeong, Graduate Student

†† E. Saperstein, Undergraduate student

* Research assistants supported by this grant, 1991–92.

† Supported by RPI Physics Department. Waiting for the DOE Grant support.

†† Independent support

Appendix B: Principal Investigator's host institutions for invited seminars, colloquia etc. in 1991–92 dealing with reports on projects under the current DOE Grant.

(1) Institute for Nuclear Theory, Seattle, WA; Program IV.

(2) Institute for Nuclear Theory, Seattle, WA; Program V.

(3) Theory Group, TRIUMF, Vancouver, B.C. Canada.

(4) Physics Colloquium, SUNY, Albany, NY.

(5) Physics Colloquium, Union College, Schenectady, NY.

(6) Physics Colloquium, RPI, Troy, NY.

(7) Theoretical Physics Seminar, Tata Institute of Fundamental Res., Bombay, India (scheduled, Jan. 1992).

Appendix C: Papers, conference contributions by the principal investigator, his students and collaborators completed/published in 1991, under the current program.

Seven journal articles [1–7] listed in the Reference Cited section: two conference abstracts [8,9] cited in the Ref. section.

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