THEORETICAL NUCLEAR PHYSICS

PROGRESS REPORT

FOR THE PERIOD

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MASTER

Abstract

This report summarizes progress during the past year in the following areas of research:

Pion double charge exchange and the role of meson exchange currents, including vector mesons, deltas, and nuclear correlations.

K^+ -nucleus scattering and the role of meson exchange currents in supplying "missing cross section".

Pion excess distributions in nuclei, and the role of nuclear correlations.

Interactions of two hyperons and the possibility of an H dibaryon.

Shell model spectra and the NN tensor interaction.

Statistical nuclear spectroscopy, including state densities and expectation values evaluated in terms of one-point and two-point (correlation) functions.

1. Scope of Intended Future Research Work

Much of the research reported below is likely to continue in 1993. We expect to complete an account of vector meson exchange in pion DCX. The new results for the study of K^+ -nucleus scattering will be completed, and the research continued as seems appropriate. The new study of pion excess distributions will be extended to explore the importance of nuclear correlations. We expect to obtain results for the H dibaryon project.

We intend to initiate new studies of the nuclear response function and sum rules for inelastic scattering.

Our plans for the future include a survey of experimental and theoretical state densities over the periodic table and a study of isospin structures. We shall turn also to the development of a compact formalism (and programs) for the nuclear two-point correlation function, replacing the very complicated formalism which we have already used for studying time-reversal invariance. With that we plan to study transition strengths, broken symmetries (in particular isospin and parity) and perhaps also the goodness of various nuclear models.

2. Pion Double Charge Exchange and Meson Exchange Currents

Pion double charge exchange (DCX) remains one of the nuclear reactions rather special to pion physics. Because of the unique selectivity imposed by the change of two charge units, it has been a natural reaction for the study of the interactions of two nucleons (or more) in a nucleus, – including correlations, meson exchange currents, and even pion absorption. Considerable recent experimental data has been produced in recent years, particularly at LAMPF. The theoretical program has been to produce a well-defined analysis which includes all important components of the reaction. The problem has been that these components each involve departures from well established theoretical tools, such as optical potentials.

For the last several years we have concentrated on the theory of the meson exchange current (MEC) contribution to DCX, which can be thought of as the scattering of a beam of pions by the virtual pions in the nuclear target (with charge exchange: $\pi^+\pi^- \rightarrow \pi^-\pi^+$). A few years ago, there was considerable uncertainty as to how large such effects could be. Our initial results for low energy DCX were discussed in the last two annual Progress Reports: basically we have established that MEC contributions at low energies are smaller than those of conventional multiple scattering (on nucleons). We were able to establish that the degree of smallness is controlled largely by chiral symmetry (and its breaking) in nuclei.

Progress during the year has been:

A somewhat expanded version of an earlier short paper on the chiral symmetry aspects of low energy DCX was completed, and has been published in Physics Letters.

An invited talk on this subject was presented at the International Workshop on Pions in Nuclei at Peniscola, Spain, in June 1991. A written version has also been published in the Proceedings.

We have continued our study of the role of vector mesons in DCX using a theory of Wess and Zumino, described in last year's Report. This provides a method of including ρ

and a_1 meson exchange in DCX, consistent with the constraints of chiral symmetry. Some results were given last year; we have also found the following:

(1) For $\pi\pi$ and πN systems at low energy, the Wess-Zumino model is completely equivalent to the well-known Olsson-Turner effective Lagrangian model with a special choice of the chiral symmetry breaking parameters. This guarantees that the Wess-Zumino model will reproduce the empirical data fit by the Olsson-Turner model. (2) The earlier estimate of heavy meson exchange current contributions to pion DCX (see Publication #1) has been carried out explicitly for this theory by calculating the ratio of isotensor/isovector (β_2/β_1) for $\pi\rho$ and πa_1 scattering respectively. The result confirms our previous observation that the heavy meson contribution is considerably smaller than that of pion exchange. A written account of this research is in preparation.

We have attempted to extend the theory to include excitations of Δ 's, since these may be of some importance for DCX reactions at energies of 75-250 MeV. An example of this is the 'DINT' mechanism ($\equiv$ Delta interaction), which from the MEC point of view, is only one of several competing terms which must be treated consistently.

Very recently we have initiated an investigation of the role of two-nucleon correlations on the MEC contribution to DCX. This is really an outgrowth of other work on K^+ -nucleus scattering, described in the next section. In that case, two-nucleon correlations generated by the tensor potential are extremely important to determining the MEC amplitudes, even up to the overall sign. The effect of tensor correlations is not expected to be as large in the DCX case, since the nucleon pairs have $T = 1$, and the tensor potential affects the odd- ℓ partial waves only. In any case, we believe it is important to settle this question.

3. K^+ -Nucleus Scattering

There has been considerable interest recently in a series of K^+ -nucleus scattering experiments at Brookhaven which have raised the possibility of anomalous behavior. The effect of interest is that experimental cross sections – most recently total cross sections –

for K^+ on ^{12}C , are larger than can be explained by optical potentials based on known K^+N amplitudes. The deviations are of order of 10% – the uncertainties in the optical theory are of similar size, but tend to be in the wrong direction to improve agreement. This difference has led to speculation in the literature about exotic effects on K^+N scattering in a nuclear target – and to more experiments.

Because of our interest in MEC effects in pion-nucleus scattering (DCX: see previous section), we felt it important to examine the importance of MEC effects in the K^+ -nucleus case – this means K^+ scattering on virtual pions exchanged in the nuclear target. Over the past year we have developed a theoretical model for this process, and have calculated the contribution of MEC to K^+C cross sections. For the total cross sections, this contribution is positive, and grows with K^+ momentum from a threshold at about 400 MeV/c. Within the range of the experiments ($p_K \sim 500 - 800$ MeV/c), MEC correction is about 5-7%, of the right magnitude and sign to improve agreement between experimental data and optical model results.

The theory requires two parts: an off-shell model of $K^+\pi$ scattering for virtual pions, and a good theory of the meson exchange current in an isoscalar nucleus (e.g. ^{12}C). The first we have worked out, partly following the theory of $\pi\pi$ scattering we used for DCX, but also including the contribution of the $K^*(892)$ resonance, which is effective in the kinematic region of interest. For the second, we followed theoretical work of Pandharipande, Wiringa, and others, who were interested originally in calculating the “pion excess” in nuclei, in connection with possible pionic contributions to the ‘EMC effect’ in deep inelastic scattering. The main point here is the rather large effect of the nuclear tensor potential on the magnitude and sign of the “pion excess” – and therefore on any isoscalar MEC amplitude.

At present we are completing our theory and writing up our results for publication. We are also further investigating the importance of nuclear correlations to the MEC amplitudes – since this has an important bearing on the present work, but also on any other physics

which depends on meson exchange. We discuss this next.

4. Pion Excess Distribution in Nuclei

The pion excess distribution, mentioned in the previous section, is the momentum distribution of pions exchanged among nucleons in a nucleus – that is, in excess of the pion “cloud” carried by each nucleon. Therefore, this distribution is relevant to any physical process involving MEC: for DCX, it is an isotensor distribution; for K^+ -nucleus scattering, the distribution is isoscalar.

As mentioned in the previous sections, it has been known that realistic nuclear correlations play an important role in calculating the excess pion distributions. We have initiated a new program to calculate these distributions for both isoscalar and isotensor cases. The theoretical calculation is carried out using shell model basis functions in LS-coupling with the inclusion of realistic two-body correlations. The advantage of this approach is that the calculation can be done in principle for all closed-shell nuclei and can serve as a qualitative check of the very few previously published results. The effects of various correlations – central and tensor, isoscalar and isovector – on the various distributions can be separated and studied individually. We would expect to obtain similar results to those published (by Wiringa and others) for the isoscalar excess pion distribution. We shall also check the effect of correlations for isotensor MEC amplitudes – as in DCX – although the effects are expected to be less dramatic than for isoscalar.

5. Λ Dibaryon and Two-Hyperon Bound States

Some progress has been made on this research project which was initiated last year, and discussed in the last Progress Report. Following the analogous method of formulating the Bonn potential, we have derived both the interactions and the transition potentials for the system ($\Lambda\Lambda, N\Xi, \Sigma\Sigma$). A computer code has been set up to calculate their partial-wave matrix elements. In order to study the uncertainties in the derived interactions, we have also considered corresponding potentials given by Nijmegen group and Virginia

group. A large difference among these potentials has been found, which may represent the status of our limited knowledge of this system. Our next step will be to apply these potentials in the R-matrix version to solve the coupled-channel problem for the interacting ($\Lambda\Lambda + \Sigma\Sigma + N\Xi$) system, to obtain the phase shifts and the mixing parameters. The approach is essentially the same as that of solving a coupled NN scattering problem with the tensor force, except that we now have more than two coupled channels. Besides our main interest in the possibility bound two-baryon system, we are also interested to learn in what way the coupling among these three channels has any effect on the binding of the system.

6. Nuclear Structure Calculations and NN Tensor Interactions

As a result of the continuing collaboration with T.T.S. Kuo at Stony Brook and R. Machleidt of University of Idaho, we have further applied our sd-shell effective interaction, derived from the Bonn potential, to calculate spectra for some sd-shell nuclei. Except for those levels identified as intruder states, our calculated spectra are greatly improved as compared with previous ones using other realistic NN potentials. This indicates clearly that the evidence from finite nuclei favors a weaker tensor NN interaction, as is consistent with the observations in NN scattering and infinite nuclear matter. This work has been combined with our early studies, and included in a revised version of an earlier submitted paper, soon to appear in Physical Review C.

7. Statistical Nuclear Spectroscopy

There are two generic laws which dominate the modern theory of statistical spectroscopy and, except in the immediate ground-state domain (which extends, say, to 1.5 MeV excitation in heavy nuclei), determine the nuclear properties, spectra, transition strengths, etc. In fact the results for expectation values and other quantities with a polynomial, rather than exponential, energy dependence commonly extend right to the ground state. The two laws are that, in shell-model spaces which may be of indefinitely large di-

mensionality, the smoothed state densities are closely determined by central limit theorems (CLT's) while the spectral fluctuations (from which fluctuations in other quantities may be deduced) are those of the Gaussian Orthogonal Ensemble (GOE). Expressed differently these two propositions are that almost everything is determined by a one-point function which follows from CLT's and a two point function which is that of a chaotic system with a time-reversal-invariant Hamiltonian. Since higher-order correlation functions play essentially no part it follows that statistical methods are remarkably more "economical" than shell-model methods which they supplement and often replace.

These two propositions work together, the second giving rise (among other things) to the results, well established numerically, that the spreading variances of basis states in exact-symmetry subspaces are closely identical in almost all representations. This leads directly to a remarkable result, also well-established numerically, namely that the interacting-particle state densities for given exact symmetries are a convolution product of three factors, the noninteracting-particle density, a back-shifting function and a spreading function, all of which are exhibited and easily calculated as explicit functions of the Hamiltonian and model-space parameters. An extended result of the same nature, whose compact form, we have not yet given (but which we have used (Ann. Phys. N.Y., 181, 198, 235 (1988)) in calculating bounds on time-reversal symmetry breaking) will emerge for more complicated problems.

By the end of last summer three papers ("Elementary Principles and Applications", "State Densities and Smoothed Partition Functions" and "Expectation Values") had been written but publication was delayed until a large set of computer programs could be tested and documented. These programs, and a fourth paper about them, have now been completed; they are designed to make calculations feasible by a person familiar with the first paper above. The first three papers will be sent next month for publication, while the fourth paper will be made available as a report.

8. Personnel

The work here includes, besides that of the principal investigators, research carried out by Research Associate M.F. Jiang and by visitors V.K.B. Kota and R.U. Haq.

Dr. V.K.B. Kota of the Physical Research Laboratory, Ahmedabad, India, and Dr. R.U. Haq of Laurentian University, Ontario, Canada, are involved in an ongoing collaborative research activity in statistical nuclear spectroscopy. Dr. Haq has made a brief visit to Rochester during the year. Both scientists are now visiting for a two-month period for research and joint writing projects during summer 1992.

On July 1, 1992, Professor J. B. French becomes Professor Emeritus at the University of Rochester. His research activity in theoretical nuclear physics continues, as described in this Report, and he will continue to be listed under Senior Personnel for this grant. However, for administrative purposes, he will not be listed as coprincipal investigator.

Dr. Ming-Fang Jiang has been a Research Associate in the group since September 1989. His appointment will end in 1992.

Dr. Thomas Ferreé, now at the University of Colorado, will join the group as Research Associate in September 1992.

Mr. Osman Turgut is a research student in the group for summer 1992.

9. Publications and Reports (July 1991 to June 1992)

1. D.S. Koltun and M.F. Jiang

Soft Pion Theorems, Meson Exchange Currents, and Pion
Double Charge Exchange
Physics Letters **B273**, 6 (1991)

[This is a revised, enlarged version of UR Technical Report ER-40425-252, listed in the previous Report.]

2. D.S. Koltun

Exchange Currents in DCX and the Role of Chiral Symmetry
in Pions and Nucleons, eds. E. Oset, M.J. Vicente Vacas, and C. Garcia Recio (World Scientific, Singapore, 1992) ; Proceedings of the International Workshop on Pions and Nuclei, Peniscola (Spain) 3-8 June 1991.

3. M.F. Jiang, R. Machleidt, D. B. Stout and T.T.S. Kuo
Bonn Potential and sd-shell Nuclei
Phys. Rev. C, to be published.
[This is a revised, enlarged version of a paper listed in the previous Report.]
4. J. Heyer, L.L. Kiang, M.F. Jiang and T.T.S. Kuo
Ring-Diagram Calculations of Normal and Spin-Polarized ${}^3\text{He}$ Using the Aziz Interactions
J. Low Temp. Phys. **82**, 89 (1991)
[This paper, listed in the previous Report, has since been published.]

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