MEDIUM-ENERGY THEORY GROUP

PROGRESS REPORT

for

DOE Contract No. EY-76-S-05-5223

July 1, 1978 - June 30, 1979

entitled

"Intermediate-Energy Nuclear Theory"

submitted by the

TEXAS A&M RESEARCH FOUNDATION

to the

U. S. DEPARTMENT OF ENERGY

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and

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MASTER

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Abstract

We report on research carried out during the contract period by R. A. Bryan, principal investigator, and associates R. B. Clark and B. J. VerWest. The research has centered on the nucleon-nucleon interaction from threshold up through intermediate energies ($T_L \leq 1$ GeV). A major protion of our time has been devoted to the inelastic channel $NN \to NN\pi$ and has resulted in a peripheral model for this reaction which gives good fits to the world data around 800 MeV. The present status of elastic NN scattering above the π-production threshold has been reviewed extensively, new parameterizations have been developed and data bases assembled for analyses of this process. The three point πNN vertex has been studied in the context of the Dual Veneziano Model where all three particles can be taken off shell. It has been shown that this form of off-shell dependence in NN interaction models, hereto ignored, can have important consequences. Finally, initial work has been completed in an attempt to use the Constituent Interchange Quark Model to constrain the short range behavior of the meson-exchange models of the NN interaction.

In the past year much effort has gone into the investigation of the NN interaction at intermediate energies. We have continued our two-fold attack on this problem comprised of phase-shift analysis of the data to obtain the on-shell amplitudes and theoretical investigation of the dynamics of the NN interaction.

We have worked on analyses of both elastic NN scattering and the inelastic reaction NN → NNπ. We have developed a new parameterization for the inelastic channel effects in NN elastic scattering which has a simple connection to the partial wave inelastic cross sections. We have also reviewed extensively the existing NN analyses and begun assembling the data base for new single-energy analyses of np scattering above the pion production threshold. We have used our field-theoretical peripheral model for the reaction NN → NNπ to correlate the world data for this reaction near 800 MeV, and have pointed out inconsistancies in the experiments and helped to plan new experiments.

Our theoretical work has involved the development of the peripheral model for NN → NNπ and several projects aimed at details of the NN interaction. Our field-theoretical peripheral model for NN → NNπ has been very successful in describing the data and is helping to separate the known parts of this interaction from the unknown for further study. We have investigated the form of the NNπ vertex for all three particles off-shell and used the results in an NN phase-shift calculation. The effect of this form of off-shell dependence turns out to be important in lower partial waves and will be included in future models. We have begun work to extract the short-range form of the NN interaction from the constituent-interchange quark model.

In April, 1978 we hosted an informal two-day conference on Nucleon-nucleon theory. About thirty people attended from all over the United States and Canada to discuss the present theoretical status of the NN, $N\bar{N}$, and πN interactions. All who attended felt this was a very fruitful meeting with a great deal of interaction between the participants. A copy of the program is included at the end of this report.

NN Phase-Shift Analysis (R.A. Bryan, R.B. Clark, J. Gruben and B.J. VerWest)

We have continued our program of analyzing NN data at troublesome energies. In particular, we have studied this effect on the 325 MeV phase shifts of new np $d\sigma/d\Omega$ data taken at LAMPF by Bonner et al. These data are consistent with the best solution, and disagree with the De Pangher $d\sigma/d\Omega$ data.

We have begun analysis of NN data above the pion-production threshold, and have derived a new parameterization of the scattering matrix by modelling it after a field-theoretical coupled-channel problem, NN → NN or NN', where NN' is a (dummy) inelastic channel. The parameterization leads to simple expressions for the total elastic and inelastic cross sections, i.e.

$$\sigma_{inel} = \frac{\pi}{p^2} \sum_{j=0}^{\infty} \left[\sin^2 2\rho_j + \sin^2 2\rho_{jj} + \left(1 - \cos 4\alpha_j \cos 4\beta_j \cos 4\gamma_j \right) \right]$$

where ρ_j and ρ_{jj} (α_j, β_j, and γ_j) are a measure of inelasticity in the uncoupled (coupled) NN channels. (This work will shortly be submitted for publication.)

We have also carried out an extensive survey of NN phase shift analysis over the entire 0 - 800 MeV range.[1] This includes analyses by Arndt & Roper, Hoshizaki, Bugg and our own group. Significantly, there is no agreement on the resonance in the $^3F_3$ state near 700 MeV reported by Hoshizaki. Additional data and analysis are indicated. An intriguing possibility of a resonance in the (np) $^1P_1$ state is suggested by Bugg's

analyses. The one clear conclusion is that a major influx of new np data above 550 MeV is required for a determination of the scattering matrix.

NN π-Production (B.J. VerWest)

Work has continued on a long-term project to study the dynamics of the reaction NN → NNπ. A field-theoretical peripheral model involving π- and ρ-meson exchanges and N - and Δ-intermediate states has been developed which gives a very good fit to the existing data around 800 MeV.[5] A survey of all existing NN → NNπ data has been made and has resulted in the detection of several errors and possible problems in the experimental analyses of the raw data. The model was also used to study the feasibility of and the information available in polarization transfer experiments for $\vec{p}p → \vec{n}X$. The indications are that from these experiments plus existing cross section measurements, one can learn about the details of the pion form factor and the amount of ρ-exchange in this reaction.[2] Such an experiment (#402 at LAMPF) has now been approved for beam time. The preliminary work for partial-wave projecting this peripheral model has been completed so that the programming can now begin for the extraction of the higher partial wave amplitudes for use in NN elastic phase shift analyses, and in studies into the consequences of unitarity in this process.

General Three-Point Vertex Functions for the NNπ Vertex in the NN Scattering Problem (C. Dominquez, R. Bryan and B. VerWest)

In analogy with the Dual Veneziano Model, one can write down the

form for a three point vertex when all three particles are off-shell.
In NN calculations using single-particle exchange diagrams in the
Blankenbecler-Sugar Equation no one had ever previously considered the
effect of the nucleons' being off-shell at the vertices besides the pion.
We have done such a calculation using these general three-point functions
and have shown that this effect is important, and in fact may be the
answer to some long standing problems with the particle-exchange models.[8]
The importance of the off-shell effects in this context also casts some
doubts on the off-shell treatment of the 2π-exchange potentials obtained
from dispersion theory. For a complete $\pi + 2\pi + \omega$-exchange model of the
NN interaction one must now use some off-shell form for the vertex
function and carefully redo the 2π-exchange calculation with special
attention to the vertices in the off-shell forms of the box and crossed
box diagrams.

Constituent Interchange Model Calculations for the Short Range Force in
the NN Interaction (R.B. Clark and R.A. Bryan)

The Constituent Interchange Quark Model (CIM) is expected to give the
form of the NN interaction at large momentum transfer which corresponds
to very short range. The dominant contribution in this model has been
calculated in the infinite-momentum frame using forms for the vertex
couplings taken from successful calculations of form factors using this
model. The asymptotic power behavior for the NN interaction can easily
be obtained from the quark model, but more specific CIM predictions for
the lowest NN-partial waves now await the projection of these amplitudes

onto the standard kinematic singularity-free invariant amplitudes for the NN interaction.

The principal investigator, R. A. Bryan, Professor, and the other investigators, R. B. Clark, Associate Professor, and B. J. VerWest, Assistant Professor, all of the Physics Department of Texas A&M University, have each spent about 50% of their time during the nine-month academic year on this contract. Full time is spent during the summer months as indicated in the budget.

Publications During Contract Period
(July 1, 1978 thru June 30, 1979)

Papers submitted to conferences during contract period:

1. "Nucleon-nucleon scattering phase shifts"; Ronald Bryan (ORO-5223-12), invited talk presented at the Eighth International Conference on Few Body Systems and Nuclear Forces, published in Lecture Notes in Physics, Vol 87, Few Body Systems and Nuclear Forces II, ed. H. Zingl, M. Haftel and H. Zankel, Springer-Verlag, 1978, pp. 2-20.

2. "Angular Dependence of $NN \rightarrow NN\pi$ Cross Sections and the Pion Form Factor"; B. VerWest (ORO-5223-14), contributed paper at Second International Conference on Meson-Nuclear Physics, Houston, Texas (March, 1979), proceedings in press.

Papers published in journals during contract period:

*3. "Unique Isospin-Zero Phase-Shift Solution for Nucleon-Nucleon Scattering"; R. Bryan, R. B. Clark and B. VerWest (ORO-5223-08), Physics Letters 74B, 321 (1978).

*4. "Effect of Recent Neutron-Proton D-transfer Measurements on Phase-Shift Analysis Near 325 MeV"; R. Bryan, R. B. Clark and B. VerWest (ORO-5223-09), Physical Review C18, 371 (1978).

Papers prepared for publication during contract period:

5. "Field Theoretical Calculation of NN Pion Production"; B. VerWest (ORO-5223-13), Physics Letters B (in Press).

* Reported in progress report for previous year.

6. "Microscopic Models of Pseudophysical $N\bar{N} \to \pi\pi$ Amplitudes"; J. W. Durso, A. D. Jackson and B. J. VerWest (ORO-5223-15), submitted for publication to Nuclear Physics A.

7. "Time-Reversal Noninvariance in Nucleon-Nucleon Scattering I. General Formalism and Zero-Range Parameterization"; J. Binstock, R. A. Bryan and A. Gersten (ORO-5223-03, revised) submitted for publication to Annals of Physics.

8. "A Model For Off-Shell Form Factors and Application to NN Scattering"; R. A. Bryan, C. A. Dominquez and B. J. VerWest (ORO-5223-16), submitted for publication to Physical Review C.

FOURTH TRIENNIAL CONFERENCE ON NUCLEON-NUCLEON THEORY

Organized by the Particle and Nuclear Theory Group
Department of Physics, Texas A&M University

All meetings take place on the Texas A&M University campus in Room 501,
RUDDER TOWER (see map for location). TRANSPORTATION FROM AGGIELAND INN
WILL BE PROVIDED FRIDAY AND SATURDAY MORNINGS. BE OUT FRONT AT 8:30 a.m.

Friday, April 21, 1978

9:00-10 a.m. Jackson (Stony Brook)
The Nucleon-Nucleon Program at Stony Brook

10:00-10:15 COFFEE

10:15-10:45 Bryan (Texas A&M)
Nucleon-Nucleon Phase Shift Analysis

10:45-11:00 COFFEE

11:00-12:00 Durso (Mt. Holyoke)
Effect of $\rho\pi$ Exchange in the NN Interaction

12:00-1:00 LUNCH - Rudder Tower

1:00- 1:30 VerWest (Texas A&M)
Single-Meson-Exchange in NN Pion-Production

1:30- 2:30 Ernst (Texas A&M)
Extended Chew-Low Model for πN Scattering

2:30- 2:45 COFFEE

2:45- 3:45 Kloet (Rutgers)
Dynamics of NN Scattering at Medium Energies

3:45- 4:00 COFFEE

4:00- 5:00 Lomon (M.I.T.)
Coupled Channels and NN Resonances

5:30- 8:30 DINNER - Beef barbeque and swim at Bee Creek Park, College Station
9:00-11:00 ENTERTAINMENT - Country music at Sons of Hermann Hall,
1104 W. 25th Street, Bryan

Saturday, April 22

9:00-10 a.m. Dover (Brookhaven)
The Nucleon-Antinucleon Interaction and the Nuclear
Force Problem

10:00-10:15 COFFEE

10:15-11:15 Brodsky (SLAC)
Quark Dynamics and the NN System

11:15-11:30 COFFEE

11:30-12:30 DeTar (M.I.T.)
The Two-Nucleon Interaction at Short Range

LUNCH