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PION INTERACTIONS AT MEDIUM ENERGIES

PROGRESS REPORT

OCTOBER 1980

FOR THE CONTRACT YEAR

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MASTER

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ABSTRACT

This report covers the intermediate energy research program at the University of Houston during the contract year December 1, 1979 to November 30, 1980. During this time experiments were proposed and implemented at the Los Alamos Scientific Laboratory and the Brookhaven National Laboratory. This work, in part, involved the determination of nucleon-nucleon spin dependent amplitudes, mainly in the inelastic channels, and hypernuclear spectroscopy using the (K^-, π^-) reaction.

Participation continued in the development of a new kaon beam facility at the AGS. The year was productive as evidenced by the data collected, the number of invited presentations, and the publication list.

I. Personnel

Personnel working on the contract at some time during the year to November 30, 1980 are:

E. V. Hungerford III	Professor of Physics
B. W. Mayes II	Associate Professor of Physics
L. S. Pinsky	Assistant Professor of Physics
T. M. Williams	Research Associate
K. K. Sekharan	Research Associate
S. Bart	Student
R. Hackenberg	Student
A. Hancock	Student
C. Horton	Student
K. Demoss	Student
L. Johnson	Secretary
D. McDonald	Secretary
B. Holt	Secretary

II. Background

Detailed background for the research activities of the Intermediate Energy Group at the University of Houston may be found in previous progress reports, renewal proposals, and beam-time proposals to various accelerators advisory committees. The objectives of this research are to: 1) investigate nuclear forces and nuclear properties at intermediate energies; 2) train graduate students in physics research; and 3) develop the instruments necessary to keep this research effort at the forefront of this area of physics.

The research program has evolved into two primary activities. These are 1) the investigation of the spin dependence of the nucleon-nucleon amplitudes at intermediate energies, especially the inelastic amplitudes; and 2) the investigation of kaon induced reactions, especially hypernuclear spectroscopy. The research effort was divided so that approximately 40% was expended on the nucleon-nucleon problem and 60% on kaon physics.

Experiments completed and published or under data analysis are listed in Table I. Those yet to receive beam or pending approval by an advisory committee are listed in Table II.

Briefly the justification for studying the inelastic spin dependent amplitudes from about .4 to 1 GeV kinetic energy is contained in the large spin asymmetries and structure observed in this energy region. As can be seen from Figure 1) the one pion production inelastic amplitude is a significant fraction of the total cross section at these energies. For this reason a number of authors have pointed out the necessity of preserving unitarity in calculations of N-N scattering in this region. Therefore many have attempted to model a system of nucleons and pion using coupled channel equations for the reactions:

TABLE I ACTIVE EXPERIMENTS
DATA ACQUISITION COMPLETED

NUMBER	DESCRIPTION	STATUS
LAMPF 82	$\pi d \rightarrow p \pi N$	paper published paper in preparation
LAMPF 197	$p d \rightarrow {}^3\text{He} \pi^0$	paper in preparation
LAMPF 341	$p d \rightarrow d \pi N$	paper in preparation
LAMPF 336	$\vec{p} p \rightarrow \Delta^{++} N$	data under analysis
LAMPF 33/366	$N p \rightarrow p p \pi \pi$	data under analysis
LAMPF 504/505	$\Delta \sigma_T / \vec{p} p \rightarrow d \pi$	data acquisition in progress
AGS 646	${}^{12}\text{C}(K^-, \pi^-){}^{12}\text{C}$	paper published
AGS 728	${}^2\text{H}(K^-, \pi^-)\Sigma N$	analysis
AGS 746	${}^{13}\text{C}(K^-, \pi^-)$	data under analysis
	${}^{18}\text{O}$	
	${}^{14}\text{N}$	
AGS 692	${}^{12}\text{C}(K^-, K^-){}^{12}\text{C}$	data under analysis
	${}^{40}\text{Ca}(K^-, K^-)$	

TABLE II FUTURE EXPERIMENTS

NUMBER	DESCRIPTION	STATUS
LAMPF 336 (variable energy)	$\vec{p}p \rightarrow \Delta^{++}n$	Submitted
LAMPF 559	Neutrino Oscillation	Submitted
AGS 754	$(K^{-}; \pi^{-}, \gamma)$	Approved
AGS 752	$^{16}_0(K^{-}, \pi^{-})^{16}_0$	Approved
AGS 756	$(\pi^{+}, K^{+})(\text{Hyper nuclei})$	Approved

Fig. 1) Total pp cross section

$NN \rightarrow NN$

$NN \rightarrow NN\pi$

$NN \rightarrow D\pi$

This approach focuses unitarity at the expense of complexity. However, such calculations are important because the strong inelastic pion production channel is especially important in the interpretation of elastic phase shifts in terms of dibaryon resonances²⁾, and in the influence of true pion absorption in the $\pi d \rightarrow NN$ channel.

Resonances in the Nucleon-Nucleon system are one of the more interesting possibilities of our new understanding of nuclear physics based on quarks and gluon exchanges. Such resonances could be viewed as particles with baryon number 2 composed of at least 6 quarks contained in one bag³⁾. Resonance states are predicted by several quark models, but experimentally remain to be unambiguously identified. Phase shift and amplitude analysis of the N-N system can show resonance like structure depending on the interpretation of the data. Phase shift analyses, such as those of Hoshizaki⁴⁾ indicate possible dibaryon resonances at (1D_2) 2.175 GeV and at (3F_3) 2.22 GeV. If such resonances exist, they will have large inelastic decay widths and therefore strong effects should appear in the $pn\pi^+$ channel. Differences in interpretation of the data arise mainly because of the large inelasticity due to the πNN channel. In fact it has been proposed that dibaryons are quasi-bound states of πNN and $\pi\pi NN$ systems. Bugg⁵⁾ has pointed out that current models for the inelastic channels ($pp \rightarrow d\pi$ and $pp \rightarrow p\pi^+n$) are inconsistent with the observed structure in $\Delta\sigma_L$ near 1.17 GeV/c. He stresses that further data on the spin dependence of the reactions $pp \rightarrow p\pi^+n$ are needed to resolve these discrepancies.

Experimentally one finds large spin asymmetries and inelasticities for the spin dependent amplitudes in this energy region. In particular there has been observed structure in $\Delta\sigma_L$ and $\Delta\sigma_T$ Nucleon-Nucleon cross sections⁶⁾. Figure 2). One is unable to fit these data especially the $\Delta\sigma_L$ data conventional phase shift analyses, but they can be successfully predicted in terms of one or two dibaryon resonances.

On the other hand the close proximity in energy of the proposed dibaryon resonances now extracted from the phase shift analyses presents a problem in itself. A resonance should be isolated in one partial wave, and if Argand diagrams show rapid rotation in many partial waves at nearly the same energy, it is suggestive of another effect such as a channel opening. Indeed it has been shown that resonance like behavior can occur in a coupled channel calculation of the N-N amplitudes due to the strong πNN system, but this structure occurs without a true pole in the NN amplitude¹⁾.

If one writes the amplitudes in terms of a non-resonant plus a standard resonant component the problem is then one of understanding and defining the non-resonant background term so that the existence of the resonant piece can be established. Precise, energy dependent spin dependent amplitudes are needed to resolve these problems.

Although the use of the (K^-, π^-) reaction to study hypernuclei has received the most attention, kaons and in particular the K^+ will provide a unique probe for nuclei⁷⁾. Positive and negative kaons interact weakly with nuclear matter at momenta below 1 GeV/c. The importance of a weak probe lies mainly in the ability to theoretically interpret a reaction and to reliably extract nuclear parameters. Rapid convergence of the non-relativistic multiple scattering series is expected for positive kaons, but it should also be pointed

Fig. 2) $\Delta\sigma_L$ and $\Delta\sigma_T$

out that the basic kaon-nucleon amplitudes must be known off the mass shell and appropriate relativistic effects included. At present this introduces some ambiguity in the scattering series, though it has been investigated and the effect reported to be small⁸⁾.

In the neighborhood of 800 MeV/c where most low energy separated beams are optimized, the K^+ nucleon amplitudes approximately contain equal contributions from the $\ell=1$ and the $\ell=0$ components. The $\ell=1$ amplitude is dominated by K^+ neutron interactions⁹⁾. Thus as a probe, the K^+ displays a simplicity similar to that of an electron, with the advantage that it is sensitive to the neutron distribution and is able to easily provide large momentum transfer.

Kaon scattering aside, the major thrust of the experimental Kaon physics program both in the United States and elsewhere has been in the study of hypernuclear spectra obtained via the (K^-, π^-) reaction¹⁰⁾. This reaction is similar to a charge exchange reaction. Note that the incident K^- momentum may be chosen so that the momentum transfer to the Λ vanishes, or is at least small, so that the (K^-, π^-) reaction can be viewed as the replacement of a neutron by a Λ in the nucleus¹¹⁾. Most of the recent work has involved hypernuclei in the 1p shell, although there have been recent studies of γ decays from excited hypernuclear levels in the 1s $A=4$ hypernuclei¹²⁾.

In a recent experiment at CERN, structure attributed to Σ hypernuclei was observed¹³⁾. These Σ levels of excited hypernuclei are narrow and were a major surprise. There are two published attempts to explain the width and structure of these levels¹⁴⁾, however much more experimental effort is required before definite conclusions may be drawn.

In hypernuclear physics, the present data are consistent with predictions based on a one step Λ substitutional process. Calculations using particle-

hole excitations are able to predict the ground state and substitutional state level spacing. Assuming this knowledge is accurate, the depth and the spin-orbit force of the lambda-nucleon potential has been obtained.

Still there are some inconsistencies and a number of questions left unanswered. Except for our most recent experiments¹⁵⁾ the substitutional states have been formed from even-even targets, and except for our data, no angular distribution of the hypernuclear excitations have been measured.¹⁶⁾ In addition, there appears to be no observed evidence for the core-excited states or splitting of the substitution states in ${}^{12}_{\Lambda}\text{C}$, though our present models would predict that these should be observed. We have apparently observed a state in ${}^{13}_{\Lambda}\text{C}$ built on the 4.44 MeV excited level of ${}^{12}\text{C}$.

Assignment of a very weak spin-orbit strength to the lambda potential is also inconsistent with the analysis of hypernuclear ground state systematics, and of course there are possible tensor, spin-spin, and multiparticle forces for the Λ -N potential yet to be resolved.¹⁷⁾ The characteristics and excitation of the Σ hypernuclei are not understood and await further investigation.

III. Abstracts of Current Research

A) Research Using Nucleon Beams

1) $pd \rightarrow {}^3\text{He}\pi^0$

The pion angular distribution of the reaction $pd \rightarrow {}^3\text{He}\pi^0$, and its isospin partner, $pd \rightarrow {}^3\text{H}\pi^0$, have been investigated at a number of energies over the past several years¹⁸⁾. However, full angular distributions at energies above 600 MeV are not available. Originally, comparison of these two reactions was proposed as a test of isospin conservation, and the older data consists of a number of measurements at isolated angles and energies. More recently the reaction $pd \rightarrow {}^3\text{H}\pi^+$ has been investigated as an example of (p,π) reaction, particularly since earlier data showed an enhancement at back angles at 470 MeV incident proton energy¹⁹⁾. The more recent data at this energy do not show this enhancement, and now seem to fit the general trend of data observed at neighboring energies²⁰⁾. These data may be described by a rapid fall at forward angles, with an almost flat distribution at the backward angles.

In summary the angular distribution of the $pd \rightarrow {}^3\text{He}\pi^0$ reaction at 800 MeV was measured between CM pion angles of 10° to 135° . It was observed that within experimental error the ratio of the cross section to the $pd \rightarrow {}^3\text{H}\pi^+$ cross section is given by isospin and the difference in the ${}^3\text{He}$ and ${}^3\text{H}$ wave functions. The PWIA calculation reproduces qualitatively the shape and DWIA calculation the correct order of magnitude of the data. However, the calculation disagrees with the data in a detailed comparison, particularly at backward angles at this energy. While there is no minimum observed in the data due to the minimum in the three body form factor, wave functions which correctly include the high momentum components (including the

D state in the deuteron wave function) clearly help the calculation. As has been pointed out, the problem may be due to the choice of energy used in the evaluation of the two body $pp \rightarrow d\pi$ amplitude¹⁸⁾. However, it is more likely that multistep processes begin to become important as one moves away from resonance allowing, perhaps, the amplitude to be evaluated at a lower effective momentum transfer. This could resolve problems observed with both the absolute value and the shape of the calculation.

2) $\vec{pp} \rightarrow p\pi N$

Analysis of the data from Experiment 336 has progressed significantly in the past year. The experiment was performed on the EPB beam-line at the Los Alamos Meson Physics Facility (LAMPF) during June of 1979. The purpose of the experiment was to measure spin effects in the reaction $p + p \rightarrow p + \pi^+ + N$ using an unpolarized target and polarized beam.

The Kinematically complete data were collected by a system consisting of a magnetic spectrometer to detect the final state proton, a time of flight detector for the pion, two ion chambers, a faraday cup, and a double arm scintillation telescope. The momentum resolution was $\Delta p/p \sim 2.5\%$. The beam polarization was measured using the LAMPF EPB beam line polarimeter and was typically 70%. The system was calibrated on proton-proton elastic data using the values of Willard, et al²¹⁾ for $A_y(\theta)$ and $\frac{d\sigma(\theta)}{d\Omega}$.

Data were collected and analyzed for 11 angle pairs. The primary results for each angle pair consists of fifth order differential cross sections for each beam polarization state as a function of final state proton momentum. Figure 3 shows the cross sections for the angle pair $\theta_{\text{proton}} = 36.5$, $\theta_{\text{pion}} = 35$. Figure 3 shows the analyzing power, A_y , for the same angle pair.

Fig. 3) A_y and $d\sigma/d\Omega$

3) $pp \rightarrow pp\pi^-$

This experiment as designed to extract the inelastic isospin amplitudes F_{01} , F_{10} , and F_{11} where the first subscript stands for the isotopic spin of the two nucleons in the initial state, and the second for the final state²²⁾.

In order to determine accurately the three amplitudes, it is necessary to observe simultaneously two particles (for example, the pion and one of the nucleons) for a large range of kinematic conditions and for all initial and final states. Such a program has been started with E-81 at LAMPF in which the reaction $pp \rightarrow p\pi^+n$ and $pp \rightarrow pp\pi^0$ have been measured at 800 MeV for several angle pairs. This data set extends these reactions to include $np \rightarrow pp\pi^-$. Future proposals will be submitted to extend the pp data set to larger angles. The goal of this series of experiments is to measure the differential cross section $d^5\sigma/dp_1 d\Omega_1 d\Omega_2$ for the same regions of phase space for all reactions.

Data analysis is complete and the results are being prepared for publication.

4) $\vec{p}\vec{p} \rightarrow pp$

The purpose of this experiment is to measure $\Delta\sigma_L$ ($\Delta\sigma_L = 1/2 \frac{\sigma_{\leftarrow\leftarrow} - \sigma_{\rightarrow\rightarrow}}{\sigma_{\leftarrow\leftarrow} + \sigma_{\rightarrow\rightarrow}}$) at energies from 400 MeV to 800 MeV. As discussed in the background, structure in this reaction can be interpreted in terms of dibaryon resonances. Data acquisition is underway on this experiment at LAMPF at the present time.

B) Detector Development

1) Pressed Silica Cerenkov Detector

The pressed power silica Cerenkov counter of A. Linney and

B. Peters²³⁾ has been developed into a practical device. Peak detection efficiencies of greater than 94% have been obtained. Indices of refraction from 1.05 to 1.10 were produced. The refractive index is reproducible to within .2% which is approximately equal to the variations in homogeneity. Tests of this device were performed at the A2 test beam at the Alternating Gradient Synchrotron, using protons with momenta in the range of 1.0 to 7.0 GeV/c.

2) Scintillation Hodoscope

In order to provide position sensitivity at high beam flux, investigation of a scintillation hodoscope with millimeter position resolution is in progress. This device employs RCA 93008 which is a small (.5 inch active area) photomultiplier tube with high gain and low cost. Tests are in progress to determine the optimum way to couple the scintillation strip to the tube and the minimum thickness scintillation strip that can be used.

From this information a prototype hodoscope will be constructed and tested at Brookhaven or Los Alamos.

C) Physics with Kaon Beams

Data on the angular distributions of the reaction (K^-, π^-) on ^{13}C , ^{14}N , and ^{18}O targets has been acquired in Experiment AGS 746. A portion of these data are shown in Figures 4, 5, and 6. Resolution is approximately 4 MeV FWHM and is due mainly to target thickness.

In the enclosed figures one can see the ground state hypernucleus, particularly at the larger angles. In addition there appears to be a state at about 4.4 MeV excitation in ^{13}C that is constructed on the 4.44 MeV core excitation of ^{12}C . This is the first indication of a core excited state that has been observed in hypernuclear spectra. The absence of the excitation of the ^{12}C core in the $^{12}_{\Lambda}\text{C}$ spectrum was and still is unresolved.

Fig. 4) Spectrum of $^{13}_{\Lambda}\text{C}$ from the $^{13}\text{C}(\text{K}^-, \pi^-)^{13}_{\Lambda}\text{C}$ reaction

Fig. 5) Spectrum of ${}^{14}_{\Lambda}\text{N}$ from the ${}^{14}\text{N} (\text{K}^-, \pi^-) {}^{14}_{\Lambda}\text{N}$ reaction

Fig. 6) Spectrum of ${}^{18}_{\Lambda}O$ from the ${}^{18}_O(K^-, \pi^-){}^{18}_{\Lambda}O$ reaction

Data analysis is continuing and should result in publication in the near future. Careful attention to the effect of cuts on the final cross section is necessary before the results can be compared to theory. Development of the equipment and software necessary to carry out the approved AGS program is continuing.

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