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NUCLEON-DEUTERON BREAKUP EXPERIMENTS

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NUCLEON-NUCLEON SCATTERING LENGTHS FROM INCOMPLETE NUCLEON-DEUTERON BREAKUP EXPERIMENTS*

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Determination of the neutron-neutron scattering length a_{nn} from either kinematically complete or incomplete experiments is based upon the success with which the known pp or np scattering lengths can be extracted from such experiments. In the case of nucleon-induced breakup of the deuteron, the final state enhancement effects observed at forward angles in incomplete experiments cannot be analyzed with the Watson-Migdal formalism because of the extended structure of the deuteron. However, the impulse approximation¹⁾ has been shown to give a fair representation of small angle final state interaction peaks observed in these reactions below 50 MeV. Although many attempts²⁻⁶⁾ have been made to extract the nn scattering length from $^2\text{H}(n,p)2n$ spectra, less work has been done to check the formalism by obtaining the pp scattering length from $^2\text{H}(p,n)2p$ spectra.

Measurements of $^2\text{H}(p,n)2p$ spectra at a lab angle of 3.5° have been made at nine proton energies between 16 MeV and 26 MeV using time-of-flight techniques with the Lawrence Livermore Laboratory cyclograaff. The neutron energy resolution obtained in these measurements is somewhat better than that of previous measurements performed at lower energies at this laboratory⁷⁾ and at 30 MeV and 49 MeV performed at the Rutherford Laboratory.⁸⁾ Experimental spectra taken at 19 MeV and 26 MeV and theoretical spectra calculated from the impulse approximation formalism of Phillips⁹⁾ are shown in fig.1. Neutron energy resolution at each energy was determined from the width of the $^{11}\text{B}(p,n)^{11}\text{C}(\text{gs})$ neutron group and was folded into the calculated spectra.

The value of the pp scattering length a_{pp} giving the best fit to the data was determined by setting equal the areas of experimental and calculated spectra integrated to 2 MeV relative energy in the two proton system and minimizing chi square as a function of scattering length. Averaging together the results obtained at each energy yields a pp scattering length of -6.6 ± 0.5 fm. The calculated spectra produced in this fashion do not fit the rise of the cross section from threshold to peak height

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equally well for all values of a_{pp} , however. This rise contains little information except the experimental resolution. Normalizing the calculated spectra to the peak cross section rather than the integrated cross section yields spectra which fit the high energy side of the peak identically well for all values of a_{pp} . The average value of a_{pp} obtained by minimizing the mean square deviation of these spectra from the data out to 2 MeV in E_{pp} is -7.4 ± 0.5 fm. The uncertainty given for both results is calculated from the spread of individual values about the average. Independent of the method used to normalize the calculated spectra to the data, an average value of a_{pp} within approximately 1 fm of the free scattering result of -7.8 fm is obtained.

Fig. 1 Neutron spectra from the ${}^2\text{H}(p,n)2p$ reaction. Best fit spectra calculated with the impulse approximation are shown here.

The limited success of the attempt to extract a_{pp} from ${}^2\text{H}(p,n)2p$ data satisfies a necessary but not sufficient condition for the extraction of a_{nn} from ${}^2\text{H}(n,p)2n$ measurements. Assuming that the impulse approximation description of nucleon-deuteron breakup is entirely valid, experimental requirements for a determination of a_{nn} with statistical uncertainty of ± 2 fm are easily calculated. In fig. 2 impulse approximation calculations for ${}^2\text{H}(n,p)2n$ spectra are shown for $a_{nn} = -16$ fm, the coulomb corrected value of a_{pp} , and $a_{nn} = -24$ fm, the np singlet

scattering length. Instrumental resolution was simulated by folding in a Gaussian function truncated at 10% of maximum height. The curves are normalized to the same peak height. A rough experimental figure of merit is the statistical accuracy required to differentiate between the curves to 2 fm at $E_{nn} = 1$ MeV. For the ideal case of no instrumental broadening of the curves the accuracy needed is 9%. As the spectra are measured with poorer resolution the required uncertainty decreases to approximately 6% for 200 keV resolution, 3.3% for 400 keV resolution and 2.8% for 800 keV resolution. Counter telescope methods have been used for all measurements of ${}^2\text{H}(n,p)2n$ spectra reported to date.²⁻⁶⁾ The instrumental resolution obtained has been 500 keV to 1 MeV and the statistical uncertainty has been typically 5% to 10%. The difference between the values of $-16 \text{ fm}^{2,3)}$ and $-22 \text{ fm}^{4-6)}$ deduced from these measurements does not seem statistically significant in the view of the experimental requirements outlined above.

Fig. 2 Proton spectra for the ${}^2\text{H}(n,p)2n$ reaction calculated with the impulse approximation for varying values of experimental resolution.

The agreement of impulse approximation calculations of proton-proton final state interaction enhancement with the present ${}^2\text{H}(p,n)2p$

measurements suggests that a measurement of $^2\text{H}(n,p)^2\text{Zn}$ small angle spectra with improved resolution for 20 to 30 MeV neutrons would allow determination of a value of the neutron-neutron scattering length limited by theoretical rather than experimental uncertainties.

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