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PROTON POLARIZATION

IN THE

$^3\text{He}(d,p)^4\text{He}$ REACTION

A thesis submitted
to the University of Auckland
for the degree of Doctor of Philosophy

BY

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ABSTRACT

The proton polarization in the $^3\text{He}(d,p)^4\text{He}$ reaction induced by unpolarized deuterons has been measured at deuteron lab. energies of 2.0, 2.8, 3.9 and 6.0 MeV for 20 angles between 0° and 150° (c.m.). Statistical uncertainties are typically ± 0.01.

The measurements were made with a proton polarimeter in which the left-right asymmetry of scattering at 60° (lab.) in $^4\text{He}$ is determined. The polarimeter employs "venetian-blind" collimation of the protons by conical vanes and 75 cm$^2$ plastic scintillator detectors. Four detectors are included for use in polarization transfer experiments. For 10.5 MeV protons and a helium pressure of 250 p.s.i. the target thickness is 3 MeV and the efficiency per detector per unpolarized proton incident is 10$^{-4}$. For each polarimeter detector a triple coincidence with a 15 ns resolving time was required with two scintillator transmission detectors preceding the polarimeter. Spectra of random coincidences were accumulated simultaneously and subtracted. Asymmetries resulting from polarimeter-target misalignment and other geometrical effects are discussed. All results quoted are geometric means of pairs of measurements for 180° rotation of the polarimeter and are also arithmetic means of such measurements to left and right of the $^3\text{He}$ target. The absolute analyzing power is estimated by computer simulation of trajectories to be -0.638 ± 0.020 for protons entering at 10.3 MeV.

The product of polarization and cross section is fitted to an expansion of first-order associated Legendre polynomials using these results and earlier measurements. Only four terms are required except at 6.0 MeV where a fifth is necessary. The energy dependence of these coefficients suggests resonances in $^3\text{Li}$ at deuteron energies of 6.0 MeV (odd coefficients) and 7.5 MeV (even coefficients) in agreement with results for the polarized-beam analyzing powers (1). Comparison of the results with vector-polarized-beam (1) and polarized-target (2) analyzing powers shows no evidence for the postulated simple relations (3) based on DWBA calculations. Comparison of the results with recent measurements of the neutron polarization in the mirror reaction (4) shows no significant differences.

The theory of angular correlations in charged particle reactions is developed and used to calculate outgoing nucleon polarizations. Expressions are given for polarization transfer coefficients. These coefficients are
evaluated in terms of the T-matrix elements for the interference of various channels with the dominant S-wave, $J^\pi = \frac{3}{2}^+$ channel in $^3$He(d,p)$^4$He at the 0.43 MeV resonance. Two experiments to measure combinations of these elements are discussed.

(2) Leemann, Ch., W. Gruebler et al., 1971, in Polarization Phenomena in Nuclear Reactions (University of Wisconsin Press), p. 548
PLATE I

The proton polarimeter, reaction target and ancillary equipment as used in the polarization measurements. The reaction target chamber and pass counters are shown in more detail in plate IV. The polarimeter is supported by the vertical plate at its left end. The polarimeter and pass counters are mounted on a frame which rotates about the reaction target.
PREFACE

The aims and scope of this investigation of the $^3\text{He}(d,p)^4\text{He}$ reaction have changed considerably since it was started. In 1965 the AURA I, 1.2 MeV polarized deuteron accelerator appeared to be nearing completion and the author, in work done for an M.Sc. thesis, tested an experimental arrangement for monitoring the deuteron tensor polarization by measuring the anisotropy of $^3\text{He}(d,p)$ protons. However later in 1965 it became apparent from studies of $T(d,n)$ at Basel and of $^3\text{He}(d,p)$ by L. Brown in Washington that even close to the $^3\frac{1}{2}^+$ resonance at 0.43 MeV there was a contribution from some other reaction mechanism and that this reduced the analyzing powers of the reaction by an unknown amount. Brown and McIntyre suggested that the second mechanism was the formation of a $^1\frac{1}{2}^+$ state by S-wave deuterons. The author's earlier work followed from this. The aim was to determine the extent to which this or any other mechanism contributed at deuteron energies near the $^3\frac{1}{2}^+$ resonance and the principal tool was the AURA I polarized deuteron beam. The construction of a proton polarimeter was originally suggested by Glavish who was interested in its use in determining the vector polarization of the AURA I beam. The author realized that by using a polarimeter to do what is now known as a polarization transfer experiment it would be possible to determine both real and imaginary parts of the interference term between the two S-wave channels. This experiment, which became the original thesis topic, is described in §3.4 The proton polarimeter described in chapter 4 and the gas-target assembly of §5.1 were designed solely for this experiment. The design, construction and some initial testing of the polarimeter were done during 1966 to mid 1968. The construction of reliable thin-walled gas-target capsules for this work was for some time a cause for concern but a completely satisfactory technique for fabricating these was evolved and is described in appendix E. The author was at the same time involved in the work on the AURA I accelerator which was not proceeding as well as had been hoped. In 1968 and early 1969 the first and only experiment was done with this accelerator. This experiment was the analyzing-power measurement $T(\bar{d},n)^4\text{He}$ at $\theta = \cos^{-1}(\pm 1/\sqrt{3})$ and the tentative conclusion from it was that P-wave channels were involved at energies below 500 keV. A repetition of this experiment on the $^3\text{He}(\bar{d},p)^4\text{He}$ reaction became the second thesis topic. This is discussed in §3.5. Work on it started in August 1968 but the accelerator was not available until May 1969. Subsequently, despite major efforts over the next year, it was found impossible to keep a satisfactory polarized beam on the target. The main problem lay in maintaining a
satisfactory vacuum in the strong field ionizer which was in the Van de Graaff terminal. The second problem was that much of the accelerator-PIS installation was now eight years old and many parts were wearing out. Eventually it became obvious that the installation could not be made to work without major changes and it was abandoned. In May 1970, with the polarimeter complete but lacking satisfactory detector electronics and still in need of mechanical changes, the author decided to make the polarization measurements $^3\text{He}(d,p)^4\text{He}$ for 2 to 6 MeV deuterons using an unpolarized beam from the AURA II accelerator. The author regrets the length of this preamble but feels it is necessary to explain the presence of chapters two and three and the length of time spent on the thesis.

The aims in measuring these $^3\text{He}(d,p)$ polarizations were:

(i) To look for levels in $^6\text{Li}$. With so few nucleons involved the system should be susceptible to detailed analysis.

(ii) To obtain information about the spin dependence of the forces involved in the interaction. This reaction is peculiarly suitable for this purpose because highly-polarized targets exist and thus three types of one-polarization experiment are possible. At the time of starting good angular distributions were known for two of these experiments (polarized-beam and polarized-target analyzing powers) but the proton polarizations were not so well known.

(iii) To obtain information about the charge independence of nuclear forces by making comparisons with the mirror reaction $^7\text{Li}(d,n)^7\text{He}$.

Chapter 1 is a review of recent work and contains no original material. Experimental observations on a large number of different reactions that suggest the existence of levels in $^5\text{Li}$ are discussed in §1.1 and theoretical predictions of levels are discussed in §1.2; these sections are the background to aim (i). The background to aim (ii) is provided in §1.3 in which relations between the observable polarization parameters and the nature of the spin dependence of the interactions involved are discussed. The data available for comparing these parameters are listed in §1.4.

Chapter 2 is a development (§2.1) of the angular correlation formalism needed in chapter 3 with particular emphasis (§2.2) on the calculation of outgoing polarization. The method used in §2.2 is simpler than that of Welton (1960); it is not original but needed to be properly stated as it has been used incorrectly several times. This formalism is applied to several types of experiment in §2.4; most of these formulae have not been given in their present form before. The theory of polarization transfer in $Y_1(X_1,\frac{1}{2})Y_2$
reactions and the hybrid \( H \) coefficients used in §2.5 are the authors own work, done before publication of the closely-related spherical tensor \( C \) coefficients used by the Basel and Zurich groups and the cartesian coefficients of the Los Alamos group.

Those polarization transfer coefficients \( H \) for the \(^3\text{He}(d,p)\) experiment which are relevant at energies near the \(^{3+}_{2/2}\), 0.43 MeV resonance are evaluated in §3.2. A more comprehensive tabulation has been published since this work was first done and the \( H \) formalism has been recast to simplify comparison of the two. In §3.3 the information now available on the original thesis topic—the extent to which various mechanisms contribute near the \(^{3+}_{2/2}\) resonance and their effect on the analyzing power—is reviewed. The original polarimeter experiment is discussed in §3.4 and shown to be still relevant. The second thesis topic, the "null-angle" \(^3\text{He}(d,p)\) measurement is discussed in §3.5. All of §3.4 and most of §3.2 is original work.

The design and performance characteristics of the proton polarimeter, reaction target, and the detectors and electronics are given in chapters 4 to 6. Achieving the present, very satisfactory polarimeter system has taken a great deal of time and effort; indeed the majority of the author's productive research time has been spent on this. Specific details of the polarimeter and apertures are in the final subsections of §4.2 and §4.3 and in tables 4-I and 5-I. Because of the marked sensitivity of \(^4\text{He}, 60^\circ\)-vanned polarimeters to misalignment a detailed and original analysis of geometrical effects is given in §4.5. The reaction target chamber is unusual in that the deuteron beam is stopped immediately behind the target; this feature, which was a consequence of designing the system for deuterons of less than 1 MeV, allows detection of protons at scattering angles down to 0° but is probably a source of much of the background radiation seen in the polarimeter detectors.

It was not possible at Auckland to calibrate the polarimeter with a proton beam of known polarization. Chapter 7 contains an estimate of the analyzing power, based on the known \(^4\text{He}\) analyzing powers and calculated by computer simulation of proton trajectories. The important results are in table 7-IV.

The \(^3\text{He}(d,p)\) polarization measurements are reported in chapter 8 with the polarizations being given in tables 8-I to 8-V and the polynomial expansion coefficients in table 8-XIII. These measurements are compared with previous results in §9.1. The conclusion relevant to aim (ii) is reported in §9.2: none of the postulated angle-independent relations between the polarization parameters holds. The conclusion relevant to aim (i) is reported in §9.3:
tentative confirmation of the resonance-like effects previously seen at deuteron energies of 60 and 7.5 MeV. The background to aim (iii) — charge independence of nuclear forces — is discussed in §9.4 and examination of the results shows them to be consistent with this hypothesis but not able to provide a good test of it.

The measurements herein are to be supplemented by further work by the Auckland few-nucleon group with the present apparatus at deuteron energies of 5 MeV and below 2 MeV. As a result of all the various types of polarization measurements there is now a large amount of data available on spin-dependent effects in this reaction. It is hoped that this will provoke more detailed attempts to understand the spin dependence of the forces involved in the five-nucleon system.

A number of technical matters have been relegated to appendices. The computer programs used have been included therein for completeness; they are all the author's work apart from the polynomial fitting program which is a modification of an existing program. The Madison Convention for polarization nomenclature has been used except that in some chapters P is used for proton polarization. Differences between symbols in §7.2 and §7.4 exist because of the desire that symbols in the text correspond to those used in writing programs.

Many people have assisted with the work described herein. I wish to thank particularly:

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J.F. Clare

Auckland,
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