



<http://researchspace.auckland.ac.nz>

ResearchSpace@Auckland

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of this thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from their thesis.

To request permissions please use the Feedback form on our webpage.

<http://researchspace.auckland.ac.nz/feedback>

General copyright and disclaimer

In addition to the above conditions, authors give their consent for the digital copy of their work to be used subject to the conditions specified on the Library Thesis Consent Form.

SCATTERING OF POLARIZED

NEUTRONS

FROM LIGHT NUCLEI

A thesis submitted to the University of
Auckland in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy.

R. Garrett
October, 1969

TO MY WIFE

P R E F A C E

My first start in nuclear physics was made during 1962. My supervisor, Professor Brown, had suggested the use of 14 MeV neutrons from the $T(d,n)He^4$ reaction for studying nuclear structure by observing the angular distribution of outgoing protons and deuterons from (n,p) and (n,d) reactions. At this time this was the only feasible method of studying nuclear structure in this laboratory as the highest accelerated beam energy then available was 400 KeV.

During the next two and a half years of part time work some familiarity with neutron sources, associated particle systems and counter telescopes was acquired. However this is a very difficult way of studying nuclear structure and by this time a much higher energy van der Graaff accelerator and a polarized ion source were looking large on the horizon. As a consequence I shifted my attention to problems that could be solved with polarized neutrons generated still by means of the $T(d,n)He^4$ reaction at low energies but using a polarized incident deuteron beam.

The outgoing neutron polarization is determined by the ingoing deuteron vector polarization and the dynamics of the $T(d,n)He^4$ reaction. It was therefore initially proposed that the neutron polarization should be measured using a helium analyzer. If one assumes that the $T(d,n)He^4$ reaction proceeds via a $3/2^+$ level in the compound state and that the incoming channel contains s waves only then the outgoing polarization and angular distribution

is dependent only on the conservation laws. As the extent to which this assumption is correct is not yet known precisely the work began to be oriented towards a study of the $T(d,n)He^4$ reaction itself. However there is a slightly easier way of doing the same thing and that is by use of the mirror reaction $He^3(d,p)He^4$. An experiment to measure the outgoing proton polarization vector is currently being set up by J. Clare of this laboratory.

For this reason and because the polarized ion source was not yet available for routine work it was decided to change the emphasis. This meant that a gas scintillation counter which was developed during 1966 was not immediately needed. However as this device is needed for the proposed absolute polarization measurements suggested in § 2.2.6 a chapter of this thesis has been devoted to it.

With the successful completion of the AURA II accelerator (Naylor (1968)) late in 1966 it became possible to generate polarized neutrons from the $T(d,n)He^4$ reaction using an unpolarized 6 MeV deuteron beam. The emphasis was therefore changed to the problem of measuring the polarization in neutron proton scattering at 16.4 MeV. The techniques and apparatus needed did not differ greatly from those already developed so that the first polarization measurement was made within a year of commencing work in the AURA II laboratory.

The first chapter of this thesis is concerned mainly with the present state of the phenomenological understanding of the nucleon-nucleon interaction. Very brief discussions of n-d and n- α polarization are included because it is intended to use the same apparatus for this work in the future. Since the only polarization measurement reported in this thesis is for n-p scattering, the need for such measurements has been the main concern of chapter 1.

Chapter 2 contains a general discussion of neutron scattering methods

concluding with details of the associated particle techniques used here which have not previously been used for neutron polarization studies at neutron energies above 3 or 4 MeV.

Chapter 3 describes the electronic system as originally set up by the author and which was used for the work with unpolarized neutrons described in chapter 5 and early work with polarized neutrons using the $T(d,n)He^4$ reaction at $E_d = 6$ MeV. This electronic system was not really designed - it was built as much as possible from available equipment in such a way as to conserve time and money and yet provide a workable system. Since the AEC standards⁺ for nuclear instrumentation were set up the electronic system has been gradually converted to comply with this standard. I am indebted to my colleague Mr. A. Chisholm for carrying out the bulk of this program. The performance of the new system does not differ from the old and the logic is the same but the convenience of interchangeable modules and standard pulse shapes has greatly accelerated the speed and efficiency of the experimental work.

Chapter 4 is devoted to the work carried out on developing a gas scintillator for reasons already explained while chapter 6 is concerned with the problems of making a practical associated particle system for 6 MeV deuteron energy and the measurement of the neutron-proton polarization at 16.4 MeV.

The research for this thesis was carried out entirely while I was a full time member of the University of Auckland teaching staff. As a consequence the demands on my "leisure" time were very great and I am greatly indebted to my wife and children for putting up with a physicist in the house for a seemingly interminable period instead of a husband and father.

⁺ NBS - AEC Standard for Nuclear Instrumentation TID - 20893 (Revised)

I would also like to thank the many people who contributed by taking part in discussions. Amongst these are my supervisor, Professor D. Brown, and colleagues R.E. White, H. Naylor and especially A. Chisholm whose active interest has contributed an immeasurable amount. Thanks are due also to Mr. F. Blair and his machine shop staff for his ready response to - "this job is really urgent" - and also to Mr. R. Noble whose electronics workshop staff have built a number of electronic "boxes" for use in this work.

The research was supported financially by the University of Auckland Physics Department and grants from the University Grants Committee totalling about \$6,000.

Finally thanks are due to Mrs. A. Bell for her typing.

Ross Garrett

Auckland

September 1969.

C O N T E N T S

	page
Preface	(i)
Chapter 1. <u>Nucleon-Nucleon and few Nucleon Interactions</u>	
1.0 Introduction	1
1.1 General remarks about the nucleon-nucleon interaction	2
1.1.2 The scattering parameters	5
1.1.3 Phase shifts	11
1.1.4 Potential models	15
1.2 Current status (May 1969) of phase shift analysis of the two-nucleon interaction	17
1.2.1 The experiments needed	18
1.2.2 Charge independence	22
1.2.3 Predicted values of some observables at 16.4 MeV from combined np + pp phase shift analyses	24
1.3 The three nucleon problem	24
1.3.1 Number of observables in n-d scattering	26
1.3.2 Neutron-deuteron polarization	26
1.4 Neutron-alpha elastic scattering	28
Chapter 2. <u>Neutron Scattering Methods for Light Targets</u>	
2.0 Introduction	33
2.1.1 Scatterer in scatterer out method	35
2.1.2 Time of flight methods	36
2.1.3 Use of scatterer recoil energy	37
2.1.4 Associated particle method	42
2.2.1 Counting rate estimates	48
2.2.2 Random background estimates for systems A, B and C	52

2.2.3	Systematic sources of background	59
2.2.4	Two dimensional analysis using on-line computer	73
2.2.5	Asymmetry corrections	74
2.2.6	Absolute polarization measurements	80
2.3	Neutron source for 14 MeV neutrons	84
2.3.1	Neutron source using 250 KeV unpolarized deuterons	85
2.3.2	Neutron source for 250 KeV polarized deuterons	91
2.4	Neutron source for 16.4 MeV polarized neutrons	94
2.4.1	Electrostatic versus magnetic separation	102
2.4.2	Theory of electrostatic separator	103
2.4.3	Design considerations of electrostatic separator	113
Chapter 3. <u>The Electronic System</u>		
3.1	Choice of detector type	116
3.2	Sources of time jitter	118
3.3	Sources of time walk	121
3.4	Principle of the tunnel diode discriminator and pulse shaper	123
3.5	A practical discriminator circuit	130
3.6	Discriminator performance	131
3.7	An improved discriminator design	134
3.8	Discriminator time walk	137
3.9	Discriminator dead time	142
3.10	Comparison of fast discriminator performance characteristics	144
3.11	Details of the complete electronic system	145
3.12	The scintillation detectors	151
3.12.1	Scatterer recoil detector	152

3.12.2	Scattered neutron detectors	159
3.13.1	Reverse walk device	163
Chapter 4. <u>Helium Gas Scintillator</u>		
4.0	Introduction	167
4.1.1	Mechanism of scintillations in gases	168
4.1.2	Review of previous work on practical gas scintillators	181
4.2	Mechanical design considerations	186
4.3.1	Fabrication methods - reflector	190
4.3.2	Fabrication methods - wavelength shifter	192
4.3.3	Pressure seals	193
4.3.4	Cleaning methods	194
4.4.1	Performance tests - effect of purifier	195
4.4.2	Quartz versus glass optics	197
4.4.3	Wavelength shifter	198
4.4.4	Resolution as a function of xenon concentration	200
4.4.5	Rise and fall time measurements	202
4.4.6	Deterioration of pulse height and resolution with time	208
4.5	Coincidence operation	209
4.6	Design improvements	215
Chapter 5. <u>Measurements with Unpolarized Neutrons</u>		
5.0	Introduction	217
5.1.1	Spatial extension of the neutron "beam"	218
5.1.2	Time extension of neutron beam	220
5.2	Associated alpha particle spectra	224
5.3	Setting up procedure for systems A, B and C	226

5.4	s - n flight time spectra	231
5.5	Recoil proton spectra	234
5.6	Gated recoil deuteron spectra	237
5.7	Gated recoil alpha spectra	240
5.8	Measurement of light output versus energy for NE102A, NE230 and He gas scintillators	244

Chapter 6. Polarization Measurements in Neutron - Proton Elastic Scattering

6.0	Introduction	249
6.1	Electrostatic separator tests	249
6.2	Deuteron veto method	255
6.2.1	Comparison of veto and electrostatic separator systems	260
6.3	Polarization measurements	263
6.3.1	Methods of setting up timing	264
6.3.2	Gated proton recoil spectra	266
6.3.3	Beam alignment	269
6.3.4	Preliminary measurement of n-p polarization at 100° C.M.	272
6.3.5	Improvements incorporated into later polarization measurements	278
6.3.6	Further polarization measurements	281

Appendix

A.1	Calculation of neutron detector efficiency	A1
B.1	Functional form for photomultiplier pulse	A3
B.2	Trailing edge triggering time of reverse walker as a function of V_0 and V_T .	A4
C.1	Transistor long tailed pair transfer characteristic	A7
D.1	Charged particle trajectories in a cylindrical electrostatic deflector	A9

E.1	Approximate formulae and graphs for position of particles in detector plane of electrostatic separator described in § 2.4	A14
F.1	Energy spectrum of proton recoils due to double scattering	A15
G.1	Precision of flight time correction with "reverse walker"	A17
G.2	Reverse walk device circuit design	A21
H.1	Formulae for calculating polarization and differential cross sections from phase shifts for interactions involving s, p and d waves between a neutron and a spin zero target	A25