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The Nucleon-Nucleon Program at TRIUMF

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TRIUMF has a long history of polarization studies for the nucleon-nucleon system in the energy range between 180 and 520 MeV. The experimental program at TRIUMF continues to be active in this field and important measurements are both in progress and being planned for the near future. In addition, there is a considerable ongoing development effort to improve the quality and flexibility of the polarized beams and targets available at TRIUMF.

EXPERIMENTAL FACILITIES

(a) Beams

The properties of the various beams used in the nucleon-nucleon program are summarized in Table I. In the past year the operation of the polarized ion source

Table I Summary of Present Beam Properties			
Proton Beams	Neutron Beams	Pion Beams	
Intensity			
600 nA delivered	$9 \times 10^3 / 100 \text{ nA} \cdot \text{cm}^2 \cdot \text{s}$	3×10^7	
300-400 nA typical		$\Delta p/p = 5\%$	
Polarization			
70-75% typical	$\sim 45\%$ at 500 MeV		
80% low currents	$\sim 60\%$ at 200 MeV		

has improved steadily. Currents from 300-400 nA are reliably obtained and recently 600 nA was delivered. During development tests up to 1 μA of polarized beam has been extracted from the cyclotron. Reliable operation at these high currents is needed to produce polarized neutron beams of adequate intensity for the present n-p scattering experiments. The LD_2 target used for the production of the TRIUMF neutron beam was upgraded in 1983. It has operated with proton beam currents up to 1.5 μA without any observable effect due to the beam heat load.

At present, vertical, horizontal or longitudinal polarizations can be obtained for neutron beams. Redesign of beamlines 4A and 4B is in progress to obtain longitudinally polarized proton beams using transport systems with two solenoids and two dipoles. Care is being taken to guarantee that 100 keV energy resolution will still be obtainable with the upgraded medium resolution spectrometer (MRS). The design of the beam transport is complicated by the twister and vertically dispersed focus used by the MRS. A new large acceptance focal plane polarimeter for the MRS is also being constructed to measure scattered proton polarizations, and take full advantage of the planned flexibility of incident proton polarizations. Longitudinally polarized beams might be available in 1986.

(b) Ion sources

No major work is planned on the present Lamb shift source. However, development work on an optically pumped polarized ion source has progressed very well. Electronic polarization $>85\%$ has been measured in the Na vapour having a linear density capable of producing 10 μA of H^- ions. Up to 5 μA of polarized protons could be produced from the TRIUMF cyclotron with such a source. With adequate laser

power there is a good possibility to have 150 μA of H^- extracted from the source. The work has been done using a single 1 watt broadband laser. An important discovery at TRIUMF was that use of a viton liner in the Na cell increased the lifetime of the Na polarization from 10 μs to 200 μs .

Production of an operational optically pumped ion source would have major implications at TRIUMF. At present, approximately 25% of scheduled beam time is for the polarized source. It may be possible to increase that figure substantially if polarized proton beam intensities $>50 \mu\text{A}$ are available. The beam properties from an optically pumped source would also be improved over the present source. Since the proton polarization is changed at the laser the negative and positive polarizations would be equal, the beam currents would be constant for all three states, and there would be no change in the beam transport properties.

(c) Targets

The TRIUMF large volume frozen spin polarized proton target was christened experimentally for the first time in November 1983. Since then it has been used for a two week run in February 1984 and a three week run in August 1984. The properties of the target are summarized in Table II. Two more long runs are planned before the end of 1984. After that improvements will be made so that an operating temperature of 50 mK can be routinely achieved and to reduce the thickness of the material around the target. The target volume can be increased to 98 cm^3 , limited by the polarizing field homogeneity.

Table II
TRIUMF Polarized Proton Frozen Spin Target

target volume:	56 cm^3	4 cm x 4 cm diam.	(present configuration)
	98 cm^3	5 cm x 5 cm diam.	(max. size allowed in polarizing field)
target material:	beads, 1.6 mm dia., formed from a Butanol - 5% H_2O mixture, density of EHBA-Cr(V) is $4 \times 10^{19}/\text{ml}$		
holding field:	2.57 kG (vertical)		
target temperature:	$60 \pm 5 \text{ mK}$		
Reliability:	the refrigerator has run for 18 consecutive days with routine maintenance. Downtime has been < 1 day in 8 weeks of operation.		
Polarization	Average (best)	Average lifetime (best lifetime)	
positive	83.8% (87.3%)	167 hours	(270 hours)
negative	91.0% (93.4%)	260 hours	(479 hours)

The Liverpool polarized target used in the BASQUE experiments is being converted to a polarized deuteron target. The aim is to achieve deuteron vector polarizations of $\sim 40\%$ and tensor polarization of $\sim 15\%$ with refrigerator operation below 50 mK. The target volume will be 5 cm^3 in a frozen spin holding field of $\sim 4 \text{ kG}$.

ACTIVE EXPERIMENTS AND RECENT RESULTS

(a) Test of Time Reversal Invariance

When the controversial violation of time reversal invariance (TRI) in a P-A measurement of two nucleon transfer reactions was reported several years ago¹), it became clear that no stringent TRI measurement existed for nucleon-nucleon scattering. A P-A experiment that observed p-p elastic scattering and p- ^{12}C elastic scattering at 16° and 200 MeV was performed by a University of Alberta group. This choice of energy and angle is particularly favourable for observation of TRV effects. Simultaneous observation of the two processes allows uncertainties in the proton beam polarization and the analyzing power of the second scattering to be eliminated. The analysis of this experiment is nearly complete with only the corrections for known systematic effects to be evaluated. A statistical precision in P-A of ± 0.0025 with a comparable uncertainty in the systematic corrections appears obtainable. This error is about a factor 3 smaller than existing limits in

(b) Charge Symmetry Measurement

A Manitoba/Alberta/TRIUMF/Basel collaboration is half-way through data collection for a measurement of charge symmetry violation in the n-p system at 480 MeV. The experiment measures the angular distributions of the analyzing powers for a polarized neutron beam scattering on an unpolarized proton target (A_n) and an unpolarized neutron beam scattering from a polarized proton target (A_p). At a given angle the difference in the scattering asymmetries is given by:

$$\epsilon_n(\theta) - \epsilon_p(\theta) = \frac{1}{2} [A_n(\theta) + A_p(\theta)] [P_B - P_T] + \frac{1}{2} [A_n(\theta) - A_p(\theta)] [P_B + P_T]$$

If charge symmetry is good then $A_n(\theta) = A_p(\theta)$ and the second term vanishes. Theoretical predictions^{2,3} show that $|A_n(\theta) - A_p(\theta)|$ is small -- of order 0.004. The aim of the experiment is to observe values of $A_n - A_p$ as small as ± 0.001 . To minimize systematic errors this is most easily done at a crossover angle where $A_n(\theta) = A_p(\theta) \approx 0$. A difference in the crossover angle of 0.04° corresponds to $|A_n - A_p| = 0.001$. Preliminary results for about 1/4 of the final data give $|A_n - A_p| = 0.23 \pm 0.11$. This does not include corrections for (n,np) background from the target and a full study of possible systematic errors has not been done. The result should only be interpreted as an indication that major deviations from theoretical predictions are unlikely.

(c) t_{20} in πd Elastic Scattering

A group from the University of Saskatchewan has built a new deuteron tensor polarimeter and have preliminary results for t_{20} in πd elastic scattering at 142 MeV. The results are shown in figure 1 along with the results of Gruebler et al.⁵⁾ and Holt et al.⁶⁾ These preliminary results appear to confirm the LAMPF data. The controversy certainly does not end here and one must wait for the final results of all the groups concerned and a detailed comparison of the experiments.

(d) Proton-proton Bremsstrahlung.

A University of Alberta/TRIUMF group is setting up to observe the $pp\gamma$ reaction at 280 MeV. The aim is to observe analyzing powers and cross sections for protons from 10° to 30° . The photon (coplanar) will be detected in 16 lead glass Cerenkov counters from 20° to 170° on the side of the low energy proton. It is hoped to obtain a total of 4×10^5 events and it may be possible to distinguish between the modern Paris and Bonn N-N potential models. Theoretical $pp\gamma$ calculations are being done at TRIUMF by Fearing and Workman. This experiment should certainly remove any question concerning the adequacy of the soft photon approximation which appears to describe all existing experiments of this type.

(e) $\bar{n}p \rightarrow d + \gamma$

Data for the $np \rightarrow d\gamma$ analyzing power at 180 and 270 MeV have been obtained⁷⁾ by an Alberta/TRIUMF collaboration. Extension of the data to higher neutron energies is currently underway. At intermediate energies the cross section is dominated by contributions from isobar formation while the analyzing power (or nucleon polarization) is sensitive to both nucleon and meson exchange terms. The 270 MeV analyzing power data show the need for meson exchange current contributions. More

Figure 1 - Comparison of SIN, LAMPF and preliminary TRIUMF t_{20} data.

details concerning radiative capture processes can be found in the proceedings of the workshop held at TRIUMF earlier this year⁸⁾.

(f) $\vec{p}d \rightarrow \pi\pi^0$

The analyzing powers for the $\vec{p}d \rightarrow \pi\pi^0$ have been measured at 350, 450 and 500 MeV⁹⁾ and compared to similar data for the $pd \rightarrow \pi\pi^+$ reaction^{10, 11)}. The data agree within statistical error (typically ± 0.03) over the angular range 30° - 150° in the c.m. system. The consistency of these data supports the charge symmetry of the nuclear force, in contrast to cross section data for $\pi^\pm$ scattering from A=3 nuclei¹²⁾ and of the pion production reactions $nd \rightarrow \pi\pi^0$ and $nd \rightarrow {}^3\text{He}\pi^-$ ¹³⁾.

FUTURE EXPERIMENTS

Measurements by an Alberta/Manitoba group of A_{nn} in n-p elastic scattering at 210, 325, 425 and 500 MeV in the c.m. angular range 60° - 150° with an accuracy of ± 0.03 per point will start data-taking in late 1985. These results will reduce uncertainties and correlations in existing n-p phase shift analyses. In addition, the A_{nn} predictions of the Bonn and Paris potentials differ and it should be possible to discriminate between these potentials. A proposal to measure t_{20} in nd elastic scattering using the new polarized deuteron target is in preparation. This may be the best way to resolve the discrepancies between existing measurements where the tensor polarization of the scattered deuteron is observed. This experiment could start data-taking in mid-1985. Following the t_{20} measurement, the same UBC/TRIUMF group will measure the outgoing proton polarizations for the nd + pp reaction. A major experiment to measure parity violation in p-p scattering is also being considered by a Manitoba/Alberta collaboration. This experiment would measure the relative difference in the total cross sections A_z for polarized proton beams of opposite helicity to a precision of $\sim 2 \times 10^{-8}$. This would be similar to other measurements at energies outside the TRIUMF range. A unique aspect of this proposed experiment would be an attempt to measure the angular distribution of A_z in order to obtain more precise information on the nucleon-nucleon parity violating amplitude.

Investigation of nucleon-nucleon spin physics at TRIUMF will form a major part of the experimental program during the next few years. There is no lack of good ideas for experiments in this field and I am sure the progress report from TRIUMF at the next conference in this series will bear witness to this continuing interest.

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