PROTON TARGET POLARIZATION MEASURED WITH A POLARIZED NEUTRON BEAM AT 477 MeV


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ABSTRACT

The polarization of a proton target is determined with elastic neutron-proton scattering at 477 MeV. The results agree well with the nuclear magnetic resonance measurements at the error level of 4%.

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CM-P00068198
(Letter to Nuclear Instruments and Methods)

Dynamically polarized proton targets are available at intermediate-energy and high-energy accelerators for the study of spin-dependent nuclear reactions. To normalize the measurements of the polarization-depending parameters, the value of the target polarization is always determined with a nuclear magnetic resonance (NMR) system. A requirement for the NMR electronics is that the output varies linearly with the nuclear polarization of the target as this polarization is increased by microwave irradiation. Deviation from linearity can be a source of systematic error and estimates of the deviations are usually based on computer simulation of the NMR circuit (e.g., see the extensive descriptions in ref. [1,2]). It is very hard to verify the results of this modeling experimentally.

A second systematic error can originate from a non-uniformity of the polarization over the volume of the sample, which might be due to inhomogeneities in the microwave or particle beam irradiation. Because the NMR system samples different parts of the target with unequal weight, the NMR output can indicate a polarization that is different from the average value for the sample. The magnitude of this error can be estimated by using several configurations for the NMR pick-up coil. From measurements with a partly filled target space, deviations of 1 part in 35 were derived in ref. [3]. Sampling the target with two [4] or eight [5] NMR coils showed variations of a few percent.

Finally, a systematic error can arise from the temperature measurement near 1 K if the NMR system is calibrated with the thermal equilibrium (TE) method. The polarization of the nuclear spin system, that is in thermal equilibrium with the lattice, is derived from the Maxwell-Boltzmann statistics. This distribution contains the magnetic field and
After tuning the device in steps of 0.02 \( q^2 \), the determinants are calculated in Table 1. 

The change in the neutron scattering cross-section \( q^2 \) with respect to the beam (\( q^2 \)) on the target is measured over the appropriate range of \( q^2 = 0.2 \) to \( 4.2 \). The change in the neutron scattering cross-section \( q^2 \) on the target is measured over the appropriate range of \( q^2 = 0.2 \) to \( 4.2 \). The difference between the two cross-sections is then calculated as a function of the beam current. The difference is calculated as a function of the beam current. The difference is calculated as a function of the beam current.

The neutron scattering on the target is measured over the appropriate range of \( q^2 = 0.2 \) to \( 4.2 \). The difference is calculated as a function of the beam current.

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well theoretically by Ge and Svenne [17]. Their result for the angular dependence of $\Delta A$ leads in the laboratory reference frame to
\[
\frac{dN}{d\theta} = \frac{dA}{d\theta} = 0.0004/\text{deg},
\]
from which a correction of 1.5% follows in view of
\[
\frac{dA}{d\theta} = -0.0284/\text{deg} [12].
\]
The neutron beam polarization $P_N$ is derived from the proton beam polarization that is measured with the polarimeter in the beam line:
\[
P_N = P \sqrt{r^2 + r'^2}.\]

Here, $r_L$ and $r'_L$ are the Wolfenstein $p-n$ polarization transfer coefficients after correction for final state interactions. These parameters are obtained from phase shift analyses of the available scattering data. In the analysis by Bugg et al., [11] a value $0.731 \pm 0.044$ is derived for $\sqrt{r^2 + r'^2}$. The work of Arndt et al. [12] gives $0.784$ based on all available scattering data and $0.787 \pm 0.013$ if the data set is restricted to the energy interval between 450 MeV and 550 MeV. The Saclay–Geneva phaseshift analysis yields $0.748$ [13]. A fair representation of these four results seems to be the average $0.763 \pm 0.013$, where the error is taken from the analysis of Arndt et al.

This error is treated below as systematic. Our data were collected during four runs that were each about three weeks in duration. Once a week a TEC calibration of the NMR system was obtained. Every day the scattering asymmetry was measured for about four hours with a polarized target and an unpolarized beam. The target was in a magnetic field of 0.257 T and at a temperature of about 60 mK. Consequently, the polarization decay times were around 150 hours which led to average polarizations of approximately $0.8$. For the part of the measurement with an unpolarized target, the only change in the set-up was an increase of the target temperature to about 0.8 K where an upper limit for the decay time of a few seconds was measured. For about 15 hours, alternating every few minutes, polarized and unpolarized beam was scattered from the target. The average neutron beam polarizations were about 0.5.

In table 1 the average values for each run are listed. The statistical error in the proton beam polarization is negligible [9]. A systematic error of 1% arises from the uncertainty in the analyzing power [7]. The ratio of the derivatives is obtained from an analysis of the scattering data that is described elsewhere [14]. The errors are statistical. The error in the target polarization $P_T$ from the NMR measurement is mainly determined by the uncertainty in the thermal equilibrium calibration which contains two components of about equal size. These are the absolute temperature calibration of the resistance thermometers and the long term (typically 1 week) stability of the NMR set-up.

The weighted average of the four measurements of the polarization ratio $R$ is 0.976. Including the 1.5% difference in the derivatives of the analyzing powers, gives the final result $0.961 \pm 0.024 (\pm 0.027)$. The systematic error of $\pm 0.027$ is due to the spin transfer parameters $(0.017)$ and the $p-p$ analyzing power $(0.010)$. It is obvious that the results from both techniques to measure the polarization agree very well. This shows that our NMR technique provides results that are free of systematic errors on the 4% level.

This work was supported by the National Research Council of Canada and the Natural Sciences and Engineering Research Council of Canada.
Table 1: Comparison of the Target Polarizations that are Obtained From the Neutron Scattering and From the NMR Measurements.