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# A Proton Polarimeter for Beam Energies below 300 keV

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## Abstract

A nuclear polarimeter based on the low energy analyzing power of the $^{6}Li(p,^{3}He)\alpha$ reaction has been developed and tested for proton energies below $E_p$=300 keV. The polarimeter uses a $^{6}LiF$ target evaporated on a water cooled tantalum backing. The target is observed at backwards angles by four silicon surface barrier detectors. The energy dependence of the analyzing power under $130^0$ for the $^{6}Li(p,^{3}He)\alpha$ reaction has been determined down to 200 keV. Spin rotation has been observed via a magnetic field incorporated in a Wien filter demonstrating that the polarimeter is operational.

(submitted to Nuclear Instruments and Methods)

## 1. Introduction

The development of polarized ion sources at large accelerator facilities like TRIUMF has made it desirable to determine nuclear polarizations at the energy of the terminal extraction voltage, thus avoiding expensive and time limited accelerator runs. For this reason a low energy proton polarimeter based on the analyzing power of the $^6Li(p,^3He)\alpha$ reaction[1] has been developed in which the polarization of the proton beam can be deduced by observing a mirror (left-right) asymmetry of the emanating $^3$He particles .

At present a continuous optically pumped proton ion source (OPPIS) [2] is under development at TRIUMF; in addition there is also an operational Lamb shift type polarized ion source available [3]. Both ion sources are housed in separate terminals extracting an $H^-$ beam at about 290 kV, the injection energy of the cyclotron. To take advantage of the well understood properties of the Lamb shift source the polarimeter has been installed in a way that beams from both sources can be accepted by the polarimeter. An overview of the ion source system and the polarimeter set-up is presented in fig. 1.

In the extraction beam lines of both the Optically Pumped as well as the Lamb shift source Wien filters are located to orientate the nuclear spin in an optimal way for the injection into, and later extraction from the cyclotron which by itself, as a matter of fact, causes a nearly $90^0$ rotation of the proton spin. No additional magnetic elements are part of the injection beam line of the cyclotron this way conserving the spin direction achieved at the exit of the Wien filter.

## 2. The Polarimeter Set Up

### *2.1. Mechanical Properties*

The polarimeter (fig. 1) is housed in a modified scattering chamber* with four 150 mm$^2$ surface barrier detectors at $110^0$ and $130^0$ in left (up) and right (down) positions, respectively. The detectors are mounted onto aluminum housings with cylindrical observation canals (1cm diameter). The detector housings are connected to a plate which is mounted to the chamber lid. This detector plate contains a multitude of positioning holes. Microdot cables connect the detectors to feedthroughs positioned above the detector plate.

In addition to the detectors the detector plate also has two beam collimators attached. These collimators have 4 mm molybdenum inserts restricting the beam diameter to about the same size. The molybdenum inserts are held in place by stainless steel holders which are mounted via insulating teflon stands to the detector plate.

Typical pumping pressures achieved with a turbo pump are around $10^{-6}$ torr.

*kindly donated by G.Roy of the University of Alberta

A target ladder able to hold up to 5 water cooled targets forms part of the polarimeter. The targets themselves are 0.1 mm tantalum sheets with the material of choice evaporated onto a layer of about 10-20 $\mu g/cm^2$ thickness (several materials) equivalent to a stopping power of about 10 keV for the proton beam [4] †. The target backings are water cooled. The water flow (fig.1) passes through the centre of the moving shaft, the copper frame of the single targets and a backflow block. The target frames are separable and exchangeable against each other. The target shaft can be moved and positioned through an O-ring seal by a mechanism based on two threads and two guiding rods. The target positions were aligned with a telescope and are marked on an outside scale. The target ladder is electrically insulated from the scattering chamber and serves as a Faraday cup in the determination of the beam intensity.

Beam current readings on the target ladder were checked with several bias settings and polarities and, in addition, compared to a reading obtained at a Faraday cup close to the entry of the polarimeter. With a collimator bias of +300V and a ladder bias of +600V the sum of the collimator and ladder current matched closely the one read at the Faraday cup in front of the polarimeter. However, the absolute current reading does not contribute to the functioning of the polarimeter, but solely serves for beam tuning and provides some estimates on reaction yields.

The scattering chamber has two viewing ports allowing for the observation of the target condition. In addition, a MgO screen was evaporated on the return flow block of the target ladder allowing the direct observation of the beam spot.

The scattering chamber has been mounted in two positions: (i) with the scattering plane horizontal, (ii) with the scattering plane vertical. The orientation of latter one is close to the spin orientation for injection into the cyclotron and ideal for beam extracted from the Lamb shift source with the Wien filter being switched off (fig.1).

### *2.2. Electronics Set Up*

Four silicon surface barrier detectors with 150 m$^2$ surface area and 100 $\mu m$ sensible depth are used to observe the charged particles emanating from the target. Each of the detectors is connected to a preamplifier (ORTEC 109A) and a main amplifier (0.5 $\mu s$ shaping time). Signals from the main amplifier are fed for diagnostic purposes into a multichannel analyzing system. This system consists of an eight channel router, a MCA card and a 286 IBM clone. An overview of the electronic setup is provided in fig. 2.

For discrimination the signals of the 130$^0$ detectors are fed into timing single channel analyzers, their logical output for pulse shaping put into a quad single channel discriminator and successive counters. Due to a lack of equipment most subsequent data were taken only at 130$^0$.

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† Fabricated by AECL, Chalk River, Canada

The discrimination levels of the timing single channel analyzers are determined via a delay amplifier and a linear gate. The discrimination levels are periodically checked.

Single channel discrimination of the detector signals turned out to be necessary because the router/multichannel analyzer system delivered results which were dependent on the counting rate.

The current on the target ladder is optimized with an electrometer or, during the run, observed with a charge integrator. A timer controls both the charge collection as well as the counter recording charged particle events.

## 3. Particle Energy Spectra

There are two kinds of targets used in low energy nuclear reactions yielding charged particles: (i) thin transmission targets and (ii) observation under back angles of thin target materials on the surface of thick backings which do not transmit the beam. The first method suffers from current limitations (about 100 nA for 300 keV protons), unlike the second method which excludes observation at forward scattering angles (at a symmetric detector situation) and produces large counting rates in the detectors by backscattered beam particles. However, the peaks in analyzing power of the $^6Li(p,^3He)\alpha$ reaction (Q=4.018 MeV) [1,5] and the $^9Be(p,\alpha)^6Li$ reaction (Q=2.126 MeV) [6,5] are at laboratory angles of around $90^0$ allowing in both cases the observation of reaction products at backward angles with a considerable analyzing power.

For this reason and the ease of handling solid targets were tested at first and turned out to be satisfactory in the case of the $^6Li(p,^3He)\alpha$ reaction. Fig. 3 a-c show the respective spectra of the $^6Li(p,^3He)\alpha$ reaction (300 nA, a) and the $^9Be(p,\alpha)^6Li$ reaction (b,c) as observed at $130^0$ degrees, the latter one for low (300 nA,b) and high (600 nA,c) currents. It should be noted that the cross section for the $^9Be(p,\alpha)^6Li$ reaction is about 7 times as high as for the $^6Li(p,^3He)\alpha$ reaction at $E_p = 300$ keV.

For the $^9Be(p,\alpha)^6Li$ reaction pile up of proton signals due to its relatively low Q-value starts to influence the background in even the highest energy $\alpha$ peak. In principle this problem could be resolved by adequate fitting and analyzing procedures. However, with the background free spectra resulting from the $^6Li(p,^3He)\alpha$ reaction and clear indications that the multichannel system used had counting rate dependent features (see above) this development was abandoned.

To lessen the number of protons impinging on the Si surface barrier detector a 1$\mu$m nickel foil has been placed in front of the detectors resulting in energy spectra like fig. 4 for a 2 $\mu$A beam for the $^6Li(p,^3He)\alpha$ reaction.

The $^3$He and the $\alpha$ peak are clearly separated from each other and the low energy parts of the spectrum. Signals of impinging protons are very close to the electronic noise. This configuration is used in the final polarimeter set up with the $^3$He peak being discriminated as described above.

In addition, 2 $\mu$m nickel foils have been tried. The $^3$He peak becomes very broad though separable, while the $\alpha$ peak shows a tail merging with the electronic noise.

## 4. Analyzing Properties of the Polarimeter

### 4.1. *Observation of Asymmetries*

The polarization of a proton beam can be observed by a mirror asymmetry of events in detectors placed symmetrically around the beam axis provided the reaction in question has some analyzing power and the spin of the proton has a perpendicular component relative to the plane defined by the two detectors and the beam spot. Such asymmetries have been observed by comparison of unpolarized and polarized beams from the Lambshift source. With an analyzing power $A_y$ of 21% as extrapolated from ref.[1] for $E_p$= 280 keV and the measured asymmetry $A_s$ a polarization ($P = \frac{A_s}{A_y}$) of about 80% has been found for the two spin states of this source and, in addition, confirmed by TRIUMF cyclotron runs using the TRIUMF high energy polarimeter.

For the polarimeter mounted in the horizontal position (see above) the dependence of the experimental asymmetry on the Wien filter current, i.e. magnetic field, was observed in the case of the Lamb shift source. In this case the direction of the magnetic field of the Wien filter is oriented $12^0$ with respect to the horizontal. Fig. 5 displays the data for the spin "down" position demonstrating a nearly $90^0$ rotation of the spin for about 11 A of current. The asymmetry observed at no current is attributed to the remnant field of the Wien Filter.

In the course of the measurements a built up of carbon deposits on the $^6LiF$ targets and as well optical, colour changes were observed. To test the energy dependence of the analyzing power and the sensitivity of the polarimeter to deposits, measurements of the analyzing power at $130^0$ have been performed down to 200 keV. In addition, the reaction yield was recorded to gain insight into the usefulness of the polarimeter at lower beam energies and determine the effects of yield deterioration for possible surface deposits on the target. Fig.6 displays the energy dependence of the analyzing power as well as the reaction yield. Both curves show a nearly linear dependence of sufficiently low slope which infer that deposits of some kilovolt thickness are not a major concern. In fact, long term runs did not show degradations in the yield or the measured asymmetry.

### 4.2. *Statistics and Measuring Times*

For background free spectra the time $t$ to achieve a relative error $\Delta_P$ in the determination of the polarization P with an analyzing power $A_y$, a detector efficiency $\epsilon$, and a current I is

$$t = \frac{1}{\Delta_P^2 \, P A_y \epsilon I}. \tag{1}$$

Fig. 7 displays the measuring times necessary for several beam currents utilizing the energy dependence of the detector efficiency $\epsilon$ and the analyzing power $A_y$ as determined in fig. 6, and assuming 50% beam polarization and a 1% relative error required. Certainly, measuring times of several minutes are now necessary for currents around 1 $\mu A$. However, for somewhat higher currents the use the present polarimeter down to 150 keV of proton energies seems possible. Plans to improve the polarimeter usefulness by doubling the solid angle as well as the number of channels are under way.

## 5. Conclusion

An in-beam proton polarimeter based on the $^6Li(p,^3He)\alpha$ reaction has been constructed and shown to be working at beam energies as low as 200 keV for currents up to 2 $\mu A$.

At present a more compact version of the polarimeter is under construction using larger solid angles and two channels of observation (about $110^0$ and $130^0$). In addition it is planned to make the target ladder as well as the collimator retractable so that the proton beam can be transmitted without losses into the TRIUMF cyclotron. By mounting a cryo pump close to the polarimeter set up it is also planned to reduce the amount of deposits on the target.

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## Figure Captions

1. The TRIUMF low energy nuclear polarimeter. Shown is the approximate position of the two ion sources (Lamb shift and optically pumped) as well as two views of the polarimeter. For further details see text.

2. The electronics set up of the TRIUMF low energy polarimeter. For a description see text.

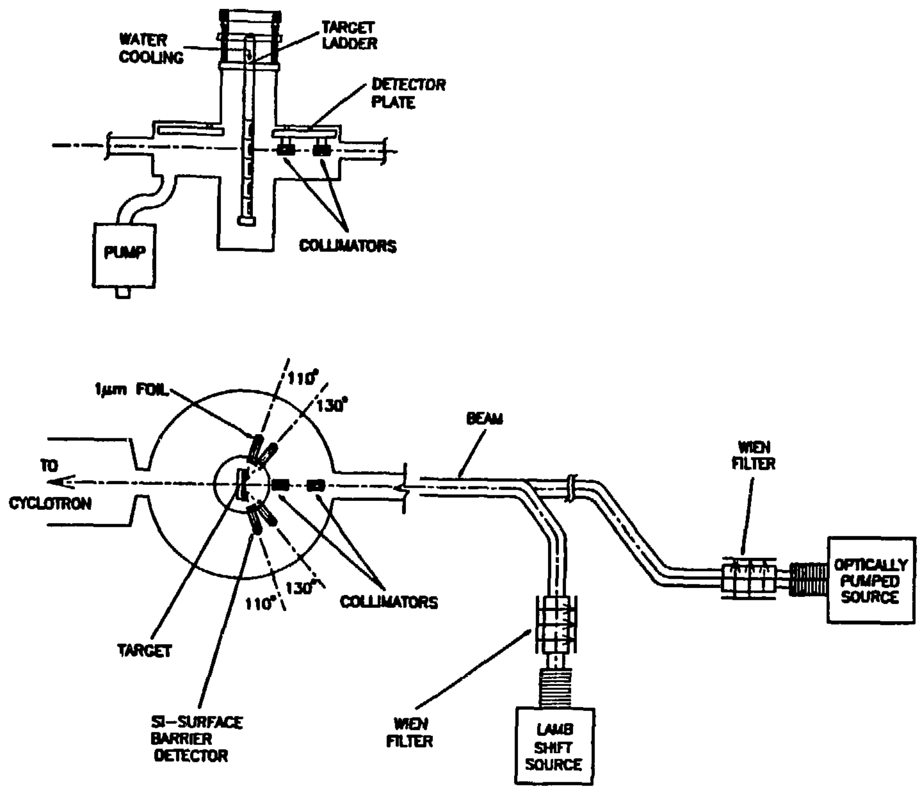
3. The particle energy spectra of the $^6Li(p,^3He)\alpha$ reaction (300 nA,a) and the $^9Be(p,\alpha)^6Li$ reaction under $130^0$ (b,c). In the case of the $^9Be(p,\alpha)^6Li$ reaction the deuterons emanating from the $^9Be(p,d)^8Be$ reaction are also visible. Figure b and c display the $^9Be(p,\alpha)^6Li$ reaction for different proton currents (300 nA, 600 nA.

4. The $^6Li(p,^3He)\alpha$ pulse height spectrum with $1\mu m$ foils in front of the detector.

5. The spin rotation in a Wien filter placed after the Lamb shift polarized source for different currents/magnetic fields in the Wien filter. The scattering plane of the polarimeter is orientated horizontally in this measurement.

6. The energy dependence of the a) analyzing power at $130^0$ (line to guide the eye) and b) the reaction yield between 180 and 284 keV as determined with the Lamb shift source. The cross section (line) is taken from ref [5].

7. The measuring times necessary in the present polarimeter for a 1% relative statistics as a function of the proton energy with 50% beam polarization assumed. The different lines refer to different beam currents as indicated. Analyzing power and detector efficiency as given by fig. 6 are assumed.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WIEN FILTER
LAMB SHIFT SOURCE

Fig. 1

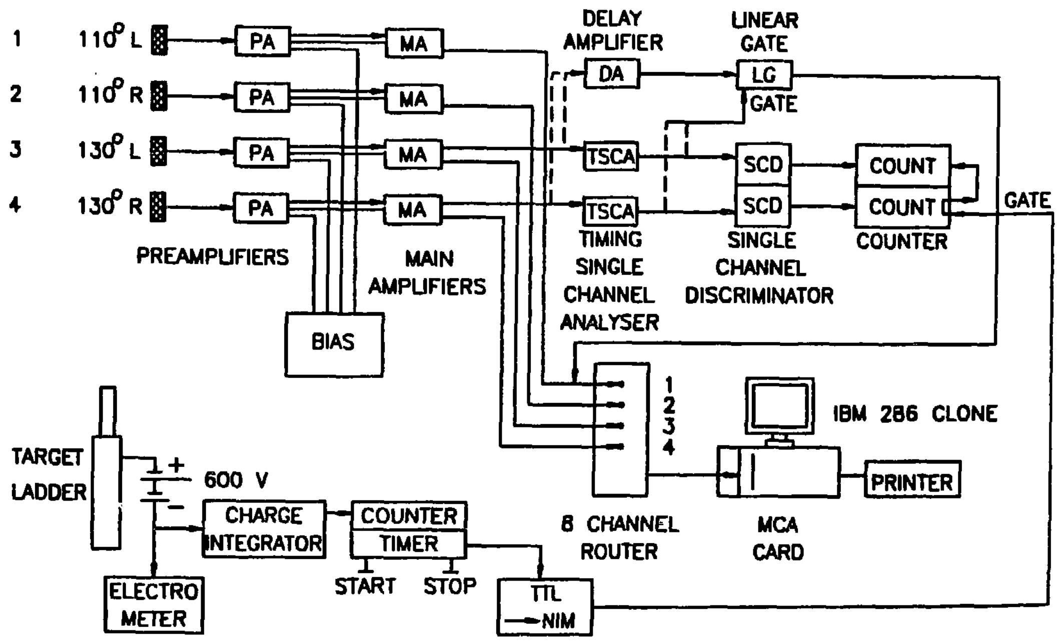
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Fig. 2

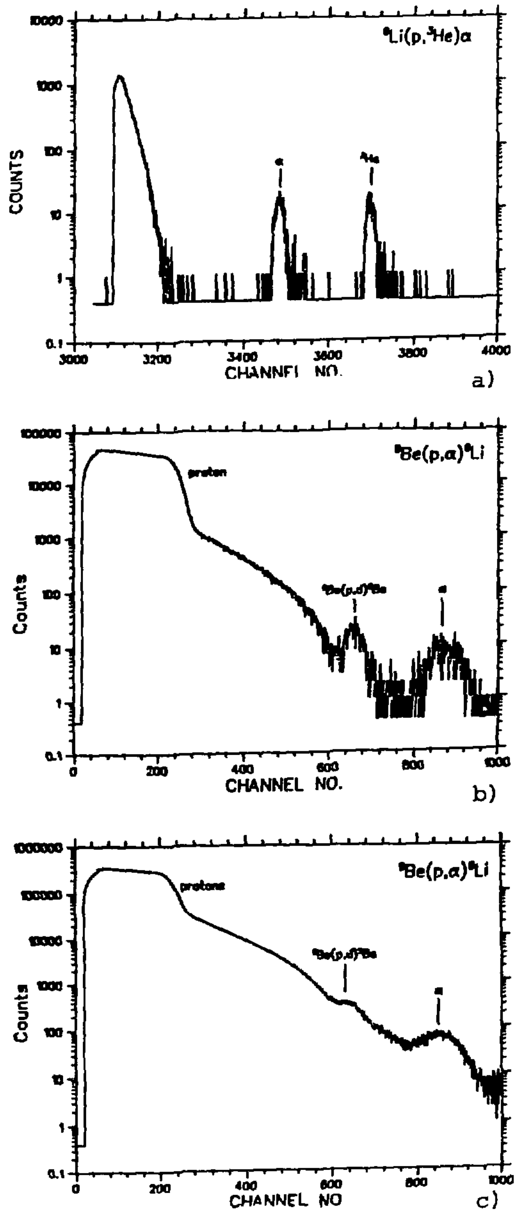


Fig. 3

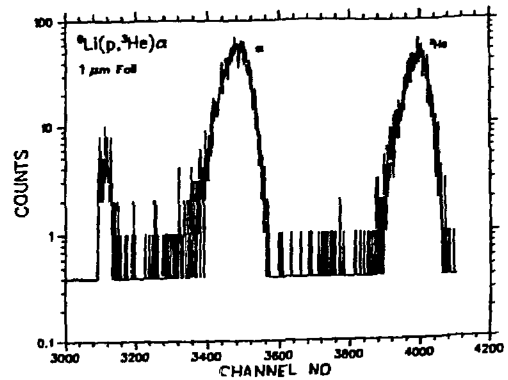


Fig. 4

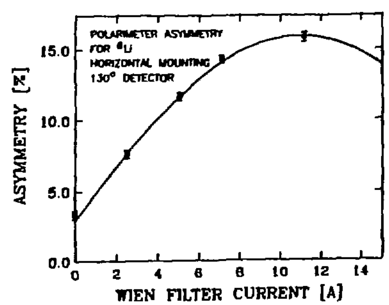


Fig. 5

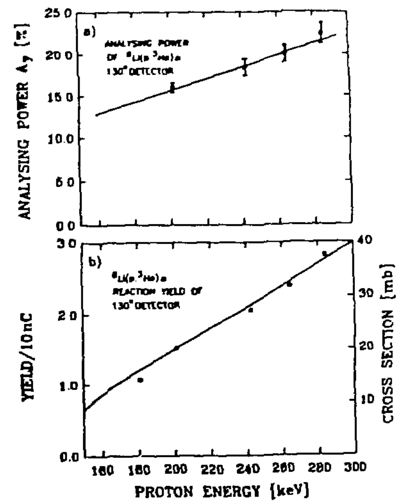


FIg. 6

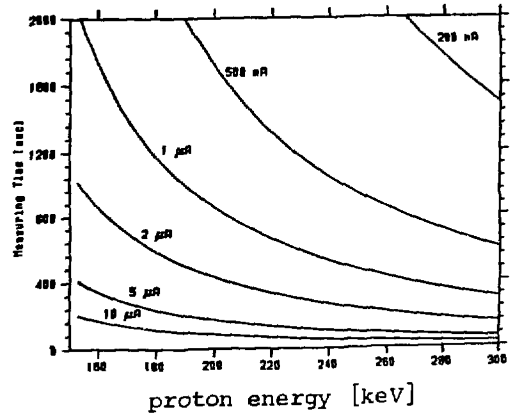


Fig. 7