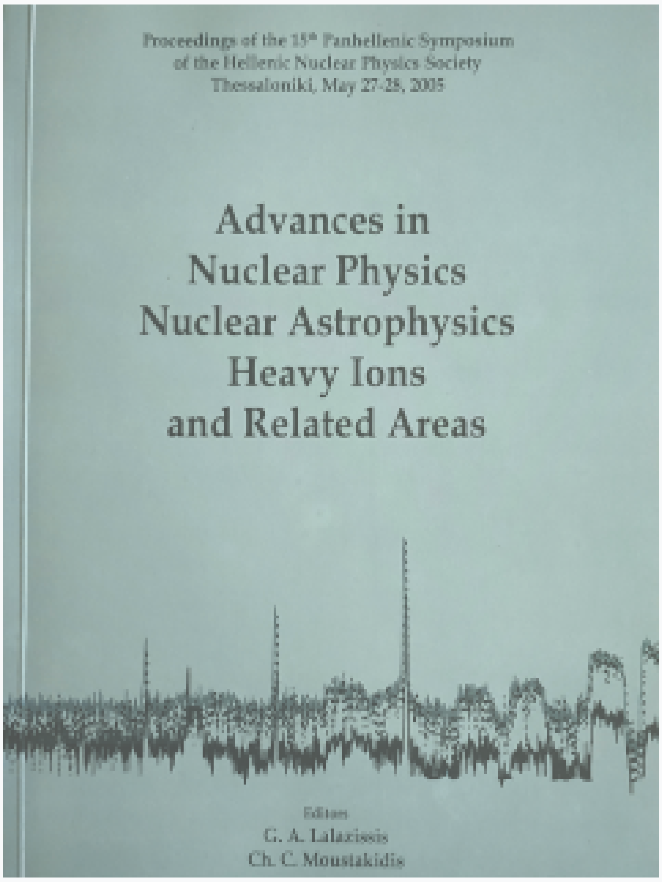
HNPS Advances in Nuclear Physics

Vol 14 (2005)

HNPS2005



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T. J. Mertzimekis, P. F. Mantica, A. D. Davies, S. N. Liddick, B. E. Tomlin

doi: [10.12681/hnps.2256](https://doi.org/10.12681/hnps.2256)

The proton-pickup reactions as a means to study the spin-polarization and the magnetic moments in $^{35,37}K$

T.J. Mertzimekis, P.F. Mantica, A.D. Davies, S.N. Liddick, B.E. Tomlin

National Superconducting Cyclotron Laboratory, Michigan State University
1 Cyclotron, East Lansing, MI 48823, USA

Abstract

Spin polarization in fragmentation reactions has been studied in several nuclei showing mainly that large polarization is produced at the *tail* of the fragments momentum distribution. Such polarization features are not so well known in pickup reactions, especially in studies of unstable nuclei, such as ^{35}K and ^{37}K. The spin polarization of ^{35}K and ^{37}K produced in single-proton pickup reactions at intermediate energies at the Coupled Cyclotrons at NSCL and the results for the ground-state magnetic moment involving the β-NMR technique are reported in the present work.

1 Introduction

Magnetic moments are extremely useful in studying a plethora of structural effects in nuclei. This is mainly due to the fact that the ground and excited states wavefunctions in a nucleus are extremely sensitive to the individual proton and neutron contributions. It is quite common to deduce the proton and neutron content of the wavefunction of a state by simply measuring its magnetic moment. Furthermore, in mirror nuclei, the isoscalar part of the spin expectation value is directly connected to their magnetic moments. This is valid only if the isospin is a good number, thus providing a nice tool to test any symmetry breaking occurring due to configuration mixing or vector meson currents existing in the nucleus, shielding the "bare" nucleons [1].

Moments of mirror nuclei of isospin $T = 1/2$ are known up to mass $A = 43$. However, measurement for mirror pairs of $T = 3/2$ are very rare. As of today, only mass 9 and 13 mirror pair magnetic moments are known, ^{9}Li-^{9}C and ^{13}Be-^{13}O, respectively. The reported anomaly in ^{9}C [2] results in a spin expectation value off the Schmidt limits, signaling the importance of structural effects in both the magnetic moment value and the symmetries in the nucleus. A measurement of the magnetic moment in the $T = 3/2$ ^{35}K nucleus will extend the knowledge to higher masses and will test these symmetries, since the mirror nucleus, ^{35}S, ground state magnetic moment is known for a long time [3].

The measurement of both magnetic moments involves the β-NMR technique which requires the presence of spin-polarized nuclei. Both ^{35}K and ^{37}K isotopes, produced in single-proton pickup reactions are studied with this technique. The spin polarization was studied extensively in terms of the momentum acceptance of the produced fragments. Pickup reactions at intermediate enerrgies are not so well-known in terms of the produced polarization and it is interesting to compare them to fragmentation reactions, since they will play a role in future applications of radioactive beams, such as in experiments being planned for RIA [4].

In the present article, the investigation of spin polarization in proton pickup reactions at intermediate energies and the results of the subsequent measurement of the ground state magnetic moments in ^{35}K and ^{37}Kare reported.

2 Experimental Technique

A primary beam of ^{36}Ar was accelerated from the coupled cyclotrons at NSCL at an energy of 150 MeV/nucleon, which impinged a Be target of 594 gr/cm^2 producing secondary beams of ^{35}K and ^{37}K, using two different single-proton pickup reactions. The pickup products were separated from the rest of the fragments produced in the reactions by the A1900 fragment separator [5] and were delivered to the β-NMR apparatus for the magnetic moment measurements. An angle was imposed on the beams to enhance the production of spin polarization. The β-NMR apparatus has been described in detail elsewhere [6]. Fig. 1 outlines the main components of the system. It consists of a large dipole magnet providing the static field, normal to the beam axis. Two beta telescopes are contained within the poles of the magnet, each consisting of a thin and a thick scintillator to detect the β particles from the subsequent β decay of the secondary beams. Within the telescopes, a pair of Helmholtz-like *rf* coils was placed to provide the *rf* field necessary for the β-NMR measurement. The direction of the *rf* field was perpendicular to both the static field and the beam axis. Within the coils, a KBr catcher foil was placed at the center of the setup with main purpose to catch the secondary beam products, where they would decay. The KBr crystal was selected because the spin relaxation time of the implanted ions in the crystal lattice is long enough to have any effect on the spin polarization of the ^{35}K and ^{37}K ions.

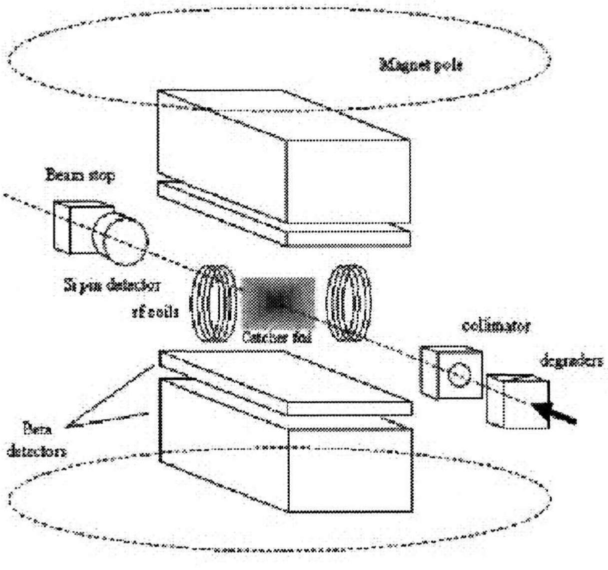

Fig. 1. An outline of the β-NMR main components.

Spin polarization was studied in terms of the momentum acceptance of the pickup products in the A1900. For this measurement, the *rf* field remained off, while the static magnetic field was switched on and off every 60s to a maximum value of 0.1 T while on. The polarization was deduced by measuring the asymmetry in the counts of the β telescopes. The asymmetry ratio, R, is defined as:

$$R = \frac{N_1(180°)/N_2(0°)}{N_1(0°)/N_2(180°)} = \frac{1+AP}{1-AP} \tag{1}$$

where A is the asymmetry of the β decay and P the polarization. The measurement completed for $\Delta P/P$=0, 0.5% in both experiments.

The magnetic moment was deduced after switching to the settings where maximum asymmetry was observed for each case. The static magnetic field was switched on and off with a 60 s cycle at a maximum field of 0.3 T and the *rf* was also on with a frequency modulation of $\pm$10 kHz. In the case of ^{37}K the cyclotron was also forced to pulse 60 s ON/60 s OFF to avoid the influence of the long-lived contaminants in the measurement. The data were collected with typical electronics used in this type of experiments and the results were extracted by both online and offline analysis. Part of the results are already published [7].

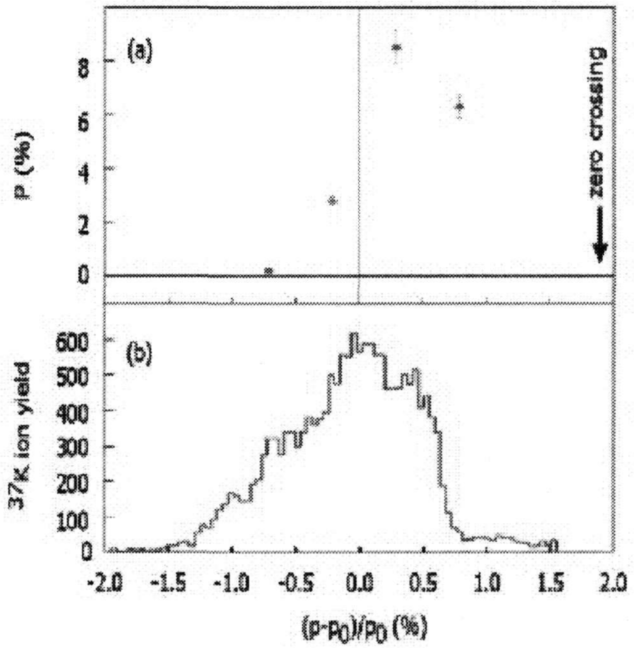

Fig. 2. Spin polarization of ^{37}K vs. the momentum distribution.

3 Results and Discussion

The results from the measurements of spin polarization as a function of the outgoing momenta distribution of the pickup products in the case of ^{37}K are presented in Fig 2. It is apparent that spin-polarization approaches a maximum value near the peak of the momentum distribution. The maximum value, occurring at $\Delta p/p = 0.5\%$, is 8.5%, a relatively large value. This value is similar to several measurements with fragmentations reactions. For the case of ^{35}K the measured asymmetry is smaller ($\sim 3\%$). There is no way to translate this result to polarization directly because the asymmetry parameter, A, which is deduced from the level scheme is unknown. However, the asymmetry obtained shows the same sign with the asymmetry in ^{37}K and it is smaller. This is expected for a $T = 3/2$ nucleus which has two fewer neutrons. During the proton-pickup reaction, neutron evaporation becomes more pronounced, reducing the overall presence of spin polarization in the reaction products. As a consequence, the results supports the main advantage of the pickup reactions compared to the fragmentation reactions, which is that they are usually cleaner, produce relatively large polarization and are an efficient tool for studies with polarized beams. Furthermore, the fact that the maximum of polarization occurs near the center of the momentum distribution is

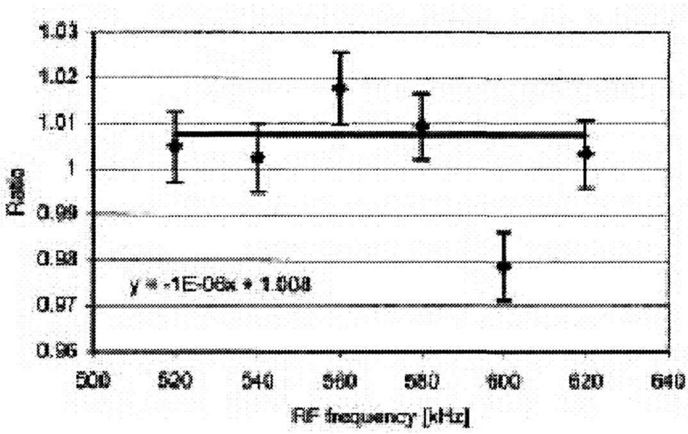

Fig. 3. Results from the frequency sweeps. The baseline was determined from separate calibration runs with a ^{22}Na source. The resonance is located 3.2σ away from the baseline.

an essential feature that can provide better statistics than similar studies with fragmentation reactions where maximum polarization is obtained at the tail of the momentum distribution.

Once the polarization profile was determined for either isotopes, the maximum polarization setting was selected to use the β-NMR technique to measure the ground state magnetic moments. The result for the case of ^{37}K has been published elsewhere [7]. For the case of ^{35}K, frequency scans in the area between 520 and 620 kHz with a frequency modulation of ± 10 kHz resulted in locating a resonance point at frequency of $f_0 = 600$ kHz (see Fig. 3). The region was chosen in accordance with a previously, rather non-precise, measured magnetic moment in ^{37}K [8]. The present result falls in range with the previous measurement and improves on the error significantly. It should be noticed that the error in the value of frequency where the resonance is located originates from the frequency modulation step.

The resonance frequency corresponds to a magnetic moment of $\mu(^{35}\mathrm{K})$=0.3920(66). The spin expectation value can be calculated, since the mirror nucleus magnetic moment is -0.284(40). The final value can be compared to the rest of the available data for mirror nuclei and it falls well between the extreme Schmidt limits, confirming the non-existence of any anomalies in the $A \sim 35$ region. This mirror pair is the heaviest known today urging for more measurements in the $T = 3/2$ nuclei. Moreover, the magnetic moment result agrees with the theoretical consideration that the wavefunction is dominated by the existence of protons in the $d_{3/2}$ subshell. Previous shell-model calculations with effective charges predicted a value of $\mu_{USD}^{eff} = 0.365$ and the experimental result lies within 20% from this prediction.

4 Summary

The experimental results for spin-polarization measurements at intermediate energies proved the efficiency of the single-proton reactions in producing spin-polarized nuclei at the peak of the momentum distributions. The magnetic moments of the ground states in ^{35}K and ^{37}K were determined by means of the β-NMR technique. The results agree with the shell-model theoretical predictions for both the structure of these nuclei and the symmetries in mirror pairs investigated by means of the spin-expectation values.

The authors would like to thank the NSCL staff for their assistance in providing beams for the two experiments. The work was partially supported by NSF grants No. PHY-01-10253 and No. PHY-99-83810.

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