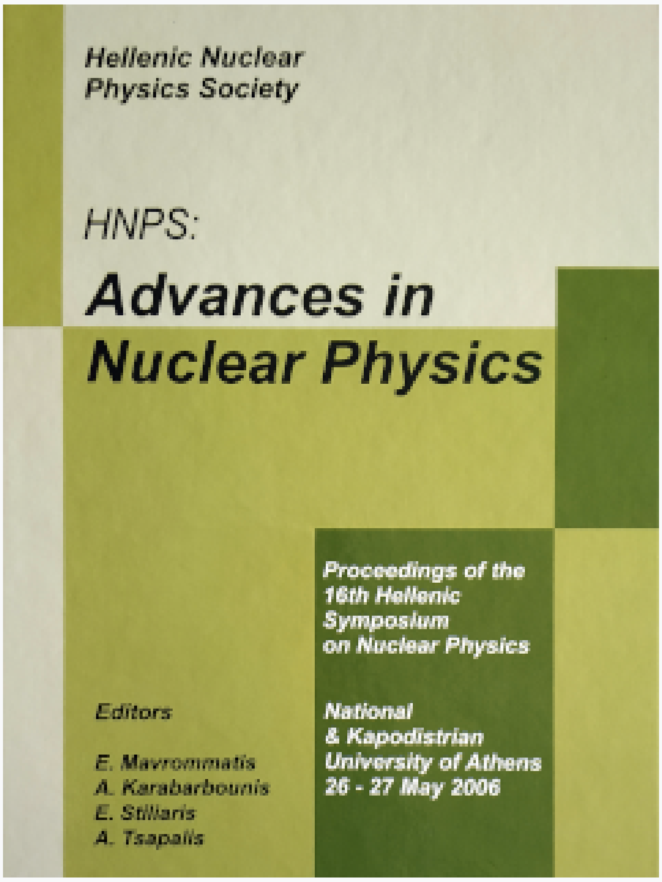
HNPS Advances in Nuclear Physics

Vol 15 (2006)

HNPS2006



Probing the Tz=–3/2 nuclei via magnetic moment measurements

T. J. Mertzimekis

doi: [10.12681/hnps.2631](https://doi.org/10.12681/hnps.2631)

Probing the $T_z = -3/2$ nuclei via magnetic moment measurements

T. J. Mertzimekis[a]

[a]*National Superconducting Cyclotron Laboratory, Michigan State University, 1 Cyclotron, East Lansing, MI 48824, USA*

Abstract

The neutron-deficient region of the nuclear chart provides unique opportunities to study several important effects near the proton-drip line pertaining to nuclear structure and nuclear astrophysics.

The present article focuses on nuclei with isospin $T_z = -3/2$ in terms of the spin polarization and the ground state magnetic moment. An experiment on measuring the ground state moment pf ^{35}K by employing the β-NMR technique leads to several interesting results that pose challenging questions to theory.

1 A little background

The west side of the nuclear chart presents unique opportunities to explore several nuclear structure effects where the number of protons is larger than the number of neutrons and Coulomb interaction is expected to play an important role, especially as the nuclear system grows heavier.

The dipole magnetic moment of the nucleus is a property of the nucleus than can be used as a special tool to study such effects. This is due to its explicit dependence on the proton and neutron components of the wavefunction. In the past, several measurements have been completed for stable nuclei employing a variety of techniques exploring interesting structural properties. Modern facilities, such as the National Superconducting Cyclotron Laboratory in Michigan State University, have advanced and are now able to provide radioactive beams closer or almost on the drip lines. In that way, new perspectives are offered to explore the nuclear landscape at its extremes.

The proton-drip line has recently attracted a lot of attention from both nuclear structure and nuclear astrophysics. In that framework, magnetic moment measurements may provide priceless information. Also, by studying additional properties of the neutron-deficient nuclei in that mass region, such as the polarization induced in fragmentation or charge-pickup reactions, conclusions can be drawn about the nature of phenomena occurring during nuclear reactions.

A recent study of ^{37}K nuclei ($T_z = -1/2$) [1] exhibited many of these properties during a measurement of the spin polarization and the magnetic moment. While ^{37}K has only a proton more than the number of neutrons, the neighboring ^{35}K is a $T_z = -3/2$ nucleus with three protons more than neutrons. The mirror nucleus (^{35}S) has a known magnetic moment [2] which may be combined with a measurement in ^{35}K to provide interesting data to test the isoscalar spin symmetry.

The behavior of $T = 3/2$ nuclei compared to the ones with $T = 1/2$ as mass grows heavier is an additional feature that can be examined in terms of mirror pair data. Buck *et al.* have developed a formalism to look into data from nuclei for both values of isospin. Until now there has been a very limited number of data available for the case of $T = 3/2$ nuclei at a level where no comparison could be realized. With the completion of the magnetic moment measurement in ^{35}K and an also recent measurement in $A = 17$ mirror nuclei, a first step to explain the systematic trends is attempted.

2 Experiment and results

The polarization/asymmetry measurement following a charge-pickup reaction as the one in the present experiment has been described recently in detail in Ref. [1,3]. With respect to the ^{37}K case, where the polarization was estimated to the relatively large amount of 8.5%, the situation in ^{35}K is somewhat less straightforward since the level scheme does not allow for a confident estimate of the asymmetry parameter, A, determined directly from theory. Therefore, the polarization, P, which is related to the asymmetry parameter and the asymmetry ratio, R, according to Eqn. 1, can not be directly determined. However, an estimate of R is equivalently significant to offer some understanding of the charge-pickup mechanism involved in the reaction.

$$R = \frac{1 - AP}{1 + AP} = \sqrt{\frac{N_1(0°)_{on} N_1(180°)_{on}}{N_1(0°)_{off} N_2(180°)_{off}}} \tag{1}$$

$N_{1,2}$ represent the counts collected in two beta telescopes placed perpendicular to the beam direction at 0° (UP) and 180° (DOWN), while the large dipole magnet of the β-NMR setup was pulsed ON/OFF in a 60s cycle.

The maximum value of the asymmetry ratio was measured at momentum acceptance Δp/p=1% and a beam angle of +2°. The final result for this setting of the delivered secondary pickup products was $R = 2.8 \pm 0.8\%$ [3].

Once the asymmetry ratio was determined, a measurement using the β-NMR technique followed with the apparatus adjusted to the settings ensuring maximum asymmetry, i.e. 1.0% and +2°. The dipole magnet was switched ON permanently and an a *rf* field, perpendicular to the static magnetic field was used to scan through a broad frequency range (500-620 kHz) with a frequency modulation of ±10 kHz. At the point where the frequency matched the energy difference of the hyperfine magnetic substates distributed unequally due to the polarization of the beam, a spin-flip was induced and a resonance was observed in our spectra. After several *rf* scans to obtain statistically significant data (3σ), the resonance was determined at a frequency of 600(10) kHz. This result corresponds to a g factor of 0.261(5), which leads to a ground state magnetic moment $\mu = 0.392(8)$ since the spin of the ground state in ^{35}K is equal to 1/2.

3 Discussion

An important property of magnetic moments in mirror nuclei is their connection to the isoscalar part of the Pauli spin operator, $\sum_i \sigma_z^i$ [4]:

$$\mu(T = +T_z) + \mu(T = -T_z) = J + (\mu_p + \mu_n - \frac{1}{2})\langle \sum_i \sigma_z^i \rangle \tag{2}$$

where $\mu_{p(n)}$ is the proton(neutron) magnetic moment of the state with spin J. Any potential deviations of the values of the above operator away from the extreme limits posed by the single-particle considerations provides a candidate for testing symmetry violations of understanding new structural phenomena. The one and only (so far) example of mirror nuclei that presents such a deviation is the $T_z = 3/2$ ^{9}Li-^{9}C pair, which offered understanding to the "unusual" wavefunction of the neutron-deficient ground state of carbon (proton-to-neutron = 2:1). Similar investigations in higher masses is expected to contribute significantly to the understanding of nuclear systems along the proton dripline. As Z grows the Coulomb force becomes stronger and is expected to play a much stronger role. The heaviest $T_z = 3/2$ mirror pair to-date is the $A = 35$ pair. The measurement of the ground state magnetic moment of ^{35}K can be combined with the existing measurement of the corresponding moment in the mirror nucleus ^{35}S [2]. The result for the Pauli spin operator presents two characteristics of interest, as can be seen from Fig. 1. First, the isoscalar part of the spin operator value for the $A = 35$ mirror pair falls within

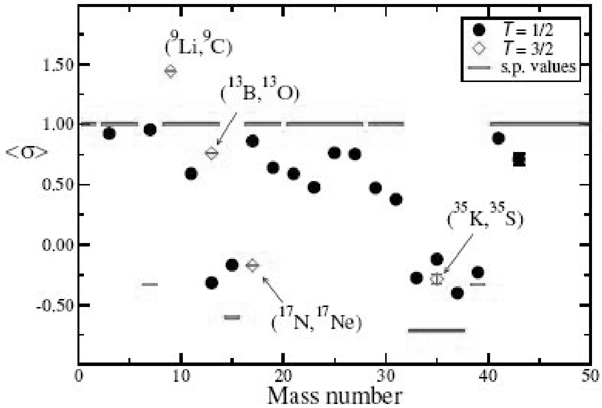


Fig. 1. Pauli spin operator values for $T = 1/2$ (solid circles) and $T = 3/2$ (open diamonds) mirror pairs. The solid lines represent the extreme limits based on the Schmidt magnetic moments

the extreme single-particle limits. Second and more interesting is the immediate observation that the value is *similar* to the corresponding one for the case of $T = 1/2$ mirror nuclei for the same mass. The reason this happens is still not quite clear.

The same argument holds by examining the newly collected data for $T_z = 3/2$ in the framework of the analysis by Buck and Perez [5]. The details are beyond the scope of this article, however, its main point is that the odd nucleons in the mirror nuclei are solely responsible for the magnetic moment of the whole nucleus. By plotting systematics of data in mirror pairs, the resulting plot (top part of Fig. 2) leads to a rather linear behavior. The important issue of this analysis is that the slope and intercept of the fitted straight line deviated significantly at a level of $\approx 5\%$ from the extreme single-particle limits.

The measurement of the g.s. magnetic moment of ^{35}K, together with a recent measurement in the $A = 17$ mirror nuclei provided two important points in studying the systematics for nuclear systems with $T = 3/2$. From the comparisons between the top and bottom figures is immediately striking that the $T = 3/2$ systems behave *similarly* with the $T = 1/2$ nuclei, as was also seen earlier in the totally independent analysis of the isoscalar part of the Pauli spin expectation value, a behavior that was not normally expected.

The reason why this happens is not clear, however, enlightenment is expected with more data accumulation for systems with an isospin value of $T = 3/2$. More data, of course, means that one has to count on measurements closer to the drip line and going towards heavier masses. At the same time, theory faces some new questions on the nature and Coulomb force that drive the structure of those extreme systems as the proton number is pushed to “difficult“ (from

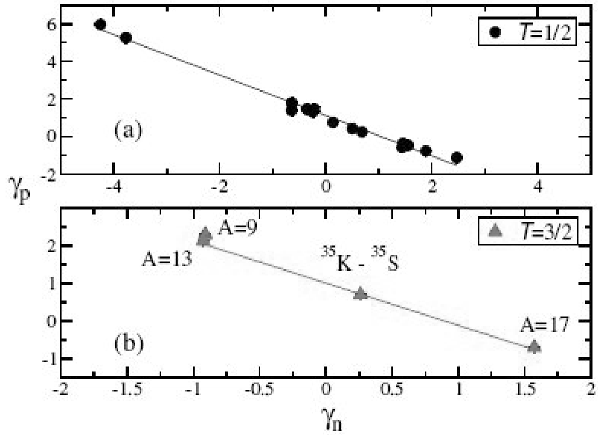


Fig. 2. Buck and Perez plot with all available data for $T = 1/2$ (top) and $T = 3/2$ (bottom) mirror pairs.

the technical point of view) limits.

The β-NMR technique is highly promising in that aspect, as promising as is the development of radioactive beams in satisfactory intensities in advanced facilities of the near future, such as RIA.

4 Acknowledgments

The author would like to acknowledge the financial support by NSF (grants No. PHY-01-10253 and PHY-99-83810)

References

[1] D.E. Groh *et al.*, Phys. Rev. Lett. **90**, 202502 (2003).

[2] B.F. Burke *et al.*, Phys. Rev. **93**,193 (1954).

[3] T.J. Mertzimekis *et al.*, Phys. Rev. C**73**, 024318 (2006).

[4] K. Sugimoto, J. Phys. Soc. Japan **34** (suppl.), 197 (1973).

[5] B. Buck and S.M. Perez, Phys. Rev. Lett. **50**, 1975 (1983).