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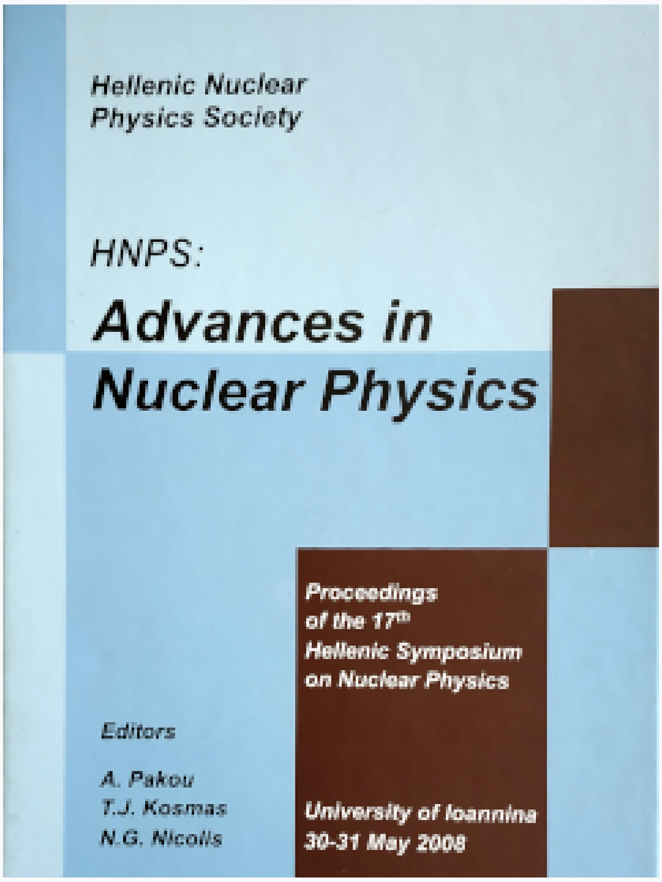

A study of the N=28 neutron shell via g-factor measurements in neutron-rich Cl isotopes

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A study of the N=28 neutron shell via *g*-factor measurements in neutron-rich Cl isotopes

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Abstract

A series of *g*-factor measurements in the Cl isotopes created as secondary radioactive beams at intermediate energies and employing the β-NMR technique have been recently carried out at GANIL. The results attempt to shed light on several open questions for the ground state properties of Cl isotopes, located just off the very interesting region of the *island of inversion*. Preliminary experimental results are presented and compared to shell-model calculations around N=28.

1 Introduction

The availability of radioactive exotic beams at large experimental facilities, such as GANIL, has recently opened the road for important nuclear studies on a wide number of nuclei that were not previously accessible. A large number of nuclear properties are now directly measurable by a number of novel or updated experimental techniques. In that direction, the magnetic dipole and electric quadrupole moments are important tools in understanding the structure of such nuclei as the proton-neutron ratio is driven to new extremes. The magnetic dipole operator is unique in the sense that it may provide crucial information on the proton and neutron contributions to the wavefunction in a nucleus, for either ground or excited states.

The observation of several interesting structural effects around the "*island of inversion*", where some nuclei exhibit inversion of the proton subshells order, as the neutron number reaches exotic values, indicates the evolution of shapes and magicity (1). The neutron-rich ^{43,44}Cl isotopes (Z=17) are located just off this mass region and their magnetic dipole moments of the ground states are largely unknown. Shell-model calculations involving the role of neutrons as the neutron number reaches the closed shell at N=28 are now available for Cl isotopes (2) providing a motivation for experiment to place a stringent test on theoretical predictions. Moreover, the application of the β-NMR technique on radioactive beams produced in fragmentation reactions has been applied successfully in the measurement of the magnetic moments of nuclei in this mass region (3; 4).

In the following paragraphs some preliminary results from the measurements of magnetic moments in ^{43,44}Cl isotopes will be reported and discussed.

2 Experimental Details

A ^{48}Ca beam was accelerated to 60A MeV by the cyclotrons in GANIL and impinged on a 500μm Be target. The fragments created by the collision were guided through the LISE fragment separator, where they were separated by setting appropriate values of the magnetic rigidity. In the present experiment, the neutron-rich ^{43,44}Cl isotopes were selected as secondary beams and directed to the β-NMR end station, where they were implanted and fully stopped in the center of a 2mm-thick, 45°-tilted with respect to the beam normal plane, NaCl crystal located in the center of the space between the poles of a large dipole magnet. Perpendicular to both the beam axis and the magnet poles was a *rf* coil in Helmholtz geometry surrounding the NaCl crystal.

A crucial requirement for the application of the β-NMR technique is the existence of polarization in the fragments. It is well known (5) that in fragmentation reactions the polarization is maximized at the tail of the fragment momentum distribution. Consequently, a full scan of the fragment momentum distribution was carried out in the first part of the experiment and subsequently a pair of horizontal slits was employed to only allow fragments with momentum around the tail of the distribution to reach the crystal, so that polarization gets a maximum. In addition, a 2° angle was imposed on the beams to enhance the fragment polarization. The final polarization was $\sim 2\%$.

Once the kinematical conditions and the polarization were set at optimum values, the secondary beams were implanted in the crystal. The spin-lattice relaxation time of the Cl isotopes in NaCl is long enough so that the implanted ions maintain their polarization till they finally β decay. The emitted β particles were detected by two β telescopes located perpendicularly to the beam axis, in front of the magnet poles. Each telescope consisted of a set of a thin (ΔE) and a thick (E) plastic scintillator. For a beam intensity of 2 enA the particle rate was averaged a value of $\sim$500 coincident ΔE-E events per telescope. Besides the plastic scintillators, one single-crystal and one dual-crystal γ detector were placed at $\pm 30°$ downstream, respectively, to monitor the γ

activity.

Once the polarization level was fixed, the static magnetic field was set to a constant value ($\sim$ 0.1–1 T) depending on the isotope. The resonances were scanned using the *rf* field with broad frequency ranges and modulation depending on the expected g factor, as predicted by theory. For instance, in the case of ^{44}Cl the frequency ranged 2090-2110 kHz (18 points) with a modulation of $\pm$0.6 kHz. Once the broad resonance was located, additional *rf* scans with finer frequency steps were carried out to improve the effect and statistics.

3 Results and Discussion

As the analysis is still ongoing, the results presented here are considered preliminary. For the case of ^{44}Cl, the resonance curve is depicted in Fig. 1, where the ratio of the difference over the sum of counts recorded in the up and down telescopes is plotted as a function of the *rf* frequency.

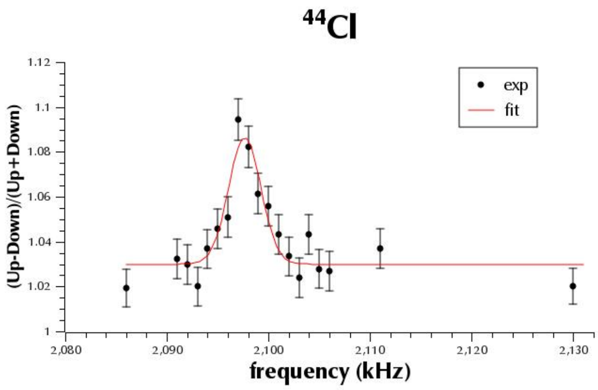

Fig. 1. NMR effect for the case of the ^{44}Cl ground state. A field-off point to better establish the baseline was also measured at 2130 kHz.

The resonance curve was analyzed to produce the result for the g factor of the ^{44}Cl ground state. The preliminary value was estimated to $|g(^{44}\mathrm{Cl})|$=0.27498(8). A similar scan for a resonance in ^{43}Cl produced the picture in Fig. 2.

The estimated value of the g factor for ^{44}Cl was compared to a theoretical calculation carried out by the code ANTOINE (6). Two separate residual interactions were employed in the calculation, *iokin.spdf.35si* (7) and *SDPF-U*, both taking into account a ^{16}O core and allowing proton excitations in *sd* states and neutron excitations in *sdpf* states above. Simulations were made for several spin assignments due to the fact that both spins and parities of

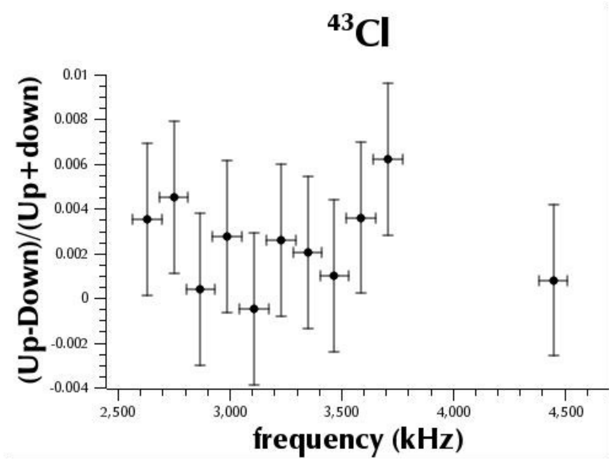

Fig. 2. NMR effect for the case of the ^{43}Cl ground state. No prominent resonance within statistical certainty is observed. See text for explanation.

the levels of the known level schemes in both ^{43,44}Cl have been assigned tentatively. Typical values for effective single-particle g factors were also considered: g_l^{π}=1.1, g_l^{ν}=-0.1 and $g_s^{\pi,\nu} = 0.75 g_{\rm free}^{\pi,\nu}$.

The assumption of 2^- for the spin and parity of the ground state seems to be the one providing an excellent agreement between theory and experiment. The corresponding values are g_{iokin} =-0.26920 and g_{sdpf-u} =-0.26919. Besides the result for the magnetic moment, the conditions described above provide an excellent agreement between the predicted and known energy levels, further strengthening the validity of the initial assumption. The validation of a 2^- state as the ground state is quite important as it paves the road for further investigation of the "softness" of the N=28. The open questions on the collapse of N=28 can be investigated through the single-particle contributions of protons and neutrons in the ground state configuration. The value of $g(^{44}\mathrm{Cl})$ is a crucial new information and is expected to assist in further theoretical studies in this mass region.

For the case of ^{43}Cl, the situation is unfortunately not clear. The search for a resonance does not provide a clear result, at least within statistical certainty. However, this does not necessarily mean that there is a problem with statistics. The spin and parity for ^{43}Cl states are not definitely known, similarly to ^{44}Cl. Moreover, the ground-state spin can be either a 1/2 or 3/2. If the latter is valid, a non-zero result would be expected, thus implying that the frequency range was entirely missed or more data were required to establish a definitive NMR effect.

On the other hand, if the spin is 1/2 a null polarization would be expected.

The reason is that in fragmentation reactions the polarization is directly proportional to the orbital angular momentum $\vec{L}$ (5). If the total spin of the state is 1/2 as in the case of ^{43}Cl, then $\vec{L} = 0$ and no polarization is expected. From a physical point of view, the present result seems to agree with that. However, more data are necessary to provide a better insight and a final conclusion on this matter.

4 Conclusions

The present work reports on some preliminary results from a β-NMR experiment taking advantage of a fragmentation reaction to create the neutron-rich ^{43,44}Cl isotopes as polarized secondary beams and measure the corresponding ground-state magnetic moments.

The results for ^{43}Cl are still highly inconclusive supporting, however, the existence of a 1/2 spin for the ground state is implied by the experimental value. The result for ^{44}Cl, on the other hand, provides a strong argument on a 2^- state and opens the road for theory to further investigate the collapse of N=28 in conjunction with an alteration of Z=16.

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