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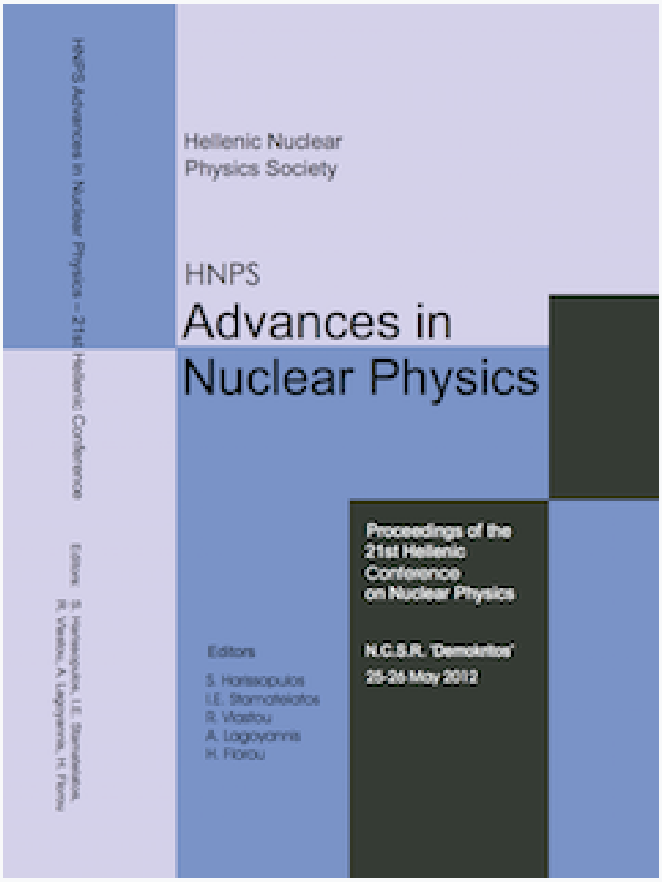

The Application of the High-Velocity Transient Field for the g(2^+_1) Measurement in the Neutron-rich 72Zn

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The Application of the High-Velocity Transient Field for the $g(2_1^+)$ Measurement in the Neutron-rich ^{72}Zn

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Abstract

The first successful application of the recently developed High-Velocity Transient Field Technique (HVTF) on European soil was performed at GANIL. HVTF is an extension of the well established Transient Field (TF) technique, which utilizes immense hyperfine magnetic fields (10-100 kG) capable of inducing a spin precession of an excited nucleus. With the advent of radioactive beams, detailed explorations of such hyperfine fields have been carried out at larger-than-usual ion velocities in an effort to introduce the technique to large radioactive beam facilities.

The neutron-rich radioactive ^{72}Zn isotope is an ideal playground for HVTF. Coulomb excitation populated the 2_1^+ state in ^{72}Zn nuclei, produced as fast secondary beams at GANIL and INFN-LNS, aiming to (a) calibrate the hyperfine field at these beam energies and (b) measure the g factor of 2_1^+ directly. The outcome of these experiments are reported and the application of the HVTF to magnetic-moment measurements are briefly described.

Keywords: g factor, high-velocity transient field

1. Scientific Background and Motivation

The importance of magnetic dipole moments (μ) is well established in Nuclear Physics. The value of the magnetic dipole operator of a particular nuclear state is determined directly by the proton and neutron contributions in the wavefunction. This is a unique feature among several quantities in nuclear structure, thus making magnetic moments extremely useful probes in understanding the composition, but also the evolution of nuclear structure along and across shells.

Measurement of magnetic moments require the interaction of some kind of magnetic field with the spin of the state, J, that is directly related to the magnetic moment: $\mu = gJ$, where g is the gyromagnetic ratio of the state. Typically, the interaction results in spin precession. De-excitation of the nucleus is followed by γ radiation with a characteristic angular distribution pattern. In case the spin of the state has processed, that pattern is perturbed and the result can be measured by placing γ detectors at appropriate angles.

Depending on the lifetime of the nuclear level, the magnetic field needs to be chosen appropriately. For levels with lifetimes in the order of picoseconds, the magnetic field needs to be extremely large to observe a measurable precession in our detectors. The generation of such fields (10-100 kG) with conventional magnets present technical difficulties and high cost. An alternative was found in the 1960's when nuclear ions crossing ferromagnetic materials, such as iron or gadolinium, experienced huge hyperfine fields in the crystal structure of the hosts at values as high as 10 T. The existence of this Transient Field (TF) was quickly utilized to measure magnetic moments of levels with very short nuclear lifetimes. The absence of a pure analytical expression for the TF has been substituted by parameterizations depending on the host kind and magnetization, as well as ion masses and velocities.

The advent of radioactive beams (RIB) in the last 10-15 years required in general revisiting several well established experimental techniques, mainly due to the fact that RIB are available for a short time, larger ion energies and much lower intensities than stable beams. In that direction, the TF technique was also modified for RIB and a first successful attempt was carried out at NSCL, measuring magnetic moments in light, unstable nuclei close to the island of inversion [1, 2].

The present article reports on the first successful application of the High-Velocity Transient Field (HVTF) technique on medium-weight unstable nuclei, and more specifically on the $g(2_1^+)$-factor measurement in ^{72}Zn. Since the TF is completely unknown for high velocities and there is no parameterization for medium-mass nuclei, the field magnitude was measured in advance for a known nucleus. The ^{76}Ge $g(2_1^+) = +0.383(20)$ is known with sufficient precision to provide a calibration of the TF strength.

2. Experimental Details

The final experiment was performed at the GANIL facility using the fragmentation of a ^{76}Ge primary beam at 59 MeV·A onto a 500 μ Be target. The LISE spectrometer was responsible for delivering the fragments of interest to the final experimental station. A combination of secondary beams and targets were used. First, a ^{76}Ge beam at 37.8 MeV·A impinged a single Pb layer (without any ferromagnetic layer) to estimate the vacuum de-orientation effect and obtain information on the excitation taking place in the iron foil that was included in the second step. In that second step, the same ^{76}Ge beam was used to measure its g factor by having the beam nuclei experiencing the TF in a polarized 94 mg/cm^2-thick iron foil. In the third step, a gadolinium target replaced the iron foil and the same g factor was measured. In the last part, the 36.5 MeV·A ^{72}Zn fragments impinged the Gd foil to complete the measurement of the unknown $g(^{72}Zn; 2_1^+)$ value.

In all runs, the scattered particles were detected by a plastic scintillator detector covering angles between 3° and 5.5° with respect to the beam axis, measured in the laboratory frame. The radioactive beam that did not interact with the target was stopped 73 cm downstream to avoid buildup activity.

The perturbed angular distribution was recorded in coincidence with the scattered particles to avoid random events, by eight EXOGAM detectors (fourfold segmented crystals) positioned on the horizontal plane at angles: $\pm 26°$, $\pm 127°$, $\pm 154°$, $+90°$, and $-60°$ with respect to the beam axis (Fig. 1). Each EXOGAM detector was treated as two "half" detectors to obtain better angular resolution for the angular correlation measurements.

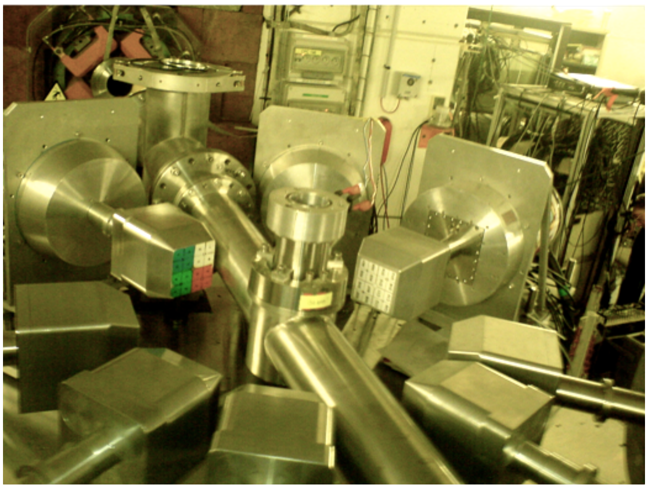


Figure 1: The experimental setup comprising eight EXOGAM segmented detectors

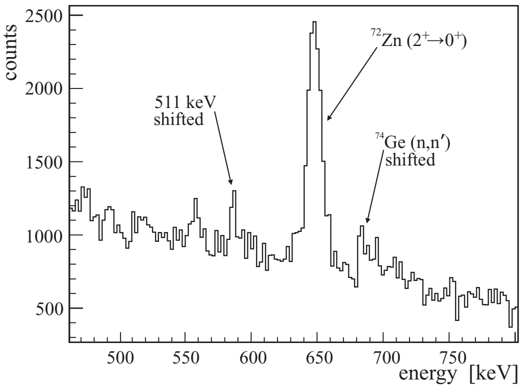
Polarization of the ferromagnetic foils was induced by an external magnetic field of $\sim 0.1\ T$ that was alternated every 200 s to minimize systematic errors. All measurements were run on an event-by-event basis.

It has to be mentioned that additional experiments took place prior to the final measurement at additional labs to optimize the setup and experimental conditions. In that ground, prior measurements focused on target integrity checks, target magnetization, particle detector configurations and Fe/Gd TF strength. For full experimental details, please see Ref. [3]

3. Analysis, Results and Discussion

Several spectra were accumulated during the experimental runs for both the angular correlation and the precession runs. Obtaining the angular correlations in the laboratory frame, $\mathrm{W}_{\mathrm{lab}}(\theta_{\mathrm{lab}})$, from that in the rest frame of the nucleus, $\mathrm{W}_{\mathrm{nuc}}(\theta_{\mathrm{nuc}})$, or vice versa, requires both transformation of the laboratory angle to the equivalent angle in the rest frame of the nucleus, and a multiplication by the appropriate solid-angle ratio so that the γ-ray flux emitted into 4π is conserved. See Fig. 2 for typical corrected spectra and the deduced angular correlation.

Precession angles $\Delta\theta_{\mathrm{exp}}$ were determined using standard analysis techniques. Since there is a Lorentz boost, $\Delta\theta_{\mathrm{exp}} = \epsilon_{\mathrm{lab}}/S_{\mathrm{nuc}}$, where S_{nuc} is the logarithmic



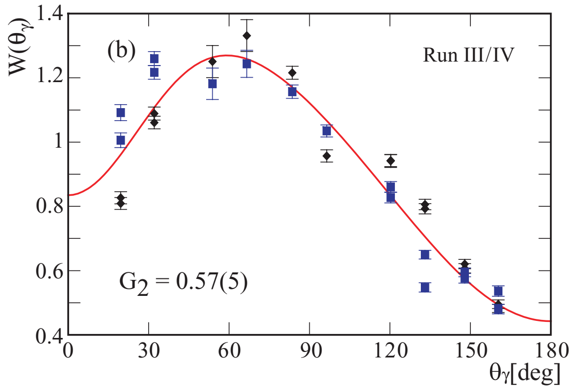


Figure 2: *Left*: Doppler-corrected random-subtracted γ-ray spectrum near the ^{72}Zn ($2^+ \rightarrow 0^+$) line. *Right*: Laboratory frame angular correlations for the combined fit for ^{76}Ge in Gd (black diamonds), and ^{72}Zn in Gd (blue squares).

slope evaluated at angle θ_γ at the rest frame of the nucleus. The slope was computed, while the precession effect $\epsilon_{\rm lab}$ was deduced by the counts registered in the detectors.

The TF strength was extracted from the ^{76}Ge data using the following relation: $\langle B_{TF}\rangle = -\frac{\hbar}{\mu_N}\frac{\Delta\theta}{g t_{eff}}$, where μ_N is the nuclear magneton, g is the g factor and t_{eff} is the interaction time with the TF. There were two values deduced, one for the iron and one for the gadolinium foil. In the former case, the measured precession was found to be zero within experimental error, signifying a null precession in the interaction field of iron at such high velocities. On the contrary, ions moving in the gadolinium host experienced a field and their spins processed. The TF strength was found equal to 0.58(28) kT.

Using this value for the TF, the ^{72}Zn g factor was further deduced equal to +0.18(17). The result poses a stringest test for nuclear theory. It is directly evident that the value of the g factor is away from the prediction of the liquid-drop model ($g = \frac{Z}{A} = 0.417$), suggesting single-particle effects playing an important role in forming the structure of the 2_1^+ state in the nucleus.

Lighter Zn nuclei have been described rather well by both JJ4B and JUN45 effective interactions in the shell-model approach. Both interactions consider a closed ^{56}Ni core, that seems to fail reproducing the rapid decrease in energies of the first 2^+ states and the onset of collectivity in heavier Zn isotopes with neutron number larger than 40. For the present experiment, the adoption of a closed ^{48}Ca core seemed to be the appropriate alternative to attempt a description within the shell model. In addition, a new interaction by Lenzi *et al.* [4], LNPS, was tested. The results of the large-scale shell-model calculations are illustrated in Fig. 3, showing a nice agreement between the new shell-model calculation and the measured g factor from this work.

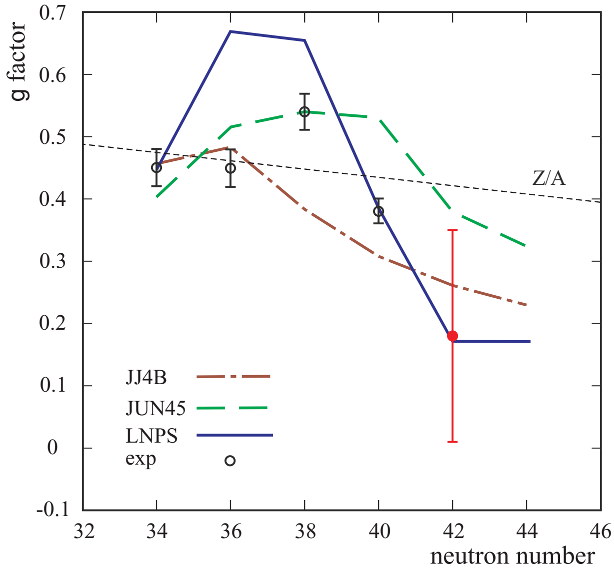


Figure 3: Experimental data and theoretical shell-model predictions based on different interactions and closed cores.

4. Conclusion

The application of the HVTF technique in a nuclear regime, where no knowledge of the hyperfine interaction at high ion-velocities existed previously, has been tested and proven successful. The hyperfine field was calibrated by measuring the known $g(2_1^+)$ in ^{76}Ge. A new value for the g factor of the 2_1^+ level in the unstable, neutron-rich nucleus ^{72}Zn was obtained. The measured value was compared to existing and new shell-model calculations. The HVTF technique is promising for future g-factor measurements with RIB and further tests are needed.

Acknowledgments

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References

[1] A. Davies et al. Phys. Rev. Lett. 96, 112503 (2006)

[2] A.E. Stuchbery et al. Phys. Rev. C. 74, 054307 (2006)

[3] E. Fiori et al. Phys. Rev. C. 85, 034334 (2012)

[4] S. Lenzi et al. Phys. Rev. C. 82, 054301 (2010)