The measurement of electromagnetic (EM) moments has traditionally played a central role in the critical evaluation of nuclear structure models since they elucidate the single-particle nature (magnetic moments) and the shape (quadrupole moments) of the nuclear state under investigation. Their particular behaviour around nuclear shell closures, approaching Schmidt values for magnetic moments and small values for quadrupole moments, makes them good tools to investigate shell closure near and far from stability.

We report [1] on the $g$-factor measurement of an isomer in the neutron-rich $^{61}$Fe ($E^*_g = 861$ keV and $T_{1/2} = 239\pm5$ ns). The isomer was produced and spin aligned via a projectile-fragmentation reaction at intermediate energy, the time dependent perturbed angular distribution method being used for the measurement of the $g$-factor. For the first time, due to significant improvements of the experimental technique, an appreciable residual alignment of the nuclear spin ensemble has been observed, allowing a precise determination of its $g$-factor, including the sign: $g = -0.229(2)$. In this way we open the possibility to study moments of very neutron-rich short-lived isomers, not accessible via other production and spin-orientation methods.

In the Figure we present the measured $g$-factors of $9/2^+$-isomeric states around $N = 40$, including also the $g$-factor of $^{61m}$Fe. The comparison with the other $g$-factors of known $9/2^+$ isomeric states in the region strongly supports the $9/2^+$ spin and parity assignment for the $^{61m}$Fe isomer.

One can observe the symmetry with respect to $Z = 28$ (proton magic number) of the $g$-factors for the $N = 35$ chain, suggesting that two particle or two hole proton configurations affect the $g$-factor in a similar way. The increase of the $g$-factor values when going away from $Z = 28$ indicates an increase of core polarization effects due to the opened proton $\pi f_{7/2}$ shell ($Z < 28$) or to the additional protons in the $\pi f_{3/2} p_{1/2}$ shell ($Z > 28$). Because of the sensitivity of the $g$-factor to single-particle properties of the wave function of the studied state, we have compared the measured value with the one predicted by large scale shell model (LSSM) calculations [2]. We considered an inert core of $^{48}$Ca, and the valence space is composed by $\nu p_{3/2} f_{5/2} g_{9/2}$ and $\pi f_{7/2} p_{3/2} f_{5/2} p_{1/2}$. We allowed up to 6$p$-$6h$ excitations, meaning that the total number of particles excited from $\nu p_{3/2} f_{5/2} p_{1/2} g_{9/2}$ to $g_{9/2}$ for neutrons, and from $\pi f_{7/2}$ to $\pi p_{3/2} f_{5/2} p_{1/2}$ for protons, was less than or equal to 6. The first $9/2^+$-state is calculated to be at 720 keV and its wave function is a mixture of a large number of configurations, the mean occupation of the $1g_{9/2}$ orbital being $\sim 1$. The very mixed structure of the wave function might be an indication of a rather deformed potential for the $9/2^+$ state. This is
supported by the spectroscopic quadrupole moment, $Q = -57.9 \text{ e fm}^2$, which corresponds to a deformation $\beta_2 = -0.24$ assuming that $^{61m}\text{Fe}$ is an axial deformed rotor with $K = I = 9/2$.

The calculated free $g$-factor is $g(9/2^+) = 0.277$. The effective value is $g(9/2^+) = -0.1627$ if a quenching factor of 0.7 is used for the nucleon spin $g$-factor. The value of the quenching factor is quite arbitrary because at present, there is no systematical comparison between experimental data and shell model calculations into the considered $fpg$ valence space. The experimental result that lies in between the free and the effective calculations may provide an important input into this issue. In conclusion, the measured $g$-factor is in very good agreement with the assigned $9/2^+$ spin and parity, both from systematics and shell model calculation points of view. From the comparison with LSSM calculations, there are indications that this state is characterized by a deformed potential. A measurement of the quadrupole moment, $Q$, of this state is therefore important. Based on the large observed residual alignment, such a measurement is currently being planned. It is important to note that for the determination of the sign of the deformation, one has to obtain a spin-polarized ensemble of isomeric states. The appreciably large residual alignment measured for the $^{61m}\text{Fe}$ and $^{54m}\text{Fe}$ fragments indicates that fragmentation reactions at intermediate energies can provide a powerful tool to align ensembles of nuclear states. As this type of reaction is up to now the only way to produce (very) neutron-rich short-lived (50 ns–µs) isomeric states, one can now use it for the investigation of the nuclear structure away from stability via EM moments measurements.

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References: