g-factor description of transitional nuclei

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Introduction

In the few decades that nuclear physics has existed as a discipline, remarkable successes have been achieved on the way to obtaining an understanding of the structure of the nucleus. As is the case in virtually all fields within physics, continuous progress was the result of close interaction between theoretical and experimental physics. New experimental results may require the introduction of new concepts into the theoretical framework, and new or improved theories have, in return, to be tested through experiment. Thus, there exists a need for an internally consistent and comprehensive set of nuclear parameters, both, as input parameters for some nuclear structure theories, as well as for comparison with the predictions of more comprehensive or more microscopic theories. Two such parameters that are of interest to the nuclear physicist are the quadrupole moment of the nucleus and its g-factor (the ratio of the nuclear magnetic dipole moment to the total angular momentum of the nucleus). It worth to mention here that the nuclear g-factor separates into a rotational g-factor (g_R) and an intrinsic g-factor (g_K). The first is due to collective rotation of the core nucleons, while the latter is characteristic of the state of the valence nucleons and is defined as the ratio of the projection of the magnetic dipole moment on the (rotating) symmetry axis to the projection of the angular momentum on the same axis. In this respect the knowledge of the magnetic dipole and electric quadrupole moments is of crucial importance, as they are providing independent information on the composition of the wave-function and on the nuclear deformation, respectively [1].

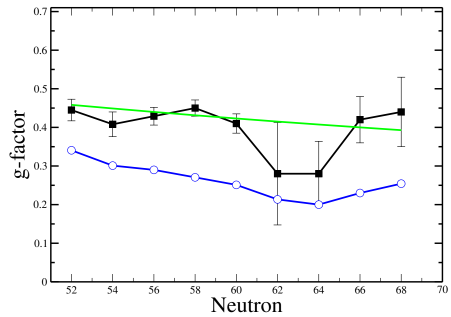

FIG. 1: (Color online) g(2^+) calculations compared with experimental Data for $^{96-112}$Ru isotopes. The green line shows Z/A.

Outline of TPSM

A major challenge in nuclear theory is to provide a microscopic and unified description of the collective and single-particle modes of excitations in triaxial nuclei. Recently, it has been demonstrated that microscopic approach of triaxial projected shell model (TPSM) provides an excellent description of various phenomena observed in the triaxial nuclei [2]. In order to probe the intrinsic structures of the 2^+ States, g-factors need to be evaluated which can be compared with the measued values. The pupose of the present work is to systematically evaluate the g-factors of the 2^+ excited states using the TPSM approach. This model has been employed in all our earlier investigations to interpret the band structures

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in transitional nuclei [3]. TPSM calculations are performed in three stages. In the first stage, triaxial basis are generated by solving the triaxially deformed Nilsson potential with the deformation parameters of ϵ and ϵ'. In the second stage, the intrinsic basis are projected onto good angular-momentum states using the three-dimensional angular-momentum projection operator. In the third and final stage, the projected basis are used to diagonalise the shell model Hamiltonian. The wave-functions obtained from the diagonalization are then used to evaluate the electromagnetic transition probabilities. The g-factor $g(\sigma, I)$ is, generally, defined as,

$$g(\sigma, I) = \frac{\mu(\sigma, I)}{\mu_N I} = g_\pi(\sigma, I) + g_\nu(\sigma, I),$$

with $\mu(\sigma, I)$ being the magnetic moment of a state (σ, I). $g_\tau(\sigma, I), \tau = \pi$ or ν. In our calculations, the following standard values for g_l and g_s [1] have been taken: $g_l^\pi = 1, g_l^\nu = 0, g_s^\pi = 5.586$, and $g_s^\nu = -3.826$. In the angular-momentum projection theory, the reduced matrix element for $\hat{m}$ (with $\hat{m}$ being either $\hat{j}$ or $\hat{s}$) can be explicitly expressed as

$$\begin{aligned} \langle & \Psi_I^\sigma || \hat{m}^\tau || \Psi_I^\sigma \rangle \\ = & \sum_{K_i, K_f} f_{IK_i}^\sigma f_{IK_f}^\sigma \sum_{M_i, M_f, M} (-)^{I-M_f} \\ \times & \begin{pmatrix} I & 1 & I \\ -M_f & M & M_i \end{pmatrix} \langle \Phi | \hat{P}_{K_f M_f}^I \hat{m}_{1M} \hat{P}_{K_i M_i}^I | \Phi \rangle \end{aligned}$$

Results and Discussion

The neutron (N) dependence of g factors in transitional nuclei has been a challenge to theory. The main reason is that the g factors are sensitive to the underlying single-particle composition of the collective quadrupole degree of freedom. The collective states of transitional nuclei have been mostly described in the framework of phenomenological collective models such as the Bohr Hamiltonian and the interacting boson model (IBM), which do not specify the fermionic structure of the collective mode. On this level, one simply assumes that only the protons are responsible for the current that generates the magnetic moment, i.e., g = Z/A. We approach the problem with TPSM, which is completely microscopic.

The deformation of the excited 2^+ state increases with the number of valence proton holes below, and neutron particles above, the Z = N = 50 shell. For isotopes Ru chain, the deformation increases with the neutron number. Figure 1 shows that the calculated g-factor trend is in overall good agreement with experiment. In particular, the deviations from the value Z/A are well accounted for. The g-factors generally decreases along the isotopic chain. This is beacuse as number of valance neutrons increases, the $g_{9/2}$ protron fraction remains nearly constant whereas the $h_{11/2}$ neutron fraction increases, which causes the decrease of g-factors. The increased neutron numbers push up the Fermi surface and, with increased deformations, the Fermi level moves into the lower half of the Nilsson orbits with $h_{11/2}$ parentage. Since the $h_{11/2}$ neutrons have g-factor negative, therefore, they progressively reduce the magnetic moment. Hence, in the studied Ru isotopes, the neutrons in the $h_{11/2}$ orbit are primarily responsible for the drop of the g-factors with increasing neutron number.

In conclusion the deformation of the 2^+ state increases with the number of valence proton holes below, and neutron particles above. It ranges from ϵ ~0.1 to ~0.25 for the studied Ru isotopes. TPSM approach gives a convincing description of the mass-dependent g-factor systematics in Ru isotopes. Further, it has been noted that the g-factors are very sensitive to the relative strength of neutron and proton pairing. More accurate g-factor calculations than those presented here will require a more sophisticated, self-consistent treatment of pairing.

References

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