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Magnetic dipole moment of the first excited 2^+ state of $Z = 50$ isotopes and $N = 82$ isotones in relativistic QRPA

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Abstract

Following relativistic quasiparticle random phase approximation we have calculated the magnetic dipole moment (g factor) of the first excited 2^+ sate in even-A spherical $Z = 50$ isotopes with $A = 100$–134, and $N = 82$ isotones with $A = 134$–152. The overall agreement with available experimental data is very satisfactory. We also discuss our findings in light of some other available theoretical results. However, these investigations also indicate that there is still a necessity to improve upon the values of the Lagrangian parameters in order to be able to describe well the properties of the excited states of nuclei over a wide range of mass numbers.

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The value of the magnetic dipole moment of a nuclear state depends on the spin and orbital angular momentum contributions of protons and neutrons which are very *diverse* in magnitudes and signs. So, data on magnetic moment or g factors are very sensitive to the single particle structure at the Fermi surface of a nucleus. For instance, from the measurement of the g factor of 2_1^+ excited state ($= -0.015 \pm 0.042$) and its numerical calculations it is concluded that ^{40}Ar can be described as a near spherical shell model nucleus [1]. As another example, consider calcium isotopes with ^{40}Ca as the doubly magic inert core nucleus. In a simple spherical shell model picture two valence neutrons of ^{42}Ca and six neutrons of ^{46}Ca can be put in the $1f_{7/2}$ orbitals. The experimental measurement of g factors of 2_1^+ states in ^{42}Ca [2] and ^{46}Ca [3] exhibit significant differences posing a challenge and opportunity to theoretical models to explain the structural changes as a function of neutron numbers. While the g factor of 2_1^+ state in ^{42}Ca is 0.04 ± 0.06, it is -0.26 ± 0.06 for ^{46}Ca which implies a significant change in structure of the 2_1^+ state after addition of 4 neutrons. It may be added that g factor for 2 neutrons in $f_{7/2}$ orbitals coupled to $J = 2$ comes out to be -0.383 with the use of single particle spin g factor, $g_s = 0.7 g_s^{\text{free}}$. Thus, the measured value of 0.04(6) for ^{42}Ca implies a significant contribution from proton particle-hole excitations across the $Z = 20$ magic shell gap.

The radioactive ion beam facilities are opening up new opportunities to investigate nuclear structure properties of extremely neutron-rich or neutron-deficient nuclei like $Z = N = 50$ doubly magic nucleus ^{100}Sn to doubly magic ^{132}Sn ($N/Z = 1.64$) or even heavier Sn isotopes. Recently we [4,5] have calculated excitation energies and electric multipole decay rates of the lowest lying 2^+ and 3^- vibrational states in Pb, Sn and Ni isotopes using relativistic quasiparticle random phase approximation (RQRPA) [6] employing NL3 set of the Lagrangian parameters and finite range Gogny D1S interaction [7] in the particle–particle pairing channel. We have obtained very satisfactory agreement with the available experimental data for a wide range of nuclear masses without any adjustable free parameter. Using the same formalism now we have computed g

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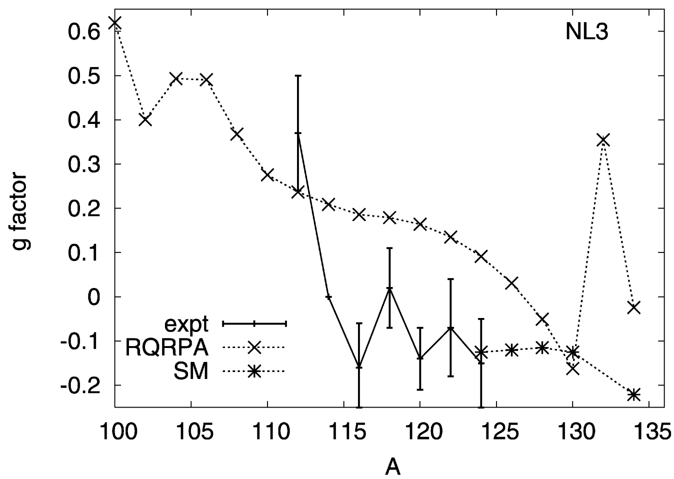

Fig. 1. g factors of the first excited 2^+ states of Sn isotopes as a function of mass number, A.

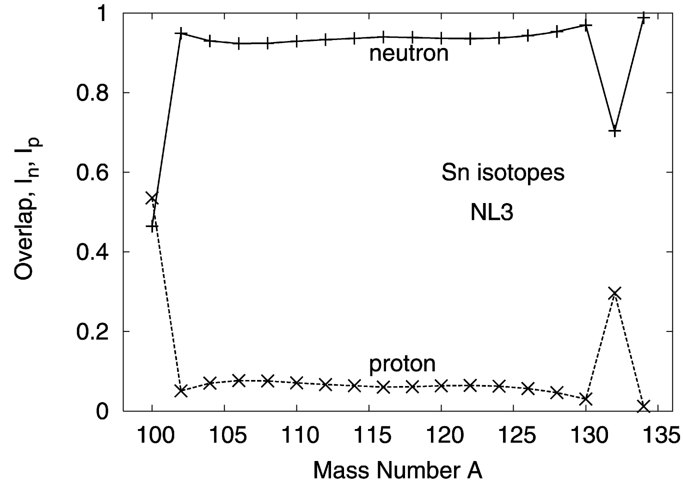

Fig. 2. Contributions of neutrons (I_n) and protons (I_p) to the total QRPA wave function normalization, unity as function of A.

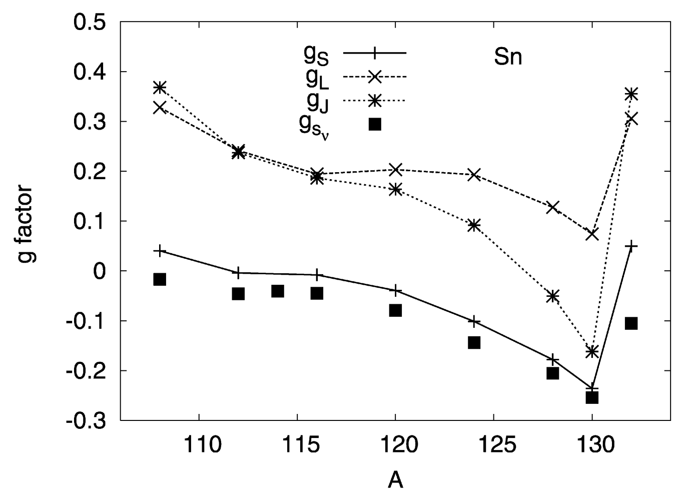

Fig. 3. Spin (g_S) and orbital (g_L) contributions to total g_J for $J = 2$ of Sn isotopes. The label g_{s_ν} indicates the spin contributions that of neutrons only.

factors of the 2_1^+ states (some times for brevity denoted as g_2) in Sn isotopes as well as in $N = 82$ isotones with $Z = 52$–70. Below we present our results first for the Sn isotopes and then for the $N = 82$ isotones.

(a) $Z = 50$ isotopes

The g factors are calculated using the free (unquenched) values of the single particle orbital and spin g factors: $g_l(p) = 1.0$, $g_l(n) = 0.0$, $g_s(p) = 5.586$ and $g_s(n) = -3.826$. In Fig. 1 the RQRPA values are compared with the available experimental data [8] and shell model (SM) results of Brown et al. [9]. In SM approach calculation is not performed for the doubly magic nucleus ^{132}Sn. The experimental data for the stable $A = 116$–124 nuclei are more or less consistent with a constant value of about -0.1. But a large positive value of about 0.35 at $A = 112$ agrees quite well with the RQRPA result. Then a sudden big drop to almost a zero value at $A = 114$ seems hard to understand as it would require a sudden cross over of some proton-neutron single particle orbitals. The theory shows a gradual decrease with the increase of A, till it finally reaches a negative value of -0.16 at $A = 130$. A considerable reduction in the experimental uncertainties is desirable to see if these values change with A more gradually than as it appears now. Like large values of the energy E_2 and $B(E2)$ decay rate we also predict a large g_2 value (≈ 0.35) for ^{132}Sn. This happens because of a sizable contribution coming from the proton particle-hole excitations [4,5]. This can be seen qualitatively from Fig. 2 where contributions of neutrons and protons to the total RQRPA wavefunction normalization, $\sum_{i<j}(X_{ij}^2 - Y_{ij}^2) = 1$, is displayed as a function of A. At $A = 132$ the contribution of protons (I_p) is about 30% as compared to $\leqslant 10\%$ for the other lighter isotopes.

Recently Terasaki et al. [10] have performed a non-relativistic QRPA calculation for Sn isotopes. However, they find maximum in g_2 for $A = 130$, which is difficult to understand in view of the fact that they also obtain the largest value of $B(E2)$ and that of I_p (see Fig. 13 in Ref. [10]) for ^{132}Sn itself. For ^{134}Sn we predict a value of $g_2 = -0.02$, while in Refs. [10] and [11] the predicted values are about -0.3 and -0.4, respectively.

In Fig. 3 we display the spin and orbital angular momentum contributions (proton and neutron contributions added) to the total g_2 value. These contributions are calculated only for some isotopes to see the trend, and we find that it shows a rather smooth behavior as a function of A. Then for some isotopes the spin contributions, only that of neutrons, g_{s_ν} (solid squares) are also shown. Clearly the decrease in g_2 value with the increase of A up to $A = 130$ is mainly due to the spin contributions of neutrons, g_{s_ν} (solid squares). But for ^{132}Sn the magnitude of the spin part of the proton contribution (0.155) becomes even larger than that of the neutrons (-0.105).

We may conclude that overall the RQRPA results, without any adjustable free parameters, are very satisfactory. Reduction in experimental uncertainties and measurements of g_2 at and around ^{132}Sn would be very useful to compare various theoretical models.