# Measurement of the g-factors of $2^+$ states in stable A=112,114,116 Sn isotopes using the transient field technique


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Abstract

Recently, an unexpected behaviour of B(E2; $0^+ \rightarrow 2^+$) transition strengths in the Sn isotopic chain has been established in a series of experiments. Coulomb excitation measurements on radioactive neutron-deficient $^{106\text{-}110}$Sn as well as stable $^{112,114}$Sn beams have shown an excess of transition strength in these isotopes in which the lower half of the N=50-82 neutron shell is filled. To gain experimental information about the origin of this behaviour we propose to measure the magnetic moments of the $2^+$ states in the stable isotopes $^{112,114,116}$Sn using the transient field technique in combination with Coulomb excitation in inverse kinematics.


Physics case

Recent experiments using Coulomb excitation of radioactive beams at low, intermediate and relativistic energies at REX-ISOLDE, MSU and GSI [1-3] established clear evidence for an unexpected behaviour of B(E2; $0^+ \rightarrow 2^+$) transition strength in the light Sn isotopes filling the lower half of the N=50-82 shell. The experimental B(E2) values in the Sn isotopes between the N=50 and N=82 shell closures are shown in Fig. 1a in comparison to results of recent shell-model calculations using a $^{100}$Sn core and a neutron effective charge of 1.0e. Since the old values for stable $^{112,114}$Sn had quite large uncertainties, a proposal by P. Doornenbal et al. to remeasure these values using low-energy Coulomb excitation at the UNILAC has been approved last year. The result of the transition strength measurement in $^{114}$Sn, B(E2)=??? [4], confirmes the increase of strength between $^{116}$Sn and $^{114}$Sn.

The asymmetric behaviour of the B(E2) values with respect to the N=66 neutron midshell at A=116 is striking (see Fig. 1a). It is in disagreement with all available different large scale shell model calculations [2,3]. One possible explanation of the observed enhancement of the electric quadrupole transition probabilities between the ground and the first excited $2^+$ state in the Sn isotopes towards $^{100}$Sn might be the increasing importance of small admixtures of proton excitations across the Z=50 shell gap. Shell model calculations [3], which allow such core excitations of up to four protons in addition to the neutrons in the full N=50-82 space and use the unscreened values of 1.5e resp. 0.5e for the proton resp. neutron effective charge, nicely illustrate how the inclusion of more and more proton core excitations increases the transition strengths while keeping the nearly symmetric parabola like shape.

The best way to detect small admixtures of proton excitations across the Z=50 shell gap to the wave functions of the $2^+$ states in even-even Sn isotopes is to measure the magnetic moments of these states. Due to the single-particle nature of the magnetic moment operator, the sign and the magnitude of the magnetic moment are sensitive to the configurations that contribute to the wave function of an individual state. Given the large and positive effective g-factors of the relevant proton orbits above the Z=50 shell closure (+1.37, +0.73 and +0.99, respectively, for the $d_{5/2}$, $g_{7/2}$ and $h_{11/2}$ proton orbits), proton admixtures would lead to a significant increase of the $2^+$ g-factors which in the pure neutron space are close to zero as indicated by shell model calculations [5] shown in Fig. 1b. The magnetic moments of the $2^+$ states in all stable Sn isotopes have been measured in 1980 using the transient field technique and Coulomb excitation by $^{35}$Cl beams [6]. The results of this experiment are shown in Figure 1b. Although the experimental values have large uncertainties, there is an overall trend from negative g-factors for the heavy isotopes to a positive g-factor for the lightest nucleus measured, namely $^{112}$Sn. Since all values have been measured in the same way the relative values are well determined and this trend does not depend on the absolute calibration of the transient field.

To qualitatively understand the experimental g-factors we have to consider the relevant single-particle configurations since the magnetic moment of a state reflects its single-particle structure. The empirical energies of the neutron single-particle configurations in the N=50-82 shell as deduced from the level structures of the odd Sn isotopes are shown in Fig. 1c as a function of the neutron number. For the heavy isotopes $^{120\text{-}124}$Sn the orbits $h_{11/2}$, $d_{3/2}$ and $s_{1/2}$ are lowest in energy and therefore expected to contribute to the $2^+$ wave function. These configurations have effective g-factors of -0.25, +0.3 and -1.8, respectively, and the measured negative g-factors in these isotopes indicate the importance of the $(h_{11/2})^n$ and $(d_{3/2} s_{1/2})$ ($g_{eff}$=-0.28) configurations in the wave function of the $2^+$ state. Since as mentioned before a proton component in the wave function would have a large and positive g-factor, the strength of a proton admixture can be estimated to be small. In $^{116}$Sn the $(d_{3/2}s_{1/2})$ configuration with $g_{eff}$=-0.28 seems to be the dominating configuration. In the lighter isotopes $^{112,114}$Sn the $g_{7/2}$ neutron configuration is coming down in energy and actually is the ground state in $^{111}$Sn. This configuration with its positive effective g-factor of +0.19 can be assumed to be responsible for the measured positive value of g=+0.37(13) in $^{112}$Sn. However, considering the effective g-factors of all neutron configurations which might contribute to the wave function of the $2^+$ state in $^{112}$Sn, namely $(g_{7/2})^2$, $(s_{1/2}\ d_{5/2})$ and $(d_{5/2}\ g_{7/2})$ with effective g-factors of +0.19, -0.17 and +0.24, the measured value seems to require a proton component in the wave function.

The above discussion indicates the sensitivity of the magnetic moments to the occupation parameters of neutrons in the various subshells and, even more important, to proton admixtures to the wavefunctions which might be responsible for the observed enhanced

B(E2) strength in the N≤64 Sn isotopes. Since 1980, when the experiment discussed above has been performed, new developments have largely increased the precision which can be reached in transient field g-factor measurements. We therefore suggest to remeasure the g-factors of the $2^+$ states in the stable A=112,114,116 tin isotopes with improved precision allowing for a severe test of the shell model wave function composition. In a later stage, an extension of these measurements to the lighter isotopes using radioactive beams (RISING at GSI and/or REX-ISOLDE) is envisaged.

## Experimental technique

The proposed measurement of $2^+$ g-factors will be performed using the well established transient field technique in combination with projectile Coulomb excitation in inverse kinematics [7]. The multilayer target will consist of a $^{48}$Ti layer to Coulomb excite the Sn beam ions, a Gd layer magnetized by an external field in which the excited Sn ions experience precessions during their passage through the transient field and a copper backing which serves as a stopper for the excited nuclei providing a hyperfine interaction-free environment. Deexcitation γ-rays are detected by two Super-Clover detectors positioned at ±70° with respect to the beam axis in coincidence with forward scattered Ti ions. The Ti target ions will be detected in two rectangular Si detectors (2cm x 2cm) positioned above and below the beam axis covering an angular range of 20°-45° degrees. This particle detector geometry has the advantage of selecting the reactions with largest spin alignment.

The transient field technique in combination with Coulomb excitation in inverse kinematics ensures high detection efficiency of coincident γ-rays due to kinematic focussing of the target ions in the beam direction and provides high spin alignment of the excited states followed by strongly anisotropic γ-angular correlations. The latter is a prerequisite to be sensitive to the spin precessions in the TF. Furthermore, the inverse kinematics implies high recoil velocities of the Sn ions and therefore large transient fields. The known lifetimes of the $2^+$ states in all three Sn isotopes of interest are short (~0.5 ps). As a by-product of our experiment we will therefore be able to deduce $2^+$ lifetime values from the analysis of the Doppler-shifted and broadened lineshapes of the $2^+ \rightarrow 0^+$ transition emitted during the stopping process in the thick target. The relative values will be free of systematical uncertainties in the description of the stopping process in the multilayer target and therefore serve as additional test of the increase of B(E2) strength between $^{116}$Sn and $^{114}$Sn.

## Beamtime estimate

The beamtime estimate is based on the following assumptions:

- target: 1 mg/cm$^2$ $^{48}$Ti + 4 mg/cm$^2$ Gd + 6 mg/cm$^2$ Cu
- beams: $^{112,114,116}$Sn at energies around 4 MeV/u

- beam intensity: 1 pnA
- γ-ray detection efficiency taken from the 2006 Coulex experiment on $^{114}$Sn performed in cave X7 under similar conditions with 2 Super-Clover detectors [4]

From this information and standard Coulomb excitation calculations we can infer an expected γ-detection rate of 50.000 counts in the $2^+ \rightarrow 0^+$ line in each Clover detector. Furthermore, taking into account the target properties and standard transient field parametrizations [7], precession angles of 22 mrad resp. 10 mrad are estimated for the $2^+$ states in $^{112}$Sn and $^{116}$Sn assuming the experimental g-factors of g=+0.37(13) and g=-0.16(10) [6]. The average logarithmic slope of the $2^+ \rightarrow 0^+$ angular distribution for a Clover positioned at Θ=70° with respect to the beam is calculated to be around -2.5 (compare Fig. 2). Under these conditions and once again assuming the experimental g-factors we conclude that:

- to measure the g-factor of the $2^+$ state in $^{112}$Sn with an uncertainty of 8% requires <u>one day</u> of beamtime (see Fig. 3)
- to measure the smaller g-factor of the $2^+$ state in $^{116}$Sn with an uncertainty of 10% <u>two days</u> of beamtime are needed
- since the g-factor of the $2^+$ state in $^{114}$Sn is not known experimentally and expected to be small, we ask for <u>two</u> more <u>days</u> of beamtime for this nucleus.

The beamtime request is

- **1 day** for preparation and calibration
- **5 days** in total for the measurement of g($2^+$) in $^{112}$Sn, $^{114}$Sn, and $^{116}$Sn

The total requested beamtime amounts to <u>**6 days**</u>.

<u>References:</u>

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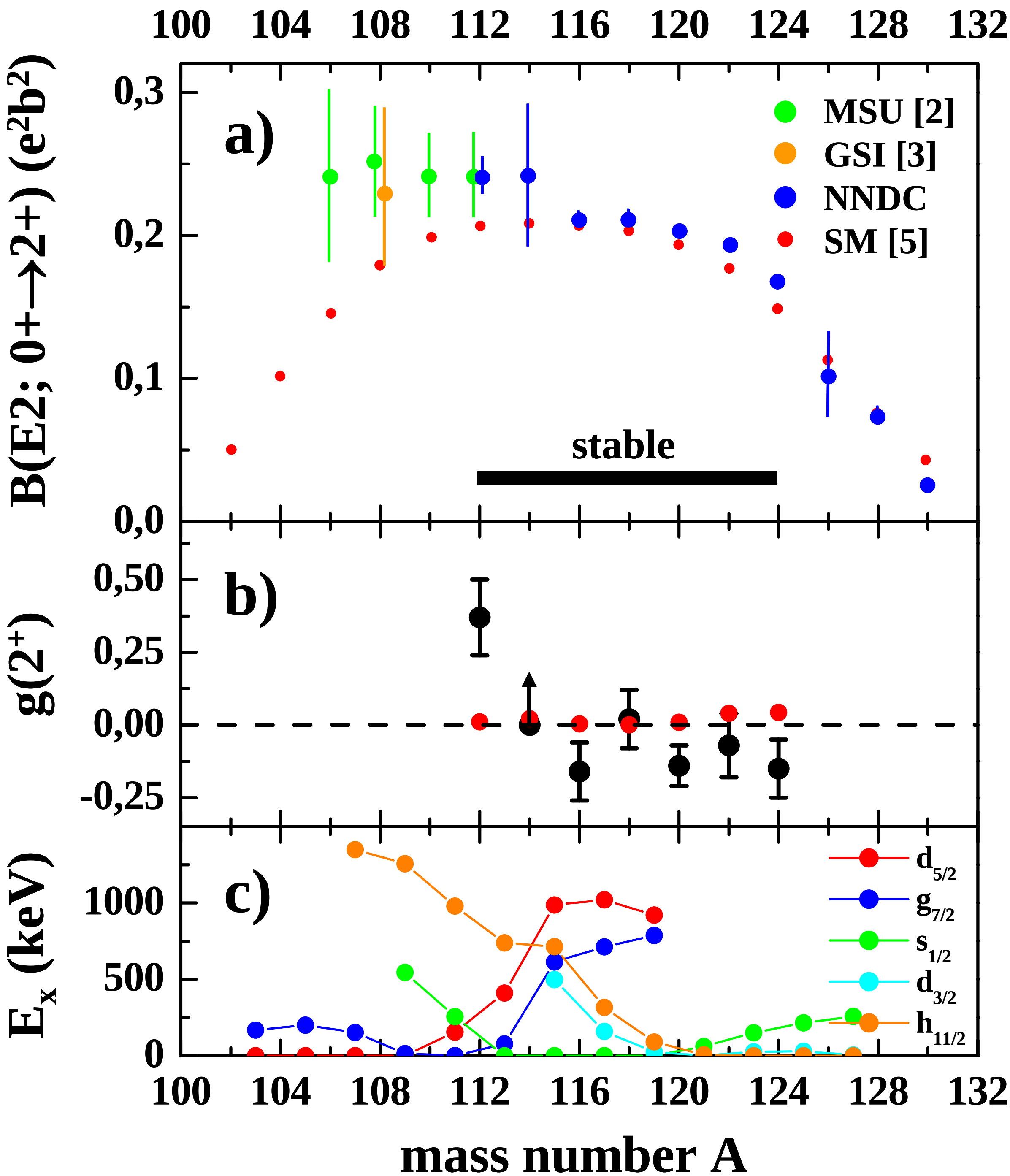


Fig. 1 : a) Experimental B(E2 ; $0^+ \rightarrow 2^+$) transition rates in the Sn isotopes compared to shell model calculations. b) Experimental g-factors of $2^+$ states [6] in stable A=112-124 Sn isotopes compared to shell model values [5]. c) Neutron single-particle energies in the N=50-82 shell deduced from low-energy levels in the odd Sn isotopes.

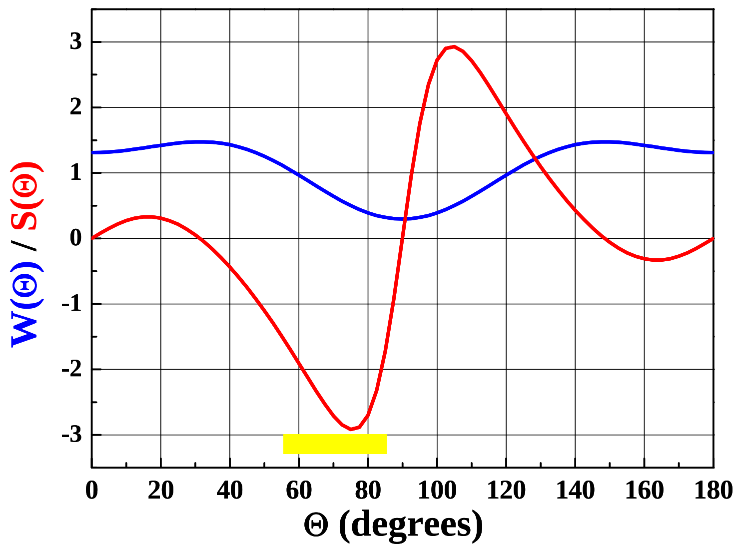


Fig. 2 : Calculated angular correlation function W(Θ) and the corresponding logarithmic slope S(Θ) for the $2^+ \rightarrow 0^+$ transition in $^{112}$Sn. The functions have been calculated for the particle detector geometry described in the text.

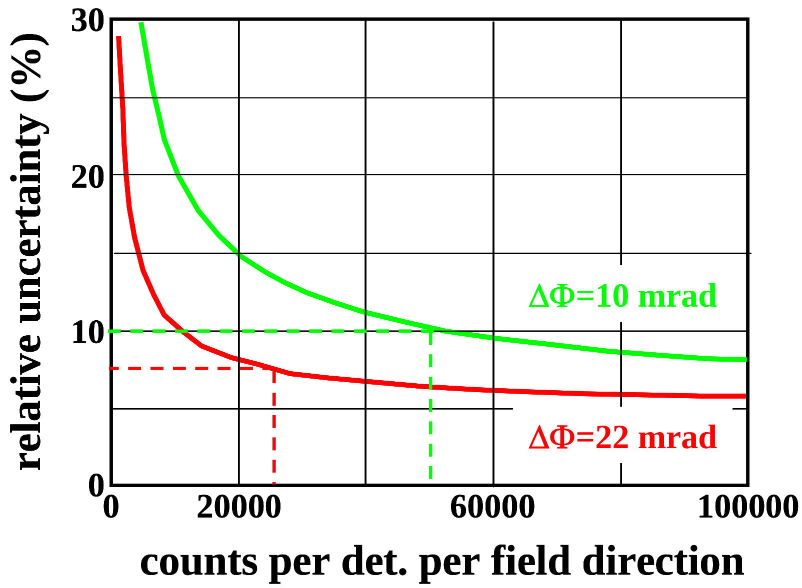


Fig. 3 : Relative uncertainty of the precession angle ΔΦ to be measured as a function of counts in the photopeak corresponding to the $2^+ \rightarrow 0^+$ transition in one Clover detector and for each direction of the magnetic field. An average logarithmic slope of S=-2.5 has been assumed in this estimation. The curves correspond to precessions of ΔΦ=22 mrad (red) and ΔΦ=10 mrad (green).