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Comment on "Shell structure of Ti and Cr nuclei from measurements of *g* factors and lifetimes"

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In a recent publication Ernst *et al.* [Phys. Rev. C **62**, 024305 (2000)] suggest a shell structure description of Ti and Cr nuclei from systematic g factor and lifetime measurements of the 2^+ and 4^+ states of these nuclei, pointing out a disagreement between previous measurements and shell model calculations. We show that the systematics of previous and present g-factor measurements are not in significant disagreement, and they do not exclude the possibility of an onset of collectivity in the middle of the fp shell. The theoretical interpretation of the data is still an open question. A conflict between the ^{50}Cr $g(4_1^+)$ measurements may be attributed to statistical fluctuations, as large errors are assigned to both existing measurements, but not to the fusion excitation technique adopted in one of the measurements. It is suggested that the moments of the higher spin states must be determined with better precision to shed more light on the situation.

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Transient field precessions as a function of nuclear spin ($J=2^+,4^+,6^+,8^+$) were measured in 1994 [1] for the ground state band of ^{50}Cr. The observed precessions were all equal within experimental error, indicating that these states have similar g factors, with a mean value of $g=+0.54\pm0.10$. In addition, limited results obtained for the 2^+ and 4^+ states in ^{46}Ti showed the same behavior with a mean g factor of $+0.51\pm0.10$. The gross compatibility of the data with the simple hydrodynamical prediction of $Z/A=+0.48$ and the clear conflict at that time with single j shell model calculations [2] led to the conclusion that the onset of collectivity occurred in the middle of the fp shell. This was consistent with other experimental findings [3–6], extending the region of collectivity, confined by Cameron *et al.* [7], to within one nucleon of the middle of the shell (^{48}Ti). This result motivated Zamick and Zheng [8] to calculate g factors as well as static quadrupole moments, Q, and reduced matrix elements, $B(E2)$, in larger shell model spaces, allowing $t=1,2,3$ nucleons to be excited from the $f_{7/2}$ shell to the rest of the f-p shell. Zamick and Zheng noticed that indeed there is an onset of collectivity in the sense that the $B(E2)$ strengths increase as t increases and the energy levels look more rotational. However, a large variation in g factor with spin was predicted (see Fig. 1) even when taking into account calculations with $t=3$ nucleons, and theory and experiment remained in conflict.

As the interest on the subject increased, new g-factor and lifetime measurements were performed by Ernst *et al.* [9,10] for the first 2^+ and 4^+ excited states in ^{50}Cr and ^{46}Ti together with full-space shell model calculations. Their results are compared with our previous measurements and the last shell model calculations of Zamick-Zheng [8] for ^{50}Cr ($t=3$ nucleons) in Fig. 1. We present in this figure individual g factors, although the emphasis of Ref. [1] was different and all conclusions were based on the similarity of the precessions. Individual g factors were obtained by modeling the time evolution of nuclei as they slowed down in a gadolinium foil under specific assumption of feeding times and field calibration. These moments, adopted by Ernst *et al.* [9] in their paper, are presented here for reasons of completeness. In the same figure the Z/A prediction is also shown. It is apparent to us that the majority of the g-factor values lean in favor of collectivity. However the new measurements on the first 2^+ excited states in both Cr and Ti have good precision and call for more elaborate calculations, capable of reproducing all the data. All measurements are mutually compatible, although the deviation between the two 4^+ state measurements in ^{50}Cr [1,9] may be attributed mainly to statistical fluctuations: large errors of the order of ~17% are assigned to both measurements due to statistics and the calibration of the field. Contributing factors to an additional error of these g factors may be due to the short nuclear lifetime and the slope determination of the γ-ray distribution function. In Ref. [1], slopes were determined both during the transient field precession measurement and in a separate an-

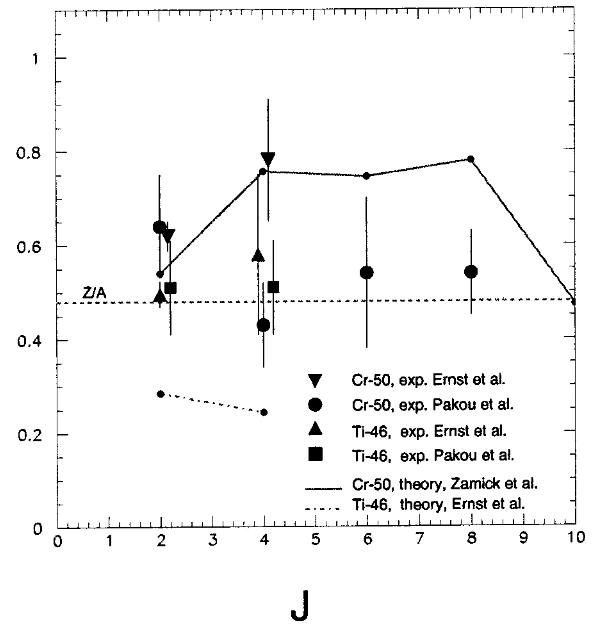

FIG. 1. Previous g-factor measurements (Refs. [1,9]) as a function of spin are compared with shell model calculations (^{50}Cr, solid line; ^{46}Ti, dot/dashed line; see text and Refs. [8,9]) and the more simplistic prediction, Z/A, of the hydrodynamical model (dashed line). The lines are drawn to guide the eye.

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gular correlation run, giving consistent results. Only the stopped γ-ray peak was taken into account in this analysis. In no circumstance, however, can the "problem" of the 4^+ Cr measurement of Ref. [1] be attributed to the heavy ion fusion reaction technique, as Ernst *et al.* do. Then the compatibility of the rest of our simultaneous measurements on Cr and Ti with previous results, and most of the new measurements, cannot be explained: our measurements [1] for the 2_1^+ states are in good agreement with all previous values $\{g_{mean}^{previous}$ $({}^{50}\mathrm{Cr},2_1^+)=0.55\pm0.10$, $g_{mean}^{previous}({}^{46}\mathrm{Ti},2_1^+)=0.48$ ±0.08 [2,17–19]$\}$ and the new measurements. These results were obtained in different laboratories by the transient field method but with various reaction techniques, namely, direct Coulomb excitation, inverse Coulomb excitation, and a heavy ion fusion reaction. Additionally, one of the measurements for ^{46}Ti was performed by an independent technique, namely, recoil in vacuum [19]. Furthermore the *g*-factor measurements of the 4_1^+ state in ^{46}Ti determined by inverse Coulomb excitation (new measurement) and a fusion reaction (our measurement) are also in good agreement.

In general, Ernst *et al.* correctly state that it may be inappropriate to use fusion reactions for precession measurements by the transient field technique, because of the complex feeding pattern. As outlined in detail in a previous publication [11] where the method was established, in order to make unambiguous measurements either additional handles to the usual transient field method must be invoked or nuclei and reactions with sufficiently simple feeding patterns must be selected. Adopting the last method, numerous measurements on (a) individual *g* factors of entry states (the $19/2^-$ state in ^{39}K, and the $19/2^-$ in ^{49}Cr [11,12]) and (b) average *g* factors for bands below and above a backbend in ^{78}Kr and *g* factors of discrete levels of bands in ^{82,84}Sr and ^{84}Zr [13–15] have been successfully performed in the past. In our case the measurements on ^{50}Cr, ^{46}Ti were based on a simple decay pattern which involves, for the state of interest, a direct population of $\sim32\%$.

Even if one takes for granted that the inverse-kinematic $g(4_1^+)$-factor measurement of Ref. [9] is correct, its large assigned error leads to a *g*-factor ratio of $g(4_1^+)/g(2_1^+)=+1.27\pm0.22$, which cannot discriminate between the ratio of the shell model prediction equal to 1.4 or the crude hydrodynamical prediction of unity. Considering other elecromagnetic properties, for example, quadrupole moments and $B(E2)$ values, the shell model calculations in general underestimate the measurements. Experiment and theory are in fair agreement for the $B(E2)$ value of the $2^+\rightarrow0^+$ transition in ^{50}Cr, but theory greatly overestimates experiment for the $4^+\rightarrow0^+$ transition.

Obviously the answer concerning the structure of the cross-conjugate nuclei ^{46}Ti and ^{50}Cr is not straightforward, and the subject remains open both in experiment and theory. Measurements of higher precision, concerning the higher excited states, are necessary to reveal the fine structure of theoretical models. In that direction, excitation techniques with higher yields may be necessary. This should be a top priority for transient field experiments on radioactive nuclei [16], since while radioactive beam facilites at ion energies compatible with transient field experiments is being realized, the available radioactive beam currents are low (10^2–10^6 pps) in comparison with stable beam currents. The inverse Coulomb excitation reaction seems to be moving forward, but it still has a long way to go to obtain the necessary high yields.

Summarizing, we have argued that in general, existing *g*-factor data in the cross-conjugate nuclei ^{50}Cr and ^{46}Ti are not in significant conflict and present a gross compatibility with the Z/A prediction of the hydrodynamical model. Due to the large errors assigned to the higher excited states, the data cannot differentiate between the gross features of the Z/A prediction [ratios $g(4_1^+)/g(2_1^+)$] and the fine structure of existing shell model calculations. Therefore, the subject remains open in both theory and experiment. It was also pointed out that heavy ion fusion reactions under specific conditions have been used successfully in transient field measurements to produce valuable information on the nuclear structure of several nuclei and subsequently the "problem" in the ^{50}Cr $g(4_1^+)$-factor measurement of Ref. [1] should not be attributed to the fusion reaction mechanism.

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