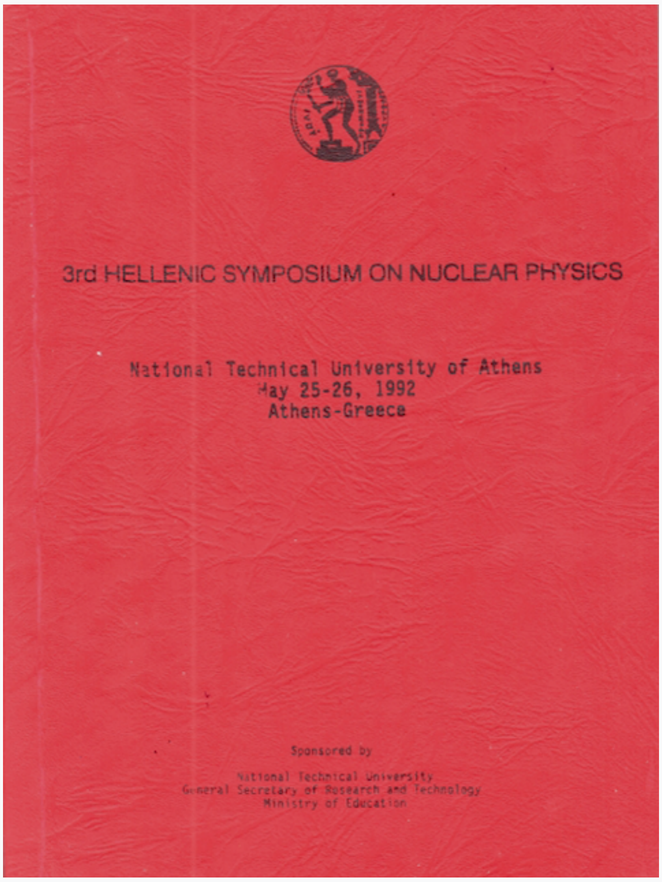
HNPS Advances in Nuclear Physics

Vol 3 (1992)

HNPS1992



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doi: [10.12681/hnps.2388](https://doi.org/10.12681/hnps.2388)

g-FACTORS OF SOME EXCITED STATES IN $^{49,50}Cr$

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Abstract

Magnetic moments of the first excited states in ^{50}Cr and of the $7/2^-$ and $19/2^-$ states in ^{49}Cr, have been measured by the transient field technique. The states were excited by the inverse reaction ^{40}Ca + ^{12}C and the recoil nuclei traversed a thick gadolinium foil. The observed rotations, of the 2^+, 4^+, 6^+, 8^+ states of the ground-state band in ^{50}Cr, were found into the experimental error to be the same, suggesting similar g-factors for these states and thus supporting a high collectivity for the ground-state band. g-factors of the $7/2^-$ and $19/2^-$ states in ^{49}Cr, were deduced by adopting both an overall parametrization of the transient magnetic field in Gd and by comparing the ^{49}Cr rotations with rotations of states with known magnetic moments, as the 2^+ ones of ^{50}Cr and of ^{46}Ti which was also populated in the same reaction. Both methods gave similar results and the g-factors adopted for the $19/2^-$ and $7/2^-$ states were +0.78(17) and +0.35(7) respectively. These results are discussed in terms of cranked shell model calculations and are found to support a proton alignment in the $f_{7/2}$ shell.

1. Introduction

fp-shell nuclei are of particular interest for testing shell model calculations and effective interactions.

Nuclei, from ^{40}Ca to ^{56}Ni have provide a good test ground for such calculations and most of them have shown a rather good shell model behaviour.

^{50}Cr and ^{46}Ti representing a pair of cross-conjugate nuclei, can put under severe test the results of single j shell calculations, in particular results concerning the symmetry under the interchange of protons with neutron holes and neutrons with proton holes. In these cases the theory[1] predicts a dramatic increase (^{50}Cr) or decrease (^{46}Ti) for the g-factors of the 4^+, 6^+, 8^+, states in comparison with the g-factor of the 2^+ one.

On the other hand, experimental results on both nuclei ^{46}Ti and ^{50}Cr suggest an onset of collectivity in the beginning of the ground- state band. In more detail, the quadrupole moments[2,3] of the first 2^+ excited states were found to be big and compatible with a prolate deformation while the B(E2) values for the 2^+, 4^+, 6^+ states[7,8], are also big but they exhibit a decreasing trend with increasing spin. g-factors are only known[1,4,5,6] for the 2^+_1 states and they can not differenciate between collective and shell model structure.

Additionaly for ^{49}Cr there is also evidence for collectivity[9] but for the low spin levels which roughly follow a I(I+1) energy rule and excibit large B(E2) values up to a maximum spin where a discontinuity occurs. This discontinuity was identified by Cameron et al[10] and was understood as a quasiparticle alignment of two protons in the $f_{7/2}$ shell.

To elucidate further the situation, in the present work, we report a) g-factor measurements of several ground-state spin states in ^{50}Cr while also attempt the measurement of states in ^{46}Ti. The last measurement was obscured by unresolved γ-rays and a substantial side feeding (25%) from states with unknown properties. b) g-factor measurements of the $7/2^-$ (rotational region) and $19/2^-$ (discontinuity region) states in ^{49}Cr.

The measurements were performed by adopting the conventional transient field method[11] and by utilizing, as an excitation process, the inverse reaction ^{40}Ca + ^{12}C, which leads to the residual nucleus via simple patterns.

2. Experimental Details

Since the conventional transient field method has been described by Benczer-Koller et al[11] and our setup outlined in a previous publication[12] we will present here only the features particular to this work.

The target layer of 500 μg/cm^2 carbon was sprayed on the front face of a thick gadolinium foil . The gadolinium foil, was first rolled down and then annealed at 600 °C for a few minutes in a vacuum of 10^{-7} bar and cleaned with glow discharge. Subsequently it's magnetization was measured as a function of external field and temperature, in a low temperature magnetometer (OXFORD LMT) and was found to be 80% (M=0.1720 T) magnetized at a field of 0.12 T. The target sandwich was clamped between the poles of an electromagnet and was polarized in a field of 0.12 Tesla which was reversed periodically. The temperature of the target was maintained at 88K by cooling with liquid nitrogen.

The inverse reaction ^{40}Ca+^{12}C was used to populate the states of interest at a beam energy of 140 MeV supplied by the 20 MV tandem accelerator of Daresbury Laboratory. The choice of beam energy was a compromise between obtaining: a) reasonable rates for the Ti and Cr nuclei and b) a low excitation for ^{50}Mn which beta decays in the low states of the ^{50}Cr nuclei.

Prompt γ-rays from the various reaction channels were detected in four Compton-suppressed, 25% efficiency, Ge detectors from the Daresbury facility. The detectors were located at ±60°, ±120° with respect to the beam, and at a distance of 8 cm from the target.

Slope measurements were carried out during the course of the experiment. For this purpose the detectors were moved by ±4° from their original position, to mimic the rotation of the γ-ray distribution. Furthermore an angular distribution measurement was performed to corroborate the slope measurements. The measurement was carried out by the four detectors which were placed at 75°, 135°, 195°, 255°, the only technically accessible positions. An efficiency measurement with a Eu source performed in the end of the experiment, allowed the combination of the results for the angular correlation fitting procedure.

3. Reduction of data and Results

Nuclear precession angles $\Delta\theta$ were deduced from the double ratios defined by

$$\rho = \frac{N_i(\uparrow)}{N_i(\downarrow)} \times \frac{N_j(\downarrow)}{N_j(\uparrow)} \quad (1)$$

where $N_i(\uparrow)$ refers to the counts in a γ-ray peak in the spectrum of detector i with field up. The rotation is then

$$\Delta\theta = \frac{1}{S(\theta)} \times \frac{\sqrt{\rho}-1}{\sqrt{\rho}+1} \quad (2)$$

where $S(\theta)$ is the slope of the γ-ray distribution.

Our experimental results are shown in Tables 1 and 2 together with other details of the measurement. Table 1 contains the ^{50}Cr rotations up to spin 8^+ and as it is seen they were found to be equal into the experimental error. This suggests similar g-factors for these states and corrections due to discrete feeding can be avoided. In the same context, a mean rotation of all these levels can be formed and be used with the known g-factor of the 2^+ levels for the field calibration.

Corrections due to continuum feeding can also be excluded, since if there is any it has been well established[13,14,15] that it is fast and can be dumped in the target material. The 10^+, 11^+ and 12^+ states were also excited in the present measurement. However, the analysis of the γ-ray deexciting the 10^+ state (1598keV) was obscured by other ovelaping lines with the same energy while the 11^+ and 12^+ states are very short lived and thus their rotation is not observable. In ^{46}Ti, due to unresolved γ-rays (1289 keV and 1598 keV), only the first two excited states were studied and their precessions were included in Table 1 . No feeding corrections were applied, assuming that the higher ground state band states will exhibit the same rotations, as they did

Table 1 : Rotations, $\Delta\theta$, and slopes, $S(\theta)$, for some of the states in even-even nuclei studied in the present experiment. The initial velocities in the gadolinium were : v/v_0= 7.8, 8.4 for ^{50}Cr and ^{46}Ti respectively

Nucleus	$J^+_i \rightarrow J^+_f$	$S(\theta)\|_{\theta=60^\circ}$	$\Delta\theta$(mrad)	$g^*_{present}$	$g^\dagger_{previous}$
^{50}Cr	$2^+\rightarrow 0^+$	0.68(3)	57.6(31)	0.57(7)	0.55(10)
	$4^+\rightarrow 2^+$	0.69(4)	51.4(40)	0.55(10)	
	$6^+\rightarrow 4^+$	0.67(6)	57.4(61)	0.56(10)	
	$8^+\rightarrow 6^+$	0.67(7)	57.5(98)	0.57(13)	
^{46}Ti	$2^+\rightarrow 0^+$	0.46(3)	46.0(40)	0.46(7)	0.48(8)
	$4^+\rightarrow 2^+$	0.47(5)	53.0(70)	0.53(11)	

* $\Delta\theta/g$ =101.6(16) mrad, 99.5(15) mrad for ^{50}Cr and ^{46}Ti respectively (Chalk River parametrization scaled by a factor 1.3(2), see text.

† Mean from references 1,4 and 5,6 for Cr and Ti respectively.

the first two excited states. However it should be pointed out here that a strong side feeding leading to the 4^+ state (3^-, 4^-, 5^- states of unknown lifetime) might alter the result of this state. However if the lifetime of the feeder states is of the order of a few picoseconds then the correction can be estimated and it was found not to exceed 1.5 miliradian .

Table 1 contains also g-factors obtained by adopting the following relation of the Chalk-River parametrization[16].

$$B = M\,154.67\,Z\,v/v_0 \exp(.135\,v/v_0) \qquad (3)$$

The above strength of the field had to be scaled by a factor of 1.3(2), valid for potassium nuclei recoiling in gadolinium[14] while a cutoff energy of 1.2 MeV was assumed for the thick target data after which the nuclei experience no rotation. As it is seen the results are in very good consistency with previous values[1,4] obtained for the $^{50}Cr(2^+)$ state by a transient field technique in Fe and a static field technique in Fe a weighted average of which is also shown in Table 1. The ^{46}Ti results follow the same trend and show also a very good consistency with values reported previously[5,6], one of them determined by a transient field in Fe while the other determined via an independ of parametrizations method-a recoil in vacumn technique. This suggests that the transient field experienced by Ti and Cr nuclei recoiling in gadolinium, can be described by the same parametization as the neighboring potassium ones.

Table 2 contains the ^{49}Cr results together with the rotations of the even - even nuclei, which were used for the calibration of the field. The even-even rotations are mean values of the results presented in Table 1. g-factors were deduced both by forming ratio of rotations, columns 6,7, and by using the Chalk River parametrization, column 5. The good consistency of the results supports the calibration of the field with either way. the g^2 values were finally adopted as the absolute g-factors determined in the present experiment since no corrections have to be applied for such a calibration.

Table 2 : Rotations, slopes and g-factors of ^{49}Cr. The ^{50}Cr and ^{46}Ti rotations which were used for the field calibration, are also shown (Initial ion velocities: v/v_o=7.8, 8.4 for Cr and Ti nuclei respectively).

Nucleus	$J^+_i \rightarrow J^+_f$	$S(\theta)\|_{\theta=60°}$	$\Delta\theta$(mrad)	g^1	g^2	g^3
^{49}Cr	$19/2^- \rightarrow 15/2^-$	0.62(6)	79.0(90)	0.71(13)	0.78(17)	0.79(18)
	$7/2^- \rightarrow 5/2^-$	0.46(1)	35.4(14)†	0.32(5)	0.35(7)	0.35(7)
^{50}Cr	$2^+ \rightarrow 0^+$	0.68(3)	55.7(22)*			
^{46}Ti	$2^+ \rightarrow 0^+$	0.46(3)	48.0(80)*			

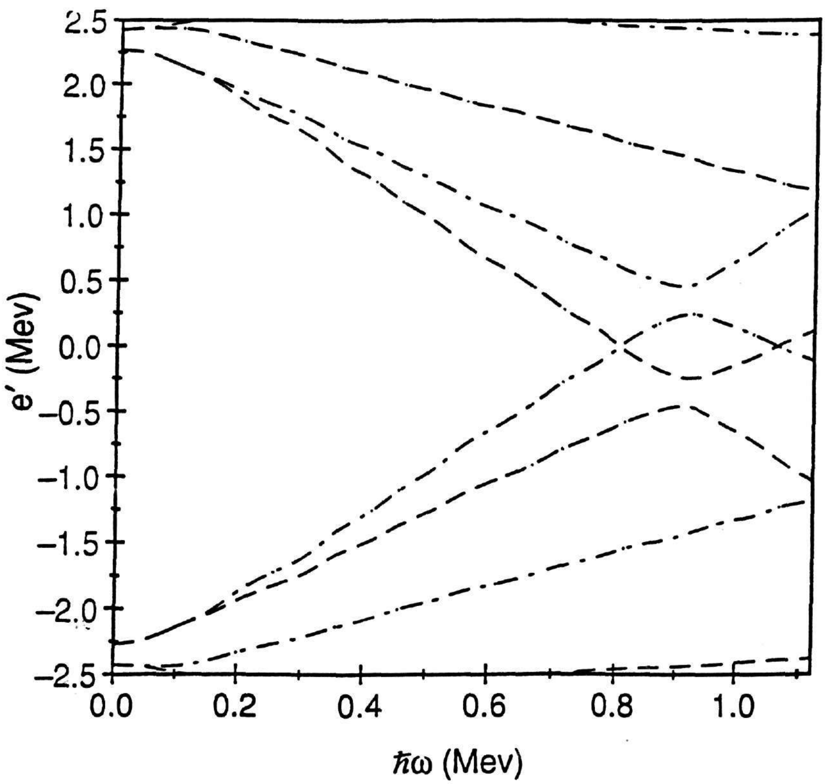
1 Adopting the Chalk River parametrization, see text
2 Forming ratio of rotations with the Cr mean precession and g(^{50}Cr, 2^+)=0.55(10) from references 1,4
3 Forming ratio of rotations with the Ti mean precession and g(^{46}Ti, 2^+)=0.48(8) from references 5,6
† corrected by 6.8% for feeding
* mean rotation see text

3. Discussion

^{50}Cr and ^{46}Ti results: g-factors were measured for several excited states of the ground- state band in ^{50}Cr. All values are close to the collective value of g=0.48 and well off, of previous shell model predictions. Therefore the present results suggest an onset of collectivity near the middle of the $f_{7/2}$ shell, consistent with previous findings[2,3,7,8]

An attempt was made to determine the moments of the ^{46}Ti ground-state band. Due mainly to unresolved gamma-rays, only the rotations of the first two excites states were determined. Nevertheless the results indicate a similar trend, like the one observed in ^{50}Cr, suggesting a close resemblance in the structure for these cross-conjugate nuclei, at least in what it concerns the low states of the ground-state band.

^{49}Cr results: Routhian plots generated from cranked shell model[17] calculations are shown in the following figure.



The calculation was performed by allowing 16 free protons between shells with N=3 to 4. The quadrupole deformation ε_2 has been extracted from the quadrupole moment Q^2_o= 0.7eb, which was deduced from our lifetime data[15]. The hexadecapole deformation ε_4 was taken to be zero, since it was found that small negative or positive values did not appreciably change the results. The parameters κ and μ were taken from Ref. 18. Finally the pairing proton interaction $\Delta/\hbar\omega$ was adjusted to the value of 0.2 to reproduce the interaction energy between the $19/2_1$ and $19/2_2$ levels, $|V_{gs}|$ =131 keV, met also in our experimental results.

From the quasiparticle diagram, Fig. 1, the crossing frequencies $\hbar\omega$ and the alignment i_s can be read and compared with the experiment. The values that we observed from the diagram are:

$$\hbar\omega_{cross} \approx 0.9\,\mathrm{MeV}, \qquad i_s \approx 3.75\,\hbar \tag{4}$$

The crossing frequency is consistent with the discontinuity to occur around spin $19/2^-_1$ where $\hbar\omega(\alpha=+1/2)=0.96$ while the alignment can be compared through the measured magnetic moment as following. If the discontinuity is due to two quasiparticle alignment, then their angular momentum, i_s, has the same direction as the collective angular momentum I_g and $I_s = I_g + i_s$. The magnetic moment then, has the direction of the rotational axis and the g-factor of the aligned state is[19] :

$$g_s = \mu/I_s = g_R + (g_i - g_R)\, i_s / I_s \tag{5}$$

with

$$g_i = g_j = g_l + (g_s - g_l)\,(2l+1)^{-1} \tag{6}$$

We have calculated g_i via eqn (6) employing for g_l and g_s the gyromagnetic ratios of the free nucleon and attenuating g_s by a factor of 0.7. The obtained values were: $g_i(\pi;f_{7/2})=1.42$ and $g_i(\nu;f_{7/2})=-0.38$. Subsequently, by using these values for g_i and the alignment i_s, from eqn (4), we can deduce the g-factor of the 19/2 via eqn (5) for either proton or neutron alignment. The obtained results were :

$$\text{two proton alignment} \quad g_{theory} = 0.85 \tag{7}$$

two neutron alignment $g_{theory} = 0.14$ (8)

A comparison of the above values with our experimental result (Table 2) supports clearly the suggestion of Cameron at al[10] for proton alignment in the $f_{7/2}$ shell and into a cranked shell model framework. In the same context, the collectivity of the ground-state band up to the discontinuity region, is reassured by the g-factor measured for the 7/2 state (Table 2).

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