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Magnetic Moment of the Lowest 6^+ State in ^{42}Ca and Effects of the Deformed States

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With the time-differential angular-distribution method the g factor of the lowest $(\nu f_{7/2}{}^2)$ 6^+ state in ^{42}Ca has been determined to be $-0.50^{+0.02}_{-0.03}$, which is closer to the Schmidt value for the $0f_{7/2}$ neutron than is that of the ^{41}Ca ground state. Strong violation of the additivity of the effective magnetic moment for these states is interpreted by a larger mixing of the core-excited deformed states into the ^{41}Ca ground state.

In the present Letter we report a g-factor measurement of the lowest 6^+ state ($t_{1/2} = 5.52$ nsec) in ^{42}Ca made by means of the time-differential perturbed angular distribution (PAD) method, which yields a g factor significantly different from the previously reported value.[1] From the shell-model point of view the 6^+ state is considered to be mainly of the $\nu f_{7/2}{}^2$ configuration. In fact recent measurements of the $E2$ transition probability between the 6^+ and 2750-keV 4^+ states proved the very pure character of this configuration.[2] The g factor of the 6^+ state, giving the $0f_{7/2}$ neutron g factor in its two-particle state, is expected to throw new light on the magnetic moment of the ^{41}Ca ground state ($-1.59460\mu_N$[3]) which is known to deviate largely from the Schmidt value ($-1.91314\mu_N$). Since the ^{40}Ca core is closed in the L-S coupling scheme, the correction due to configuration mixing vanishes according to first-order perturbation theory.[4] The deviation from the Schmidt value therefore comes from the higher-order configuration mixing and from some other possible effects such as mesonic exchange currents and $L\cdot S$ and tensor interactions. If these effects can be renormalized into the effective magnetic moment of the $0f_{7/2}$ neutron, we expect $g(6^+, {}^{42}\mathrm{Ca})$ to be nearly equal to $g(\frac{7}{2}^-, {}^{41}\mathrm{Ca})$. Such an additivity of the renormalized magnetic moment has recently been shown to hold well for the protons in the ^{208}Pb and ^{88}Sr regions[5] in which the spin core polarization (the first-order configuration mixing) is an important contribution to the deviation from the Schmidt value.

The experimental method used in this work is essentially the same as described earlier.[6] The 6^+ state in ^{42}Ca was excited by the reaction ^{40}Ca(α, $2p$)^{42}Ca with 25-MeV α particles from the cyclotron at the Institute of Physical and Chemical Research. A thick metallic Ca (natural) target was used. Time distributions of γ rays were measured by the use of the natural cyclo-

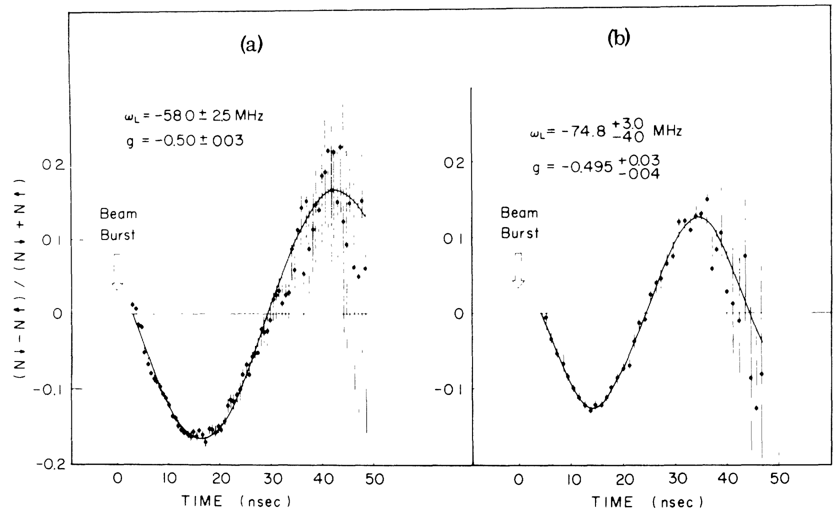

FIG. 1. Normalized time-differential patterns of the γ-ray angular distribution. The data were taken for the cascade transitions from the 6^+ state in ^{42}Ca at (a) $H = 24.20 \pm 0.15$ and (b) 31.5 ± 0.3 kOe, where counts $N\uparrow$ and $N\downarrow$ correspond to the magnetic field up and down, respectively. The solid curves are the best fits.

tron beam bursts at 132-nsec intervals. Since delayed γ-ray spectra taken with a 20-cm^3 Ge(Li) detector at this bombarding energy exhibited strong 439-, 1227-, and 1524-keV peaks (the cascade transitions from the 6^+ state in question) and other peaks were very weak, we used a $1\frac{3}{4}$-in.$\times$2-in.-diam NaI(Tl) crystal in the PAD measurements. The scintillator was coupled with a model No. 56 AVP phototube and placed at 135° with respect to the beam direction. An external magnetic field was applied up and down perpendicularly to the beam-detector plane. The time-distribution measurements were carried out twice independently, at $H = 24.20 \pm 0.15$ kOe and at $H = 31.5 \pm 0.3$ kOe.

The results are shown in Fig. 1, from which we obtain

$$g(6^+, {}^{42}\mathrm{Ca}) = -0.50^{+0.02}_{-0.03},$$

where the given errors include the statistical ones, ambiguity of time and magnetic field calibrations, and other possible experimental uncertainties. The Knight-shift correction is not known but it is expected to lie well within the experimental errors. The present value is appreciably different from the one ($g = -0.42 \pm 0.03$) obtained by Marmor, Cochavi, and Fossan[1] who used the time-integral perturbed-angular-correlation method. Although the reason for the disagreement is not well understood, our measurements were based on the time-differential PAD method and are free from uncertainties often encountered in the time-integral measurements.

In Table I the present results are compared with some theoretical considerations. First of all, it is to be noted that the g factor of the 6^+ state in ^{42}Ca is closer to the Schmidt value of the $0f_{7/2}$ neutron than that of the ^{41}Ca ground state. The most probable correction to the pure $\nu f_{7/2}{}^2$ configuration of the 6^+ state is an admixture of $f_{7/2}f_{5/2}$ configuration, of which the effect is, as will be shown later, to bring the magnetic moment toward the inside of the Schmidt lines. Consequently, the g factor carried by the $0f_{7/2}$ neutron itself will become even closer to the Schmidt value.

In order to explain the magnetic moment of the ^{41}Ca ground state, a calculation of the second-order configuration mixing has been done by Ichimura and Yazaki[8] and later by Mavromatis, Zamick, and Brown.[7] Their results are in qualitative agreement with the observed magnetic moment, but it seems difficult to explain why the effective magnetic moment of the $0f_{7/2}$ neutron is different in ^{41}Ca and ^{42}Ca because the effect of the second-order configuration mixing is expected to give almost the same correction for both nuclei.

Recently, a large amount of mixing of core-excited states has been revealed in Ca and Sc isotopes from experimental[9] as well as theoretical sides.[10-12] For example, enhanced $E2$ transition rates such as $\frac{3}{2}^-$ (first) $\to \frac{7}{2}^-$ (ground) in ^{41}Ca and 2^+ (first) $\to 0^+$ (ground) in ^{42}Ca were well accounted for in the work of Gerace and Green[10]

TABLE I. The experimental g factors for the $\nu f_{7/2}{}^n$ configuration in comparison with the theoretical estimates.

	$\frac{7}{2}^-$ (^{41}Ca)	6^+ (^{42}Ca)
Main configuration	$f_{7/2}$	$f_{7/2}{}^2$
$g_{\rm expt}$	-0.4556[a]	$-0.50^{+0.02}_{-0.03}$[b]
$g_{\rm sp}$ (Schmidt estimate)	-0.546	-0.546
δg_1 (first-order correction)		0.07
$\delta g_{\rm def}$ (correction due to the deformed states)[c]	0.13	0.02
$g_{\rm cal}$ $(=g_{\rm sp}+\delta g_1+\delta g_{\rm def})$	-0.42	-0.46
$g(\nu f_{7/2})$[d]	-0.59	-0.59
δg_2 (second-order correction)	0.08[e]	0.08[f]
$g_{\rm cal}$ $(=g_{\rm sp}+\delta g_1+\delta g_2+\delta g_{\rm def})$	-0.34	-0.38
$g(\nu f_{7/2})$[d]	-0.67	-0.67

[a]From Ref. 3.
[b]Present value.
[c]Calculated for the wave functions given in text assuming $g_R = 0.5$.
[d]g factor carried by the $0f_{7/2}$ neutron itself $(=g_{\rm expt} - \sum \delta g)$.
[e]Taken from Ref. 7.
[f]The same value as for the $\frac{7}{2}^-$ state is assumed.

by admixture of core-excited states such as three-particle, two-hole (^{41}Ca) and four-particle, two-hole (^{42}Ca) configurations which cause positive deformation. As a possible cause of large mixing of the deformed states into the ^{41}Ca ground state, Gerace and Green[10] considered a rotational state built on the Nilsson orbital No. 14 having $\Omega = \frac{1}{2}$. They showed that because of the decoupling effect the deformed $\frac{7}{2}^-$ state posesses an appreciably low excitation energy and thus a considerable mixing to the spherical state takes place. Their results are

$$|\tfrac{7}{2}^-, {}^{41}\text{Ca}\rangle = 0.924|1\text{p-0h}\rangle + 0.388|3\text{p-2h}\rangle,$$

where $|1\text{p-0h}\rangle$ is spherical $0f_{7/2}$ state and $|3\text{p-2h}\rangle$ is a deformed state in the above-mentioned sense. For this wave function we calculate the g factor to be -0.42, which is reasonably close to the observed value. As to the 6^+ state in ^{42}Ca, mixing of the deformed 4p-2h state is expected to be relatively small because of the lack of such a decoupling effect. In fact extensive calculations of Flowers and Skouras[11] showed its mixing to be 0.19, which changes the g factor by only 0.02. However, an important correction arises from a mixing of $\nu f_{7/2} f_{5/2}$ configuration. With the Hamada-Johnston potential Kuo and Brown[13] found the wave function of the 6^+ state to be $0.99 f_{7/2}{}^2 + 0.13 f_{7/2} f_{5/2}$ (a small admixture of $g_{9/2}{}^2$ configuration is neglected here), where their interaction matrix includes the renormalization due to core polarizations. For this wave function the g factor is calculated to be -0.48, which agrees well with the experimental value. To summarize, strong violation of the additivity of the effective magnetic moment can be considered to originate from a larger mixing of the core-excited deformed states into the ^{41}Ca ground state.

From the above wave functions we can deduce the g factor carried by the $0f_{7/2}$ neutron itself, which amounts to $g(0f_{7/2}) = -0.59$ in both cases. It lies slightly outside the Schmidt lines. Moreover, if we take the correction due to the second-order perturbation mentioned before, the discrepancy will become even larger as shown in Table I. (It is to be noticed here that we do not count the corrections two times because the second-order correction comes mainly from the 2p-1h excitation[8] and not from 3p-2h states.) It is consistent with the results pointed out by Blin-Stoyle[14] that after reasonable corrections the observed magnetic moments of the doubly-closed-shell-plus-or-minus-one nuclei might lie outside the Schmidt limits, which may be explained by the meson exchange effects.[15] On the other hand there has been some evidence[5,16] that the orbital g factor of the nucleons in a nucleus is enhanced by $0.1\tau_z$ (τ_z is $+1$ for a proton and -1 for a neutron), which can also be caused by the meson exchange currents. Such an anomalous g_l factor shifts the Schmidt lines downwards for neutrons and upwards for protons. The present result is also consistent with this tendency. A careful study of the magnetic moments of nuclei with $j=l-\frac{1}{2}$ could determine which effect is dominant in the f-p shell region.

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Investigation of 2^+ Core Excitation in ^{141}Ce by Inelastic Scattering of Polarized Protons

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Inelastic scattering of polarized protons from ^{140}Ce to the 2_1^+ ($E_x=1.596$ MeV) state near isobaric analog resonances shows the importance of direct, off-resonant inelastic scattering, and provides enough information to determine parentage coefficients for six p and f states in ^{141}Ce up to an excitation energy of 1.88 MeV.

This Letter is concerned with inelastic scattering of polarized protons near isobaric analog resonances (IAR's). The observed resonance structure of the analyzing power for the reaction ^{140}Ce$(p,p_1)^{140}$Ce*$(2_1^+$, $E_x=1.596$ MeV) shows the importance of direct background scattering, a feature which has been neglected in earlier work.[1,2] The present analysis gives detailed information on the contribution of the 2^+ core excitation to states in ^{141}Ce.

To include core excitation into the shell-model description of a nucleus with even proton number Z and odd neutron number N, the wave function ψ^λ is assumed to be a linear combination (parentage expansion) of single-particle neutron shell-model states $n(j)$ coupled to the ground state $C_0(0^+)$ and to the various excited states $C_i(I)$ of the $(N-1,Z)$ nucleus[3]:

$$\psi^\lambda(J^\pi)=\sum_{i,j}a_{ij}{}^\lambda[n(j)\otimes C_i(I)]_{J\pi}, \quad (1)$$

where $a_{0j}{}^\lambda$ is the square root of the spectroscopic factor. Excited core states with spin I different from zero may couple with a number of neutron wave functions of different total angular momentum j, restricted by the conditions $\vec{J}=\vec{j}+\vec{I}$ and $\pi(\psi)=\pi(n)\pi(C)$. This expansion is particularly suitable for nuclear spectroscopy with IAR's because the C_i represent target nucleus states, and resonant proton-scattering channels c are observed with partial-width amplitudes proportional to the parentage coefficients $a_{ij}{}^\lambda$.

From the analysis of inelastic scattering the contributions of excited 0^+ core states have been