The ground state $g$ factor of $^{44}$Cl: a probe for the reduced gaps at $Z=16$ and $N=28$.

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Abstract. The $g$ factor of the $^{44}$Cl ground state is measured at the LISE fragment separator at the Grand Accélérateur National d’Ions Lourds (GANIL) using the $\beta$ nuclear magnetic resonance technique, resulting in $g(^{44}\text{Cl})=-0.2749(2)$. An analysis of the $g$ factor value and of the theoretical level scheme in the shell-model framework reveals the presence of odd-proton $s_{1/2}$ configurations and neutron excitation across the $N=28$ shell gap in the $^{44}$Cl ground state. In addition, the measured $g$ factor strongly supports a $2^-$ spin assignment for the $^{44}$Cl ground state.

Keywords: $^{44}$Cl, $g$ factor, magnetic moment, $\beta$-NMR, nuclear polarization, beam fragmentation

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INTRODUCTION

Nuclei with extreme proton-neutron ratios have attracted a lot of attention recently. Novel phenomena, such as new magic numbers and shell closures have been observed. For the neutron-rich $N=28$ isotopes, extensive experimental and theoretical studies revealed the erosion of the $N=28$ shell gap and the collapse of the $Z=16$ subshell closure, resulting in collectivity, shape coexistence and configuration mixing. $^{44}$Cl is a nucleus that is expected to be very sensitive to the $\pi(s_{1/2})-\pi(d_{3/2})$ near degeneracy and to neutron excitations across $N=28$. The measurement of the $^{44}$Cl magnetic moment is a unique tool to provide answers to its nuclear structure.

This proceedings describe the findings of a measurement at the $^{44}$Cl ground-state $g$ factor carried out with the $\beta$-NMR technique on polarized nuclei at the LISE spectrometer of GANIL. A theoretical interpretation of the measured value is also briefly discussed.

EXPERIMENTAL DETAILS

Spin-polarized $^{44}$Cl nuclei were produced in a fragmentation reaction of a $^{48}$Ca beam at 60A MeV impinging on a 1212-$\mu$m-thick rotating Be target. $^{44}$Cl fragments were separated by the LISE spectrometer at GANIL. The spin-polarization needed for the application of the $\beta$ nuclear magnetic resonance, a $2(1)^\circ$ angle was imposed on the primary beam with respect to the downstream direction. Furthermore, the highest amount of polarization was achieved by selecting the right wing of the longitudinal momentum distribution. Beam purity at the level of 90% was further realized by means of a degrader wedge and appropriate settings of the Wien filter in front of the $\beta$-NMR setup [1]. Additional details on the application of the method may be found in Ref. [2].
The $g$ factor of the state may be found using the following relation:

$$hv_L = g\mu_n H_o$$

(1)

where $hv_L$ is the hyperfine states energy splitting, $H_o$ is the static dipole magnetic field and $\mu_n$ is the nuclear magneton. When scanning a broad range of rf-frequencies $v$, a resonance is observed when the $v$ equals the Larmor frequency $v_L$. Afterwards, finer successive scans may follow to reduce the experimental error on the $g$ factor. In the present experiment, and for an external magnetic field $H_o=1.0001(7)$ T, five different $\beta$-NMR scans at different combinations of rf frequency and frequency modulation were performed. From the measurement with a frequency step of 1 kHz and a modulation of 0.6 kHz, the Larmor frequency $v_L=2096.5(2)$ kHz could be deduced. The corresponding frequency $\beta$-NMR scan is shown in Fig. 1.

**FIGURE 1.** Resonance curve for frequency sweeps of 1 kHz with a modulation of 0.6 kHz

**RESULTS AND DISCUSSION**

The weighted mean of all independent Larmor frequencies resulted in the final value, $|g^{(44}\text{Cl})|=0.2749(2)$.

Shell-model calculations using the ANTOINE code [3] with the SDPF-U residual interaction [4] and effective nucleon $g$ factors, $g_\pi=1.1$, $g_v=-0.1$, and $g_s=0.75g_s^{\text{free}}$ were carried out. These calculations, in comparison with experimentally obtained results, were used to study the reduction of the N=28 shell gap and the collapse of the $Z=16$ subshell closure.

The theoretical calculation with the ANTOINE code produces a very fragmented configuration for the ground state with $(\pi d_{3/2})^3(\nu f_{7/2})^7$ and $(\pi s_{1/2})^1(\nu p_{3/2})^1$ as the main components. The calculated level scheme Fig. 2 predicts $2^-$ as the spin/parity of the $^{44}\text{Cl}$ ground-state wave function. The calculated ground-state $g$ factor is $g^{\text{th}}=-0.2692$ and agrees well with the experimental value. The absolute value of the measured $g$ factor is much smaller than the single-particle value for the normal $d_{3/2}f_{7/2}$ configuration. This can be understood in the framework of configuration mixing. The $s_{1/2}p_{3/2}$ contribution,
which has a positive single particle $g$ factor, indeed reduces the $g$ factor with respect to the value observed for a single-particle $d_{3/2}f_{7/2}$ configuration. In addition, the agreement between theory and experiment supports the adoption of the $2^-$ spin and parity for the $^{44}\text{Cl}$ ground state.

\begin{center}
\begin{tabular}{|c|c|}
\hline
$^{44}\text{Cl}$ & \\
\hline
$|g_{\text{exp}}(g,s)| = 0.2740(2)$ \\
$g_o (g,s) = -0.2092$ & \\
\hline
\end{tabular}
\end{center}

\begin{center}
\begin{tabular}{|c|c|}
\hline
1178 & $5^-$ \\
560 & $4^-$ \\
523 & $3^-$ \\
521 & $0^-$ \\
512 & $1^-$ \\
\hline
\end{tabular}
\end{center}

\begin{center}
Calculation
\end{center}

\textbf{FIGURE 2.} $^{44}\text{Cl}$ theoretical level scheme as predicted by shell-model calculations.

In conclusion, the $^{44}\text{Cl}$ ground state and $g$ factor are very sensitive to the subtle interplay between proton configurations originating from the collapse of the $Z=16$ subshell closure and neutron excitations across the reduced $N=28$ shell gap. From the comparison of the $^{44}\text{Cl}$ level scheme and $g$ factor with calculated and experimental values in neighboring nuclei, it is deduced that both effects play a major role in the ground state of $^{44}\text{Cl}$.

\textbf{REFERENCES}
