We conclude that the R dependence of our field gradient is in good agreement with experiment.

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Magnetic Moments of the 7^- and 5^- $(\pi h_{9/2}, \nu g_{9/2})$ States in ^{210}Bi

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The g factors of the 433-keV 7^- state and the 439-keV 5^- state in ^{210}Bi which are predominantly $(\pi h_{9/2}, \nu g_{9/2})$ have been measured as $g(7^-) = 0.302 \pm 0.007$ and $g(5^-) = 0.306 \pm 0.009$ by a time-differential method using the reaction ^{208}Pb(^{7}Li,αn)^{210}Bi. From these experimental results, a magnetic moment for the $g_{9/2}$ neutron of $\mu = -(1.33 \pm 0.06)\mu_N$ $[g(\nu g_{9/2}) = -0.296 \pm 0.014]$ has been deduced. This $g_{9/2}$-neutron magnetic moment is in agreement with the Schmidt value corrected for core polarization.

The large anomaly that exists in the magnetic moment of the $h_{9/2}$ proton single-particle state outside of ^{208}Pb has represented for some time an important difficulty for nuclear theory. Expected corrections to the magnetic moment for core polarization do not give a satisfactory explanation.[1,2] The high purity of the single-particle states relative to the doubly closed shell of ^{208}Pb makes the understanding of their magnetic moments essential for the interpretation of nuclear magnetic properties in general. Despite this importance and the $h_{9/2}$ proton anomaly, there is as yet no experimental information on the magnetic moments of neutron single-particle states outside of ^{208}Pb. In this context, a measurement of the g factor of the $g_{9/2}$ neutron state, which is the lowest neutron single-particle state outside of ^{208}Pb, is of considerable interest to the basic understanding of this anomalous magnetism. Recently, Nagamiya and Yamazaki[3] have concluded that magnetic moments measured for several proton particle states including the $h_{9/2}$ state and neutron hole states of the ^{208}Pb core show evidence for anomalous orbital g factors. They suggest an increase in the orbital g factor for the proton of $\Delta g_l = 0.10$ which in turn gives an explanation for the anomalous $h_{9/2}$ magnetic moment. Their analysis and other more recent work for neutron hole states[4] suggest with less evidence a $\Delta g_l \sim -0.05$ for the neutron. The knowledge of the $g_{9/2}$ single-neutron g factor would also give an additional check of any Δg_l for the neutron. A theoretical basis for the Δg_l has been discussed in terms of meson exchange currents.[5,6] The low lying levels in ^{210}Bi have been interpreted[7] as the $(\pi h_{9/2}, \nu g_{9/2})$ negative-parity multiplet with angular momentum J from 0 to 9 (see Fig. 1). Since the g factor of the $h_{9/2}$ proton is known, a measurement of the magnetic moment of a pure member of this multiplet in ^{210}Bi can yield the $g_{9/2}$ neutron g factor. The known g factor of the 1^- state in ^{210}Bi fails to give this value, since this specific state has admixtures which make significant contributions to its magnetic moment. The 7^- and 5^- members of this multiplet in ^{210}Bi are, however, quite pure with negligible magnetic-moment contributions from admixtures. The lifetimes[8] of both of these states are also conve-

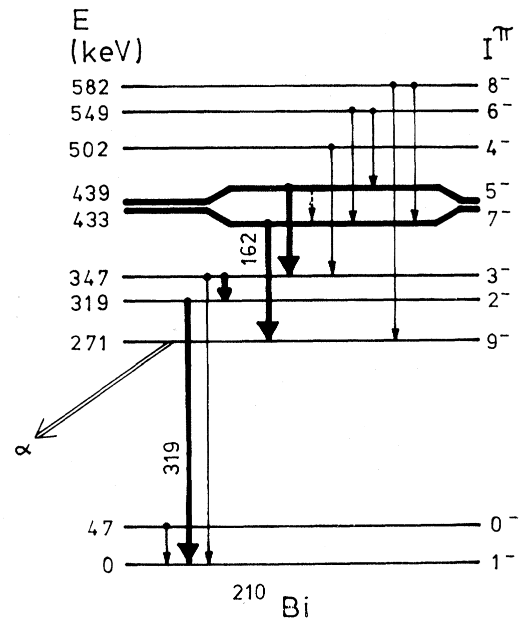

FIG. 1. A partial level scheme of ^{210}Bi, taken from Ref. 8.

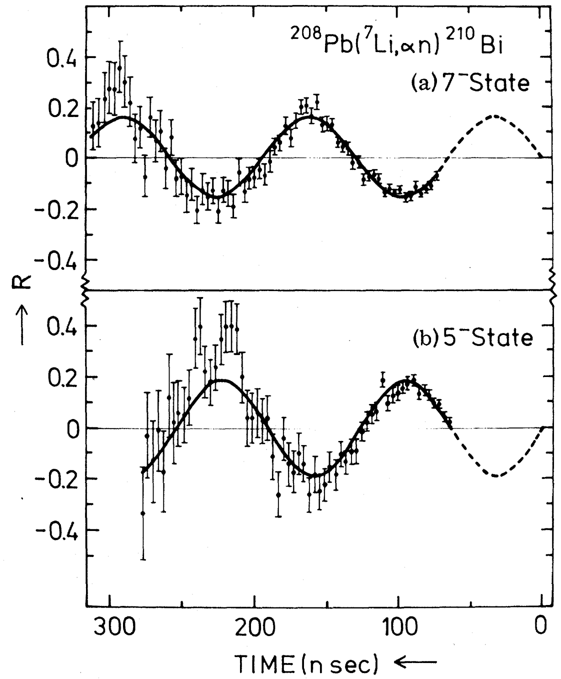

FIG. 2. Experimental results of the ratio R (see text) for the 162-keV (representing the decay of 7^- level) and the 319-keV (representing the decay of 5^- level) transitions. The solid curves are least-squares fits to the data.

nient for experimental magnetic-moment measurements. The present Letter reports on measurements of the g factors of the 7^- and 5^- states in ^{210}Bi by a time-differential spin-rotation method. The experimental results for both of these states lead to a magnetic moment of $\mu = -(1.33 \pm 0.06)\mu_N$ for the $g_{9/2}$ neutron single-particle state. After correction of the single-particle value for the core-polarization effects obtained from the work of Arima and co-workers,[1] the resulting calculated value agrees with the experimental result. The experimental magnetic moment for the $g_{9/2}$ neutron thus does not show an anomaly.

The reaction ^{208}Pb(^{7}Li, αn)^{210}Bi was used in the present work to populate the 7^- and 5^- states at 433- and 439-keV excitation, respectively, in ^{210}Bi. This reaction has the advantage of producing a good spin alignment which results in a large γ-ray anisotropy, and the ^{208}Pb target, which has a cubic lattice, preserves the alignment for observable decay times. A 30-MeV pulsed ^{7}Li beam (400 nsec repetition rate and <1 nsec pulse width) from the Munich MP tandem was used to bombard a thick ^{208}Pb target of 100 mg/cm^2. The target was placed between pole tips of an electromagnet with a field strength of 16.64 ± 0.05 kG. The 162- and 319-keV γ transitions representing the decay of the 7^- and 5^- states, respectively (see Fig. 1), were detected in 5-cm×5-cm NaI detectors positioned at $\pm 45°$ relative to the beam direction. The delayed portion of the 319-keV cascade γ ray contains the magnetic-precession information of the 5^- isomeric state because the lifetimes[8] of the 3^- and 2^- intermediate states are relatively short. Timing between the beam pulse and the decay γ rays was performed by a time-to-pulse-height converter. The four time spectra corresponding to 162- and 319-keV photopeak windows for each of the two detectors were routed to the four quadrants of a multichannel analyzer. The γ-ray energy spectrum, which was measured at 90° with a 30-cm^3 Ge(Li) detector, showed dominant and well-isolated 162- and 319-keV γ rays.

The timing data from the NaI detectors were analyzed to form the ratio $R(t) = [N(-45°, t) - N(45°, t)]/[N(-45°, t) + N(45°, t)]$ for each of the two γ-ray windows after proper normalization. This ratio for an angular distribution given by $1 + A_2P_2(\cos\theta)$ is related to the g factor through the relation $R = -[3A_2/(4+A_2)]\sin 2\omega_L t$, where $\omega_L = -gH/\hbar$ is the Larmor precession frequency [the $A_4P_4(\cos\theta)$ term was observed to be small from the sum spectra]. The experimental data for the ratio R and the least-squares fit with $-\sin 2\omega_L t$ are shown in Fig. 2. From the least-squares analysis, ω_L

$= -24.28 \pm 0.12$ MHz was obtained for the 7^- state and $\omega_L = -24.60 \pm 0.20$ MHz for the 5^- state. After applying a Knight-shift and diamagnetic correction totaling $+(1.0 \pm 1.0)\%$ to the magnetic field, the resulting g factors are $g(7^-) = 0.302 \pm 0.007$ and $g(5^-) = 0.306 \pm 0.009$. The signs of the g factors were obtained from the observed ratios R and the signs of A_2, which are theoretically expected[9] for the spin sequences and γ-ray multipolarities involved. The signs of A_2 so deduced are positive for the 162-keV transition and negative for the 319-keV transition. The sum of the time spectra for the $\pm 45°$ detectors, which is proportional to $\exp(-t/\tau)$, yields mean lifetimes of $\tau = 81.9 \pm 1.5$ and 53.4 ± 2.0 nsec, respectively, for the 7^- and 5^- states, in agreement with the previous results.[8]

The 7^- and 5^- states have a dominant $(\pi h_{9/2}, \nu g_{9/2})$ configuration. For this pure configuration, the g factors of the 7^- and 5^- states would be equal and be given by $\frac{1}{2}[g(\pi h_{9/2}) + g(\nu g_{9/2})]$. The admixtures of other configurations have been calculated by Kim and Rasmussen[10] and by Kuo and Herling.[11] Contributions to the g factors of the 7^- and 5^- states due to these small admixtures have been evaluated; the resulting g factor for just the $(\pi h_{9/2}, \nu g_{9/2})J$ configuration is 0.302 ± 0.007 from the 7^- g-factor result and 0.310 ± 0.009 from the 5^- result. Since the differences between these values and the $g(7^-)$ and $g(5^-)$ are small, any uncertainties in the theoretical mixing amplitudes do not influence the experimental value of the $(\pi h_{9/2}, \nu g_{9/2})J$ g factor. From the average of these two results and the known g factor of the $h_{9/2}$ proton,[12] the extracted g factor of the $g_{9/2}$ neutron is $g = -0.296 \pm 0.014$ which corresponds to $\mu = -(1.33 \pm 0.06)\mu_N$.

The single-particle (Schmidt) value for the magnetic moment of a $g_{9/2}$ neutron state is $-1.91\mu_N$ as compared with the experimental value of $-(1.33 \pm 0.06)\mu_N$. A significant correction to the Schmidt value is expected from core polarization, namely, excitation of the core particles $\pi h_{11/2}$ and $\nu i_{13/2}$ to their spin-orbit partners outside the core. This correction was made on the basis of the calculations of Arima and co-workers,[1] and is summarized in Table I. The correction with a δ-function interaction gives a value of $0.46\mu_N$, while the calculation of Arima and Huang using Kuo and Brown's matrix elements gives a value of $0.59\mu_N$. Both of these are first-order corrections. Several other calculations[2] using realistic interactions and taking into account higher-order effects are in essential agreement with the Arima calculations for the $h_{9/2}$ proton state. Thus, the value $(0.52 \pm 0.10)\mu_N$ represents a good estimate for the total core polarization correction. An additional small correction due to two-body spin-orbit interaction estimated from Chemtob[5] is $0.03\mu_N$. With these two corrections applied to the Schmidt value, the resulting calculated value is $\mu_{\text{calc}} = -(1.36 \pm 0.10)\mu_N$. The experimental value for the $g_{9/2}$ neutron of $\mu = -(1.33 \pm 0.10)\mu_N$, which agrees with μ_{calc}, thus shows no anomaly. The absence of an anomaly is consistent with nonanomalous orbital and spin g factors.

Recently, there have also been calculations of the single-particle magnetic moments in the ^{208}Pb region following the many-body theory of Migdal. One such calculation,[13] which used renormalized magnetic-moment operators $[\Delta g_l(\pi) = 0.10,\ \Delta g_l(\nu) = -0.03$, and $\delta g_s/g_s = -0.06]$, yielded theoretical values of $\mu = 3.88$ and $-1.39\mu_N$ for the $\pi h_{9/2}$ and $\nu g_{9/2}$ magnetic moments, in fair agreement with the experimental values of $\mu = 4.079$ and $-(1.33 \pm 0.06)\mu_N$, respectively.

With the present experimental value for the $g_{9/2}$-neutron g factor, one can calculate the magnetic moment of the 1^- state in ^{210}Bi on the basis of the wave functions of either Kim and Rasmussen[10] or Kuo and Herling.[11] Outside of the dominant $(\pi h_{9/2}, \nu g_{9/2})$ contribution, the main addition to the mag-

TABLE I. Comparison of experimental and calculated values for the magnetic moment of the $g_{9/2}$ neutron state. All numbers are in units of μ_N.

μ_{Schmidt}	$\delta\mu_{\text{core-pol}}$		$\delta\mu_{LS}$	$\delta\mu_{\text{tot}}$	μ_{calc}	μ_{expt}
-1.91	0.46[a] 0.59[b]	0.52 ± 0.10	0.03[c]	0.55 ± 0.10	-1.36 ± 0.10	-1.33 ± 0.06

[a]Calculated using a δ-function interaction and energy separations $\Delta E(\pi h_{9/2}-\pi h_{11/2}) = 5.60$ MeV and $\Delta E(\nu i_{11/2}-\nu i_{13/2}) = 5.85$ MeV.
[b]Calculated by Arima and Huang (Ref. 1).
[c]Calculated from the formula of Chemtob (Ref. 5).

netic moment of the 1^- state comes from the $(\pi h_{9/2}, \nu g_{7/2})$ part of the wave function, which makes a contribution linear in the mixing amplitude. In the evaluation of this term, $g_s(\nu) = -2.66$ was used, which is the value for the $g_{9/2}$ neutron from the present experiment. Other smaller additions require the knowledge of the g factors for the $f_{7/2}$ proton, and the $d_{5/2}$ and $i_{11/2}$ neutrons. These terms have been estimated using the core-polarization corrections of Arima and co-workers.[1] Including all of the contributions one gets $g(1^-) = (0.07 \pm 0.04)\mu_N$ and $(0.00 \pm 0.04)\mu_N$ on the basis of the wave functions of Kim and Rasmussen[10] and Kuo and Herling,[11] respectively. The uncertainties in the calculation come from the uncertainty in the core-polarization correction which is taken as 20% in each case. These calculations have to be compared with the experimental value[12] of $|g(1^-)| = 0.0442 \pm 0.0001$. The agreement is good.

In conclusion, we would like to make a few comments in regard to anomalous nucleon g factors in the ^{208}Pb region. The evaluation of anomalous orbital and spin g factors is strongly dependent on the calculation of the core-polarization effects. Although the nature of these core-polarization corrections is theoretically understood, there are uncertainties in these corrections which arise from the choice of energy denominators and interaction strengths, and from higher-order effects. Extensive core-polarization calculations for the $h_{9/2}$ proton state have been made[1,2] and the results are in agreement with each other to within $0.2\mu_N$. These corrections to the Schmidt value fail to account for the observed magnetic moment for the $h_{9/2}$ proton state and thus an anomaly exists in this case. Even though such extensive calculations have not been made for the other single-particle cases in this region, first-order corrections incorporating the most recent information on the interaction potentials and energy denominators have been made by Arima and Huang.[1] All measured magnetic moments for these other cases are consistent with Schmidt values corrected for core polarization as above (with an estimated 20% uncertainty in these corrections) without assuming any anomalous orbital and spin g factors.[14] Hence, any conclusions on anomalous nucleon g factors rest mostly on the $h_{9/2}$ proton anomaly. Thus it is our opinion, that although the question of anomalous orbital magnetism is interesting, the lack of conclusive evidence from these other cases prevents a definite confirmation of the conclusions[3] about anomalous orbital g factors. It is hoped, that the presently available experimental information on magnetic moments in the ^{208}Pb region will encourage a re-examination of the different theoretical approaches to this problem.

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