PHYSICAL REVIEW VOLUME 124, NUMBER 6 DECEMBER 15, 1961

Nuclear Magnetic Moment of the 158-kev 5/2$^-$ State of Hg^{199}†

L. Grodzins, R. W. Bauer, and H. H. Wilson
Laboratory for Nuclear Science and Physics Department, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received August 2, 1961)

The nuclear magnetic moment of the 158-kev, $\frac{5}{2}^-$ state has been measured by precessing, in a solid gold environment, the $\frac{3}{2}^-$(334 kev)$\frac{5}{2}^-$(158 kev)$\frac{1}{2}^-$ gamma ray–gamma ray angular correlation in an external magnetic field of 26 000 gauss. The value obtained, $\mu_{\frac{5}{2}}=+1.03\pm0.08$ nm, includes a 5% correction for quadrupole attenuation as determined by studying the angular correlation as a function of the delay of the intermediate state. The value is compared to the recent prediction of de-Shalit assuming that the $\frac{5}{2}^-$ state originates from the coupling of the $\frac{1}{2}^-$ ground state ($\mu_p=+0.504$ nm) with the 2+ excitation of the core. The magnetic moment of the core excitation was obtained from the $M1$ gamma-ray mean life of the 50-kev transition between the $\frac{3}{2}^-$(208 kev) and $\frac{5}{2}^-$(158 kev) core-particle doublet. That mean life, determined to be $\tau_\gamma(50)=(4.46\pm1.0)\times10^{-9}$ sec, leads to predicted magnetic moments of $\mu_{\text{core}}=(+0.33_{-0.25}^{+0.17})$ mn and $\mu_{\frac{5}{2}}=(+0.84_{-0.25}^{+0.17})$ nm.

In this paper we report on the measurement of the nuclear magnetic moment of the $\frac{5}{2}^-$ first excited state of Hg^{199} by the precession of a gamma ray–gamma ray angular correlation in an external magnetic field. The value obtained is compared to and found to be in accord with the prediction of de-Shalit[1] based on the premise that the $\frac{5}{2}^-$ state is the lower member of a doublet formed by the coupling of the $p_{\frac{1}{2}}$ ground state to the 2^+ excitation of the core.

The relevant level structure of Hg^{199} is shown in the insert of Fig. 1(a). It is based on internal conversion measurements of Jung and Svedberg[2] corroborated by gamma-ray spectroscopy.[3] Those results from the latter work necessary to the prediction of the magnetic moment will be given here.

The sources of Tl^{199} were prepared by 27-Mev alpha bombardment of 0.1-mil gold foils. The sources were used *in situ*; neither chemistry nor heat treatment was performed on the foils. The sources, directly after production, contained $<1.0\%$ Hg^{200} and were useful over seven half-lives. The electronic and magnetic equipment used for this study has been described elsewhere.[4]

The determination of the magnetic moment of an excited state by the method used here requires the knowledge of the lifetime of the state, the angular correlation pattern through the state, and the perturbation effects on that correlation.

The mean life of the 158-kev state was measured by 247-kev–158-kev gamma ray–gamma ray coincidences using NaI crystals, one of which (detecting 158 kev) was unactivated and kept at 77°K. The decay curve of the 158-kev state observed with the time-to-pulse height converter is shown in Fig. 1(a). The finite time resolution of the circuit is illustrated by the prompt 247-kev–208-kev cascade. The result of these measurements, plus those on the delayed 334-kev–158-kev cascade, yields a mean life

$$\tau_m=(3.35\pm0.12)\times10^{-9}\text{ sec},$$

in agreement with the measurement of Bell, *et al.*[5]

The $\frac{3}{2}$(334 kev)$\frac{5}{2}$(158 kev)$\frac{1}{2}$ gamma ray–gamma ray cascade was used for the magnetic moment measurement. Its unperturbed angular correlation after subtracting backgrounds was found to be

$$W(\theta)=1-(0.42\pm0.02)P_2(\cos\theta)+(0.01\pm0.02)P_4(\cos\theta).$$

The perturbation of this correlation by quadrupole fields was determined by measuring the anisotropy parameter A_2 as a function of delay time, Fig. 1(b). The perturbation is ≈5% per mean life.

To measure the magnetic moment, the Tl^{199} source, placed in an external magnetic field of 26 000±75 gauss, was viewed by two magnetically shielded NaI(Tl) counters placed at an angle of 135° to each other and the 334–158-kev integral coincident counting rate determined as a function of direction of the magnetic field; $2\tau=35$ nsec. For each of the fifteen separate runs (two at a magnetic field of 13 000 gauss) the angular correlation at zero field was also determined. The weighted average of all runs yielded a difference

$$\Delta=2\frac{[W(\frac{3}{2}\pi,+H)-W(\frac{3}{2}\pi,-H)]}{W(\frac{3}{2}\pi,+H)+W(\frac{3}{2}\pi,-H)}=0.118\pm0.005,$$

and an angular anisotropy, corrected only for chance rate, of

$$\delta=[W(\pi)-W(\tfrac{1}{2}\pi)]/[W(\pi)+W(\tfrac{1}{2}\pi)]=0.200\pm0.005.$$

(Only the A_2 term was needed, since $A_4\ll A_2$.) The gyromagnetic ratio of the 158-kev state is then

$$g_{\frac{5}{2}}=\frac{\hbar}{2\mu_N H\tau_m}\left(\frac{\delta\pm(\delta^2-\Delta^2)^{\frac{1}{2}}}{\Delta}\right)=+0.413\pm0.032,$$

where $\mu_N=5.05\times10^{-24}$ erg gauss^{-1}. Thus $\mu_{\frac{5}{2}}=+1.03$

---

† This work is supported in part by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Air Force of Scientific Research.

[1] A. de-Shalit, Phys. Rev. **122**, 1530 (1961).

[2] B. Jung and J. Svedberg, Nuclear Phys. **20**, 630 (1960)

[3] R. W. Bauer, L. Grodzins, and H. H. Wilson (to be published).

[4] R. Stiening and M. Deutsch, Phys. Rev. **121**, 1484 (1961).

[5] R. E. Bell, R. C. Graham, and H. E. Petch, Phys. Rev. **84**, 380 (1951).

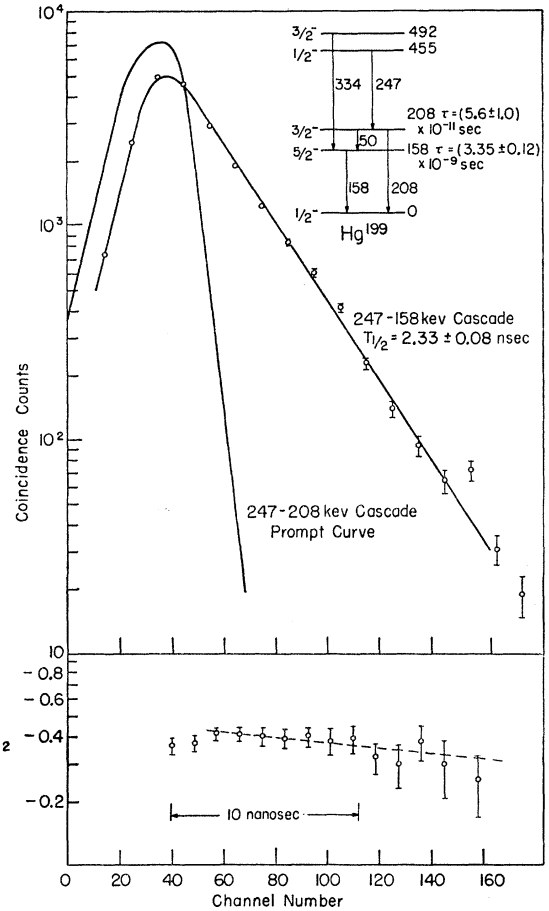

FIG. 1. (a) Decay curves of the 158-kev and 208-kev states in Hg^{199}, the latter illustrating the time resolution for "prompt" coincidences. The insert shows the relevant level structure of Hg^{199}. (b) The dependence on delay time of the anisotropy, $A_2=[W(\pi)-W(\pi/2)]/[W(\pi/2)+\frac{1}{2}W(\pi)]$, valid for $A_4\simeq 0$, of the 334 kev—158 kev gamma-gamma correlation corrected for chance rate and solid angle. The dashed line, showing 5% attenuation per mean life, is a least-squares fit to the data.

±0.08 nm, including the diamagnetic correction of 0.96%.

de-Shalit recently proposed that the 158-kev and 208-kev states may be an example of a doublet arising from the coupling of the $\frac{1}{2}^-$ ground state to the 2^+ excitation of the core. Though the center of gravity of this doublet is ~200 kev lower than that of the first 2^+ excitations of the neighboring even-even nuclei, the electromagnetic transition probabilities satisfy the criteria for particle-core coupling. The reduced $E2$ transition probabilities of the 158-kev and 208-kev transitions are approximately the same and equal to that of the neighboring $2^+\rightarrow 0^+$ transition; i.e., 20 times faster than single-proton speeds. The $M1$ transition probability of the 208-kev transition is 70 times slower than the single-proton estimate, while the 50-kev stopover transition, which contains[6] $<0.1\%$ $E2$, is only 20 times slower. Such speeds are difficult to reconcile with a simple shell-model interpretation of these levels, which cannot account for the enhanced $E2$ speeds and predicts that the $M1$ speed of the 50-kev transition should be l-forbidden, hence slower than the 208-kev $M1$ speed which should be allowed.

One of the consequences of a particle-core interpretation is that the magnetic moment of the $\frac{5}{2}^-$ state should be the sum of the magnetic moments of the 2^+ core excitation μ_c and the ground state μ_p. The latter value has been measured[7] as $\mu_p=+0.504$ nm. A further consequence is that the former value may be deduced from the $M1$ gamma-ray transition probability of the 50-kev "spin-flip" cascade, $T_\gamma(50)$, plus the knowledge of μ_p, the relationship being[1]

$$\frac{T_\gamma(50)}{E^3}=a_1(2J_f+1)j(j+1)(2j+1)\times\begin{Bmatrix} J_i & J_f & 1 \\ j & j & J_c \end{Bmatrix}^2 (g_c-g_p)^2, \qquad (1)$$

where E is the energy of the transition in Mev; g stands for gyromagnetic ratio; J_i, J_f, J_c, and j are the angular momenta of the initial, final, core, and single-particle states, respectively; and $a_1=4.2\times 10^{12}$ $\text{sec}^{-1}\ \text{Mev}^{-3}$.

The measurement of $T_\gamma(50\text{ kev})$ proceeded as follows. The 208 kev–50 kev total branching rate was determined by gamma-gamma coincidences with the 248-kev transition as 3.24 ± 0.15. The total internal conversion of the 50-kev transition was determined by 158–50-kev gamma-gamma coincidences using a Au^{199} source; the result being $\alpha_{50}=18_{-2}^{+1}$. These values, combined with resonance fluorescence data[8] of Knapp on the 208-kev state, lead to $\tau_\gamma(208)=(1.43\pm 0.2)\times 10^{-10}$ sec and $\tau_\gamma(50)=1/T_\gamma(50)=(4.46\pm 1.0)\times 10^{-9}$ sec. The predicted value of the 2^+ core is then, from Eq. (1),

$$\mu_c=(+0.33_{-0.25}^{+0.17})\text{nm},$$

and hence

$$\mu_{\frac{5}{2}}=(+0.84_{-0.25}^{+0.17})\text{nm}.$$

The agreement of this value with the direct measurement, while supporting the core-particle coupling interpretation of these states, must be qualified by the remarks that the experimental errors, especially on the value of $T_\gamma(50\text{ kev})$, are large, and the agreement does not exclude substantial mixing of the wave functions of the states.

ACKNOWLEDGMENTS

We would like to thank M. Deutsch for the use of the equipment and A. de-Shalit for numerous clarifying discussions of his model.

---

[6] J. C. Null, Q. L. Baird, and S. K. Haynes, Phys. Rev. **118**, 1278 (1960).

[7] B. Cagnac and J. Brossel, Compt. rend. **249**, 77 (1959). The quoted value includes the diamagnetic correction of 0.96%.

[8] V. Knapp, Proc. Phys. Soc. (London) **A70**, 142 (1957); F. R. Metzger, J. Franklin Inst. **261**, 219 (1956).