PHYSICAL REVIEW VOLUME 177, NUMBER 4 20 JANUARY 1969

g Factors of the 210-keV and 240-keV States of ^{195}Pt

L. VARGA, I. DEMETER, L. KESZTHELYI, Z. SZŐKEFALVI-NAGY, AND Z. ZÁMORI
Central Research Institute for Physics, Budapest, Hungary

(Received 27 May 1968)

The g factors of the 210- and 240-keV states of ^{195}Pt, evaluated from the measured angular rotation in the internal magnetic field after Coulomb excitation, were found to be 0.24 ± 0.06 and 0.104 ± 0.022, respectively, in disagreement with current theoretical predictions.

1. INTRODUCTION

MEASUREMENT of the angular correlation perturbed by the internal magnetic field existing at the nuclei in ferromagnets is a useful method for the evaluation of the magnetic moments of excited nuclear states.[1] In the last few years, many attempts have been made to extend the number of nuclei which can be studied experimentally by employing Coulomb excitation.[2–4]

In these experiments, the material to be investigated was evaporated onto thin Fe foils to form "sandwich" targets and the excited nuclei of the sample were propelled into the Fe lattice by the bombarding ^{16}O ions having energies of 30–40 MeV. Difficulties have arisen, however, in the g-factor measurements because of the effect of the large transient magnetic fields produced at the nuclei of the atoms recoiling with energies of $E_r \approx$ 3–20 MeV.[5] In the recent experiments of Kalish and Kossler,[6] who measured the integral rotation of the angular distribution of the 847 keV γ radiation from Fe(p, p, γ) reaction at $E_p = 7.8$ MeV ($E_{r\,\max} \sim 500$keV), the transient effects could not be observed within the experimental error in metallic Fe.

We have worked out a new method of g-factor measurement. Instead of "sandwich" targets, ferromagnetic alloys are used for which there is no need for high-energy bombarding ions to recoil the excited nuclei into the ferromagnetic lattice. Thus the nuclear states can be Coulomb excited in alloys by protons of 2.5-MeV energy. The recoil energy in such cases is small ($E_{r\,\max} \approx$ 50–100 keV). The γ radiation is measured with Ge(Li) detectors, which enable one to discriminate between the γ rays from Coulomb excited level and those from the background due to (p, γ) and (p, p', γ) reactions in Fe.

2. EXPERIMENTAL

The g factors of the 210- and 240-keV states of ^{195}Pt were measured using Fe$_{0.73}$-Pt$_{0.27}$ alloy as target. The internal magnetic field at the Pt nucleus was evaluated by making use of the well-known g factor of the 329-keV state of ^{194}Pt.[7–9] On bombardment with 2.5-MeV protons, the maximum recoil energy of Pt nuclei is $\approx$50 keV.

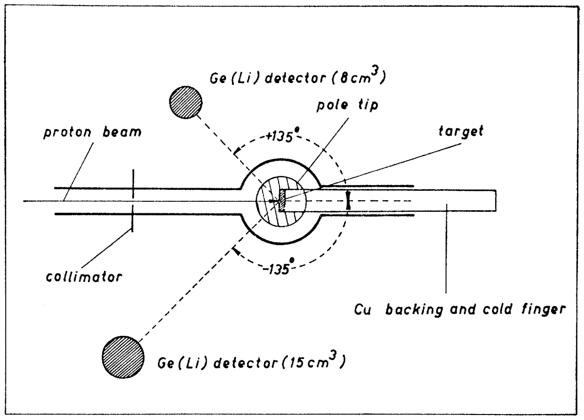

FIG. 1. Target and detector arrangement.

The 0.1-mm-thick foil prepared from the alloy was soldered to the end of a copper rod which was cooled by liquid nitrogen during the bombardment. For the magnetic polarization of the target an external magnetic field of $\approx$1.5 kOe was applied. To avoid deadtime effects in the multichannel analyzer due to small current instabilities of the accelerator, the γ radiation was measured simultaneously with two Ge(Li) detectors of 15 cm^3 and 8 cm^3 volume. The pulse-height distributions were analyzed into the submemories of a 4096-channel analyzer. In Fig. 1, the target and detector arrangement, in Fig. 2 the pulse-height distribution for one of the detectors are shown. The peaks of the different γ lines from the excited states in the Pt isotopes are well

---

[1] E Karlsson, E Matthias, and K Siegbahn, *Perturbed Angular Correlations* (North-Holland Publishing Co., Amsterdam, 1964).

[2] F. Boehm, G. B. Hagemann, and A. Winther, Phys. Letters **21**, 217 (1966).

[3] L. Grodzins, R. Borchers, and G. B. Hagemann, Phys. Letters **21**, 214 (1966).

[4] R. Brenn, L. Lehmann, and M. Spehl. Report from the Physikalisches Institut der Universität Freiburg/brsg., Germany (unpublished).

[5] L. Grodzins, in *Hyperfine Structure and Nuclear Radiation*, edited by E. Matthias and D. A. Shirley (North-Holland Publishing Co., Amsterdam, 1968), p. 602.

[6] R. Kalish and W. J. Kossler, Phys. Rev. Letters **20**, 271 (1968).

[7] L. Keszthelyi, I. Berkes, I. Dézsi, and L. Pócs, Nucl. Phys. **71**, 662 (1965).

[8] Y. K. Agarwal, C. V. Baba, and S. K. Bhattacherjee, Nucl. Phys, **79**, 437 (1966).

[9] R. Kalish, L. Grodzins, R. R. Borchers, J. D. Bronson, and B. Herskind, Report MIT (unpublished).

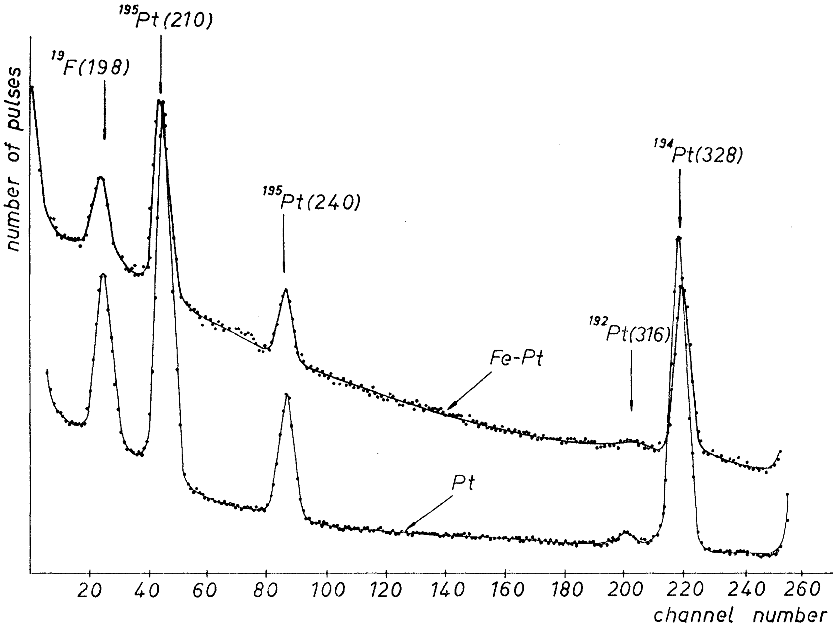

FIG. 2. Pulse-height distributions under proton bombardment of Pt and $Fe_{0.73}$-$Pt_{0.27}$ alloy.

separated from the background [mainly (p,γ) reaction in Fe]. The counts in the peaks were extracted by computer fitting.

After measuring the angular distribution and calculating the coefficients, counts were taken at ±135° with the magnetic field up and down. The ratios

$$Q^2 = N_1(+H)N_2(-H)/N_2(+H)N_1(-H)$$

were evaluated for the 210-, 240-, and 329-keV γ lines. Here $N_1(\pm H)$ and $N_2(\pm H)$ are the numbers of counts in the peaks from counters 1 and 2, respectively, with the external field up and down. The rotation angle $\omega\tau = \frac{1}{2}x$ due to the influence of the internal magnetic field was calculated from the equation

$$Q = \frac{1 + b_2[x/(1+x^2)] - b_4[1/(1+4x^2)]}{1 - b_2[x/(1+x^2)] - b_4[1/(1+4x^2)]},$$

where b_2 and b_4 are the coefficients of the unperturbed angular distribution written in the form $W(\theta) = 1 + b_2 \cos 2\theta + b_4 \cos 4\theta$.

The results are summarized in Table I in which also the g factor of the 99-keV state of ^{195}Pt, as measured by other authors,[10–12] has been included. The values of the coefficients b_2 and b_4 agree within the experimental error with the reported data.[13]

The g factors of the 210- and 240-keV states in ^{195}Pt were evaluated by taking for the internal magnetic field the value determined by the known g factor of the 329-keV state in ^{194}Pt. This implies the assumption that the magnetic field at the nuclei remains essentially static after Coulomb excitation, since if the internal field depended on time, its value determined from the above measurement could not be used for states with very different lifetimes from that of the 329-keV state.

In the experiments of Grodzins *et al.*,[3,5] large time-dependent positive transient fields were observed after Coulomb excitation and recoil of nuclei in Fe. The characteristic time of this field is ≈1 psec and its effect can be approximated as an impulse precession.[5] The value of this impulse precession turned out to depend on the velocity and atomic number of the recoiled atom. If the velocity of the recoiled atom is smaller than the velocities of the polarized electrons in Fe, then no transient field is observed. Grodzins estimates the limit value of the energy of Fe atoms moving through Fe for remaining neutral to be ≈350 keV. This limit recoil energy is ≈1.2 MeV in the case of Pt atoms moving through Fe. The recoil energy maximum in our case is ≈50 keV, thus much lower than the above limit. Therefore, we do not expect the appearance of the time-dependent transient field. This reasoning was corroborated by the measurement of Kalish and Kossler[6] and by the experiment on Fe-V alloy in our laboratory.[14] It was found that the g factor determined with the assumption of static internal field from the rotation of the angular distribution of the 320-keV γ radiation from

---

[10] D. Agresti, E. Kankeleit, B. Persson, Phys. Rev. **155**, 1339 (1967).

[11] M. Atac, P. Debrunner, and H. Frauenfelder, Phys. Letters **21**, 699 (1966).

[12] A. Buyrn, L. Grodzins, N. A. Blum, and J. Wulff, Phys. Rev. **163**, 286 (1967).

[13] F. K. McGowan and P. H. Stelson, Phys. Rev. **116**, 154 (1959).

[14] L. Keszthelyi, I. Demeter, Z. Szökefalvi-Nagy, L. Varga, and Z. Zamori, Nucl. Phys. **A120**, 540 (1968).

TABLE I. Results of the measurements.

Nucleus	E keV	b_2	b_4	$\omega\tau$	$H(10^6G)$	τ(psec)	g(exp)	g(theor)[a]
^{194}Pt	328			0.095 ± 0.004[b]	1.21 ± 0.05[c]	51 ± 4[e]	$+0.32\pm0.04$[c]	
^{194}Pt	328	0.200 ± 0.008	-0.040 ± 0.010	0.0772 ± 0.0048	0.98 ± 0.08			
^{195}Pt	99					230 ± 28[e]	-0.40 ± 0.10[d]	-0.042
^{195}Pt	130					884 ± 98[e]		$+0.36$
^{195}Pt	210	0.062 ± 0.009	0.009 ± 0.007	0.108 ± 0.025	0.98 ± 0.08	97 ± 7[e]	$+0.219\pm0.060$	-0.011
^{195}Pt	240	0.150 ± 0.015	-0.018 ± 0.017	0.160 ± 0.022	0.98 ± 0.08	333 ± 43[e]	$+0.104\pm0.022$	$+0.43$

[a] Reference 19.

[b] Averaged value from References 7–9.

[c] Reference 9.

[d] References 10–12.

[e] A. Marelius, P. Sparmann, and T. Sundström, in *Hyperfine Structure and Nuclear Radiations* edited by E. Matthias and D. A. Shirley (North-Holland Publishing Co., Amsterdam, 1968), p. 1043.

^{51}V produced by Coulomb excitation with 2.5 MeV protons has the same value as that measured with an external field.[15] The recent results of Murnick *et al.*,[16] which seem to contradict the data of Kalish and Kossler, can be explained by the fact that in their experiment[16] the energy of the recoiled Fe atoms moving through Fe was just in the above mentioned critical range of $\approx$350 keV.

The internal field evaluated using the g factor of the 329-keV state of ^{195}Pt is smaller by 20% than the static field in dilute Fe-Pt alloy. This is not surprising if one considers the much greater Pt content of our alloy. Benczer-Koller *et al.*[17] showed by Mössbauer measurement a decrease of 20% in the internal field on increasing the Pt-concentration from 10–30 at.%. This effect was not observed in the measurements of Buyrn *et al.*[12] On heating, the magnetization curve of our alloy abruptly decreases at 400°C, indicating some phase transition. On cooling, the magnetic order appears at 80°C. This shows the complexity of this type of alloy, the properties of which can depend on the method by which it is prepared.

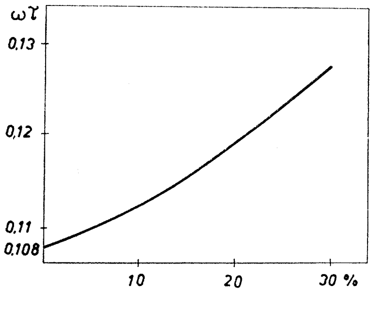

FIG. 3. $\omega\tau$ versus intensity of 210-keV state due to stopover from 240-keV state.

The internal field in alloys with 30 at.% Pt is assumed by Benczer-Koller *et al.* to be inhomogeneous because of the difference in the number of Fe neighbors in the environment of Pt atoms. In spite of the Fe_3Pt ordering in the concentration region of our sample, inhomogeneities may occur since the recoiled Pt atoms may stop in different environments. The field determined with the data of the 329-keV state can thus be an average value. If the field is static, averaging does not induce an appreciable error in the evaluation of the g factor of the states in ^{195}Pt from the measured values of $\omega\tau$.

The data on the 210-keV state may become uncertain because of the possible 30-keV transition from the 240-keV state. However, this transition has not been observed and it is assumed to be of negligible intensity.[18] Its possible influence on the value of $\omega\tau$ of the 210-keV state was evaluated as a function of the contribution from the 240-keV state to the 210-keV line (Fig. 3). Assuming the probability of the 30-keV transition from the 240-keV $5/2^+$ state to be the same as that from the 130-keV $5/2^+$ to the 99-keV $3/2^+$ state in ^{195}Pt it can be estimated as 20%; we then have $\omega\tau=0.119$. This 10% increase does not exceed the statistical error of our measurement.

3. DISCUSSION

With these new data on g factors the values of the most important parameters (energy, spin, parity, transition probability and g factor) of the first four excited states in ^{195}Pt are known, with the exception of the g factor of the 130-keV, $5/2^+$ state.

No detailed calculations have been made yet to predict the properties of the excited states in ^{195}Pt with spin assignments $\frac{3}{2}, \frac{5}{2}, \frac{3}{2}, \frac{5}{2}$.

An attempt was made by Gal[19] to calculate the spectroscopic data in terms of the core-excitation model

---

[15] I. Y. Krause, Phys. Rev. **129**, 1330 (1963).

[16] D. E. Murnick, J. R. McDonald R. R. Borchers G. Heestand, and B. Herskind, Conference on Ion Implantation and Hyperfine Interactions, London, 1968 (unpublished).

[17] N. Benczer-Koller, J. R. Harris, and G. M. Rothberg, Phys. Rev. **140**, B547 (1965).

[18] L. Grodzins, R. R. Borchers, and G. B. Hagemann, Nucl. Phys. **88**, 474 (1966).

[19] A. Gal (Braunstein) Phys. Letters **20**, 414 (1966).

of de-Shalit.[20] To do this, Gal modified the simple theory (coupling of states of core excitation and one particle) by coupling the odd particle (a $p_{1/2}$ neutron) outside the core to the first two vibrational states of ^{194}Pt, which both have spin and parity 2^+.

The wave functions thus have the form

$$|J^-\rangle_E=\alpha_E\,|\,2^+,\tfrac{1}{2}^-;J^-\rangle+\alpha_E{}^1\,|\,2^{+1},\tfrac{1}{2}^-;J^-\rangle$$
$$+\lambda_E\,|\,0^+,J^-,J^-\rangle,$$

where E is the energy and J the spin of the excited states, and the values of the constants α_E, α_E', and λ_E are estimated from the different transition probabilities between these states and the ground state.

This formula was used with the constants determined by Gal[19] and the g factors measured[7] for the two vibrational states of ^{194}Pt core nucleus to predict the g factors of the 99-, 130-, 210-, and 240-keV states of ^{195}Pt. The results are listed in Table I.

It can be seen that the predictions disagree with the experimental values. A similar comparison made by Buyrn *et al.* for the 99-keV $\frac{3}{2}$ state shows the same discrepancy. It is thought, therefore, that the completeness of the data on ^{195}Pt calls for a more thorough theoretical treatment.

---

[20] De-Shalit, Phys. Rev **122**, 1530 (1961).

PHYSICAL REVIEW VOLUME 177, NUMBER 4 20 JANUARY 1969

Measurement of the Nuclear Moments of the First-Excited State of Er^{170} by the Mössbauer Effect*

J. W. WIGGINS AND J. C. WALKER†
Department of Physics, The Johns Hopkins University, Baltimore, Maryland 21218

(Received 16 August 1968)

The Mössbauer effect has been used to measure the hyperfine splitting of Er^{170} in $ErFe_2$. Since there is no suitable β-decay parent nuclide, the first-excited state was populated by Coulomb excitation with 3.0-MeV α particles. The same measurement of hyperfine splitting was made for Er^{166} by using a β-decay source. Assuming the internal field at the Er nucleus in $ErFe_2$ to be an axially symmetric electric-field gradient along the same axis as the magnetic field, we have obtained a good fit to the data. The results are $g_R{}^{170}/g_R{}^{166}=1.002\pm0.013$ and $Q_0{}^{170}/Q_0{}^{166}=1.05\pm0.16$. Using a previously determined value for $g_R{}^{166}$, we derive $g_R{}^{170}=0.319\pm0.011$.

We have observed the Mössbauer effect in Er^{170} and Er^{166}. By comparing the hyperfine structure observed with each isotope we have measured the ratios $g_R{}^{170}/g_R{}^{166}$ and $Q_0{}^{170}/Q_0{}^{166}$. The gyromagnetic ratio of Er^{166} has been previously measured by standard Mössbauer-effect techniques,[1] so we have used it as a reference. There is no suitable β-decay parent nuclide for Er^{170}, so Coulomb excitation was used to populate the first-excited state (see Fig. 1). The Coulomb-excitation–Mössbauer-effect technique has been previously reported by our laboratory and by others.[2]

Considerable effort has been expended on measuring the gyromagnetic ratio g_R of first-excited states in the rare-earth region of the periodic table. The measurement of g_R provides a check on collective-model calculations. In the case of Er^{164}, Er^{166}, and Er^{168}, g_R has been measured to greater accuracy than for any other series of isotopes.[1] Then the measurement of $g_R{}^{170}$ is quite important in that it extends this series of stable even-even isotopes, and allows one to see how g_R varies within an isotopic series.

The target material used was the intermetallic compound, $ErAl_2$. It was bombarded by the beam from The Johns Hopkins University 3-MeV Van de Graaff accelerator. An attempt was made to use a proton beam since, for this case, it gives the largest γ-ray yield. However, the 79-keV first excited state γ ray is obscured, primarily by Compton scattering in the NaI detector of 847-keV γ rays from the reaction, $Al^{27}(p,p')Al^{27*}$. An optimum signal-to-noise ratio of 1:3 was obtained with 2.7-MeV protons. Although α particles give a much lower γ-ray yield, they are preferable because they produce essentially no background. Using 3.0-MeV α particles, a signal-to-noise ratio of 3:1 was obtained. A β-decay source was used in the Er^{166} experiment. $HoAl_2$ was irradiated in a reactor to produce Ho^{166} which decays to Er^{166}.

The data were accumulated by standard multiscaling technique. Accumulation of all the spectra required two weeks of operation. Spectra of the Fe^{57} Mössbauer effect in a metallic iron absorber were taken at several intervals to verify that there was no drift in the velocity scale. A closed-cycle helium-gas refrigerator was used

---

* Work supported in part by the U.S. Atomic Energy Commission.

† Alfred P. Sloan Foundation Fellow.

[1] E. Munck, D. Quitmann, and S. Hufner, Phys. Letters **24B**, 392 (1967).

[2] J. S. Eck, Y. K. Lee, and J. C. Walker, Phys. Rev. **163**, 1295 (1967).