[13]R. N. Keller, reported in P. C. Stephenson and W. E. Nervik, Radiochemistry of the Rare Earths, Scandium, Yttrium, and Actinium, "Nuclear Science Series," Nuclear Research Council, Committee on Nuclear Science, Report No. NAS-NS 3020, 1961 (unpublished).
[14]G. R. Choppin, B. G. Harvey, and S. G. Thompson, J. Inorg. Nucl. Chem. 2, 66 (1956).
[15]S. G. Thompson, B. G. Harvey, G. R. Choppin, and G. T. Seaborg, J. Am. Chem. Soc. 76, 6229 (1954).
[16]MOIRAE, an oscilloscope code developed primarily by R. Au and G. Berzins for use on the Michigan State University Sigma 7 computer in the Cyclotron Laboratory.
[17]L. Nemet, Izv. Akad. Nauk SSSR Ser. Fiz. 25, 68 (1961) [transl.: Bull. Acad. Sci. USSR, Phys. Ser. 25, 68 (1961)].
[18]R. L. Auble, D. B. Beery, G. Berzins, L. M. Beyer, R. C. Etherton, W. H. Kelly, and Wm. C. McHarris, Nucl. Instr. Methods 51, 61 (1967).
[19]E. E. Berlovich, V. N. Klementyev, L. V. Krasnov, M. K. Nikitin, and I. Yursik, Nucl. Phys. 23, 481 (1961).
[20]R. S. Hager and E. C. Seltzer, Nucl. Data 4A, 1 (1968).
[21]M. P. Avotina, as quoted in Ref. 7.
[22]Reference 11, using the results of P. A. Seeger, Nucl. Phys. 25, 1 (1961).
[23]K. Way and M. Wood, Phys. Rev. 94, 119 (1954).
[24]J. R. Grover, Phys. Rev. 116, 406 (1959).
[25]J. H. E. Matlauch, W. Thiele, and A. H. Wapstra, Nucl. Phys. 67, 1, 32, 73 (1965).
[26]P. Alexander, F. Boehm, and E. Kankeleit, Phys. Rev. 133, B284 (1964).
[27]C. V. K. Baba, G. T. Ewan, and J. F. Suárez, Nucl. Phys. 43, 264, 285 (1963).
[28]B. Harmatz, T. H. Handley, and J. W. Mihelich, Phys. Rev. 123, 1758 (1961).
[29]E. E. Berlovich, Yu. K. Gusev, V. V. Ilin, V. V. Nikitin, and M. K. Nikitin, Zh. Eksperim. i Teor. Fiz. 42, 967 (1962) [transl.: Soviet Phys.–JETP 15, 667 (1962)].
[30]S. A. Moszkowski, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, The Netherlands, 1965); S. A. Moszkowski, Phys. Rev. 89, 474 (1953).
[31]D. B. Beery, W. H. Kelly, and Wm. C. McHarris, Phys. Rev. 188, 1851 (1969).
[32]J. R. Van Hise, G. Chilosi, and N. J. Stone, Phys. Rev. 161, 1254 (1967).
[33]R. E. Eppley, Wm. C. McHarris, and W. H. Kelly, to be published; also in Michigan State University Report No. COO-1779-13, 1969 (unpublished), p. 55.
[34]J. Felsteiner and B. Rosner, Phys. Letters 31B, 12 (1970).
[35]B. H. Wildenthal, Michigan State University, private communication.
[36]Wm. C. McHarris, D. B. Beery, and W. H. Kelly, Phys. Rev. Letters 22, 1191 (1969).

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g Factors of the First Two Excited 2^+ States in Pt^{192}†

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The *g* factors of the first and the second excited 2^+ state in Pt^{192} have been measured by observing the integral rotation of the directional correlation pattern in the internal magnetic field acting on Pt nuclei implanted in an iron host. Both values, $g_{316} = 0.27 \pm 0.02$ and $g_{612} = 0.30^{+0.06}_{-0.04}$, are higher than those predicted by the pairing-plus-quadrupole model of Kumar and Baranger.

I. INTRODUCTION

Magnetic moments of excited nuclear states of even W, Os, and Pt nuclei were predicted by Kumar and Baranger on the basis of the pairing-plus-quadrupole model.[1] For spherical nuclei in this region the predicted values of the *g* factors are considerably more reduced with respect to Z/A (hydrodynamic value) than *g* factors derived from the model proposed by Greiner.[2] Measurements of the mixing ratios of the γ transitions[3] in Pt^{192} show surprisingly good agreement with pairing-plus-quadrupole model calculations of Kumar.[4] It was of interest, therefore, to check the agreement between experiment and theory also for the *g* factors of the first two excited 2^+ states in the same nucleus. The "physical boson mixing theory" proposed by Ikegami and Hirata,[5] which was able to explain small measured values of the pentration parameter ($\lambda \approx 1$) for the strongly hindered *M*1 component between the first and second excited 2^+ states in spherical nuclei of the Pt region,[6] predicted $|g_{2_1^+}| > |g_{2_2^+}|$ for those nuclei.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The levels in Pt^{192} were populated from the decay of Ir^{192} (Fig. 1). The *g* factors of the first two excited 2^+ states in Pt^{192} were measured using the time-integrated directional-correlation method.[8] In view of the short lifetimes of the states, the internal field acting on Pt nuclei embedded in an

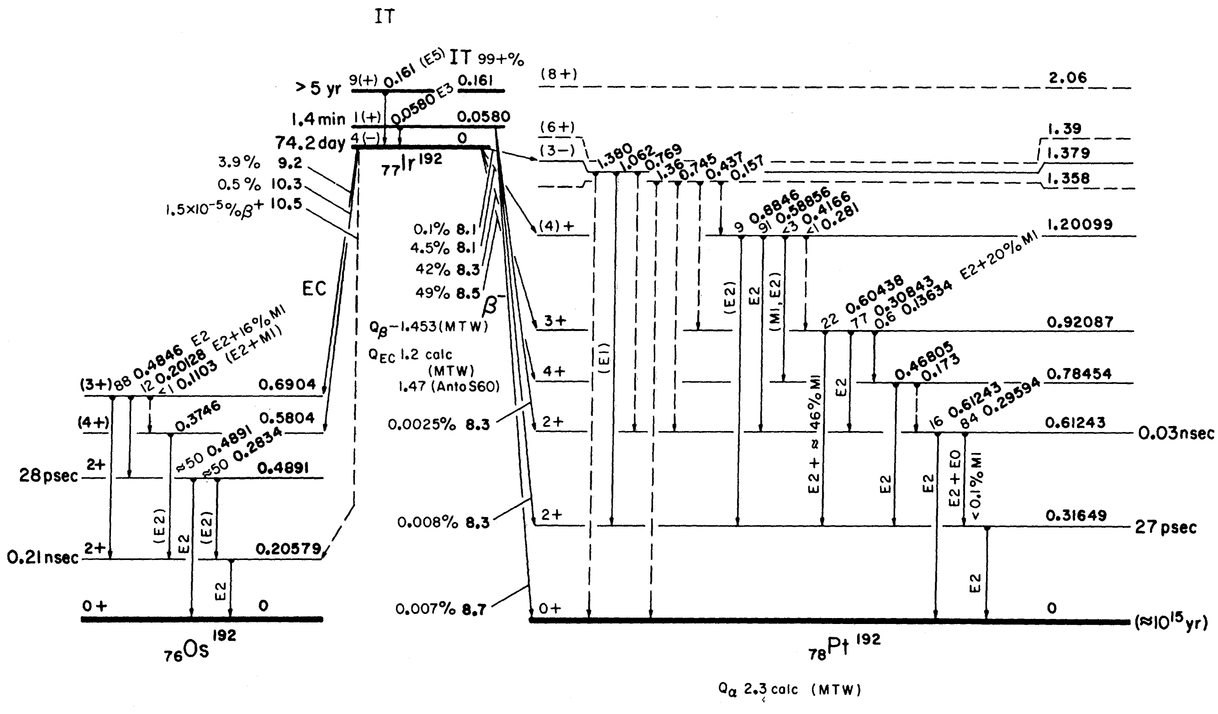

FIG. 1. Decay scheme of Ir^{192} (see Ref. 7).

iron lattice was utilized. The precession of spin of the 612-keV level (2_2^+) was observed by measuring the angular shift of the $3^+(308)2^+(612)0^+$ cascade in a magnetic field B perpendicular to the plane defined by the counters. As a control measurement the $4^+(468)2^+(316)0^+$ cascade yielding the spin precession of the first excited 2^+ state (2_1^+) was measured simultaneously. To resolve the 308- and 316-keV γ rays, a coaxial Ge(Li) detector (25 cm^3; 3.0 keV full width at half maximum) was used in one channel of the spectrometer. The second channel was equipped with an integrally mounted magnetically shielded 3-in.×3-in. NaI(Tl) detector. A spectrum stabilizer was also used in this channel. To check reproducibility of the results three different samples were measured. They were all prepared by melting a mixture of spectroscopically pure iridium and iron powder using the electron-bombardment technique. The melted spheres (diam ~1 mm) were subsequently irradiated in the reactor and were used for the measurements without being annealed after irradiation. A check measurement using an annealed source did not reveal any differences.

A small electromagnet (1000 ampere-turns; field ~ 2 kG in the 5-mm gap) was used to magnetize the samples. The magnetic saturation was checked by measuring spin precession of the first 2_1^+ state as a function of the current I through the electromagnet (Fig. 2). Samples were already saturated at $I = 79$ mA, but as a safety factor all measurements were performed with the current in the coil increased to 100 mA.

The coincidences were recorded at seven different angles for both directions of the magnetic field ("up" and "down"). A least-squares fit of the experimental data to the function

$$W(\theta, \pm B) = \sum_{k=0}^{4} A_{kk} P_k[\cos(\theta - \Delta\theta_k)], \quad (k\omega\tau)^2 << 1,$$

where $\Delta\theta_k = \omega\tau$ yielded[8] the coefficients A_{kk} and the

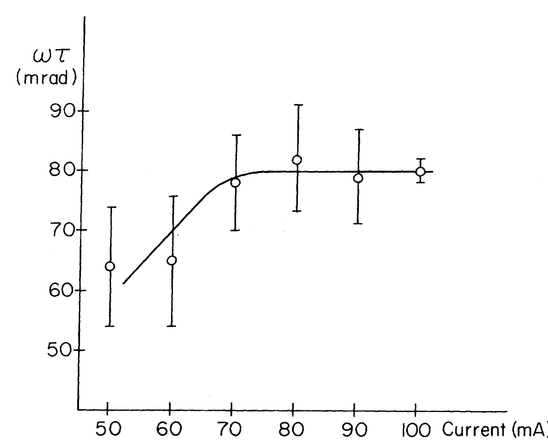

FIG. 2. $\omega\tau_{316}$ as a function of magnetizing current in the coil of electromagnet.

$\omega\tau$ values given in Table I. The absence of attenuation due to other extranuclear fields ($G_{kk} \approx 1$ in the formula above) was confirmed by comparing the A_{kk} coefficients measured with metal and with liquid sources.

The experimental results given in Table I were reported previously.[9] However, the experimental result for the $(\omega\tau)_{612}$ should be corrected for a contribution from the $3^+(604)2^+(316)0^+$ cascade. This contribution which was only $(3.0^{+0.5}_{-0.0})\%$ in intensity (see Fig. 3) has a substantial effect on the value of $(\omega\tau)_{612}$. This is due to the large anisotropy of the $3^+(604)2^+(316)0^+$ correlation combined with the opposite sense of rotation in the applied magnetic field [the first transition of this cascade was accepted in the rotating detector; for the $3^+(308)$-$2^+(612)0^+$ cascade it was the second]. Application of this correction to the weighted average of measured $(\omega\tau)_{612}$ values gives

$$(\omega\tau)^{\text{corr}}_{612} = 0.056^{+0.010}_{-0.006} .$$

The larger upper value of the error limit reflects the uncertainty in the applied correction. The measured directional-correlation coefficients (corrected for the geometry and contributing cascades) for the $4^+(468)2^+(316)0^+$ and $3^+(308)2^+(612)0^+$ cascades were correspondingly: $A_{22} = 0.098 \pm 0.005$, $A_{44} = 0.005 \pm 0.008$ and $A_{22} = -0.102 \pm 0.010$, $A_{44} = -0.070 \pm 0.013$. The last A_{22} value was measured slightly lower than reported in Ref. 3.

The lifetime of the 316-keV level as measured by Schwarzschild[10] was about 25% larger than previously reported by de Boer, Voorthuis, and Block.[11] The recent value reported by Béraud *et al.*[12] is in excellent agreement with the result of Schwarzschild. Taking a weighted average of results reported in Refs. 10 and 12, one obtains $\tau_{316} = (5.0 \pm 0.3) \times 10^{-11}$ sec. The weighted average of the two available results for the lifetime of the 612-keV level[12,13] and the recent result of Keszthelyi, $\tau_{612} = 3.8 \pm .5 \times 10^{-11}$ sec,[14] gives $\tau_{612} = (3.1 \pm 0.3) \times 10^{-11}$ sec. Using these values with the corresponding $\omega\tau$'s reported above and H_{int} (300°K) $= -(1.24 \pm 0.03) \times 10^3$ kG,[15] one obtains

$$g_{316} = 0.27 \pm 0.02 ,$$

$$g_{612} = 0.30^{+0.06}_{-0.04} .$$

TABLE I. Summary of the $\omega\tau$ values (given in rad) as measured in the present investigation.

Source	at% IrFe Alloy	$(\omega\tau)_{316}$	$(\omega\tau)_{612}$
1	1.2	0.075 ± 0.005	0.040 ± 0.010
2	0.6	0.080 ± 0.003	0.036 ± 0.010
3	1.2	0.081 ± 0.003	0.035 ± 0.005
	Weighted average	0.080 ± 0.002	0.036 ± 0.004

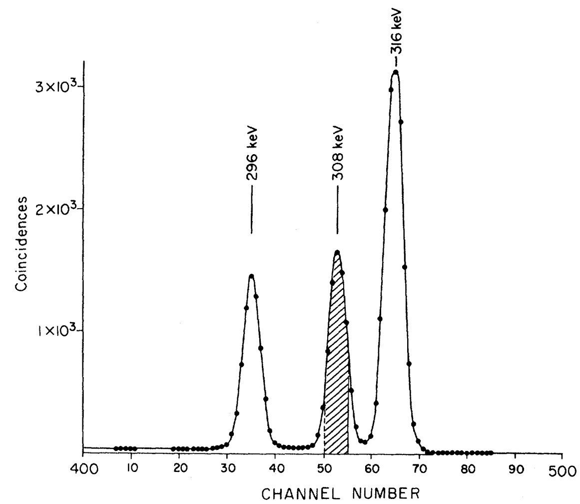

FIG. 3. γ-ray spectrum in coincidence with the 600-keV region [selected in the NaI(Tl) scintillation detector] recorded at the angle $\theta = 145°$ with the 25-cm^3 Ge(Li) detector.

III. DISCUSSION

Both experimental values for the g factors reported here are higher than those predicted by Kumar and Baranger ($g_{316} = 0.21$ and $g_{612} = 0.22$).[1] The measured g_{316} value is lower than that predicted by Greiner ($g_{316} = g_{612} \approx 0.33$).[2] The ratio of the two, $g_{2_2^+}/g_{2_1^+} = 1.11^{+0.24}_{-0.15}$ is in agreement with both these theories, but it does not support the "physical boson mixing theory" proposed by Ikegami and Hirata.[5]

Recently, three other measurements of the g factors for the first and the second excited states in Pt^{192} have been reported.[12,16,17] In all three the time-integrated precession method has been used, and the results, in terms of the $\omega\tau$'s, are summarized in Table II.

The result of Ref. 17 for $(\omega\tau)_{612}$ quoted in the table is the average of two independent measurements using the $3^+(308)2^+(612)0^+$ and $4^+(588)2^+(296)2^+$ cascades. The results for the $(\omega\tau)_{316}$ in the table are consistently about 10% higher than the present result. They are also higher than all results for the $(\omega\tau)_{316}$ published previously.[18] Good agreement between the three values cited in Table II and the three measurements with different samples used in the present investigation (see Table I) seems to indicate that the internal field is the same in different samples. However, if this is indeed so, then the difference between these two sets of values is difficult to explain. The val-

TABLE II. Comparison with results obtained recently by other authors.

$(\omega\tau)_{316}$	$(\omega\tau)_{612}$	Ref.
0.088 ± 0.005	0.047 ± 0.011	16
0.087 ± 0.002	0.053 ± 0.009	12
0.088 ± 0.006	-0.025 ± 0.010	17
0.080 ± 0.002	$0.056^{+0.010}_{-0.006}$	Present work

ues for $(\omega\tau)_{612}$ reported in Refs. 16 and 12 are in agreement with the present result within the error limits.

The negative sign of the result of Levanoni[17] (giving a negative value of the magnetic moment of the 612-keV state) could be due to misinterpretation of the sense of precession. In a spectrometer equipped with a Ge(Li) detector in one channel and a NaI(Tl) crystal in the other, the sense of rotation of the $3^+(308)2^+(612)0^+$ cascade would be opposite to that of the $4^+(468)2^+(316)0^+$ (assuming that magnetic moments of both states have the same sign) if the 308-keV γ ray for the first, and the 316-keV γ ray for the second measurement are accepted in the Ge(Li) detector. It is puzzling, however, that the negative sign of the magnetic moment of the 612-keV state was in this case consistently derived from the measurements on two cascades $[3^+(308)2^+(612)0^+$ and $4^+(588)2^+(296)0^+]$. The smaller absolute value of $(\omega\tau)_{612}$ obtained in Ref. 17 is most probably due to contribution of other cascades in the energy channels selected.

Note added in proof: The value for $(\omega\tau)_{612}$ in Pt^{192} as remeasured by Levanoni[19] using two Ge(Li) detectors is $(\omega\tau)_{612}=0.054\pm0.011$ rad. This value is in very good agreement with the value reported in this paper.

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[1]K. Kumar and M. Baranger, Nucl. Phys. A122, 273 (1968).

[2]W. Greiner, Nucl. Phys. 80, 417 (1966).

[3]Z. W. Grabowski, Phys. Rev. 183, 1019 (1969).

[4]K. Kumar, Phys. Letters 29B, 25 (1969).

[5]H. Ikegami and M. Hirata, J. Phys. Soc. Japan Suppl. 24, 639 (1968).

[6]H. Ikegami, T. Hirose, M. Sakai, T. Yamazaki, and K. Sugiyama, J. Phys. Soc. Japan Suppl. 24, 167 (1968).

[7]C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (John Wiley & Sons, Inc., New York, 1967), 6th ed.

[8]H. Frauenfelder and R. M. Steffen, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy,* edited by K. Siegbahn (North-Holland Publishing Company, Amsterdam, The Netherlands, 1965), Chap. XIX; L. Grodzius, Ann. Rev. Nucl. Sci. 18, 291 (1968).

[9]Z. W. Grabowski, in *Proceedings of the International Conference on Properties of Nuclear States, Montreál, Canada, 1969,* edited by M. Harvey *et al.* (Presses de l' Université de Montréal, Montréal, Canada, 1969).

[10]A. Schwarschild, Phys. Rev. 141, 1206 (1966).

[11]Th. J. de Boer, H. Voorthuis, and J. Block, Physica 28, 417 (1962).

[12]R. Béraud, I. Berkes, R. Chéry, R. Haroutunian, M. Lévy, G. Marguier, G. Marest, and R. Rougny, Phys. Rev. C 1, 303 (1970).

[13]D. K. Butt and D. A. Jackson, Proc. Phys. Soc. (London) 86, 31 (1965).

[14]L. Keszthelyi, private communication.

[15]M. Kotani and J. Itoh, J. Phys. Soc. Japan 22, 345 (1967).

[16]D. B. Kenyon, L. Keszthelyi, and J. A. Cameron, Can. J. Phys. 47, 2395 (1969).

[17]M. Levanoni, Phys. Rev. 186, 1253 (1969).

[18]J. A. Cameron, Can. J. Phys. 42, 1680 (1964); L. Keszthelyi, I. Berkes, I. Dezsi, and L. Pocs, Nucl. Phys. 71, 662 (1965); Y. K. Agarwal, C.V.K. Baba, and S. K. Bhattacherjee, *ibid.* 79, 437 (1965).

[19]M. Levanoni, private communication.