Magnetic Moment of the 99-keV First Excited State of Pt^{195}†

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The Mössbauer effect in Pt^{195} was measured at 20°K with a Au^{195} source electroplated onto a platinum foil and $Pt_{0.1}Fe_{0.9}$, $Pt_{0.3}Fe_{0.7}$, $Pt_{0.5}Fe_{0.5}$, and Pt_3Fe absorbers. A split absorption spectrum was observed for the first three absorbers, while Pt_3Fe showed no hyperfine structure. The absorption spectrum of the body-centered cubic $Pt_{0.1}Fe_{0.9}$ is compatible with an internal field at the platinum nucleus in the range $[1.2\times10^6 \leqslant H \leqslant 2.9\times10^6]$Oe and a ratio of the excited- to ground-state magnetic moments $-1.5 \leqslant \mu_e/\mu_g \leqslant +0.3$. The measurement by Ho and Phillips of the internal field in a sample of $Pt_{0.03}Fe_{0.97}$, $H=1.39\times10^6$, can be taken as an upper limit for the field value in the $Pt_{0.1}Fe_{0.9}$ sample. The present results can thus be combined with the Ho-Phillips measurement and with the measured ground-state moment to give -0.9 nm $\leqslant \mu_e \leqslant -0.7$ nm. The Mössbauer fractions f at 20°K for these absorbers were determined to be (26.9±4.1)%, (24.3±2.6)%, (11.6±0.8)%, and (9.6±1.0)%, respectively.

INTRODUCTION

THE Mössbauer effect of the $M1$, 99-keV transition, from the first $\frac{3}{2}^+$ excited state to the $\frac{1}{2}^+$ ground state of Pt^{195} has been measured with a Au^{195} source embedded in a platinum matrix and several iron-platinum alloy absorbers in order to study the nuclear Zeeman structure of Pt^{195}, and therefore determine the magnetic moment of the 99-keV state. The magnetic moment of the ground state is known: $\mu_g=0.6$ nm. In the present case, because of the very short lifetime of the first excited state[1] [$\tau\simeq(1.7\pm0.2)\times10^{-10}$ sec], the width of each of the Zeeman components is likely to be larger than the separation between them, unless the effective internal magnetic field H at the platinum nuclei is very large. However, even when the Zeeman structure is not entirely resolved, estimates of the excited-state magnetic moment μ_e and the internal field H, or at least of the product $\mu_e H$, can be made[2] by fitting the observed absorption spectrum with a calculated spectrum characterized by the following parameters: (1) the number of Zeeman components (6 in the case of an $M1$ transition between a $\frac{3}{2}^+$ and a $\frac{1}{2}^+$ state), (2) the relative intensity of the components (3:2:1:1:2:3 for the $M1$ case, and unpolarized source and absorber), (3) the total intensity, (4) the ratio of excited-state to ground-state magnetic moments μ_e/μ_g, and finally (5) the internal magnetic field.

MEASUREMENTS

The measurements were carried out at 20°K in the same cryostat and with the same technique that were described in a previous paper,[1] and some preliminary results have been reported.[3] The absorbers used were $Pt_{0.1}Fe_{0.9}$, $Pt_{0.3}Fe_{0.7}$, $Pt_{0.5}Fe_{0.5}$, and Pt_3Fe which were kindly supplied to us in ingot form by Dr. J. H. Wernick of Bell Telephone Laboratories. These were finely ground, spread over a 1-in-diameter area and coated with Krylon to hold the powder together. No further heat treatments were applied after the grinding. The amount of Pt in each of the four absorbers was (229±22), (147±14), (216±21), and (418±40) mg/cm², respectively. Two additional absorbers of $Pt_{0.3}Fe_{0.7}$ were prepared by rolling out some of the compound into foils 203 mg/cm² and 109 mg/cm² thick, respectively. The same absorption spectra were obtained with the foil absorbers as with the powder sample.

The spectra obtained with the first three absorbers exhibit a two-line structure, but not the six-line hyperfine splitting that would be observed if the linewidth were narrower than the splitting between components. The Pt_3Fe sample shows no fine structure at all. The spectra obtained with $Pt_{0.1}Fe_{0.9}$ and pure Pt absorbers of approximately the same effective thickness are shown in Fig. 1. These spectra are similar to those measured by A. B. Buyrn and L. Grodzins.[4]

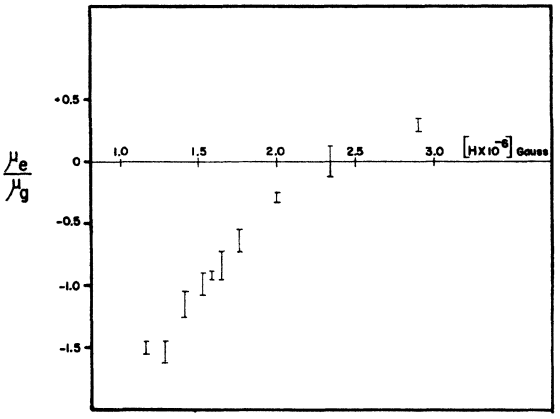

FIG. 1. Mössbauer absorption spectra obtained with a Au^{195} source embedded in a platinum matrix, and (a) a platinum foil absorber 217 mg/cm² thick, (b) a $Pt_{0.1}Fe_{0.9}$ absorber containing 216 mg/cm² of platinum.

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[1] J. R. Harris, G. M. Rothberg, and N. Benczer-Koller, Phys. Rev. 137, A1101 (1965).

[2] This technique has already been applied successfully for other isotopes, Sn^{119}, Au^{197}, rare earths, which were located either in an iron matrix or in other types of ferromagnetic alloys or compounds.

[3] G. M. Rothberg, N. Benczer-Koller, and J. R. Harris, Rev. Mod. Phys. 36, 357 (1964).

[4] A. B. Buyrn and L. Grodzins, Bull. Am. Phys. Soc. 9, 410 (1964).

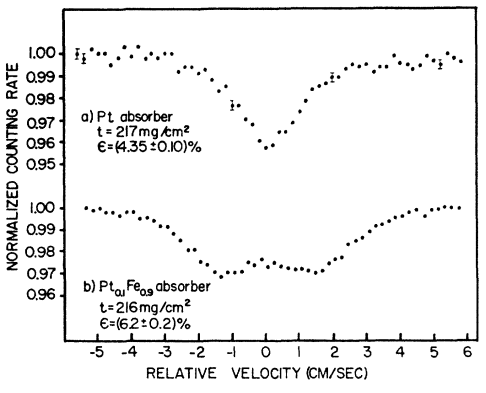

FIG. 2. Range of values of the ratio of the excited-state magnetic moment μ_e to the ground-state magnetic moment μ_g which are compatible with the data for a particular value of the internal magnetic field H at the platinum nucleus. The errors on the points are much larger than the statistical errors. They represent the limiting values of μ for a particular H which are compatible with the raw data.

The observed spectra were analyzed by matching the actual data with a great many "comparison" spectra which were calculated by computer for a whole range of values of μ_e/μ_g, of the effective field at the platinum nucleus H, of the linewidth Γ, and of the total absorption ϵ. Since both the source and the absorber exhibit cubic symmetry, no quadrupole splitting was considered. Furthermore, because the possible isomer shifts expected would be much smaller than the linewidth and would not displace the centroid of the spectrum by an observable amount, isomer shifts were also ignored. It turns out that ϵ is not very sensitive to the choice of the other parameters. Thus, from the observed magnitude of the absorption effect, the fraction f of recoilless radiation was determined, and in turn the "effective thickness," $t_{\text{eff}}=\frac{1}{2}na\sigma_0 rf/(1+\alpha)$ of the absorber. As usual, n is the number of atoms of Pt per cm³, a is the relative abundance of Pt^{195}, σ_0 is the cross section for resonance absorption, α is the conversion coefficient of the transition, and t is the absorber thickness. The expected linewidth Γ for an absorber of such an effective thickness was then obtained from Fig. 5(a) in Ref. 1 which shows the variation of linewidth with absorber thickness. Finally, given a narrow range of Γ and ϵ the best fits to the data for various H and μ_e/μ_g were selected. A summary of all the Mössbauer data obtained with the four absorbers is displayed in Table I.

TABLE I. Summary of the Mössbauer data obtained at 20°K with different absorbers: Pt, $Pt_{0.1}Fe_{0.9}$, $Pt_{0.3}Fe_{0.7}$, $Pt_{0.5}Fe_{0.5}$ alloys and Pt_3Fe compound.

t Absorber	(thickness) (mg/cm²)	δ (10^{-6} eV)	ϵ (%)	f(20°K)	θ_{DW} (°K)
Pt	217	0	4.35±0.10	0.129±0.008	238± 8
$Pt_{0.1}Fe_{0.9}$	229±22	8.5±0.9	6.11±0.22	0.269±0.041	358±40
$Pt_{0.3}Fe_{0.7}$	147±14	7.0±0.8	5.00±0.18	0.243±0.026	333±24
$Pt_{0.5}Fe_{0.5}$	216±21	6.3±0.7	4.23±0.15	0.116±0.008	230± 8
Pt_3Fe	418±40	0	5.28±0.2	0.096±0.010	212± 8

DISCUSSION

The splitting δ between the two resolved peaks increases as the iron concentration in the alloy increases. However, we will not attempt in this paper to interpret this smooth variation of δ and hence of the average magnetic field at the platinum nuclei in terms of the varying electronic configurations in the three alloys because the iron-platinum alloys exhibit phase changes as the platinum concentration is changed. The three alloys that showed splitting were subjected to an x-ray analysis. $Pt_{0.1}Fe_{0.9}$ showed the characteristic line spectrum of a bcc lattice with a lattice parameter $a=(2.907\pm0.007)$Å which is intermediate between the lattice parameters of bcc Fe ($a_{Fe}=2.8664$ Å) and of fcc Pt ($a_{Pt}=3.9239$ Å). $Pt_{0.3}Fe_{0.7}$ and $Pt_{0.5}Fe_{0.5}$ possessed disordered fcc lattice structures with lattice parameters $a=(3.749\pm0.007)$Å and $a=(3.807\pm0.007)$Å, respectively. In $Pt_{0.1}Fe_{0.9}$ the platinum nuclei are likely to see only iron atoms as nearest neighbors. This is no longer true in the two other samples where the platinum concentration is larger. In these the splitting in the spectrum is indicative of only an average magnetic interaction. Therefore only the data obtained with the $Pt_{0.1}Fe_{0.9}$ sample were analyzed in detail.

It appears impossible to fit the $Pt_{0.1}Fe_{0.9}$ data with a unique H and μ_e/μ_g ratio. Instead there are several value of H and μ_e/μ_g which provide equally acceptable fits. These are shown on Fig. 2 which indicates the range of values of μ_e/μ_g that are compatible with a selected value of H. The experimental curve can only be fitted for internal field values in the range $[1.2\times10^6 \leqslant H \leqslant 2.9\times10^6]$Oe, and magnetic-moment values in the range $-1.5<\mu_e/\mu_g<+0.3$.

However, Ho and Phillips have recently[5] made a calorimetric determination of the hyperfine field on Pt dissolved in Fe in a $Pt_{0.03}Fe_{0.97}$ sample. They find $H=1.39\times10^6$ Oe. This value of the effective field may be considered as an upper limit of the field present in the $Pt_{0.1}Fe_{0.9}$ sample and the estimate of the magnetic moment can then be narrowed to $[-0.9\leqslant\mu_e\leqslant-0.7]$ nm.

Another recent measurement[6] of the internal field at the platinum nucleus in a $Pt_{0.1}Fe_{0.9}$ alloy, $H=1.080\times10^6$ Oe, by polarized neutron-spin-resonance techniques is not at all compatible with the present Mössbauer data. There was no value of μ for which the absorption spectrum could be fitted with a field $H=1.08\times10^6$ Oe.

The observed magnetic moment can be compared with theoretical predictions based on various models and with measured magnetic moments of $\frac{3}{2}^-$ states of even-Z odd-N nuclei in the same shell. The shell-model predicts for a $(P_{3/2})$, $j=l+\frac{1}{2}$ neutron nucleus, a magnetic moment $\mu=-1.91$ nm. Only two nuclei in this region of the periodic table, $_{80}Hg_{121}^{201}$ and $_{76}Os_{113}^{189}$,

[5] J. M. Ho and N. E. Phillips, Phys. Rev. **140**, A648 (1965) and private communication.

[6] A. Stolovy, Bull. Am. Phys. Soc. **10**, 17 (1965).

have $\frac{3}{2}^-$ ground states whose magnetic moments have been measured[7] and these are $\mu(Hg^{201})=-0.55670$ and $\mu(Os^{189})=+0.65596$, respectively. Hecht and Satchler[8] have attempted to fit the observed energy-level spectrum of Pt^{195} with a symmetric and an asymmetric rotator model. Although the level scheme seems to be in fair agreement with the asymmetric-rotator calculation, the model fails in its prediction of electric transition probabilities and magnetic moments. They conclude that neither a simple rotational, nor a simple vibrational model can be applied to Pt^{195}, but a more sophisticated calculation which would include strong mixtures of states might prove more successful. Clearly, there are still insufficient data to make reliable predictions on the basis of either a model or systematics.

[7] I. Lindgren, in *Perturbed Angular Correlations*, edited by P. Karlsson, E. Matthias, and K. Siegbahn (North-Holland Publishing Company, Amsterdam, 1964).
[8] K. T. Hecht and G. R. Satchler, Nucl. Phys. **32**, 286 (1962).

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Properties of the State in P^{31} at 7.14 MeV*

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The $F^{19}(p,\alpha\gamma)O^{16}$ reaction has been used as the source of Doppler-broadened radiation in the study of resonance fluorescence from a level at 7.144 ± 0.013 MeV in P^{31}. The angular distribution of the scattered radiation is consistent with a spin of either $\frac{1}{2}$ or $\frac{3}{2}$. For a spin of $\frac{3}{2}$ the quadrupole-dipole amplitude ratio δ is such that either $+0.15<\delta<+0.40$ or $-2.5>\delta>-6.5$. The mean lifetime of the ground-state transition, as determined by a self-absorption measurement, is $\tau_0=(4.8\pm0.6\times10^{-16}$ sec for a spin of $\frac{1}{2}$, or $\tau_0=(1.0\pm0.1)\times10^{-15}$ sec for a spin of $\frac{3}{2}$. The resonant scattering cross section is consistent with these values only if little branching to intermediate states is assumed, which is consistent with the observed pulse-height distribution.

1. INTRODUCTION

THE $F^{19}(p,\alpha\gamma)O^{16}$ reaction has been used as a source of gamma rays in the study of resonance scattering from light nuclei, and a large effect has been observed with a phosphorus scatterer. Three prominent gamma rays of energies 6.131, 6.916, and 7.115[1] MeV are emitted by the (p,α) reaction at an incident proton energy of 2.5 MeV; however, only the 6.92- and 7.12-MeV gamma rays are Doppler-broadened to a width of 130 keV. No levels in P^{31} in this energy region had been reported,[2] consequently it was not known whether the 6.92 or 7.12 gamma ray or both were giving rise to the observed resonance scattering. An estimate of the level spacing at this excitation energy in P^{31} suggested the possibility that more than one level may have been excited, and the early work[3] still left some doubt concerning this question, since there seemed to be a discrepancy between the self-absorption and scattering cross sections which could not be accounted for by branching.

To determine which gamma ray was being resonantly scattered, the experiment was repeated using a thin target and incident proton energies of 2.1 and 2.5 MeV for which the relative yields of the two gamma rays differ by a factor of 4. Furthermore, the energy of the scattered radiation was measured by a direct comparison between the pulse-height distributions of the resonantly scattered radiation from P^{31} and O^{16}. The evaluation of the scattering cross section requires a detailed knowledge of the line shape of the incident radiation, and this was measured using a Li-drifted germanium detector.

2. EXPERIMENTAL PROCEDURE

The apparatus is shown in Fig. 1, the experimental procedure being similar to that used in the study of the 7.10-MeV level in Na^{23}.[4] The initial measurements were

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