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NUCLEAR MAGNETIC RESONANCE ON ORIENTED PLATINUM-195m IN IRON*

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ABSTRACT

The magnetic hyperfine splitting of ^{195m}Pt(Fe) was determined by the NMR-ON technique as ($\mu H/hI$) = 89.5±0.5 MHz. With additional gamma ray anisotropy data for the 129 keV and 99 keV γ rays, the spin, I = 13/2, and the magnetic moment of the isomeric state, $\mu(13/2) = (+)\ (0.597\pm0.015)$ n.m., as well as the E2/M1 mixing ratio of the 99 keV γ transition, $\delta = -(0.16\pm0.02)$, were derived.

Nuclear magnetic resonance on oriented nuclei (NMR-ON) [1] provides precise information on the magnetic splitting of nuclear sublevels ($\mu H_{eff}/I$). On the other hand, the magnetic hyperfine interaction (μH_{eff}) results from an analysis of the temperature dependence of γ-ray anisotropies. By a combination of both measurements the spin of the nuclear state can therefore be obtained directly. The present paper reports on the first application of this method to an isomeric state, in determining the spin of the 259 keV state ($T_{1/2}$ = 4.1 d) of ^{195}Pt. In addition the magnetic moment of the isomeric state and the mixing ratio of the 98.8 keV γ transition of ^{195}Pt were derived.

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†On leave from Hahn-Meitner Institut, Berlin.

The ^{195m}Pt activity was produced by neutron irradiation of 57% enriched ^{194}Pt metal in a neutron flux of $2.5 \cdot 10^{15}$ n/cm^{2}s for a period of two weeks. Samples containing 1 at. % Pt in an iron matrix were prepared by melting the ^{195m}Pt activity under a hydrogen atmosphere with high-purity iron, already containing a matched amount of ^{60}Co activity, to be used for thermometry. Thin foils (~ 20000 Å thick), produced by cold-rolling and annealing, were attached to both sides of the Cu-fin of an adiabatic demagnetization apparatus with Bi-Cd solder. Using CMN as a cooling salt, temperatures down to $1/T = 165\ K^{-1}$ were obtained. The samples were magnetized in a homogeneous external magnetic field H_{ext}, produced by a superconducting Helmholtz pair. Gamma-ray spectra were taken at 0 and 90 degrees relative to the polarizing field with high-resolution coaxial Ge(Li)-diodes. For the NMR-ON experiment an rf field H_1 was applied perpendicular to H_{ext}, and the amplitude of H_1 was measured by a pick-up coil.

Figure 1 shows the results of the NMR-ON experiment, with the counting rate of the 98.8 keV γ rays, observed at 0 degree, plotted versus the rf frequency. The temperature of the sample increased during the run from $1/T = 145 \pm 5\ K^{-1}$ to $125 \pm 5\ K^{-1}$, causing the sloping background noticable in fig. 1b. The frequency was modulated with a modulation frequency of 100 Hz over a bandwidth of 1 MHz, and the rf amplitude was 0.8 mOe. Despite a total time span of 3.5 min. between adjacent data points, the resonance curves measured for increasing viz. decreasing frequencies in steps of 1 MHz are shifted relative to each other by more than 1 MHz. This is due to the rather long nuclear spin-lattice relaxation time T_1' for ^{195m}Pt(Fe), which was determined in a separate experiment [2] to be $T_1' = 10 \pm 1$ min. at a temperature

of $1/T = 150\pm5\ K^{-1}$, using a single-exponential fit [3]. The observed resonance effect represents a 30% destruction of the γ-ray anisotropy. With a modulation bandwidth of 2 MHz this value increased to 40%. The same resonance curves were simultaneously observed for the 129 keV γ rays of ^{195}Pt, while the γ-ray anisotropy of the 158 keV γ rays, originating from the decay of ^{199}Au, which was also present in our sample, did not show any frequency effect, thus excluding the possibility of heating by a coil resonance. This was additionally ruled out by passing over the resonance region with the rf modulation switched off, when no resonance effect was observed, and by counting at resonance frequency with rf modulation on and off, respectively. From the results in fig. 1 we determine the resonance frequency

$$\mu H_{eff}/h\cdot I = 89.5\pm0.5\ \text{MHz},$$

corresponding to $(5.930\pm0.033)\cdot10^{-19}$ erg.

In a separate experiment the temperature dependence of the anisotropies of the 99 keV and 129 keV γ rays of ^{195}Pt were measured at angles of 0 and 90 degrees relative to the polarizing field. During the warm-up of the samples over a typical period of 7 hours, spectra were taken continuously for periods of 15 min. and analyzed with a PDP-7 computer. The anisotropy of the ^{60}Co γ lines was used for thermometry. The data shown in fig. 2 are the results of three individual demagnetizations of the same ^{195m}Pt source. The anisotropy curves were least-squares fitted with

$$W(\theta) = 1 + \sum_{k=2,4} B_k\, U_k\, F_k\, Q_k\, P_k(\cos\theta)$$

using suitable solid angle correction factors Q_k for each case [4]. In the analysis of the anisotropy of the 129 keV γ rays the influence of the 129.6 keV M4 γ transition was taken into account. With the branching ratios of ref. 5, and the conversion coefficient $\alpha_{exp} = 1.76 \pm 0.19$ for the 129.8 keV E2 transition [6], and $\alpha_{th} = 1230$ for the 129.6 M4 transition [7], the ratio of the γ intensity of the M4 transition to that of the E2 transition at 129 keV was found to be 0.029. Using this value the anisotropy curve of the 129 keV γ rays, shown in fig. 2b, was fitted with μH_{eff} as a single parameter, and various values for the spin I of the isomeric state. As expected the results obtained for μH, given in table 1, are independent from the assumed spin within the limits of error, clearly demonstrating that from anisotropy curves only a value for the magnetic moment can be obtained. Only for a spin I = 13/2 does $(\gamma H)_{NO}$ agree with $(\gamma H)_{NMR}$. The sensitivity of the method is shown by a plot of the ratio $(\gamma H)_{NO}/(\gamma H)_{NMR}$ versus the assumed spin, given in the insert of fig. 2.

The anisotropy curve of the 98.8 keV γ rays (fig. 2a) was least-squares fitted with the E2/M1 mixing ratio δ[†] as the single free parameter, taking $\mu \cdot H/I$ from the NMR experiment. This leads to a value of

$$\delta = -(0.16 \pm 0.02)$$

for the mixing ratio of the 98.8 keV γ transition. The absolute value of δ is in good agreement with previous measurements [9,10], but the negative sign is opposite to the one given by ref. 10.

[†] In the definition of Biedenharn and Rose, ref. 8.

For a derivation of the magnetic moment of the $13/2^+$ state we use the hyperfine field $H_{hf} = -(1280\pm26)$ kOe, measured for the $1/2^-$-ground state of ^{195}Pt in iron [11]. This leads to

$$\mu(13/2) = (\pm)\ (0.597\pm0.015)\ \text{n.m.}$$

for the magnetic moment of ^{195m}Pt, with the negative sign assumed from systematics. The error is mostly due to the 2% uncertainty in the value for the hyperfine field. A correction for a possible hyperfine anomaly between the $13/2^+$ isomeric state and the $1/2^-$ ground state has not been applied. In the neighbouring odd mercury isotopes ^{195}Hg and ^{197}Hg, however, the hyperfine anomalies between the $13/2^+$ isomeric states and the $1/2^-$ ground states have been measured [12]: $^{195m}\Delta^{195} = +0.91\pm0.02\%$ and $^{197m}\Delta^{197} = +0.97\pm0.07\%$. A hyperfine anomaly of this size can also be expected between the analogous states of ^{195}Pt. Thus the quoted value for $\mu(13/2)$ should perhaps be decreased by 1%.

Our result for the spin of the isomeric state, I = 13/2, confirms the spin assignment made on the basis of the M4-multipolarity of the 129.6-keV isomeric transition [13]. For ^{195m}Pt a neutron configuration $(i_{13/2})^{13}(f_{5/2})^4$ outside of the N = 82 core and the filled $f_{7/2}$ and $h_{9/2}$ neutron shells is expected, since the $p_{3/2}$, $p_{1/2}$, $f_{5/2}$ and $i_{13/2}$ levels lie very close together, and hence the neutron pairs are expected to fill the states of higher angular momentum first due to the pairing energy. Following the core-polarization approach of Arima and Horie [14] we obtain for this neutron configuration a value of -0.64 n.m. for the magnetic moment, in rather good agreement with our experimental result. The magnetic moment may be compared with the known

magnetic moments of other $13/2^+$ states in neighbouring even-odd nuclei [12,15]: ^{193}Hg(μ = -1.0416(3) n.m.), ^{195}Hg(μ = -1.0280(2) n.m.), ^{197}Hg(μ = -1.0112(3) n.m.), and ^{205}Pb(μ = -0.975(39) n.m.). Going from Pt to Hg, the effect of two additional protons, filling up the $d_{3/2}$ shell, on the magnetic moment is obviously quite drastic, and much larger than expected on the basis of the single-particle model with configuration mixing. For the Hg isotopes the magnetic moments of the $13/2^+$ states have been interpreted assuming mixed neutron configurations with less than 13 neutrons in the $i_{13/2}$ shell. This interpretation is in agreement with the small spectroscopic factor (S = 7.4) for the $13/2^+$ state of ^{199}Hg derived from (d,p)-stripping and (d,t)-pick-up reactions on ^{198}Hg and ^{200}Hg, respectively [16]. The question of whether such a difference in the neutron configuration or drastic changes in the collective admixtures are responsible for the large difference in the magnetic moments of the $13/2^+$ state of ^{195}Pt and the even-odd Hg isotopes cannot be clarified at the present time, since too little is known about the wavefunctions of these states.

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Table 1. Results of a one parameter fit of the anisotropy curve of the 129 keV γ rays for various values of the spin I of the isomeric state.

I	$\mu \cdot H_{eff}$ $[10^{-18}$ erg]	$(\gamma H_{NO}/(\gamma H)_{NMR}$
9/2	3.872±0.031	1.451±0.020
11/2	3.867±0.030	1.186±0.016
13/2	3.873±0.030	1.005±0.013
15/2	3.882±0.030	0.873±0.012
17/2	3.892±0.030	0.772±0.010

FIGURE CAPTIONS

Fig. 1. Frequency dependence of the 99 keV γ-ray intensity, observed in the direction of the polarizing field H_{ext} = 1 kOe, for increasing (a) and decreasing (b) frequency, respectively. The rf frequency was modulated with 100 Hz and a bandwidth of 1 Mhz, and the rf amplitude was 0.8 Oe. The time span between neighbouring points is 3.5 min.

Fig. 2. Temperature dependence of the γ-ray anisotropy $W(\theta=0)$ of the 99 keV (a) and 129 keV (b) γ rays of ^{195}Pt(Fe) for H_{ext} = 4 kOe. The solid curves are the results of least-squares fit procedures (see text). In the insert the ratio $(\gamma H)_{NO}/(\gamma H)_{NMR}$ is plotted versus the value of the assumed spin.

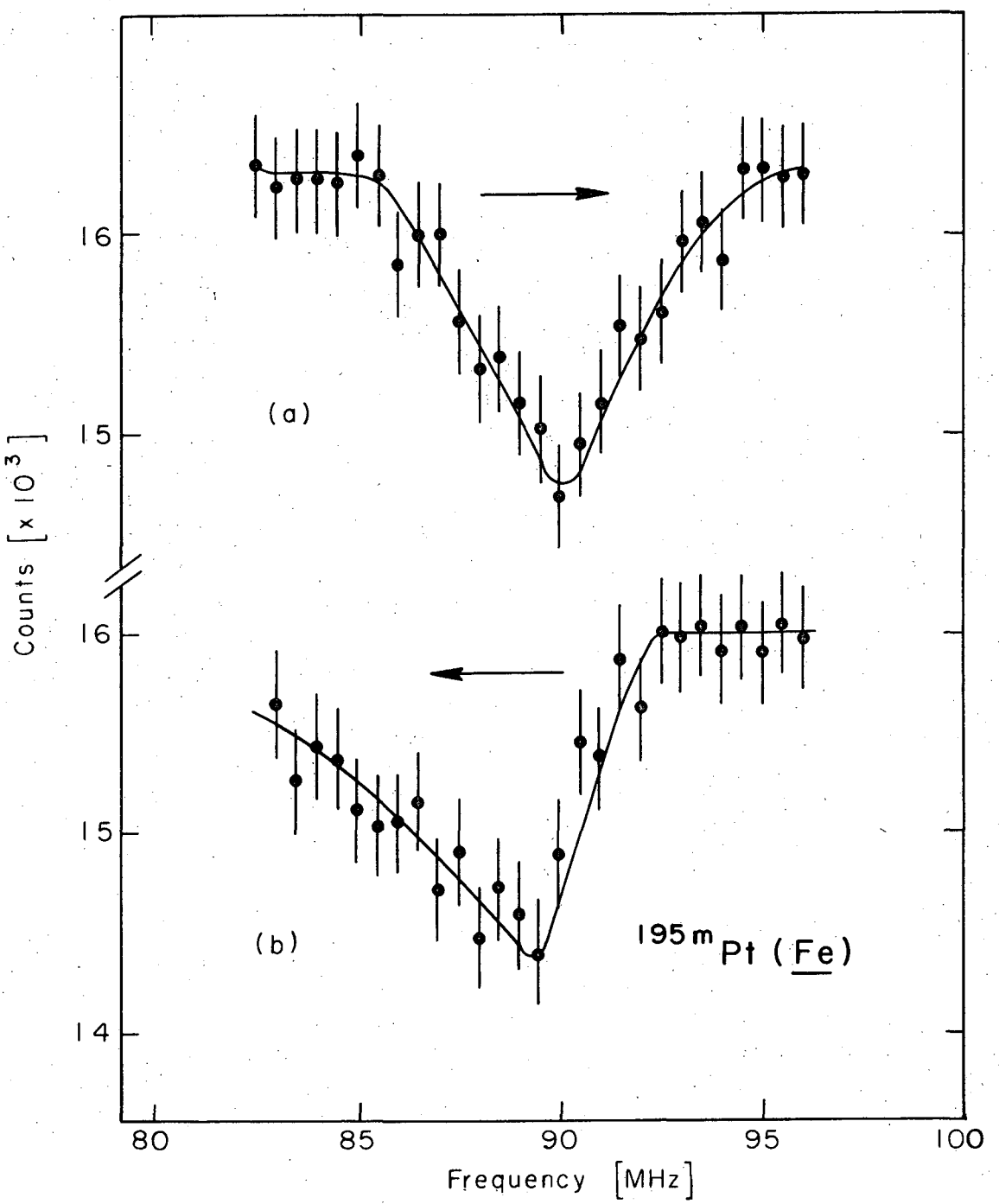

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Fig. 1

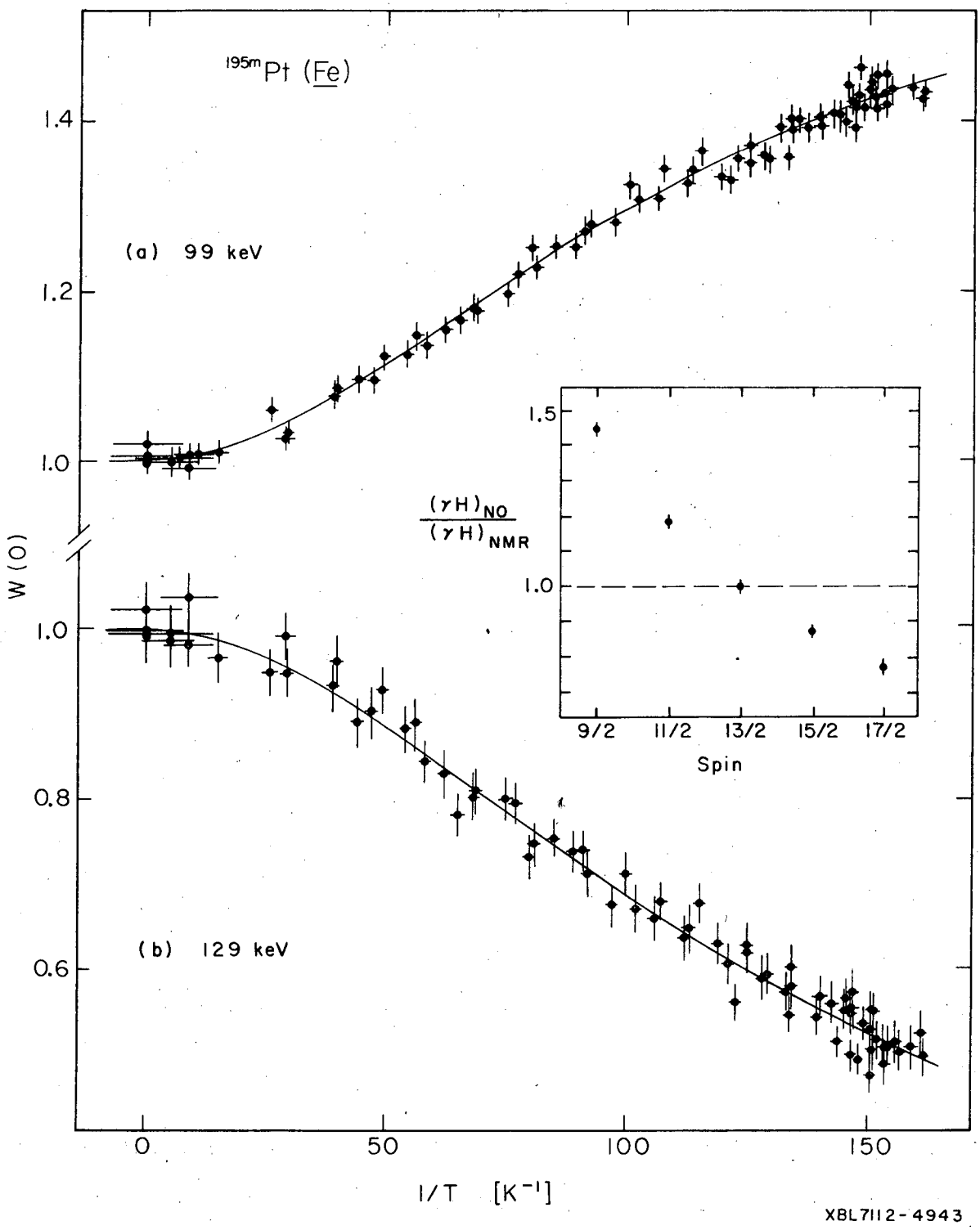
^{195m}Pt (Fe)
(a) 99 keV
(b) 129 keV
W (0)
1/T [K^{-1}]
$\frac{(\gamma H)_{NO}}{(\gamma H)_{NMR}}$
Spin
9/2
11/2
13/2
15/2
17/2
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Fig. 2

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