Nuclear Magnetic Resonance on Oriented $^{194}$Ir ($T_{1/2} = 19.4\ h$) in Fe and Ni

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The hyperfine interaction of $^{194}$Ir ($J^* = 1^-$; $T_{1/2} = 19.4\ h$) in Fe and Ni has been investigated with the technique of nuclear magnetic resonance on oriented nuclei. For both systems the electronic-orbital-momentum induced electric quadrupole splitting could be resolved. The magnetic and electric hyperfine splitting frequencies, $\nu_M = |g\mu_B B_{\text{hf}}/\hbar|$ and $\nu_Q = e^2 \mathcal{Q} / \hbar$, respectively, were measured as: $^{194}$Ir$_{\text{Fe}}$: $\nu_M = 408.54 (23)\ MHz$; $\nu_Q = -2.47 (20)\ MHz$; $^{194}$Ir$_{\text{Ni}}$: $\nu_M = 135.24 (5)\ MHz$; $\nu_Q = -1.23 (3)\ MHz$. Taking into account a 3% uncertainty arising from hyperfine anomalies the g-factor is deduced as $|g| = 0.39 (1)$. The electric quadrupole moment, $Q = +0.352 (18)\ b$, is slightly smaller than expected from the known systematics of deformation parameters in this mass region.

1. Introduction

The $^{197}$Ir nuclei lie in a shape-transitional region between the strongly deformed rare-earth nuclei and the spherical nuclei near $^{208}$pb. In the neighbouring $^{76}$Pt nuclei a prolate-oblate phase transition occurs with increasing neutron number at $A \sim 188$, which has been established experimentally by the observation that the quadrupole moments of the first excited $2^+$ states in the even-even Pt isotopes change sign. For the $^{76}$Os isotopes a similar transition was predicted to occur at $A \sim 192$ [1]. Recent measurements of quadrupole moments of the first excited $2^+$ states in stable $^{186, 188, 190, 192}$Os [2] and of the ground states of radioactive $^{183}$Os [3] and $^{191, 193}$Os [4] showed no evidence for the existence of such a phase transition in the Os isotopes with $A \leq 193$. In this context a systematic investigation of the quadrupole moments of the Ir isotopes is of interest, especially in the neutron-rich region. The NMR-ON technique [5] allows a simultaneous determination of the nuclear g-factor and the electric quadrupole moment if the quadrupole-subresonances can be resolved. The resonance splitting is based on the fact that for high-Z impurities in ferromagnetic Fe and Ni a small electric field gradient (EFG) is present besides a large magnetic hyperfine field, which originates from the unquenched orbital momentum of the d-electrons at the impurity site. Especially for 5d Ir in Fe and Ni this effect is relatively large; it was first detected by conventional NMR on stable $^{191}$Ir and $^{193}$Ir in Fe and Ni [6, 7]. In NMR-ON experiments on $^{192}$Ir$_{\text{Fe}}$ and $^{192}$Ir$_{\text{Ni}}$ the subresonance structure could be well resolved [8], while for $^{186}$Ir$_{\text{Ni}}$ only an unresolved asymmetric resonance structure could be observed [9]. Here we report on NMR-ON measurements on $^{194}$Ir$_{\text{Fe}}$ and $^{194}$Ir$_{\text{Ni}}$. With the Ni host the two quadrupole subresonances could be resolved well, thus allowing a precise determination of the ground state nuclear moments of $^{194}$Ir.

2. Principle of Measurement

The angular distribution of $\gamma$-rays emitted in the decay of oriented nuclei is most conveniently written as [10]

$$W(\Theta) = 1 + \sum_{k=2}^{k_{\text{max}}} A_k B_k (\mu B / k_B T) P_k (\cos \Theta) Q_k.$$  \hfill (1)

Here $A_k$ are parameters which depend on the specific properties of the nuclear decay (spins, multiplicities, mixing ratios), they are products of the nor-
nally used angular correlation coefficients $F_k$ and $U_k$, which, e.g., are tabulated in [11]. The $B_k$ describe the degree of orientation; they depend on the magnetic hyperfine splitting $\mu B$ and on the temperature $T$. The $P_k(\cos \Theta)$ are Legendre polynomials, $\Theta$ being the angle between the orientation axis (here the direction of the magnetic field) and the direction of observation, and $Q_k$ are solid angle correction coefficients.

A simplified decay scheme of $^{194}$Ir is illustrated in Fig. 1. The 328 keV level is fed directly only by 9.2%. For the calculation of the $A_k$ coefficients for the 328 keV transition the indirect feeding via higher levels (~4.8%) may not be neglected. Taking into account the side feeding via ~30 levels according to the decay scheme of [12] $A_2(328) \sim -0.20$ is estimated. As the oriented state has $j=1$ only the $k=2$ component in (1) will be nonzero.

In NMR-ON experiments the low-temperature $\gamma$-anisotropy is used as detector for NMR. For the case of a combined magnetic dipole plus electric quadrupole interaction the resonance condition for transitions between state $|m\rangle$ and $|m+1\rangle$ is given by

$$v_{m\rightarrow m+1} = v_0 + A v_Q(m + 1/2)$$

$$v_0 = v_M + |g\mu_N/(1 + K)\, \text{sgn}(B_HF)\, B_0$$

$$v_M = |g\mu_N B_HF/h|$$

$$v_Q = e^2 Q/h$$

$$A v_Q = 3v_Q/[2j(2j - 1)].$$

(2)

Here $v_0$ is the "pure" magnetic resonance, as expected in the absence of a quadrupole splitting, $v_M$ and $v_Q$ are the usually quoted magnetic dipole and electric quadrupole splittings, respectively, $B_0$ and $B_HF$ are the external magnetic field and the hyperfine field, respectively, $K$ is the Knight shift parameter, $g$ is the nuclear $g$-factor, $eq$ is the EFG, $Q$ is the spectroscopic quadrupole moment, and $A v_Q$ is the quadrupole subresonance separation. It is obvious that a set of $2j$ subresonances exists, which are separated by $A v_Q$. In the present case two subresonances are expected which are separated by $A v_Q = 3v_Q/2$.

For the following we will denote the subresonance which corresponds to rf-transitions between the energetically lowest sublevels as $v_1$-resonance and the second as $v_2$-resonance. (In the ultra-low temperature limit only the $v_1$-resonance can be observed.) Theoretical resonance amplitudes $A_1$, $A_2$ for realistic temperatures can be calculated as described in detail in [8]. The corresponding resonance spectra for $T = 10$, 20, and 30 mK are illustrated in Fig. 2. The following features are remarkable: The resonance "destruction" in the $v_1$-resonance can be larger than the $\gamma$-anisotropy itself. (Without quadrupole splitting the maximum resonance effect is given by the $\gamma$-anisotropy). In the $v_2$-resonance the $\gamma$-anisotropy is always enhanced. Both effects facilitate the observation of NMR-ON resonances on systems for which the total $\gamma$-anisotropy is small.

3. Experimental Details

The samples were prepared by alloying of $^{193}$Ir (isotopic enrichment ~95%) with highly pure Fe