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THE EFFECTIVE MAGNETIC FIELDS ON Zn NUCLEI IN Fe, Co, AND Ni

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The Larmor precession frequency of the magnetic moment of the 184 keV state in ^{67}Zn in internal magnetic fields of ferromagnetic materials was measured, using differential and integral PAC methods. The values of the internal fields on Zn nuclei in Fe, Co, and Ni were obtained. Their ratios are: $H_{Zn}(Fe) : H_{Zn}(Co) : H_{Zn}(Ni) = 1 : (0.60 \pm 0.06) : (0.13 \pm \pm 0.03)$.

1. Introduction

The question of the origin of internal magnetic fields acting on nuclei of elements embedded in ferromagnetic hosts has been investigated by many authors. Watson and Freeman [1] discussed mechanisms responsible for the existence of the internal fields, but calculations of different contributions are fairly complicated and are often of a semi-empirical character [2, 3] The interest in experimental investigations of the effective fields lies, on the one hand, in their rôle in the better understanding of the structure of dilute solid solutions and on the other in the fields themselves; these fields, being in general of high values, serve as a tool in measurements of *g*-factors of short-lived excited nuclear states.

The effective fields for elements with closed 3*d* shell have not yet been thoroughly investigated. In order to draw some conclusion on the mechanism predominantly responsible for the fields in this region of elements, it would be of interest to compare their values and their *Z*-dependence with the well-investigated fields in the region of the 4*d* closed shell.

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The internal field on Zn in the Fe lattice was measured by Inia *et al.* [4]. In the present paper results of measurements of the effective H_{Zn}(Fe), H_{Zn}(Co), and H_{Zn}(Ni) are presented. Measurements were performed by the IPAC and DPAC methods for the 206–184 keV cascade in the decay of ^{67}Ga. Preliminary results of this work were presented in Ref. [5].

2. *Source*

The source of ^{67}Ga ($T_{1/2}$ = 78h) was produced in the ^{59}Co(^{12}C; 4n)^{67}As→^{67}Ge→^{67}Ga reaction in the U-300 heavy ion cyclotron of JINR in Dubna. For measurements of H_{Zn} in Co host the 6 mg/cm^2 cobalt foil was irradiated for 3 hours by the ^{12}Co ions with the energy of 81 MeV. In order to obtain the ^{67}Ga activity in Fe and Ni, the x mg/cm^2 cobalt target had backings of Fe or Ni, respectively. The backing foils were 3 mg/cm^2 thick. This method of source preparation guaranteed that all nuclei recoiled from the Co foil were embedded in the respective ferromagnetic material. In the case of Fe or Ni backing 30% of the total activity produced in the target was introduced to the catcher. The obtained sources were satisfactorily pure. The experiments started two days after the irradiation. The impurities (mainly ^{66}Ga) for the source in Co were then less than 2% and less than 5 and 10% for the sources in Fe and Ni respectively.

To polarize the foils, external magnetic fields of 1–1.8 kG were used. For these field strengths the saturation was reached, which is in agreement with the results of Murnick *et al.* [8].

3. *Measurements and results*

For ^{67}Ga in the Fe lattice the differential PAC method was used. The 206–184 keV cascade in ^{67}Zn was detected with two NaI(Tl) scintillation counters and a conventional fast-slow coincidence circuit with a TPH converter. For the energy region of 160–230 keV, selected in both channels, the time resolution was 2.1 ns. From the time spectra $N_+(t)$ and $N_-(t)$ registered for the angels θ = 135° and for the two opposite directions of the polarizing field the usual curve

$$R(t) = 2\frac{N_+(t)-N_-(t)}{N_+(t)+N_-(t)}$$

was determined (Fig. 1). This experimental curve was then compared with the theoretical function

$$R(t) = 2b_2\frac{\int_0^\infty e^{-\lambda x}[P(t-x)-P(t+x)]\sin 2\omega x dx}{\int_0^\infty e^{-\lambda x}[P(t-x)+P(t+x)]dx} \qquad (1)$$

where $P(t\pm x)$ is the experimental prompt curve. The correlation function in (1) is of the form $1+A_2P_2[\cos(\theta\mp\omega t)]$, as A_4 is equal to zero in the limits of experimental errors [6, 7]. The life-time of the 184 keV state in ^{67}Zn τ = 1.47 ns was taken from [6, 7].

It should be mentioned that with NaI(Tl) counters the 206 and 184 keV peaks could not be selected separately and that the decay of the 184 keV state was observed on both sides of the prompt curve. This was accounted for in (1). The comparison of the experi-

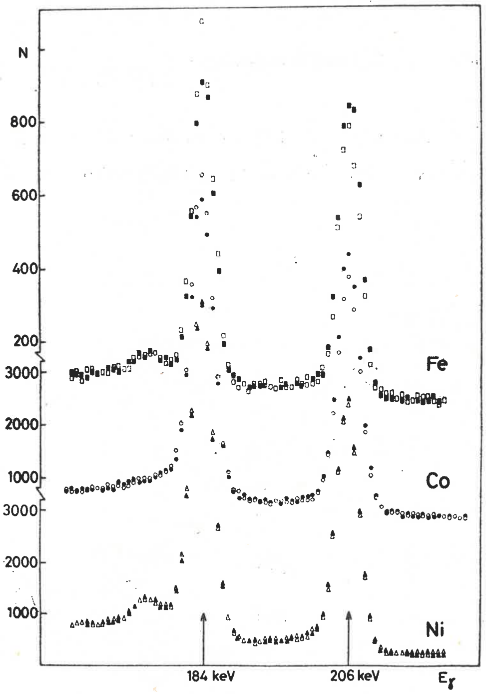

Fig. 1. Experimental $R(t)$ values compared with the theoretical curve

mental curve $R(t)$ with the theoretical function (1) gave the following values of b_2 and ω:

$$b_2 = 0.162 \rightarrow 0.005$$

$$\omega = (1.82 \pm 0.10) 10^8 \text{ sec}^{-1}.$$

The coefficient b_2 corrected for the geometry is equal to 0.182 ± 0.008, which is in good agreement with the results given in [4, 6, and 7].

The experiments on ^{67}Ga in the Ni and Co lattices were carried out with the integral PAC method. This method was also applied in the case of the Fe lattice to check the consistency with the DPAC result. In these experiments coincidence spectra were measured with a Ge(Li) detector and a NaI(Tl) counter at the angle $\theta = 135°$ and for the two opposite directions of the external polarizing field. The time resolution of 100 ns was used. The example of a coincidence spectrum from the Ge(Li) detector is shown in Fig. 2. As the gate of the NaI(Tl) counter covered the energy range of 160–230 keV, the two peaks 184 keV and 206 keV are seen in the coincidence spectrum. The $R = 2(N_+ - N_-)/(N_+ + N_-)$ values were calculated independently for each of them, the equality $R(184) = -R(206)$

being satisfied in the limits of the experimental error. The chance coincidences below the 184 keV and 206 keV peaks were determined from the area of the 93 keV photopeak, as the 93 keV transition in ^{67}Zn goes from the isomeric 9 μs state.

The $\omega\tau$ values were evaluated from the formula

$$R = \tfrac{1}{2}[R(184)-R(206)] = \frac{2b_2 \cdot 2\omega\tau}{1+(2\omega\tau)^2}. \tag{2}$$

In (2) the b_2 coefficient was taken from the differential experiment for the source in Fe. The b_2 coefficient was also determined from the independent measurements of the aniso-

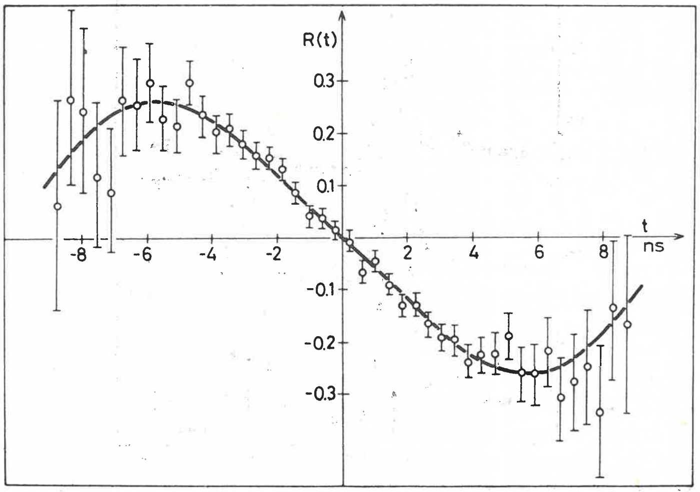

Fig. 2. Example of the coincidence spectra from a Ge(Li) detector for ^{67}Zn in Fe, Co, and Ni. The open and full points correspond to the two opposite directions of the polarizing magnetic field

tropy of the 206–184 keV cascade for ^{67}Ga sources in the Fe, Co and Ni lattices. After taking into account the attenuation due to the randomly oriented domains in unpolarized smaples and the geometrical corrections, the obtained b_2 values are consistent among themselves

$$b_2(\text{Fe}) = 0.182 \pm 0.008$$

$$b_2(\text{Co}) = 0.170 \pm 0.014$$

$$b_2(\text{Ni}) = 0.184 \pm 0.011$$

and with b_2 obtained for a liquid source and for Zn in the Cu lattice. This consistency of b_2 might suggest that the quadrupole interaction which can be present in the case of the Co lattice is negligible in comparison with the magnetic interaction.

Values of $\omega\tau$, ω and H_{Zn} for Fe, Co, and Ni hosts were calculated using the mean values of $\tau = (1.47 \pm 0.05)$ ns and $g = 0.31 \pm 0.04$ for the 184 keV state in ^{67}Zn [6, 7]. Results are listed in Table I.

TABLE I

Host material	$\omega\tau$	$\omega(10^8 s^{-1})$	H_{Zn} (kG)
Fe	$0.26{+0.06 \atop -0.05}$	1.82 ± 0.10^a	-123 ± 17
		$1.8{+0.4 \atop -0.3}$	
Co	0.160 ± 0.012	1.09 ± 0.09	-73 ± 11
Ni	0.033 ± 0.008	0.23 ± 0.05	-16 ± 4

[a] DPAC result. The errors of the internal field intensities are large because of the large, 13%, error of the g-factor. More accurate are the ratios of these fields: $H_{Zn}(Fe) : H_{Zn}(Co) : H_{Zn}(Ni) = 1 : (0.60 \pm \pm 0.06) : (0.13 \pm 0.03)$.

5. *Discussion*

The main contribution to the internal magnetic field acting on nuclei of dilute atoms of Zn in a ferromagnetic lattice has been considered to come from the conduction electron polarization effect CEP [2]. This contribution in the Fe lattice was estimated by Inia *et al.* [4] as H_{Zn}^{CEP} (Fe) $\simeq -250$ kG. It is far beyond their experimental value and the value obtained in the present work.

The semiempirical model of Balabanov and Delyagin [3] gives $H_{Zn}(Fe) = -140$ kG in fair agreement with the experimental values. However, this model implies the linear dependence of the effective fields from the host atom magnetic moment, which is not reproduced by the experiment. This indicates that other effects not accounted for in the present calculations are responsible for these fields.

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