Evidence for Ion Beam Induced Attenuations of the Static Hyperfine Field at Recoil Implanted ^{56}Fe ions in Fe Host ◇

K.-H. Speidel [a], G. Jakob, H. Busch [a], U. Grabowy [a], A. Gohla [a], and J. Gerber [b]
[a] Institut für Strahlen- und Kernphysik, Universität Bonn
[b] Centre de Recherches Nucléaires, Strasbourg

In systematic studies of static hyperfine fields (SF) at nuclei in ferromagnetic Fe- [1] and Gd- [1,2] hosts employing the IMPAC (Implantation Perturbed Angular Correlation) technique, it was shown that the field strengths are mostly substantially smaller compared to measurements of dilute radioactive impurities in which the nuclear probes were implanted with subsequent annealing of the host. In the latter case the full experimental strength of the SF on Fe in Fe was found with high precision [3] to be $B_{SF}(rad) \equiv B_{SF}(\text{Fe in Fe}) = -33.04(3)\,Tesla$ (with the minus sign indicating that the SF direction is antiparallel to the magnetization of the ferromagnet).

The difference between this value and those obtained from in-beam experiments has been generally attributed to radiation damage of the lattice sites where the recoiling ions come to rest. Until now no evidence for an influence of the ion beams on the SF has been found. This is in contrast to the case of Transient Magnetic Fields (TF), where the phenomenon of *ion beam induced attenuations* is experimentally very well established, provided that the mean stopping power of the beam ions exceeds a threshold value of $\frac{dE}{dx} \approx 8\,MeV/\mu m$ in Fe-host [4]. The degree of this attenuation G_{TF} is generally expressed by the ratio of the measured TF to its calculated value using the empirical linear parametrization [5]

$$G_{TF} \equiv \frac{B_{TF}}{B_{lin}} \qquad (1)$$

$$\text{with} \quad B_{lin} = 12\,Tesla \cdot Z \cdot \frac{v}{v_0}\,, \qquad (2)$$

whereby the ion velocity v in Fe is expressed in units of the Bohr velocity $v_0 = \frac{c}{137}$.

Here we report on measurements on ^{56}Fe(2_1^+) probe ions implanted in Fe host, which clearly exhibit a striking dependence of the SF strength on the ion beam used. For the precession measurements in question the ^{56}Fe(2_1^+) state at $0.847\,MeV$ with lifetime $\tau = 9.6(4)\,ps$ and g-factor $g = 0.61(8)$ [6] was populated by Coulomb excitation of $150\,MeV$ ^{56}Fe beams on Mg nuclei. Ion beams of $\approx 2\,pnA$ intensity were provided by the Munich MP tandem accelerator. The γ-rays emitted from the excited ^{56}Fe(2_1^+)-ions were detected with $9\,cm \times 9\,cm$ large BaF_2 scintillators in coincidence with forward scattered Mg ions measured in a Si detector at 0^0 to the beam axis. An additional Cu foil was placed behind the target for stopping the beam ions. As the ^{56}Fe(2_1^+)-ions slow down in the magnetized Fe layer and come to rest there after the time t_s, they interact with both the TF and the SF. The total precession angle is therefore given by $\Phi_{tot} = \Phi_{TF} + \Phi_{SF}$, which was determined applying the perturbed angular correlation method [4]. The two contributions Φ_{TF} and Φ_{SF} to the experimental result of $\Phi_{tot} = 3.14(36)\,mrad$ depend on the g-factor g, the lifetime τ and the stopping time t_s of the probe ions in the Fe layer according to

$$\Phi_{TF} = g\,\frac{\mu_n}{\hbar} \int_{t_{in}}^{t_s} B_{TF}(t) \cdot e^{-\frac{t}{\tau}}\,dt \qquad (3)$$

$$\text{and} \quad \Phi_{SF} = g\,\frac{\mu_n}{\hbar} \cdot B_{SF} \cdot \tau \cdot e^{-\frac{t_s}{\tau}}\,, \qquad (4)$$

where t_s was calculated for the given target thickness and the reaction kinematics using known stopping powers of the probe ions [7].

As the attenuation factor G_{TF} (see eq. 1) at the same stopping power value of $\frac{dE}{dx} \approx 17.5\,MeV/\mu m$ is known from earlier TF measurements, $G_{TF} = 0.74(5)$ [8], the TF-precession could be calculated from eqs. 3 and 2 to $\Phi_{TF} = 7.4(5)\,mrad$. Thus, from the difference to the measured precession angle, the SF-precession of $\Phi_{SF} = -4.2(6)\,mrad$ was obtained implying a SF strength of (from eq. 4) $B_{SF}(\text{Fe in Fe, Fe beam}) = -18.3(3.5)\,Tesla$. This value corresponds to an attenuation factor for the SF of $G_{SF,\,tot} = \frac{B_{SF}(IMPAC,\ Fe\ beam)}{B_{SF}(rad)} = 0.55(8)$.

In view of further analysis of this very strong SF-reduction one can factorize the total attenuation as $G_{SF,\,tot} = G_{SF}(beam) \cdot G_{SF}(recoil)$, as the contributions by the beam- and the recoil-ions are independent. The $G_{SF}(recoil)$-contribution had been determined in earlier measurements using ^{16}O beams of $33\,MeV$ [9] and $36\,MeV$ [10] for C.E. in backscattering geometry and implantation of the ^{56}Fe(2_1^+) probe ions with nearly the same recoil energy. As in these measurements no beam induced attenuation of both the TF and the SF is expected due to the light beams applied [4], the recoil contribution of $G_{SF}(recoil) = 0.87(7)$ could be derived. Applying this value to the Fe-beam result, one obtains for the beam induced attenuation:

$$G_{SF}(Fe\ beam) = 0.64(11)\,, \qquad (5)$$

which agrees very well with the known TF attenuation of $G_{TF} = 0.74(5)$ and is a further indication of the heavy ion beam induced depolarization of the ferromagnet.

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◇supported by BMBF, GSI, DFG