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THE USE OF A SINGLE-CRYSTAL IRON FRAME IN TRANSIENT FIELD g-FACTOR MEASUREMENTS

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A single-crystal Fe frame has been used as a target backing in a transient field perturbed angular correlation measurement on $^{28}Si(2_1^+)$ with the $^{28}Si(\alpha, \alpha')$ reaction at $E_\alpha = 7.50$ MeV. Two sides of the frame are parallel to the ⟨1, 0, 0⟩ axis, the direction of easy magnetization, such that the frame could be magnetized with a field of only $H = 240$ A/m. Beam-bending effects, caused by fringing fields, are therefore negligible, which results in a reduction of measuring time by a factor of four.

The ion-implantation perturbed angular correlation technique (IMPAC) for the measurement of g-factors of short-lived nuclear states ($\tau_m \approx 0.3 - 3$ ps) has shown to be highly successful [1–4]. In this method recoiling nuclei in an excited state are produced by a nuclear reaction. For such very short-lived states the measured rotation of the angular correlation of deexciting γ-rays is mainly due to the transient magnetic field experienced by the ion slowing down in a magnetized ferromagnetic medium. These fields were found to be anomalously enhanced for high ion velocities [5]. Although the magnitude and the velocity dependence of these fields are as yet not fully understood the method has proved to be a powerful tool for the measurement of relative g-factors.

In the transient field experiments performed so far polycrystalline Fe target backings have been used. As has been shown by De Waard et al. [6], there is a striking difference between surface and bulk magnetization in such a foil if the magnetizing field is too small. This phenomenon is probably due to demagnetizing fields in the foil. For full surface magnetization, external fields of more than 0.1 T are needed. This inevitably causes a non-negligible fringing field which bends the trajectories of the incident and outgoing particles. As a result the reference z-axis is turned and the outgoing particles are not detected along this axis. This off-axial detection causes a change in the substate populations which is observed as a rotation of the angular correlation. This so-called beam-bending effect is unpredictable except for pure Coulomb excitation and must be measured independently with a non-ferromagnetic target backing in order to obtain the proper transient field contribution to the total rotation angle. Since the experimental conditions for the two measurements must be closely similar, the counting rates, the measuring times and consequently the errors are approximately equal. Thus the measuring time required for a given error in the net rotation is four times longer than it would be in absence of the beam-beding phenomenon.

In the present experiment, a single-crystal iron frame was used as target backing. It was cut by spark erosion from a single-crystal plate made by the strain anneal method [7] and then polished and annealed. The frame is 1 mm thick, its outside dimensions are 15 mm × 15 mm and its sides are 3.5 mm wide (see insert in fig. 1). Two of its sides are parallel to the ⟨1,0,0⟩ axis (direction of easy magnetization) and two parallel to the ⟨1, 1,0⟩ axis. The bulk hysteresis curve of the frame for the ⟨1,0,0⟩ direction has been determined by a magnetic induction measurement and the surface hysteresis curve by an optical Kerr effect measurement [6]. The results are shown in fig. 1. Full saturation of both bulk and surface magnetization is apparently reached at about 6 ampere turns.

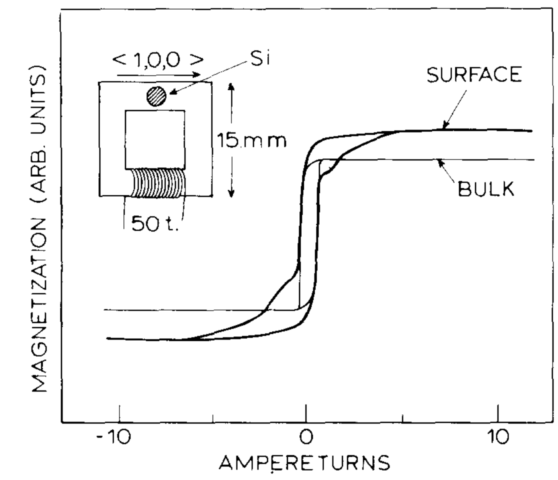

Fig. 1. Hysteresis curves of the Fe monocrystal frame. The curve for bulk magnetization was obtained from an electromagnetic induction measurement, that for surface magnetization from the optical Kerr effect [6]. The vertical scales of the two curves are in different arbitrary units.

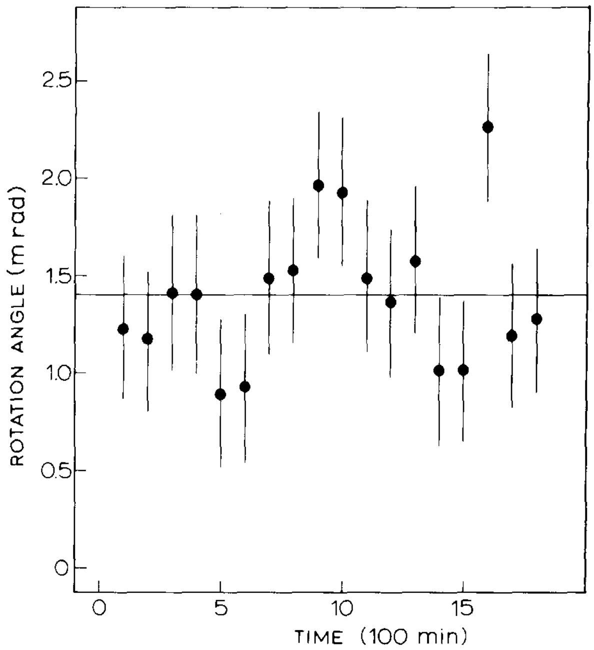

Fig. 2. The measured rotation angle $\Delta\theta$ of the angular correlation as a function of time. Each point corresponds to a measuring time of 100 min. The line represents the average value.

To test the usefulness of this frame, an IMPAC measurement was performed on the first excited 2^+ state of ^{28}Si (E_x = 1.78 MeV, τ_m = 0.7 ps) with the ^{28}Si(α, $\alpha'\gamma$)^{28}Si reaction at a bombarding energy of $E(^4He^+)$ = 7.50 MeV. So far this case has provided the cleanest, fastest and most accurate of all transient field measurements [3].

A natural Si target with a thickness of 200 μg/cm^2 was evaporated onto the centre part of one of the sides of the frame parallel to the ⟨1,0,0⟩ direction. This side was placed vertically in the target chamber such that the beam would be perpendicular to the frame within a few degrees. The frame was magnetized by 10 ampere turns (0.2 A through a coil of 50 turns), which yields a magnetizing field of H = 240 A/m. The fringing field was measured to be less than $B = 2 \times 10^{-5}$T, at least 1000 times lower than in the earlier set-up [2]. Therefore no additional magnetic shielding was applied. The magnetization direction was reversed every 2 min to aboid systematic effects.

In order to maintain a good true-to-random coincidence ratio as well as to prevent excessive heating of the Fe bakcing frame the beam current was kept at about 80 nA. The calculated increase in temperature of the frame is less than 50°C which is comparable to the conditions in the reference experiment [3].

Inelastically scattered α-particles were detected between 173° and 166° with respect to the beam direction in an annular Si surface barrier detector, The corresponding Si ions then recoil at angles between two cones with half-angles of 3° and 6°. Channeling of the ions may therefore be neglected as at most a fraction of 4% of the ions can have a proper channeling direction. Coincident γ-radiation was detected by six 12.7 cm diam. by 12.7 cm long NaI(Tl) detectors at angles of ±18°, ±72° and ±108° in the horizontal plane and at a distance of 20 cm from the target. During the total irradiation time (30 h) the target area exposed to the beam was fixed in order to detect possible radiation damage effects. The data collection system, including a CDC-1700 on-line computer, has been described in ref. [2].

The mean rotation angle $\Delta\theta$ can be expressed to first order by

$$\Delta\theta = \frac{1}{4}\,\frac{\epsilon W(\theta)}{\mathrm{d}W(\theta)/\mathrm{d}\theta}\,,$$

where $W(\theta)$ represents the γ-ray angular correlation.

The effect ϵ for one pair of detectors, defined as the ratio of coincident counts N accumulated in the γ-ray detectors at angles $\frac{1}{2}\pi(n \pm \frac{1}{5})$ for $n = 0, \pm 1$ with the magnetic field up and down, is given by

$$\epsilon = \frac{N(n\pi/2 + \pi/10)\uparrow N(n\pi/2 - \pi/10)\downarrow}{N(n\pi/2 - \pi/10)\uparrow N(n\pi/2 + \pi/10)\downarrow} - 1 \, .$$

The data accumulated yield a rotation angle $\Delta\theta = 1.40 \pm 0.09$ mrad.

To investigate if radiation damage has an effect on the measured rotation, the experiment was divided into 18 runs of 100 min each and the rotation angle per run was calculated. The result per run is displayed as a function of time in fig. 2. A least-squares fit of a linear function to the data yields a slope of $+0.03 \pm 0.03$ mrad/100 min. The data are also consistent with a constant value with a goodness-of-fit of $\chi^2 = 0.97$. Thus there is no significant effect of radiation damage on the rotation.

Such damage is caused in principle both by the incident α-particles and the recoiling Si ions stopped inside the iron frame. Most of the damage due to the α-particles is near the end of their 20 μm range, far beyond the penetration depth of the Si ions. The Si ions used for this transient field experiment, selected by coincidence with backscattered α-particles, have an average penetration depth of 1 μm. Non-coincident Si ions recoiling from α-particle impact under various angles have a projected range of 0–1 μm. The total dose of Si atoms implanted during the experiment with energies exceeding 5 keV is about 10^{12} cm^{-2}. Under the assumption of a range straggling of only 0.1 μm the maximum concentration of Si ions would be 10^{17} cm^{-3}, or about one per 10^6 Fe atoms. At such low concentrations no noticeable radiation damage effects are expected.

The result for the rotation angle, $\Delta\theta = 1.40 \pm 0.09$ mrad, obtained in 30 h with six detectors should be compared to the earlier result [3], $\Delta\theta = 1.42 \pm 0.15$ mrad obtained in 106 h with four detectors. The agreement is excellent, showing that a good Fe polarization is obtained and preserved during the experiment.

It may be concluded that a considerable improvement in the transient field IMPAC technique can be obtained by the use of a single-crystal iron frame. If the transient field can be calibrated the method can now be extended to more difficult cases e.g. when the angular correlation is not very anisotropic, when the lifetime is of the order of 100 fs or when the reaction yield is low. Further, the use of a single-crystal iron frame should allow a more accurate measurement of the velocity dependence of the transient field [5].

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