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journal or publication title	CYRIC annual report
volume	1980
page range	66-69
year	1980
URL	http://hdl.handle.net/10097/48570

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A nuclear level-crossing effect in hyperfine interactions[1)] of the 398 keV level of ^{69}Ge in a Zn single crystal was investigated with the time integral perturbed angular distribution (TIPAD) method. As a supplementary experiment the pure quadrupole interaction of ^{69}Ge in Zn was also studied with the time differential perturbed angular distribution (TDPAD) method.

The simultaneous presence of a static magnetic field and of an axially symmetric electrostatic gradient with its symmetry axis collinear to the magnetic field removes the spatial degeneracy of nuclear sublevels with a nuclear spin I and its projections m along the direction of the symmetric axis, and energy eigenvalues of the sublevels are given in terms of the Larmor frequency ω_L $(=-g\mu_N H/\hbar)$ and the quadrupole frequency ω_Q $(= e^2qQ/4I(2I-1)\hbar)$:

$$E_m = m\omega_L + 3m^2\omega_Q + a \ , \qquad (1)$$

where a is an uninteresting constant independent of m. Eq. (1) shows that sublevels m and m' cross or have the same energy when the ratio ω_L/ω_Q fulfills the relation $\omega_L/\omega_Q = -3(m+m')$.

When the collinear perturbation fields mentioned above are perpendicular to the beam-detector plane, the TIPAD of the γ-ray following the nuclear reaction is represented[2)] by a distribution function

$$W(\theta) \simeq 1 + (1/4)A_2B_2 + (3/4)A_2B_2 \sum_n a_n[\{\frac{1}{1+(\omega_n^+\tau)^2} + \frac{1}{1+(\omega_n^-\tau)^2}\}\cos(2\theta)$$

$$+\{\frac{\omega_n^+\tau}{1+(\omega_n^+\tau)^2} + \frac{\omega_n^-\tau}{1+(\omega_n^-\tau)^2}\}\sin(2\theta)] \ , \qquad (2)$$

where A_2 is the angular distribution coefficient of the γ-ray, B_2 the spin orientation parameter, τ the mean life of the relevant nuclear level, and θ the angle measured with respect to the beam direction. The summation index n is defined as the set of positive integer values (including 0):

$$n = |m^2 - m'^2| \qquad \text{for integer I,}$$

$$n = (1/2)|m^2 - m'^2| \qquad \text{for half-integer I.}$$

The quantities ω_n^+ and ω_n^- are defined by $\omega_n^+ = 2\omega_L + n\omega_0$ and $\omega_n^- = 2\omega_L - n\omega_0$, where ω_0 is the basic quadrupole frequency:

$$\omega_0 = 3\omega_Q \qquad \text{for integer I,}$$

$$\omega_0 = 6\omega_Q \qquad \text{for half-integer I.}$$

At the level-crossing point where $\omega_L/\omega_Q = -3(m+m')$, ω_n^- vanishes for the n value

$$n = -2(m+m') \qquad \text{for integer I,}$$

$$n = -(m+m') \qquad \text{for half integer I.} \qquad (3)$$

Thus, around the level-crossing point the term in expression (2) including the factor $1/[1+(\omega_n^-\tau)^2]$ with n satisfying condition (3) shows a Lorentz type resonance behaviour, and the one including the factor $\omega_n^-\tau/[1+(\omega_n^-\tau)^2]$ a dispersion type resonance behaviour.

We have made a TDPAD study on the quadrupole interaction of the 398 keV level of ^{69}Ge produced in a Zn single crystal by the ^{66}Zn(α,n) reaction. A single-crystal Zn target with the symmetric axis (the hexagonal c axis) perpendicular to the beam-detector plane was placed in 0.1 atm He gas to suppress evaporation of the target material, and was held at a temperature of about 530 K in an oven to reduce the spin relaxation effect due to the radiation-induced vacancies. The target was bombarded with a pulsed beam of 20 MeV α-particles from the CYRIC cyclotron. The pulse repetition interval was chosen to be 7.5 μs by the use of a beam pulsing system, which is described elsewhere in this annual report. Relative yields of the 398 keV γ-rays were measured as a function of time using two NaI(Tl) detectors placed at angles of 0° and 90° with respect to the beam direction. Fig. 1 shows the mesured time dependence of the anisotropy R = [N(0°)-N(90°)]/[N(0°)+N(90°)], where N(θ) stands for the normalized yield of the 398 keV γ-rays at direction θ. A least squares fitting analysis of the data has given ω_0 = 19.27±0.01 Mrad/s.

The nuclear g-factor of the 398 keV level in ^{69}Ge, for which I = 9/2 and τ = 4.1 μs, has been determined[3] to be 0.2224±0.0007. From this value of g-factor and the ω_0 value given above, we expect the first (n=1) level-crossing resonance of the 398 keV level of ^{69}Ge in a Zn single crystal to occur at an external magnetic field of about 9.4 kG and to have a width of about 0.23 kG.

To observe the level-crossing resonance, an additional external magnetic field was applied to the target assembly used in the measurement of ω_0. The magnetic field parallel to the symmetry axis of the Zn crystal was produced with an electromagnet. The single-crystal Zn target was bombarded with 20 MeV α-particles and yields of the 398 keV γ-rays were measured as a function of the magnetic field H using three Ge(HP) detectors placed at θ = 45°, 90° and 135°. Fig. 2a shows the observed H dependence of the anisotropy R_D = [N(45°)-N(135°)]/[N(45°)+N(135°)], and Fig. 2b shows that of R_L = 2N(90°)/[N(45°)+N(135°)].

It is expected from eq. (2) that around the level crossing point the H dependence of R_L shows a Lorentz type resonance and that of R_D a dispersion type resonance. Assuming that the behaviour of the experimental data shown in Fig. 2 represent the n=1 level-crossing resonance, we made a least-squares fitting analysis of the data, and obtained the resonance parameters, position H_R and width W, listed in Table 1.

The observed values of H_R and W listed in Table 1 are in rather good agreement with the expected values mentioned above, H_R = 9.4 kG and W = 0.23 kG. To make a closer comparison, we deduced from the H_R values given in Table 1 and the g-factor reported in Ref. 3 the ω_0 values contributing the relevant level-crossing resonance, which are also given in Table 1. They are slightly larger than the ω_0 value of 19.27±0.01 Mrad/s obtained in the present TDPAD study. The discrepancy, small but clearly beyond the statistical uncertainty, might be due to a small difference in temperature between the targets used in the TDPAD and TIPAD measurements.

It may be concluded that the present study, the first attempt to observe the nuclear level-crossing resonance in TIPAD, has been successful.

References

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Table 1. Resonance parameters obtained from the observed level-crossing resonance, and basic quadrupole frequency deduced from the resonance position.

Type of resonance	Position (kG)	Width (kG)	ω_0 (Mrad/s)
Lorentz	9.34±0.03	0.23±0.06	19.90±0.08
Dispersion	9.37±0.03	0.22±0.03	19.96±0.08

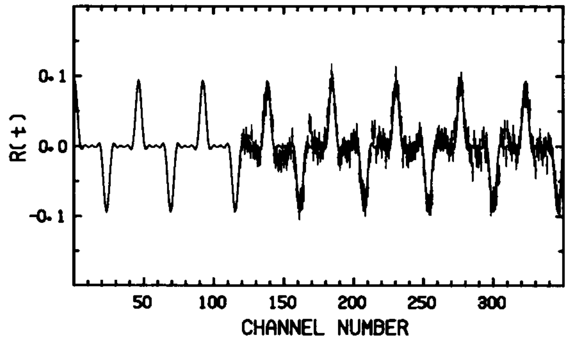

Fig. 1. Time spectrum of the anisotropy of the 398 keV γ-ray emitted from reaction-produced ^{69}Ge in a Zn single crystal held at a temperature of about 530 K. The solid curve is the result of a least-squares fitting analysis with a single ω_0 of 19.27 Mrad/s. On the abscissa the width of 100 channels correspondends to 0.71 μs.

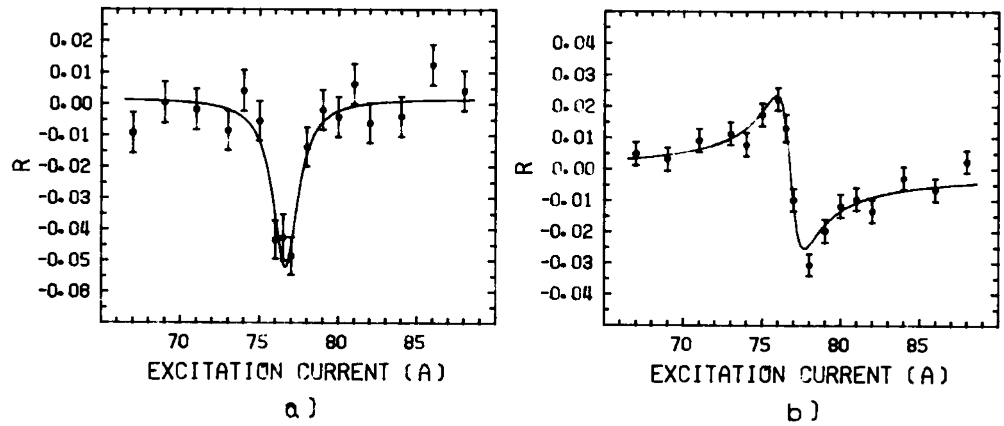

Fig. 2. Lorentz-type (a) and dispersion-type (b) level-crossing resonances for the 398 keV level of reaction-produced ^{69}Ge in a Zn single crystal held at a temperature of about 530 K. Curves represent the results of least-squares fitting analysis with the resonance parameters listed in Table 1.