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THE g-FACTOR OF THE 108 keV EXCITED STATE IN ^{151}Gd

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1. Introduction

The $^{151}_{64}Gd_{87}$ nucleus belongs to the region of transition nuclei. Therefore, it is very interesting to study the nature of its excited states.

The purpose of this investigation was to determine the unknown g-factor of the 108 keV level in ^{151}Gd. The lifetime of this level is $\tau_N = 4.33 \pm 0.15$ ns (ref. /1/) and the spin is $I = 5/2$ (ref. /2/).

The reversed field method with hyperfine magnetic field of Gd implanted in iron was used for the γ–γ integral perturbed angular correlation (IPAC) determination of this g-factor.

Problems regarding PAC measurements using the hyperfine interactions experienced by radioactive nuclei embedded in iron foil by means of isotope separators are discussed in several recent articles, proceedings and reviews (refs /3,4,5/).

The magnetic precession $\Delta N/N$ is defined to be

$$\frac{\Delta N}{N} = \frac{W(\uparrow) - W(\downarrow)}{\frac{1}{2}(W(\uparrow) + W(\downarrow))}, \tag{1}$$

where the arrow denotes the sence of the magnetic field, which is perpendicular to the plane of the detectors.

For an integral angular correlation, with just a P_2 term and in the presence of time-dependent magnetic interactions caused by paramagnetic spin relaxation, one finds (ref. /6/) for an angle $\theta = 135^\circ$ between the detectors

$$\frac{\Delta N}{N} = \frac{3A_2}{4a + A_2} \sin 4\Delta\theta', \tag{2}$$

where the relaxation coefficient a and the rotation $\Delta\theta'$ of the angular correlation are

$$a = 1 + \lambda \cdot \tau_N \tag{3}$$

$$\Delta\theta' = \frac{1}{2} \operatorname{arc\,tg} \left(\frac{2\omega\tau_N}{1 + \lambda\cdot\tau_N}\right) \tag{4}$$

and

$$\lambda = \left(\frac{2\tau_s}{\hbar^2}\right) < H_{int}^2 >^{1/2} g^2 \mu_N^2 . \qquad (5)$$

Here, $\omega = (g \mu_N H/\hbar)$ is the Larmor frequency, g is the g-factor of the intermediate state, H and $< H_{int}^2 >^{1/2}$ are the effective and the mean-free ionic magnetic field acting on the nucleus, respectively. In the above relations the assumption was made that the spin relaxation time τ_S is smaller than the lifetime of the intermediate nuclear level τ_N.

In the case of the large hyperfine fields and large τ_N, the ambiguity appears on the rotation $\Delta\theta'$ and therefore, on the experimental g-value. It is also possible that a large attenuation of the angular correlation, i.e. a very small effect $\Delta N/N$, takes place. To avoid this ambiguity and to be able to know the attenuation of AC we have made some preliminary studies.

2. The Lifetime Dependence of the $\Delta N/N$ Magnetic Precession

Using the usual non-relaxation model (i.e. $\alpha = 1$) eq. (2) becomes

$$\frac{\Delta N}{N} = \frac{3 A_2}{4 + A_2} \sin 4 \Delta\theta , \qquad (2')$$

where

$$\Delta\theta = \frac{1}{2} \, arc \, tg \, (2 \mu_N \tau_N H / \hbar) \qquad (4')$$

The magnetic field dependence of $\Delta N/N$ for different τ_N is represented in fig. 1. The g and τ_{N_1} values of the 86 keV level of ^{155}Gd and the A_2 -coefficient of the 180-86 keV cascade of the same nucleus have been used.

For each value of τ_N, there is one single value of H for which $\Delta N/N$ is unattenuated and corresponds to the same value of the rotation $\Delta\theta = 22°30'$. This H -value increases, when τ_N decreases. If the experimental value of $\Delta N/N$ is smaller than the unattenuated one (and this is usually the case) there is an ambiguity on $\Delta\theta$. Experimentally one can decide between the two possible values by measuring $\Delta N/N$ for two or more different values of the magnetic field H. Usually, large magnetic fields are produced by a magnetization procedure, which gives saturation for large magnetizing coil current I.

The coil current dependence of $\Delta N/N$ for different lifetimes τ_N is shown in fig. 2. The curve (a) corresponds to the case when $\tau_N(a)$ and the saturation field gives just a rotation of $22°30'$, i.e. the maximum value for $\Delta N/N$. For larger coil currents $\Delta N/N$ has a plateau at this maximum value.

The curve (b) shows the case when τ_N is smaller than τ_N (a). The plateau appears for a rotation smaller than $22°30'$, i.e. for an attenuated $\Delta N/N$ value. Such an experimental curve has been obtained by Deutch et al /5/.

The curve (c) corresponds to the case when τ_N is larger than τ_{Na}, i.e. the $\Delta N/N$ plateau appears for the rotation $\Delta\theta$ larger than $22^{\circ}30'$.

In all these cases, the presence of the relaxation processes will further attenuate the $\Delta N/N$ effect. Thus, even the maximum value of $\Delta N/N$ may be very small. Fig. 3. shows the strong effect of the relaxation processes in the case of 86 keV level in ^{155}Gd (τ_N= 9.64 ns). Here, (a) and (b) denote the theoretical curves for the magnetic field dependence of $\Delta N/N$ calculated with the non-relaxation and with the relaxation models, respectively; the relaxation coefficient a= 2.14 has been experimentally determined in this paper.

3. Experimental Procedure and Results

3.1. Sources

The ^{155}Tb and ^{151}Tb sources were obtained from the spallation reaction, bombarding a tantalum target with 660 MeV protons from the Dubna synchrocyclotron.

The ^{155}Tb and ^{151}Tb sources have been implanted simultaneously into the iron X-ray filter foil 0.0012 cm (obtained from Johnson Matthey Chemicals Ltd) by means of an isotope separator. The measurements were made with non-annealed sources.

3.2. Apparatus

The angular correlation apparatus used in these experiments is a conventional automatically operated coincidence system using the fast-slow electronics with a 40x40 mm $NaI(Tl)$ and a 50-cc $Ge(Li)$ detectors /7/. The alignment of the iron domains in the direction of applied magnetic field was obtained using a small magnet with a great number of amper-turns. The sense of the magnetic field was automatically changed every 5 minutes. The information obtained for the two directions of the magnetic field was analysed in a 1024-channel pulse-height analyser. Simultaneously the background coincidences were analysed.

3.3. PAC Measurements in ^{155}Gd

The purpose of these studies was to evaluate the effect of the relaxation processes on the magnetic precession for Gd isotopes implanted in Fe. Therefore, we have determined the relaxation constant a for the 86 keV excited level of ^{155}Gd, using the well known 180-86 keV cascade. The angular correlation coefficients for this cascade were measured in ref. /8/ A_2= -0.214 ± 0.006 and A_4 = 0.009 ± 0.015.

The g-factor of 86.5 keV state was previously measured in refs. /9, 10, 11/. We adopted the values g = -0.376 ± 0.026 (ref. /9/), τ_N (9.64 ± 0.17) ns (refs. /8, 12/) and I = 5/2.

Firstly, we performed the coil current dependence of $\Delta N/N$ for $\theta = 135°$. The result is shown in fig. 4. The experimental points lie on a curve similar to curve (c) from fig. 2. Our measurements were carried out for a coil current $I = 100\,mA$, which gives the saturated hyperfine field. This magnetic field value was determined in refs. [13,14], $H = (200 \pm 50)$ kG.

In view of the discussion given in sect. 2 we can conclude that $\Delta\theta' > 22°30'$. The relaxation constant α was determined at room temperature by observing the change in coincidence rate of 180 and 86 keV gamma-rays when the sense of the coil current was reversed. The experimental results are: $\Delta N/N = 0.044 \pm 0.008$, $\alpha = 2.14$, $\Delta\theta' = 36°25'$.

It is seen from rel. (5) that the ratio (λ/g^2) will be the same for all the isotopes of Gd (obtained from Tb desintegration) implanted in iron. With the above value of α we have obtained $(\lambda/g^2) = 8.62 \times 10^8\ sec^{-1}$. This value was used in section 3.4 for the g-factor determination in ^{151}Gd.

3.4. The g-factor of 108 keV Excited State in ^{151}Gd

The reversed field method was also used for the g-factor determination of the 108 keV level in ^{151}Gd. The measurements were also performed for $\theta = 135°$ and for $I = 100\,mA$, i.e. with the saturated magnetic field.

To obtain the g-factor we have used the 287-108 keV cascade which has the angular correlation coefficients [15] $A_2 = -0.240 \pm 0.015$ and $A_4 = -0.008 \pm 0.016$.

Our experimental results are

$$\frac{\Delta N}{N} = +0.070 \pm 0.015$$

$$g = -0.54 \begin{array}{l} +0.07 \\ -0.10 \end{array}$$

Using the (λ/g^2) ratio determined in sect. 3.3 we obtain for the 108 keV level of ^{151}Gd the relaxation coefficient $\alpha = 2.08$ and the rotation $\Delta\theta' = 31°25'$. The magnetic moment of 108 keV excited state in ^{151}Gd is $\mu = (-1.35 {}^{+0.18}_{-0.25})\mu_N$.

4. Discussion

The quantum characteristics of ^{151}Gd ground state agree with the prediction of the shell model $(f_{7/2})$. The 108 keV state cannot be interpreted as a single particle state. The Schmidt model predicts for a single neutron $f_{5/2}$ state the magnetic moment $\mu = +1.37\mu_N$, which is in complete disagreement with our experimental value. With the Arima and Horie [16] model which takes into account the configuration mixing, we obtained for the same $f_{5/2}$ state the value $\mu = 1.07\mu_N$, also in disagreement with the experimental value. Within the de Shalit model [17] the 108 keV state can be interpreted as a coupling of the $f_{7/2}$ single neutron state of the ground state to the collective excitation of the even-even core. This core-excitation model predicts for the g-factor of a member of of the core multiplet [18]

$$g(J_i) = \frac{1}{2}(g_c + g_p) + \frac{1}{2}(g_c - g_p) \cdot \frac{J_c(J_c+1) - j(j+1)}{J_i(J_i+1)}, \qquad 6)$$

where J_i, J_c, j are the spins of the excited state, of the excited core and of the single-particle state, respectively; g_c and g_p are the g-factors of the excited core and of the single-particle state. In the absence of measurements for the g-factor of the 2^+ state of ^{150}Gd we have used the value $g_c = \frac{Z}{A} = 0.41$. For the g-factor of the ground state of ^{151}Gd we have used in eq. (6) both the Schmidt and Arima and Horie theoretical values. The magnetic moment values obtained for 108 keV excited state in ^{151}Gd are $\mu_{Sch} = -1.72\mu_N$ and $\mu_{A-H} = -0.87\mu_N$. From the comparison with experimental result one can conclude that this level is of collective nature. The same conclusion was obtained from life-time measurements /1/.

Now, we can predict the magnetic moment of the ground $f_{7/2}$ state in ^{151}Gd. Using rel. (6) and $g_c = 0.41$ we obtain $\mu = (-1.61^{+0.25}_{-0.35})\mu_N$. We remark that for g_c -values varying between 0.2 and 0.5 the results are the same in the limits of the experimental errors.

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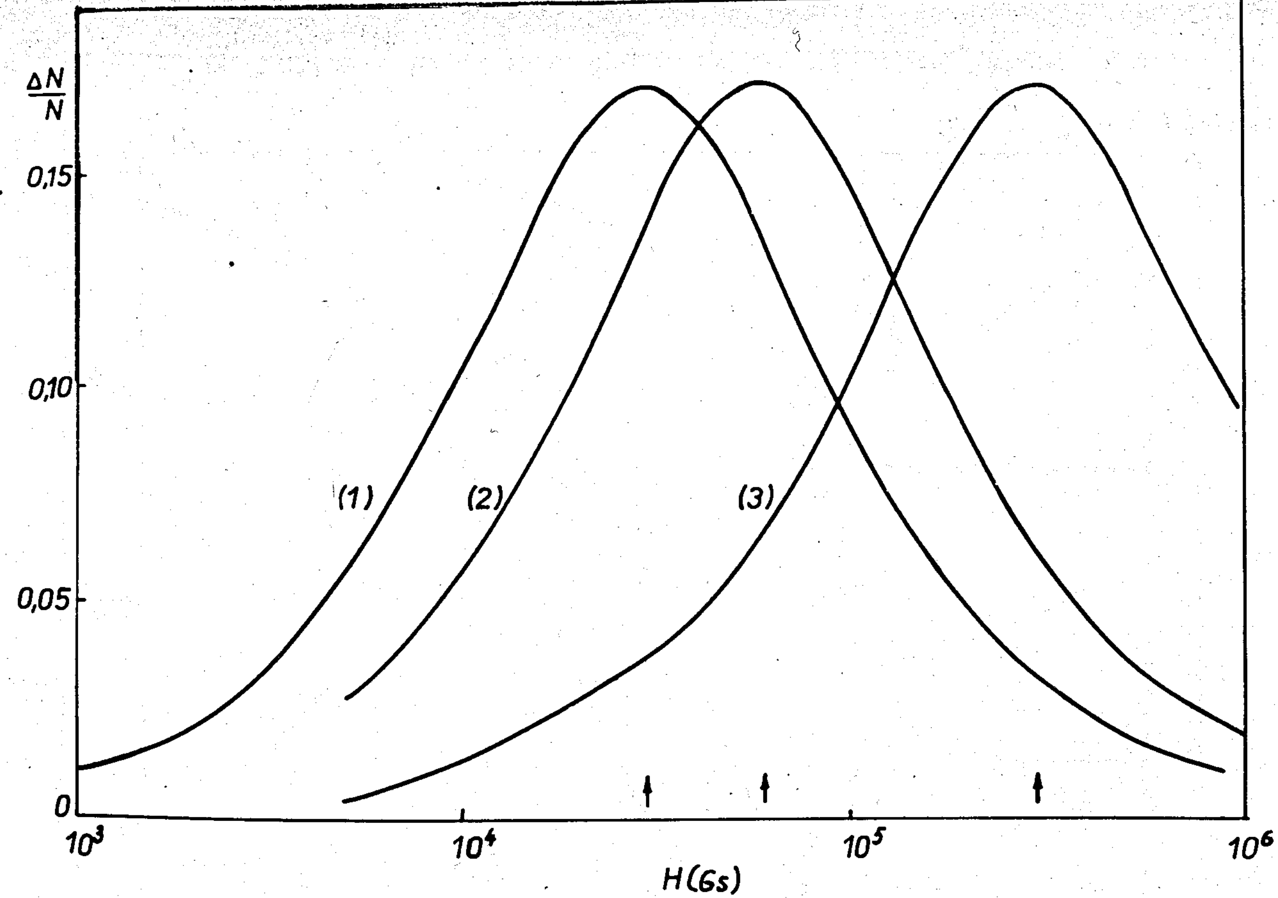

Fig. 1. The theoretical magnetic field dependence of $\Delta N/N$ for different lifetimes non-relaxation model (A_2 = -0.214, g = -0.376; (1) τ_{N_1} = 9.6 nsec; (2) τ_{N_2} = 4.8 nsec; (3) τ_{N_3} = 0.96 nsec).

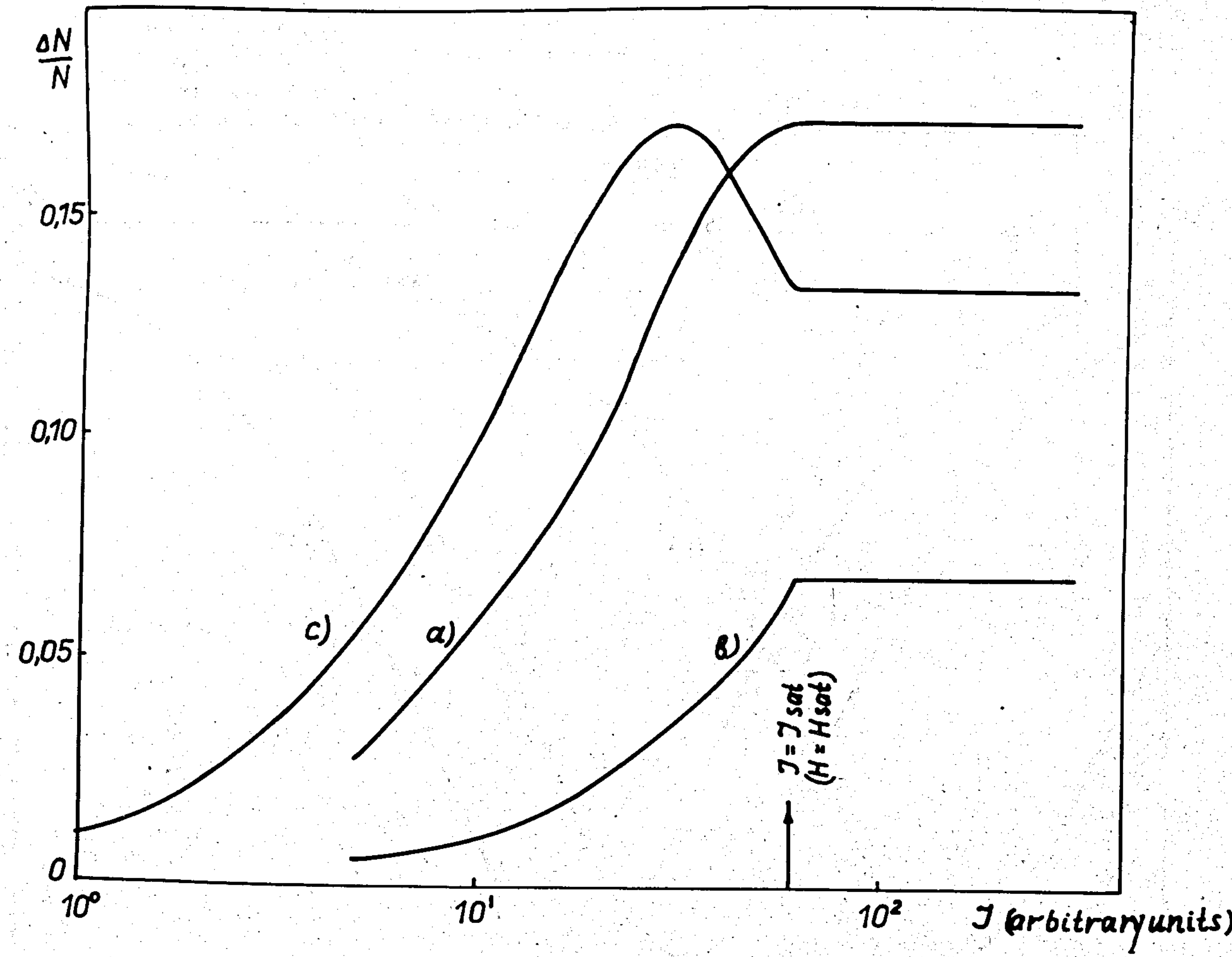

Fig. 2. The theoretical coil current dependence of $\Delta N/N$ for different lifetimes (τ_N (c) > τ_N (a) > τ_N (b)).

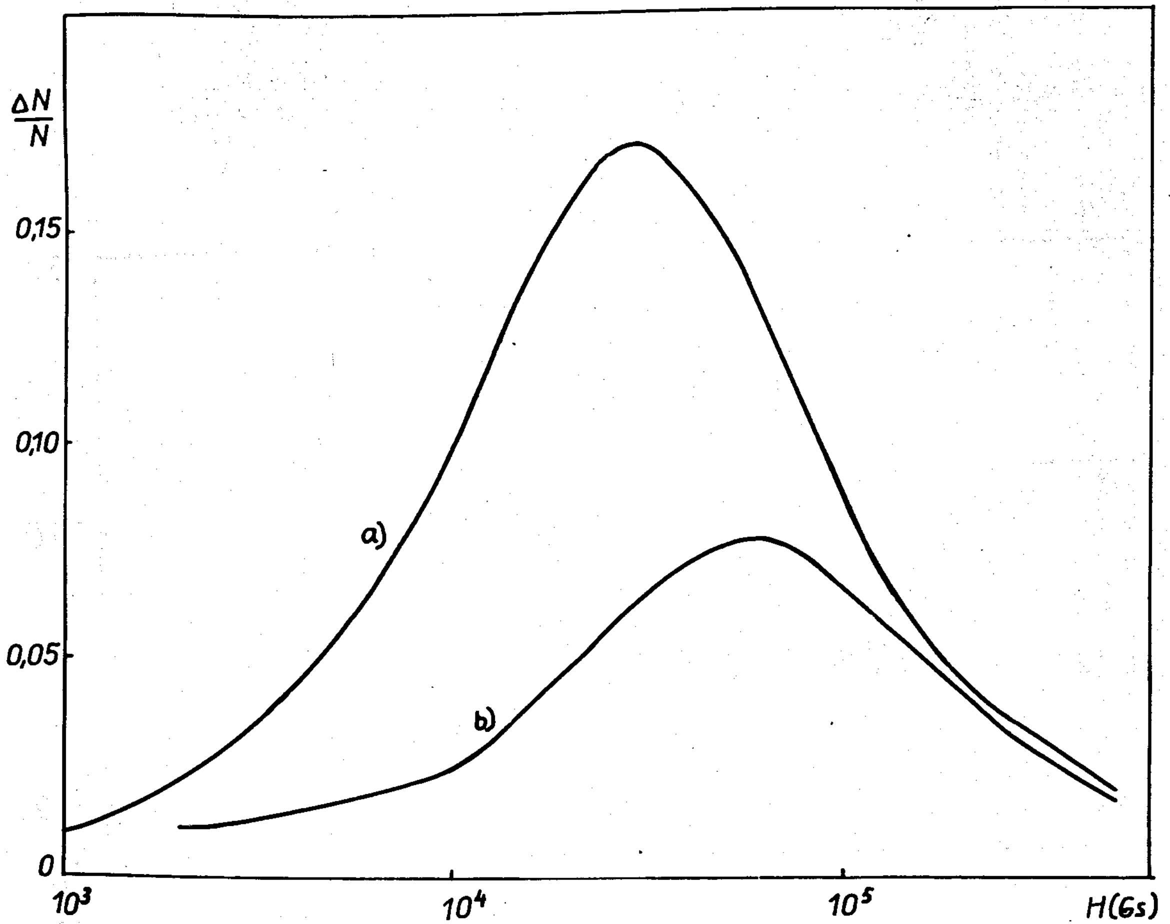

Fig. 3. The theoretical $\Delta N/N$ curve calculated with the non-relaxation model (a) and with relaxation model (b) (α = 2.14).

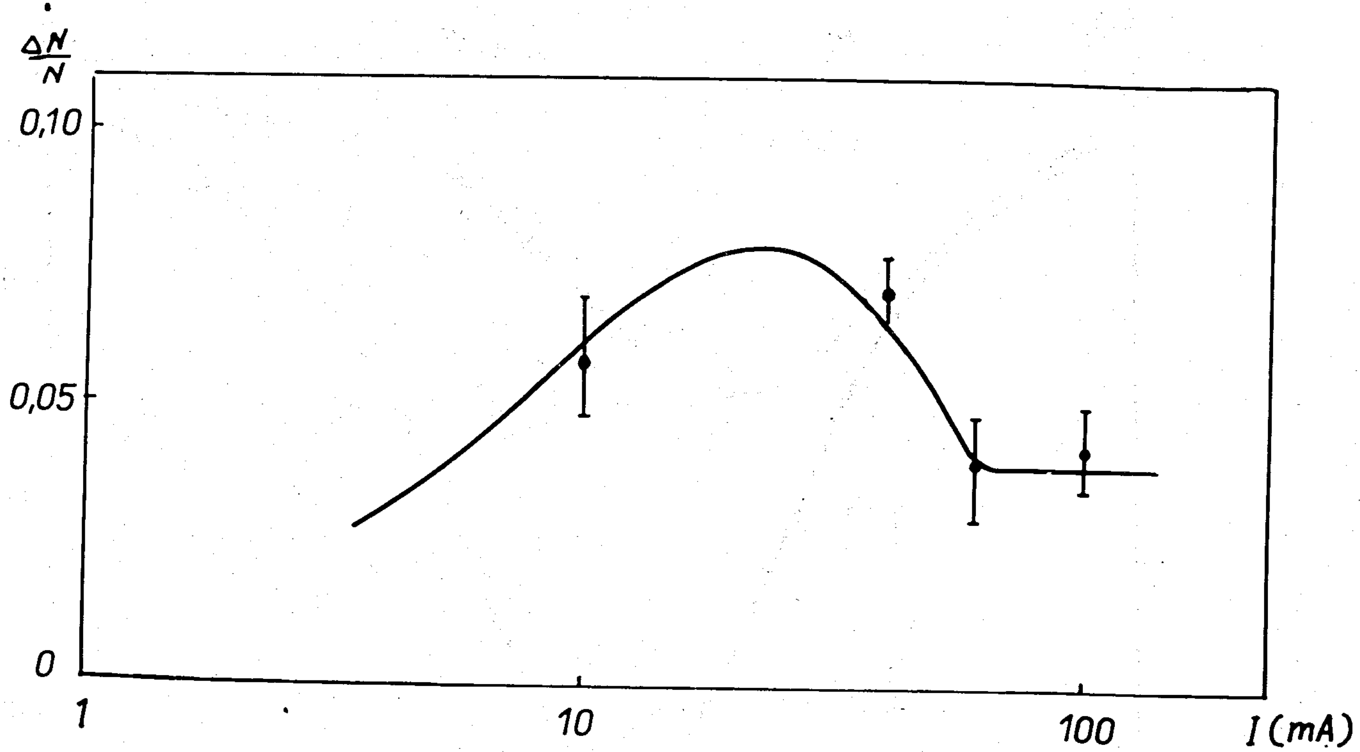

Fig. 4. The experimental coil current dependence of $\Delta N/N$ for 180-86 keV cascade in ^{155}Gd implanted in Fe.