DETERMINATION OF THE SIGN OF THE LOCAL MAGNETIC FIELD AT GOLD NUCLEI DISSOLVED IN IRON AND NICKEL

B. N. SAMOĬLOV, V. V. SKLYAREVSKII, and V. D. GOROBCHENKO

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The sign of the local magnetic field at the gold nucleus has been determined by measuring the asymmetry of the β radiation from Au^{198} polarized in dilute solutions of gold in iron and nickel. The most probable values for the fields are $H_n = -1.0 \times 10^6$ oe in iron and $H_n = -1.8 \times 10^5$ oe in nickel.

MEASUREMENTS have been made of the asymmetry of the β radiation from Au^{198} nuclei, polarized in dilute solutions of gold in iron and nickel, in order to determine the sign of the local magnetic field at the dissolved gold nuclei. The study of the anisotropy of the γ radiation of Au^{198}, oriented in an Fe-Au alloy, could give only[1] the absolute value of the local field H_n, since the angular distribution of the γ radiation from oriented nuclei depends only on even powers of the product $\mu_n H_n$ (where μ_n is the magnetic moment of the nucleus). The direction can be found from measurements of the asymmetry of the β radiation from oriented nuclei.[2]

The angular distribution of the β electrons emitted by oriented nuclei can be written in the form

$$N(\theta) = S_n\left[1 + \sum_k (f_k/f_{km})\, B_k P_k(\cos\theta)\right], \qquad (1)$$

where S_n is a factor determined by the spectrum shape for an n-th forbidden β transition; the f_k are parameters describing the degree of orientation of the nuclei, and f_{km} their maximum possible values; the B_k are parameters which contain the dependence of the β ray distribution on the nuclear matrix elements, and $P_k(\cos\theta)$ are Legendre polynomials.

The overwhelming majority of Au^{198} nuclei decay according to the scheme 2^- (β) 2^+, which corresponds to a first-forbidden β transition. The electron spectrum has an end point $W_0 = 2.9\ mc^2$ (where m is the electron mass and c is the velocity of light) and has an allowed shape. In the case of a first-forbidden transition, the summation in (1) goes over k = 1, 2, 3; i.e., the electron angular distribution is determined by the orientation parameters f_1, f_2 and f_3. At not too low temperatures, f_3 is negligibly small and the term with k = 3 can be dropped. Using the approximate expressions for B_1 and B_2, which were found by M. Morita and R. Morita[3] for the case of $\alpha Z/2\rho \gg W_0$ and $(\alpha Z)^2 \ll 1$,* (where ρ is the nuclear radius in units of the Compton wavelength $\hbar/mc$, and α is the fine structure constant), and also making use of the fact that the electron spectrum has an allowed shape, one can show that the approximate expression

$$N(\theta) \approx S_1\left[1 - \frac{1/3 + 2\sqrt{2/3}\,\lambda/\mu}{1 + (\lambda/\mu)^2}\,\frac{p}{W}\,\frac{f_1}{f_{1m}}\,P_1(\cos\theta)\right] \qquad (2)$$

gives the angular distribution correctly. Here $p = \sqrt{W^2 - 1}$ is the momentum of the electron, and λ and μ are parameters which are linear combinations of the nuclear matrix elements, in the notation of M. and R. Morita.

The asymmetry of the β radiation can be characterized by the value of the quantity

$$\varepsilon_\beta = [N(0) - N(\pi)]/N_0, \qquad (3)$$

where $N(\theta)$ is the β counting rate at an angle θ relative to the direction of the magnetizing field on the sample, and N_0 is the isotropic counting rate in the absence of orientation. Substituting the values of $N(0)$ and $N(\pi)$ from (2) into (3) and using the approximate equation $f_1/f_{1m} \approx \mu_n H_n/2kT$, we find for ϵ_β the expression

$$\varepsilon_\beta \approx -\frac{1/3 + 2\sqrt{2/3}\,\lambda/\mu}{1 + (\lambda/\mu)^2}\,\frac{p}{W}\,\frac{\mu_n H_n}{k}\,\frac{1}{T}. \qquad (4)$$

This expression was used for determining the intensity of the local magnetic field H_n, since all the other parameters appearing on the right side of the equation are determined independently. The

*The latter inequality is satisfied only approximately, but this does not affect the form of (2) and manifests itself only in the definition of the parameters λ and μ in terms of the matrix elements.

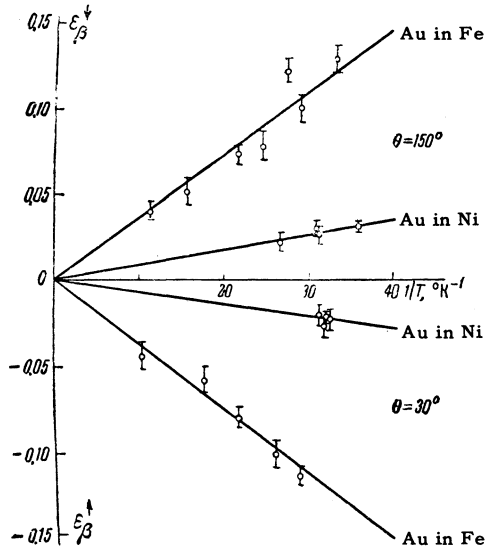

FIG. 1. Temperature dependence of asymmetry of β radiation from Au^{198} dissolved in iron and in nickel; $\varepsilon_\beta^\uparrow = [N(30°)-N_0]/N_0$; $\varepsilon_\beta^\downarrow = [N(150°)-N_0]/N_0$, $\varepsilon_\beta = \varepsilon_\beta^\uparrow - \varepsilon_\beta^\downarrow$.

ratio λ/μ can be found from the results of Steffen,[4] who studied the β-γ angular correlation. The average value of $\overline{p/W}$ over the portion of the electron spectrum recorded by us was taken to be 0.78; and the nuclear moment was set at μ_n = +0.5 n.m. No direct measurements of the sign of the magnetic moment of Au^{198} have been made, but according to the shell model it is very probably positive. The values of ϵ_β and 1/T were determined separately in the experiments.

The apparatus and experimental method were the same as in our previous work.[2] The samples contained ~0.3 w % of gold for the iron alloy ~1 w % for the nickel alloy. After activation with thermal neutrons the samples were annealed for 2—3 hours at ~1000°C. Figure 1 shows the results of several series of experiments with the Fe-Au alloy and of one series with Ni-Au. Each point was determined from the change in intensity of the β radiation when the sample was artificially heated to the temperature of the helium bath. We see that the points lie well on a straight line, which corresponds to a dependence of ϵ_β only on 1/T, i.e., only on f_1. After making corrections for the fact that the direction of polarization and the direction of the β radiation which is recorded are not the same, and for the fraction of scattered electrons in the recorded radiation* (this was done in supplementary experiments), we found from the slopes of the lines the following values for ϵ_β:

$$\varepsilon_\beta = -(8.9 \pm 0.3)\cdot 10^{-3} T^{-1}$$

for gold dissolved in iron, and

$$\varepsilon_\beta = -(1.6 \pm 0.1)\cdot 10^{-3} T^{-1}$$

for gold in nickel.

Substituting these values in (4), we can find the dependence of the local field on the parameter λ/μ. For gold in iron,

$$H_n = (6.2 \pm 0.2)\frac{1+(\lambda/\mu)^2}{1/3 + 2\sqrt{2/3}\,\lambda/\mu}\cdot 10^5 \text{ oe};$$

for gold in nickel

$$H_n = (1.1 \pm 0.07)\frac{1+(\lambda/\mu)^2}{1/3 + 2\sqrt{2/3}\,\lambda/\mu}\cdot 10^5 \text{ oe}.$$

The dependence is shown graphically in Fig. 2.

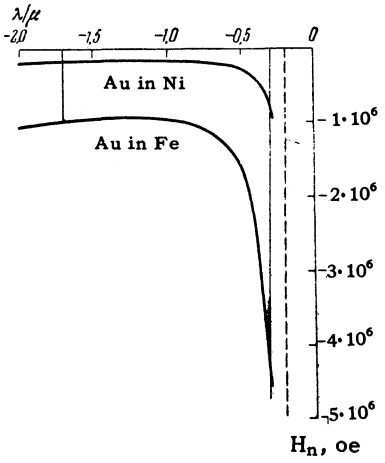

FIG. 2. Dependence on the parameter λ/μ of the local magnetic field at gold nuclei dissolved in iron and nickel. The most probable value is $\lambda/\mu = -1$.

From Steffen's work we can get only the approximate value $\lambda/\mu = -1 \pm 0.7$. But as we see from the curve, despite the large uncertainty in the determination of λ/μ, the local field intensity in iron is apparently close to the value $H_n \approx -1.0 \times 10^6$ oe, which agrees in absolute value with our previous results.[1] The local field in nickel is 5.6 times smaller and is equal to $H_n \approx -1.8 \times 10^5$ oe.* Thus in both iron and nickel the direction of the local field at the gold nuclei is opposite to the domain field.

At present only one mechanism has been proposed which leads to a negative sign for the local magnetic field. This is the contact field of the electrons of the inner s shells. This mechanism assumes that there is a partial polarization of the

*Corrections were made only for back-scattering of electrons from the material of the cold pipe. No corrections were made for electrons scattered from the walls of the apparatus.

*The degree of quadrupolarization of the gold nuclei is approximately 30 times smaller in nickel than in iron. This may explain the negative result of the attempt to detect the field at the nuclei of gold in nickel from the anisotropy of the γ radiation.[5] Probably insufficient sensitivity is the reason why Roberts et al. give a zero value for the field at gold nuclei in nickel, as found by them from an investigation of the Mössbauer effect.[6]

inner shells by the exchange and dipole interaction with the unfilled shell of the paramagnetic ion. The assumption of such a mechanism for the origin of the local field is equivalent to assuming an uncompensated shell for the impurity atom. Also not completely excluded is the possibility of explaining the negative sign of the local field as the result of contact interaction with the polarized conduction electrons of the alloy, assuming that their polarization has the opposite sign. However such an assumption is not in agreement with the conclusions of Kondorskii.[8]

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