Letters to the Editor

ASYMMETRY OF THE BETA RADIATION OF Co^{60} NUCLEI POLARIZED IN A COBALT-IRON ALLOY

B. N. SAMOĬLOV, V. V. SKLYAREVSKII, V. D. GOROBCHENKO, and E. P. STEPANOV

Submitted to JETP editor April 3, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **40**, 1871-1874 (June, 1961)

WE reported earlier[1] on the results of investigating the asymmetry of beta radiation from Co^{60} nuclei polarized in Permendur (a ferromagnetic alloy containing 50% Co and 50% Fe). From the experimentally determined sign of the asymmetry we established that the effective magnetic field at the cobalt nuclei is directed oppositely to the external, magnetizing field. Hanna and his co-workers arrived at similar conclusions[2] as a result of investigating by the Mössbauer method the hyperfine splitting of levels of the Fe^{57} nucleus in metallic iron and of measuring the dependence of this splitting on the added external field. Dash and co-workers[3] showed by an indirect method that the effective field at Co^{57} nuclei in iron has the same direction as the field at Fe^{57} nuclei, i.e., opposite to the domain field. This letter presents the final results of our investigations of asymmetry of the beta radiation of Co^{60} nuclei polarized in Permendur.

The orientation was effected by the ferromagnetic method.[4] The sample was cooled by bringing it into thermal contact with an adiabatically demagnetized block of potassium chrome alum. To magnetize it, a small (~ 1000 oe) magnetic field created by coils placed inside the helium Dewar was applied. The sample, in the form of a thin plate ($3 \times 1.5 \times 0.01$ mm), was positioned in such a way that its plane made an angle of 30° with the direction of the magnetic field. The beta radiation was counted in the same direction. Such a placement of the sample satisfied at the same time two requirements: a small thickness along the direction of emission of the recorded beta radiation and a small angle between the polarization axis of the nuclei* and the direction in which the counting is performed (the maximum asymmetry value corresponds to the zero value of this angle). A diagram of the low-temperature part of the apparatus is presented in Fig. 1. The beta radiation was registered by a disc of scintillating plastic (diameter 9 mm, thickness 1.5 mm). Scintillations were led from the scintillator via a methyl metacrylate light pipe (~ 1000 mm long) to the photocathode of a FEU-13 multiplier tube. Another multiplier with a 40×40-mm NaI(Tl) crystal recorded the gamma radiation of the sample in a direction perpendicular to the axis of polarization. The remaining devices employed to record radiation and measure the temperature of the salt, as well as the experimental procedure, were the same as in our previous experiments.[5]

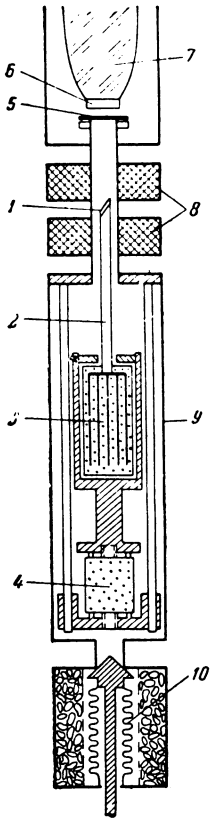

FIG. 1. Diagram of the apparatus: 1 – sample; 2 – cold conductor; 3 – cooling salt with contact plates; 4 – insulating salt; 5 – aluminum foil (thickness 25 μ); 6 – scintillator; 7 – light pipe; 8 – coils for magnetizing the sample; 9 – vacuum jacket; 10 – adsorption pump.

Figure 2 represents the results of one of the experiments. Every fifteen minutes the direction of the magnetizing field was reversed, and after thirty minutes the sample was warmed up to the temperature of the surrounding bath. It is evident that reversal of the field has no effect on the anisotropy of the gamma radiation, but that it does reverse the direction of preferred emission of electrons. Quantitatively, the anisotropy of the gamma radiation and the asymmetry of the beta radiation may be described by the parameters

$$\varepsilon_\gamma = N_\gamma(\pi/2)/N_\gamma^0 - 1, \quad \varepsilon_\beta = [N_\beta(0) - N_\beta(\pi)]/N_\beta^0,$$

where $N_\gamma(\theta)$ and $N_\beta(\theta)$ are the intensities of the gamma and beta radiation of the oriented nuclei at

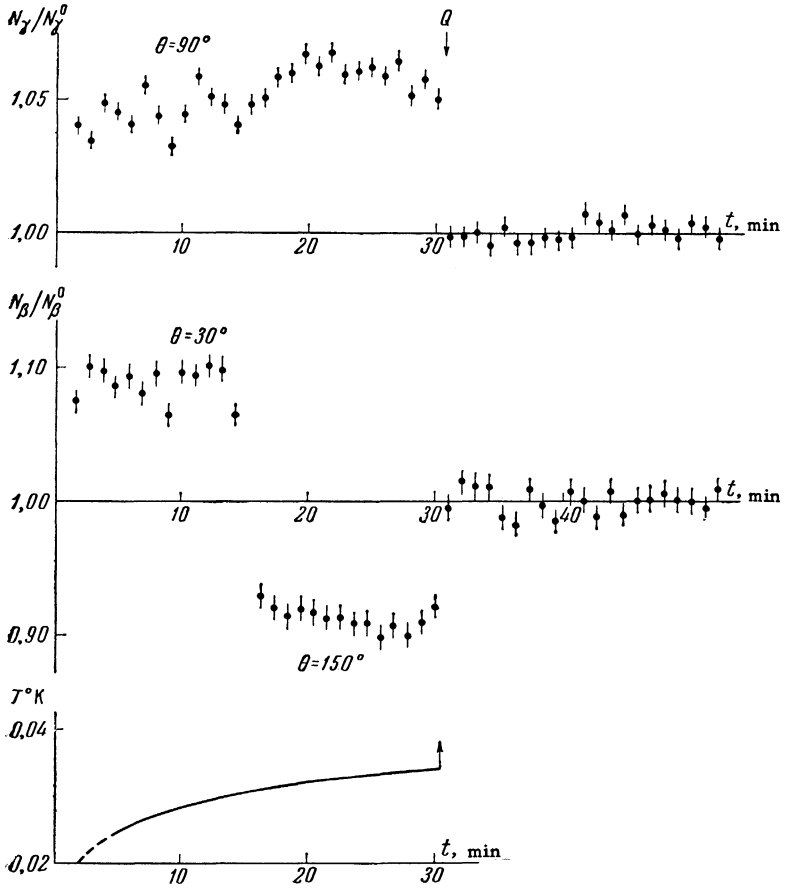

FIG. 2. Intensities of gamma and beta radiation of of the sample as a function of time. Below is shown the dependence of the salt temperature on time; the arrow marks the moment at which artificial warming of the salt begins.

an angle θ to the direction of the magnetizing field, and N_γ^0 and N_β^0 are the radiation intensities of the warmed-up sample. ϵ_γ and ϵ_β can be expressed in terms of the decay characteristics of the nucleus and the degree of orientation. For not very low temperatures in the case of Co^{60} decay, we can restrict ourselves to the first terms in the expansions of ϵ_γ and ϵ_β in powers of $\mu H/IkT$, writing the approximate equalities

$$\varepsilon_\gamma \cong \tfrac{13}{14}\left(\frac{\mu H}{IkT}\right)^2, \qquad \varepsilon_\beta \cong -\tfrac{2}{3}(I+1)\frac{v}{c}\left(\frac{\mu H}{IkT}\right),$$

where μ is the magnetic moment, I is the spin of the Co^{60} nucleus, H is the effective field at the nucleus, and v is the electron velocity.

Measurement of beta asymmetry obviously allows us to determine not only the magnitude but also the sign of the product μH, and if the sign of one of the factors is known the sign of the other can be determined. The sign of the magnetic moment of Co^{60} is known, allowing us to determine the sign of the effective field at the nucleus. Taking into account corrections for the imperfect coincidence between the directions of polarization and counting of beta radiation, as well as for the gamma background in the beta count, and adopting an average v/c value for the recorded part of the spectrum of ~ 0.6, we obtained for the effective field strength at the nucleus the value $H = -2 \times 10^5$ oe; this agrees with the magnitude $|H| = 2.8 \times 10^5$ obtained from ϵ_γ and with the value $|H| = 2.5 \times 10^5$ reported by us earlier.[6]

The experimentally obtained negative sign of the effective magnetic field at the cobalt nuclei can be explained by assuming that the contact interaction between the nucleus and the polarized inner s electrons determines the principal contribution to the field.† However Goodings and Heine[7] and also Freeman and Watson[8] have shown that, for the case of the free atom or ion electron configuration, such a mechanism cannot explain the large size of the negative field found at the nuclei in metal. The latter authors presented the interesting results of calculations of the dependence of the effective field at the nucleus on the position of the maximum of the density distribution of 3d electrons in the atom. They also suggested that the magnitude of the effective magnetic field at the nuclei of ferromagnetic atoms would apparently be explained if allowance were made for the real distribution of 3d electrons in the metal.

The authors sincerely thank E. K. Zavoĭskii and L. V. Groshev for their constant attention to the work, V. N. Agureev, N. V. Razzhivin and I. B.

Filippov for their help in preparing the apparatus and carrying out the experiments, and also N. E. Yukovich, V. A. Drozdov and V. D. Sheffer for furnishing the liquid helium.

*The axis of polarization of the nuclei, in our opinion, lay in the plane of the sample because of the considerable difference between longitudinal and transverse demagnetizing factors of the thin plate.

†This mechanism was also considered in Marshall's work,[9] but his calculations did not lead to the correct sign for the resulting field.

[1] Samoĭlov, Sklyarevsky, and Stepanov, Proc. of the VIIth Int. Conf. on Low Temp. Phys., Univ. of Toronto, Canada, 1960, Univ. of Toronto Press, 1961, pp. 171-173.

[2] Hanna, Heberle, Perlow, Preston, and Vincent, Phys. Rev. Lett. **4**, 513 (1960).

[3] Dash, Taylor, Craig, Nagle, Cochron, and Keller, Phys. Rev. Lett. **5**, 152 (1960).

[4] N. E. Alekseevskii and I. F. Shchegolev, Получение ориентированных ядер и их исследование, (The Obtaining of Oriented Nuclei and Their Investigation), Report, Inst. Phys. Prob., U.S.S.R. Acad. Sci., 1954. G. R. Khutsishvili, JETP **29**, 984 (1955), Soviet Phys. JETP **2**, 744 (1956). Grace, Johnson, Kurti, Scurlock, and Taylor, Comm. Conf. de Physique des basses Températures, 263, Paris, 1955.

[5] Samoĭlov, Sklyarevskii, and Stepanov, JETP **38**, 359 (1960), Soviet Phys. JETP **11**, 261 (1960).

[6] Samoĭlov, Sklyarevskii, and Stepanov, JETP **36**, 1366 (1959), Soviet Phys. JETP **9**, 972 (1959).

[7] D. A. Goodings and V. Heine, Phys. Rev. Lett. **5**, 370 (1960).

[8] A. J. Freeman and R. E. Watson, Phys. Rev. Lett. **5**, 498 (1960).

[9] W. Marshall, Phys. Rev. **110**, 1280 (1958).

Translated by Mrs. J. D. Ullman
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TEMPERATURE DEPENDENCE OF HYPERFINE SPLITTING OF Dy^{161} *LEVELS IN PARAMAGNETIC DYSPROSIUM OXIDE*

V. V. SKLYAREVSKII, B. N. SAMOĬLOV, and E. P. STEPANOV

Submitted to JETP editor April 3, 1961

J. Exptl. Theoret. Phys. (U.S.S.R.) **40**, 1874-1876 (June, 1961)

We have investigated spectra of the resonant absorption of Dy^{161} gamma rays of energies 26 and 75 kev. The source used was $Gd_2^{160}O_3$ (97% Gd^{160}) in which Gd^{161} is formed by irradiation in a reactor and then goes over ($\tau_{1/2}$ = 3.7 min) to Tb^{161} ($\tau_{1/2}$ = 7.15 days). The Dy^{161} gamma rays are emitted upon beta decay of the Tb^{161}. The compound $Dy_2^{161}O_3$ (90% Dy^{161}) was used as the absorber.

The dependence of the intensity of the gamma rays passing through the absorber on the rate of motion of the absorber toward the stationary source was measured. The absorber was set in motion by a mechanical system that converts (by means of a suitably shaped cam) rotary motion into reciprocating motion with constant speed. Different rates were obtained by changing the rate of rotation of the cam. The gamma rays were registered by a scintillation spectrometer using a crystal of NaI(Tl).

For the 26-kev gamma rays it turned out that the magnitude of the resonance absorption depended weakly on the temperature. This allowed the measurement of spectra at a series of temperatures: 80, 300, 400, 510, 640, and 840°K. In all cases the $Dy_2^{161}O_3$ absorber had a thickness of 15 mg/cm^2. Thicker absorbers gave a larger effect, but poorer resolution.

Figure 1 shows three of the spectral measurements. It can be seen that in all cases five almost equidistant peaks appear (besides the fundamental one at v = 0). Such a spectrum indicates that one of the levels of Dy^{161} between which the 26-kev gamma transition occurs ($5/2^- \rightarrow 5/2^+$) is split into six magnetic sublevels, such that the magnitude of the splitting is approximately the same for emitting and absorbing nuclei, but the splitting of the other level is significantly less and apparently is responsible for the width of the peaks. These splittings are caused by the interaction of the nuclear magnetic moment of Dy^{161} with the magnetic field produced at the nucleus by the electron shell.

The observed equal separation of the hfs (hyperfine splitting) levels is apparently associated