POLARIZATION OF SOME RADIOACTIVE ISOTOPES IN ALLOYS

A. V. KOGAN, V. D. KUL'KOV, L. P. NIKITIN, N. M. REĬNOV, I. A. SOKOLOV, and M. F. STEL'MAKH

Leningrad Physico-Technical Institute, Academy of Sciences, U.S.S.R.

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Polarization of the nuclei of the radiactive isotopes Au^{199}, Ir^{192}, Ir^{191m}, Re^{186}, and V^{48} alloyed with iron was studied at ultra-low temperatures. The magnetic field acting on the nuclei of the isotope mixture was $H_{eff} \geq 2 \times 10^6$ oe for Au^{199}, $H_{eff} \geq 2 \times 10^5$ oe for Re^{186}, and $H_{eff} \sim 10^6$ oe for Ir^{192}. No polarization was found in the Ir^{191m} isomer produced as a result of β decay of Os^{191m} introduced in the iron or in V^{48} in an alloy containing iron and 2% titanium. The comparatively small value of H_{eff} for Re^{186} may be due to the large disorientation of the nuclei during the β transition. The increase in the value of H_{eff} with the atomic number of the weakly magnetic mixture is in qualitative agreement with the theory proposed by Marshall.

THE method proposed by Samoĭlov, Sklyarevskiĭ, and Stepanov[1] for orienting nuclei of weakly magnetic elements alloyed with ferromagnetics opens new possibilities for carrying out investigations with oriented nuclei.

The nature of the large magnetic fields acting on the nuclei of weakly magnetic elements is still not entirely clear.

The only theoretical work deveoted to the question of the production of internal fields in metallic ferromagnetics, that of Marshall,[2] is only qualitative in character. As shown by that author, in general, both the conduction electrons and the atomic shell play a role in the production of this field; its value also depends on the type of lattice of the alloy. Recently, Khutsishvili[3] showed that at sufficiently low temperatures one may expect an essential orientation of nuclei and ions in the lattice of a dielectric antiferromagnetic.

Thus far, there are not very many experimental data on the orientation of nuclei in ferromagnetics[4-7] and, apart from the work of Samoĭlov, Sklyarevskiĭ, and Stepanov,[1,8,9] they deal with the question of the size of the internal field in ions of cobalt in cobalt single crystals and its various alloys.

In the present article, we present the results obtained from the orientation of Au^{199}, Ir^{192}, Ir^{191m}, Re^{186}, and V^{48} alloyed with iron. The first results for Sc^{46} and Co^{60} and the experimental method are described in a previous report.[10]

The study of the anisotropy of γ radiation of oriented nuclei allows one to obtain data on the value of μH_{eff}, where μ is the magnetic moment of the nucleus and H_{eff} is the effective magnetic field producing the orientation of the nucleus in the alloy.

However, for all the isotopes investigated in the present work, apart from V^{48}, the effect of the β transition on the anisotropy following γ radiation cannot be calculated in a single-valued way.

The temperature dependence of the anisotropy of the γ radiation was calculated without taking into account the preceding β transition.

The quantity $\beta = \mu H_{eff}/IkT$, where μ and I are the magnetic moment and spin of the nucleus, k is Boltzmann's constant, and T is the absolute temperature, serves as the temperature parameter. From the experimental dependence $\sqrt{\epsilon} = f(1/T)$ at a given source temperature, we determined the quantity $\epsilon = [J(\pi/2) - J(0)]/(\pi/2)$, and then, from the calculated curve, the value of β. In order to find H_{eff}, we inserted in the expression for β the value of the gyromagnetic ratio for the initial β active nucleus. Such a calculation does not take into account the fact that the nuclei are partially disoriented after the β decay, and the degree of orientation of the initial nuclei can be greater than the calculated value. Of course, the estimate of the value of H_{eff} obtained in this way is only the lower limit of the quantity we are seeking.

Au^{199}

Au^{199} is the daughter nucleus of the Pt^{199} obtained by neutron irradiation of Pt^{198}. Alloy samples with a 0.7% platinum content (by weight) were irradiated by neutrons and annealed in vacuo for

two days after irradiation, in which time the Pt^{199} isotope is almost entirely transformed into Au^{199}. The polarization of the Au^{199} nuclei was measured from the anisotropy of the 158-kev γ radiation. The part of the decay scheme of interest to us is shown in Fig. 1. A plot of $\sqrt{\epsilon}$ vs the reciprocal of the temperature of the cooling salt is shown on the same figure.

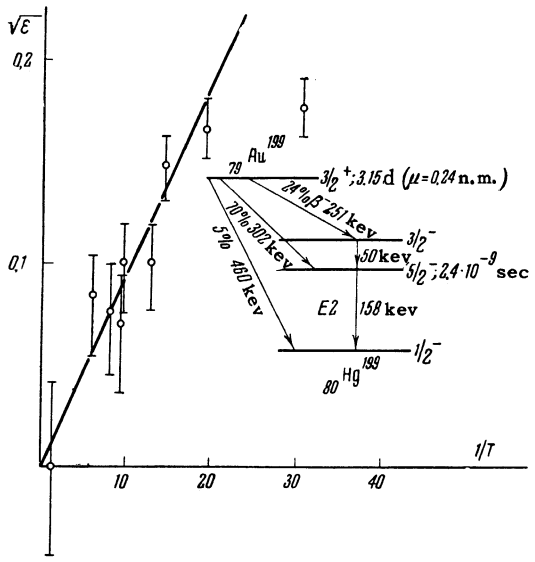

FIG. 1

Since the magnetic moment of the Au^{199} nucleus is known [$\mu = 0.24$ nuclear magnetons (n.m.)], the analysis of the experimental data leads to a value $H_{eff} \geq 2 \times 10^6$ oe. The value $H_{eff} \geq 10^6$ oe obtained for the Au^{198} isotope by Samoĭlov et al.[1] is in agreement with our value of H_{eff}. The presence of a level of Hg^{199} with a lifetime of $\sim 10^{-9}$ sec in the decay scheme of Au^{199} does not lead to any essential disorientation of the nuclei.

Ir^{192}

The iron-iridium alloy samples contained less than 0.2% iridium by weight. The anisotropy of the γ radiation was measured after the decay of the Ir^{194} isotope.

Figure 2 shows the basic decay scheme of Ir^{192} and a plot of $\sqrt{\epsilon}$ vs 1/T. The value of ϵ attained 40%. We note that the 537-kev β transition is unique and its effect on the anisotropy of the subsequent γ radiation can be evaluated. However, the cascade γ transitions with energies 308 and 296 kev are mixtures, and small errors in determining the mixture coefficients lead to considerable errors in the calculation of the γ-radiation anisotropy. Therefore in order to determine the internal field, we used the 468-kev γ transition

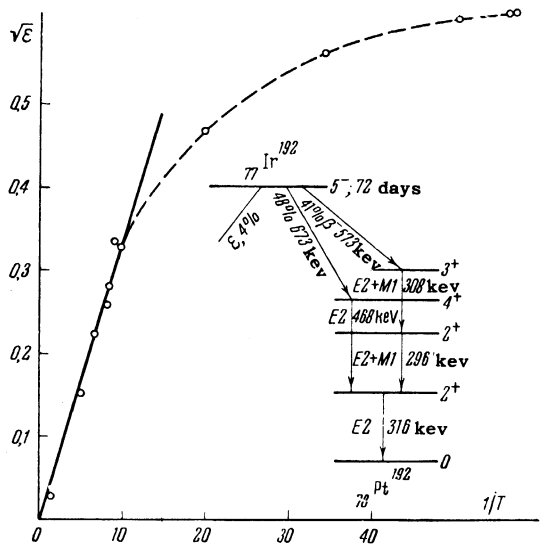

FIG. 2

following the 673-kev β transition. As in the case of the Au^{199} nucleus, we determined only the lower limit of the quantity μH_{eff}:

$$\mu H_{eff} \geqslant 1.5 \cdot 10^{-17} \text{ erg}.$$

The value of μ for Ir^{192} was not determined experimentally, and there were not sufficiently complete data for calculating the magnetic moment from the formulas of the nuclear shell theory. It is evident that $H_{eff} \sim 10^6$ oe for Ir^{192}, since there is no basis to expect values of μ greater than a few nuclear magnetons.

Ir^{191m}

The Ir^{191m} isomer with an excitation energy of 171 kev and half-life period of 6.9 sec is obtained from the β decay of Os^{191}.

The decay scheme $Os^{191} \rightarrow Ir^{191}$ is shown in Fig. 3. The sample of the alloy of iron with 0.5% osmium was prepared in the same way as the previous samples. After the decay of Os^{193}, we investigated the anisotropy of the 129-kev γ radiation. One can expect considerable anisotropy for this γ radiation, since the internal field in iridium is sufficiently large and the value of μ for Ir^{191m}

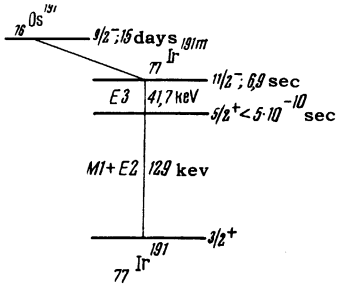

FIG. 3

estimated from Schmidt's curve is ~5 n.m. In the experiment, however, it turned out that $|\epsilon| < 0.3\%$. It can be assumed that the absence of an anisotropy in the given case is connected with a mixture of transitions of the M1 and E2 type. However, our experiments on the measurement of the plane polarization of the 129-kev radiation indicates the absence of the effect within the limits of 3%. It is clear that the Ir^{191m} nucleus in an alloy with iron is practically unoriented.

Re^{186}

Samples of the alloy with Re^{186} were prepared by the usual method. The Re content in the alloy did not exceed 0.2%. The decay scheme of Re^{186} and the plot of $\sqrt{\epsilon}$ vs T^{-1} is shown in Fig. 4. We obtained the value $\mu H_{eff} \geq 2 \times 10^{-18}$ erg. The magnetic moment of Re^{186} can be calculated from the formulas of the nuclear shell model: $\mu \sim 2$ mn.

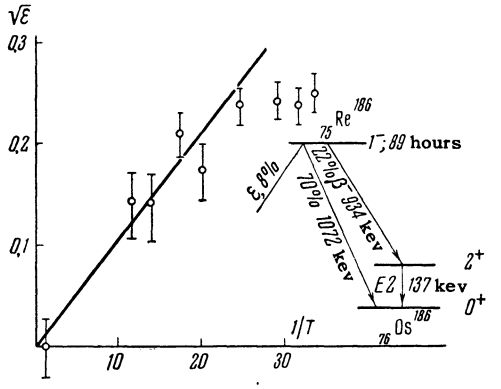

FIG. 4

Thus, $H_{eff} \geq 2 \times 10^5$ oe for Re^{186}.

V^{48}

The orientation of the V^{48} nucleus is of interest in investigating the question of the conservation of combined parity in β decay. The V^{48} was introduced into the iron together with metallic titanium, from which it was obtained by means of the (d, n) reaction. The titanium content in the alloy did not exceed 2% and the V^{48} content was minute. We investigated the anisotropy for 1320- and 990-kev γ transitions. The effect did not exceed 0.7%. If we estimate the magnetic moment of V^{48} from the formulas of the nuclear shell model, we obtain $H_{eff} \leq 50{,}000$ oe, while in the field of the V^{+++} ion $H_{eff} \sim 250{,}000$ oe. It is not excluded that the presence of titanium in the alloy has some effect on the effective magnetic field. We note, however, that the solubility of titanium and vanadium in iron is quite high. In the experiments with Au^{199}, the presence of an ~0.7% admixture of platinum did not lead to any essential effect on the orientation of the Au^{199} nucleus. It is more likely that the internal field in the metal is essentially different from the field in vanadium sulfate. It is possible that there is also a partial compensation of the effective field component associated with the atomic shell and conduction electrons. This possibility follows from the work of Marshall.[2]

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