[1)] E. V. Shulakov, I. N. Ivoĭlov, and A. I. Erko participated in the experiments.

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V. S. Shpinel'. *Nuclear-spectroscopic studies of hyperfine interactions for impurities in metals.* Investigations of hyperfine interactions (HFI) by different nuclear methods, employing radioactive nuclei and accelerators, have made it possible to obtain a number of fundamental results, which are important for both nuclear and condensed-matter physics. Some results of investigations of magnetic HFI for magnetic impurities in dilute alloys Pd (Fe, Co) at ultralow temperatures and for nonmagnetic (NM) impurities Sn in rare-earth metals (REM), performed at the Scientific-Research Institute of Nuclear Physics at Moscow State University by methods of Mössbauer spectroscopy and oriented nuclei and by the method of the Mössbauer effect on oriented nuclei, are described in the report. The examples studied demonstrate the types of problems in the magnetism of metals that can be solved by such methods.

1. Studies of HFI in alloys of 3d elements with Pd are of special interest because of the unique properties of Pd. In this work the emission Mössbauer spectra with a ^{57}CO source, introduced into Pd(Fe) alloys with different Fe dopant concentrations, were studied. The samples were cooled with the help of an ^{3}He–^{4}He dilution refrigerator.

The hyperfine (HF) field on Fe measured at $T = 4.2$ K as a function of the applied field H_0 for the alloy with an Fe concentration of 0.01 at. % follows the Brillouin curve, describing the magnetization of the free spin with the "giant moment" $\mu_g = 10\mu_B$, known from other experiments. As the temperature was lowered to 0.55 K the magnetization curve corresponding to a reduction of μ_g down to $8\mu_B$ changed smoothly.[1] This behavior was predicted in Ref. 2.

When there is no applied field, at these temperatures the γ-resonance spectra contain a single line corresponding to fast paramagnetic relaxation. As the temperature is lowered still further, in this sample, just as in the more concentrated alloy with 0.06 at. % Fe, slow electronic relaxation, which is unusual for metals and as a result of which a nonzero HF field appears on the Fe nucleus, was observed. For the first and second alloys the spectra, for $T < 25$ mK and $T < 52$ mK, respectively, have the form of standard sextets, corresponding to almost maximum splitting (see Fig. 1; $T = 0.052$ K).

Computer analysis of the relaxation spectra showed that there exists a wide set of relaxation frequencies, which is a consequence of the distribution of exchange interactions in disordered alloys. The temperature dependence of the mean relaxation frequency is linear, and in addition the corresponding straight line for the most dilute alloy passes near 0 K, while for the alloy with 0.06 at. % Fe this dependence at temperatures near 0.1 K becomes markedly weaker.

Spectra obtained in longitudinal fields ($H_0 < 600$ Oe) at ultralow temperatures contain components corresponding to forbidden transitions with $\Delta m = 0$ (see Fig. 1; $H_0 = 200$ Oe). This indicates the existence of transverse spin components, i.e., the spins are not completely oriented along the applied field. The observed disorientation is explained by the sign-alternating RKKY interaction between the spins, which can lead to the spin-glass state. Our data showed that the alloy with an Fe concentratoin of 0.01 at. % must transform into the "spin-glass" state at a temperature below 20 mK.[3] Indeed, for this alloy a susceptibility peak characteristic for a spin glass was recently observed at $T = 8$ mK.[4] For the second more concentrated alloy this transition is manifested in the above-noted sharp change of the relaxation regime at ~ 0.1 K.[5]

The results of γ-resonance experiments and studies performed by the method of oriented nuclei show that the Co impurity in our alloys is in a Kondo state with $T_K = 0.14 \pm 0.04$ K, in agreement with the results of Ref. 6. The observed asymmetry of the spectra at temperatures below 52 mK with $H_0 = 0$ (see Fig. 1) is explained by the appearance of a molecular field, leading to a reduction of the spin compensation on Co and, therefore, the appearance of H_{hf} on the Co nucleus. This also supports the appearance of an ordered state of the spin-glass type, whose relaxation frequency spectrum contains frequencies of the order of or less than the nuclear spin-lattice relaxation frequency for Co $\bar{\lambda}_{sl} \sim 10^2$ rad/s. We measured this relaxation frequency in

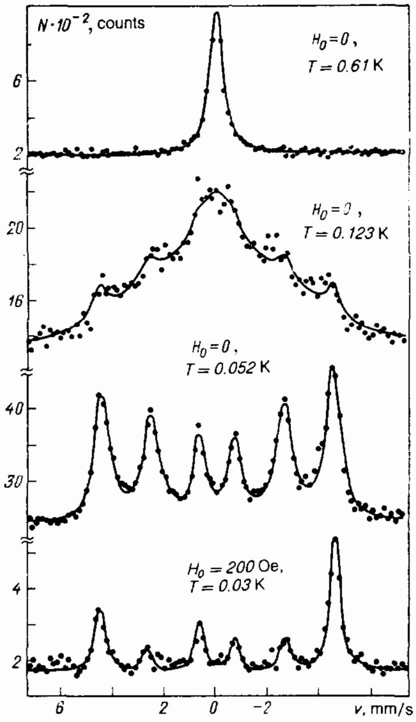

FIG. 1.

this alloy at ultralow temperatures jointly with a Czechoslovakian research group by the method of thermocycling of oriented nuclei on the "spin" setup at the Laboratory of Nuclear Studies at the Joint Institute for Nuclear Research (Dubna).[7] It should be emphasized that the characteristic time of the experiment in the method of the Mössbauer effect on oriented nuclei, which we employed, is determined both by the lifetime of the excited state of the nucleus ($\sim 10^{-7}$ s) and the nuclear spin-lattice relaxation time, which significantly extends the range of relaxation frequencies accessible to observation.

The distribution functions of the molecular fields at different temperatures, showing that the spontaneous magnetization of the alloy is described well by the percolation model,[8] were determined for a ferromagnetic alloy with an impurity concentration of 0.15 at. % Fe. Such distribution functions, determining the main magnetic properties, were also obtained for alloys in the paramagnetic phase in applied fields.

2. There now exist data on HF fields on nonmagnetic impurities in Fe, Co, and Ni ferromagnetic matrices for most elements in Mendeleev's table. The theoretical calculations of these fields are in good agreement with experiment (see, for example, Ref. 9). The studies of the HF saturation fields $H_{\rm hf}(0)$ on the nonmagnetic impurity Sn in a rare-earth metal showed that in different matrices $H_{\rm hf}(0)$ deviates from the expected linear dependence on the projection of the spin of the rare-earth ion on the total moment $(g-1)J$. Analogous deviations have been observed for other nonmagnetic impurities in other studies. This behavior was also observed in a series of intermetallic compounds of rare earths, which supports the idea that the exchange interaction Hamiltonian does not have a purely spin character $(J\mathbf{S},\mathbf{s})$, but rather contains other interactions also, which take into account orbital motion and the spin-dipole contribution (see, for example, the review of Ref. 10).

It was found that the HF field on Sn as a function of temperature $H_{\rm hf}(T)$ follows the spontaneous magnetization curve only in the case of a Gd matrix. In other heavy rare-earth metals, as in the case of 3d matrices, large deviations are observed in the behavior of these curves. Based on these "temperature" anomalies in the HF fields we concluded that the spontaneous polarization of the conduction electrons $P=(N_\uparrow - N_\downarrow)/N_\uparrow + N_\downarrow$) inducing an HF field on the impurity, generally speaking, is not proportional to the magnetization $\langle Jz\rangle/J$.[11] The absence of such a proportionality should be manifested in cases when near the Fermi level the curves of the distribution of the electronic density of states in subbands with spin $\uparrow$ and $\downarrow$ rapidly change in an energy interval of the order of the magnitude of the exchange splitting. Existing results of calculations of band structures for pure matrices and for the contributions of electrons with spin $\uparrow$ and $\downarrow$ to the HF field on the impurity agree qualitatively with this assumption.

The magnetic ordering of REM is characterized by a large diversity of magnetic structures, and HFI for the nonmagnetic impurity Sn can be employed to obtain additional information about them. The phenomenon of hysteresis of the HF field, caused by the change produced by the applied field in the magnetic structure which after the field is removed does not return to the starting state because of the existence of a potential barrier, was discovered by this method.

Data confirming the proposition that the nonmagnetic impurity distorts the magnetic structure of the nearest-neighbor environment were obtained.[12] Model numerical calculations performed in Ref. 13 showed that the impurities, regarded as magnetic defects, can create local magnetic structures, the interactions between which can give rise to a new type of magnetic state, which in Ref. 13 was given the name psuedo-spin glass. The existence of such a state has not yet been demonstrated, but the complex Mössbauer spectra observed, for example, for Sn in Dy can be understood by assuming that we are dealing with a system in a pseudo-spin glass state.

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G. B. Khristiansen. *Apparatus for studying extremely high energy cosmic rays.* The energy spectrum of galactic (and possibly metagalactic) cosmic rays encompasses a colossal energy range from several tens of MeV up to at least 10^{20} eV. Cosmic rays have in recent years been studied especially intensively by so-called "direct" methods, i.e., by recording and studying the primary cosmic radiation itself (which is possible in practice up to energies of 10^{14}–10^{15} eV). These studies led to the following picture of the generation and propagation of galactic cosmic rays with energies