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OBSERVATION OF THE EFFECT OF STABILIZATION OF THE HYPERFINE STRUCTURE OF TRIVALENT Fe^{57} IN CORUNDUM BY A WEAK EXTERNAL MAGNETIC FIELD

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The Mossbauer effect is used more and more frequently for investigations of the hyperfine structure (hfs) of nuclear levels in paramagnetic substances with sufficiently large electron-spin relaxation times. The possibility of successfully using the Mossbauer effect for this purpose was first established by A. M. Afanas'ev and Yu. M. Kagan [1]. An investigation of the hfs in paramagnets makes it possible in principle to study the behavior of spin-lattice relaxation as a function of the temperature, to draw conclusions concerning the character of the spin-spin relaxation, and also to obtain useful information on the crystal surroundings and valence state of a paramagnetic ion. The complexity of the hfs in paramagnets frequently makes it very difficult to extract the necessary information from the experimentally measured spectra.

There exists, however, a class of interesting phenomena, predicted by A. M. Afanas'ev and Yu. M. Kagan [2], which greatly facilitate the solution of the problems raised above, and in addition, are of great independent interest for research. We have in mind primarily the effect of stabilization of the hfs in paramagnets by means of an external magnetic field.

As shown in [2], the hfs is sensitive not only to the relaxation time of the electron spin of the paramagnetic ion, but also in many cases to very weak external magnetic fields acting on this ion. The reason for such a sensitivity is that in a weak field the states between which nuclear transitions take place in the paramagnetic ion are not purely nuclear, but mixed nuclear-electronic states, and therefore the transition changes not only the state of the nucleus, but also the state of the electron shell. If the ion is in a magnetic field H, this causes the levels between which the transition takes place to shift in turn by an amount $\sim\mu_B H$, where μ_B is the Bohr magneton. (We note that for Fe^{57} nuclei this shift is on the order of 1.34 natural widths at H = 1 Oe.) Therefore, small magnetic fields (for Fe^{57} - on the order of several Oe) suffice to change noticeably the hfs, and in the case of randomly distributed fields they can smear out the hfs completely.

On the other hand, if the external magnetic field is not too weak, so that the magnitude of its interaction with the spin of the shell is much larger than the constant of the hyperfine interaction (we note that in this case we are dealing with fields only on the order of several hundred Oe), then the Mossbauer transitions again become purely nuclear. This is caused by the fact that now the states of the ion, between which the transition takes place, are products of purely nuclear states by purely electronic states, and the corresponding selection rules for the nuclear transitions do not in themselves provide for a change in the electronic state. Therefore those hfs spectra, which would become smeared out by weak internal fields due to paramagnetic impurities (or by scattered external magnetic fields) in the absence of an external magnetic field, should acquire a distinct structure when an external relatively weak magnetic field is superimposed, although this structure may generally speaking differ from the structure which is expected for the case when H is strictly equal to zero.

We have undertaken to observe this effect. The investigated sample, serving as the absorber, was chosen to be corundum, α-Al_2O_3, containing as an impurity 0.2 wt.% Fe enriched to 60% with the isotope Fe^{57}. The radioactive source was Co^{57} in Pd. We used a polycrystalline sample, since it was shown in [2] that the stabilization effect takes place in polycrystals, too.

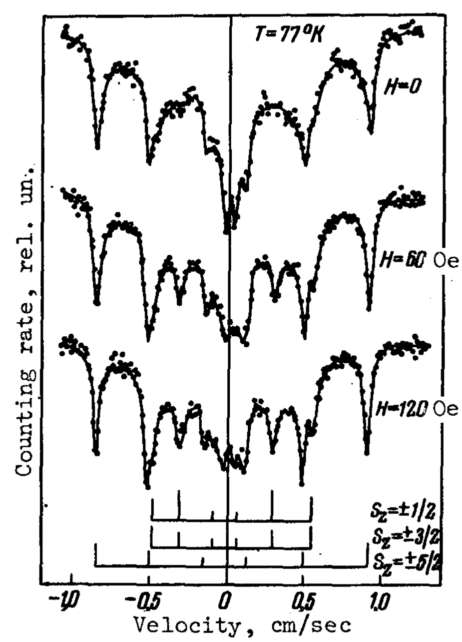
As is well known, the impurity ion Fe^{3+} in corundum is in a high-spin state (S = 5/2). The crystal field at the location of the ion has a symmetry close to axial. The ground-state term of the Fe^{3+} ions splits into three Kramers doublets, the eigenfunctions of each of which are equally-probable mixtures of states with spin projections respectively S_z = ±1/2, ±3/2, and ±5/2. We can therefore speak of the doublets (±1/2), (±3/2), and (±5/2). The hyperfine interaction

$$\mathcal{H} = AIS + P[I_z^2 - \frac{1}{3}I(I+1)]$$

turns out to be sharply anisotropic for the doublets (±3/2) and (±5/2). Therefore, in accordance with the results of [2], the hfs corresponding to these doublets is not very sensitive to the magnetic fields acting on the ion.

The structures due to the states of the ion Fe^{3+} with S_z = ±3/2 and ±5/2 were observed in an analogous sample already by Wertheim and Remeika [3], but their spectra did not have at all the expected hfs corresponding to the doublet (±1/2). The reason for this now becomes perfectly obvious - the hyperfine interaction for the ions in the state with S_z = ±1/2 is not sharply anisotropic and the corresponding hfs becomes smeared out by the weak magnetic fields.

We therefore expected to obtain lines from the doublet (±1/2) by applying a stabilizing external magnetic field. The figure shows three spectra taken at 77°K in fields H = 4, 60, and 120 Oe. In the lower part of the figure are shown the positions of the lines corresponding to the doublets (±5/2) and (±3/2) and to the doublet (±1/2) under stabilization conditions.



Stabilization of the hfs of the Mossbauer line of Fe^{57} in corundum by an external magnetic field ($\vec{H} \parallel \vec{k}_\gamma$)

As seen from the figure, two distinct lines appear when a field is superimposed, their positions corresponding exactly to the positions of the most intense lines of the stabilized structure from the doublet (±1/2), predicted by A. M. Afanas'ev and Yu. M. Kagan. An important fact in this case is also that the entire spectrum as a whole becomes sharper and more distinct. This greatly facilitates its interpretation.

The results show that the distances between the external lines of the spectra correspond to a hyperfine field 548 ± 3 kOe at the nucleus, and that the quadrupole interaction is $e^2qQ = 4P \approx 0.09$ cm/sec. These values agree well with the data of [3].

In connection with the great advantages afforded by this method of investigating the hfs in paramagnets when a stabilizing field is applied, we are now carrying out such investigations in a wide interval of temperatures, for the purpose of revealing the character of the spin-lattice relaxation, and also in a wide interval of Fe^{3+} impurity ion concentrations, for the study of the spin-spin relaxation.

Great interest attaches also to an investigation of single-crystal samples, which would make it possible to obtain detailed information on the structure of the crystalline environment (in particular, to sense very small deviations from axial symmetry), and also to verify the effect of the dependence of the positions of the lines of the stabilized spectrum on the direction of the external magnetic field relative to the crystal-symmetry axis.

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HEATING OF PLASMA IONS BY AN EXTERNAL STOCHASTIC FIELD

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High-frequency heating is regarded as one of the effective methods of heating ions in a plasma. This method was used to heat ions to energies 1 - 2 keV at particle densities $10^{13} - 10^{14}$ cm^{-3} in a volume of several liters [1]. Inasmuch as in high-frequency heating the ion energy is contained initially in the form of regular motion of the ions in the field of the wave, so that there are no particle collisions, a process leading to randomization of this motion is essential in order to ensure the fusion reaction.

When particles are accelerated in a stochastic field, there is no need for a special thermalization process, since the thermalization is ensured by the field itself. The possibility of heating particles by a stochastic field was first indicated in [2]. Heating of the electronic plasma component by a stochastic field was considered in [3]. To ensure stochastic heating of the plasma ions, it is necessary to ensure penetration of the field into the dense