[1] Yu. Kagan, A. M. Afanas'ev, and V. K. Voitovetskii, ZhETF Pis. Red. 8, 342 (1968)[sic!]
[2] C. Sauer, E. Matthias, and R. L. Mossbauer, Phys. Rev. Lett. 21, 961 (1968)

NATURE OF THE AMPLIFICATION OF THE NMR SIGNAL OF Fe^{57} IN HEMATITE CRYSTALS

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A distinguishing freature of NMR in ferromagnets is that the resonance frequencies are determined by the values of the effective (hyperfine) field at the nucleus, and the absorption intensity depends in a complicated manner on the magnetization processes occurring at the radio frequencies. Such processes may be the rotation of the magnetization inside the domains and the displacement of the domain boundaries. These processes cause the nucles to be acted upon by a much larger alternating component of the effective field (compared with the external radio-frequency field). The resultant amplification amounts in the case of hematite (α-Fe_2O_3) to 25000, according to [1], and is due to a displacement of the domain boundaries. Sedlak [2] has also concluded that the NMR in hematite is due to the domain boundary motion. A convincing argument in favor of the domain boundary displacement mechanism is the domain-boundary resonance (DBR) observed by Sedlak and Szydlowski [3] in hematite in a wide range of frequencies, including the NMR frequency of Fe^{57} (71.1 MHz at room temperature). According to [3], the NMR signal vanished in constant fields $H \sim 200$ Oe, whereas the DBR remained up to fields $H \sim 1$ kOe. It was assumed on this basis that both phenomena are due to motion of different types of boundaries (in particular, NMR is due to motion of boundaries parallel to the [111] axis).

There exist, however, also other points of view concerning the origin of the NMR signal of Fe^{57} in hematite. Anderson [4] reached the conclusion that the predominant mechanism causing the intensity of NMR absorption in a natural hematite crystal investigated by him was the rotation of the magnetization. Owing to the very low energy of the magnetic anisotropy of hematite in the basal plane, the amplification factor connected with the rotation process may reach, according to his calculations, also values on the order of 10^4.

An interesting feature of hematite is that anisotropy of the NMR signal of Fe^{57} has been observed in it [2, 4]. In the first of the references this phenomenon is explained by means of the domain-wall mechanism, and in the second from the point of view of the rotation of the magnetization.

In this communication we present certain results favoring, in our opinion, a domain-wall origin for the NMR signal in hematite, as well as additional data on the character of the anisotropy of the NMR signal of Fe^{57}.

We used a frequency-modulated NQR radio spectrometer designed at the Institute of Radio Engineering and Electronics of the USSR Academy of Sciences. To be able to operate at low radio-frequency (RF) oscillation levels and to increase the high-frequency generation limit, we modified somewhat its high-frequency block. Depending on the required sensitivity, either the regenerative or the superregenerative mode was used. The main results were obtained with a sample made up of several platelike α-Fe_2O_3 crystals enriched with Fe^{57} and glued to one

another along the basal plane (111) (the method of growing was reported in [5]).

The results reduce to the following:

1. The NMR singal of Fe^{57} was observed only in the presence of an RF field component parallel to the (111) plane. Curve 1 of Fig. 1 (the first derivative of the absorption in the regenerative mode) was obtained with the sample so placed in the tank circuit that the RF field h was parallel to (111). At $h \perp (111)$, the signal was so weak (at the same sensitivity) that it was lost in the noise (curve 2); it could be registered only in the more sensitive superregenerative mode (curve 4). By performing experiments with crystals of varying thicknesses we verified that if $h \perp (111)$ the observed signal is due only the component $h \parallel (111)$ inside the sample; it was impossible to avoid the presence of such a component in a coil consisting of only three turns. Also favoring this conclusion is the fact that the amplitudes of the NMR signals have the same dependence on the direction and magnitude of the constant field H for both orientations of h.

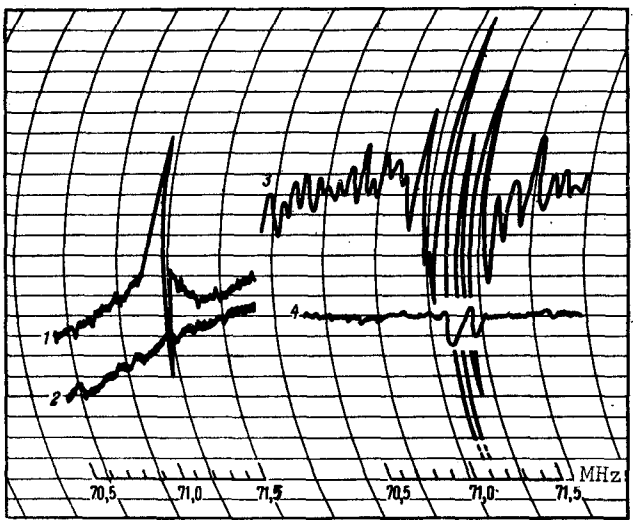

Fig. 1. First derivative of the absorption of NMR of Fe^{57} with the spectrometer operating in the regenerative mode (curves 1, 2) and the superregenerative mode (curves 3, 4): curves 1, 3 - $h \parallel (111)$; curves 2, 4 - $h \perp (111)$. Curve 3 shows the DBR spectrum.

2. Our measurements have confirmed that hematite has a complicated spectrum with all the attributes characterizing the DBR [3, 6]. The spectrum could be observed in a wide range of frequencies from 20 to 80 MHz. At frequencies including the NMR frequency of Fe^{57}, the DBR was observed only when the radio spectrometer operated in the superregenerative mode (quenching frequency 35 kHz). Curve 3 of Fig. 1 shows by way of an example an intense Fe^{57} NMR signal against the background of the DBR spectrum. The NMR signals on curves 3 and 4 constitute a superposition of the central and side lines of the supergenerator spectrum. Just as in the case of the NMR signal, the maximum amplitude of the DBR spectrum corresponded to the case when $h \parallel (111)$ (curve 3) and was missing completely when $h \perp (111)$ (curve 4).

3. The influence of the external field H on the amplitude of the NMR signal and on the DBR spectrum, in contradiction to the data of [3], is similar (see Fig. 2). Application of a field $H \perp (111)$ does not lead to the vanishing of the NMR and DBR signals; a certain decrease of the amplitudes (curve 1) can be attributed to the influence of the component $H \parallel (111)$, resulting from the inhomogeneity of the field H and from an inaccurate orientation of the crystals. Application of a field H parallel to (111) greatly lowers the amplitudes of the NMR signal and of the DBR spectrum (curve 2). In fields stronger than 500 Oe, the NMR signal vanishes and only a weak residual DBR spectrum remains, apparently connected with the motion of the boundaries pinned to the defects of the crystal.

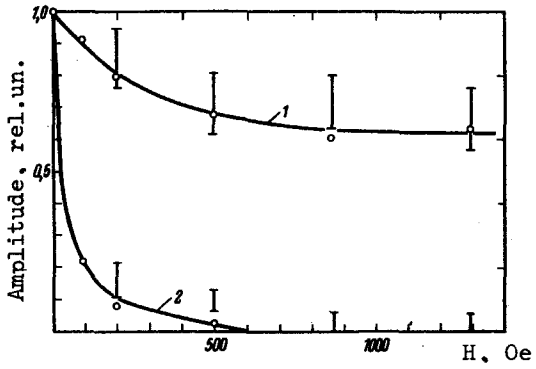

Fig. 2. Influence of external constant field H on the amplitudes of the NMR signal of Fe^{57} (curves drawn through the circles) and on the DBR spectrum (segments): 1 - $H \perp (111)$, 2 - $H \parallel (111)$. In all cases $h \parallel (111)$. The NMR and DBR amplitudes at H = 0 are taken as unity.

The fact that the amplitudes of the NMR signal and the DBR spectrum have the same dependence on the direction and magnitude of H indicates, first, that the NMR signal is due to the motion of the domain boundaries and, second, that both effects are due to the same type of boundary. It also follows from the results reported in Secs. 1, 2, and 3 that the motion of the domain boundaries in hematite occurs only when h and H have a component parallel to the (111) plane. This is connected with the fact that the ferromagnetic moment of the domains in hematite is "rigidly" coupled to the basal plane. Inasmuch as the domain structure of hematite has not been firmly established as yet, it is still difficult to indicate the type of boundary with which the NMR signal is connected. It is apparently due to the easily-moving boundaries parallel to (111), which were observed most clearly in a recent investigation reported by Eaton and co-workers [7].

[1] M. Matsuura, H. Yasuoka, A. Hirai, and T. Hashi, J. Phys. Soc. Japan 17, 1147 (1962).
[2] B. Sedlak, Czech. J. Phys. 18B, 1374 (1968)
[3] B. Sedlak and H. Szydlowski, ibid. 17B, 889 (1967).
[4] D. H. Anderson, Phys. Rev. 151, 247 (1966).
[5] R. A. Voskanyan and I. S. Zheludev, Kristallografiya 12, 539 (1967) [Sov. Phys.-Crystall. 12, 473 (1967)].
[6] E. L. Boyd, J. I. Budnick, L. J. Bruner, and R. J. Blume, J. Appl. Phys. 33, 2484 (1962).
[7] J. A. Eaton, A. H. Morrish, and C. W. Searl, Phys. Lett. 26A, 520 (1968).

INFLUENCE OF MAGNETIC SURFACE LEVELS ON THE IMPEDANCE OF POTASSIUM AT RADIO FREQUENCIES

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In measurements of the surface impedance $Z = R + iX$ of potassium in the radio-frequency range $\omega/2\pi \approx 10^6 - 10^7$ Hz we observed a nonmonotonic dependence of X on H in weak magnetic fields H from 0 to 50 kOe. The samples were placed inside the coil of the tank circuit of a radio-frequency oscillator; the change of the sample impedance changed the oscillation frequency ($d\omega \sim -dX$), and the change was registered by a modulation method. The figure shows one sample of the obtained curves. The curves are outwardly very similar to those obtained in analogous experiments on bismuth [1] but, unlike in bismuth or gallium [2], the shape of the potassium curves does not depend on the amplitude of the high-frequency field, so that the