solute values, was established with accuracy 50%, since use is made here of measurements of the power of the generators, of the coefficients of coupling of a resonator with waveguides, and of the absolute values of τ_{M1} and τ_{M2}, which can not be done with high accuracy.

The dotted line in Fig. 4 shows the theoretical function

$$T_{12}(H)=T_{21}(H)\propto H_\Delta^2/T_n+4H^2$$

according to formula (4). Qualitative agreement of the theoretical and experimental functions is observed.

We are grateful to P. L. Kapitza for his interest in the research; to A. S. Borovik-Romanov for frequent useful discussions; to V. S. Lutovinov, Yu. K. Dzhikaev, and V. S. L'vov for valuable discussions; to Yu. M. Bun'kov for critical comments; and to K. I. Rassokhin for technical assistance.

[1]F. Bloch, Z. Phys. 61, 206 (1930).
[2]A. I. Akhiezer, V. G. Bar'yakhtar, and M. I. Kaganov, Usp. Fiz. Nauk 72, 3 (1960) [Sov. Phys. Usp. 3, 661 (1961)].
[3]F. J. Dyson, Phys. Rev. 102, 1217 and 1230 (1956).
[4]V. E. Zakharov, V. S. L'vov, and S. S. Starobinets, Usp. Fiz. Nauk 114, 609 (1974) [Sov. Phys. Usp. 17, 896 (1975)].
[5]B. Ya. Kotyuzhanskiĭ and L. A. Prozorova, Zh. Eksp. Teor. Fiz. 65, 2470 (1973) [Sov. Phys. JETP 38, 1233 (1974)].
[6]A. G. Gurevich and A. N. Anisimov, Zh. Eksp. Teor. Fiz. 68, 677 (1975) [Sov. Phys. JETP 41, 336 (1975)].
[7]G. A. Melkov, Fiz. Tverd. Tela 17, 1728 (1975) [Sov. Phys. Solid State 17, 1123 (1975)].
[8]A. I. Smirnov, Zh. Eksp. Teor. Fiz. 73, 2254 (1977) [Sov. Phys. JETP 46, 1180 (1977)].
[9]V. S. L'vov and M. I. Shirokov, Zh. Eksp. Teor. Fiz. 67, 1932 (1974) [Sov. Phys. JETP 40, 960 (1974)].
[10]M. S. Khaĭkin, Prib. Tekh. Eksp. #3, 95 (1961) [Instrum. Exp. Tech. #3, 509 (1961)].
[11]L. A. Prozorova and A. I. Smirnov, Zh. Eksp. Teor. Fiz. 67, 1952 (1974) [Sov. Phys. JETP 40, 970 (1974)].
[12]V. A. Tulin, Zh. Eksp. Teor. Fiz. 55, 831 (1968) [Sov. Phys. JETP 28, 431 (1969)].
[13]V. A. Kolganov, V. S. L'vov, and M. I. Shirokov, Pis'ma Zh. Eksp. Teor. Fiz. 19, 680 (1974) [JETP Lett. 19, 351 (1974)].
[14]V. V. Kveder and L. A. Prozorova, Pis'ma Zh. Eksp. Teor. Fiz. 19, 683 (1974) [JETP Lett. 19, 353 (1974)].

Translated by W. F. Brown, Jr.

NMR in hematite crystals with tin impurity

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(Submitted 22 October 1977)
Zh. Eksp. Teor. Fiz. 74, 1562–1565 (April 1978)

NMR of Fe^{57} nuclei in the domain walls of hematite crystals with 0.8 wt.% tin impurity is investigated by the autodyne method. On the whole, the crystals remain weakly ferromagnetic down to 4.2 K, but an analysis of the temperature dependence of the NMR line shape and of the specific weakly ferromagnetic moment indicates that the most perfect sections of well-annealed crystals become antiferromagnetic at $T<200$ K. Quenching, which increases the defect content, makes practically the entire volume of the crystals ferromagnetic when they are cooled. The results point to an exceedingly strong sensitivity of the Morin temperature to the distributions of the defects and of the internal stresses.

PACS numbers: 76.60.–k, 71.55.Ht

It follows from earlier studies[1-4] that NMR of Fe^{57} nuclei in hematite is observed only in the weakly ferromangetic phase, where conditions exist for high values of the gain, and the signal is due only exclusively to the nuclei in the domain walls.

Analyzing the line shape obtained by the autodyne method, Hirai *et al.*[4] have concluded that hematite crystals have walls of two types which lead to the appearance of NMR signals with opposite phases. The first type of wall is easily mobile, exists in well-annealed crystals, and is characterized by a small rigidity constant α in the equation of motion of the domain wall:

$$\mu\ddot{x}+\beta\dot{x}+\alpha x=2MH,$$

where μ is the effective mass of the wall, β is the damping constant, M is the weakly ferromagnetic moment, and H is the magnetic field.

For mobile walls walls, the domain-wall resonance frequency ω_W lies below the NMR frequency ω_N;

$$\omega_N>\omega_W=(\alpha/\mu)^{1/2}.$$

Mobile walls are easily annihilated in constant magnetic fields of the order of 10 Oe.

The second type of wall is characterized by high values of α and correspondingly by high domain-wall resonance frequency, so that the condition $\omega_W>\omega_N$ is satisfied for it. Such walls vanish in stronger magnetic fields.

The difference between the phases of the signals from pinned and free walls is due to the fact that at resonance the absorbed energy is proportional to

$$1+m\chi_n'$$

(χ_n' is the real part of the nuclear susceptibility), where the parameter m depends on the ratio of the frequencies

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ω_N and ω_W:

$$m \sim (\omega_N^2 - \omega_W^2)^{-1}.$$

We used the autodyne and spin-echo method to study NMR in synthetic hematite crystals with tin impurity. The cyrstals were grown by the method described in[5] and were plates with thickness of the order 0.1 – 0.2 mm. An x-ray analyzer has shown that the tin, 0.8 wt.%, was distributed with high uniformity.

Crystals with the indicated tin content remain weakly ferromagnetic down to liquid-helium temperature; this made it possible to trace the NMR singularities in the wide temperature interval 4.2 – 300 K.

The first derivative of the NMR signal at room temperature, for samples cooled slowly from 1300 °C (not faster than 5 deg/hr), is a superposition of two curves with different phase, with predominance of the broad band with (arbitrarily) positive phase, typical of mobile domain walls (Fig. 1, curve 1).

Quenching the crystals from 1300 °C, by increasing the density of the defects and the internal stresses, pins the walls and causes the component with the positive phase to vanish (Fig. 1, curve 2).

It is characteristic that the NMR line with the positive phase is much broader, since the resonance in the mobile walls is effected under conditions of larger saturation, in view of the higher effective gain. We point out in this connection that the signals shown in Fig. 1 were registered at minimum possible generator-power levels (almost at the generation stalling limit).

At 77 K, the narrow line typical of rigid walls (Fig. 1, curve 3), is always observed, for both cooled and quenched crystals. The component with the positive phase vanishes in the interval 150 – 200 K for slowly cooled crystals when the temperature is decreased.

The vanishing of the signal with the positive phase typical of mobile walls indicates that when the temperature is lowered the crystal apparently still becomes partly antiferromagnetic. This is also attested by the temperature dependence of the specific weakly ferromagnetic moment σ for the slowly cooled crystals (Fig. 2, light circles). If the canting angle between the sublattice moments is constant, the temperature dependence of σ should be similar to the temperature dependence of the sublattice magnetization (solid line of Fig. 2, plotted on the basis of the NMR temperature dependence shown in Fig. 3). It is seen from Fig. 2, however, that the specific moment begins to decrease noticeably at $T < 200$ K and amounts at 77 K to approximately 82% of its value at room temperature. This can occur if some part of the crystal volume becomes antiferromagnetic.

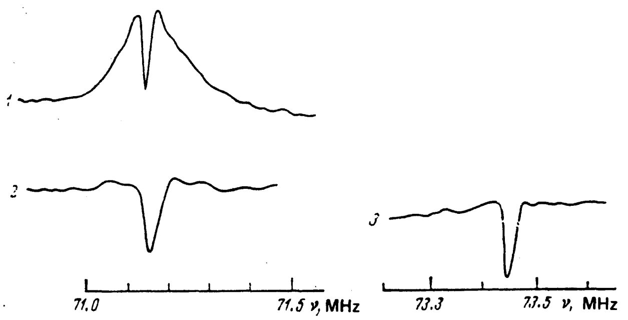

FIG. 1. First derivative of NMR signal for hematite crystals: 1—slowly cooled crystals, 295 K, 2—quenched crystals, 295 K, 3—crystals following any heat treatment, 77 K.

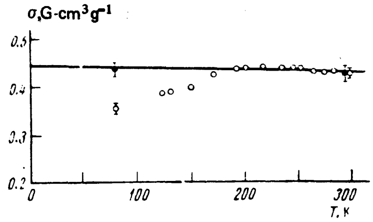

FIG. 2. Temperature dependence of the specific weakly ferromagnetic moment: ○—after slow cooling from 1300°C, ●—after quenching at 1300°C. Solid curve—temperature dependence of sublattice magnetization (the curve is "normalized" to the value of σ at room temperature).

We propose that the crystal sections that become antiferromagnetic are those which are most perfect and free of internal stresses and defects. It is precisely the low-defect sections of the crystal that should contain the easily mobile domain walls which produce the broad NMR line with positive phase. As the crystal becomes more antiferromagnetic the signal with the positive phase vanishes and the main contribution to the NMR signal comes from the nuclei in the rigid domain walls, which are present in the sections that have the increased content and remain weakly ferromagnetic.

Quenched crystals have practically no perfect sections, so that the weakly ferromagnetic phase is preserved in the entire volume of the crystal. The value of σ at 77 K for quenched crystals does not differ from the values at room temperature (dark circles in Fig. 2). The NMR signal from quenched crystals is characterized at all temperatures by the negative phase (curves 2 and 3 of Fig. 1) typical of rigid domain walls.

The preservation of the weakly ferromagnetic state at low temperatures has made it possible to trace, for

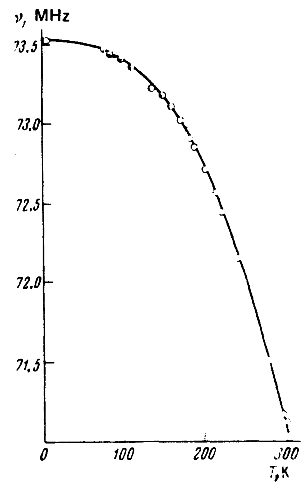

FIG. 3. Temperature dependence of the NMR frequency for hematite.

the first time ever, the variation of the NMR frequency down to 4.2 K. This variation, which reflects the temperature dependence of the sublattice magnetization, is shown in Fig. 3. The measurements at 4.2 K were made by the spin-echo method. Unfortunately, the spin-echo apparatus could be operated only with strong pulses, and we were therefore unable to detect the difference between the nuclear relaxations of the rigid and free walls (low power levels are necessary to observe the echol in the free walls).

We arrive thus at the conclusion that the temperature of the transition to the antiferromagnetic state (the Morin point) of hematite crystal with 0.8% tin is extremely sensitive to the distribution of the defects and of the internal stresses, and therefore the transitions proceeds unevenly over the entire volume of the crystal. The bulk of the crystal remains weakly ferromagnetic down to 4.2 K, but in well annealed crystals there exist perfect sections in which the transition does take place. These sections can be made weakly ferromagnetic by quenching.

[1]M. Matsura, H. Yasuoka, H. Hirai, and T. Hashi, J. Phys. Soc. Jpn. **17**, 1147 (1962).
[2]B. Sedlak, Czech J. Phys. B **18**, 1374 (1968).
[3]A. V. Zalesskiĭ, I. S. Zhëludev, and R. A. Voskanyan, Zh. Eksp. Teor. Fiz. **59**, 673 (1970) [Sov. Phys. JETP **32**, 367 (1971)].
[4]H. Hirai, J. A. Eaton, and C. W. Serle, Phys. Rev. B **3**, 68 (1970).
[5]R. A. Voskanyan and I. S. Zhëludev, Kristallografiya **12**, 539 (1967) [Sov. Phys. Crystallogr. **12**, 473 (1967)].

Translated by J. G. Adashko

ERRATUM

Erratum: Nonlinear theory of the low-frequency oscillations in a weakly turbulent plasma [Sov. Phys. JETP 46, 922–927 (November 1977)]

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PACS numbers: 52.35.Bj, 52.35.Dm, 52.35.Ra

The first reference in the bibliography is a collection of translations. The actual paper referred to is by H. A. Bethe, Phys. Rev. 72, 339 (1947).