hand wing of the spectrum, which is due to scattering of higher multiplicity, has a higher intensity in the spectrum of the neutrals.

These results indicate that different mechanisms govern the production of ionic and neutral components. Apparently, the mechanism of scattering by a chain of atoms [11] plays a relatively larger role in the formation of the neutral component, whereas the ionic component is produced predominantly via pair collisions.

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SPLITTING OF THE SPECTRUM OF LOW-FREQUENCY ANTIFERROMAGNETIC RESONANCE IN $NiCl_2$

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The low-frequency antiferromagnetic resonance (LF AFMR) in $NiCl_2$ was investigated in [1, 2], where it was shown that it can be described by the expression

$$\nu_{LF} = \frac{\gamma}{2\pi}\sqrt{H_0^2 + \Delta^2}, \qquad (1)$$

where Δ is the isotropic gap, which in all likelihood is due to magnetostriction [3, 4]; $\Delta = 3$ kOe at $T = 4.2°K$ [2].

We have investigated the frequency-field dependence of LF AFMR in the frequency region 27 - 43 GHz. Samples, in the form of single-crystal plates measuring 1.5 - 3 × 2.5 - 5 × 0.1 - 0.5 mm, were placed near a short-circuiting plunger in a waveguide of cross section 3.6 × 7.2 mm. The waveguide was placed in a duct passing inside a superconducting solenoid. The duct was filled with helium gas, and a thermoresistor, a bifilar heater winding, and insulating liners of teflon film and wool filaments were placed at the end section of the waveguide. This construction has made it possible to vary the sample temperature from 4.2 to ~70°K. The magnetic field was directed along the waveguide axis. The C_3 axis of the sample was always perependicular to the plane of the employed plate. By varying the mounting of the samples we could perform

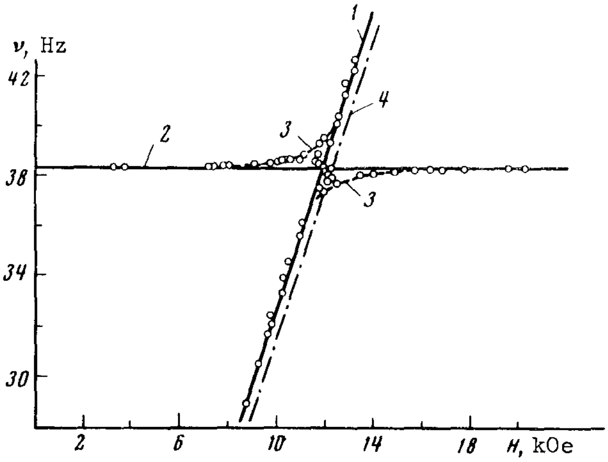

Fig. 1

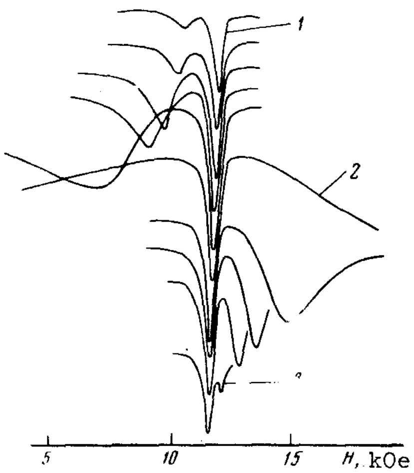

Fig. 2

Fig. 1. Frequency-field dependence of LF AFMR in the region of the anomalous splitting (for one of the samples): 1) LF AFMR (Eq. (1)); 2) $\nu = \nu_{cr}$; 3) "wings"; 4) $\nu = (\gamma/2\pi)H_0$.

Fig. 2. Family of LF AFMR spectra plotted at different frequencies near the anomalous splitting (one of the samples): 1) ν = 40.00 GHz ($>\nu_{cr}$); 2) ν = 39.72 GHz ($\sim\nu_{cr}$); 3) ν = 39.23 GHz ($<\nu_{cr}$).

measurements under the following conditions: 1) $H_0 \perp C_3$, $h_{micr} \parallel C_3$; 2) $H_0 \perp C_3$, $h_{micr} \perp C_3$, $H_0 \perp h_{micr}$; 3) $h_{micr} \parallel H_0 \perp C_3$. The AFMR was revealed by the decrease of the reflected microwave power and was registered with an x-y recorder, the x-input of which was the voltage from a standard resistor, through which the solenoid was fed, and the y-input was the amplified current from the microwave detector. The microwave frequency was measured with a resonant wavemeter of accuracy $\pm 2 \times 10^{-3}$, and the solenoid was calibrated against a free-radical EPR signal, the field-measurement error being ±100 Oe. The LF AFMR signals were registered at all three methods of sample mounting, although according to [3] they should not be observed in the third method. This may be due to the use of samples of linear dimension comparable with the half-wave of the magnetic wave in the waveguide, and to the insufficiently pure polarization of the microwave field.

In the case of sample mounting of type 1 and 2, we observed in the frequency region 27 - 43 GHz a splitting of the LF AFMR spectrum near a frequency ν_{cr} that differed for different samples and also, in the case of the same sample, with the type of mounting (1 or 2). The differences in the values of ν_{cr} did not exceed 15% of the mean value of ν_{cr}. Figures 1 and 2 show the frequency-field dependence of the positions of the maxima of the absorption lines for one of the samples, and a family of spectra obtained at various frequencies in the vicinity of ν_{cr} (for another sample). We see that the spectrum consists of a line described by Eq. (1) (the deviations of the position of the central line in the intersection region can be due to the apparent shift due to the superposition of the lines; we therefore do not assign any significance to them), and of "wings" characteristic of the case when there is "repulsion" of the levels upon interaction. The lines describing the behavior of the "wings" correspond, within the limits of experimental accuracy, to solutions of the equation

$$\nu^4 - \nu^2(\nu_{LF}^2 + \nu_{cr}^2 + K^2) + \nu_{cr}^2\nu_{LF}^2 = 0, \tag{2}$$

where K is a coupling constant equal to the splitting between the "wings" at $\nu_{LF} = \nu_{cr}$. For all samples, regardless of the spread of ν_{cr}, the value of K was constant at 2.1 ± 0.05 GHz.

When the crystal is inclined relative to the waveguide axis, the magnetic field leaves the basal plane and the LF AFMR shifts towards stronger fields. The intersection frequency ν_{cr} also shifts upward in frequency with decreasing angle between the waveguide axis and the C_3 axis of the crystal $(\Delta\nu/\Delta\theta) \approx -0.04$ GHz/deg. It was observed that ν_{cr} depends on the sample dimensions, increasing with decrease of any of the linear dimensions, but this dependence is quite weak, when one of the dimensions is decreased by ∿30% the frequency ν_{cr} increases ∿10%. In many samples, a strong decrease of the linear dimensions caused the splitting of the spectrum to disappear in the investigated frequency interval. In each of two samples (of rather low quality) we observed two regions of splitting, with different values of ν_{cr}. One of the samples, ∿0.3 mm thick, was cleaved along the plane into two equal plates. No splitting at frequencies <43 GHz was observed in each of the resultant plates, but when the two plates were mounted together in the waveguide, they produced a spectrum with splitting. The frequency ν_{cr} increased from ∿38 to ∿43 GHz when the distance between the plates increased from zero to 2.5 mm.

An unexpected result was the independence of ν_{cr} and K of the temperature at any mounting of the sample. It turned out that the splitting of the spectrum is conserved, with the same value of ν_{cr}, on going over into the paramagnetic region (Fig. 3). It follows therefore that the frequency ν_{cr} is not connected with the orientation of the sublattice magnetization, which changes on going through the Neel point (T_N = 49.6°K), from $M \perp H_0$ to $M \parallel H_0$. This circumstance, as well as the fact that $\nu_{cr}(H)$ is constant, suggests that the dependence of ν_{cr} on the sample orientation is connected not with the angle between H_0 and the sample axis, but with the angle between h_{micr} and the sample axis, or else with the influence of the placement of the sample relative to the waveguide walls, in analogy with the situation that obtains in ferromagnetic resonance [6]. The experiment with the cleaved sample favors the second assumption. In this case the oscillations of frequency ν_{cr} should be accompanied by oscillations of the magnetic (electric) moment of the sample.

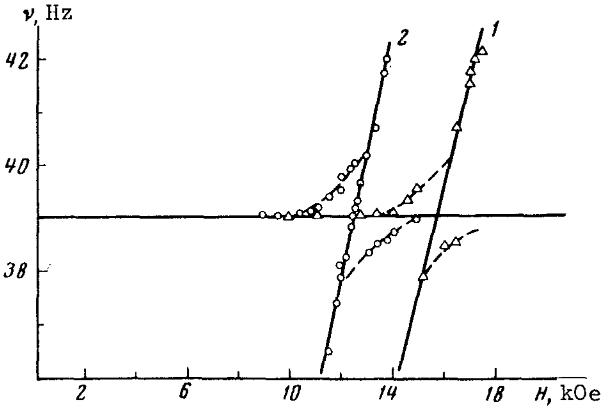

Fig. 3. Conservation of splitting at $T > T_N$. All the spectra were plotted at a fixed position of the sample relative to the waveguide axis (the direction of H_0). The angle θ between C_3 and H_0 equals ∿50°. Triangles - LF AFMR (T = 4.2°K), circles - EPR (T ≈ 70°K); 1) $\nu_{LF} = (\gamma/2\pi)\,[H_0^2 \sin^2\theta + \Delta^2]^{1/2}$; 2) $\nu_{EPR} = (\gamma/2\pi)H_0$.

None of the cases known from the literature, where splitting of the AFMR spectrum was observed [7 - 10], agree with the independence of K and ν_{cr} of the temperature and of the orientation of the sublattice magnetization. The weak dimensional dependence of the large value of ν_{cr} do not agree with the hypothesis of standing acoustic waves in the sample. Equation (2), which describes the behavior of the "wings," is typical of the interaction of two types of spin waves [7 - 9], but the high-frequency AFMR in $NiCl_2$ [11] occurs at frequencies that are twice as high, and depends strongly on the temperature. The value of ν_{cr} might be due to surface spin waves, but their spectrum could hardly be independent of the temperature. The interaction with impurities is also contradicted by the size effect and by the independence of K and ν_{cr} of the temperature. For ordinary optical phonons, the frequency $\nu_{cr} \sim 1.2$ cm^{-1} is too low, and the dependence on the sample dimensions seems strange.

The simultaneous presence in the spectrum of an unsplit line and of "wings" suggests that the split spectrum is characteristic of one part of the sample, and the unsplit one of another, or else that the oscillations of frequency ν_{cr} interact with the LF spin waves of one polarization but not of the other polarization. It seems to us that the second assumption contradicts the experiment with the cleaved crystal. The presence (in most samples) of only one frequency ν_{cr}, and its reproducibility (within 5 - 7%) from crystal to crystal, indicate that the local oscillations near defects and inhomogeneities cannot be responsible for ν_{cr}. It can be assumed that these oscillations are standing surface waves of the membrane-vibration type for the flexural phonons [12, pp. 102 and 167]. For them to be accompanied by electromagnetic oscillations it is necessary that these be optical oscillations. The planes of the metal ions and of the chlorine ions in $NiCl_2$ are oppositely charged, and out-of-phase flexural vibrations of such planes can have the necessary properties, such as a weak dependence of the frequency on the dimensions of the crystal and a low frequency (compared with the ordinary optical oscillations). Unfortunately, the spectrum of the flexural vibrations (and all the more of surface vibrations) in this crystal has not been investigated, and there are no data for estimates needed to confirm this assumption concerning the nature of the oscillations of frequency ν_{cr} interacting with LF spin waves.

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