# FEATURES OF RESONANCE ABSORPTION IN COPPER CHLORIDE DIHYDRATE IN AN INCLINED MAGNETIC FIELD\

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## Abstract

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## PHYSICS

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# FEATURES OF RESONANCE ABSORPTION IN COPPER CHLORIDE DIHYDRATE IN AN INCLINED MAGNETIC FIELD*

**1.** Studies of antiferromagnetic resonance in copper chloride dihydrate in an inclined magnetic field have been the subject of works ([1,2]), concerned with high frequencies.

The present work is devoted to a study of the dependence of the resonance fields on the angle $\psi$ between the easy axis and the external magnetic field, lying in the $(ab)$ plane, at low frequencies $\nu_1 = 5.2$ GHz, $\nu_2 = 3.0$ GHz, $\nu_3 = 1.1$ GHz, and $\nu_4 = 0.65$ GHz. Resonance absorption was observed only in the case when the angle of inclination $\psi$ did not exceed a certain critical value $\psi_k$, depending on the frequency. At the frequencies $\nu_1, \nu_2, \nu_3$, two resonance lines were found, while at the frequency $\nu_4$ only one was found. The curves of the dependence $H_{\text{res}}(\psi)$ were investigated at $T = 1.52^\circ$ K. It was found that there is a characteristic depression in the curves $H_{\text{res}}(\psi)$ in the region of small angles for the larger resonance field. The "depth" of the depression is $\simeq 19$ Oe at the frequency $\nu_1$, $\simeq 20$ Oe at the frequency $\nu_2$, and $\simeq 10$ Oe at the frequency $\nu_3$. The only absorption line at the frequency $\nu_4 = 0.65$ GHz exists only in the case when the magnetic field $H$ is strictly parallel to the "easy" axis $a$ (see Fig. 1). At the frequency $\nu_2 = 3$ GHz, the change in the shape of the curve $H_{\text{res}}(\psi)$ with changing temperature was investigated in the temperature range from 1.52 to 3.5° K. It was found that the depression in this curve in the region of small angles exists only at temperatures from 1.52 to 2.2° K. At higher temperatures the depression is absent and the curves of the dependence $H_{\text{res}}(\psi)$ are convex (see Fig. 2). At the minimum temperature $T = 1.52^\circ$ K, at the frequency $\nu_2 = 3$ GHz, in addition to two absorption lines, a third absorption line was found on the side of the higher resonance field ([3]). This line was observed in the region of small angles $\psi$. As the angle $\psi$ increased, the intensity of the line rapidly decreased. The line has an asymmetric shape, with greater steepness on the side of smaller fields and a slower falloff on the side of larger fields. Investigation in the region of small angles $\psi \lesssim 0.2^\circ$ showed that the values of the resonance

Figure 1

Figure 1: Figure 1

**Fig. 1.** Dependence of the resonance field on the angle $\psi$: at frequencies $\nu_1 = 5.2$ GHz (points), $\nu_2 = 3$ GHz (points), $\nu_3 = 1.1$ GHz (points), $\nu_4 = 0.65$ GHz (triangles); temperature $T = 1.52^\circ$ K

* The work was reported at the All-Union Conference on the Physical Properties of Ferrite Single Crystals. Krasnoyarsk, June 1969.

fields corresponding to the main resonant absorption remain practically constant, whereas the field corresponding to the maximum of the additional absorption increases noticeably with increasing angle $\psi$. This line is observed when the microwave magnetic field is oriented along the $c$ axis. Small changes in the orientation of the crystal, in which the $c$ axis deviates from the direction of the microwave magnetic field, lead to the disappearance of the third absorption line.

2. For an interpretation of the described absorption properties of the microwave field in antiferromagnetic resonance, we shall start from the following expressions for the resonance fields in a two-axis antiferromagnet in a field parallel to the easy axis ([4]):

$$H_{1p}^2 = H_\Pi^2(1+2\varepsilon) - 3\omega^2 +$$

$$+(2\omega^2 - 3\varepsilon H_\Pi^2)\frac{H_\Pi^4 \sin^2 2\psi}{(3\omega^2)^2} +$$

$$+\frac{(72\varepsilon^2 H_\Pi^4 - 51\varepsilon H_\Pi^2\omega^2 + \omega^4)H_\Pi^8 \sin^4 2\psi}{12\omega^2(3\omega^2)^4}; \qquad (1)$$

$$H_{2p}^2 = H_\Pi^2(1-2\varepsilon) + \omega^2 + 3\varepsilon H_\Pi^6\omega^{-4}\sin^2 2\psi -$$

$$-\frac{(72\varepsilon^2 H_\Pi^4 + 15\varepsilon H_\Pi^2\omega^2 + \omega^4)H_\Pi^8 \sin^4 2\psi}{4\omega^2(3\omega^2)^4}, \qquad (2)$$

where $H_{1p}, H_{2p}$ are, respectively, the smaller and larger resonance fields; $H_\Pi$ is the critical field at which the magnetic sublattices are overturned by a first-order phase transition; $\psi$ is the angle between the magnetizing field and the easy axis; $\omega$ is the frequency of the microwave field (divided by the gyromagnetic ratio); $2\varepsilon = (H_1 - H_2)H_1^{-1}$; $H_1, H_2$ are the lability fields of the phases with non-overturned and overturned sublattices, respectively. Formulas (1), (2) are written for antiferromagnetic $CuCl_2 \cdot 2H_2O$.

Figure 2

Figure 2: Figure 2

The experimentally observed dip on the curve $H_{2p} = H_{2p}(\psi)$ in the region of small angles is in qualitative agreement with formula (2) for $\varepsilon > 0$. It follows from formulas (1) and (2) that the depth of the dip decreases as the frequency decreases. In addition, the angle $\psi_k$ at which $H_{1p} = H_{2p} = H_p$ decreases, while the field $H_p$ increases with decreasing $\omega$. These consequences of formulas (1) and (2) are also in agreement with the experimental results of the present work (see Fig. 1). It follows from formula (1) that, for $\omega^2 < {}^3/_2 \varepsilon H_\Pi^2$, the curve $H_{1p} = H_{1p}(\psi)$ ceases to be convex in the region of small angles. However, such behavior of the smaller resonance field was not found in the present work.

**Fig. 2.** Dependence $H_{\text{res}}(\psi)$ at frequency $\nu_2 = 3$ GHz at temperatures $T_1 = 1.52°$K, $T_2 = 2°$K, $T_3 = 2.5°$K, $T_4 = 3°$K, $T_5 = 3.5°$K

The occurrence of an additional maximum on the curve of the dependence of microwave-radiation absorption on the external magnetic field can be associated either with the presence of a new resonance frequency or with features of the shape of the second absorption line. The appearance of a new resonance frequency in the low-frequency region could be explained by features of microwave-field absorption in an antiferromagnet divided into domains. However, division into domains with 90° boundaries occurs in a magnetic field smaller than the field,

in which a third absorption line is observed. Another possible explanation is associated with the complex shape of the absorption band at a given frequency. In Ref. ([4]) it is shown that, in addition to the peak corresponding to resonant absorption at $H = H_{\text{res}}$, there is a maximum in the region of nonresonant absorption, related to the character of the polarization of the microwave field. Moreover, in accordance with the results of Ref. ([4]), the field separation between $H_{\text{res}}$ and $H_{\text{nonres}}$—the field corresponding to the maximum of nonresonant absorption—increases with increasing angle according to the law

$$H_{\text{res}} - H_{\text{nonres}} = -a \sin^2 \psi,$$

where $a > 0$. As the angle $\psi$ is increased, the maximum corresponding to $H_{\text{nonres}}$ decreases, and its width increases. It should also be noted that the shape of the maximum of nonresonant absorption qualitatively coincides with the shape of the third absorption line observed in the present work. At low frequencies, the maximum of nonresonant absorption can be observed only when the polarization of the microwave field is very close to linear, with the polarization vector along the $c$ axis. This also agrees qualitatively with the conditions under which the third absorption line is observed in the present work.

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*Note: Figure translations are in progress. See original paper for figures.*