

CHAPTER 4

First-order structural phase transition. Low-frequency properties of a low-temperature dielectric

In magnet-containing media, phase transitions are accompanied by changes of states and physical properties. The formation and evolution of the structural phase transitions of types 1 and 2 are initiated by temperature, pressure, magnetic field effect through the mechanisms of elastic stresses. The processes resulting in change of the phase state of a solid are accompanied by physical phenomena and effects able to explain the nature of inner interactions in the structure and evaluate their parameters.

The complex study of magnetic, elastic, magnetoelastic, high-frequency properties peculiar to the first order structural phase transition is an urgent problem from the viewpoint of both the object, i.e. the phase transition, and special properties.

$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ crystal with isotopic modification $\text{CuCl}_2 \cdot 2\text{D}_2\text{O}$ are the classical objects of investigation of the physics of magnetism. They are associated with an important set of physical properties and phenomena studied at low frequencies, within centimetric and decimetric wave bands, in magnetic fields up to 12-15 kOe, at the temperature of 4.33 K and lower and under pressures up to 12 kbar.

The studied physical processes and phenomena are inherent to multiple magnet-containing structures and as a consequence, the obtained results contribute a lot to the fundamental physics of magnetism.

The current approach to the problem of low-temperature magnetism is connected with investigations of phase transition neighborhood, i.e. the range of fields corresponds to the first order superconducting state.

By the example of secondary indications, this fact is confirmed by a peculiar jump of the properties of low-frequency resonance band and by magnetization [6, 7]. The separation of metal and superconducting phases occurs in the region of the first-order phase transition. The nature of magnetic properties of solids can be revealed due to investigations of the resonance absorption in inclined magnetic fields and changes of dependences of the low-temperature spectrum, explanation of the character of phase transition, characterization of different pre-critical and super-critical states.

4.1. Experimental investigation of the low-frequency resonance branch in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$

First studies of the resonance were done by Nagamiya [73] and Kittel [74]. They studied an uniaxial magneto-dielectric and the absolute zero temperature

within the model of the molecular field. Next, the model theoretical representations were spread to rhombic single crystals studied at arbitrary temperatures. For rhombic $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ structure, the resonance theory was developed in parallel with the accumulation of experimental results [75-86, 130]. The resonance absorption frequencies were calculated first for the rhombic single crystal at zero temperature in the magnetic field directed along the crystallographic axis [75] with the anisotropy of neighbor ions exchange interaction taken into account. The calculation of frequencies with Lande factor of anisotropy taken into consideration and for arbitrary orientation of the magnetic field with respect to crystal axis is given in [87]. The theory represented complete resonance properties at zero temperature. Otherwise, the proposed theories do not practically make it possible to determine phase-transition character and resonance features in inclined magnetic fields. The papers [88] give the most successive resonance spectra for all the possible phases in the external magnetic field and for the first-order phase transition. The developed theory of resonance in the inclined magnetic field [76-79, 87] does not explain resonance features (the existence of linearity). It still determines the sensitivity of field deviation from the easy axis in the region of phase transition.

In copper chloride dehydrate, the resonance has been experimentally detected by a group of Dutch researchers [89, 90] for frequencies of 9.4 GHz in magnetic fields up to 10 kOe and at the low-temperature range (Fig. 4.1).

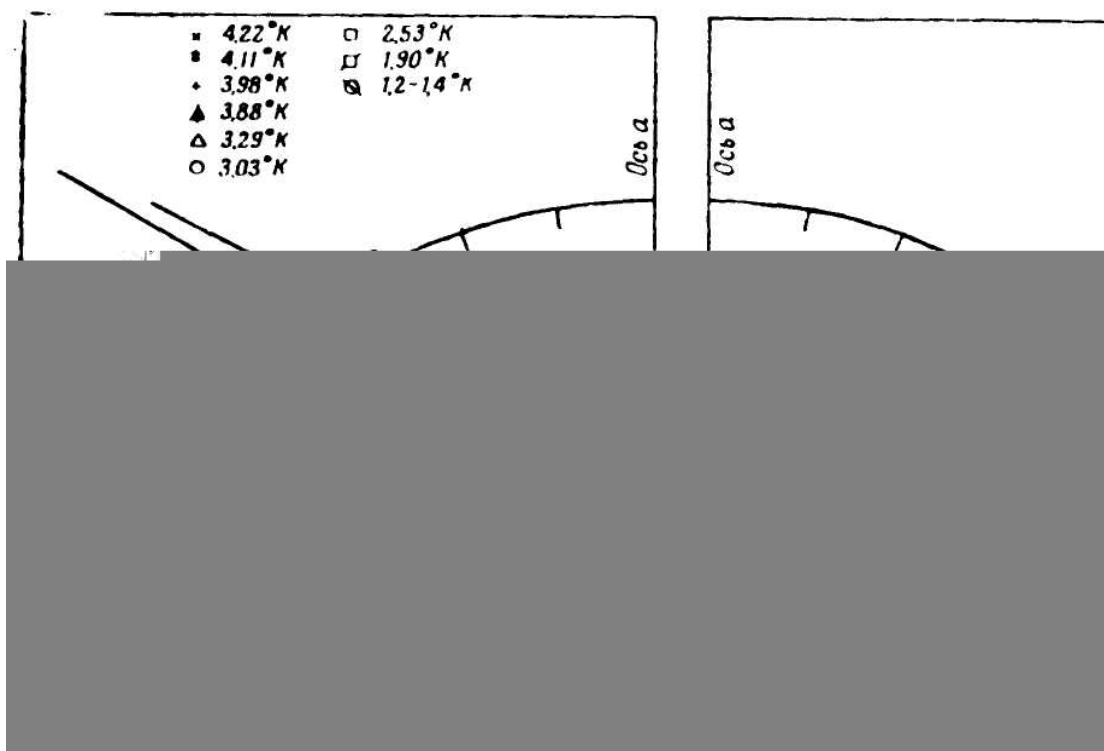


Figure 4.1. The polar diagrams of resonance field location at the frequency of 9.4 GHz in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ [90].

High-frequency power absorption was measured as a function of the magnitude and orientation of the external magnetic field relatively to crystallographic axes. The objects of studies were samples with a,b and a,c planes pre-oriented by means of X-ray methods. In ab plane, the values and the direction of resonance fields were found down to the lowest temperatures, on the dependences of closed curves near the critical field H of the corresponding region of the structural phase transition. With the temperature increase, the closed curves of the dependences (Fig. 4.1) shifted towards the rising field and the distance between the resonance fields was increasing, too.

The investigations of the resonance gave typical parameters for the relation of exchange energies and anisotropy in a- and c-directions at the frequencies of 323 GHz [91] and 3.5 MHz [92]. The frequency spectrum has been restored for rhombic crystal at $T=0^{\circ}\text{K}$ [90, 91]. It was noted that the values of resonance fields of the region of phase transition agreed well with those from NMR experiment and, as a consequence, the resonance field dependence coincided qualitatively with the estimates obtained by using the molecular field theory.

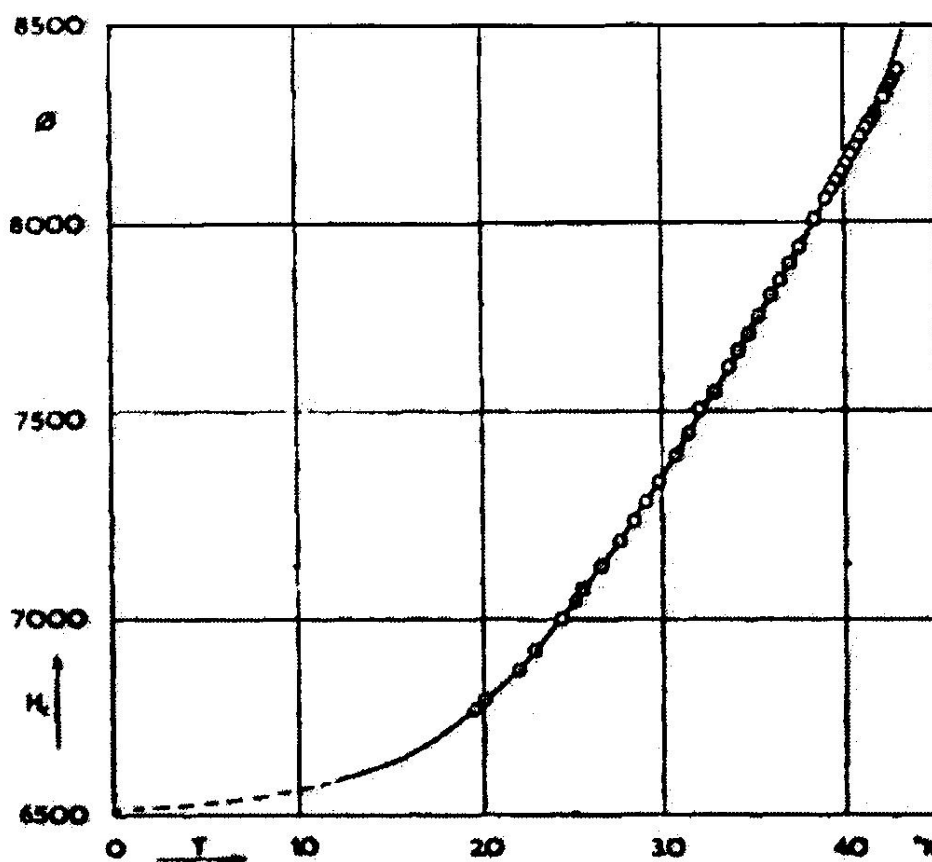


Figure 4.2. Temperature dependence of the critical field aligned with a-axis for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ [92].

The result obtained at frequencies of 3.5 MHz in ab -plane is the resonance in so-called heavy plane at HII-a, and it has the form of a single resonance line [92]. The value of the field corresponds to the region of PT realization. The results of PT studies through changes of the field H in ac -plane demonstrate the regularity as a hyperbolic dependence (Fig. 4.2).

Unfortunately, the variety of resonance frequencies [79, 89-93] could not explain the peculiarities of magnetodielectric behavior in the fields corresponding to the phase transition. The results obtained for the low-frequency resonance range [81] gave more information about the character of the phase transition. There, the measurements were made at four frequencies $\nu_1 = 5.2 \text{ GHz}$, $\nu_2 = 3.0 \text{ GHz}$, $\nu_3 = 1.1 \text{ GHz}$, $\nu_4 = 0.65 \text{ GHz}$ at 1.58 K. With the magnetic field H aligned with the a -axis, there were two lines of resonance absorption at each of three frequencies, and only one absorption line was present at ν_4 that corresponded in magnitude to both PT region and the value of resonance field H_{2p} in the region of the phase state for all frequencies mentioned above. This result allowed us to state that in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, the phase transition is of the first order (Fig. 4.3).

The peculiarities of the resonance fields were studied in [84] in the case of the inclined magnetic field if the easy ab -plane (Fig. 4.4). It has been revealed that the angles of coincidence of the resonance fields vary with the temperature increase. There was also a dip on the diagram position change with the angle. The dip depth decreases with the frequency and the temperature as well as with the width of the resonance line.

This region of the phase transition was studied by resonance methods in numerous papers [81, 94-99]. NMR method was used to determine the range of

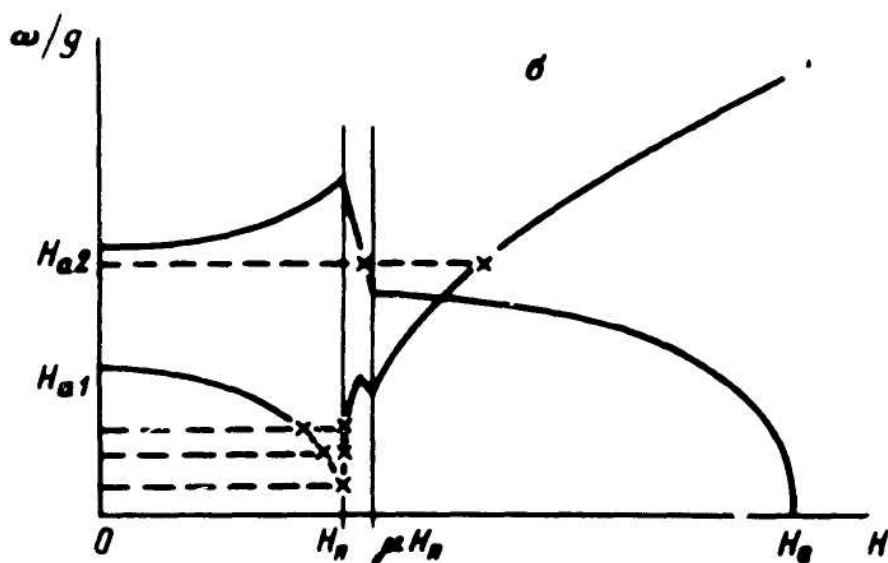


Figure 4.3. Resonance frequencies in magnetic field $H||a$ [81].

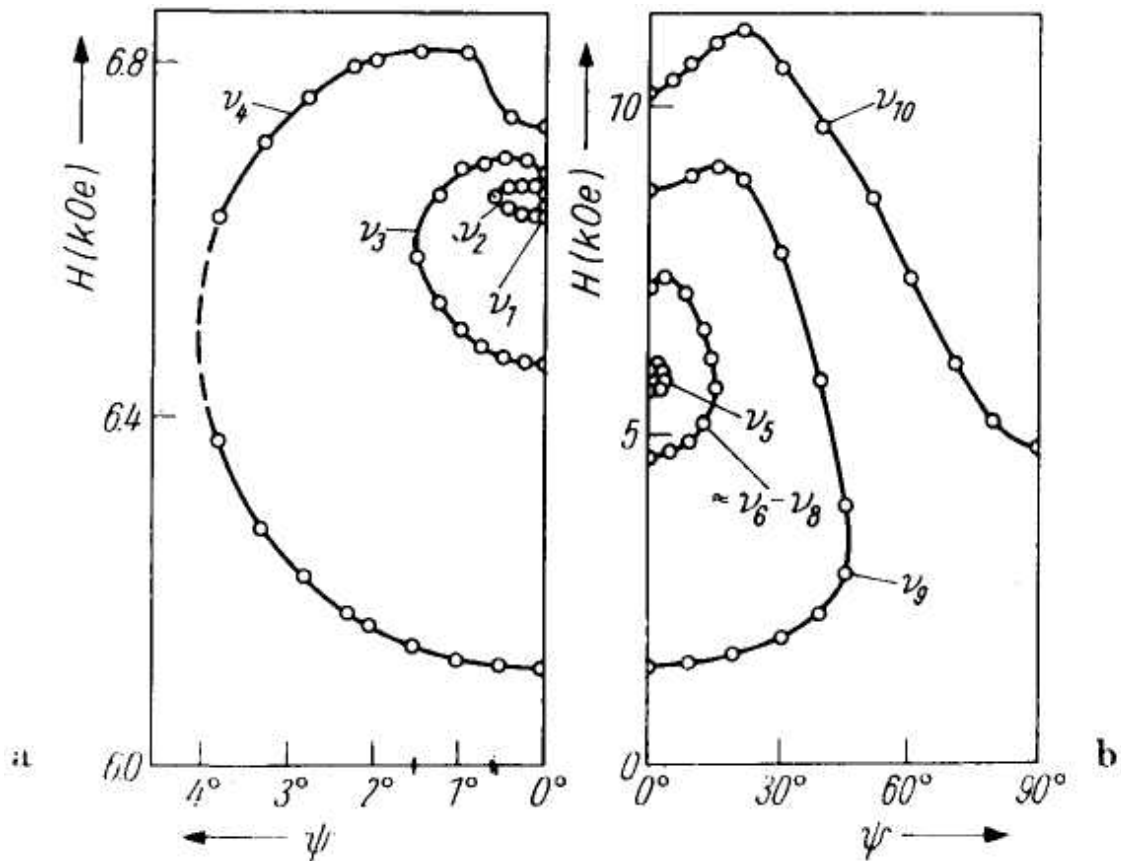
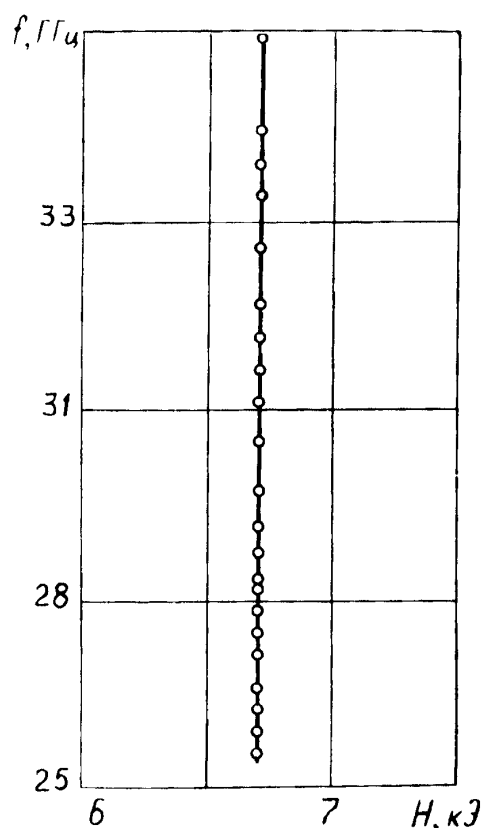


Figure 4.4. Angular dependences of resonance fields within the frequency range of (0.65 GHz-5.2 GHz) at $T=1.57$ K and (4.2 GHz-24.2 GHz) at $T=1.4$ K [84, 94].

existence of PT region for ellipsoidal sample at $T=1.65$ K and to confirm the typical features of the first-order transition [95]. The study of the low-temperature branch [81] has revealed regularity to state changes of phase states corresponding to different regions. A lower resonance field relates to the absorption in the region of one phase (the superconducting one). The position of a higher resonance field does not depend on the frequency. Moreover, it corresponds to the region of PT realization. A similar result was obtained for the high-frequency resonance branch [96], where $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ was studied under pressure and temperature ($T=1.65$ K) within the frequency range of 25-36.5 GHz, see Fig. 4.5. This result demonstrates the resonance absorption in the region of PT to be regular with an enough exact orientation of the magnetic field with respect to the “easy” axis of the crystal. The deviation of the angle by 10-20 increases the values of the resonance field.

We should mention the results of [98, 99] where the high-frequency properties were studied in high magnetic fields. The experiment was done with plates of 3×0.3 mm size. The accuracy of the orientation of magnetic field H was equal to 3. It appeared impossible to separate the resonance absorption that contradicted to [81, 96]. It is connected with an insufficient accuracy of



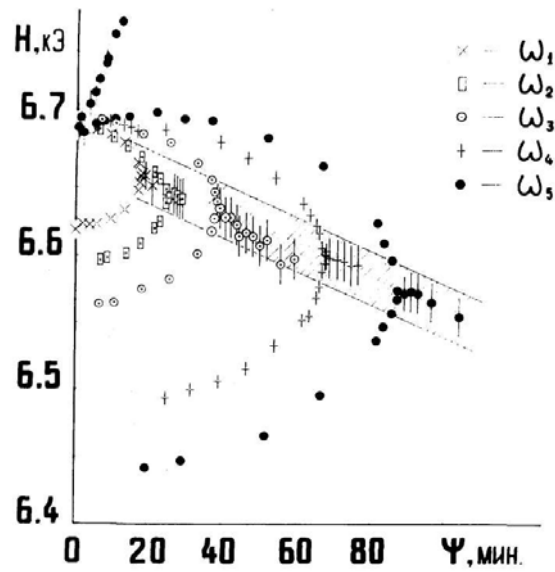


Figure 4.6. Angular dependences of the resonance fields of varied frequencies in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ [101]:

$\omega_1=1.8$ GHz, $T=1.64$ K; $\omega_2=2.02$ GHz, $T=1.65$ K; $\omega_3=2.42$ GHz, $T=1.66$ K; $\omega_4=2.98$ GHz, $T=1.66$ K; $\omega_5=3.34$ GHz, $T=1.66$ K.

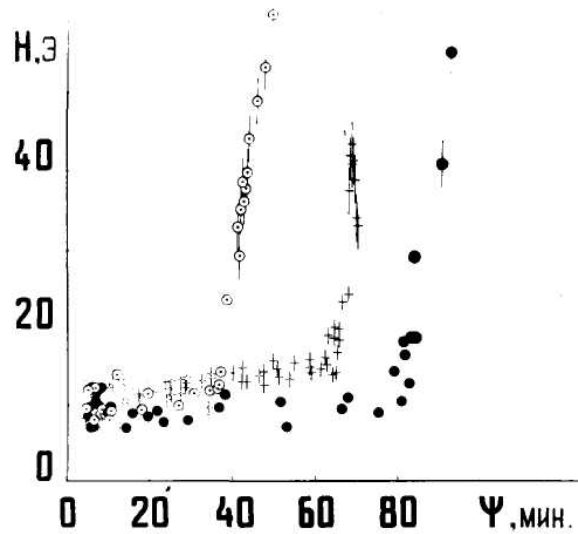


Figure 4.7. The width of the line of the resonance field [101].

frequency environment of the resonator. The process is accompanied by a newly formed resonance absorption observed near a-axis. Similar results were observed at the frequency of 3 GHz for $T=1.57$ K [84, 100] with the lines of additional absorption fixed at small angles of magnetic field deviation. For small angles of 0.2° , the resonance field value was found to be relative and permanently corresponding to the field of the structural phase transition, whereas the field of additional absorption is growing with the gradual decrease of the intensity and with the temperature rise up to 2 K in this interval of angles.

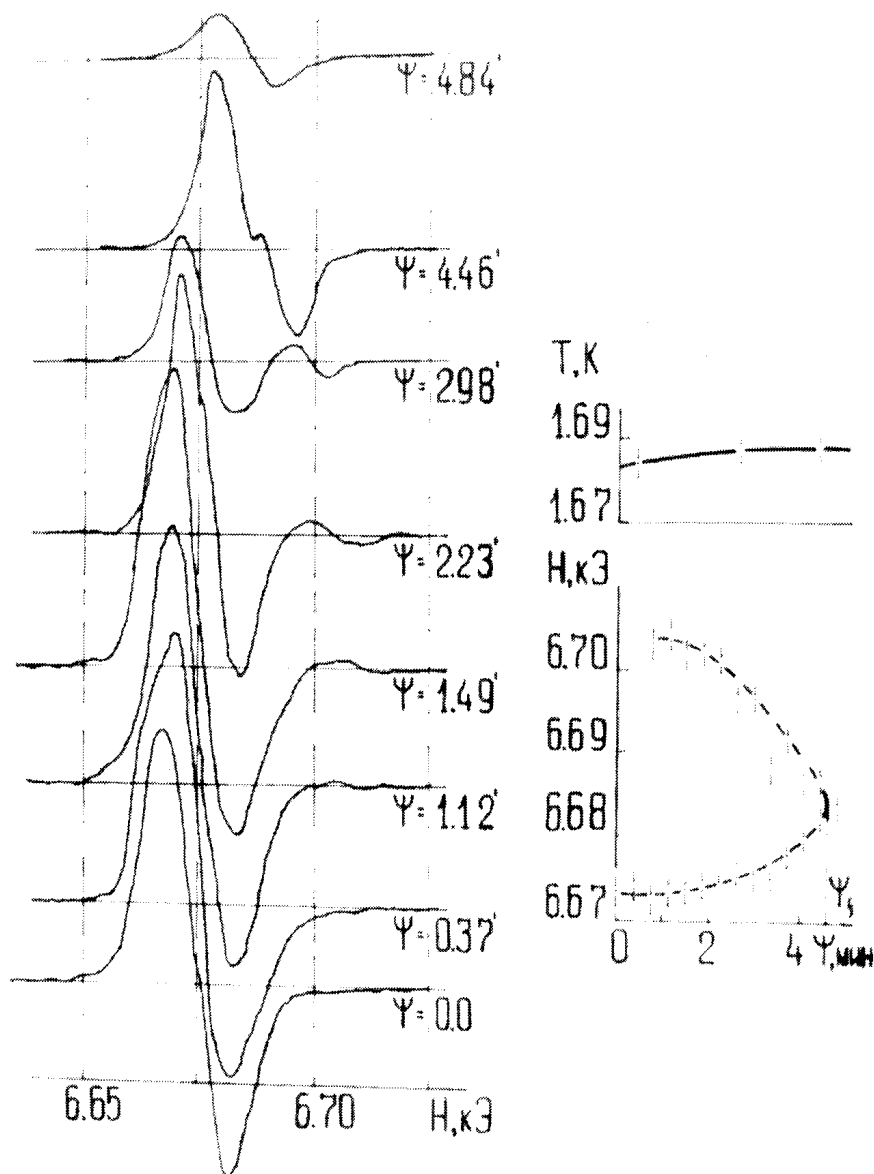


Figure 4.8. The dependence of the lines of resonance absorption on the angle of deviation of the magnetic field H from a -axis at the frequency of 1.085 GHz [104].

One of the mechanisms of non-resonant absorption can be related to the character of HF-field polarization and to electronic mobility of the phase relating to the region of the phase state.

The resonance investigations have one more interesting peculiarity developing in ab -plane of the easy plane in a wide interval of angles [84, 90, 102]. In this interval, the highest and the lowest resonance fields superpose. There was broad resonance absorption of low intensity (Fig. 4.6, 4.7). It should be noted that the auxiliary non-resonant absorptions on the background of the basic resonance effect have not been studied beforehand. To elucidate the mechanisms forming the structural phase transitions and separate phases, the nature of the whole of resonance peculiarities should be known.

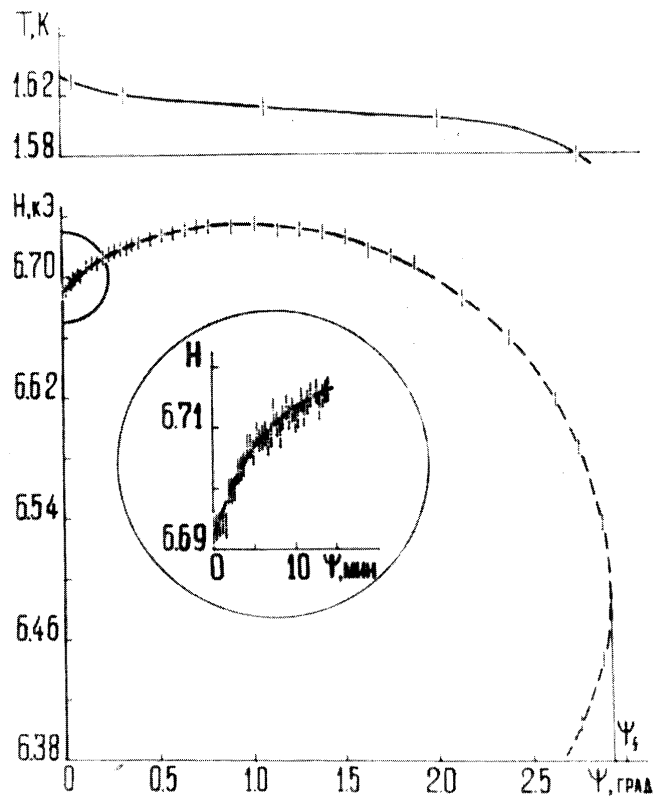


Figure 4.9. The dependence of the field of resonance on the angle of deviation of the magnetic field H near a-axis at the frequency of 4.55 GHz, $T=1.6$ K [104].

For a systematic presentation of resonance peculiarities in a two-axial magnetodielectric, the authors of [101] studied samples of different shape in a wide frequency range. The absorption was studied in the low-frequency range $\nu = 0.39 - 4.55$ GHz in a spiral-type resonator where frequencies can be changed without sample removal. It is the range that represents the region of superconducting phase state and the phase transition [6]. Detailed information is illustrated on Figures 4.8-4.10. The recorded is the derivative of the circuit of resonance absorption band for the frequency of 1.085 GHz and $T=1.68$ K. In the vicinity of easy axis, the system is not sufficiently sensitive to discriminate the absorption. With the magnetic field deviation of 0.3, there is an absorption line with the well-resolved maximum (10 Oe wide). The absorption lines approach (Fig. 4.8) and merge to the form of a single line as a result of angle increase. The regularity of alignment of lines depends on the frequency (Fig. 4.11). The descriptive picture of the results of resonance - frequency experiments in inclined magnetic field (Fig. 4.6, 4.7) is given for 5 frequencies. It is also typical of another frequencies observed earlier. At these frequencies, there is a wide absorption line at the side of higher resonance field if the region of PT (Fig. 4.6). It fixes the strong dependence on the angle between easy axis and the field of the easy axis H . It is also symmetrical with

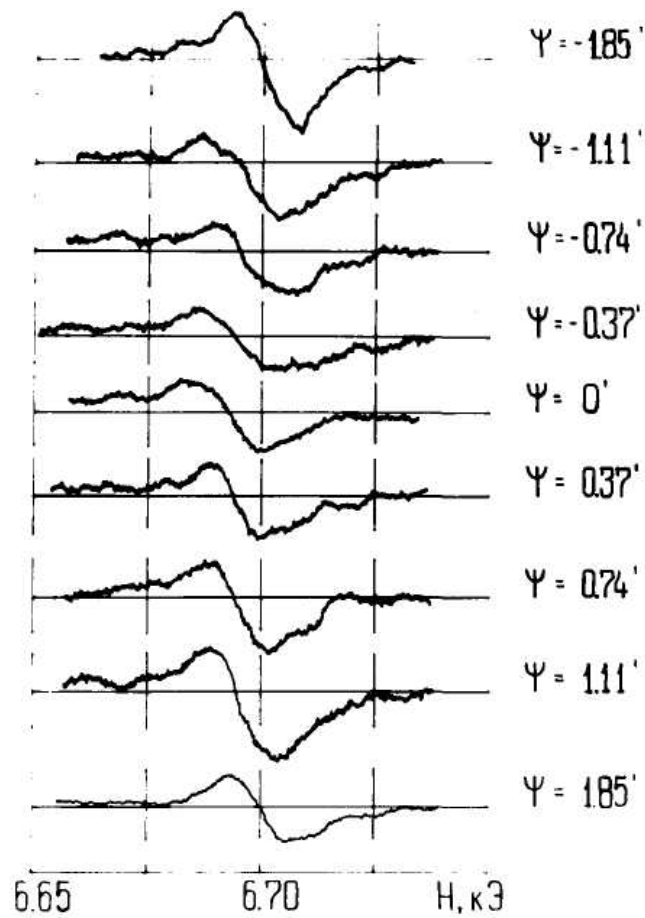


Figure 4.10. The dependence of the line of absorption of the higher resonance field at small deviations of the magnetic field from a-axis at $\omega=4.55$ GHz, $T=1.63$ K [104].

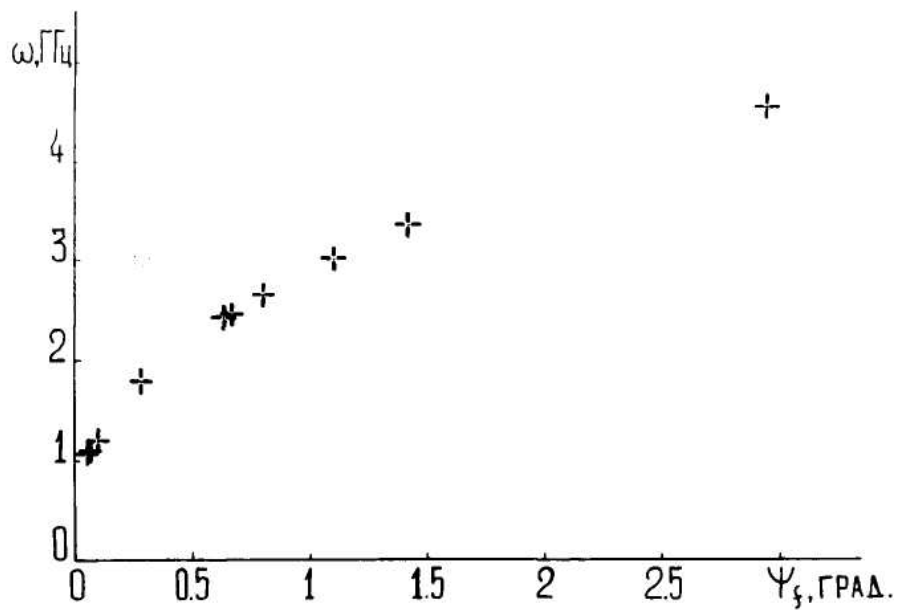


Figure 4.11. The resonance frequency dependence of the angles of shedding at $T=1.58$ K [104].

respect to the symmetry plane (ac-plane of the crystal). The magnitude is wide under exact orientation of the magnetic field. This effect enables fixing of the field direction to within 20-30°. We can suppose that the resonance absorption related to the established features is of relaxation origin. The most important fact is that variable results for resonance absorption observed in a wide temperature range are consequences of changes of the structural phase transition at 0° K followed by distinguished phase states under magnetic field. The next important fact is the resonance absorption related to both the phase state properties and the region of the phase transition. The mentioned non-resonant absorption in the vicinity of the external field orientation with respect to the easy axis can result from peculiarities of high-frequency field polarization.

4.3. Effect of sample shape on resonance high-frequency properties

Experimental investigation of the effect of sample shape for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ is of interest because of the typical change of the low-frequency resonance with selective absorption of HF-electromagnetic field in the region of phase state and phase transition. While studying the resonance absorption for the samples of different shapes and phase states in the external magnetic field, we can generalize and unite the conditions of the resonance mode development in the region of the structural phase transition as well as the methods of observation. The purposeful application of this method is of high value for the study of PT and phase states.

The standard was a $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ single crystal, 4x4x4 mm in size. The structure inhomogenities were detached during the observation in a polarizing microscope. By means of X-ray diffractometer, the samples were disoriented and a-, b- and c-axes were grinded to the dish form.

The investigations of the region of structural phase transition with the observed jump of the properties were the most interesting. This region is characterized by the behavior of the upper resonance absorption line (Fig.4.12). The experiment shows that as the angle between the easy axis and the field H decreases, the resonance absorption intensity decreases and becomes low at $\psi=0$. The intensity was enhanced by an insignificant increase of the amplitude of the modulating field. As a result, the absorption line was somewhat distorted but the position remained practically unchanged. The deviation of the position of the maximum with respect to the field was registered by NMR transducer.

Considering the results of the phase transition state in magnetic field $H \parallel$ easy axis, we should mention the presence of the temperature. The combined influence of H and T on the structural changes in the region of PT, the same as the anisotropy of elasticity, magnetoelasticity, responds to any changes of the shape of the sample. The magnetoelasticity anisotropy is the most evident on both angular diagrams and additional absorption lines at the fixed temperature below 2 K.

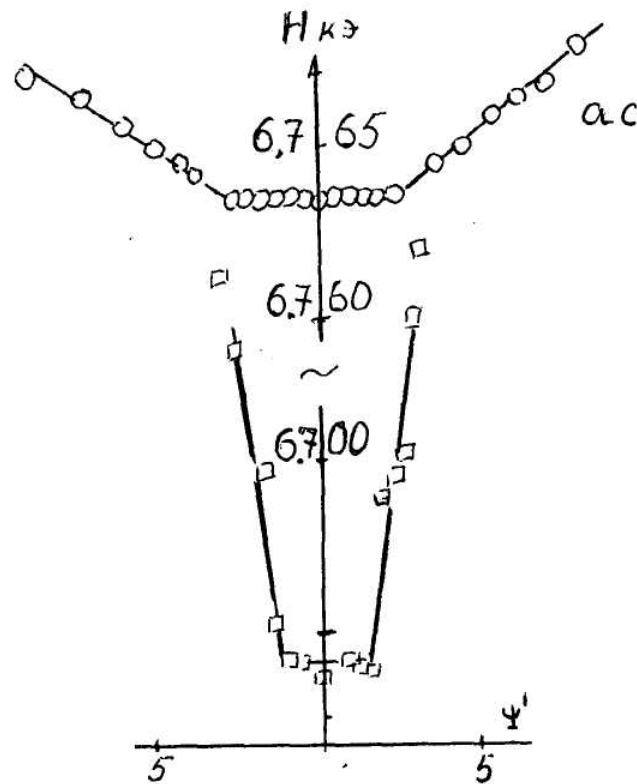


Figure 4.12. The higher resonance field near a-axis for a cubic sample at $T=1.68$ K and for a plate at $T=1.98$ K at $\omega=5$ GHz.

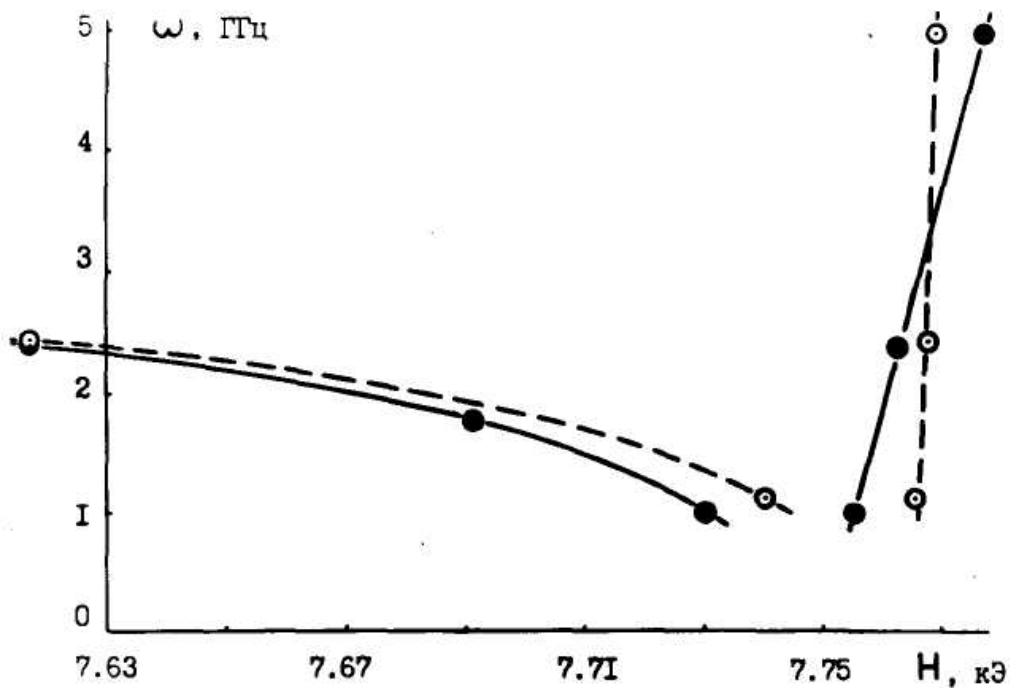


Figure 4.13. Frequency-field dependence of the field of resonance absorption in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ at $T=1.94$ K ((●) denotes a disk normal to a-axis and (○) means a disk normal to b-axis).

On the illustrated dependences (Fig. 4.13) of the resonance absorption frequencies for bc- and ac-plates, we note the vertical region with a weak field dependence of the frequency for the upper resonance line. At the same time, the dependence is essential for bc-plate. Here the slope has changed very much. But in the both cases, the resonance absorption responds to the first-order phase transition.

The first resonance line is related to the high-frequency field absorption in the superconducting phase state during H effect on the electron density change through mechanisms of magnetoelastic stresses at the fixed temperature. The position of the line slightly changes depending on the shape of the sample. In the region of formation of the structural phase transition, the resonance occurs in the form of the upper resonance field. It covers a narrow range of magnetic-field values with a thermodynamically stable PT and shows qualitatively the difference between resonance absorption in ac- and c-plates.

The discussion of the experimental results relates to the analysis of the nature of the upper resonance absorption field at frequencies of 2-5 GHz. The process of the structural phase transition is connected with the rupture and the change of bonds in the mechanisms of structure rearrangement and with the jump of properties including the high frequency ones. The nature of the resonance absorption is interpreted in view of the electron density in the region of PT and the relaxation and polarization peculiarities.

The changes of the upper resonance field with the magnetic field orientation along easy axis (Fig. 4.13) can be interpreted as those resulting from structure changes and elasticity properties. We see on the field-temperature dependences that the resonance fields are of the same value for ac-plate and three frequencies of about 20 Oe. They form the vertical part of the dependence. This part is 15 Oe for bc-plates. The elastic stresses and the anisotropy of elasticity are involved to the mechanisms of the influence of magnetic field and temperature. These quantities are tensor-like. The redistribution and changes of both the elastic stresses and anisotropy of elasticity are initiated by changes of the shape of a sample. Is it not the fact that defines the processes of the evolution of the shape of a sample?

4.4. Regularities of PT and resonance absorption in the vicinity of the hard plane

In $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, the resonance absorption was studied in the easy plane and assigned easy axis for the magnetic field oriented along ab-plane of the crystal. The behavior of this magnetodielectric has not practically been investigated in magnetic fields oriented along ac-plane called the difficult one. In [92], the resonance method was used and the resulting were dependences of changes of resonance absorption in ac-plane in the form of a hyperbola (Fig 4.14). The studies of PT peculiarities and the low-frequency branch of resonance

absorption in the hard plane [101, 103, 104] may help in throwing light on wide domain of phenomena and effects by using the fine resonance procedures and give an answer to important problems of formation of the structural phase transition in the hard plane. These researches of the character and peculiarities of PT in magnetic field lying in the hard plane of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ helping revealing

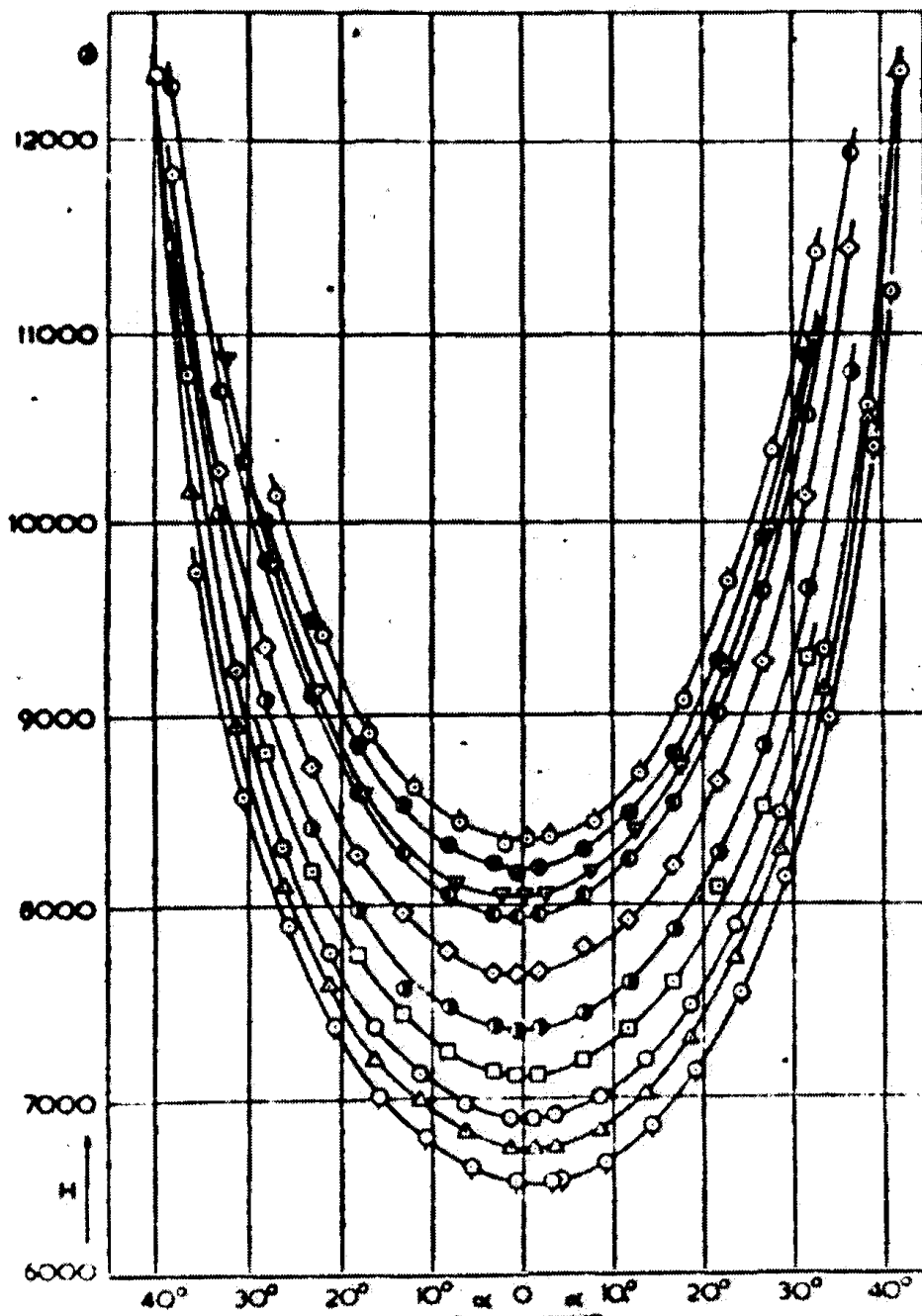


Figure 4.14. The dependence of the higher resonance field at the 3 deviation of H magnetic field from a-axis on $\bar{a}\bar{c}$ hard plane in $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ at $T_1=1.22$ K, $T_2=1.939$ K, $T_3=2.275$ K, $T_4=2.672$ K, $T_5=3.018$ K, $T_6=3.411$ K, $T_7=3.783$ K, $T_8=4.067$ K, $T_9=4.206$ K, $T_{10}=4.235$ K [92].

of regularities for relationship between elastic properties and magnetism in the region of low temperatures.

Single-crystalline samples of 1x1x1 mm in size were pre-oriented by X-ray diffractometer DRON-1.5 along a, b, c axes. Then, the sample was fixed with ac-plane of the substrate base. So, the sample could be mounted in resonator with b-axis movable in horizontal plane. The accuracy of orientation makes 25. In the course of the measurements, the sample was oriented completely by signal intensity and the position of the resonance fields. The frequencies of the lower branch had two resonance lines each. The signal level was fixed at any magnetic field deviation. Fig.4.15 illustrates experimental results for dependences of resonance fields of both the fixed angle in the hard plane and varying magnetic field in the soft plane. Angular diagrams show that when the magnetic field in ac-plane is changed, the intensity of higher resonance field decreases and vanishes near ac-plane, i.e. the region of PT realization.

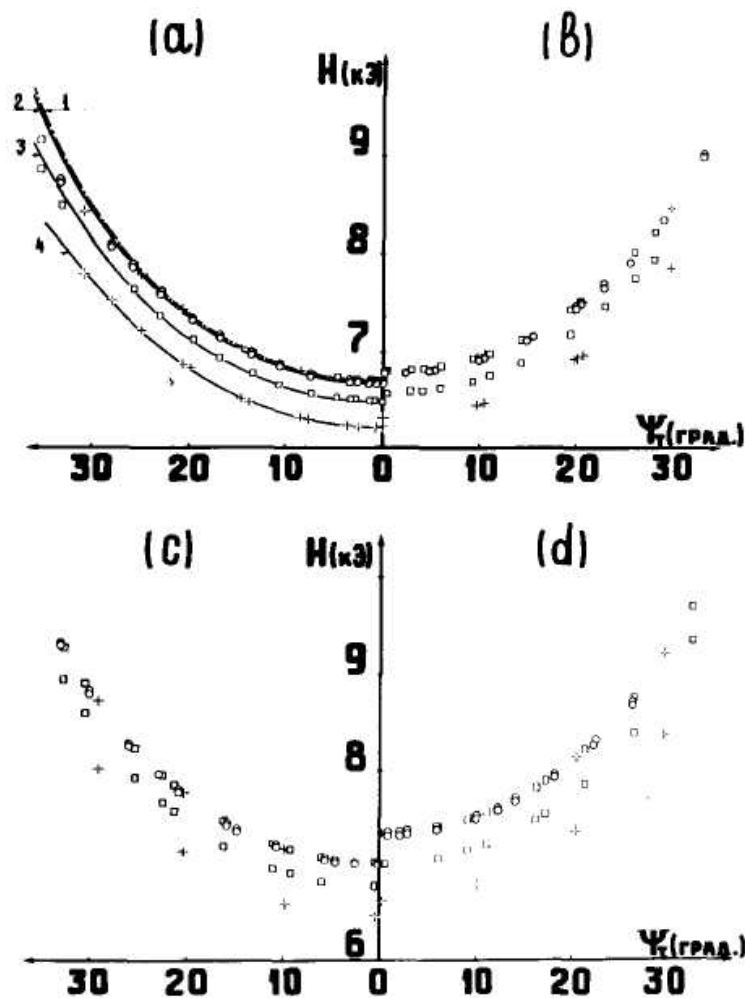


Figure 4.15. The dependence of resonance fields at the deviation of the magnetic field H on the hard plane [103] at $T_1=1.63$ K (a), $T_1=2$ K (b), $T_3=2.5$ K (c), $T_4=3.01$ K (d) at the frequencies $\omega_1=1.1$ GHz, $\omega_2=3.01$ GHz, $\omega_3=4.5$ GHz.

The dependences of fig. 4.15 illustrate the systematic displacement to the region of high fields with both the temperature increase and the rise of the angle of deviation from the axis of easy magnetization toward the hard axis. Here, the attention is paid to the correspondence of results of [81, 103] to analogous data represented on fig. 4.16 in a more explicit form. The resonance absorption lines are in planes parallel to ab -plane in the magnetic field with the varying fixed angle directed to the hard axis and H varying its direction in the easy plane. The type of the dependence is found to be recurrent. But at low temperatures of 2 K, the valley near the axis of hard magnetization becomes increasing much (Fig. 4.17). The application of orientation methods near the axes under consideration helps in finding identity for the low-frequency absorption line in the both planes (Fig. 4.18).

The analysis of results of the observed resonance absorption in magnetic fields lying in the hard plane demonstrates that the higher resonance field does not depend on the frequency within the experimental accuracy. This behavior of frequencies was analyzed in [6, 81, 104] and related to the absorption in the region of structural phase transition. The resonance absorption pattern lasts under H change near the easy axis followed by the orientation thereof near the

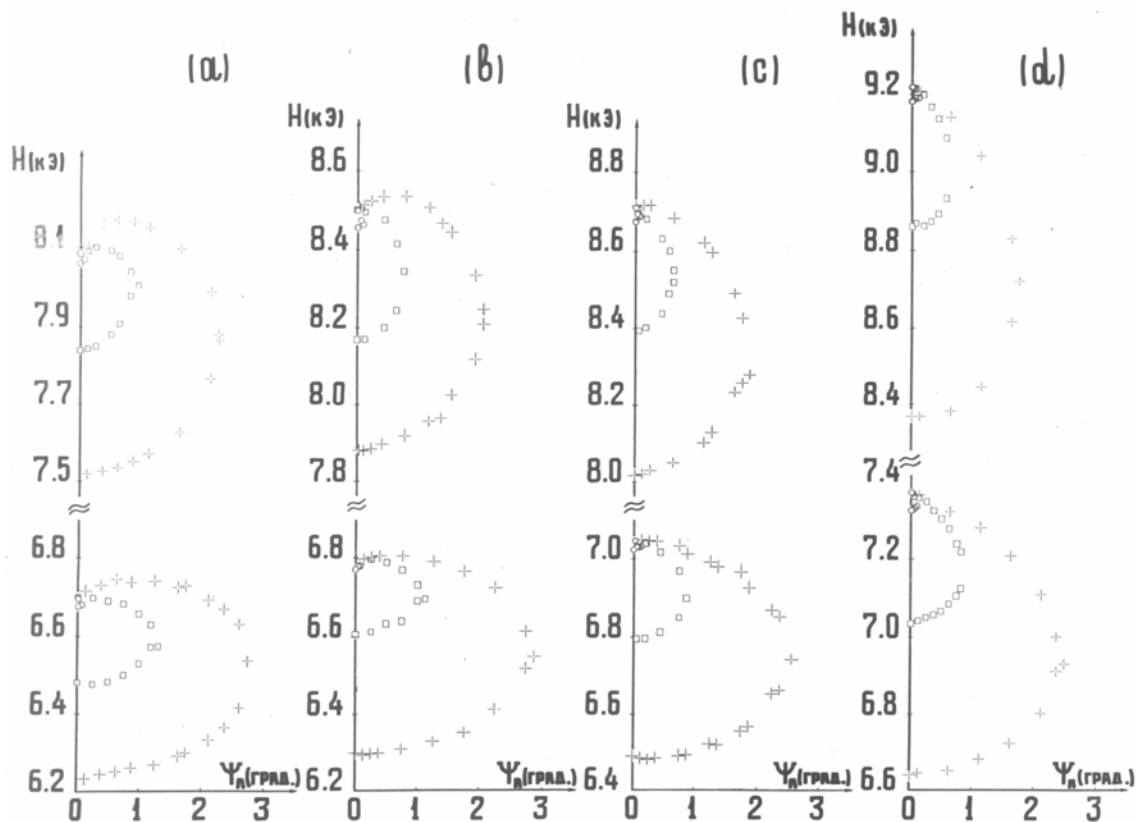


Figure 4.16. The dependence of the resonance fields at the deviation of the magnetic field on the easy plane at the fixed angles of deviation on the hard plane: a) $\psi_1=0^\circ, \psi_2=28^\circ$; b) $\psi_1=0^\circ, \psi_2=30^\circ$; c) $\psi_1=0^\circ, \psi_2=29^\circ$; d) $\psi_1=0.3^\circ, \psi_2=29.5^\circ$.

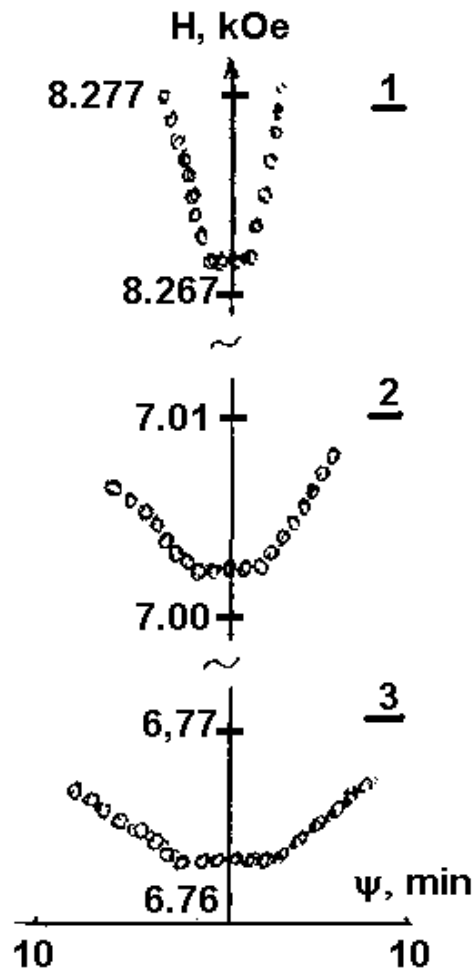


Figure 4.17. The dependence of the higher resonance field near the hard plane [103] for $\bar{a}\bar{c}$ plate at $T=1.98$ K. 1: $\psi_T=29.7^\circ$, $\psi_T=14.7^\circ$, $\psi_T=0^\circ$.

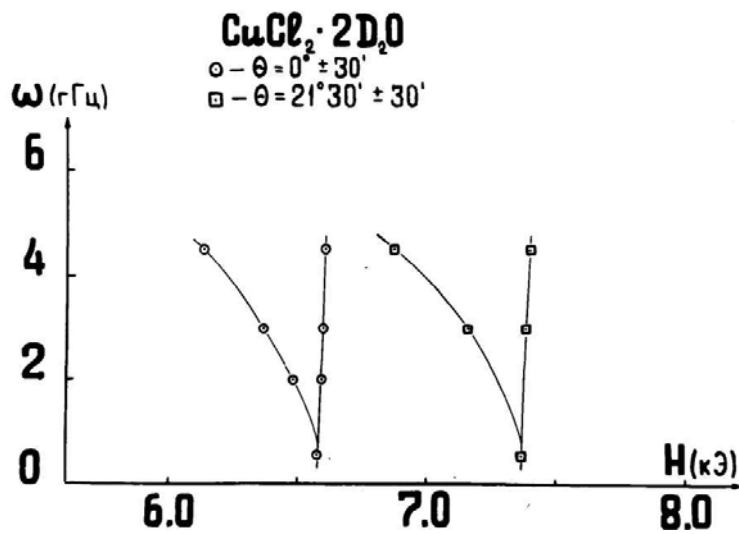


Figure 4.18. Frequency-field dependence of the resonance absorption in $\text{CuCl}_2 \cdot 2\text{D}_2\text{O}$ at $\psi_T=0^\circ$ and $\psi_T=21^\circ 30'$ ($T=1.68$ K)[104].

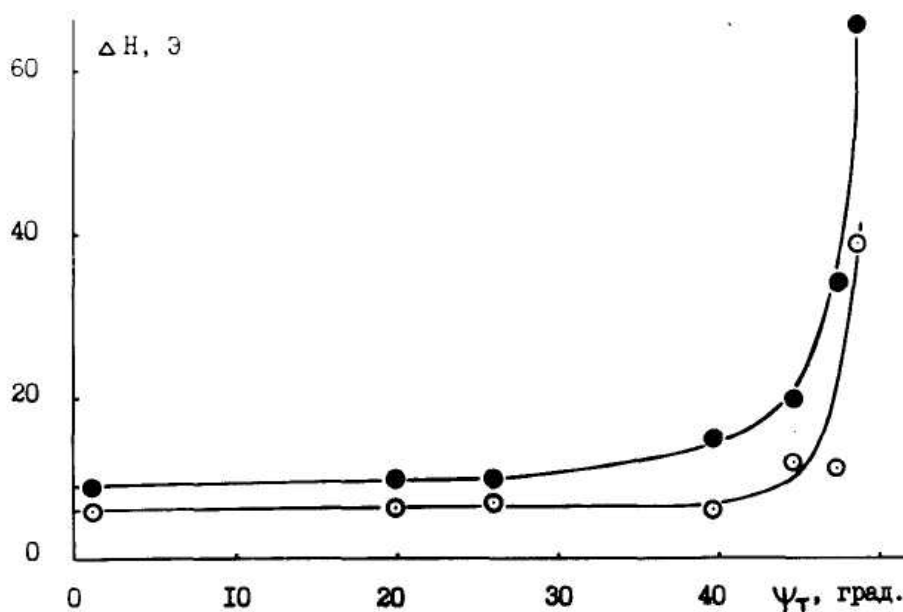


Figure 4.19. The width of lines of resonance fields for $\omega=2.4$ GHz, $T=1.94$ K ((●) denotes ΔH_1 and (○) means ΔH_2).

hard plane [6]. The absorption remains near the hard plane even at very low angles. It does not practically depend on the frequency up to 30° deviation of the magnetic field in the hard plane, i.e. the PT character remains unchanged though the symmetry of phase states changes very much.

Analogous results of the resonance absorption in $\text{CuCl}_2 \cdot 2\text{D}_2\text{O}$ single crystals in the magnetic field lying near the hard axis are represented in [107]. The difference was in the position of resonance fields at all angles, it was 130 Oe lower. The same behavior was observed in ab-plane [105].

By extending the limits of magnetic field to 16 kOe, it becomes possible to treat angles of 48° in the hard planes and to observe changes of the dependences of resonance absorption fields. For every investigated frequency, there are two lines of the resonance absorption for the high-frequency field and the behavior of the lines is similar till the angles of deviation in the hard plane of 40° . With the angle increase, noticeable changes of the resonance fields took place. A growth of the resonance field results in the resonance absorption line broadening and the lines become 5-fold broadened for angles of 48° (Fig. 4.19). The distance between absorption fields becomes much longer, the intensity reduces and the lines are not visible for angles of 43° . The behavior of resonance absorption lines is limited under magnetic field orientation change in the hard plane for 40° deviation. The above results give us grounds to state that the recorded resonance fields of the low-frequency branch of the field-frequency dependence determine the position of phase state and of the region of the first-order structural phase transition for the all angles of magnetic field deviation in the hard plane with the typical change of PT region where

magnetoelastic properties and the anisotropy of magnetoelasticity are specific and typical of two-axis magnetodielectrics. The role of magnetoelastic anisotropy for PT state is also noted. Being in correspondence with the position in the easy plane, it has the dependence for the critical line in exponent form showing the position of the first-order structural phase transition if the hard plane.

4.5. Conclusions

The investigation of the resonance peculiarities in the inclined magnetic field, the revealed changes of the resonance spectra in magnetic fields directed along the assigned directions helped in identification of both the character of the first-order phase transition and the phase states.

The observations demonstrate that the frequency independent part of the upper resonance field belongs to the region of the structural phase transition while the frequency-dependent part of the lower resonance field is of a phase state. The available experimental data make it possible to analyze the resonance spectrum in the easy plane for varying T and H in the selected directions and in samples of different shape in detail.

The resonance absorption in the vicinity of the easy axis is of low intensity. Strict requirements to the magnetic field orientation allow us to confirm the existence of the first-order structural phase transition from estimates of the critical angles as well as a sample shape and temperature effects. It means that the chosen region of resonance absorption studies is a community of several factors that is the role of thermo- and magneto-elasticity anisotropy, the state of the electronic system at varied parameters T and H. The mentioned results point to high importance of high-accurate external field orientation to the symmetry plane of the single crystal. Using these results, it was possible to select and to evaluate the region of the structural phase transition in order to offer mechanisms of the resonance absorption [6] and to show the first-order phase transition boundaries.

With a single crystal in the resonator, it is possible to vary the properties of the structural and magnetic symmetry with respect to the magnetic field orientation in the vicinity of so-called hard axis, i.e. going through the easy axis normal to the easy plane, where the critical region with the first-order phase transition is present. At the hard plane, there are numerous phenomena and effects among PT peculiarities. Thus, when H is directed from the easy axis toward the hard plane, the resonance absorption character is preserved to within 40° and the resonance field is shifted towards increase in this case.

Comparative investigations of $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and $\text{CuCl}_2 \cdot 2\text{D}_2\text{O}$ show the coincidence in the character of the field-temperature dependences. With the varying sample shape and a constancy of the upper resonance field (after the structural PT) for different angles of the hard plane, the resonance fields

demonstrate that the absorption is independent of the angle of deviation, i.e. that the region of PT formation is uniform. The represented results make us to conclude that the component appearing in the hard plane is a consequence of the displacement of properties in the processes of elastic deformation. Resonance absorption of the low-frequency branch satisfies the condition of the formation of critical points and aids in restoration of the picture of structural phase transitions induced by T and H due to the mechanisms of thermoelastic and magnetoelastic stresses in the region with structure peculiarities (in the hard plane). In this case, PT character is not changed.

It follows that the observed low-frequency resonance-absorption fields occur in the region of the phase state and structural phase transition for all the investigated angles of deviation (in both the easy and hard plane) with the typical features of magneto- and thermoelastic anisotropy that is typical of the two-axis low-temperature magnetodielectrics.