ESR of the quasi-two-dimensional antiferromagnet CuCrO$_2$ with a triangular lattice

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Using electron-spin-resonance (ESR) technique we investigate the magnetic structure of CuCrO$_2$, quasi-two-dimensional antiferromagnet with weakly distorted triangular lattice. Resonance frequencies and the excitation conditions in CuCrO$_2$ at low temperatures are well described in the frame of cycloidal spin structure, defined by two susceptibilities parallel and perpendicular to the spin plane ($\chi_\perp$ and $\chi_\parallel$) and by a biaxial crystal-field anisotropy. In agreement with the calculations, the character of the eigenmodes changes drastically at the spin-flop transition. The splitting of the observed modes can be well attributed to the resonances from different domains. The domain structure in CuCrO$_2$ can be controlled by annealing of the sample in magnetic field.

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I. INTRODUCTION

Magnetic materials with frustrated exchange interactions are one of the attractive issues in modern solid state physics. In these materials unconventional magnetic orders appear as a subtle balance of exchange energies and they are often governed by much weaker interactions or fluctuations. Such frustrated systems are known in nature for quasi-one-dimensional, quasi-two-dimensional and for three-dimensional cases. For one(two)-dimensional magnets the interactions within the chain (plane) are much larger then the coupling of spins from different chains (planes).

Magnetic properties of an antiferromagnet on a regular triangular planar lattice have been intensively studied theoretically. The ground state in the Heisenberg and XY-models is a “triangular” planar spin structure with theoretically.

In CuCrO$_2$ three magnetic sublattices arranged by 120° away from each other. Adjacent planes are separated by nonmagnetic copper atoms. The magnetic ordering is accompanied by a simultaneous crystallographic distortion of the regular triangular lattice and by the appearance of a magnetic phase. The electric polarization in CuCrO$_2$ can be influenced by comparatively weak magnetic field. Microscopic mechanism of this complex magneto-elastic transition is not well understood and is a subject of actual investigations.

II. CRYSTAL STRUCTURE AND MAGNETISM IN CuCrO$_2$

CuCrO$_2$ crystallizes in a delafossite structure (space group R3m) with the following hexagonal unit cell parameters at room temperature: $a = 2.98$ Å, $c = 17.11$ Å. The unit cell of CuCrO$_2$ contains three formula units. Chromium ions occupy the positions (0; 0; 1/2), (1/3; 2/3; 1/6), (2/3; 1/3; 5/6) in the crystal cell (see Fig. 1) and Cu$^+$ ions occupy the positions (0; 0; 0), (1/3; 2/3; 2/3), (2/3; 1/3; 1/3) (Ref. [11]). Magnetic Cr$^{3+}$ ions ($S = 3/2$) form a triangular lattice in the ab-planes. Adjacent planes are separated by nonmagnetic copper ions along the c-axis. At temperatures above the Néel temperature ($T > T_N \approx 24$ K) the triangular lattice is regular. In the magnetically ordered state the triangular lattice is distorted, such that one side of the triangle becomes slightly smaller then two other sides: $\Delta a/a \approx 10^{-3}$ (Ref. [12]).

According to neutron diffraction experiments at low temperatures a spiral incommensurate spin structure
FIG. 1: Crystal structure of CuCrO$_2$ in projection on the ab-plane. The positions of Cr$^{3+}$ ions are marked by circles. The crystal cell is outlined with dashed line.

with a wave vector $q_{ic} = (0.329, 0.329, 0)$ is established. The cycloidal rotation of the magnetic moments $M_i$ of Cr$^{3+}$ ions may be written as:

$$M_i = M_1 e_1 \cos(q_{ic} \cdot r_i + \psi) + M_2 e_2 \sin(q_{ic} \cdot r_i + \psi), \quad (1)$$

where $e_1$ and $e_2$ are two perpendicular unit vectors determining the spin plane orientation with the normal vector $n = e_1 \times e_2$, and $\psi$ is an arbitrary phase. The values of the magnetic components ($M_1$, $M_2$) depend on the arrangement of the spiral plane with respect to the crystal axes. For zero magnetic field $e_1$ is parallel to [110] with $M_1 = 2.2(2)$ $\mu_B$ and $e_2$ is parallel to [001] with $M_2 = 2.8(2)$ $\mu_B$, respectively (Ref. [13]). The difference between $M_1$ and $M_2$ reflects the ellipticity of the helix.

According to the results of inelastic neutron scattering the interaction is strongest in the trigonal plane between the nearest Cr$^{3+}$ ions with the exchange constant $J_{ab} = 2.3$ meV. The inter-plane interaction is frustrated and at least one order of magnitude weaker than the in-plane interaction. The nature of the incommensurability of magnetic structure is not clear at present. The value of the incommensurate vector $(0.329, 0.329, 0)$ is very close to the vector of the regular triangle structure $(1/3, 1/3, 0)$ and can be explained by weak interactions. For example, the incommensurability can be influenced by small difference of in-plane interactions of distorted triangles: $J_{ab}/J'_{ab} = -2 \cos(2\pi q_{ic}) \approx 1.05$. Here $J'_{ab}$ is the exchange interaction along the nonequal edges of the distorted triangle. Alternatively, the observed incommensurability can be explained by joint influence of the inter-plane and the next-nearest intra-plane interactions.

The plane of the spin cycloid in CuCrO$_2$ is perpendicular to one side of the triangle. Accordingly, three equivalent magnetic domains coexist in the ordered state. Such arrangement of the spin plane is in agreement with a strong “easy axis” single ion anisotropy along the c-axis as obtained from inelastic neutron scattering experiments. Therefore, the magnetic domains are characterized by both, the distortion of the triangular plane parallel to [100], [010], [110] and the orientation of the cycloidal spin plane with the normal vector $n_{1,2,3} \parallel [100],[010],[110]$, respectively. Such domains will be referred in the text as [100], [010] and [110] domains.

The orientation of the spin plane with respect to triangular plane is defined by a weak in-plane anisotropy and can be influenced by moderate external magnetic field. For $H \parallel [110]$ the spin reorientation transition was observed at 5.3 T.

III. EXPERIMENTAL DETAILS

Single crystals of CuCrO$_2$ were grown by a flux method in Pt crucibles using Bi$_2$O$_3$ as a solvent and starting with polycrystalline pellets. Powder X-ray diffraction measurements of the single crystals did not show any impurity phases. The crystals had a platelet shape (approximately $3 \times 3 \times 0.5 \, \text{mm}^3$) with the large surface perpendicular to the hexagonal c-axis.

Initial polycrystalline CuCrO$_2$ samples were prepared by solid-state reaction from a stoichiometric mixture of CuO and Cr$_2$O$_3$. The mixture was pressed into pellets and sintered at 1000°C for 40 hours in air. This procedure was repeated after intermediate grinding for 40 h at the same temperature.

The ESR experiments were performed with a transmission-type spectrometer using various resonators in the frequency range $14 < \omega/2\pi < 140 \, \text{GHz}$. The superconducting solenoid has provided magnetic fields up to 8 T.

The high frequency branch of the spectra was studied using the quasi-optical technique. In the case of magnetic excitations the transmission through the sample can be obtained as a function of either temperature, frequency, or external magnetic field. Due to well-defined polarization of the electromagnetic radiation the orientation of the ac magnetic field is also known in addition to the direction of the static field. For the present study the following ranges of external parameters have been utilized: $300 < \omega/2\pi < 450 \, \text{GHz}$, $0 < H < 7 \, \text{T}$, and $2 < T < 30 \, \text{K}$. The spectra have been analyzed using Fresnel optical expressions for the transmission of a plane-parallel sample assuming Lorentzian form of the complex magnetic permeability:

$$\mu^* (H) = 1 + \frac{\Delta \mu H_0^2}{H_0^2 - H^2 - iH\delta}. \quad (2)$$

Here $\Delta \mu$, $H_0$, and $\delta$ are magnetic contribution, resonance field and resonance width, respectively.
FIG. 2: (color online) Upper panel: Magnetic field dependence of the ESR frequencies for CuCrO$_2$ single crystal. Magnetic field is directed parallel to one side of the triangular structure: $H \parallel [110]$. Red circles can be attributed to the ESR from the domains with the distorted side aligned along the [110] direction. The black-blue squares correspond to resonances from the domains with the distortions along [100] and [010], respectively. The geometry of the experiment is shown in the inset. Solid line shows the calculated $\omega(H_{\text{res}})$ within the model discussed in the text. The dotted line corresponds to a paramagnetic mode with $g$-factor equal 2. Lower panel: Examples of ESR absorption spectra at $T = 4.2$ K. Black and red arrows mark the absorption modes corresponding to the black and red symbols on the top panel.

FIG. 3: (color online) Upper panel: ESR frequencies in CuCrO$_2$ for magnetic field directed perpendicular to one side of the triangular structure: $H \parallel [\overline{1}10]$. Red circles can be attributed to the modes from the domains with the distorted side aligned along [110]. The black-blue squares corresponds to resonances from the domains with distortions along [100] and [010]. Orientations of the crystallographic axes, applied field and spin planes of three domains are shown in the inset. Solid lines show the calculated $\omega(H_{\text{res}})$ dependences within the model discussed in the text. The dotted line corresponds to a paramagnetic mode with $g = 2$. Lower panel: Examples of ESR absorption lines at $T = 4.2$ K. Black and red arrows mark the absorption lines corresponding to the black and red symbols on the top.

IV. RESULTS

Lower panels of Figs. 2 4 show magnetic field dependencies of the ESR signal in CuCrO$_2$ at different radiation frequencies. These curves were obtained for the magnetic field directed parallel (Fig. 2) and perpendicular (Fig. 3) to one side of the triangular lattice. Corresponding frequencies of the resonance field ($H_{\text{res}}$) are shown in the upper panels. Since the distortion of the triangle at $T < T_N$ can happen along arbitrary side of a triangle structure, we can expect three absorption lines from the three domains shown in the insets. For field directions parallel and perpendicular to one side of the triangular structure, two of three domains will be in equivalent resonance conditions.

Red symbols in Figs. 2 3 correspond to domain with the distortion along the [110] direction. Black and blue symbols throughout this paper correspond to the resonances from two other domains with distortions along the [100] or [010] directions. The $\omega(H_{\text{res}})$ dependence measured for $H \parallel [\overline{1}10]$ direction for [110] domain (red symbols on Fig. 3) shows abrupt softening of one resonance frequency at $H_c \approx 5.3$ T. This field corresponds to the spin reorientation transition observed in Ref. [10]. The spin reorientation can only be observed in the geometry with the static magnetic field applied along the plane of one of the spin cycloids. If magnetic field is ap-
plied perpendicular to the cycloidal plane (as in Fig. 2) then two other domains rotate continuously and no spin reorientation occurs.

For the [110] domain the frequency-field dependence is quasi-linear with field: \( \nu = k\sqrt{H^2 + \Delta^2} \). The coefficient \( k \) is noticeably smaller than the gyromagnetic ratio \( g\mu_B/h \) in two cases: i) at \( \mathbf{H} \parallel [110] \) in full studied field range (red circles in Fig. 2), and, ii) at \( \mathbf{H} \parallel [110] \) for fields higher than spin-flop transition \( H > H_c \) (red circles in Fig. 3). Such a field dependence is typical for a planar spin structure with strong “heavy axis” anisotropy (red circles in Fig. 3, blue triangles in the lower panel of Fig. 4 taken at \( \omega/2\pi = 36.1 \) GHz for the [110] domains is shown in Fig. 4). Magnetic field is rotated within the plane of the triangular structure, i.e. within the(001)-plane. Red circles, black squares, and blue triangles in the \( \omega(H) \) spectra and red, black and blue arrows at the absorption lines from the lower panel can be attributed to the resonances from three magnetic domains. The angular dependence of resonance field (\( H_{res} \)) from every domain has 180 degrees periodicity. The angles at which the resonance fields of different modes coincide follow a triangular geometry. The spectrum in the lower panel of Fig. 4 taken at \( \varphi = 0^\circ \) is equivalent to the spectrum in the lower panel of Fig. 2 measured at the same frequency (36.1 GHz). In a similar way, the spectrum at \( \varphi = 30^\circ \) in Fig. 4 is similar to the spectrum at 36.7 GHz in Fig. 3. Thus, the results in Fig. 4 establish a continuous transformation of spectra in Fig. 2 to the spectra in Fig. 3. These dependencies allow to separate absorption features from different domains.

Fig. 3 shows the angular dependence of the resonance field for the out-of-plane rotation of \( \mathbf{H} \). Solid symbols in the upper panel correspond to experiments with field rotated within the (110) plane. The resonance field initially increases with increasing angle and for \( \theta > 70^\circ \) rapidly exceeds our experimental field range. Since the frequency in these experiments was near the gap of the low frequency branch (\( \approx 33 \) GHz) we can conclude, that for field directions perpendicular to trigonal plane, the low frequency branch is almost independent on \( H \). This fact indicates strong anisotropy along the hexagonal axis in CuCrO₂.

Similar angular dependencies of the resonance positions were obtained for the field rotated within (110) plane. The corresponding angular dependence of \( H_{res}(\theta) \) at \( \omega/2\pi = 89.7 \) GHz for the [110] domains is shown in Fig. 5 with red open symbols. We can expect, that for such field rotation and for \( H < H_c \) the orientation of the (110) spin plane does not change. Therefore, in case of strong anisotropy along the hexagonal axis, the resonance field will be defined by the field projection on the hexagonal plane, i.e.: \( H_{res} = H_{res}(\theta = 0)/\cos(\theta) \). This dependence is given in Fig. 5 with a solid line and agrees well with the experimental points.

The high frequency branch of the ESR spectra
in CuCrO$_2$ was studied using the quasi-optical technique. Transmitted power through the CuCrO$_2$ single-crystalline platelet at various magnetic fields $H \parallel [110]$ are shown in Fig. 6. These frequency dependencies were obtained by division of transmitted power measured at $T = 3$ K by transmitted power measured in the paramagnetic state, $T = 30$ K ($T > T_N$). Such procedure was used to separate the weak signal of the magnetic resonance absorption from other contributions like standing waves within the sample. Fitting of the absorption with Lorenz line shape is shown with a thick solid line. Magnetic field dependencies of the parameters of the observed modes are shown in Fig. 7. The measurements were performed in Voigt geometry with $k \perp \mu_0 H$ and at two polarizations of electromagnetic waves: $h \perp H$ and $h \parallel H$. Here $k||[001]$ is the wave vector of the electromagnetic radiation.

In the case $h \perp H$, as shown in the upper panel of Fig. 7, only the high-frequency mode of the [100] and [010] domains is excited for $H < H_c$. After the spin flop transition for $H > H_c$ the [110] domains are rotated by 90 degrees and they can be excited by the ac field $h \perp H$ as well. This explains the increase in the mode intensity in high magnetic fields as observed in the upper panel of Fig. 7 and given as solid circles in the upper panel of Fig. 7.

In the geometry with $h \parallel H$ (lower panel of Fig. 6) both [100] and [010] domains are only weakly excited because the excitation conditions are more favorable for [110] domains. In this case the observed signal basically comes from the [110] domains which dominate the spectra. In low magnetic fields the resonance frequency of these domains is practically field-independent (solid triangles in the lower panel of Fig. 7). After the spin flop transition for $H > H_c$ the [110] domains cannot be excited in the geometry $H||h$ (see the right inset in Fig. 7). In this case only a weak signal from [100] and [010] domains is observed. This is in agreement with a suppression of the mode intensity as shown in the upper panel of Fig. 7 by solid triangles.

V. BUILDING AND CONTROL OF MAGNETIC DOMAINS IN CuCrO$_2$

As discussed above, the ESR technique allows to recognize the absorption modes originating from different domains. In this sections we demonstrate that structural and magnetic domains are strongly sensitive to thermal and magnetic history of the sample and that magnetic domains are mobile already at temperatures close to 5 K.

To obtain the results presented in this chapter we repeated the experiments within the geometry of Fig. 3 i.e. at magnetic fields perpendicular to one side of triangle structure: $H \parallel [100]$. The data have been obtained at the lowest temperature of our spectrometer $T = 1.2$ K and at two frequencies of 36.1 GHz and 17.1 GHz. As discussed above, within this geometry the spectra at lower frequency show a magnetic mode above critical spin-flop field and they are sensitive to [110] domains only. The spectra at 36.1 GHz show two modes at about 0.5 T and 0.9 T (i.e below the spin-flop field) and they correspond to a signal from [110] and ([100]+[010]) domains, respectively. Therefore, analyzing the intensities of the corresponding modes as a function of magnetic and thermal history, we obtain information about relative population of different domains.

Figs. 8,9 show the ESR spectra measured within the geometry of Fig. 6 but for different magnetic and thermal history of the sample. In the experiments presented in Fig. 8 the sample was cooled in various static magnetic fields as indicated (field-cooled regime). In the experi-
ments presented in Fig. 9 the mobility of the domains was investigated. The sample was initially cooled down to 1.2 K in zero magnetic field, producing all three domains. In a second step the sample was annealed at various temperatures $T_{\text{heat}}$ and at static magnetic field $\mu_0 H_{\text{heat}} = 7.7$ T applied along the [110] direction. Such field annealing lasted two minutes. In a following step first the temperature and then the field were reduced to $T = 1.2$ K and to $H = 0$. Such treatment has been done prior to every field scan shown in Fig. 9.

First, we start the discussion with the results of the field-cooling experiments, which are shown in Fig. 8. The absorption lines measured at 17.5 GHz and attributed to the domains with distorted [110] side are shown on the top panel of Fig. 8. These absorption modes appear at magnetic fields higher the spin-flop field: $H > H_c$.

Clearly, the intensity of the observed mode is strongly suppressed for the field-cooled sample. The middle panel of Fig. 8 shows the spectra measured at fields below the spin-flop transition: $H < H_c$.

The mode that is marked by red arrow corresponds to the absorption line from [110] domains and it obviously demonstrates the same behavior as the spectra in the upper panel. In addition, the mode from two other domains, [100] and [010], is observed in these experiments as well. This mode is more intensive in this geometry and it is marked by black arrow. The field cooling reduces the integral intensity of absorption line from the [110] domains and increases the intensity from two other domains. This experiment shows, that a comparatively small external field suppresses the energetically less favorable domains and shifts the ESR intensity to two other domains. This qualitative analysis is supported by the values of integrated intensities of the ESR modes as given in the bottom panel of Fig. 8.

The absorption lines shown in Fig. 9 were obtained using the cooling history as described above. Here the
FIG. 8: (color online) ESR absorption lines measured for magnetic field perpendicular to one side of the triangular structure ($\mathbf{H} \parallel [110]$) and at $T = 1.2$ K. Top panel: absorption line measured at 17.5 GHz which corresponds to the [110] domains and is seen for $H > H_c$. Middle panel: absorption lines of the [110] domains and [100]+[010] domains measured at 36.1 GHz, marked with red and black arrows respectively. The data were obtained for a field-cooled sample at different fields $H_{cooling}$. Bottom panel: the integral intensity of the ESR lines as function of $H_{cooling}$ for [110] domains obtained from the curves in the top panel (red circles) and for [100]+[010] domains obtained from the middle panel (black squares). Dotted lines are guides for the eye.

FIG. 9: (color online) ESR absorption lines measured for magnetic field perpendicular to one side of the triangular structure ($\mathbf{H} \parallel [110]$) and at $T = 1.2$ K. Top panel: absorption line measured at 17.5 GHz which corresponds to the [110] domains and is seen for $H > H_c$. Middle panel: absorption lines of the [110] domains and [100]+[010] domains measured at 36.1 GHz and marked with red and black arrows respectively. The data were measured after annealing of the sample at different $T_{heat}$ and at $\mu_0H_{heat} = 7.7$ T. Bottom panel: the integral intensity of the ESR lines as a function of $T_{heat}$ for the [110] domains obtained from the data of the top panel (red circles) and for [100]+[010] domains obtained from the middle panel (black squares). Dotted lines are guides for the eye.
The field and angular dependencies of the resonance frequencies as observed at $T \ll T_N$ in CuCrO$_2$ can be consistently described by the model of coplanar exchange spin-structure whose orientation in space is defined by weak relativistic interactions with external field and by the crystal environment. The phenomenological hydrodynamical theory of macroscopic dynamics of magnets with dominant exchange interactions was developed in Ref. [20]. The application of this theory to the coplanar magnetic structures was described in Ref. [21] and will be used in the following discussion. The anisotropic part of the energy of magnetic structure of CuCrO$_2$ can be written as:

$$U = -\frac{\chi_\parallel - \chi_\perp}{2}(\mu \mathbf{H})^2 + \frac{1}{2}(A n_\parallel^2 + B n_\perp^2), \quad (3)$$

where $\mathbf{n}$ is a unit vector perpendicular to the spin plane; $\chi_\parallel$ and $\chi_\perp$ are the susceptibilities of the planar structure parallel and perpendicular to $\mathbf{n}$ and they are defined by exchange interactions; $A$ and $B$ are the anisotropy constants. For the case of CuCrO$_2$: $\mathbf{z} \parallel [001]$, $\mathbf{y} \parallel [110]$, $\mathbf{x} \parallel [110]$, $A < B < 0$ and $\chi_\parallel > \chi_\perp$. The minimum of energy at $\mathbf{H} \parallel \mathbf{x}$ is realized for the structure with $\mathbf{n} \parallel \mathbf{x}$. At field directions $\mathbf{H} \parallel \mathbf{z}$ and $\mathbf{H} \parallel \mathbf{y}$ a spin reorientation take place at critical fields $H_{cz}^2 = A / (\chi_\parallel - \chi_\perp)$ and $H_{cy}^2 = (B - A) / (\chi_\parallel - \chi_\perp)$, respectively. For fields below $H_c$ the spin plane is oriented by crystal anisotropy: $\mathbf{n} \parallel \mathbf{x}$. At $H > H_c$ the spin plane is oriented by field: $\mathbf{n} \parallel \mathbf{H}$. The resonance frequencies of acoustic modes of planar spin structures can be obtained in the frame of Lagrangian formalism$^{20}$ using the potential energy in form of Eq. (3). The resonance frequencies at zero magnetic field are: $w_{10}^2 = \gamma(-A) / \chi_\parallel$; $w_{20}^2 = \gamma(B - A) / \chi_\perp$, and $w_{30}^2 = 0$, where $\gamma$ is the gyromagnetic ratio. These frequencies correspond to oscillations of the spin structure around three axes as schematically shown in the inset to Fig. 10. The zero energy oscillation $w_3$ indicates the degeneracy of the ground state with respect to rotations of the structure around the vector $\mathbf{n}$. The experimental values of $w_{10} / 2\pi = 340$ GHz and $w_{20} / 2\pi = 33$ GHz and the spin-flop field $H_{cy} = 5.3$ T at $\mathbf{H} \parallel \mathbf{y}$ obtained here are in a good agreement with the results given in Ref. [10]. The theoretical curves describe well the experimental points. A small deviation (7%) of experimental points ascribed to domain [110] at $\mathbf{H} \parallel [110]$, $H < H_c$, from theoretical dependence (See Figs. 3-10), is most probably due to higher order anisotropy terms in Eq. (3), which are not considered in the discussed model.

The values of $w_{20}$ and $H_{cy}$ allow to define the susceptibility anisotropy of the spin structure: $\eta = (\chi_\parallel - \chi_\perp) / \chi_\perp = (w_{20} / \gamma H_{cy})^2 = 0.045 \pm 0.03$. This small anisotropy is a result of close similarity of the magnetic structure of CuCrO$_2$ to the regular 2D triangular structure, for which, if we neglect fluctuations, $\chi_\parallel$ is equal to $\chi_\perp$.

From the present results we can evaluate the spin-
flop field for $H \parallel z$ as: $H_{cz} = H_{cy}(w_{10}/w_{20}) \approx 55$ T. This value exceeds by far our available experimental range, but is still much below the expected saturation field of CuCrO$_2$. The latter can be estimated using the susceptibility value $\chi = 0.006$ emu/mol as: $H_{sat} \approx M_{sat}/\chi \approx 280$ T.

Theoretical field dependence of the resonance frequencies for field directions $H \parallel [110]$ and $H \parallel [1\bar{1}0]$ are shown in Fig. 10. The spectra are defined by three parameters $\omega_{10}, \omega_{20}$ and $H_{cy}$ as given above. The experimental resonance frequencies for the domains with distortion of the triangular structure along $[1\bar{1}0]$ direction are shown in the same figure with red symbols. Open black symbols in Fig. 10 show the high frequency excitation branches from all three domains.

The experimental study of the magnetic domain distribution in the single crystals of CuCrO$_2$ shows that their relative size depends on the magnetic history of the sample. The sample cooled at zero magnetic field has three domains of comparable volume. Both, the field cooling and the field annealing reduces the volume of the domains which are oriented unfavorably with respect to static field. The data demonstrates that the rebuilding of the domains takes place at temperatures much below the Néel temperature. Such behavior indicates an anomalously large mobility of magnetic domain walls in CuCrO$_2$. The observed effect needs further investigations in order to test the magnetic structure during the rebuilding of the domains. In particular, it is necessary to prove experimentally that the wave vector direction within the domains agrees with the in-plane anisotropy.

We note that for each magnetic domain with a specific orientation of the spin plane two different directions of the chirality vector exist. According to Refs. [12] and due to magnetoelastic coupling in CuCrO$_2$ these magnetic domains can be switched by external electric fields. Such high sensitivity of the magnetic structure in CuCrO$_2$ to external effects makes this system very attractive from the experimental point of view.

VII. CONCLUSIONS

We performed detailed electron-spin-resonance studies of a frustrated triangular quasi-two-dimensional antiferromagnet CuCrO$_2$. The results of low temperature ESR experiments are well described in the frame of phenomenological model of coplanar spin structure with bi-axial anisotropy. Our calculations reproduce well the experimentally observed changes of the character of the eigenmodes at the spin-flop transition. The observed splitting of the modes is attributed to resonances from different domains which can be controlled by annealing of the sample in magnetic field.

CuCrO$_2$ is an example of a frustrated triangular quasi-two-dimensional antiferromagnet with spin $S = 3/2$. This material thus occupies an intermediate position between the systems with large spin which are intensively studied experimentally and theoretically and the systems with $S = 1/2$, for which the experimental objects are still far from being a model for theory.

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