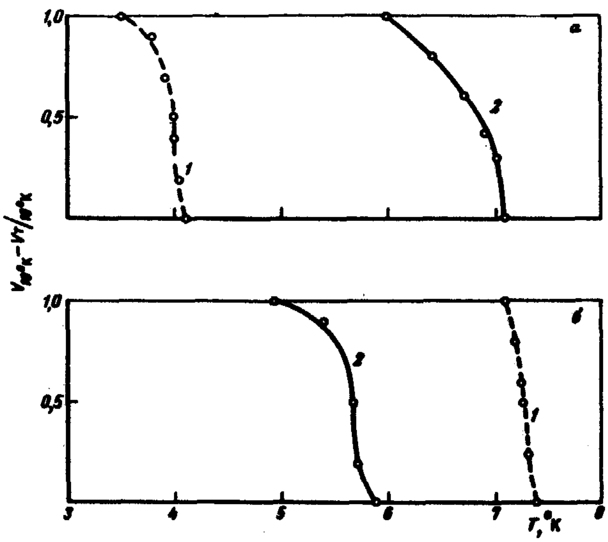

Curves showing transitions of Tl-Sn (a) and Pb-Sn (b) alloys into the superconducting state after various treatments.

[1]. After pressure treatment, as already noted, T_c increases for the Tl-Sn alloys and decreases for Pb-Sn, assuming in both cases (particularly Tl-Sn) a value close to the $T_c \approx 6.4°K$ that Sn II should have at P = 0, as would follow from a linear extrapolation of the data of [6, 7] on the pressure dependence of the critical temperature T_c of Sn II.

These facts give grounds for drawing the preliminary conclusion that the intermediate phases produced under pressure in these alloys are solid solutions based on the high-pressure modification of Sn II. Of course, to confirm this conclusion it is necessary to determine the structures under pressure by x-ray diffraction.

[1] E. Yu. Tonkov and I. L. Aptekar', Dokl. Akad. Nauk SSSR 188, No. 2 (1969) [Sov. Phys.-Dokl. 14, No. 9 (1970)].
[2] M. Hansen and K. Anderko, Constitution of Binary Alloys, McGraw-Hill, 1968.
[3] N. Ryoichi, O. Eisei, and H. Hisato, Bull. Univ. Osaka, A15, No. 1, 137 (1966).
[4] E. G. Ponyatovskii and A. G. Rabin'kin, ZhETF Pis. Red. 6, 471 (1967) [JETP Lett. 6, 10 (1967)].
[5] A. I. Zakharov and A. G. Rabin'kin, Fiz. Met. Metallov. 26, 921 (1968).
[6] I. Wittig, Zs. Physik, 195, 215 (1966).
[7] N. B. Brandt and I. V. Berman, ZhETF Pis. Red. 7, 198 (1968) [JETP Lett. 7, 152 (1968)].

ANTIFERROMAGNETIC RESONANCE IN COPPER CHLORIDE DIHYDRIDE AT LOW FREQUENCIES FOLLOWING TURNING OF THE SUBLATTICE MAGNETIC MOMENTS

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The dependence of the antiferromagnetic-resonance (AFMR) frequencies on the external magnetic field was investigated by many workers, and the experimental data are in good agreement with the theory [1]. However, some data [2] concerning the AFMR frequencies near the field H_t at which the magnetic moments are turned have not yet been explained. The purpose of this paper is to investigate AFMR at low frequencies. Particular attention is paid to the magnetic-field region close to the field H_t.

The dependence of the AFMR frequencies at $|H - H_t| << H_t$ on the magnetic field H (which is parallel to the easy axis) is determined by the character of the phase transition in which the antiferromagnetism vector $\vec{\ell}$ is rotated by $\pi/2$. If the transition from the phase $\ell_\parallel$ in which $\vec{\ell}$ is parallel to the easy axis to the phase $\ell_\perp$ where $\vec{\ell}$ is perpendicular to the easy axis

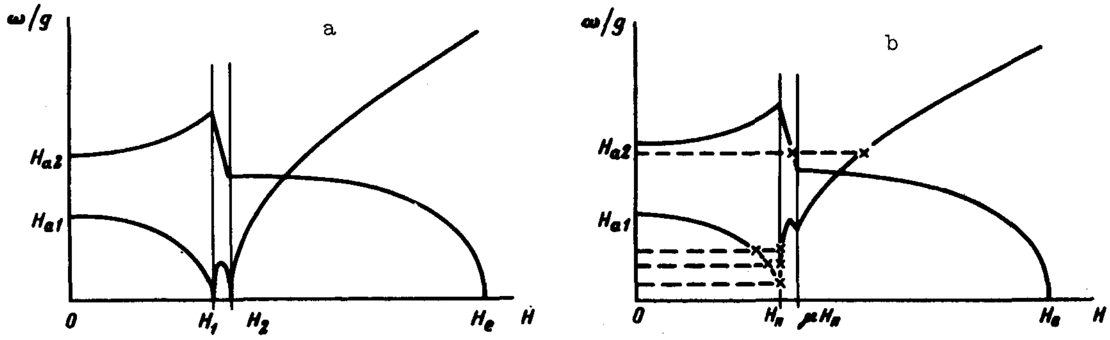

Fig. 1. Schematic plot of AFMR frequencies vs. magnetic field H. The crosses in Fig. 1b represent the resonant fields corresponding to the frequencies ν_1, ν_2, and ν_4 of the present work and to the 32 GHz frequency of [2].

proceeds continuously (via a phase $\ell_{\angle}$) [3], then the dependence of the AFMR frequencies on the magnetic field has the form shown in Fig. 1a [4]. On the other hand, if the transition from the phase $\ell_{\parallel}$ to the phase $\ell_{\perp}$ occurs jumpwise (via a first-order phase transition through an intermediate state of the antiferromagnet) [5], then the dependence of the AFMR frequencies on the magnetic field has the form shown in Fig. 1b (see below).

To determine the character of the transition, we investigated the AFMR at low frequencies, ν_1 = 5.2 GHz, ν_2 = 3 GHz, ν_3 = 1.1 GHz, and ν_4 = 0.65 GHz. At the frequencies ν_1, ν_2, and ν_3 we observed two resonance lines each, and at ν_4 only one resonance line. At none of the investigated frequencies did we observe four resonance fields at $T \geq 1.5^{\circ}K$ (see Fig. 1a).

We investigated the dependence of the resonance fields corresponding to the frequencies ν_2 and ν_4 on the temperature T in the temperature range from 1.52 and 4.2°K. These data are shown in Fig. 2.

The resonance fields corresponding to the frequencies ν_1 and ν_3 were measured at T = 1.52°K. The results were: the frequency ν_1 corresponds to resonance fields H_1 = 6.12 and H_2 = 6.73 kOe, while ν_3 corresponds to H_1 = 6.63 and H_2 = 6.65 kOe.

The temperature dependences of the larger of the resonance fields, corresponding to the frequency ν_2, and of the resonance field corresponding to ν_4 are the same, within the limits of the experimental error, and coincide with the temperature dependence of the field $H_t(T)$ in which the phases $\ell_{\parallel}$ and $\ell_{\perp}$ are in equilibrium.[1)]

Let us calculate the resonance frequencies of an antiferromagnet broken up into domains, starting from the equations of motion of the magnetic moments

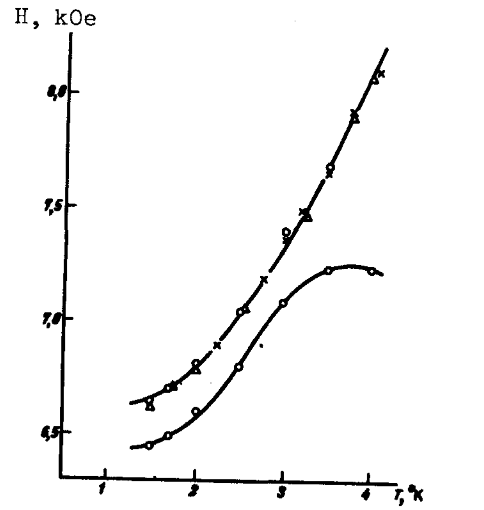

Fig. 2. Temperature dependence of the resonant and transition fields. o - ν_2, Δ - ν_4, × - H_{tr}.

1) The measurements were made on the same sample under invariant experimental conditions.

$$\frac{\partial M_1}{\partial t} = \gamma[M_1, \tilde{H}_1], \quad \frac{\partial M_2}{\partial t} = \gamma[M_2, \tilde{H}], \qquad \tilde{H}_i = -\frac{\delta W}{\delta M_i} \tag{1}$$

and an antiferromagnet energy equal to

$$W = \int\{ I_o M_1 M_2 + \alpha \frac{\partial M_1}{\partial x_i}\frac{\partial M_2}{\partial x_i} + \beta' M_1^* M_2^* + \rho' M_1^y M_2^y + \frac{1}{2}\beta[(M_1^*)^2 + (M_2^*)^2] + \frac{1}{2}\rho[(M_1^y)^2 + (M_2^y)^2] - \mu(H, M_1 + M_2)\} dV, \tag{2}$$

where $\vec{I}_0$ and α are the constants of the homogeneous and inhomogeneous exchange interaction, ρ and β are the anisotropy constants, and we are considering the case $\beta - \beta' > \rho - \rho' > 0$, which corresponds to a first-order transition from the phase $\ell_{\|}$ to the phase $\ell_{\perp}$. The z axis is directed along the easy axis, and the y axis along the b axis of the rhombic cell of $CuCl_2 \cdot 2H_2O$. The equilibrium values of the magnetic moments $\vec{M}_{10}$ and $\vec{M}_{20}$ depend on the coordinates in accordance with the fact that the antiferromagnet is broken up into domains of phases $\ell_{\|}$ and $\ell_{\perp}$ [5].

In the phase $\ell_{\|}$, $\vec{M}_{10}$ is parallel and $\vec{M}_{20}$ is antiparallel to the easy axis; in $\ell_{\perp}$, M_{10} and M_{20} lie in the same plane on opposite sides of the easy axis, the angle between which and each magnetic moment is θ.

Putting $\vec{M}_{10} = \vec{M}_{10} + \vec{m}_1$ and $\vec{M}_{20} = \vec{M}_{20} + \vec{m}_2$, where $\vec{m}_1$ and $\vec{m}_2$ are small deviations from the equilibrium values of the magnetic moments, and using (1) and (2), we can obtain, after averaging the linearized equations for $\vec{m}_1$ and $\vec{m}_2$ over the domain structure, the following expression for the AFMR frequencies

$$\omega_{1,2} = \{ A^2 + (\xi\gamma H)^2 + A_{12}^2 + B_{11}^2 + B_{12}^2 \pm 4[(AA_{12} - B_{11}B_{12})^2 + (\gamma\xi H)^2(A^2 - B_{12}^2)]^{1/2}\}, \tag{3}$$

where

$$A = \gamma M_o[I + \frac{1}{2}(\beta + \rho)]\xi + \gamma M_o[I + \rho' + \frac{1}{2}\beta - \frac{1}{2}\rho(1 + \sin^2\theta)](1 - \xi),$$

$$A_{12} = \frac{1}{2}\gamma M_o[\beta' - \rho']\xi + \gamma M_o[I\cos^2\theta + \frac{1}{2}\beta' + \frac{1}{2}\rho'\cos^2\theta](1 - \xi),$$

$$B_{11} = \frac{1}{2}\gamma M_o(\beta - \rho)\xi + \frac{1}{2}\gamma M_o(\beta - \rho\cos^2\theta)(1 - \xi), \tag{4}$$

$$B_{12} = \gamma M_o[I + \frac{1}{2}(\beta' - \rho')]\xi + \gamma M_o[I\sin^2\theta + \frac{1}{2}(\beta' - \rho'\cos^2\theta)](1 - \xi)$$

ξ is the fraction of the matter in phase $\ell_{\|}$. In the derivation of (3) we have neglected the domain-wall thickness.

If the antiferromagnet is in the form of a plate whose surface is perpendicular to the external magnetic field, and if $H < \mu_{\|} H_t(T)$ (where $\mu_{\|}$ is the longitudinal permeability of the ferromagnet), then we must put $\xi = 1$ in (3) and (4), and we arrive at the resonance frequencies in a biaxial antiferromagnet in the $\ell_{\parallel}$ phase. When $H > \mu_{\perp} H_t(T)$ ($\mu_{\perp}$ is the transverse permeability of the antiferromagnet), it is necessary to put $\xi = 0$ in (3) and (4), and we arrive at the resonance frequencies of a biaxial antiferromagnet in the $\ell_{\perp}$ phase. Finally, the variation of the frequencies in the field interval $\mu_{\parallel} H_t < H < \mu_{\perp} H_t$ is described by formulas (3) and (4) in which we must put $H = H_t$ and $\xi = (\mu_{\perp} H_t - H_E)(\mu_{\perp} - \mu_{\parallel})^{-1} H_t^{-1}$. The field dependence of the AFMR frequencies, in a wide range of fields, as described by formulas (3) and (4), is plotted in Fig. 1b. The AFMR frequencies for bodies of different shapes are similar, but the field interval in which ξ varies from zero to unity depends on the shape of the body. Since $\chi_{\perp} = (\mu_{\perp} - 1)/4\pi$, the field interval from $\mu_{\parallel} H_t$ to $\mu_{\perp} H_t$ is very small. Therefore the temperature dependence of the resonance fields corresponding to the intersection of the line ω = const with the resonance curves $\omega = \omega_{1,2}(H)$ in the interval from $\mu_{\parallel} H_t$ to $\mu_{\perp} H_t$ will duplicate the temperature dependence of the field $H_t(T)$, as was indeed observed in our experiments.

As seen from Figs. 1b and 2, the values of the larger resonance fields at the frequencies ν_2 and ν_4 and their dependence on the temperature coincide with those for $H_t(T)$. These data, together with the data of [2] concerning the smaller resonance field at 32 GHz offer evidence, in our opinion, that[2)] the transition from the phase $\ell_{\parallel}$ to the phase $\ell_{\perp}$ in $CuCl_2 \cdot 2H_2O$ at $T \geq 1.52°K$ is of first order, and that the antiferromagnet breaks up in this transition into domains of the phases $\ell_{\parallel}$ and $\ell_{\perp}$, as was deduced theoretically in [5].

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[1] A. S. Borovik-Romanov, Itogi nauki FMN (Science Summaries, Physico-mathematical Sciences), No. 4, AN SSSR, 1962.
[2] H. J. Gerritsen, Physica, 21, 639 (1955).
[3] E. A. Turov, Fizicheskie svoistva magnitouporyadochennykh kristallov (Physical Properties of Magnetically Ordered Crystals), AN SSSR, 1963.
[4] V. A. Popov and E. V. Zarochentsev, Ukr. fiz. zh. 10, 368 (1965).
[5] V. G. Bar'yakhtar, A. E. Borovik, and V. A. Popov, ZhETF Pis. Red. 9, 634 (1969) [JETP Lett. 9, 394 (1969).
[6] G. E. G. Hardeman and N. J. Poulis, Physica, 21, 728 (1955).
[7] R. J. Joenk, Phys. Rev. 126, 565 (1962).
[8] M. Garber and H. J. Gerritsen, Physica, 22, 189 (1956).

LINE SHAPE OF RESONANT STIMULATED RAMAN SCATTERING IN NEON

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Much interest is being evinced at present in stimulated shifted (Raman) scattering. In the quantum theory of radiation [1, 2], the scattering is regarded as a process that proceeds via definite intermediate states (virtual levels). The presence of real levels leads to a

[2)] It might be assumed that absorption of the high-frequency field energy in the antiferromagnet at $H = H_t$ is connected with heterophase fluctuations, but this assumption is contradicted by the data of [8], where no absorption was observed at 9 GHz in a field $H = H_t$ and at $T < 2.2°K$.