Antiferromagnetic resonance in the field-induced AFM state.

- V.N.Glazkov, A.I.Smirnov, A.Kolezhuk, H.Tanaka, A.Oosawa, "Low-energy dynamics of the spin-gap magnet $TlCuCl_3$ at the critical field", J. Magn. Magn. Mater. **310**, e454-e456 (2007)
- A.K.Kolezhuk, V.N.Glazkov, H.Tanaka, and A.Oosawa , "Dynamics of an anisotropic spin dimer system in a strong magnetic field", Physical Review B **70**, 020403 (2004)
- V.N.Glazkov, A.I.Smirnov, H.Tanaka, A.Oosawa, "Spin-resonance modes of the spin-gap magnet $TlCuCl_3$", Physical Review B **69** 184410 (2004)

Application of the magnetic field usually tends to destroy antiferromagnetic order as it tries to align all spin parallel to the field to gain in Zeeman energy. Spin-gap magnets demonstrate a surprising phenomenon of induction of the antiferromagnetic order by the applied magnetic field.

A ground state of the spin-gap magnet is a nonmagnetic singlet and the excited triplet levels are separated from the ground state by the energy gap Δ of the exchange origin. One of the triplet sublevels shifts downwards with the increase of the applied magnetic field (see insert of the Figure 1) and at certain critical field $H_c \sim \Delta/(g\mu_B)$ it crosses with the singlet state, i.e. the energy gap "closes". As the energy gap is closed, the nonmagnetic spin-liquid state became unstable and, since antiferromagnetic interactions dominates in the spin-gap magnets, antiferromagnetic order appears. (Formation of the antiferromagnetism above H_c was confirmed, e.g., by the appearance of the magnetic Bragg reflexes.) In the Heisenberg exchange approximation the phase transition to the field-induced antiferromagnetic state lies in the same XY universality class as the superfluid transition in liquid helium-4 or the BCS-model superconducting transition. This similarity leads to the numerous speculations in literature, describing the formation of the field-induces antiferromagnetism as a Bose-Einstein condensation of magnons.

A dimer compound $TlCuCl_3$ is a convenient system to study this phenomenon due to the relatively small values of H_c (~50kOe) easily obtainable in the experiment.

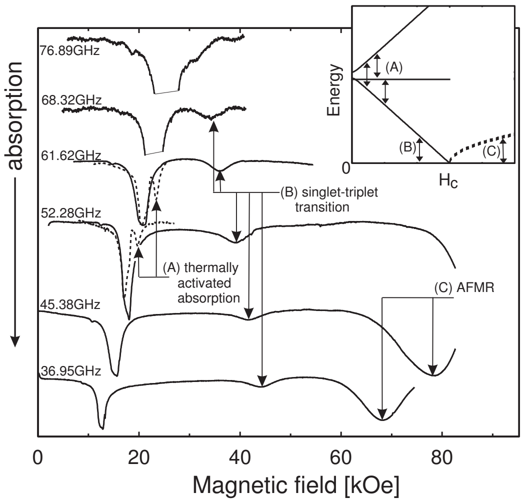

Figure 1: ESR absorption spectra at different frequencies for $\mathbf{H}||b$. Solid lines, T=1.5K; dashed lines, T=4.2K. Insert: Qualitative scheme of the energy levels of the spin-gap system in a magnetic field in the presence of orthorhombic anisotropy.

In our experiment we have observed directly resonance transitions between different states of spin gap magnet (Figure 1). Below H_c we have observed both singlet-triplet and triplet-triplet transitions. We also observed a specific strongly-anisotropic antiferromagnetic resonance signal above H_c. Complete frequency-field diagram is presented at the Figure 2. Observation of the non-Goldstone resonance mode above H_c, splitting of the triplet sublevels and observation of the "forbidden" singlet-triplet transition indicates presence of the anisotropic interactions breaking the XY symmetry. Thus, the model of Bose-Einstein condensation of magnons is, at best, only approximately applicable to the $TlCuCl_3$. Our results can be quantitatively described (see solid lines on Figure 2) assuming reasonable microscopic anisotropic interactions (for the details of the implied model see A.K.Kolezhuk *et al.* Physical Review B **70**, 020403 (2004)).

A characteristic feature of the field-induced antiferromagnetic state is small and unsaturated value of the antiferromagnetic order parameter in the vicinity of H_c even at T=0. Thus, a mode with longitudinal oscillations of the order parameter is possible in addition to the convenient transverse-oscillations modes. Theoretical analysis demonstrates, surprisingly, that the lowest magnon branch contains very strong admixture of the longitudinal oscillations (Figure 3).

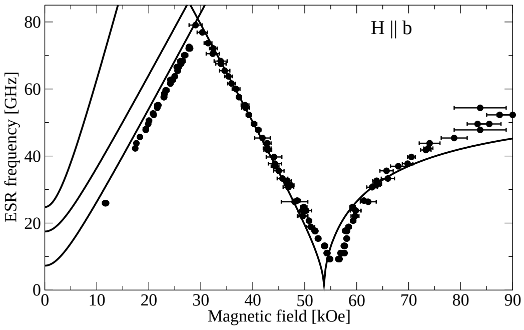

Figure 2: ESR frequency-field dependences taken at T=1.5K for $\mathbf{H}||b$ (circles) in comparison with the model calculations (solid lines).

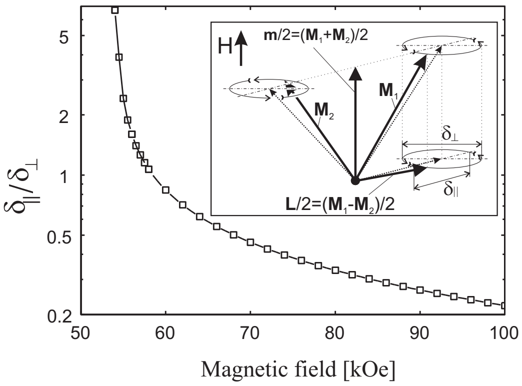

Figure 3: Field dependence of the order parameter precession ellipse axes ratio (ratio of the amplitudes of longitudinal ($\delta_{||}$) and transverse ($\delta_{\perp}$) order parameter oscillations) for the lowest magnon branch at $\mathbf{H}||b$. Insert: scheme of the sublattice magnetization precession.

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