Spinon resonance in Cs_2CuCl_4.

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Spinons, fractionalized magnetic excitations, carrying spin $S = 1/2$, are usually observed in highly one–dimensional antiferromagnetic chains. Nonetheless, non-1D systems can sometimes possess this sort of quasiparticles as well. This is the case of Cs_2CuCl_4, a nominally 2D system, where frustration leads to effective decoupling of a distorted triangular lattice into a set of non-interacting chains. Such a dimensional reduction due to frustration results in a characteristic neutron scattering continuum, which is a

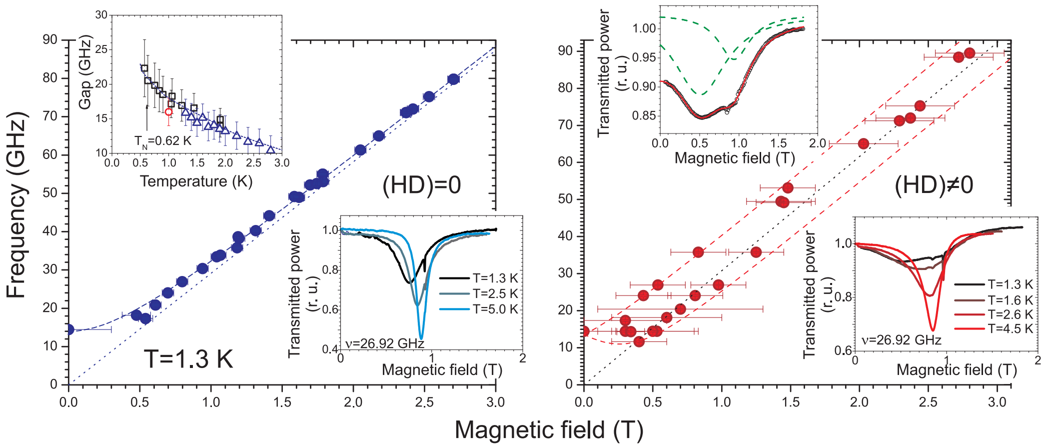

Figure 1: Main panels — ESR spectra in a spin–liquid phase of Cs_2CuCl_4 for field directions $\mathbf{H} \perp \mathbf{D}$ and $(\mathbf{H} \cdot \mathbf{D}) \neq 0$ (points are experimental data, dashed lines are theory). Examples of ESR lines for corresponding field directions at different temperatures are given in the bottom inserts. Left upper insert shows temperature dependence of the gap, right upper insert demonstrates a two-lorenzian fit of the resonance line.

hallmark of spinon excitations (see Coldea *et al*, Phys. Rev. Lett. **86**, 1335 (2001)). Another peculiarity of Cs_2CuCl_4 is the uniform Dzyaloshinskii–Moriya interaction $\mathbf{D}$ on the chain bonds J. It can be shown, that individual spinons experience this interaction as an effective magnetic field with "+" or "-" sign, depending on the direction of their propagation (Gangadharaiah, Sun, Starykh, Phys. Rev. B **78**, 054436 (2008)). Hence, the frequency of the magnetic resonance is modified. Considering $\mathbf{D}$, one has instead of $2\pi\hbar\nu = g\mu_B H$ the following relation:

$$2\pi\hbar\nu = |g\mu_B\mathbf{H} \pm \pi/2\mathbf{D}|.$$

So, uniform Dzyaloshinskii–Moriya interaction manifests itself in a single gapped mode $2\pi\hbar\nu = \sqrt{(g\mu_B H)^2 + (\pi/2\mathbf{D})^2}$ when $\mathbf{H} \perp \mathbf{D}$ and in a doublet of resonance lines when $(\mathbf{H} \cdot \mathbf{D}) \neq 0$.

This novel type of magnetic resonance has indeed been observed in a spin–liquid phase of Cs_2CuCl_4, as shown at Fig. 1. With lowering the temperature, the ESR response gradually transforms from a single line of paramagnetic resonance into a shifted line for $\mathbf{H} \perp \mathbf{D}$ and into a doublet of lines for other orientations. This behavior becomes pronounced when $T < J$. At frequencies $\nu \simeq D/4\hbar$ we also observe zero-field microwave power absorbtion at low temperatures. Existence of a finite gap in zero external field and anisotropic line splitting clearly distinguish this "spinon resonance" from other exotic and regular kinds of ESR in disordered systems. In fact, uniform Dzyaloshinskii–Moriya interaction allows one to access spinon continuum width at non-zero wavevector $q \propto D/J$ by means of ESR. This presents a novel way of probing spinon-like excitations.

Below T_N, when a spiral long–range order develops in Cs_2CuCl_4, a coexistence of two distinct types of ESR spectra is observed. Low-frequency spectrum is well described as an antiferromagnetic resonance of an incommensurate planar spin structure with biaxial anisotropy, while at high frequencies spinon resonance gets restored. A typical ESR spectrum is present at Fig. 2. The difference is also seen through the evolution of ESR response with cooling through T_N: at low frequencies a broad doublet of lines transforms into a single narrow low-field antiferromagnetic resonance line, and at high frequencies the doublet remains nearly unchanged. Crossover between these two types of resonance takes place at $\nu \sim J/2\pi\hbar$, the exchange frequency, which determines the overall energy scale. Such a coexistence of different resonance types is consistent with the results of neutron scatter-

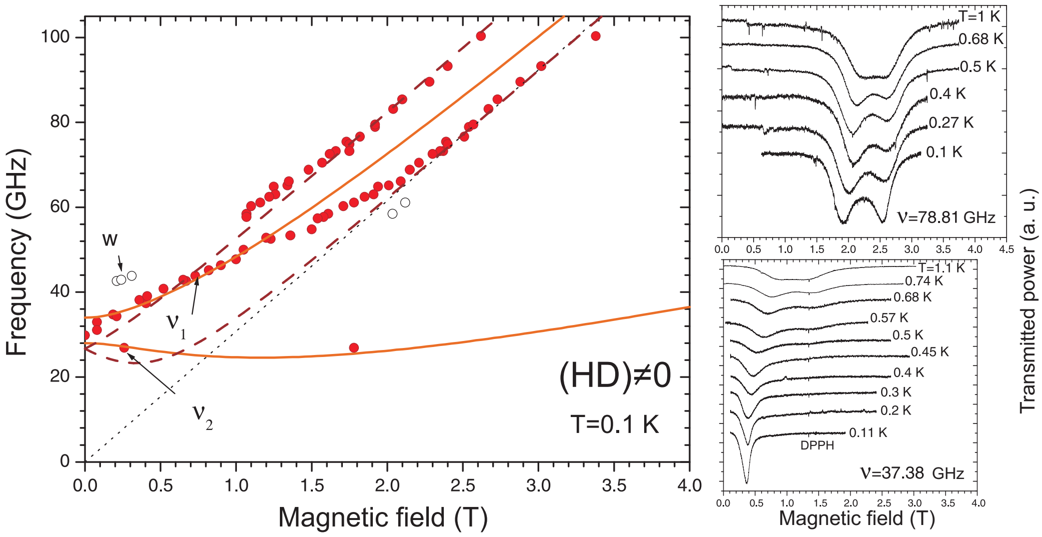

Figure 2: Left panel — ESR spectrum below T_N for $(\mathbf{H} \cdot \mathbf{D}) \neq 0$ direction. Points are experimental data, solid lines correspond to calculated AFMR modes, dashed lines — spinon resonance. Right panels exhibit examples of ESR line temperature evolution at low and high frequencies.

ing and reflects basically the same property of antiferromagnetic ordering in Cs_2CuCl_4: a low-energy response is that of an ordered system, while a high-energy response is that of a disordered one. This implies Cs_2CuCl_4 being close to a quantum critical point (Coldea, Tennant, Tylczynski, Phys. Rev. B **68**, 134424 (2003)). This is the first observation of such manifestation of quantum criticality by ESR.

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