Quantum critical point in $CuGeO_3$ doped with magnetic impurities

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Abstract

Using high frequency (up to 450 GHz) ESR and low temperature specific heat measurements we find that insertion of 1% Fe and 2% Co damps spin-Peierls and Neel transitions and for T<30K gives rise to onset of a quantum critical behaviour characteristic for a random dimer Griffiths phase.

Key words: $CuGeO_3$; quantum critical phenomema; ESR

Most of the available data for doped inorganic spin-Peierls compound $CuGeO_3$ correspond to the limit of weak disorder when density of states have a pseudogap [1,2]. In the oppposite case of a strong disorder the situation is expected to change dramatically: the ground state of $CuGeO_3$ should be a Griffiths phase (GP) which thermodynamic properties are controlled by relatively rare spin clusters correlated more strongly than average [3,4]. In the absence of both long range spin-Peierls and antiferromagnetic orders density of states becomes gapless and diverges at ϵ=0: $\rho(\epsilon) \propto |\epsilon|^{-\alpha}$ [1]. As a consequence the temperature dependences of magnetic susceptibility χ and magnetic contribution to specific heat c_m for Cu^{2+} spin-Peierls chains acquire the forms [3,4]

$$\chi \propto T^{-\alpha}; c_m \propto T^{1-\alpha} \quad (1)$$

where α<1. As long as T=0 becomes singular or critical point, the aforementioned situation is often described in terms of quantum critical (QC) behaviour [3].

The experimental information about feasibility of the QC point in $CuGeO_3$ is very limited [5]. The aim of the present work consists in providing possible evidence of onset of the QC point in $CuGeO_3$ doped with magnetic impurities Co and Fe.

Single crystals of $CuGeO_3$ doped with 1% of Fe (S=1) and 2% of Co (S=3/2) impurities have been grown using self-flux method. The quality of crystals was controlled by X-ray and Raman scattering data; the actual contents of dopant in the sample was controlled by chemical analysis [6]. Magnetic properties of the samples in the temperature range 1.8-300K have been studied by high (up to 450 GHz) frequency ESR technique [2], ESR magnetoabsorption spectra have

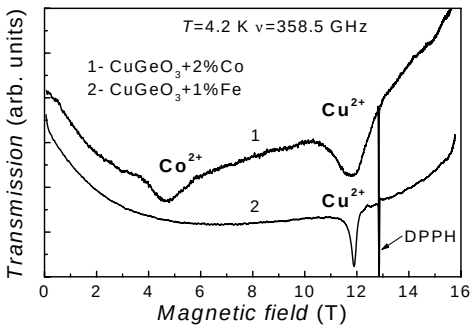

Fig. 1. Magnetoabsorption spectra for the samples studied.

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been measured for **B**‖**a** geometry. Together with the sample spectrum a reference spectrum for DPPH was recordered. Specific heat for the temperature interval 6-20K was studied with the help of low temperature small sample relaxation calorimeter.

Doping of $CuGeO_3$ with magnetic impurities causes (i) rapid damping of the spin-Peierls transition and (ii) onset of a strong paramagnetic background [7]. Therefore the deriving of the effects of doping on Cu^{2+} S=1/2 chains in convenient magnetisation measurements requires *ad hoc* assumptions about background behaviour [7]. This difficulty overcomes in ESR experiment, where magnetic impurity in $CuGeO_3$ matrix and Cu^{2+} chains modified by impurity gives rise to a different absorption lines [8].

Typical magnetoabsorption spectra for $CuGeO_3$:Co and $CuGeO_3$:Fe at helium temperatures are shown in Fig.1. For the Co-doped sample spectrum is formed by two broad lines which becomes resolved for frequencies ν>100 GHz. The spectrum of Fe-doped sample is characterised by a single resonance. The resonant fields B_{res} for all modes presented in Fig.1 are found to vary linearly with frequency $B_{res}\sim\nu$. This result suggests that the observed magnetoabsorption features correspond to different ESR modes rather than coexistence of the ESR and antiferromagnetic resonance [1,9].

The analysis of the g-factor values together with the frequency and temperature dependences of the linewidth [2] have allowed to attribute the high field resonances with $g\approx2.15$ to ESR on disordered Cu^{2+} chains and the low field resonance with $g\approx4.7$ for $CuGeO_3$:Co to ESR on Co^{2+} impurity in $CuGeO_3$ matrix (Fig.1). A strong g-factor renormalisation for the Co-doped sample may reflect formation of the impurity spin clusters [8].

As long as the integrated intensity of the ESR line in the region of linear response is proportional to magnetic susceptibility it was possible to subtract contribution of Cu^{2+} chains unambiguously and find $\chi(T)$ dependence from the spectra taken at different temperatures (Fig.2). We also calculated $\chi(T)$ for Co^{2+} impurity (Fig.2). It is visible that for magnetic impurities studied spin-Peierls transition is already damped and Neel ordering is missing up to 1.8K.

Quantitative analysis of $\chi(T)$ data for doped Cu^{2+} chains indicates that Eq.(1) holds for T<30K (curves 1 and 2 in Fig.2) and the power law provides reasonable description of experimental data. The best fit was obtained using index values α =0.36±0.03 and α =0.69±0.04 for Fe-doped and Co-doped crystals respectively. In contrast to the magnetic properties of Cu^{2+} chains, the susceptibility for Co^{2+} impurity is better fitted by Curie-Weiss law, $\chi\sim1/(T\text{-}\Theta)$, with characteristic temperature Θ =-2.8K (Fig.2, curve 3) corresponding to antiferromagnetically interacting Co^{2+} impurities.

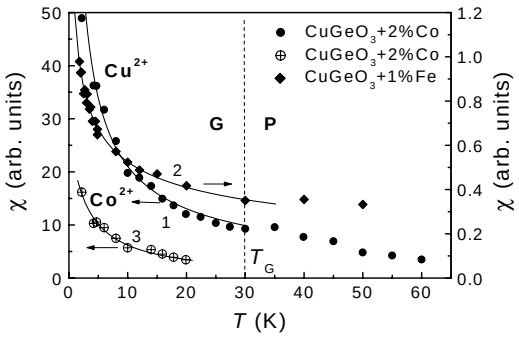

Fig. 2. Temperature dependence of magnetic susceptibility for doped Cu^{2+} chains and Co^{2+} impurity. $\chi(T)$ data suggest a transion from paramagnetic (P) to Griffiths (G) phase at T=30K (see text for details).

The observation of the power asymptotics of $\chi(T)$ in the absence of any type of long range magnetic order for the wide range 1.7<T<30K (where temperature varies more than 15 times) agrees with the theoretical predictions [3,4] for the QC point. An additional argument in favour of proposed interpretation follow from specific heat data for $CuGeO_3$:Fe. It was found [2] that magnetic contribution c_m follows power law with the index α =0.37±0.03 which coincide within experimental error with the value obtained from magnetic susceptibility.

In conclusion, we provide possible experimental evidence that doping of $CuGeO_3$ with magnetic impurities Co and Fe induces a strong disorder limit and low temperature T <30K ground state becomes gapless random dimer GP [4]. Futher studies of the magnetic ordering of these solids at very low temperatures may be prospective.

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