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The Thermoelectric Power of Ferromagnetically Ordered $\text{Cu}_{1-x}\text{Ga}_x\text{Cr}_2\text{Se}_4$ Spinels

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Abstract: Single crystals of $\text{Cu}_{1-x}\text{Ga}_x\text{Cr}_2\text{Se}_4$ have been prepared using a chemical vapor method. The absolute thermoelectric power S and the electrical resistivity ρ of single crystals with compositions $x = 0.036, 0.158, 0.374, 0.394$, have been measured in the temperature range from 5 to 400K. All compounds are p-type metallic conductors with the residual resistance increasing with increasing gallium concentration. The temperature dependence of the resistivity is almost constant for temperatures $T < T_c$ and increases close to the Curie temperature T_c , indicating a spin scattering contribution. A broad hump $\Delta S(T)$ which goes to zero close to T_c apparently is superimposed on a linear diffusion thermopower, suggesting magnon drag.

1. SPIN - VERSUS ALLOY SCATTERING

The increase of the residual resistance with x alone could be interpreted either with direct alloy scattering, i.e. potential scattering arising from the random distribution of x and $1-x$ atoms and/or a vacancies or other defects which for some reason are correlated with x . The average ratio $\frac{\rho_x}{x}$ is $5.8 \pm 0.9 \frac{\mu\Omega\text{m}}{\text{at}\%}$ [1], allowing for both options. Another possibility is that these structural entities invite a proportional number of defects in the spin lattice and thus act indirectly as scattering centers, i.e. through spin scattering potentials. Then an increase of ρ_r should also mean a reduction in saturation magnetization with x through frustration and eventually a spin glass state is introduced. Indeed, such a behaviour is found, with the spin glass state at $x = 0.5$ [2]. If structural scattering dominates, one should also find strong phonon scattering, as the same type of potential is involved. However, the corresponding linear increase of the resistivity is not found. If consequently we change to spin scattering, we expect a continuous rise of ρ for $T \leq T_c$ and a constant value of ρ for $T \geq T_c$, i.e. approximately $\rho(T)$ should run like the inverse magnetization [3]; this is indeed found for small $x = 0.036$ [1]. However, for $x \geq 0.158$ the resistivity stays rather constant up to T_c and only increases for $T > T_c$. Recently [4] it has been proposed that a large number of topological spin scattering centers in amorphous ferromagnets may lead to such a behaviour: when the spin lattice melts at T_c one would only find the small difference between the large topological spin scattering and the maximum scattering on thermal spin excitations. It has been pointed out further, that in such strongly spin disordered systems one always finds a distribution of magnetic couplings which manifests itself in a spin cluster distribution, half of which has higher than average (T_c) coupling strength. These clusters are the last to be excited with increasing temperature and are also thought to be responsible for the gradual increase of ρ for $T > T_c$, which finally should level off (paramagnetic limit), just as is observed in fig.1 for $x = 0.158$.

2. THERMOELECTRIC POWER

A consistent interpretation of the thermoelectric power $S(T)$ is also possible. Fig. 1 shows that at high temperatures apparently one only has a positive linear diffusion thermopower S_d ; it obeys the Nordheim-Gorter rule and yields a Fermi energy of 0.28 eV [1]. Extrapolation to lower temperatures reveals an additional contribution which goes to zero close to T_c , suggesting an influence of the spin system. The hump shape in particular suggests a magnon drag

contribution; this contribution is largest for $x = 0.036$ [1]; for $x = 0.158$ it is somewhat reduced, which is probably connected with the increasing spin disorder.

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Figure 1: Electrical resistivity versus temperature $\rho(T)$ (c) and thermoelectric power $S(T)$ (b) for a $\text{Cu}_{1-x}\text{Ga}_x\text{Cr}_2\text{Se}_4$ mixed spinel with $x = 0.158$. Straight line: diffusion thermopower S_d ; upper graph (a): magnetic contribution S_m

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