Spin-glass ordering in the diluted magnetic semiconductor $Zn_{1-x}Mn_xTe$

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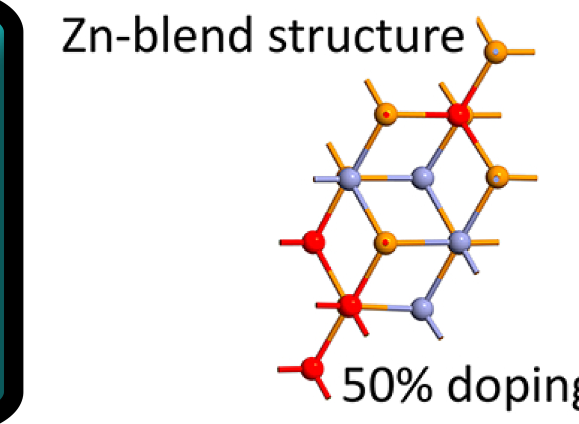
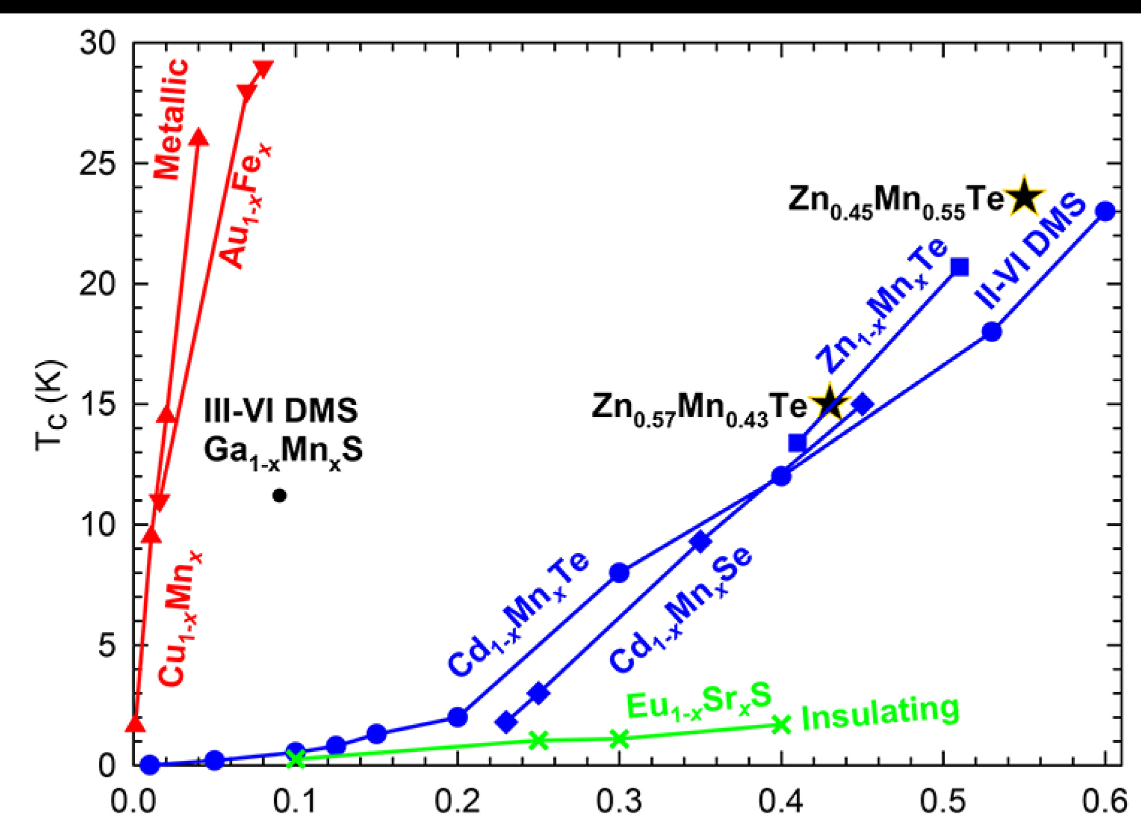


Abstract:

Magnetic measurements on the spin-glass behavior in the bulk II-VI diluted magnetic semicoductor (DMS) $Zn_{1-x}Mn_xTe$ were made on two crystals of concentrations $x = 0.43$ and 0.55 taken from the same boule. Magnetization and density functional theory studies have shown paramagnetic behavior in both samples between 30 and 400 K. Below 30 K, there is a prominent peak at $T_c = 15$ and 23.6 K for concentrations $x = 0.43$ and 0.55, respectively. The splitting of the field cooled (FC) and zero field cooled (ZFC) data below this peak is indicative of a transition to a spin-glass state at low temperature for semiconductors. Therefore, through the *p*- and *d*- orbits hybridization a magnetic exchange produces the spin-glass behavior seen in $Zn_{1-x}Mn_xTe$.

Spin-glass Transitions

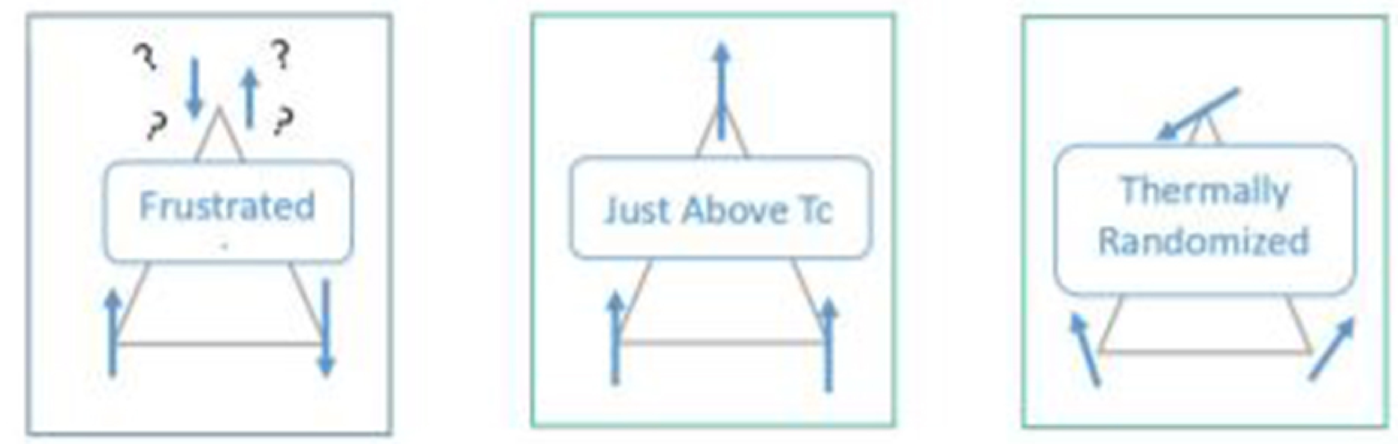


Spin-glass transition temperature T_c versus concentration x for various spin-glass materials. The metallic spin-glass systems have high values of T_c for small values of x. In contrast, T_c remains below 2 K for insulating materials for a wide range of x. The II-VI DMS system $Zn_{1-x}Mn_xTe$ have T_c values similar to the insulating spin-glass systems for $x < 0.2$. For the same values of x, the III-VI DMS $Ga_{0.91}Mn_{0.09}S$ system is an order of magnitude larger than the insulating and II-VI DMS systems and about a factor of three smaller than the metallic systems.

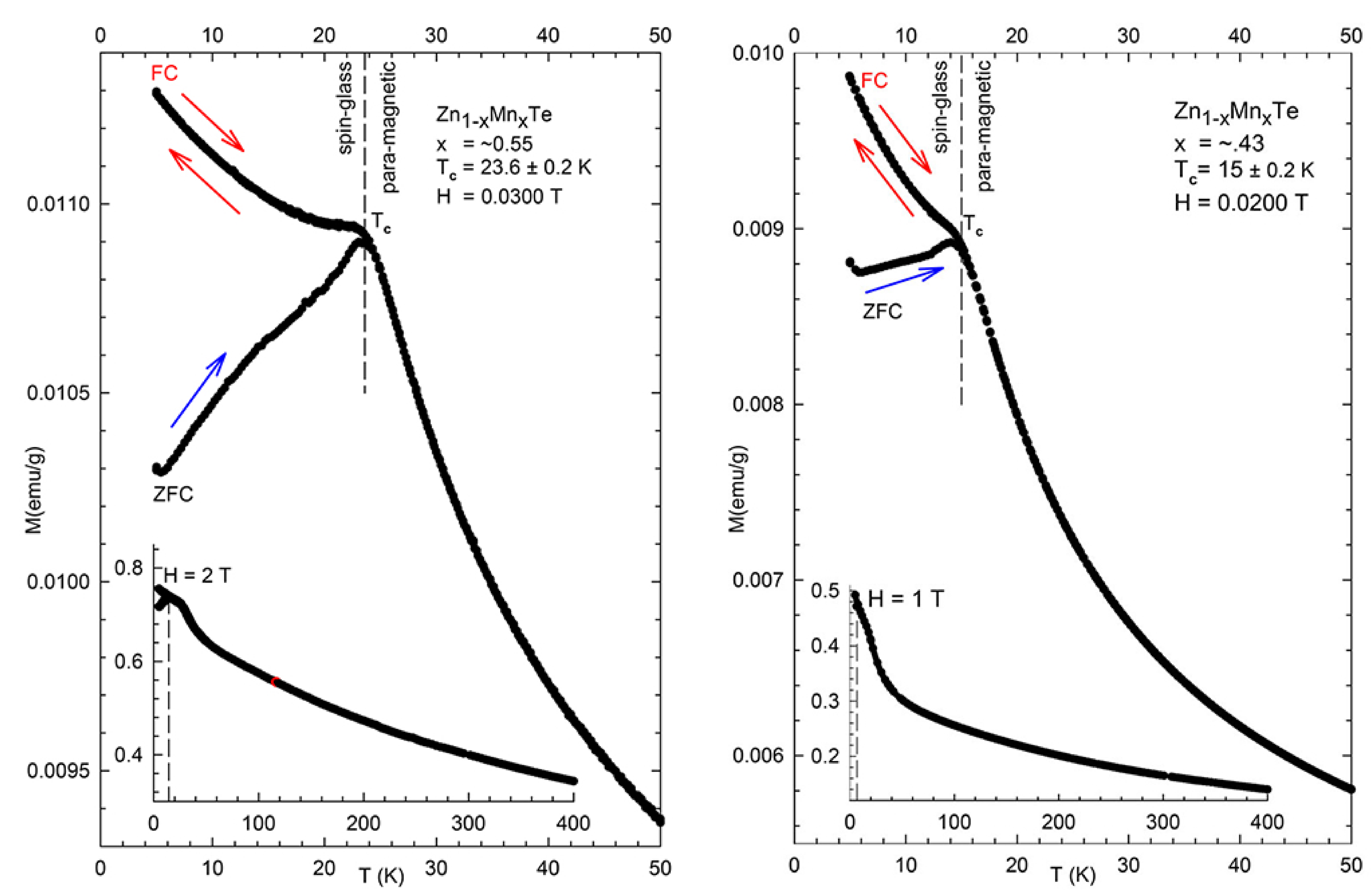
Acknowledgements

I would like to thank the UNF Physics department for the equipment provided, Professor Pekarek, and especially the OUR grant received which allowed this research to be completed.

What is a Spin-glass

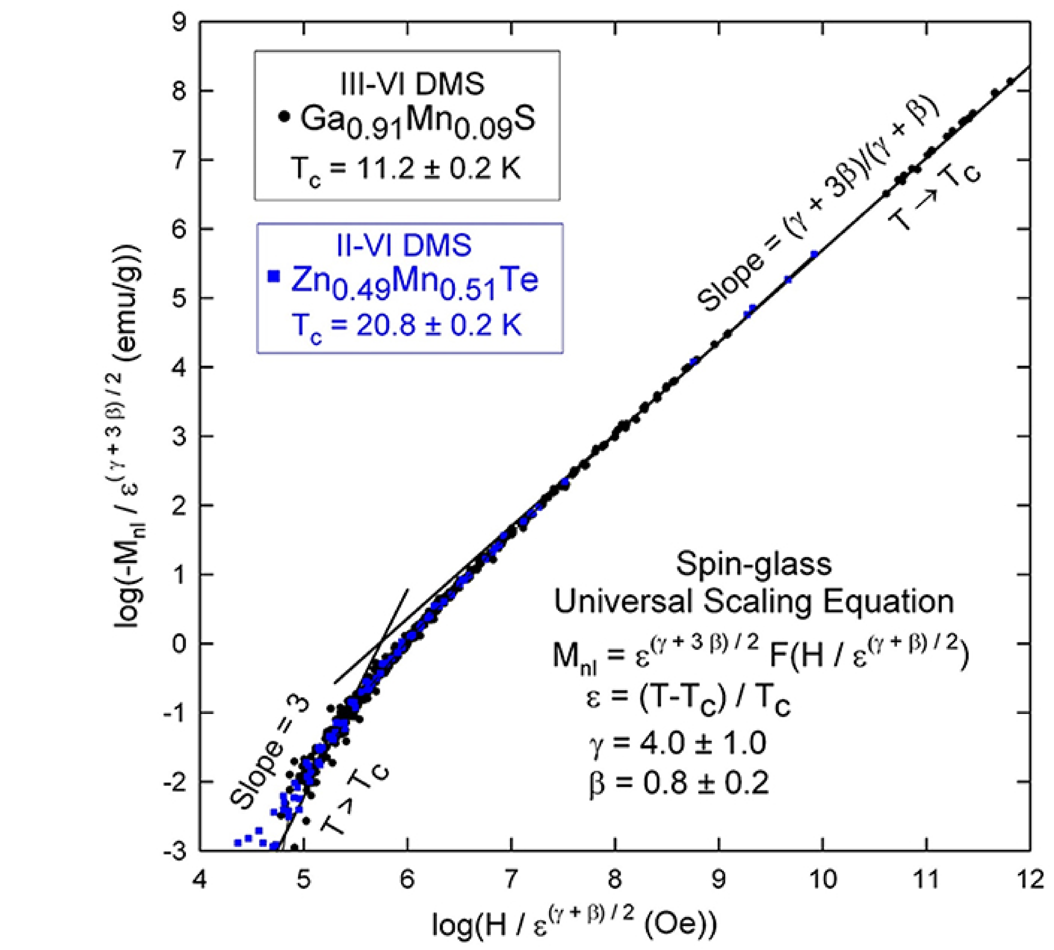


Spin-glass systems consist of frustrated magnetic moments or spins. Above the transition temperature T_c, the spin-glass exhibits paramagnetism. Below T_c, the magnetization typically exhibits a history dependent behavior that is clearly seen in the FC and ZFC traces below. In this region, the spins have a relaxation time long enough that they appear to be frozen in place.



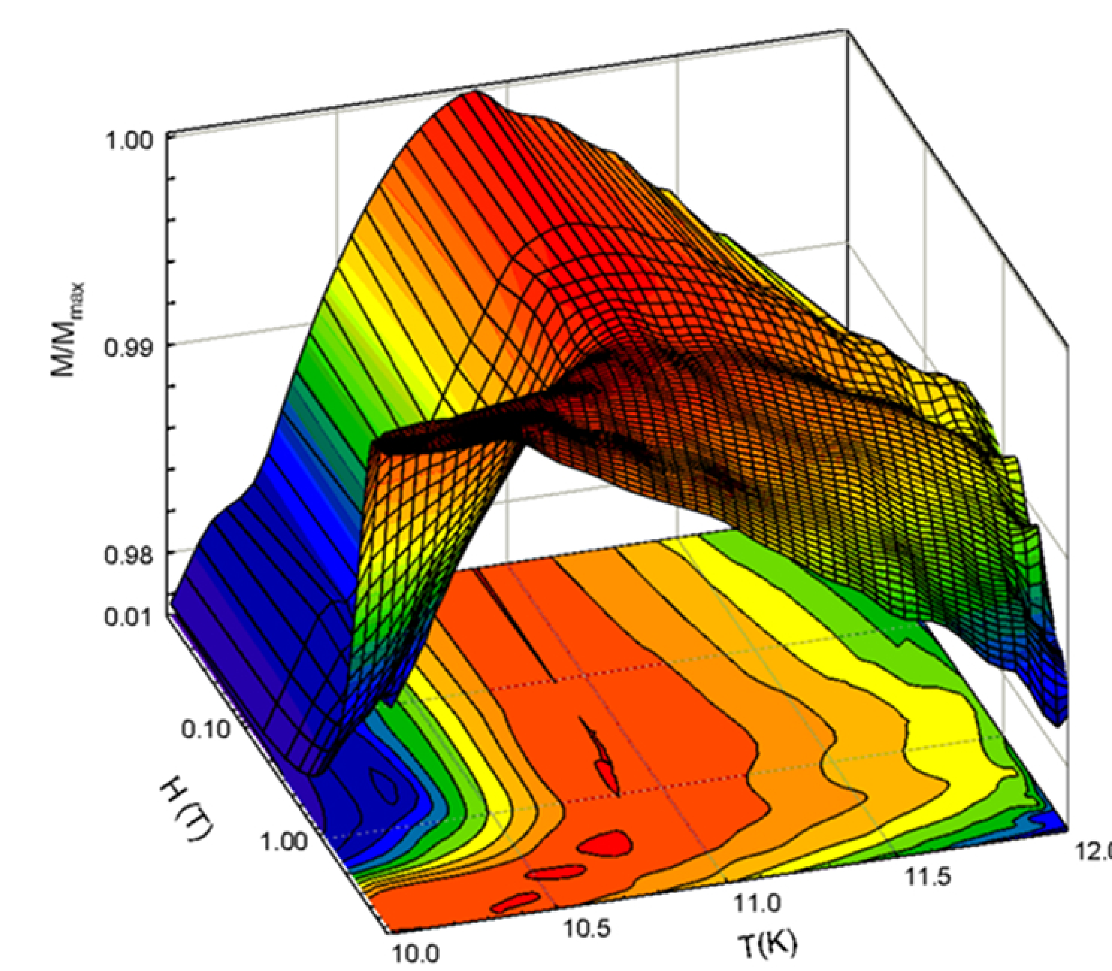
ZFC and FC magnetization versus temperature for $Zn_{0.45}Mn_{0.55}Te$ and $Zn_{0.57}Mn_{0.43}Te$, respectively. The prominent cusp at 23.6 ± 0.2 K for the 0.0300 T field run on the left figure above is characteristic of a spin-glass transition, with a key feature being inverse temperature dependence where standard paramagnetic behavior is found. The prominent cusp at 15 ± 0.2 K for the 0.0200 T field run on the right figure above is also a likewise indicative characteristic of a spin-glass transition. Standard paramagnetic behavior is when there are induced magnetic fields in the direction of the applied magnetic field from the compound. Standard paramagnetism is found in the temperature regime of 30-400 K for these materials. This is shown in the inset figure with a field strength of 2 and 1 T, respectively, where there is a flattened tail above the spinglass transition temperature. This once again indicates a transition to the spin-glass phase of this material. T_c is found to shift into lower temperatures at higher field strengths as seen in these figures.

Spin-glass Universal Scaling Equation



The nonlinear magnetization data analyzed according to a universal scaling model for $Ga_{0.91}Mn_{0.09}Se$ and $Zn_{0.49}Mn_{0.51}Te$. There is an excellent overlap following the same universal scaling function over the entire range. The universal scaling relations was used to confirm $Ga_{0.91}Mn_{0.09}Se$ alongside $Zn_{0.49}Mn_{0.51}Te$ undergoes a true spin-glass transition.

Cusp near T_c



Normalized magnetization versus temperature and field for $Ga_{0.91}Mn_{0.09}Se$. Note the log scale on the H(T) axis. The critical temperature T_c at 11.2 K is just above the 10.9 K cusp at low fields. Above T_c, the spin-glass exhibits paramagnetism. Below the T_c, the magnetization exhibits behavior that suggests that a spin-glass transition is taking place.