AC Magnetometer

Principle, design and applications

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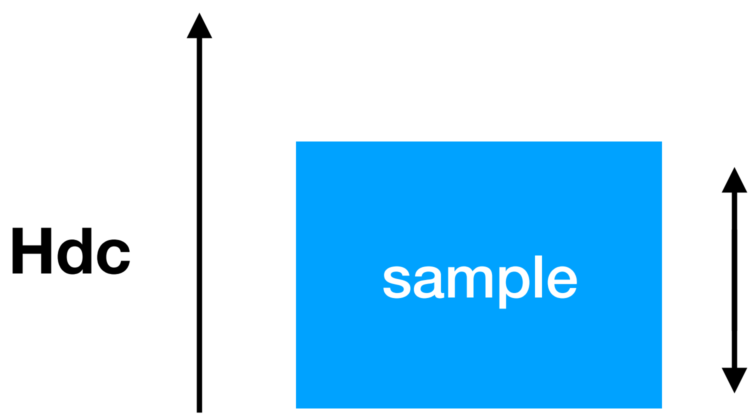
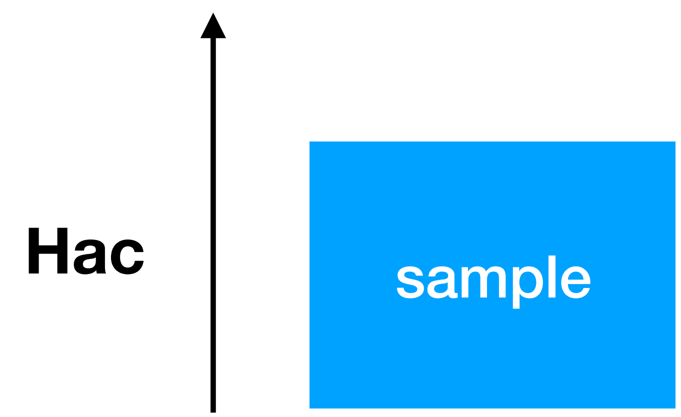
590B presentation

AC vs DC measurement





DC - ‘M’ is measured for some applied dc field, H_{dc}. Since the applied magnetic field is constant, there will be no emf induced due to Hdc. The induced emf is generated in the detection coil by moving the sample. (measure of M/H)

AC - the sample is magnetized by an ac magnetic field H_{ac}. So, detected change in flux is related to the changing moment of the sample (dM) as it responds to the ac field and not to the moment itself as in dc technique. (measure of dM/dH)

So DC measurements probe only static equilibrium values while AC can give us dynamics of magnetization

AC susceptibility

$$H(t) = H_{DC} + H_{AC}\cos\omega t = H_{DC} + H_{AC}Re(e^{i\omega t})$$

(most general form) $$M(t) = M_0 + H_{AC}\sum_{n=1}^{\infty}[\chi_n'\cos n\omega t + \chi_n''\sin n\omega t]$$

$$\chi_n = \chi_n' + i\chi_n''$$

So,

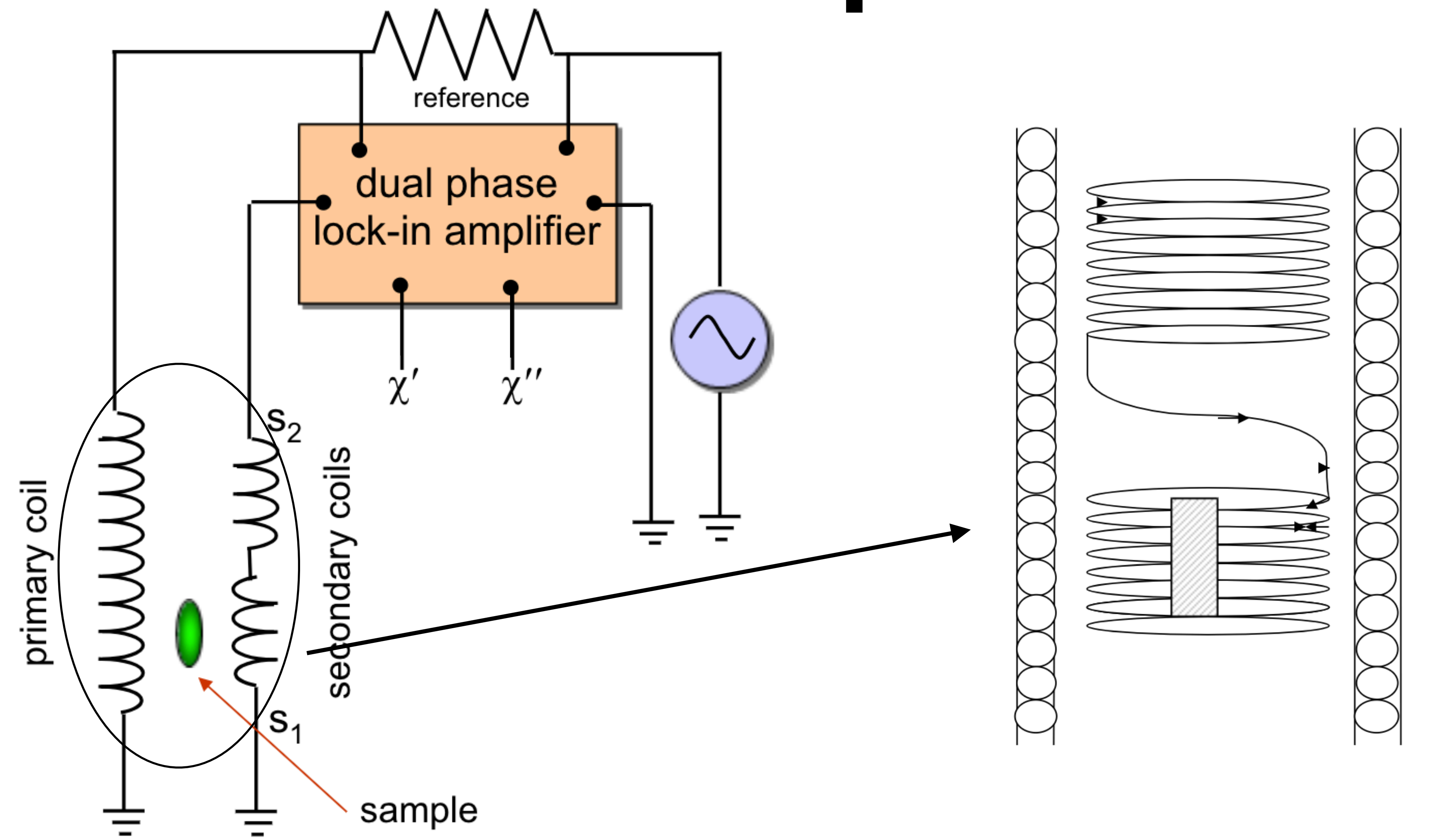
$$\chi_n' = \frac{1}{\pi H_{AC}}\int_0^{2\pi} M(t)\cos(n\omega t)d(\omega t)$$

$$\chi_n'' = \frac{1}{\pi H_{AC}}\int_0^{2\pi} M(t)\sin(n\omega t)d(\omega t)$$

- $\chi_{n=1}'$ - the fundamental ‘real’ component describes the reversible magnetization processes and stays in phase with the applied AC field

- $\chi_{n=1}''$ - the fundamental ‘imaginary’ component is associated to losses due to irreversible processes and is out of phase with the applied field. eg. hysteresis loops in FM, spin-lattice relaxation, etc

AC susceptometer



- sample subjected to small alternating field through the primary coil
- sample induces emf on secondary coil s1 while s2 nulls out any flux changes other than the sample
- relevant χ components are read off from the lock-in output

Figures borrowed from an online presentation named ‘design of AC susceptometer using closed cycle helium cryostat’ by N.Alzayed, King Saud University, Saudi Arabia .

Examples:Ferromagnetic transition

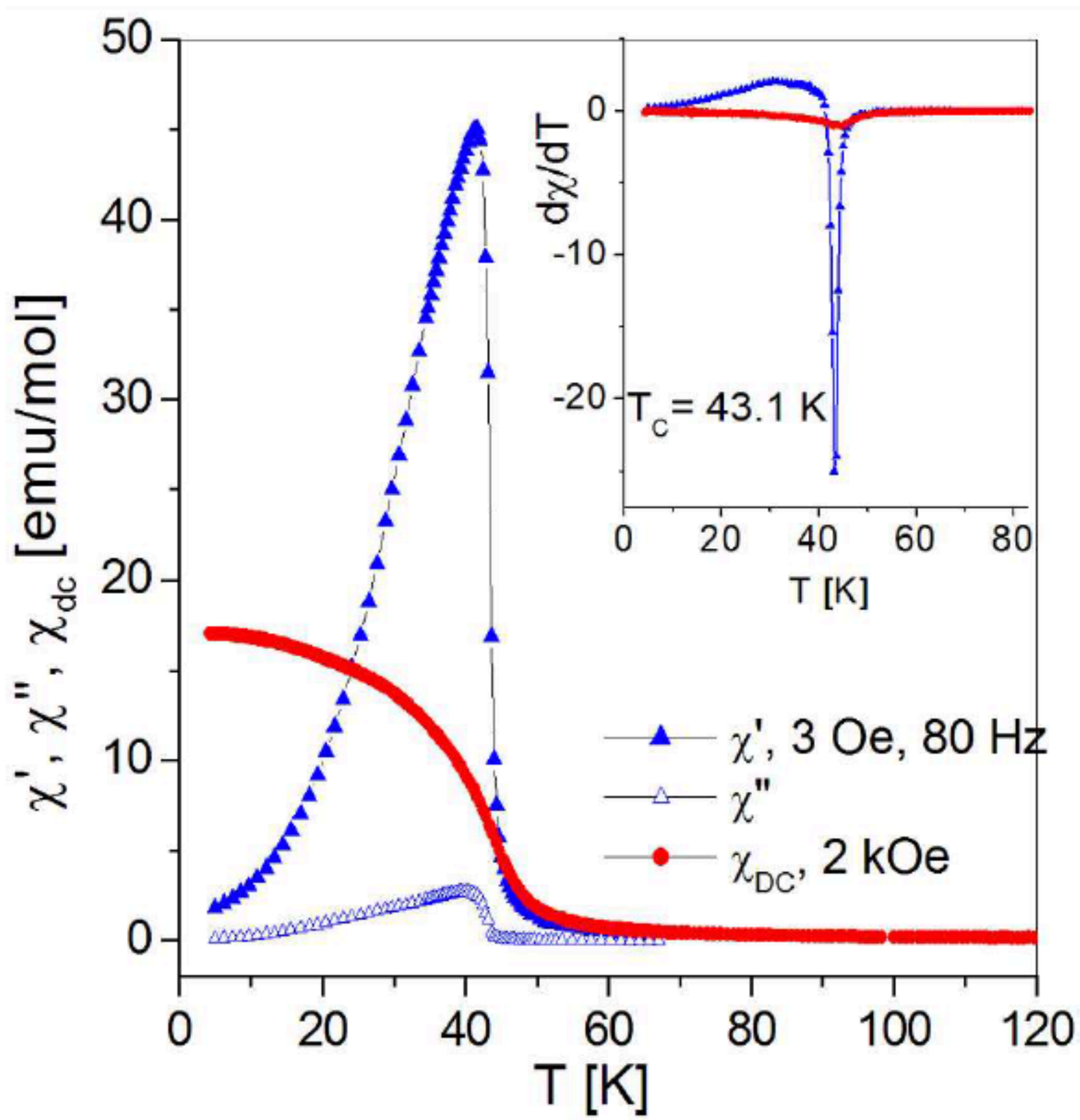


Fig. 1. AC and DC magnetic susceptibility at the transition from a ferromagnetic to the paramagnetic state for the molecular $[Fe^{II}(H_2O)_2]_2[Nb^{IV}(CN)_8]\cdot 4H_2O$ 3D ferromagnet [6]. The related temperature derivatives $d\chi'/dT$ and $d\chi_{DC}/dT$ are depicted in the inset.

D. Pinkowicz, et.al , Dalton Trans. Issue, 7771 (2009).

Detection of Spin glasses

- neutron scattering, specific heat, etc not very useful
- AC magnetometry being one of the most used techniques for spin glass detection

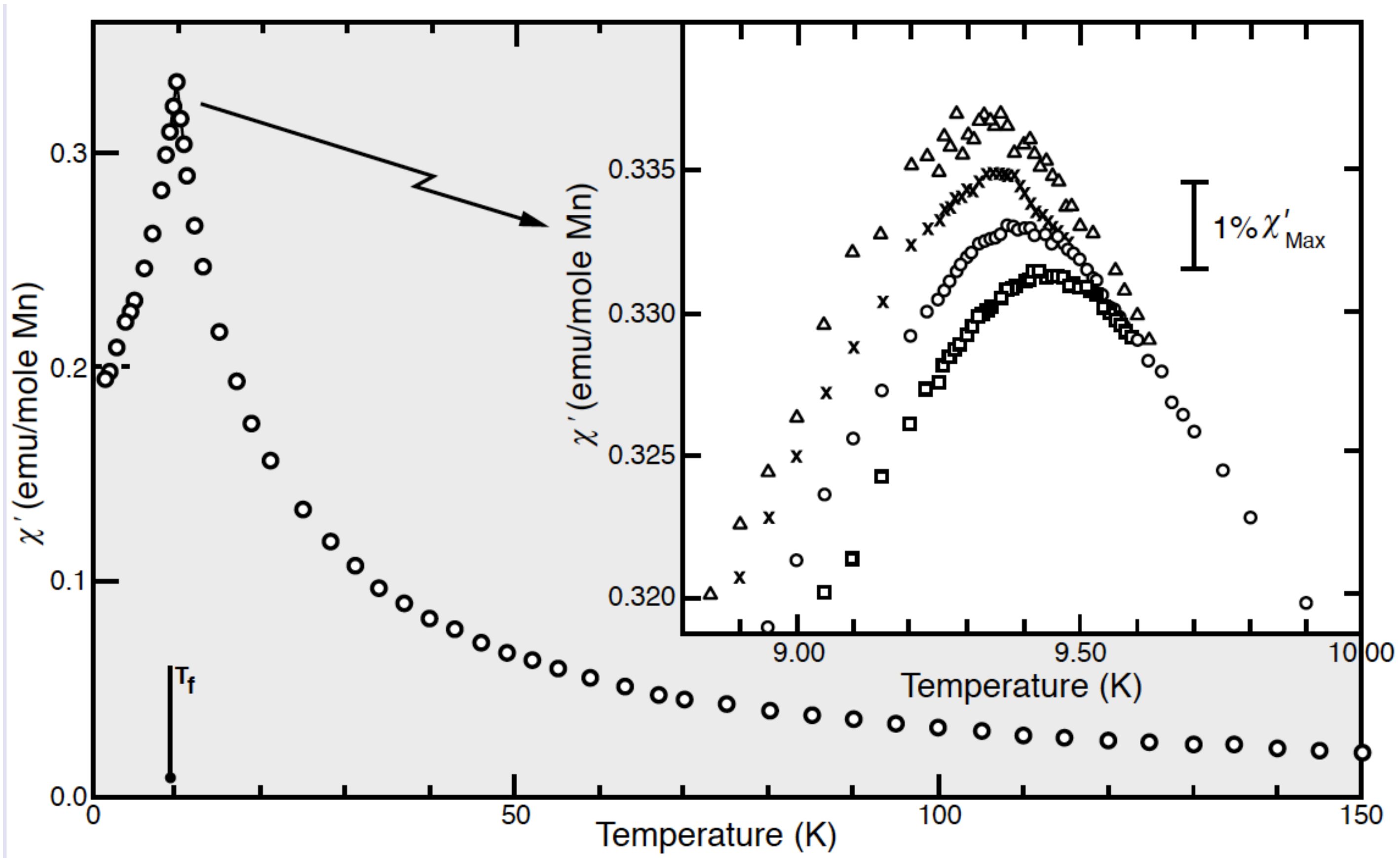


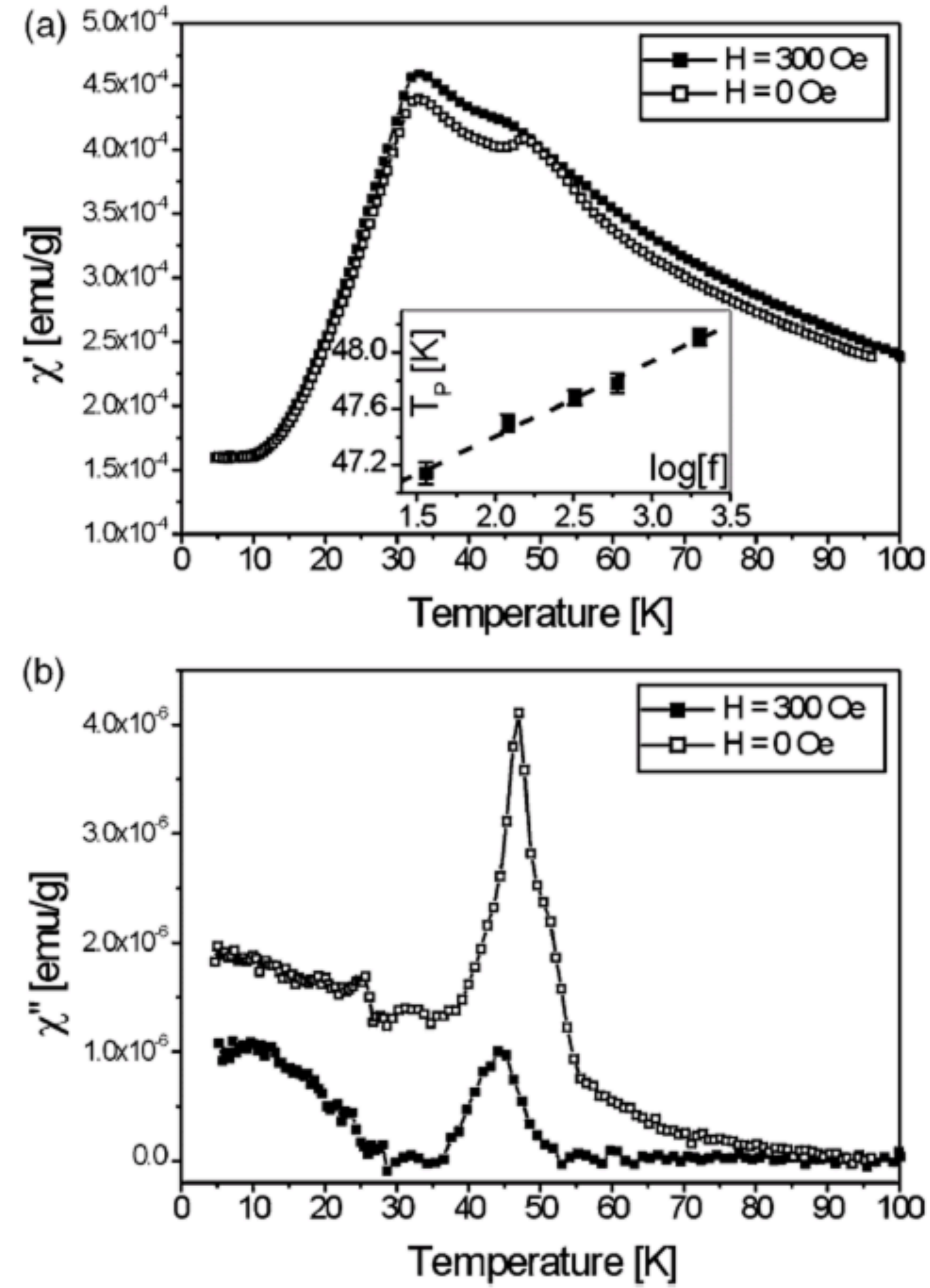
Figure 1. AC susceptibility of CuMn (1 at% Mn) showing the cusp at the freezing temperature. The inset shows the frequency dependence of the cusp from 2.6 Hz (triangles) to 1.33 kHz (squares). Figure reprinted with permission.[2]

C. A. M. Mulder et al, Phys. Rev. B 23, 1384 (1981).

Anomalies in TbAuIn

The figures shown (here and next slide) describe the AC susceptibility measurements done on the frustrated antiferromagnet TbAuIn which has a hexagonal structure and has a transition below 33K to a 120^o ordered AFM state.

The other anomaly around 45K seems to have some indication of an antiferromagnetic cluster-glass state of Tb magnetic moments. **Evidence**: Strong influence of the external magnetic field and driving field frequency on the position as well as on the magnitude of the AC susceptibility anomaly



Note:

In a cluster-glass groups of spins are locally ordered creating small domains which interact between each other similar to single spins in simple spin glass.

L. Gondek et al, Solid State Commun. 136, 26 (2005).

Detection of Cluster-glass phase by higher harmonics

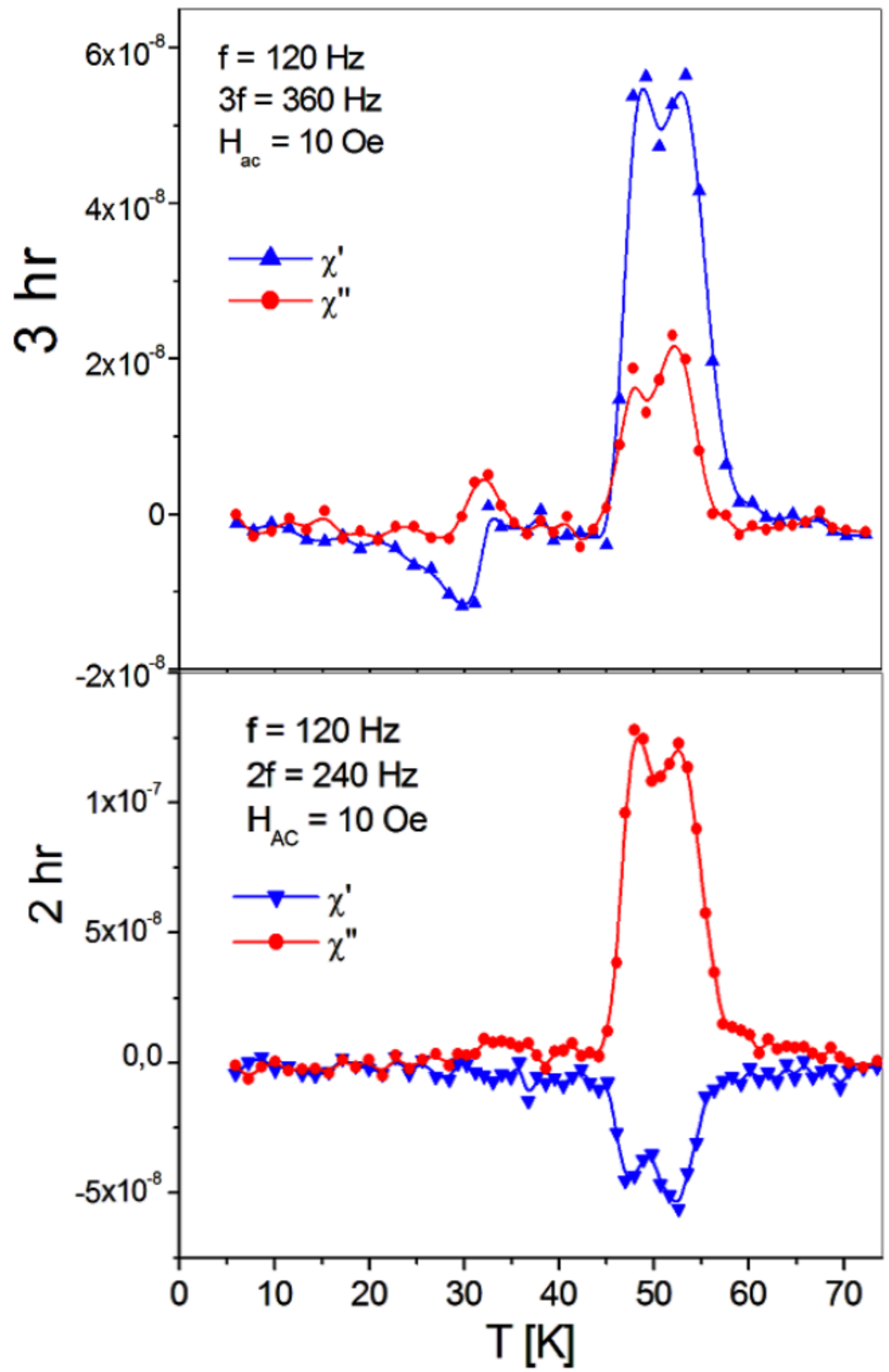


Fig. 5. Nonlinear susceptibilities for Tb uIn: transition at T_N is detected only with 3hr, while cluster glass phase with $T_g \approx 52$ K is marked with anomalies of both harmonics [12].

L. Gondek et al, Solid State Commun. 136, 26 (2005).

superparamagnetism

In this theory, the particles exhibit single-domain ferromagnetic behavior below the blocking temperature, TB , and are superparamagnetic above TB . In the superparamagnetic state, the moment of each particle freely rotates, so a collection of particles acts like a paramagnet where the constituent moments are ferromagnetic particles(rather than atomic moments as in a normal paramagnet).

The utility of AC susceptibility for superparamagnetism stems from the ability to probe different values of τ by varying the measurement frequency.

Note:

-Typical frequency range of the AC field can vary depending on the size of the single-domain particles considered (which ultimately translates to the flipping rate of the moments). Considering the moment flipping time scales to be τ and that of the measurement to be τ_m. So for τ of the order of 10^{-9} s, to satisfy the criterion $\tau_m >> \tau$, one can chose frequencies below the MHz range to see the super paramagnetic behavior. While for 10^{-6}s τ values , one needs to stick to frequencies within the KHz range.