Determining the magnetocaloric effect in hysteretic materials

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Fundamental Aspects of Materials and Energy

Reactor Instituut Delft

Delft Days on Magnetocalorics

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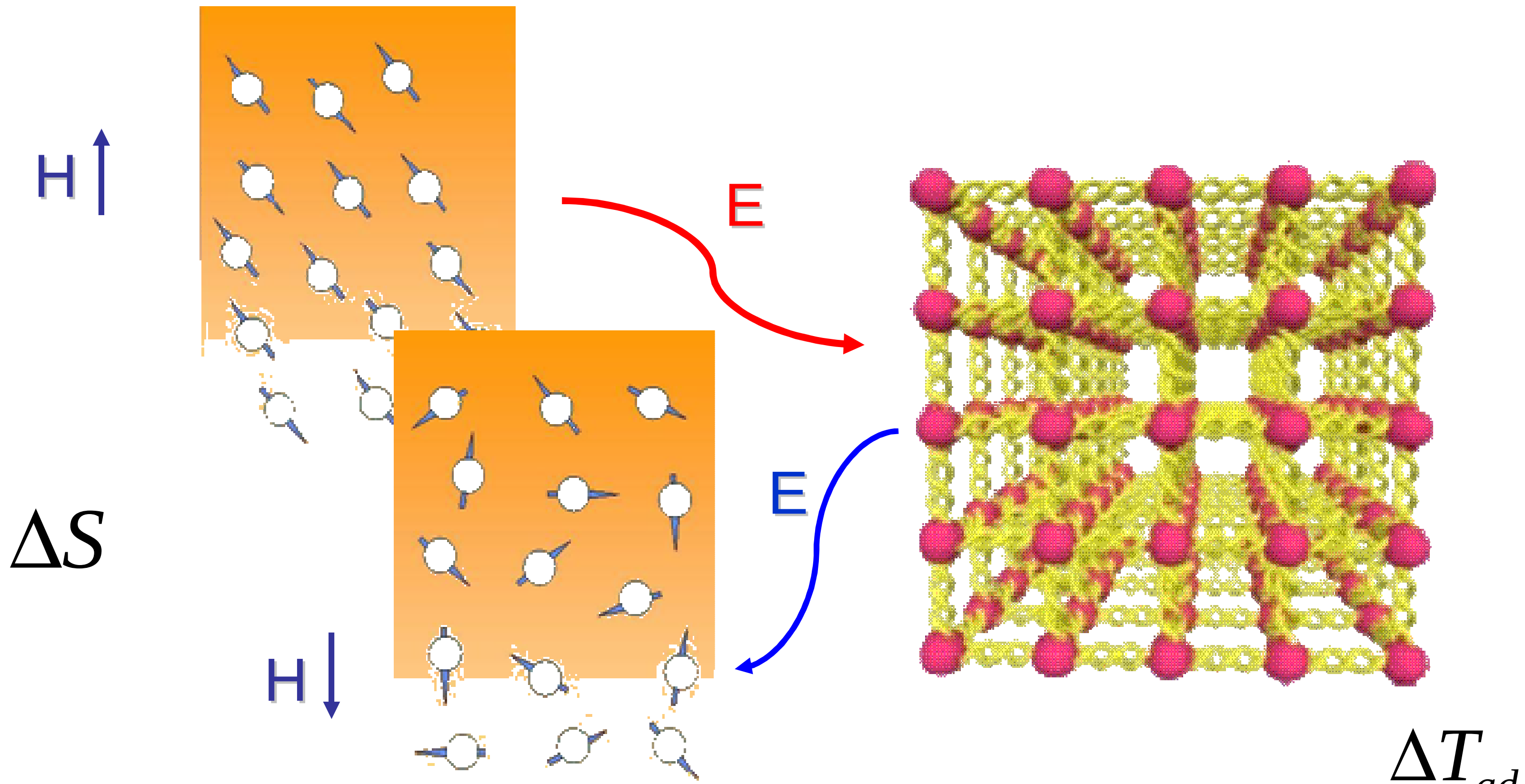
Delft University of Technology

The magnetocaloric effect



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Measurement

Direct measurements - ΔS and ΔT_{ad}

Indirect measurements – calculate ΔS from isothermal magnetization

Maxwell relations

$$\left(\frac{\partial S(T,H)}{\partial H}\right)_T = \left(\frac{\partial M(T,H)}{\partial T}\right)_H \rightarrow \Delta S_T(T)_{\Delta H} = \int_{H_1}^{H_2} \left(\frac{dM}{dT}\right)_H dH$$

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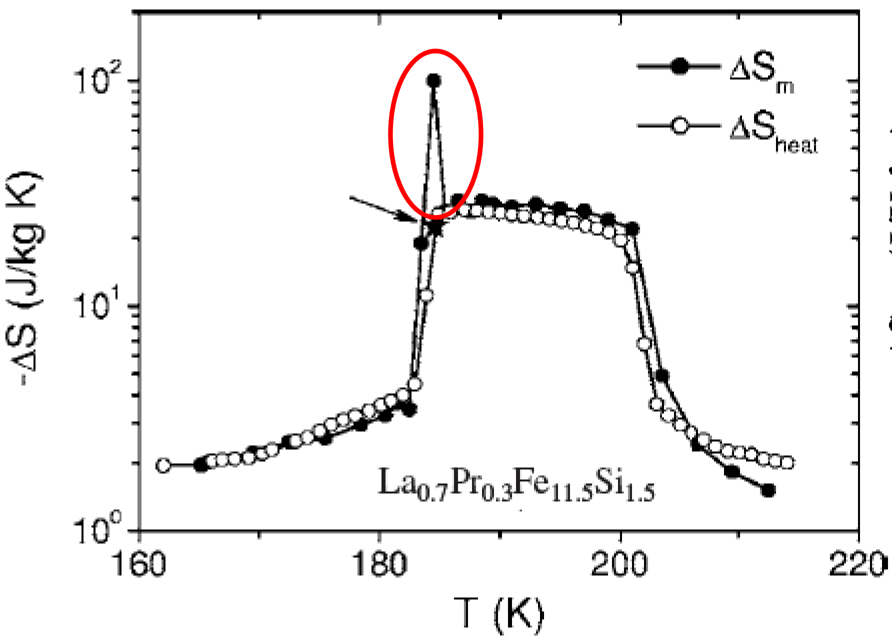
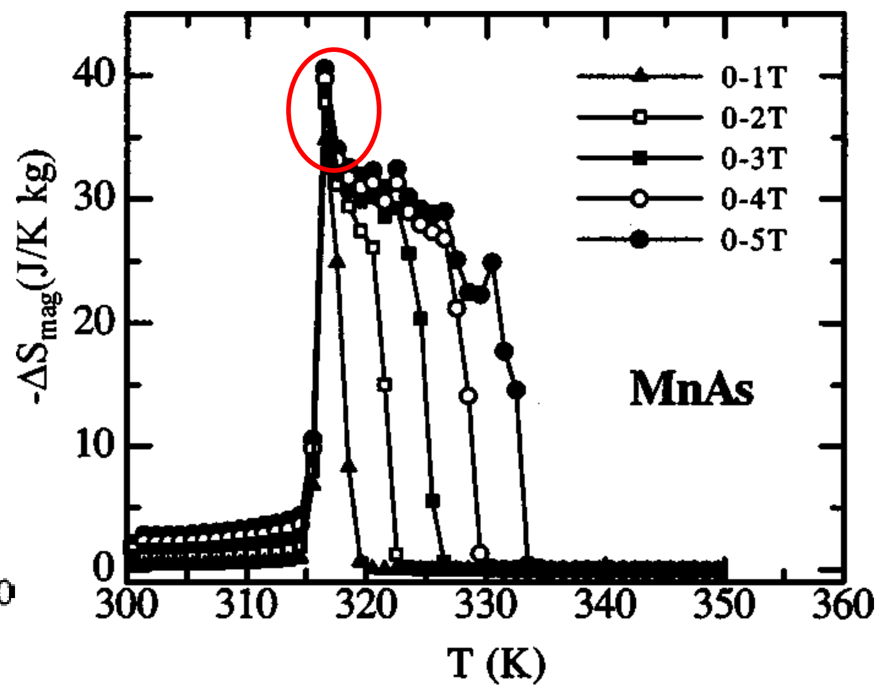
Reasons for questioning the validity of the Maxwell relations



Liu et al. Appl. Phys. Lett. ***90*** *p. 032507*



Wada et al. Appl. Phys. Lett. ***79*** *p. 3302*

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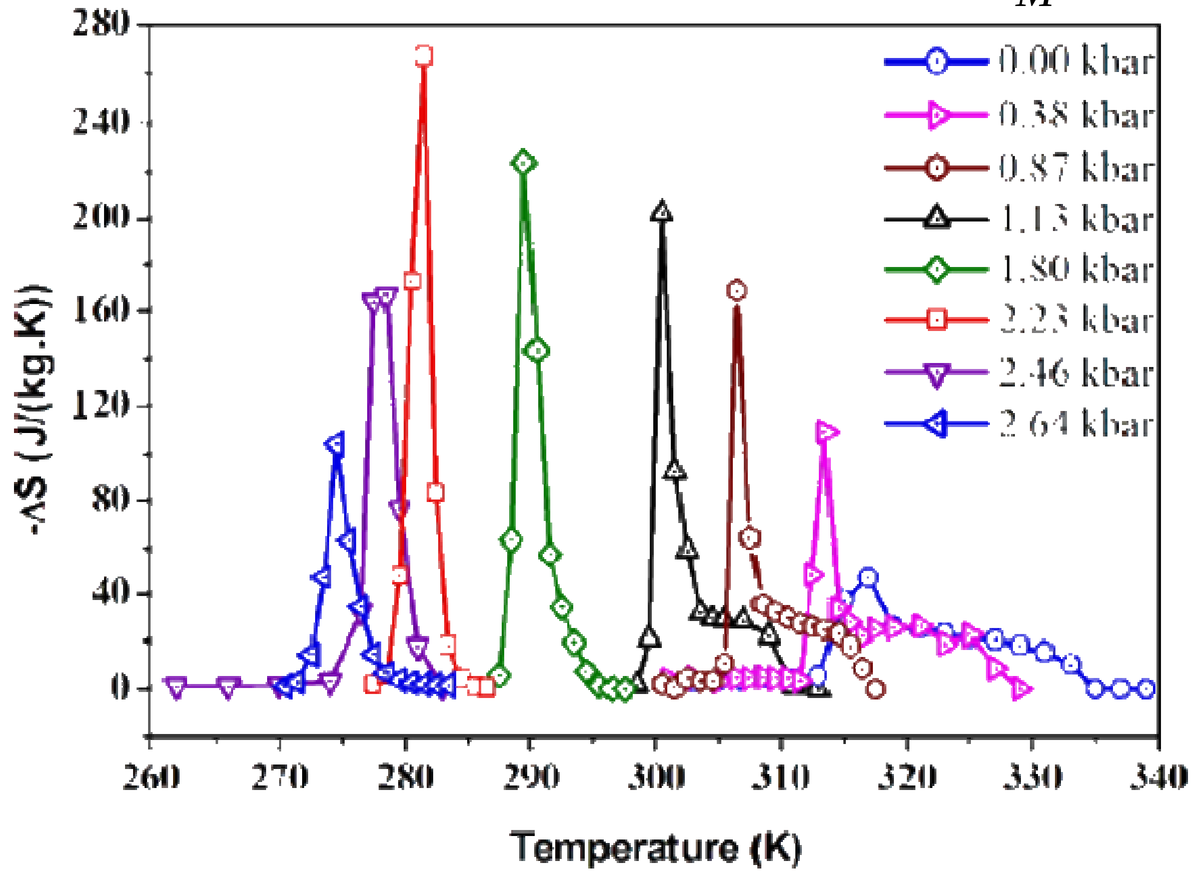
Colossal Magnetocaloric Effect

MnAs under pressure: $$\Delta S_M^{\max} = \ln(2J+1)$$



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Validity of the Maxwell relations

2nd order – Maxwell is valid

1st order – Clausius-Clapeyron or Maxwell?

$$\frac{dH}{dT} = -\frac{\Delta S_M}{\Delta M} \Leftrightarrow \left(\frac{\partial S}{\partial H}\right)_{T,P} = \left(\frac{\partial M}{\partial T}\right)_{H,P}$$

Sun et al. PRL 85 4191

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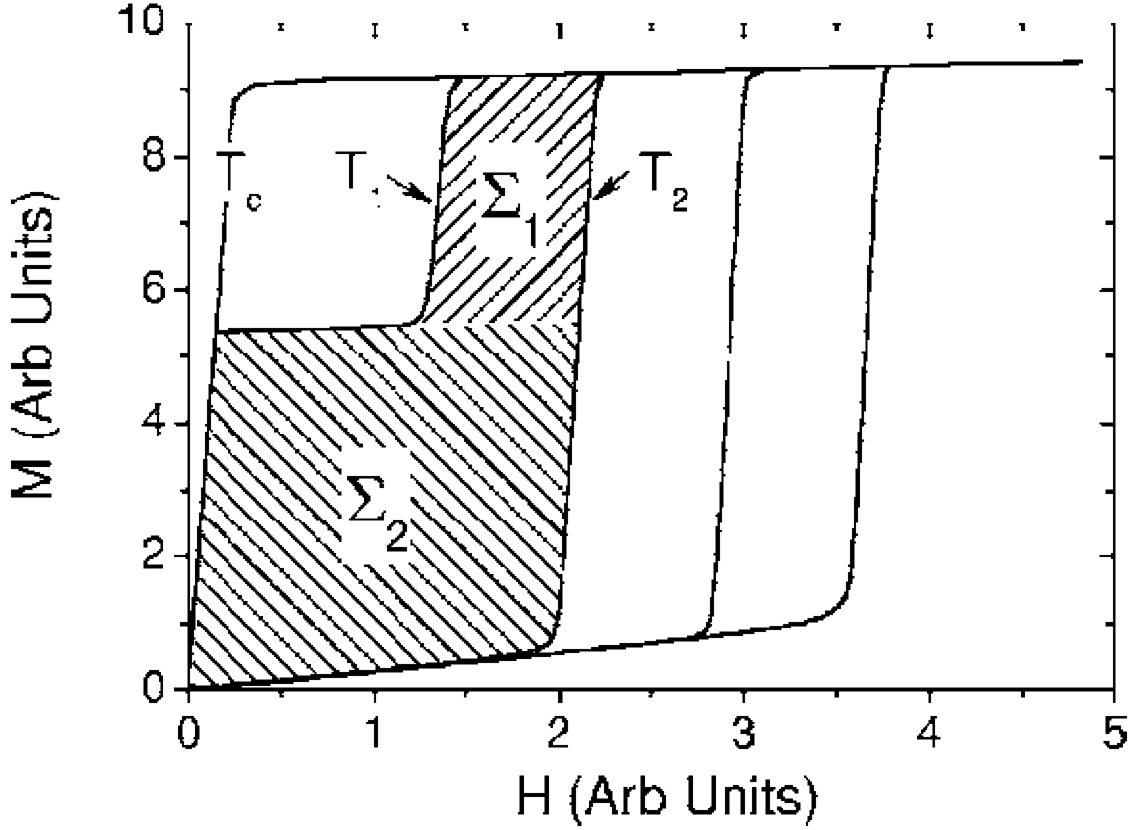
Liu’s solution



Liu et al. Appl. Phys. Lett. 90 032507

What are we measuring?

Measure MxB @ T_1

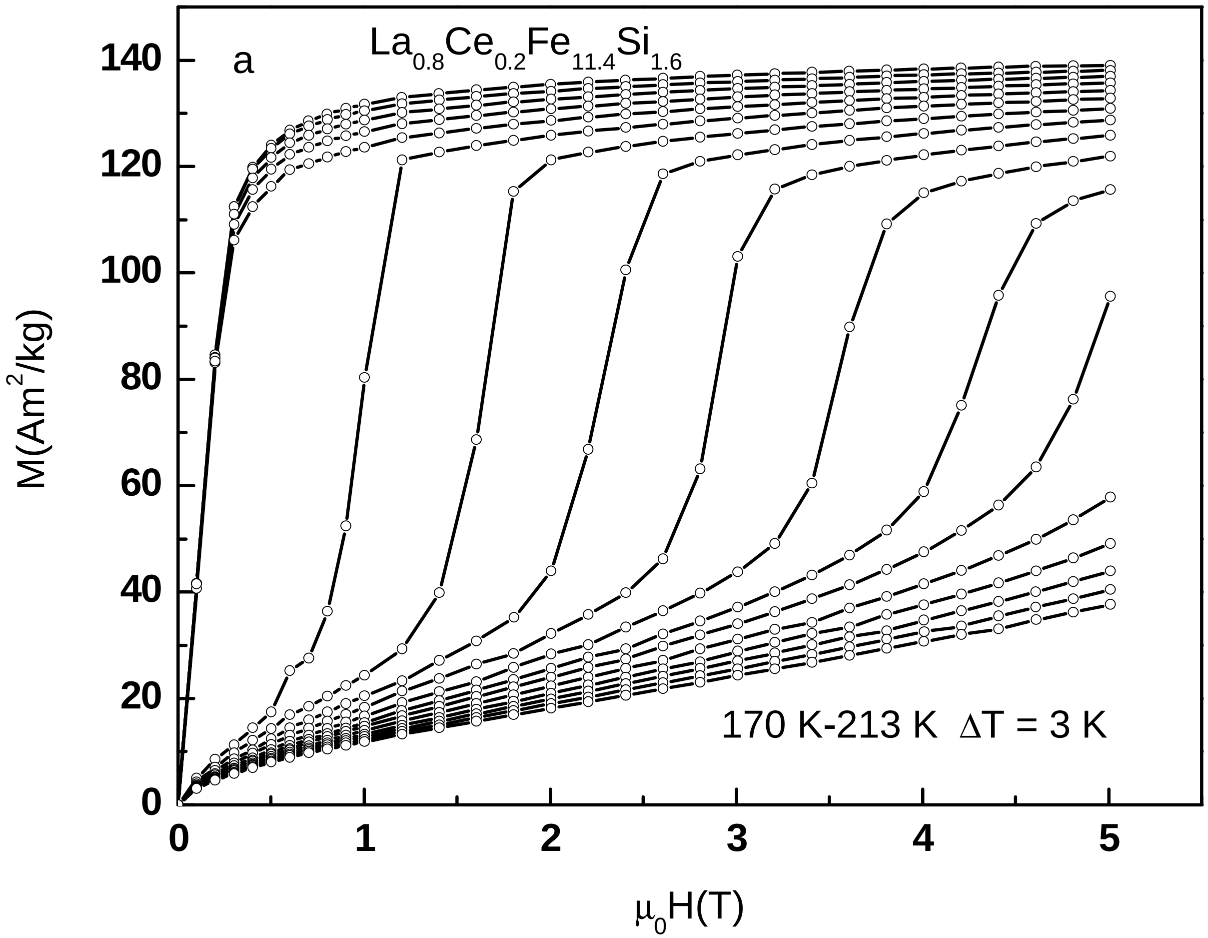
Set B = 0

Set $T = T_2$

$T_2 = T_1 + \delta T$

Measure MxB @ T_2

And so on...



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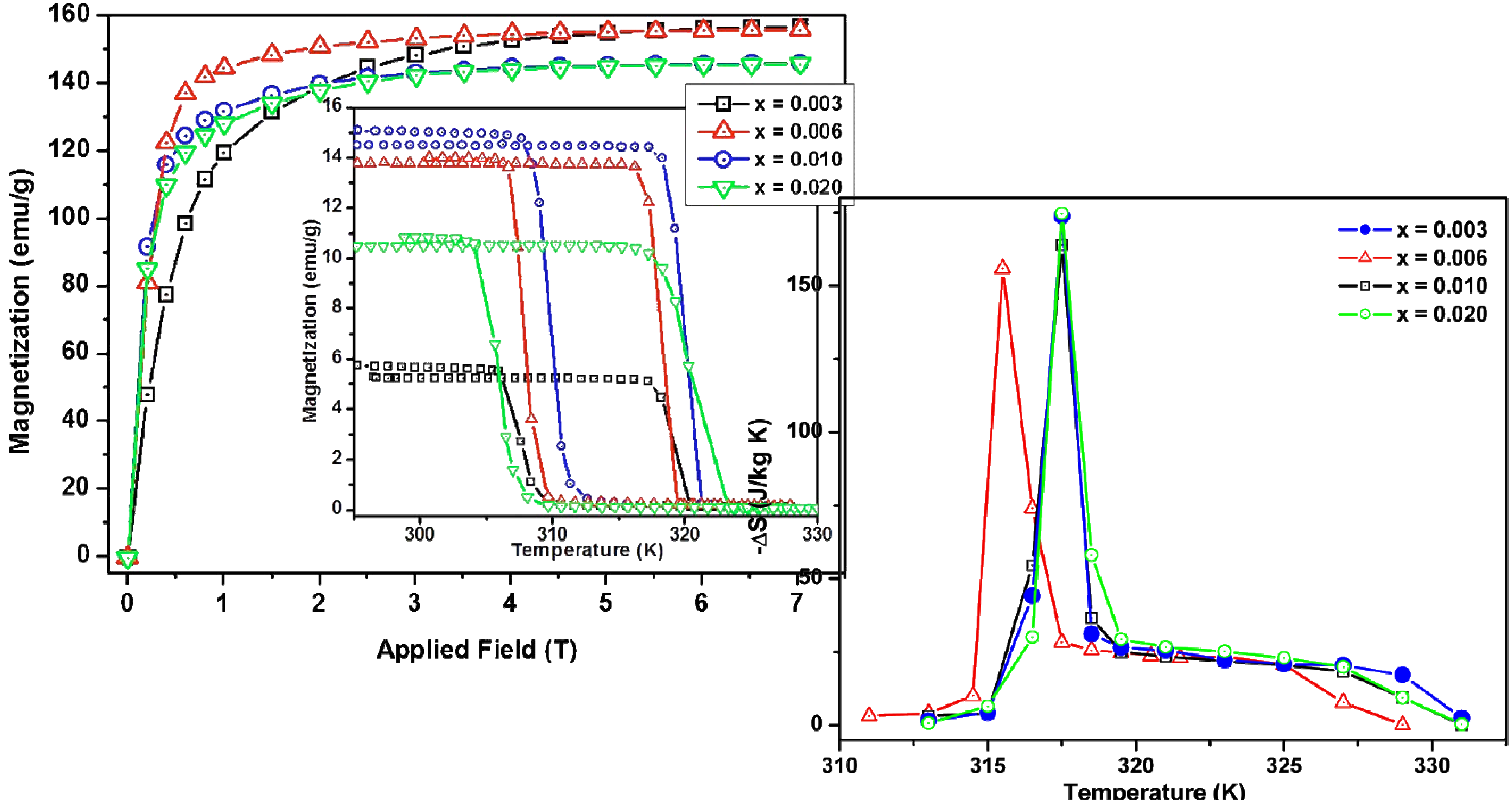
$Mn_{1-x}Cu_xAs$ – Colossal MCE



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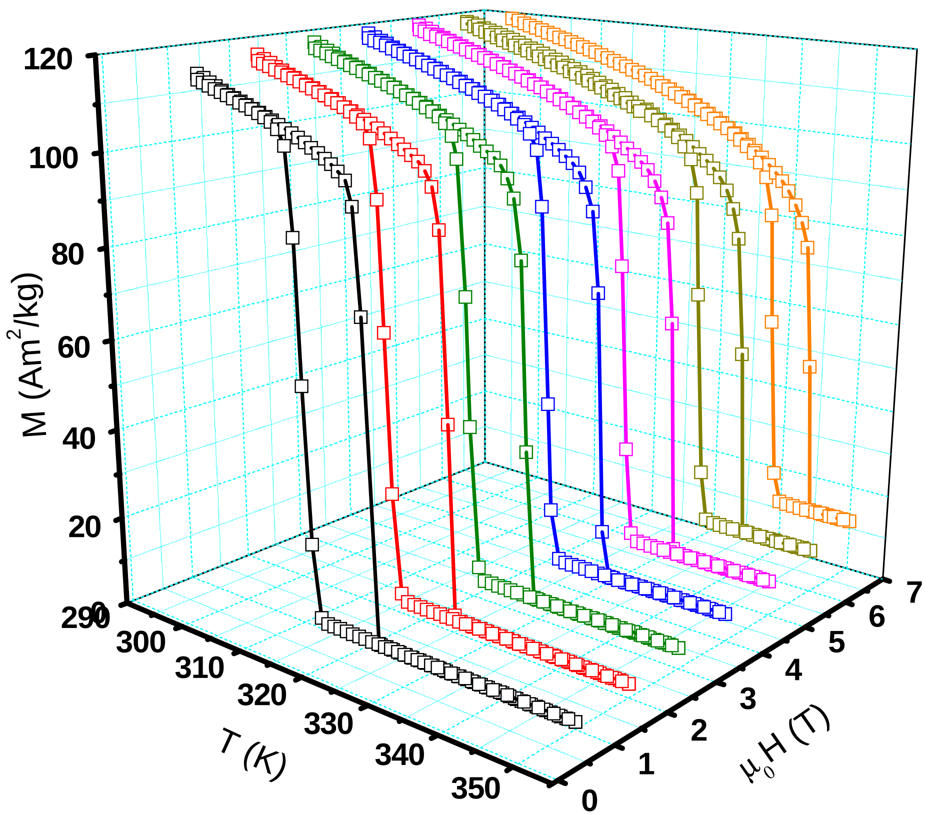
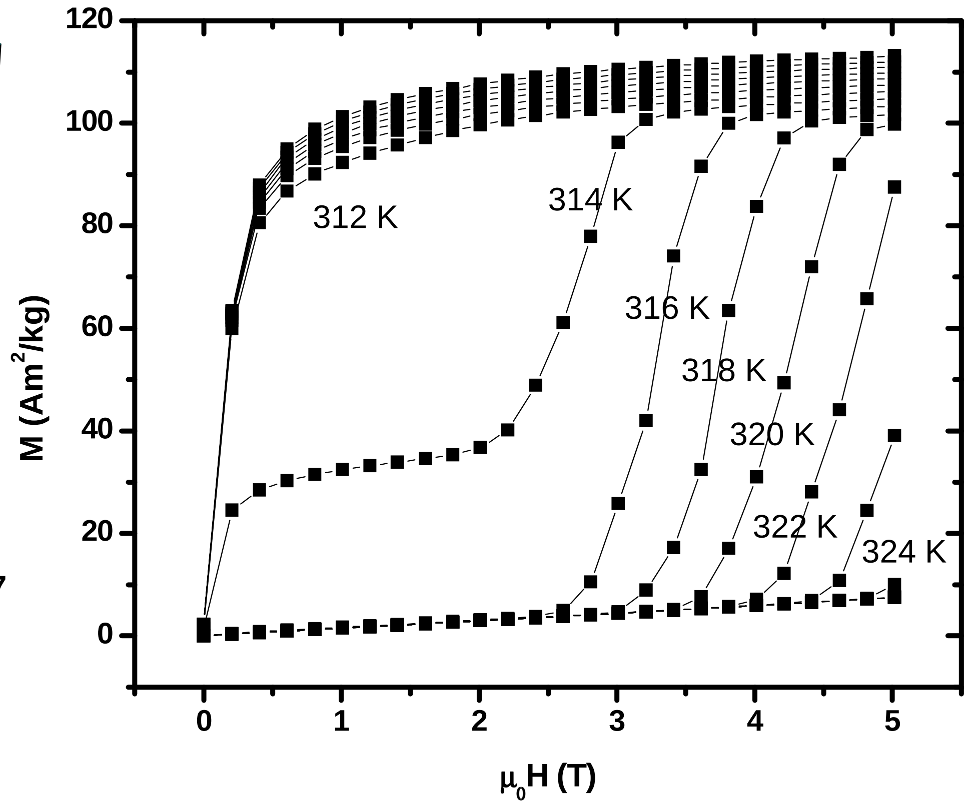
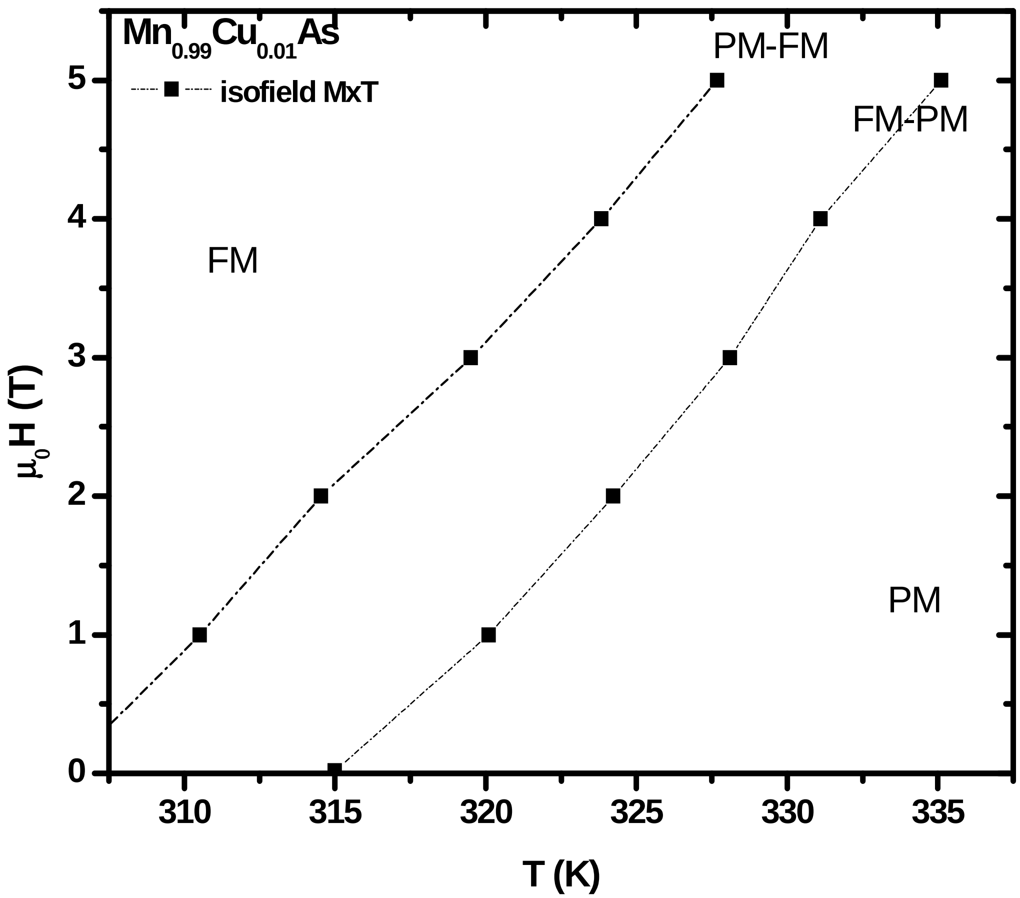
Alternate measurement method

$$\left(\frac{\partial S(T,H)}{\partial H}\right)_T = \left(\frac{\partial M(T,H)}{\partial T}\right)_H$$





Alternate measurement method



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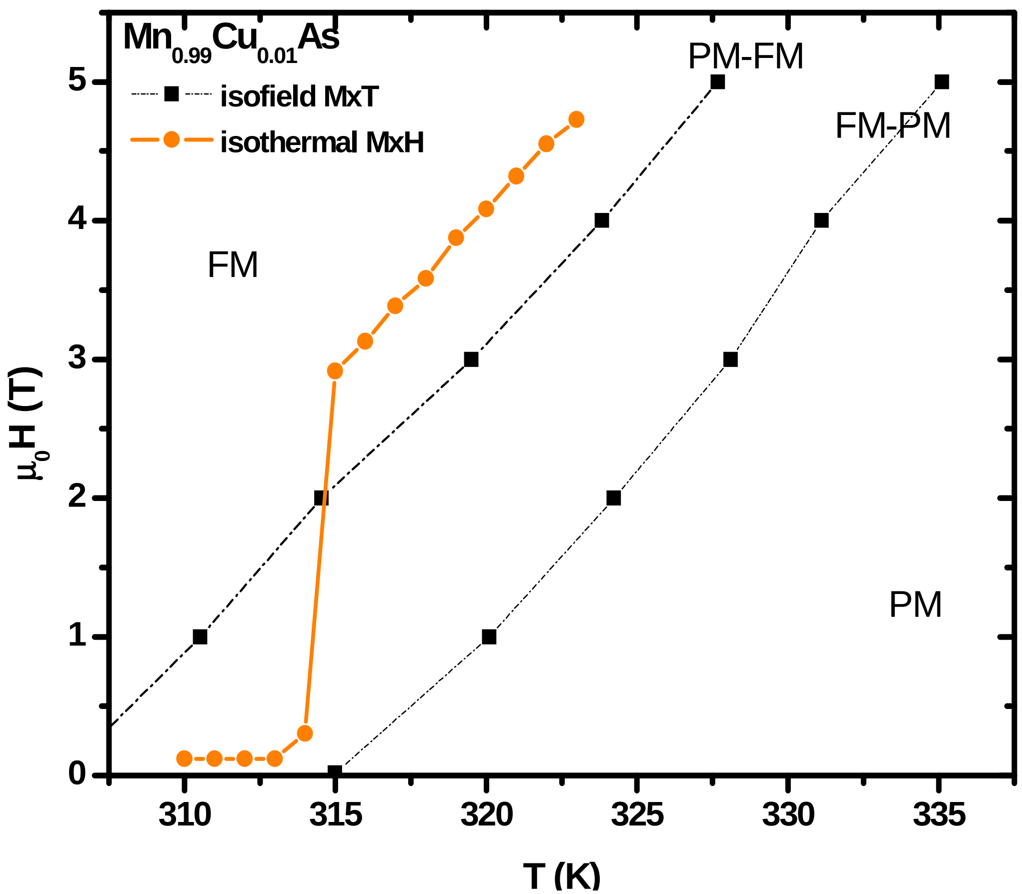
Alternate measurement method



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Alternate measurement method

Measure MxB @ T_1

Set B = 0

Set T = T_{high}

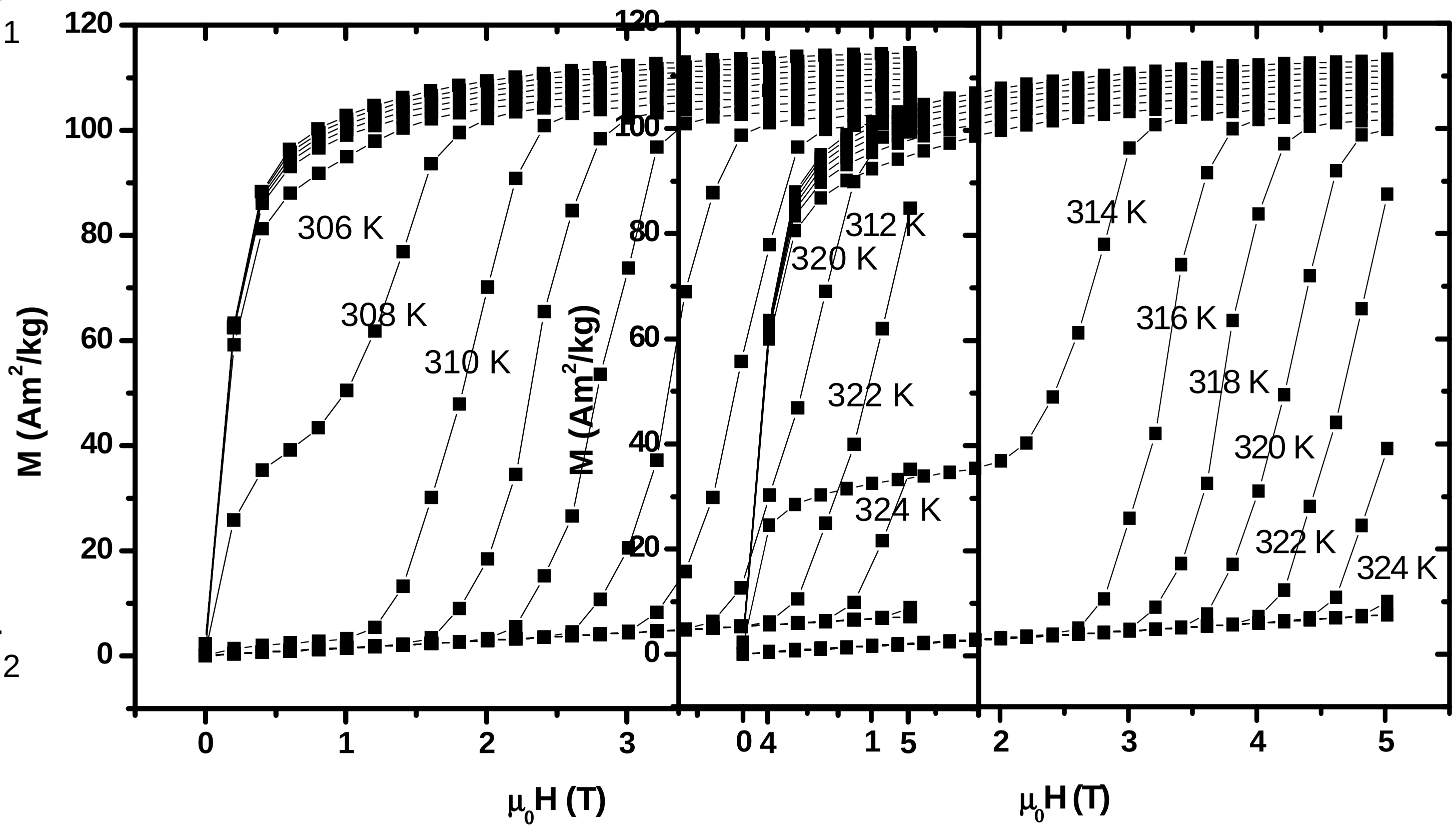
$T_{high} >> T_C$

Set T = T_2

$T_2 = T_1 + \delta T$

Measure MxB @ T_2

And so on...



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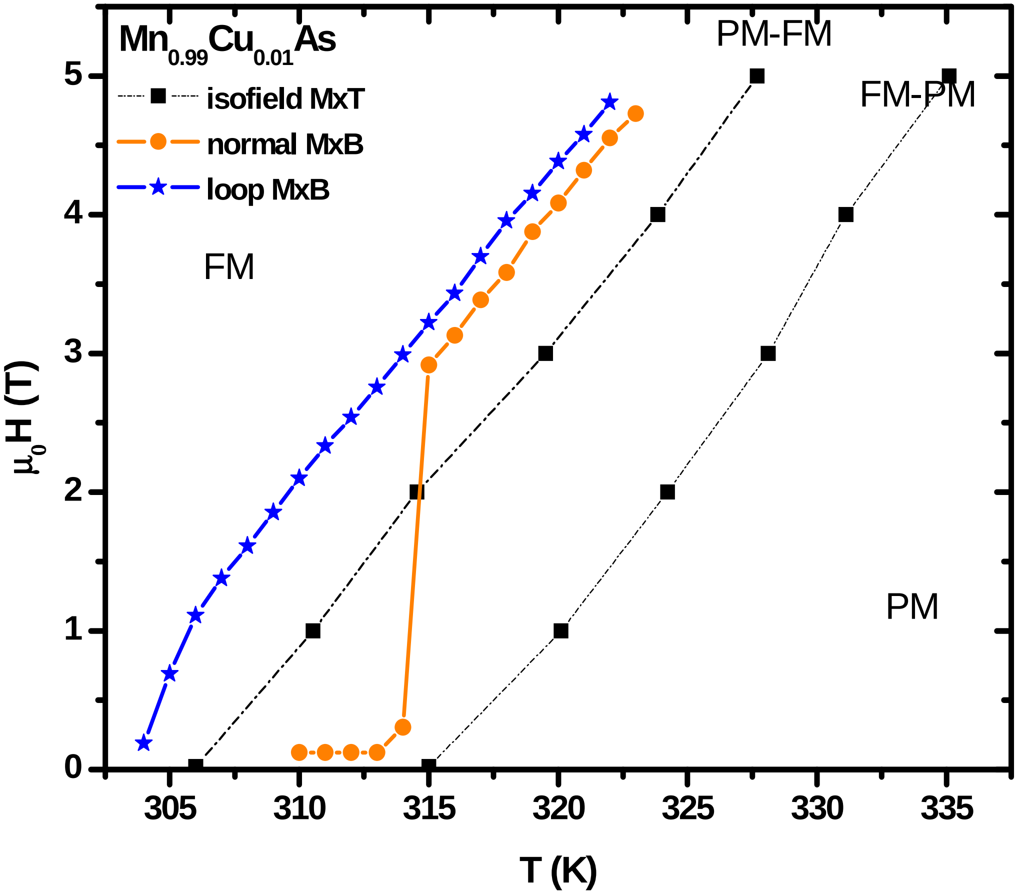
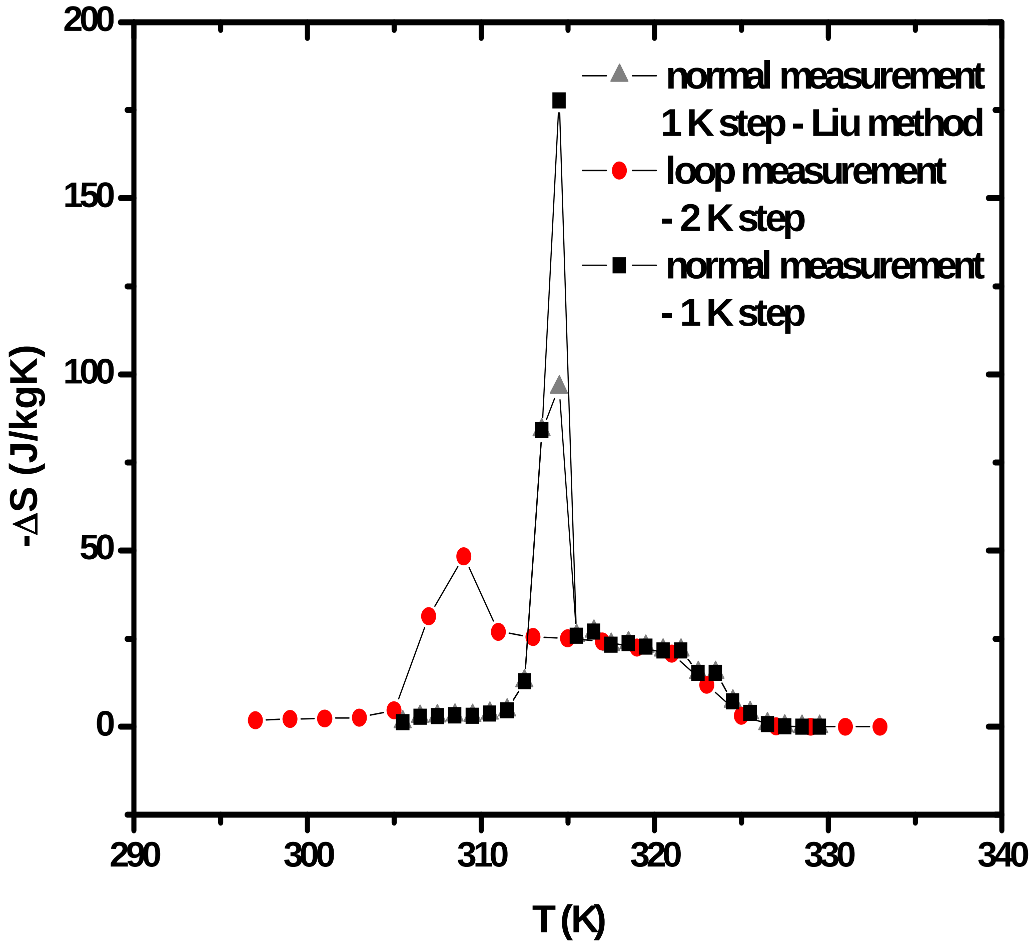
Alternate measurement method



Alternate measurement method



Conclusions

The entropy change calculated from magnetic isothermal measurements using the Maxwell relation is a very good tool around 1st order magnetic phase transitions as long as the history of the sample is taken into account when planning a measurement.

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