Handout 15

Phase transitions

Classification of phase transitions

Discontinuous phase transitions are characterised by a discontinuous change in entropy at a fixed temperature. The change in entropy corresponds to **latent heat** $L = T\Delta S$. Examples are solid–liquid and liquid–gas transitions at temperatures below the critical temperature.

Continuous phase transitions involve a continuous change in entropy, which means there is no latent heat. Examples are liquid–gas transitions at temperatures above the critical temperature, metal–superconductor transitions and many magnetic ordering transitions.

Ehrenfest's classification scheme: the **order** of a transition is the order of the lowest differential of G which shows a discontinuity.

First order transitions have discontinuities in the first derivatives of G:

$$\left(\frac{\partial G}{\partial T}\right)_p = -S, \qquad \left(\frac{\partial G}{\partial p}\right)_T = V.$$

First order transitions are therefore discontinuous.

Second order transitions have discontinuities in the second derivatives of G:

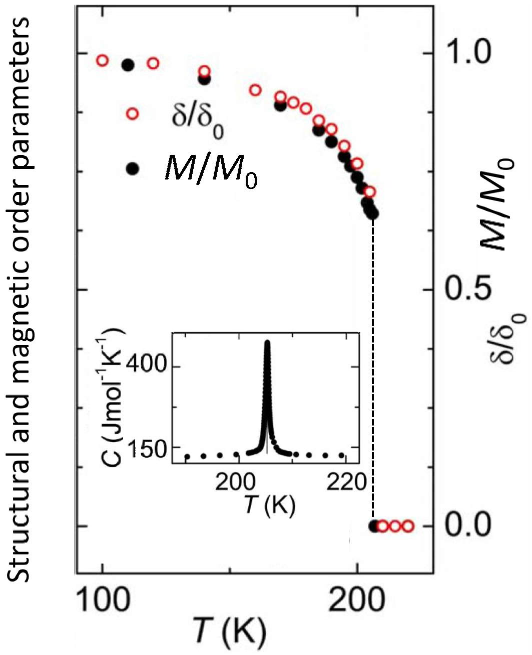
$$\left(\frac{\partial^2 G}{\partial T^2}\right)_p = -\frac{c_p}{T}, \quad \left(\frac{\partial^2 G}{\partial p^2}\right)_T = -V\kappa_T, \quad \left(\frac{\partial^2 G}{\partial T \partial p}\right) \; = \; V\beta_p$$

Second order transitions are examples of continuous transitions.

Phase transitions often involve the development of some type of order with an associated **symmetry breaking**. The broken symmetry is described by an **order parameter** which usually increases on moving deeper into the ordered phase, and which measures the degree of order as the phase transition proceeds. The order parameter is a physical observable, usually related to a first derivative of G. Examples of order parameters are magnetisation M for a ferromagnet, electrical polarisation P for a ferroelectric, and the degree of alignment of the molecules in a liquid crystal.

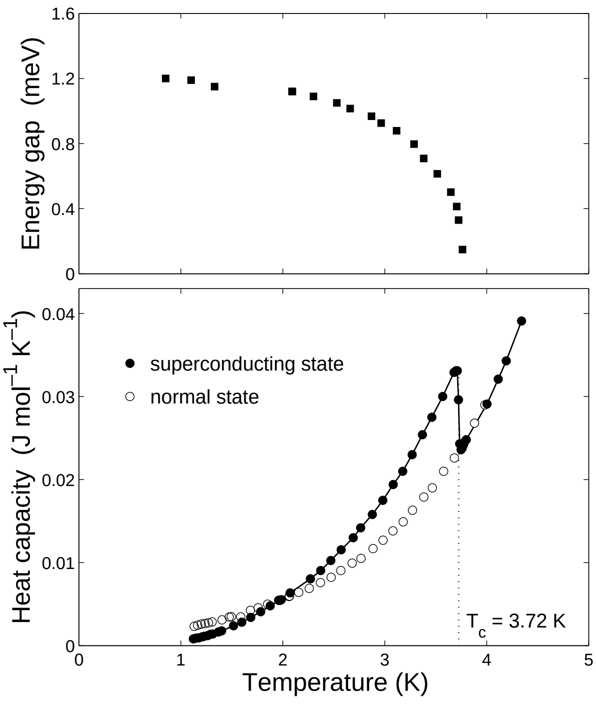
First-order magnetic and structural transition in $SrFe_2As_2$. At 205 K the crystal lattice undergoes a discontinuous distortion represented in the figure by the parameter δ. The structural transition is accompanied by magnetic order, represented by M. A very sharp peak in the heat capacity appears at the structural/magnetic transition, as may be seen in the inset figure.

[Data from A. Jesche *et al.*, Phys. Rev. B **78**, 180504 (2008).]



Superconducting transition in tin — an example of a second-order phase transition. The upper figure shows the temperature dependence of the superconducting order parameter, which is represented by an energy gap centred on the chemical potential in the electronic spectrum. The order parameter is seen to increase continuously below the superconducting transition temperature $T_c = 3.72$ K. The lower figure shows that there is a discontinuity in the heat capacity at T_c. The data for the normal state (i.e. non-superconducting state) of tin were obtained by applying a magnetic field to suppress the superconductivity.

[Data from W.S. Corak and C.B. Satterthwaite, Phys. Rev. **102**, 662 (1956), P. Townsend and J. Sutton, Phys Rev. **128**, 591 (1962) and D.H. Douglass and R. Meservey, Phys Rev. **135**, A19 (1964).]



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