Landau theory, susceptibility

Add a magnetic field

and **au theory, susceptibility**

\nmagnetic field

\n
$$
f = f_0 + \alpha_0 (T - T_c) m^2 + \frac{1}{2} \beta m^4 - m
$$
\n
$$
\frac{df}{dm} = 2\alpha_0 (T - T_c) m + 2\beta m^3 - B = 0
$$
\nwe T_c , m is finite for finite B . For small m ,

\n
$$
B = T_c \times T
$$

Above T_c , *m* is finite for finite *B*. For small *m*,

Landau theory of phase transitions

$$
\varepsilon_r = 1 + \chi \qquad \qquad \chi = \frac{1}{2\alpha_0 (T - T_c)}
$$

Curie-Weiss law

Fitting the α_0 and β parameters

First order transitions

 $f = f_0 + \alpha_0 (T - T_c) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 + \cdots \quad \alpha_0 > 0, \quad \beta < 0, \quad \gamma > 0$

There is a jump in the order parameter at the phase transition.

First order transitions

First order transitions

$$
f = f_0 + \alpha_0 \left(T - T_c \right) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 + \cdots \qquad \beta < 0
$$

First order transitions
\n
$$
f = f_0 + \alpha_0 (T - T_c) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 + \cdots \qquad \beta < 0
$$
\n
$$
\frac{df}{dm} = 2\alpha_0 (T - T_c) m + 2\beta m^3 + 2\gamma m^5 = 0
$$
\nsolution for $m = 0$.

One solution for $m = 0$.

$$
\alpha_0(T - T_c) + \beta m^2 + \gamma m^4 = 0
$$

$$
m^{2}=0, \frac{-\beta\pm\sqrt{\beta^{2}-4\alpha_{0}(T-T_{c})\gamma}}{2\gamma}
$$

There will be a minimum at finite m as $\frac{m}{m}$ ^{0.0} long as m^2 is real

$$
T_1 = \frac{\beta^2}{4\alpha_0 \gamma} + T_c
$$

Jump in the order parameter

First order transitions, entropy, c_v

$$
f = f_0 + \alpha_0 \left(T - T_c \right) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 + \cdots \qquad \beta < 0
$$

$$
\begin{aligned}\n\text{rst order transitions, entropy, c} \\
f &= f_0 + \alpha_0 \left(T - T_c \right) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 + \dots \quad \beta < 0 \\
m &= 0, \pm \sqrt{\frac{-\beta \pm \sqrt{\beta^2 - 4\alpha_0 \left(T - T_c \right) \gamma}}{2\gamma}}\n\end{aligned}
$$

$$
s = -\frac{\partial f}{\partial T} = \frac{\alpha_0}{2\gamma} \left(\beta - \sqrt{\beta^2 - 4\alpha_0 \gamma (T - T_c)} \right)
$$

parameter is nonzero

branch where the order

$$
c_v = T \frac{\partial s}{\partial T} = \frac{\alpha_0^2 T}{\sqrt{\beta^2 - 4\alpha_0 \gamma (T - T_c)}}
$$
 parameter is nonzero

First order transitions, susceptibility

st order transitions, susceptibility

\n
$$
f = f_0 + \alpha_0 \left(T - T_c \right) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 - m \beta \quad \beta < 0
$$
\n
$$
\frac{df}{dm} = 2\alpha_0 \left(T - T_c \right) m + 2\beta m^3 + 2\gamma m^5 - B = 0
$$
\ninima

\n
$$
B = 2\alpha_0 \left(T - T \right) m + 2\beta m^3 + 2\gamma m^5
$$

At the minima $B = 2\alpha_0 (T - T_c) m + 2\beta m^3 + 2\gamma m^5$

For small m,

$$
\alpha_0 (T - T_c) m^2 + \frac{1}{2} \beta m^4 + \frac{1}{3} \gamma m^6 - mB \qquad \beta < 0
$$

\n
$$
2\alpha_0 (T - T_c) m + 2\beta m^3 + 2\gamma m^5 - B = 0
$$

\n
$$
B = 2\alpha_0 (T - T_c) m + 2\beta m^3 + 2\gamma m^5
$$

\nFor small *m*,
\n
$$
\chi = \frac{dm}{dB}\Big|_{m=0} = \frac{1}{2\alpha_0 (T - T_c)}
$$
 Curie - Weiss
\n
$$
\chi = \frac{dm}{dB}\Big|_{m=\sqrt{\frac{-\beta}{2\gamma}}} = \frac{1}{2\alpha_0 (T - T_1)}
$$

Outline Quantization Photons Electrons Magnetic effects and Fermi surfaces Linear response Transport **Crystal Physics** Electron-electron interactions Quasiparticles Structural phase transitions Landau theory of second order phase transitions Superconductivity Exam questions **Appendices** Lectures **Books** Course notes TUG students Making presentations **Advanced Solid State Physics**

Landau theory of a first order phase transition

The free energy for a first order transition in Landau theory is,

$$
f\big(T\big)= f_{\,0}\big(T\big)+ \alpha_{\,0}\big(T-T_{c}\big)m^{\,2} + \tfrac{1}{2}\,\beta m^{\,4} + \tfrac{1}{3}\,\gamma m^{\,6} \qquad \alpha_{\,0} > 0, \quad \beta < 0, \quad \gamma > 0.
$$

Here $f_0(T)$ describes the temperature dependence of the high temperature phase near the phase transition.

Order parameter

Institute of Solid State Physics

Superconductivity

Primary characteristic: zero resistance at dc

There is a critical temperature T_c above which superconductivity disappears

About 1/3 of all metals are superconductors

Metals are usually superconductors OR magnetic, not both

Good conductors are bad superconductors

Kittel chapter 10

Superconductivity

Heike Kammerling-Onnes

Superconductivity was discovered in 1911

Critical temperature

 $90₁$

 ${\rm Th}$

1.368

 91

 $\rm Pa$

 1.4

 $92₂$

93

 Np

 94

 Pu

 $95[°]$

Am

96

 Cm

97

 $\rm Bk$

 $98₁$

 Cf

 99_o

 $\mathrm{E}\mathrm{s}^{-}$

 $100[°]$

 \mathbf{Fm}

 101

 $_{\rm Md}$

 102

 \rm{No}^-

 103

 Lr

Superconductivity

Antiaromatic molecules are unstable and highly reactive

No measurable decay in current after 2.5 years. $\rho < 10^{-25}$ Ω m.