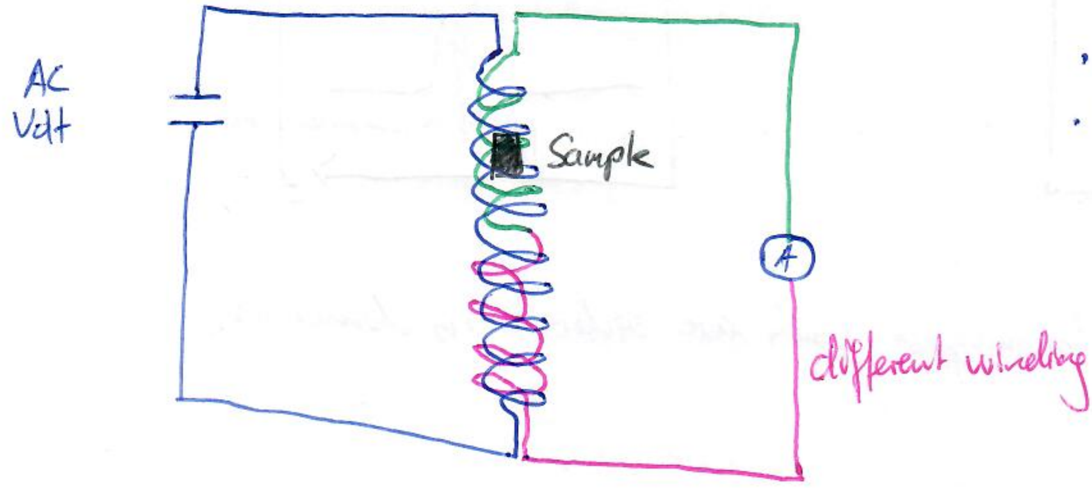
Measuring magnetic susceptibility



- no mutual induction
- inductance $\sim \chi$

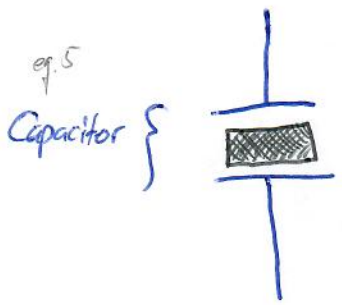
Dielectric susceptibility

capacitance with no dielectric

$C = C_0(1+\chi_e)$ eq. 5

$\Leftrightarrow \vec{D} = \vec{E}\varepsilon_0\left(1 - \frac{\chi(q)}{\varepsilon_0 q^2}\right)$

measure in capacitor



also possible via laser, total reflection

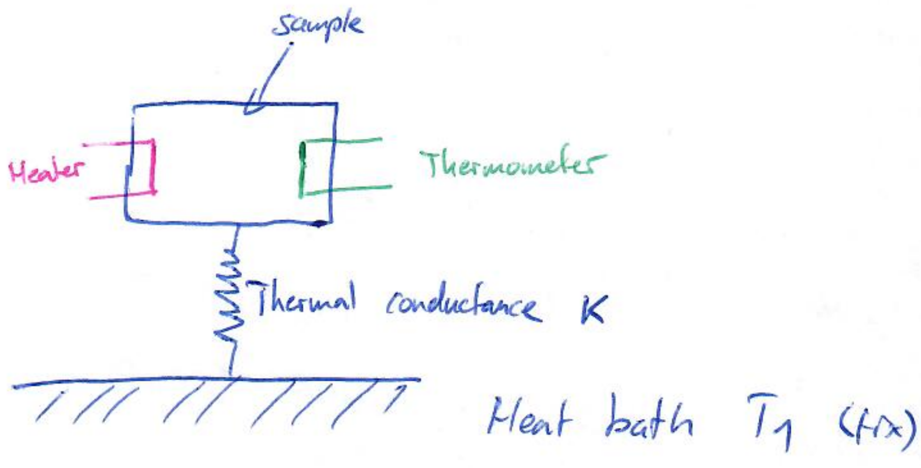
$\rightsquigarrow n \rightsquigarrow \chi \rightsquigarrow \varepsilon$

I: T_H, E-Field strong
II: cool down with field, no breaking up in domains
III: remove E-Field, heat up in capacitor
IV: measure the current

Specific heat measurement

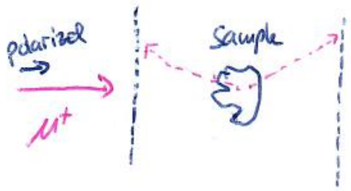
p. 1492 Garden

Relaxation calorimetry



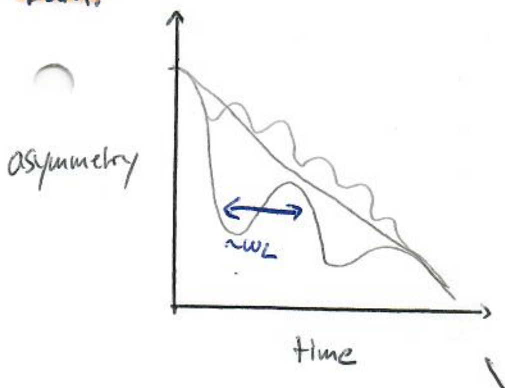
Muon spin rotation

Experimental technique:



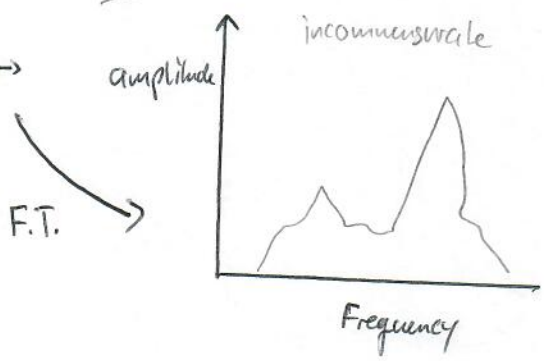
Muon spin spectroscopy is an experimental technique based on the implantation of spin-polarized muons in matter and on the detection of the influence of the atomic or crystalline surroundings on their spin motion. The motion of the muon spin is due to the magnetic field experienced by the particle and may provide information on its local environment.

Data:



$\omega_L \sim \gamma \cdot B$
γ ← const.

Positrons are emitted preferentially along the muon spin. The frequency of the oscillations is directly proportional to the local field.

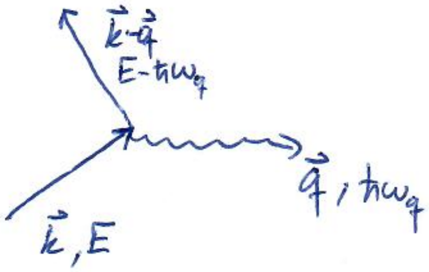


Application:

SDW, MuSR extremely sensitive to even very weak local fields.

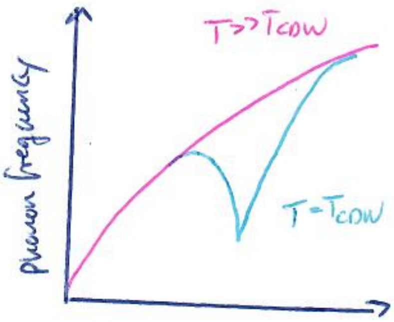
3-axis neutron Spectrometer

Experimental technique:



Neutron spectroscopy is a powerful technique to study phonon dispersion curves. A high count rate means that at that particular momentum $\vec{q}$ it is possible to excite a phonon with that particular energy $\hbar\omega$.

Data



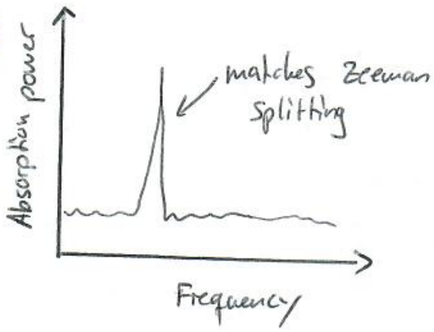
$[0,0,\xi]$, $\xi = \frac{q}{\pi} \cdot c$

Nuclear magnetic resonance

Experimental technique:

The initially degenerate nuclear spin states are subject to a Zeeman splitting by the local field at the nuclear site. The magnitude of the splitting is proportional to the loca field, and thereby to the order parameter.

Data:

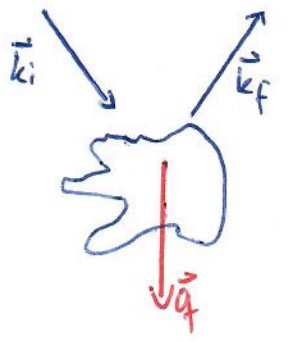


Application:

- net magnetization zero for ferromagnets broken up in domains
- insulating antiferromagnets

Diffraction

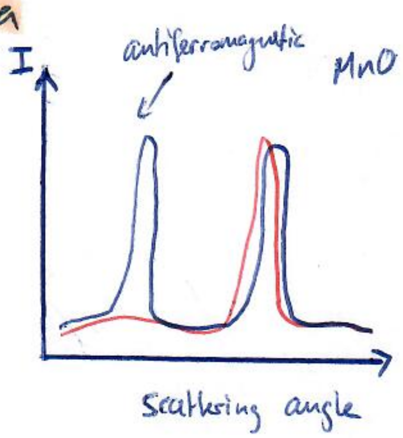
Experimental technique:



Diffraction is the tool of choice to study phase transitions where the order parameter is a particular spatial Fourier component of some microscopic density. $\Rightarrow I_q \sim |\rho_q|^2$

Neutrons are only scattered by spin components that are perpendicular to the scattering vector.

Data



How to determine the spatial structure

p. 31 Chaikin

$$2d \sin\theta = n\lambda \qquad \text{(Bragg's Law)}$$

Intensity at 2θ reflects a fluctuation with periodicity $\frac{\lambda}{2\sin\theta}$.

Fermi Golden rule $\Rightarrow$

$$M^2_{\vec{k},\vec{k}'} = |\langle \vec{k}|U|\vec{k}'\rangle|^2 \sim \text{Transition rate } \vec{k} \to \vec{k}'$$

U: Scattering potential

#part. in $d\Omega$/per second

$$\frac{d^2\sigma}{d\Omega} \sim \frac{2\pi}{\hbar} |M_{\vec{k},\vec{k}'}|^2$$

X-ray diffraction and not neutron diffraction! Why?

identical atoms $\Rightarrow$

$$\frac{d^2\sigma}{d\Omega} \sim \underbrace{|U_\alpha(\vec{q})|^2}_{\text{atomic form factor, FT of atomic potential}} \underbrace{I(q)}_{\text{structure function}} = |U_\alpha(\vec{q})|^2 N \underbrace{S(\vec{q})}_{\text{structure factor}}$$

Measurement

$$G(\vec{r}) = \int d\vec{R} \langle \rho(\vec{R})\rho(\vec{R}+\vec{r})\rangle \, , \quad S(\vec{k}) = \int G(\vec{r}) e^{-i\vec{k}\cdot\vec{r}} d\vec{r}$$

F.T.

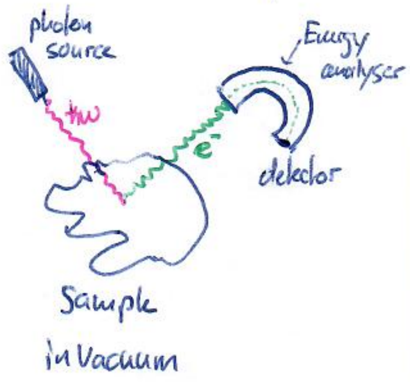
$$\Rightarrow S(\vec{k}) = \langle |\rho_{\vec{k}}|^2 \rangle$$

Important!

Restrictions: Scattering mean-free-path $\gg$ thickness of sample.

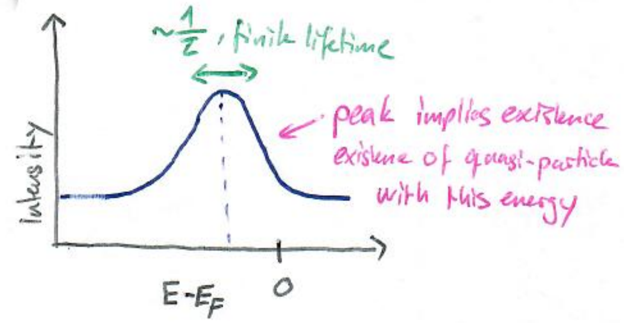
Angle-resolved photoemission spectroscopy

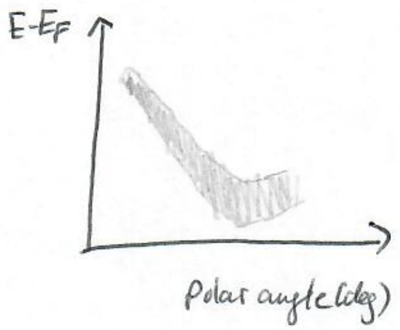
Experimental technique:



ARPES is a technique which uses the photoelectric effect and can be used to determine the hole dispersion relation. A photon is fired at the sample where its energy is transferred to the ejected electron and the quasi hole left behind. One can then plot the quasihole energy vs the quasi hole momentum to get the dispersion relation.

Data:





Application:

- ARPES probes occupied electronic states and therefore cannot measure quasi particles above the Fermi energy.
- Useful to measure the shapes of Fermi surfaces.
- Is only sensitive to the surface

Photons, Neutrons or Electrons

p. 33 Chaikin

Bragg's law $\Longrightarrow$ $\lambda < 2d$, usually $d \sim$ Å

Photons

Energy: $\sim 10^4 eV$, penetrate up to 1 mm
$\rightarrow$ provides bulk information

difficult to measure
$\Delta E \sim 0{,}1\ eV$

Cant go very low in temp., thin walls for Xray to enter

Electrons

Energy: 100eV , problems with multiple scattering unless sample < 1micron

Neutrons

Energy: 0,1eV ~ 400K , scatter from nuclear forces and electron spin

good for $\Delta E \sim 0{,}1 eV$

needs crystal of size $1cm^3$
if smaller use X-Ray

Neutrons are only scattered by spin components which are perpendicular to scattering vector

thermal neutrons (250K) ~ 2Å