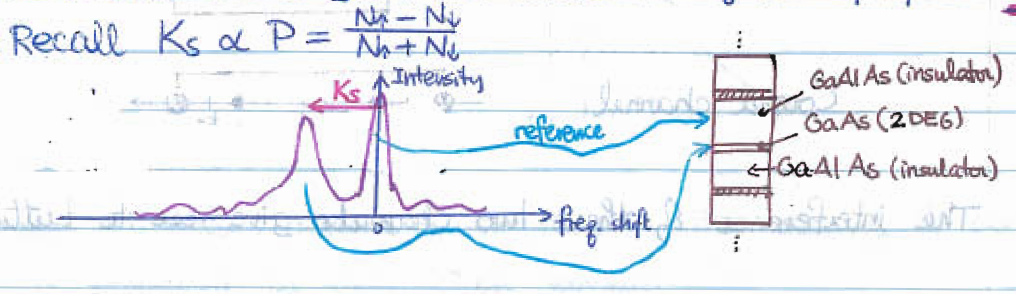
NMR: Formalism and Techniques (II) [Mitrovic]

- NMR is local probe ⟶ useful in probing short-ranged magnetic order.

- Next consider 2D e⁻ gas, with lowest LL of ONE spin filled

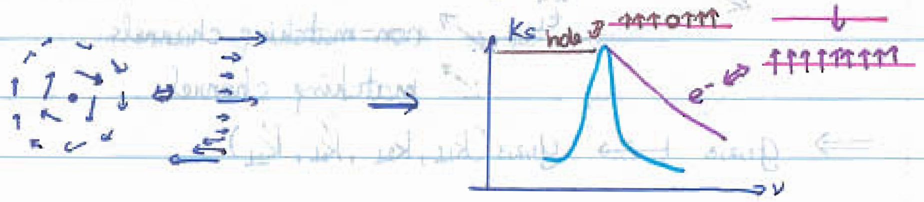
▲ Recall $K_s \propto P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$



▲ With reference & shift at full polarized system, polarization can be measured.

▲ Relaxization can also be measured by measuring P at various times.

- NMR can also measure the texture of skyrmion:



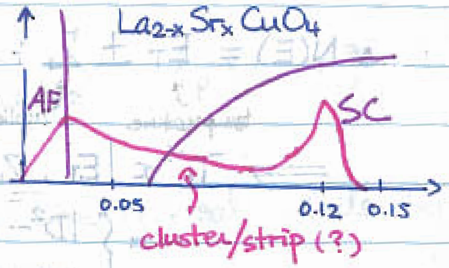
- For system of slow relaxation time, one can trade faster repeat time higher signal/noise ratio using small tip technique.

▲ i.e. instead of an initial π/2-pulse, use a small θ-pulse.

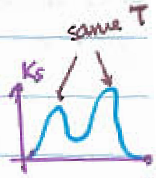
▲ Since signal/noise $= f(\underset{\text{relaxation}}{T_R}/\underset{\text{equilibrate}}{T_1}$, tip angle). If a sample has different T_1, one can tune the repeat time so as to suppress signal of certain T_1 & favor only signal of specific T_1

⟹ seperating the quantum well (2DEG) signal from the substrate (background) signal.

- Inhomogenous Systems



  - ▲ The precise strip order in cluster/strip state is unclear.
  - ▲ For NMR, 3 possibilities



    (1) spatially resolved measurement

    If (1) fails { (2) phenomenological fit ⟹ exponent α quantify disorder strength

    (3) convolve with distribution function ⟹ deduce parameter.

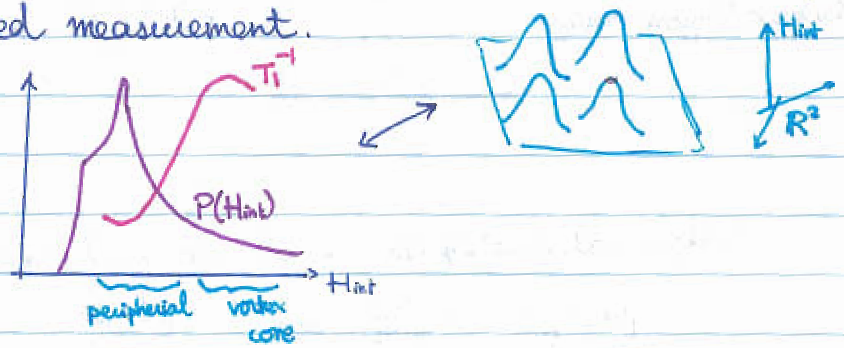
$$〰 : \frac{M_0-M_\infty}{M_\infty} = \underbrace{\sum_k C_k \cdot e^{-\frac{b_k t}{T_1}}}_{=\mathcal{M}_{\alpha=1}(t)} \longmapsto \underbrace{\sum_k C_k \cdot e^{-\left(\frac{b_k t}{T_1}\right)^{\alpha}}}_{=\mathcal{M}_{\alpha}(t)}$$

$$〰 \quad M_G(t) = \int d(\ln R_1)\, \mathcal{P}(\ln R_1 - \ln T_1^{-1}) \cdot \mathcal{M}_{\alpha=1}(t)$$

  - ▲ Assuming $\langle S(0)S(t)\rangle = S_\perp^2 e^{-t/\tau_c}$, $\frac{1}{T_1} \propto \frac{\tau_c}{1+\omega_n^2\tau_c^2}$

    ⟹ T_1^{-1} enhancement until maximum at $\tau_c^{-1} = \omega_n$. NMR freq.

- For vortex state, unlike the strip state, allow spatially resolved measurement.



  - ▲ Outside vortex core,

    (1.) T_1^{-1} ↗ as H_0 ↗

    (2.) T_1^{-1} ↗ as H_{int} ↗ (H_{int} ↗ ⟹ closer to core)

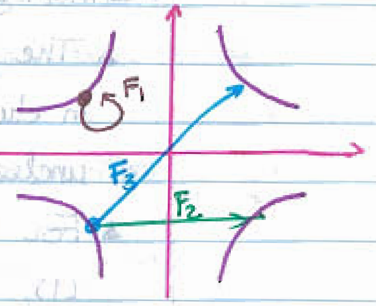
    (3.) $(TT_1)^{-1}$ is constant.

  - ▲ For s-wave, low energy excitation bounded to core. For d-wave, low energy excitation extended along nodal direction.
  - ▲ Since $T_1^{-1} \propto \langle N_i(E) N_f(E)\rangle$, energy spectrum of nodal QP can be measured for outside-the-core region

- ▲ $N(E) = \underset{\text{temperature}}{E_T} \pm \underset{\text{applied field}}{Z} + \underset{\text{internal field}}{D}$

$$\Longrightarrow T_1^{-1} \propto |E_T + Z + D_i| \cdot |E_T - \underbrace{Z + D_f}_{\text{NMR process flip spin}}|$$

$$= \begin{cases} |D^2 - Z^2| & F_1 \\ |D^2 + Z^2| & F_3 \end{cases}$$



- ▲ Experiment suggests that F_3 is dominate
- ▲ For this to be valid one should measure at low temperature $T \lesssim \Delta/2$.