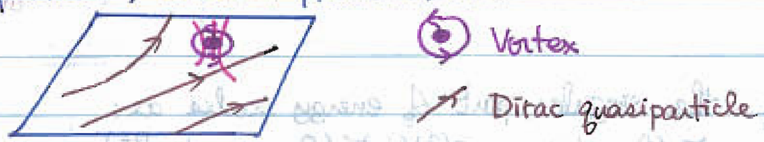
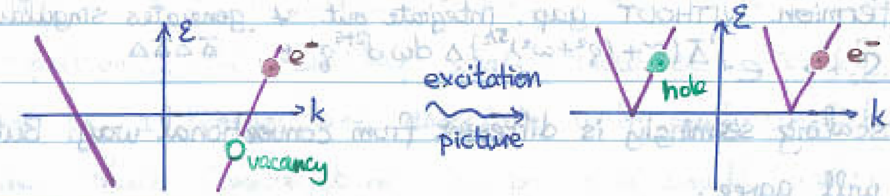
# Quasiparticle in d-wave Superconductor [Ong]

- By doing charge-heat excitation, one can differentiate between quasiparticles, vortex, phonons, etc.

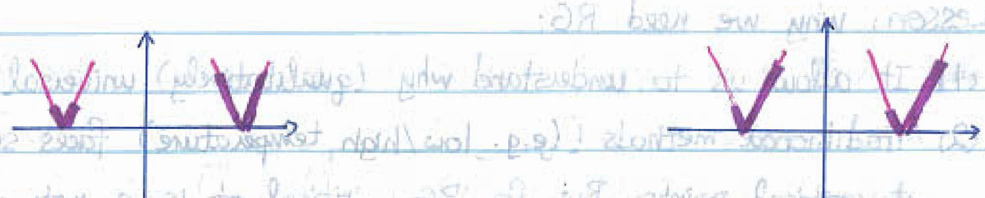



- Theoretically, $\overleftrightarrow{\sigma}$ in $\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E}$ is easier to calculate, but experimentally it is $\overleftrightarrow{\rho}$ is $\vec{E} = \overleftrightarrow{\rho} \cdot \vec{J}$ that's measured.

- Including heat current, $\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E} + \alpha(-\partial_x T)$
  $\overleftrightarrow{\sigma}$ and $\alpha$ can be computed by Boltzmann Eqn.

- 

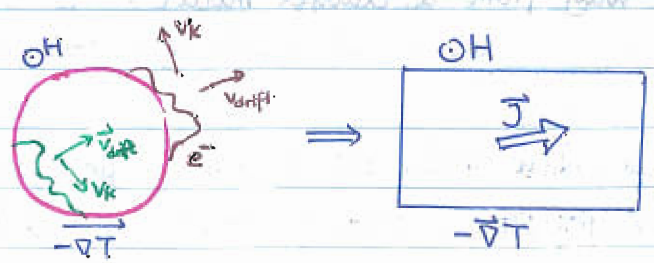

- Electric field : vs. Heat Gradient



Large charge current

Small mass current

- Thermal Hall



- Nernst effect

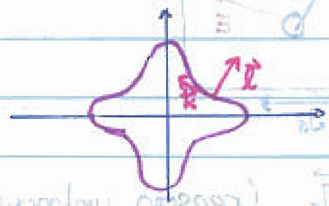
  Setting $\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E} + \overleftrightarrow{\alpha}(\nabla T)$ with $\vec{J} = 0$

  $\Longrightarrow \vec{E} = -\overleftrightarrow{\rho} \cdot \overleftrightarrow{\alpha} \cdot (\vec{\nabla} T)$

  Effect is small since $\alpha_{xy}$ and $\sigma_{xy}$ cancels

- The Hall effect coeff. can be written as:

  $\sigma_{xy} = e^3 B \cdot \frac{1}{2} \oint d\vec{l} \times \vec{l}$ $\Longrightarrow$ area swept out in $l$-space. ($l$ ← mean free path)




- Note that Hall effect is $2^{nd}$-order: need both $\vec{E}$ and $\vec{B}$ presense.

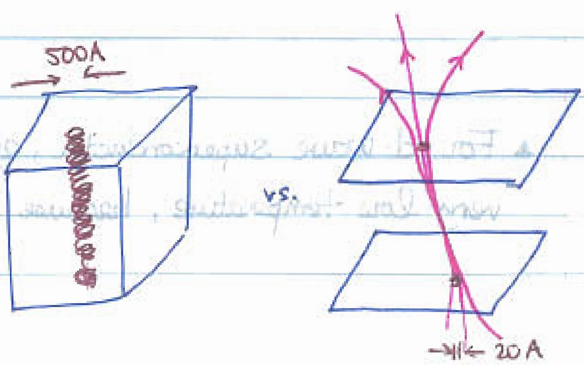
- In ordinary metal, Hall coeff. ($\rho$) should be approx. const. at Kelvin scale. But in cuprates it varies drastically. When convert to Hall angle ($\sim \sigma_{xy}/\sigma_{xx}$) it shows a $T^2$ (rather than $T$) dependence.

- In Cuprates, Fermi arc ends abruptly, and its length is roughly propotion to T.

  $\Longrightarrow$ Take a model where only states on Fermi arc have long mean free path.

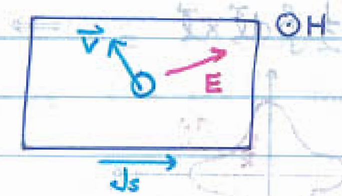
- The model fit data well EXCEPT at small temperature, where observed $R_H$ becomes small.

- Since Curprate is 2D, vortex forms "pancakes". Vortex size much smaller than in 3D.



• Bardeen — Stephen Theory

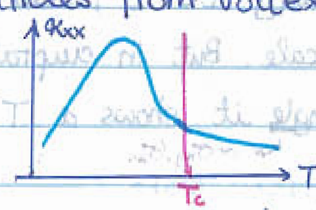
- Supercurrent exert forces on vortex core
- As vortex moves, an internal $\vec{E}$-field is produced by Faraday effect
- The internal $\vec{E}$-field attract pairs into core, where they break into normal particles, disipate, and recombine.
- A marcoscopic, observable $\vec{E}$-field is then generated by Josephson effect.




- In clean limit $\vec{V}_{//} \propto -\vec{J}_s$ (reason unknown)

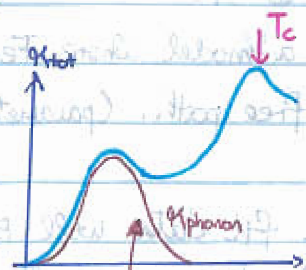
• Problem — seperates quasiparticles from vortex.

- Consider thermal power:



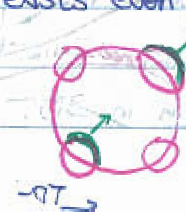

Is peak caused by phonon or quasiparticle? (vortex has small contribution, supercurrent carry no entropy)

- Case of old SC (Pb):




For low T, phonon-e⁻ scattering vanishes, giving 2nd peak.

- For d-wave superconductor, quasipaticle exists even down to very low temperature, because of nodes.



- Quasipaticle and phonon can be distinguished since scattering of q.p. by vortex is asymmetric, while phonon-vorte scattering is symmetric.
  - ▲ Cause by Doppler shift


- Conclusion: peak is caused mostly by quasipaticles.