Superconductivity - Basic Phenomena

- Many metals superconduct below a critical temperature ($T_c$).

- $T_c$ ranges from $\sim$ mK to $\sim$ 100 K. For elemental metals often $T_c \sim$ a few Kelvin (e.g. Pb, Al, ...)

- $T$ - $H$ phase diagram ("Type I" superconductors)

  \[ H_c(T) \]
  \[ \text{Normal metal} \]
  \[ SC \]

  \[ T_c \sim \text{7 K (Pb)} \]
  \[ \sim \text{1 K (Al)} \]

  $L \rightarrow$ e.g. Pb, Al

  $H_c(T=0) \sim 800$ gauss (Pb)
  \[ \sim 100 \] (Al)

- Apply field destroys superconductivity.
\[ M \text{eisser effect } \rightarrow \text{ expulsion of B-field} \]

\[ B \]

\[ T > T_c \quad \text{cooling} \rightarrow T < T_c \]

\[ \text{Not same as } "\text{perfect conductivity}," \text{ that is a bunch of particles move } \frac{\partial J}{\partial t} \propto B. \text{ In a true } "\text{perfect conductor}," \text{ flux is not expelled.} \]

\[ \text{Perfect diamagnetism: } \quad \vec{B} = \vec{H} + 4\pi \vec{M} \quad \vec{M} = -\frac{\vec{H}}{4\pi} \text{ in SC state} \]

\[ M \]

\[ \text{slope } - \frac{1}{4\pi} \]

\[ \Rightarrow \vec{B} = 0 \]
"Type II" Superconductors. E.g. Cuprate high-$T_c$ superconductors. Nb$_3$Sn, ...  

\[ H \]

\[ H_{c1} \]

"Mixed State"  

\[ B \neq 0 \]

Meissner  \( B = 0 \)  

\[ \rightarrow T \]

Normal metal

Here field penetrates in discrete flux lines (Abrikosov vortices), each with \( \Phi_0 = \frac{h}{2e} \) flux.  

\[ \rightarrow \text{Flux quantization.} \]

\( \text{Nb, Sn: } T_c \sim 18 \text{ K, } H_{c1} \sim 0.02 \text{ T, } H_{c2} \sim 24.5 \text{ T} \)

\[ B \]

\[ \rightarrow H \]

\[ H_{c1}, H_{c2} \]

\[ \text{Superconducting.} \]

Large!
Isotope Effect:

Roughly, $T_c \sim \frac{1}{\sqrt{M}}$, where $M$ is isotope mass.

→ Evidence that phonons are important.

Heat Capacity:

- In metal $C(T) = C_{el}(T) + C_{ph}(T) = \gamma T = CT^3$

Superconductor:

- Exponential decay $\sim e^{-A/\kappa T}$

"energy gap"
Other probes of energy gap:

Normal - SC tunneling

\[ V = \frac{\Delta}{e} \]