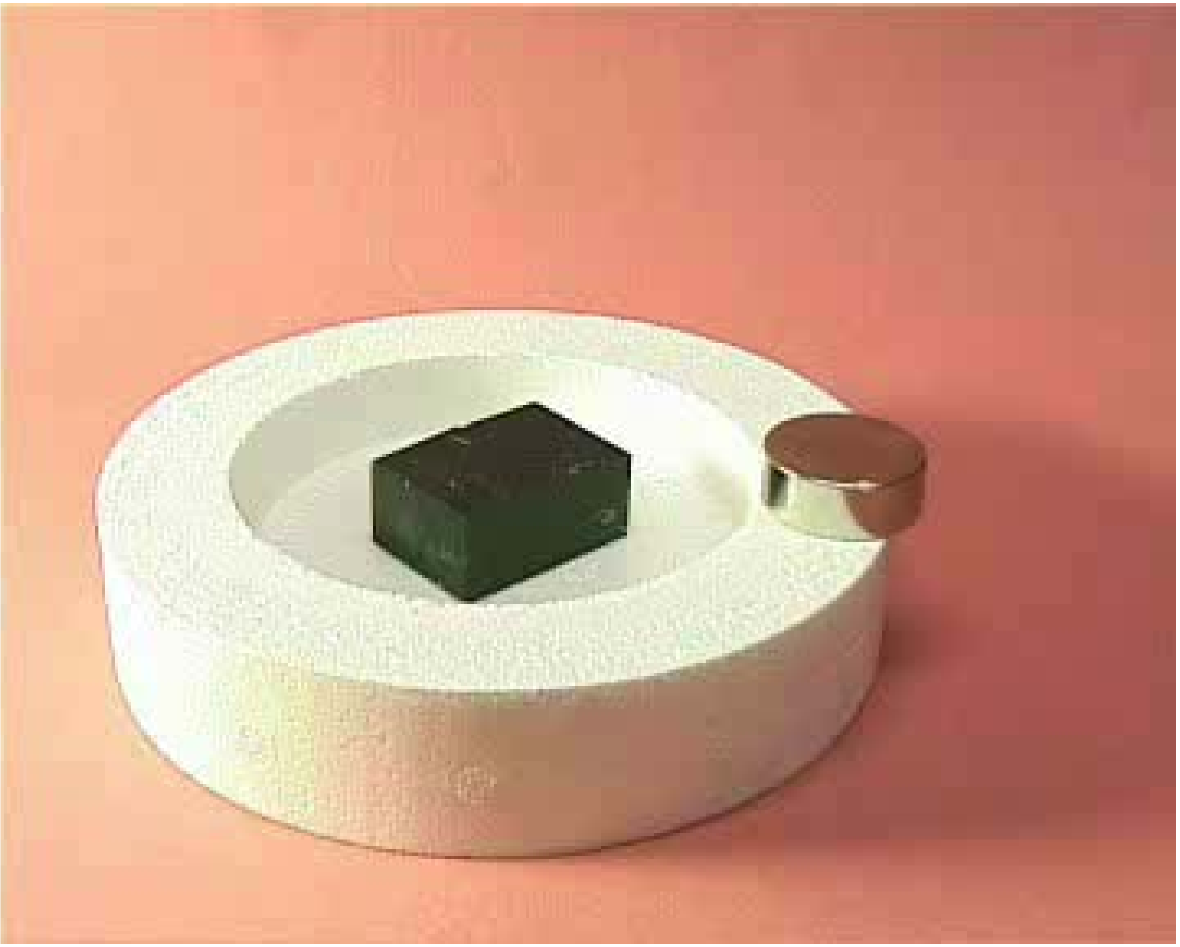
Lecture 20
Superconductivity

Defining characteristics of the superconductivity are the Meissner effect and the infinite conductivity, *in **that** order.*

Meissner Effect



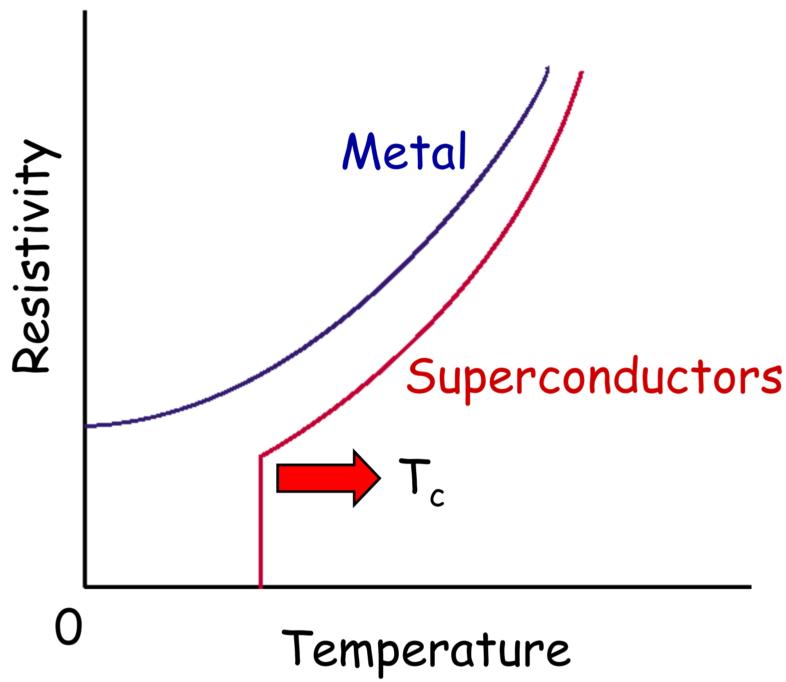
http://www.fys.uio.no/super/levitation/

Essential Characteristics

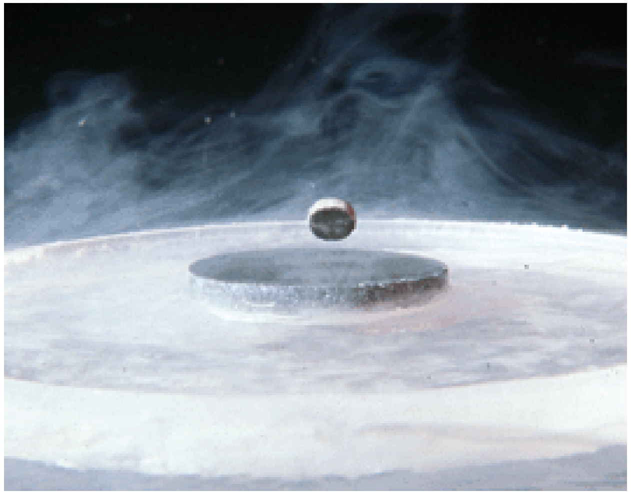
1911 **K. Onnes Superconductivity in Hg**

1933 **Meissner effect**

RESISTANCELESS CONDUCTION



MEISSNER EFFECT:
Perfect diamagnetism

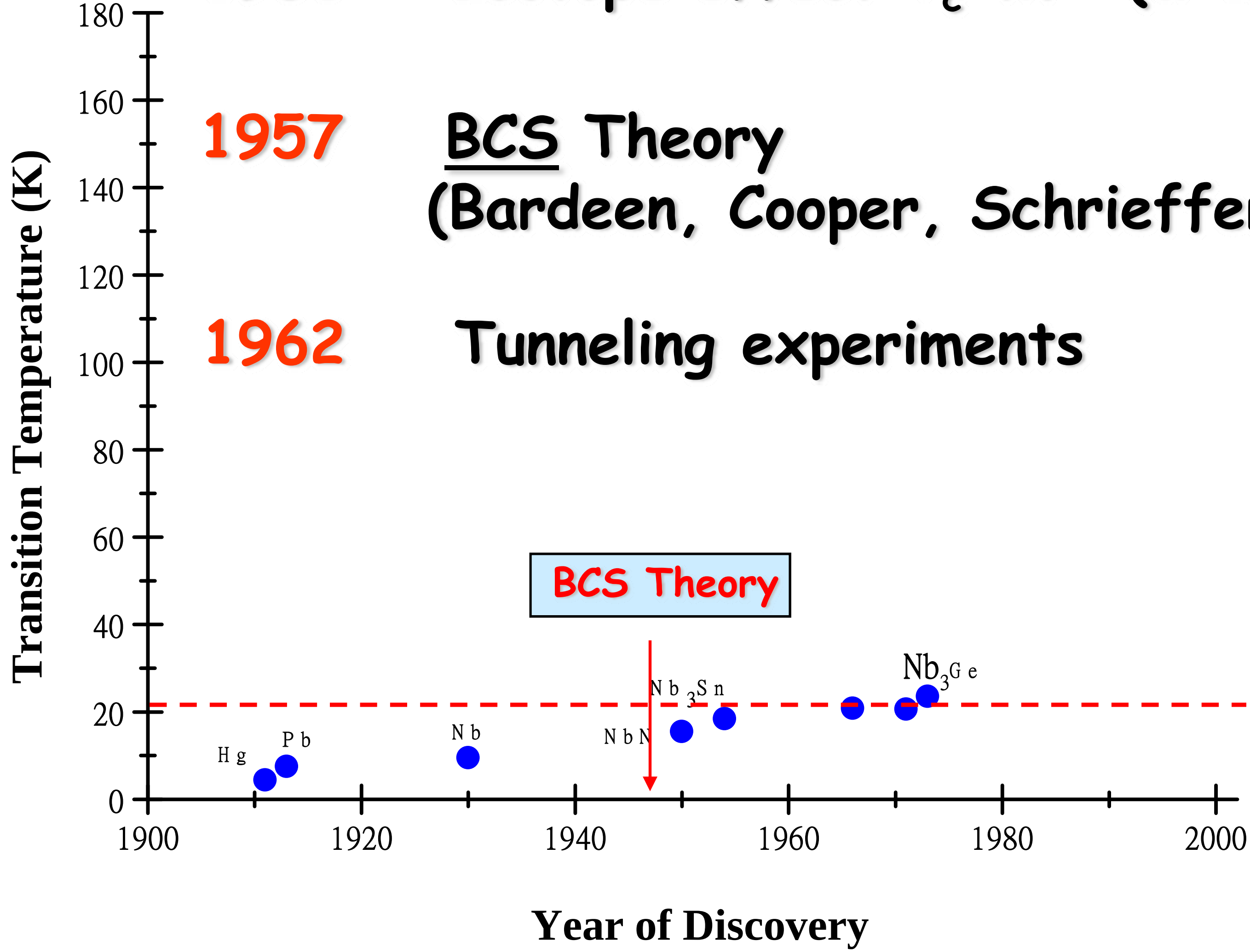


Understanding of Superconductivity

1950 Isotope effect $T_c \sim M^{-\alpha}$ ($\alpha \sim 1/2$)

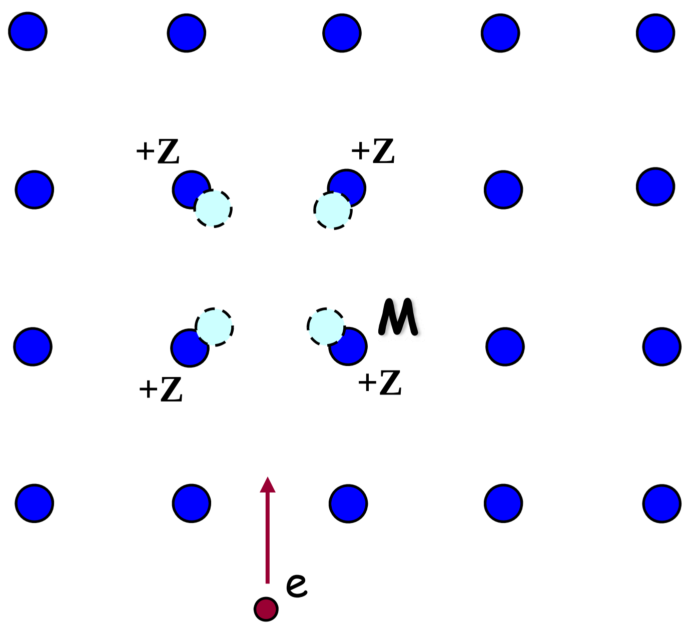
1957 <u>BCS</u> Theory (Bardeen, Cooper, Schrieffer)

1962 Tunneling experiments



BCS theory

PHONON MEDIATED PAIRING
(phonon = lattice vibration)



Pairs of electrons: Cooper pairs

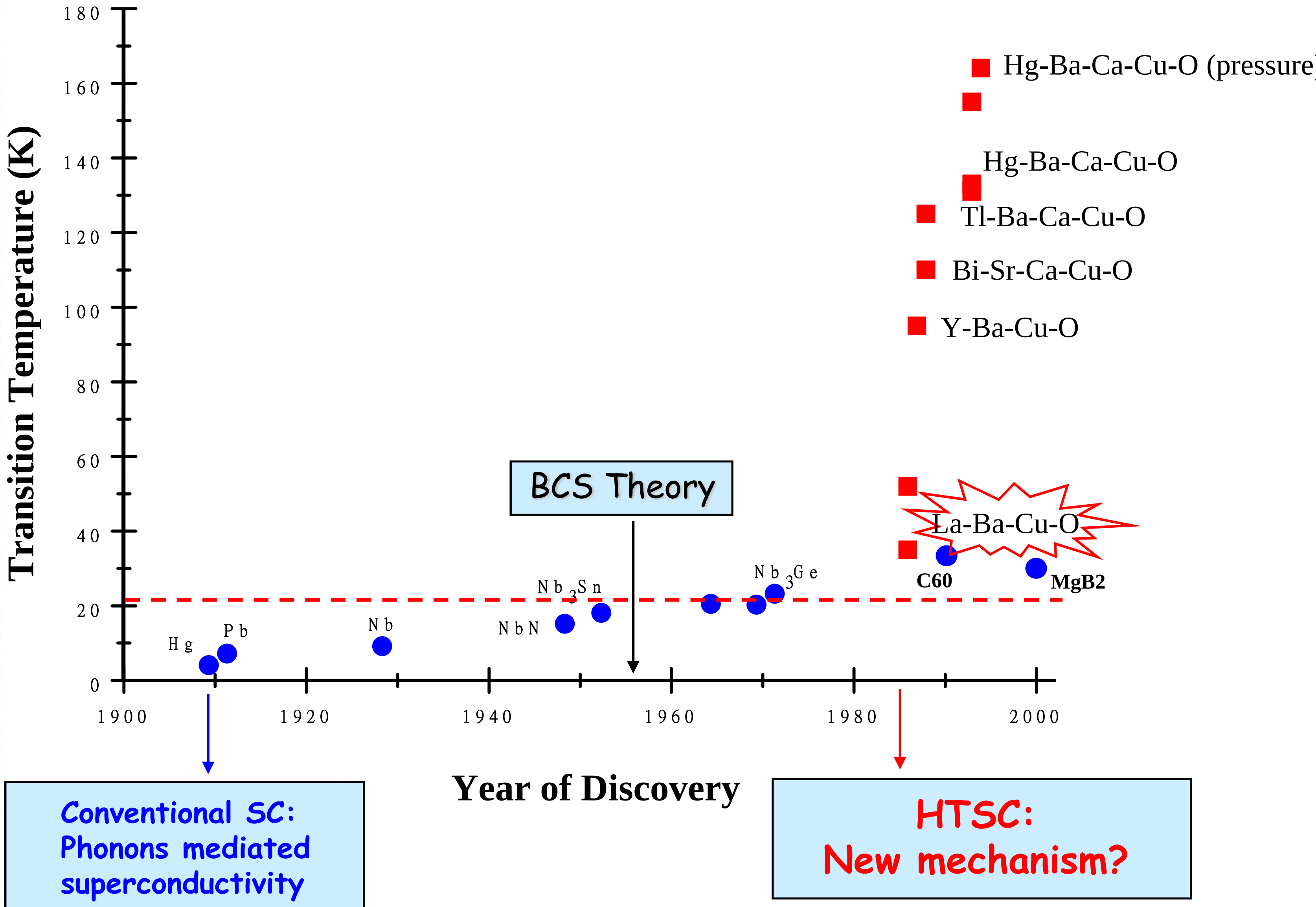
Superconducting gap: Δ

El-ph coupling constant: λ

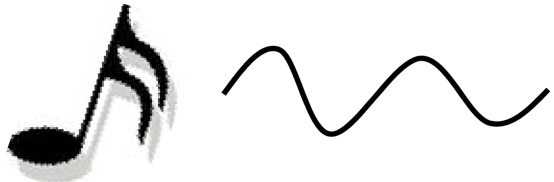
$$T_c \sim \omega_{ph} \exp(-1/\lambda) \sim M^{-1/2}$$

e-ph wins e-e at low freq. (Slow Wins!)

HTSC – New Superconductivity



Superconductivity – Dance of Electron Pairs



Origin of SC = **PAIRS** dancing to the **SAME** tune

Phys. Today, March '04

Superconducting Order Parameter (Ginzburg-Landau; Gorkov)

- Can be viewed as the "wave function" of the condensate (i.e. ALL electron pairs)
- All electron pairs (**Cooper pairs**) have the same phase (like photons in laser)

$$\psi = \sqrt{n_s}\, e^{i\phi}$$

n_s: density of superconducting e^- pairs

ϕ: phase

So How does it work?

$$\vec{j}_0 = \frac{\hbar q}{2im}\left(\psi_0^* \vec{\nabla}\psi_0 - (\vec{\nabla}\psi_0)^*\psi_0\right)$$

QM, e.g. Sakurai

$$\vec{j} = \vec{j}_0(\psi_0 \to \psi) - \frac{q^2\vec{A}}{mc}|\psi|^2$$

$$H = \frac{1}{2m}\left(\vec{p} - \frac{q\vec{A}}{c}\right)^2 + \text{pot.}$$

(QM or H&H 7.3.1)

$\psi \approx \psi_0$ (energy gap, many-body coherence)

$$\vec{j}_0 = 0 \qquad \vec{j} = -\frac{q^2\vec{A}}{mc}n_s$$

London Equation

$q = -2e, \quad m \approx 2m_e$

$$\vec{\nabla}\times\vec{B} = \frac{4\pi}{c}\vec{j}$$

$$-\vec{\nabla}^2\vec{A} = \frac{4\pi}{c}\vec{j} = -\frac{4\pi q^2 n_s}{mc^2}\vec{A}$$

$\lambda \sim$ a few 100 Å

$$\vec{\nabla}^2\vec{A} = \frac{\vec{A}}{\lambda^2} \qquad \lambda = \sqrt{\frac{mc^2}{4\pi q^2 n_s}}$$

$\vec{B}$ field is screened within the length scale λ

Meissner Effect

Steady state No electrostat. pot.

$$\frac{\partial\vec{j}}{\partial t} = 0 \qquad \vec{E} = -\frac{1}{c}\frac{\partial\vec{A}}{\partial t} \qquad \vec{E} = 0$$

Infinite Conductivity

cgs unit

Two Length Scales and two types of SC

λ = London Penetration Depth

ξ = coherence length $\sim \frac{\hbar v_F}{\Delta}$

Δ : pair binding energy

$\xi \sim$ Pair wavefunction Size

Pippard non-local E&M $\leftarrow$ due to ξ

As material becomes impure, λ and ξ change in opposite manners.

Type 1 SC : $\lambda(T=0) \ll \xi$

Type 2 SC : $\lambda(T=0) \gg \xi$ (most useful)