The Discovery of Superconductivity

Physics Today September 2010

Figure 1. Heike Kamerlingh Onnes (right) and Gerrit Flim, his chief technician, at the helium liquefier in Kamerlingh Onnes's Leiden laboratory, circa 1911.

The Discovery Measurement

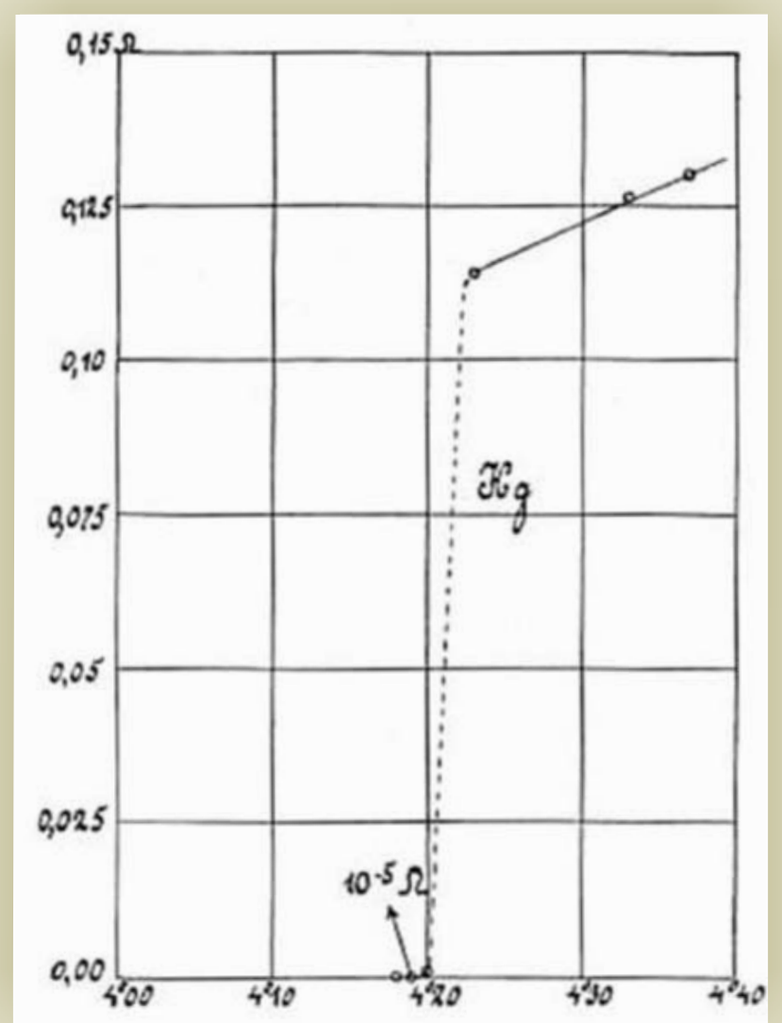
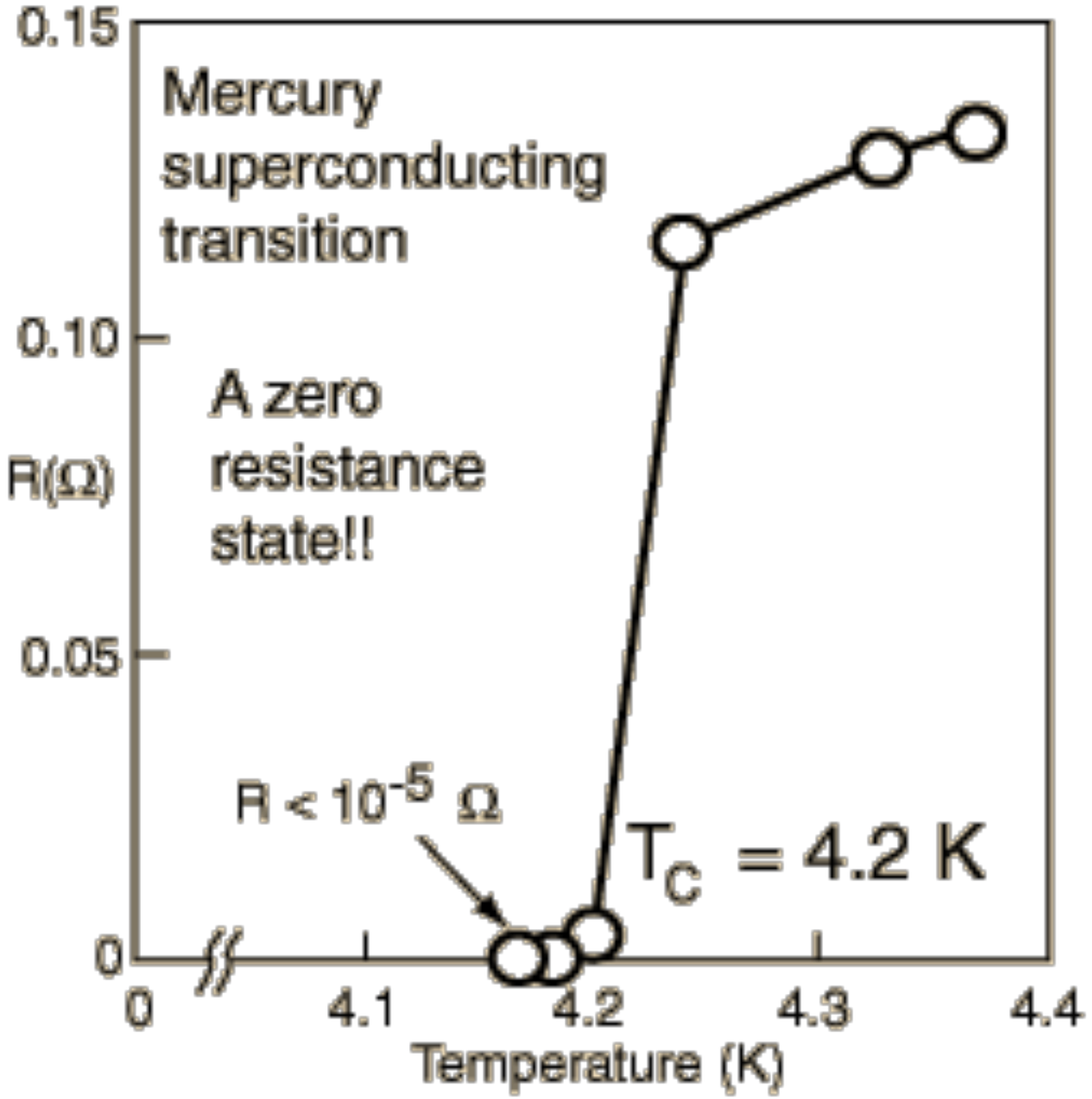
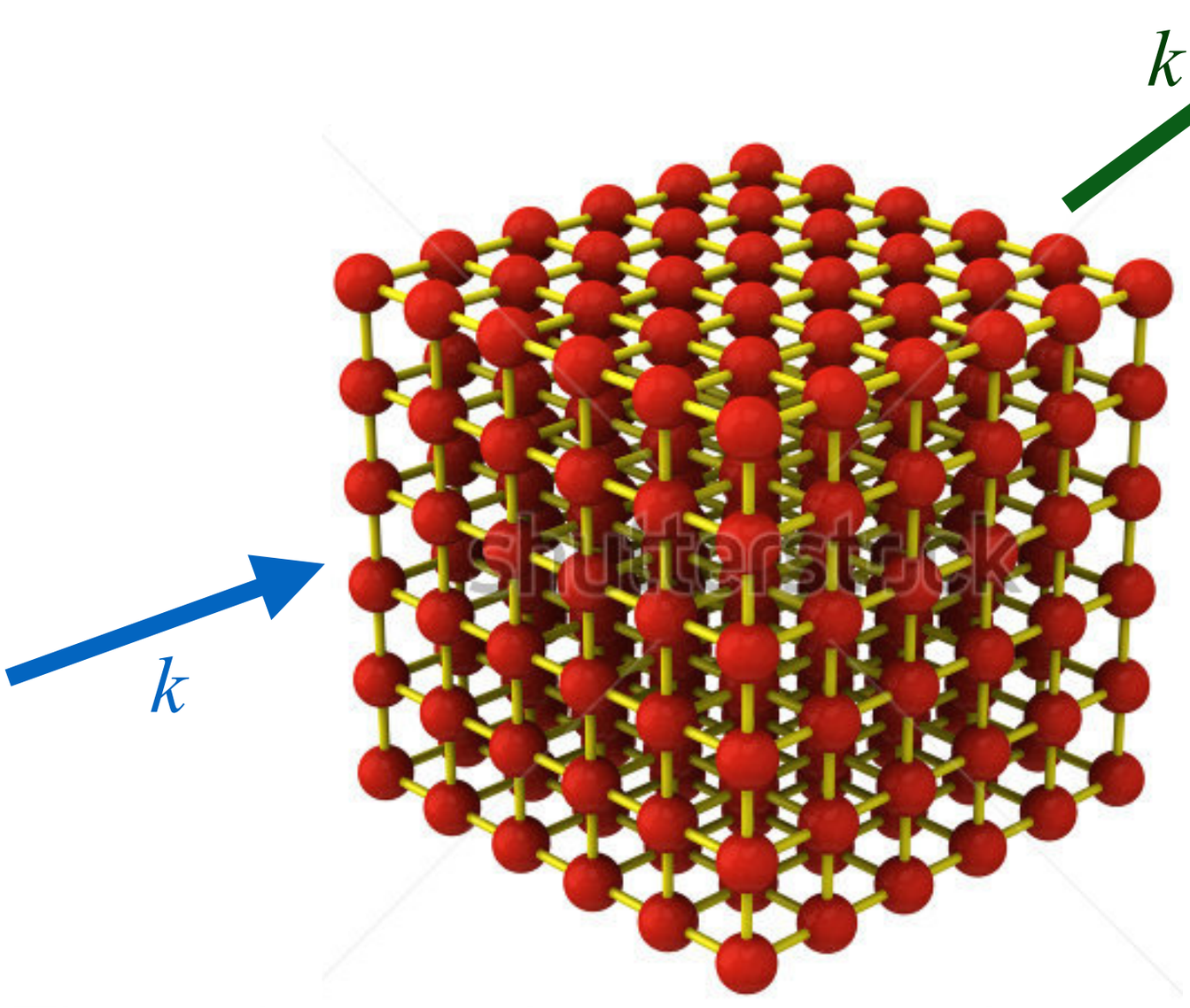


Figure 4. Historic plot of resistance (ohms) versus temperature (kelvin) for mercury from the 26 October 1911 experiment shows the superconducting transition at 4.20 K. Within 0.01 K, the resistance jumps from unmeasurably small (less than 10^{-6} Ω) to 0.1 Ω. (From ref. 9.)



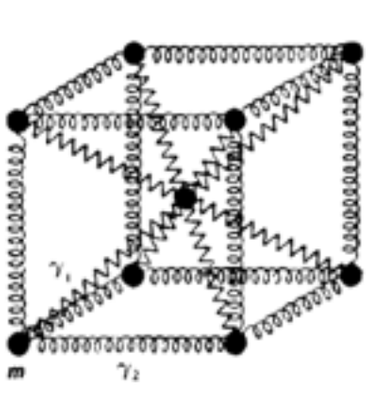
Electrical Resistance of Metals

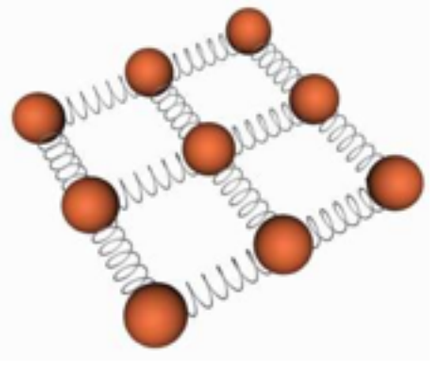
The Correct (Quantum Mechanical) Explanation



Electrons travel in Bloch Waves, so expect no resistance.

But electron-lattice interactions deform the lattice (vibration)

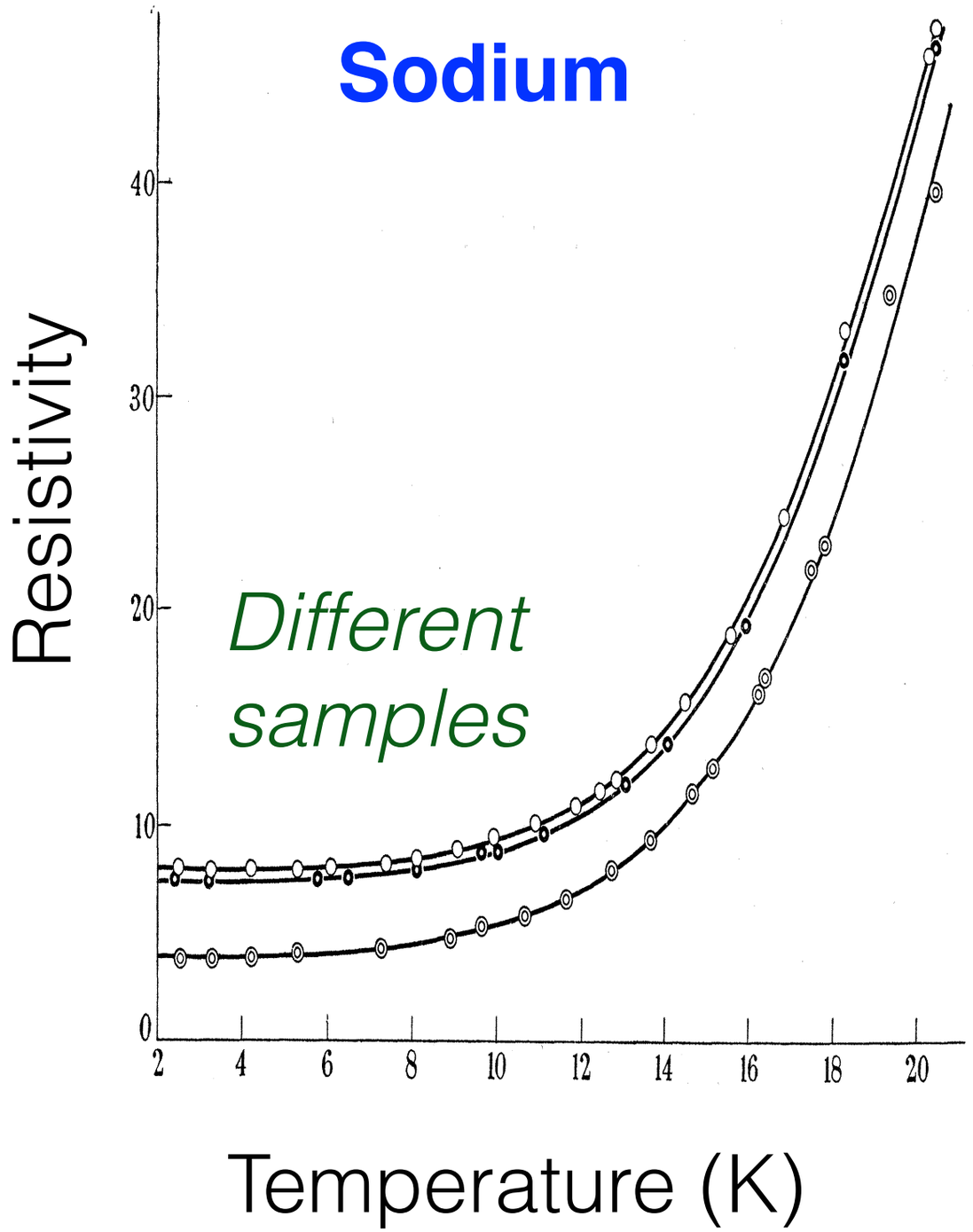




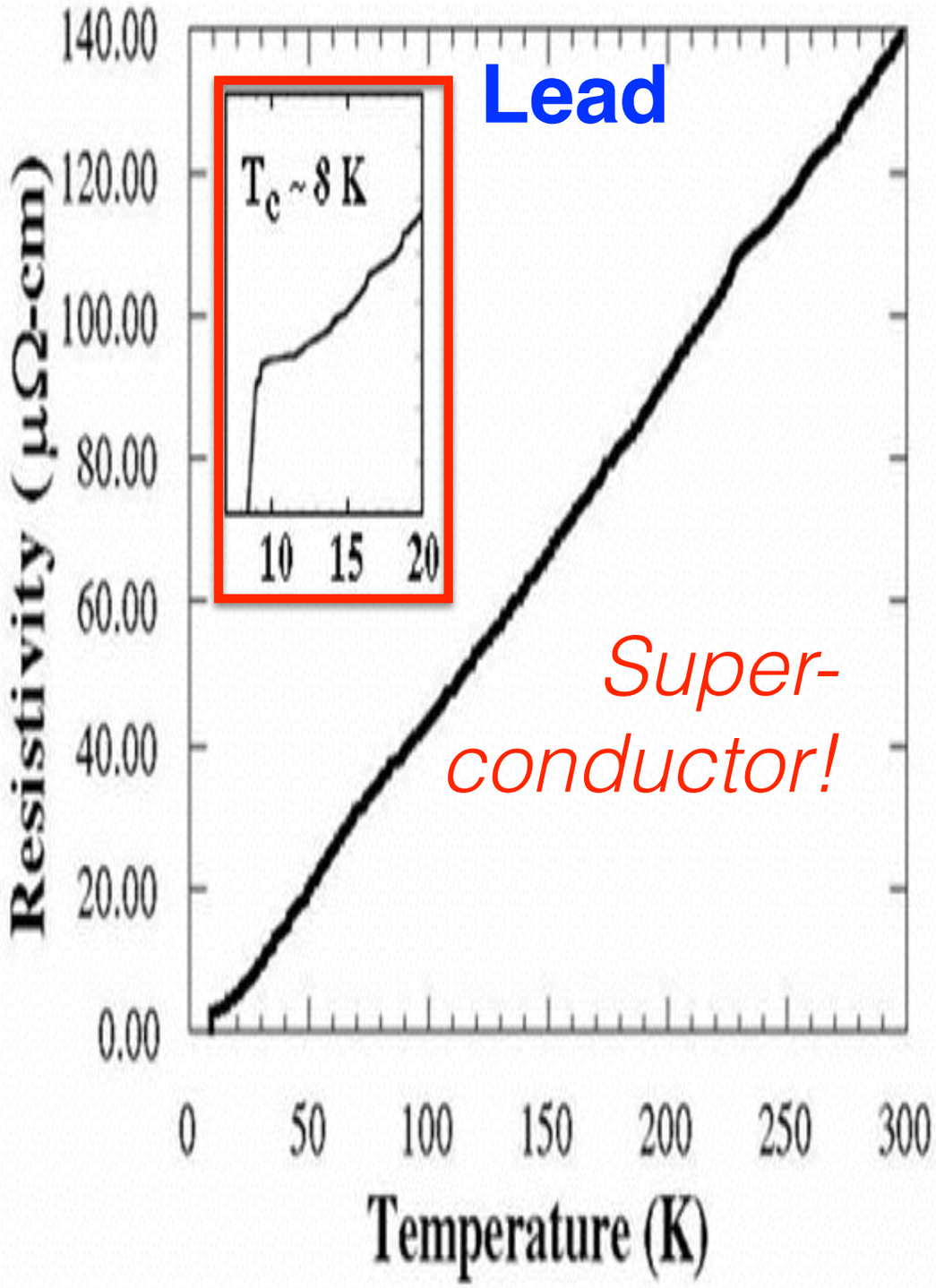
These interactions scatter the electrons, i.e. electrical resistance

Some Data

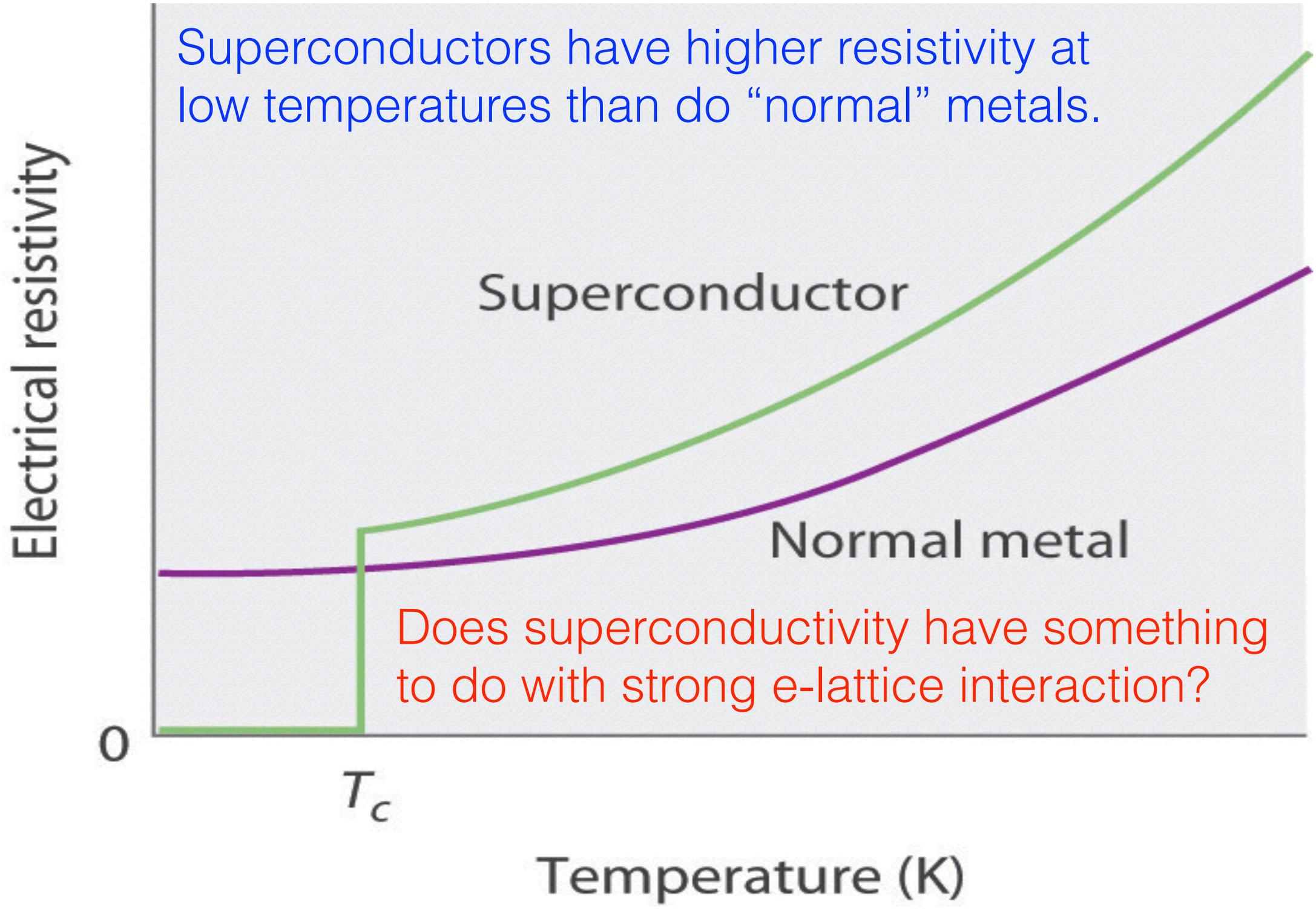
Sodium



Lead



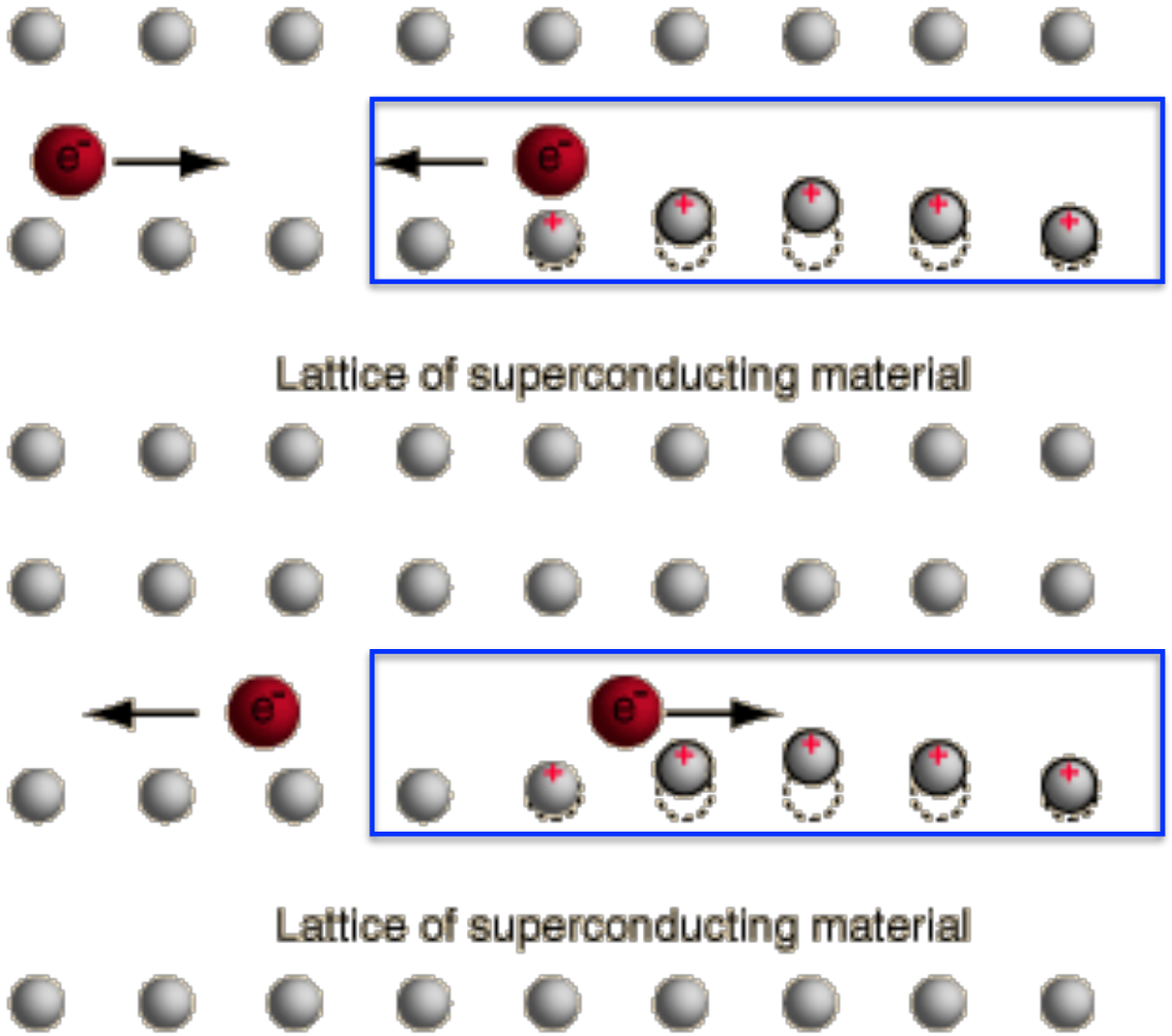
“Normal” or Superconducting



Bardeen Cooper Schrieffer (BCS)

Creation of “Cooper Pairs” of opposite spin electrons

Electrons attract each other through positive ion distortion



An electron moves through the lattice, distorting it and creating a phonon

Another electron moving in the opposite direction, is attracted to the distortion

Bardeen Cooper Schrieffer (BCS)

The attraction gets stronger as temperature lowers. (Less random oscillator excitation at low temps?)

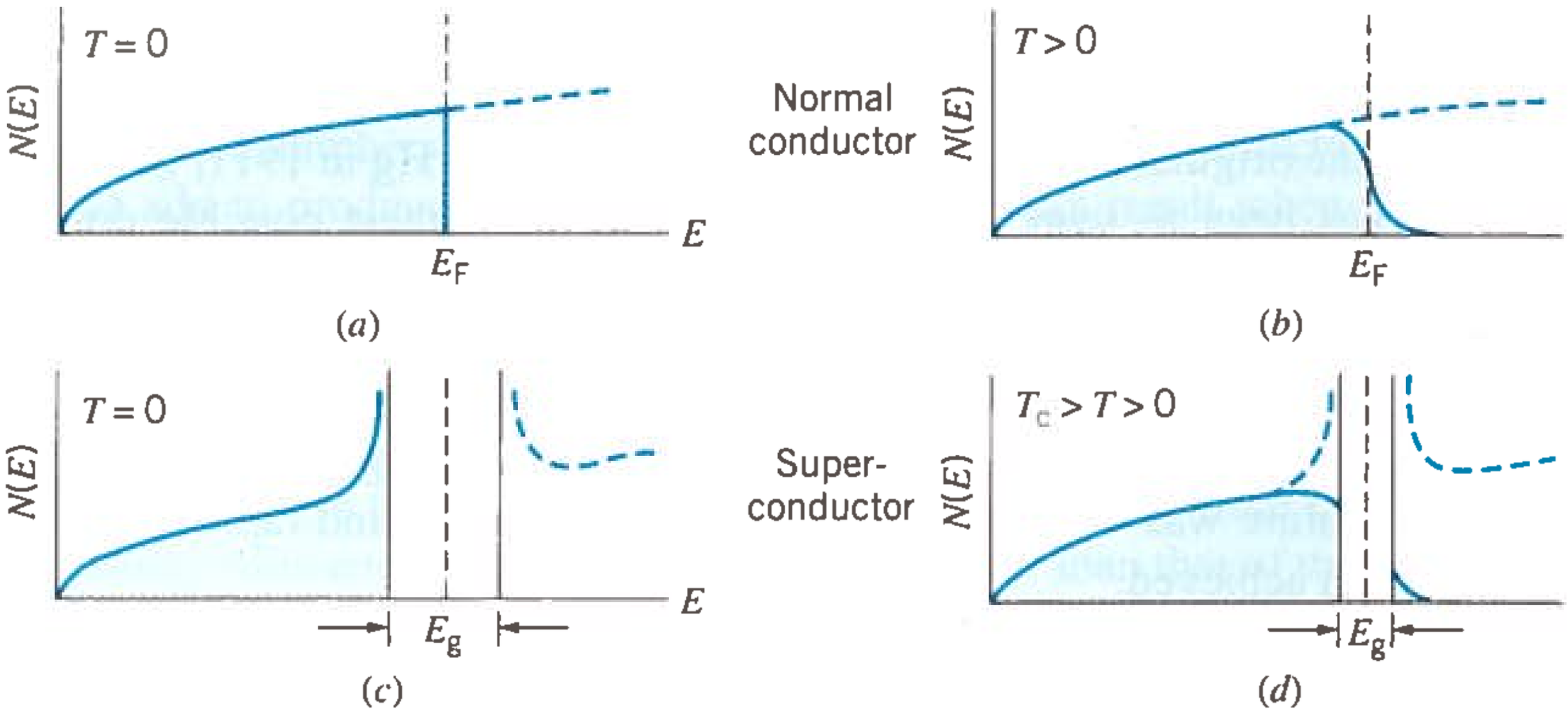
At a “critical temperature” the Cooper Pair binds, and a boson is created from the two fermion electrons, removing electrons from the Fermi sea.

More bound pairs form, and a “superconducting phase transition” occurs.

Lower the temperature further, and the attraction gets stronger, so the Cooper Pairs are bound even more tightly.

The BCS Band Gap

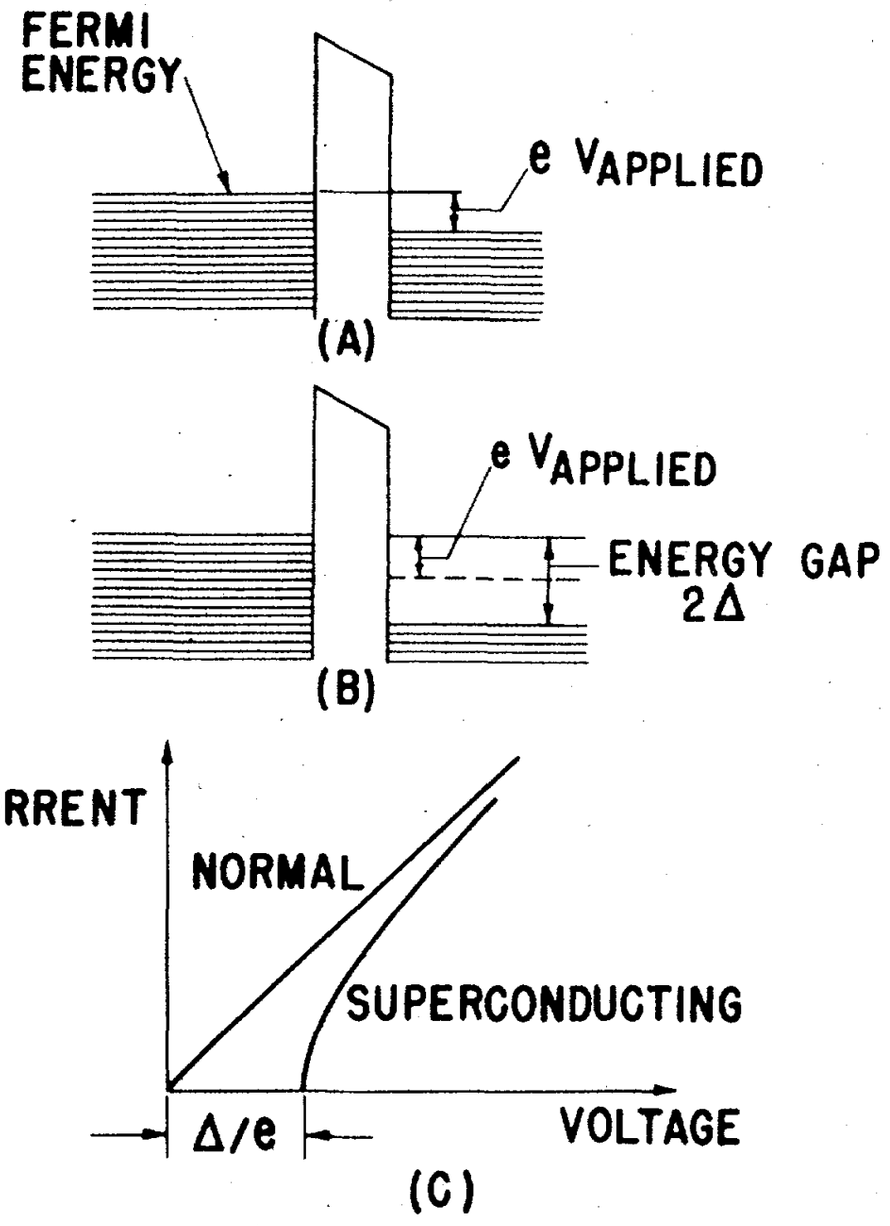
Krane "Modern Physics" 3e, Figure 11.34

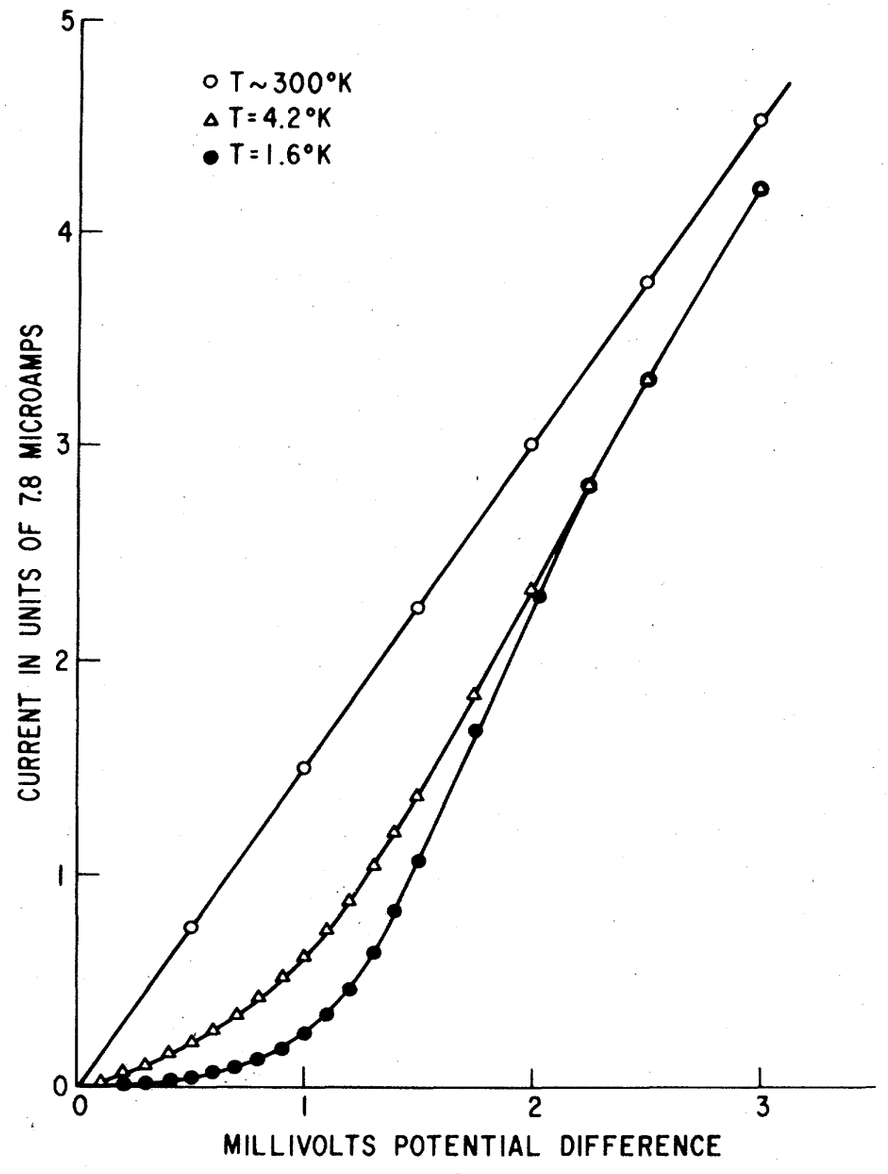


Measuring the Band Gap

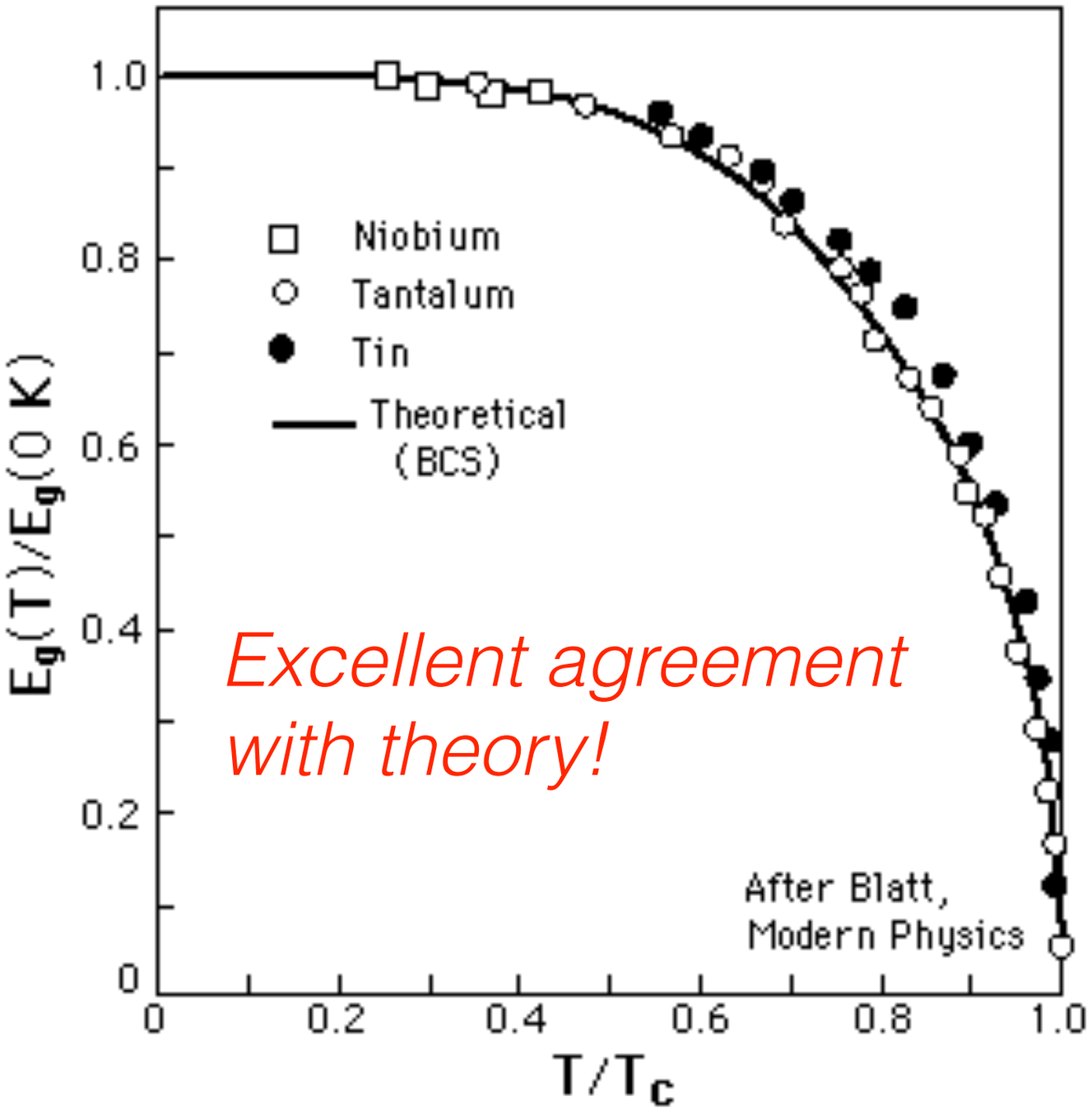
Electron tunneling and superconductivity **Ivar Giaever**

Reviews of Modern Physics, Vol. 46, No. 2, April 1974





Comparison with BCS



Excellent agreement with theory!

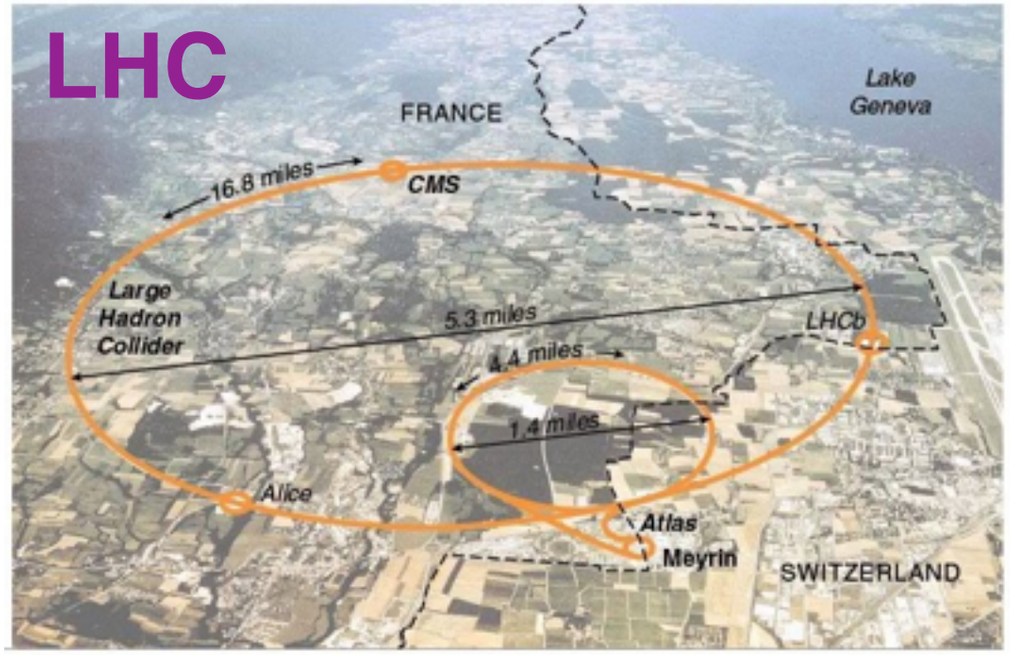
BCS Predicts:
$E_g(0)=3.53\ kT_C$

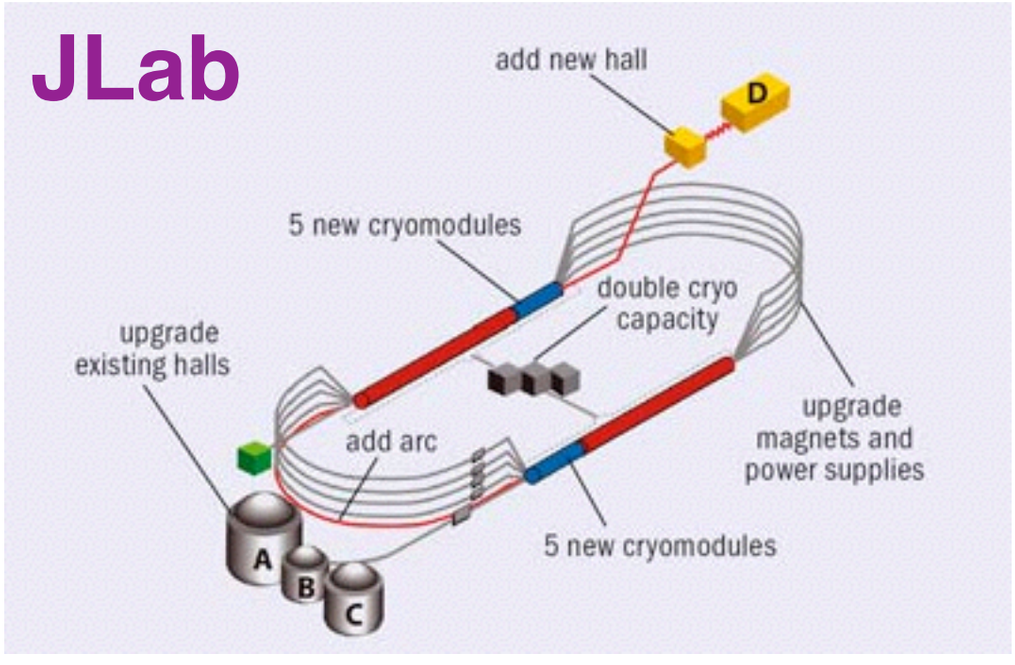
"Binding energy" of a Cooper Pair

For T_C=10K get $E_g(0)$=3 meV

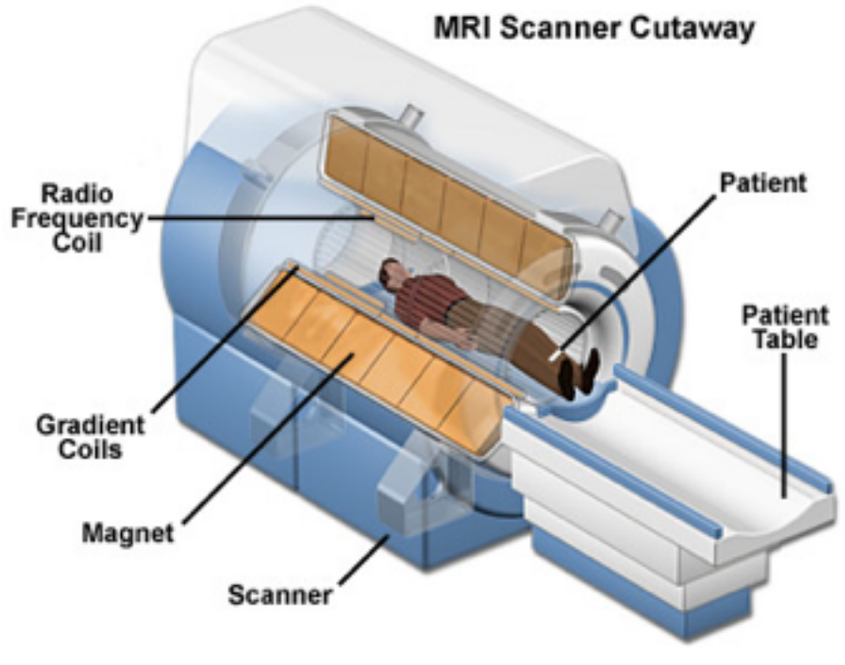
Applications

Accelerator Technology



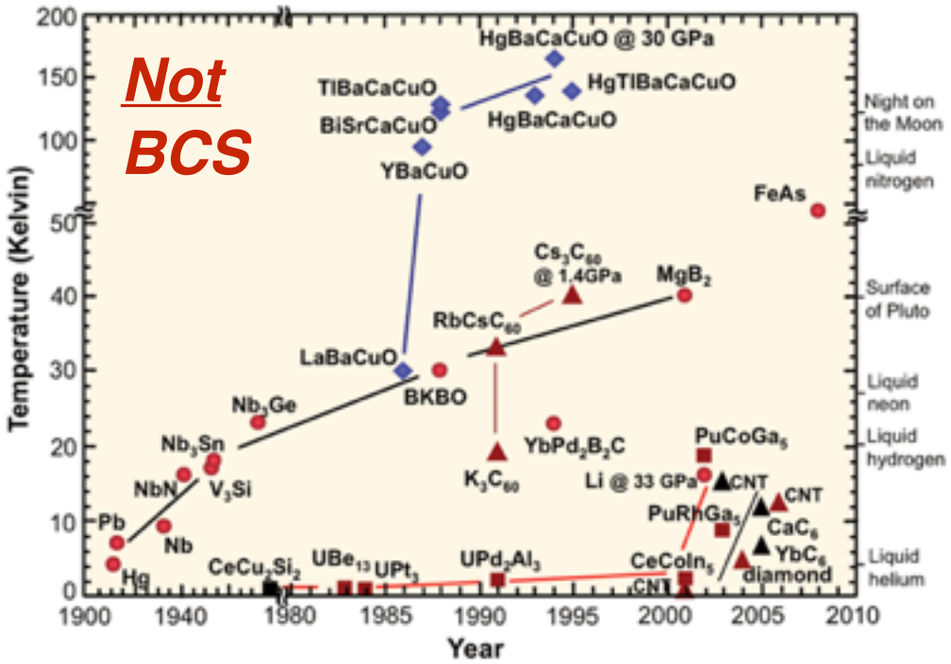


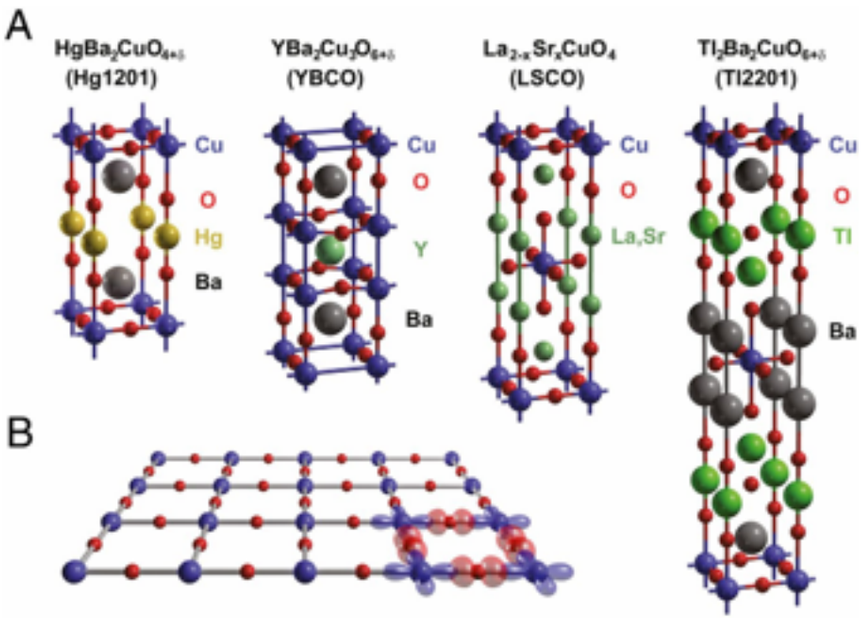
Medicine



Modern Developments

So-called Hi-T_C Materials





MgB_2: Profs Xi and Iavarone