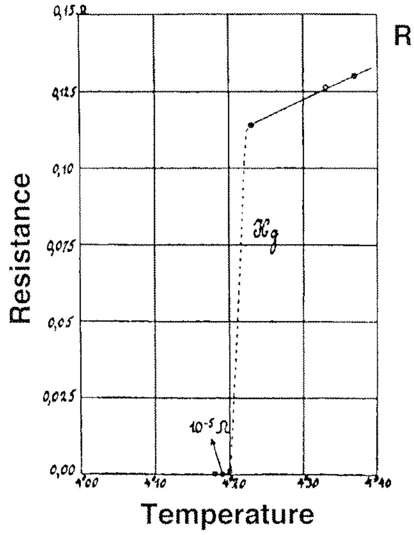
FMI036 Superconductivity and Low Temperature Physics

Out line lecture 1

History

Kamerling-Onnes
Liquefication of Helium 1908
Resistivity of Mercury dropped to zero (1911)



R=0 for T<T_c **1911**

Figure 1 Resistance in ohms of a specimen of mercury versus absolute temperature. This plot by Kamerlingh Onnes marked the discovery of superconductivity.

Mercury Tc=4.15 K, impurities did not affect Tc.
Many more elements were found to be SC shortly after the init

Electro magnetic properties of Superconductors (SC)

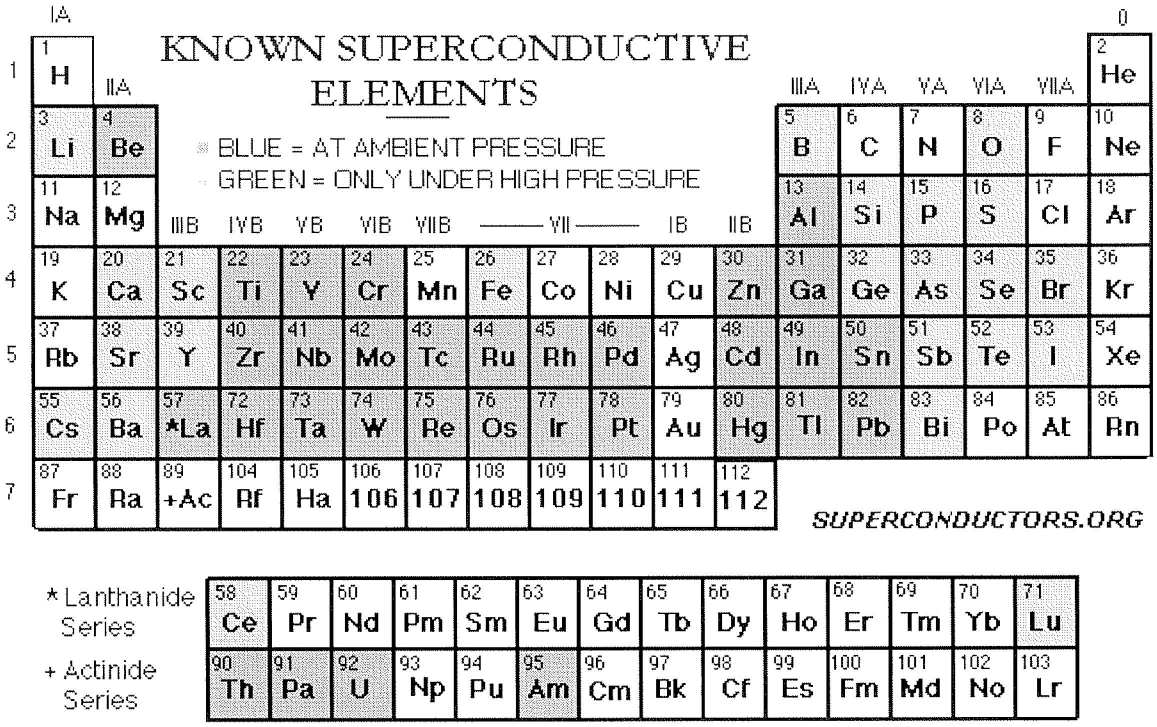
R=0, Critical temperature T_c
B=0, Meissner effect, screening currents c.f. perfect conductor. Penetration depth λ
Maximum Magnetic field: The critical field H_c and its temperature dependence. T,H,I surface.

Thermal Properties:

Specific heat C_p has a discontinuity at T_c, T^3, jump indicates phase transition
Heat conductivity graph, perfect electrical conductor very poor thermal conductor.
The electronic part of Ķ decreases rapidly below Tc, this indicates an energy gap for excitations, Δ=1.76 $k_B T_C$.

Overview of Periodic table

Which elements are SC: Nb, Ta, Pb, Sn, In, Al,… Nb highest T_C=9.2K.
Two regions in the periodic table
Which elements are not SC: coin metals, magnetic metals
Which elements are not superconducting, Alkali , rare earth, magnetic, and coin metals.
Why are good conductors such as Cu, Ag, not SC, whereas more resistive metals such as Pb and Sn are? This indicates that the mechanism has something to do with electron phonon scattering.



Comparing properties of different elements

Table with different parameters T_c, H_c, …

Explaining other parameters: ξ, λ, κ, Δ, ..

Parameters for superconducting elements

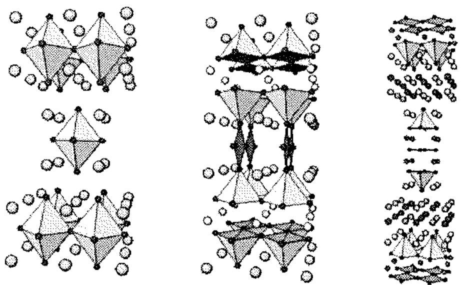
	Tc K	Density kg/l	λ nm	ξ nm	κ	2Δ meV	Hc Gauss	Θ Debey K	γ mJ/mol/K
Nb	9.250	8.57	39	38	1.03	3.050	2060.0	276	7.80
Pb	7.196	11.34	37	83	0.45	2.730	803.0	96	3.10
V	5.400	6.11				1.600	1408.0	383	9.82
Ta	4.470	16.65				1.400	829.0	258	6.15
Sn	3.722	7.31	36	230	0.16	1.150	305.0	195	1.78
In	3.408	7.31	21	440	0.05	1.050	281.5	109	1.67
Re	1.697	21.01				0.514	198.0	430	2.35
Al	1.175	2.70	16	1600	0.01	0.340	104.9	420	1.35
Ga	1.083	5.91				0.328	58.3	325	0.60
Mo	0.915	9.01				0.277	96.0	460	1.83
Zn	0.850	7.13				0.257	54.0	310	0.66
Zr	0.610	6.51				0.185	47.0	290	2.77
Cd	0.517	8.65	110	760	0.15	0.157	28.0	209	0.69
Ti	0.400	4.57				0.121	56.0	415	3.30
Hf	0.126	13.31				0.038	12.7	254	2.21
W	0.015	19.30				0.005	1.2	383	0.90

Other Superconducting , compounds and alloys

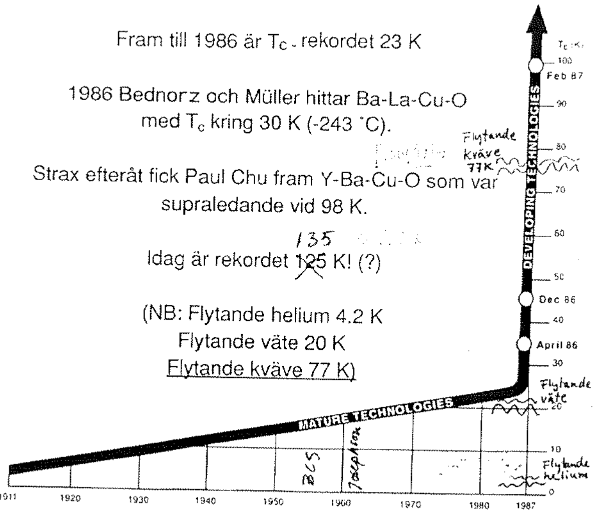
Alloys behave differently from elements (Type II) allows high field e.g. NbTi
A15 Compounds NbSn3, Tc≈23K
Heavy Fermions, UBe13, UPt3 magnetic interaction f electrons => renormalized e-mass.
Organic superconductors, fullerenes, nanotubes

There was a rapid increase of the best T_c's with the discovery of the High Tc Superconductors (HTS)
Anisotropic structure and anisotropic gap.

1986: Bednorz and Müller,	LaBaCuO	36K
1987: Paul Chu,	$YBa_2Cu_3O_7$	93K
1988:	$Bi_2Sr_2Ca_2Cu_3O_x$	110K
2001:	MgB_2	39K



$La_{2-x}Ba_xCuO_4$ $YBa_2Cu_3O_{7-\delta}$ $Tl_2Ca_2Ba_2Cu_3O_{10}$



Overview of different theories

1934 **The two fluid model**, Gorter and Casimir (phenomenological)
One fluid with "super electrons" and one fluid with "normal electrons", n_S, n_n
1935 **London equations**, Fritz and Heinz London (phenomenological)
Describes electromagnetics of the superconductor, based on the two fluid model
1951 **Ginzburg Landau Theory**, Starts from phase transitions, valid near Tc, explains vortecies
GL describes phase transitions, Strictly speaking only valid close to Tc but it work pretty well also at lower temperature. The theory explains vortices and other phenomena when the order parameter changes over short distances.
1959 **BCS theory**, "Full" microscopic theory (does not explain HTS)
Describes a quantum mechanical ground state for the superconducting condensate. Many properties can be calculated.

John Bardeen, Leon Cooper and J. Robert Schrieffer

Vitaly Ginzburg

2007 There is still no accepted theory for High Tc superconductors.

Overview of Superconducting devices

Power applications

    Strong magnets

Electronic devices based on tunnel junctions

    SQUIDs Magnetometers

    SIS mixers, microwave detectors

    RSFQ logic

High Q rf- and microwave- filters

The two fluid model

It seems as if there was two different fluids mixed, one with "superconducting electrons" and one with "normal electrons". On this point there is a clear relation to superfluid helium.
The super fluid would carry current without resistance and without entropy whereas the normal fluid would carrying entropy and bee subject to scattering.
Temperature dependence of the densities, n_s and n_n
Examples: Conductivity, Thermal conductivity, Thermo electric effects.
Absence of electric field also leads to absence of thermoelectric effects.

Meissner effect

R=0 implies that the electric field in a superconductor is zero also.
Applying Faradays law to a ring of superconductor implies that the Magnetic flux is constant in a superconducting ring.
$\oint E \cdot dl = -\frac{\partial \Phi}{\partial t} = -A\frac{\partial B}{\partial t}$ implies $\partial B / \partial t = 0$. In fact, not only $\partial B / \partial t = 0$ but also $B=0$.
Perfect dia-magnetism, $B=\mu_0(H+M)=\mu_0(1+\chi)H$, Superconductor: $\chi=-1$

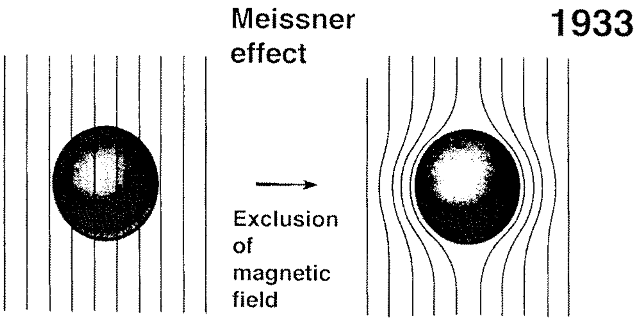
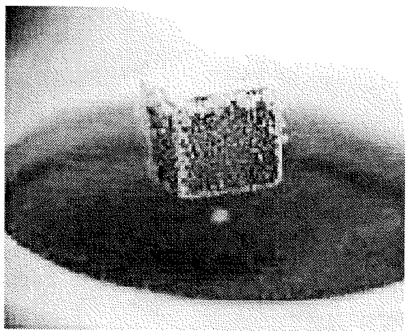


Figure 2 Meissner effect in a superconducting sphere cooled in a constant applied magnetic field; on passing below the transition temperature the lines of induction **B** are ejected from the sphere.



Type I versus Type II superconductors.

Type I: Either Superconducting or Normal
B=0 up to Hc, graph M versus H.
Positive SN interface energy => minimize number of interfaces
Intermediate state, few domains
Type II:
B=0 up to Hc1 and gradually increasing up to Hc2
Graph M versus H
Negative SN interface energy.
Mixed state between Hc1 and Hc2, many domains