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Microtechnology and nanoscience, MC2, Chalmers

Low Temperature Physics 2004

Lecture 1
Subject: Superconductivity: Introduction

Concepts:
History, Kamerling Onnes 1911
R=0, Critical temperature, T_c, crit field, H_c, and crit current, I_c
B=0: Meissner effect and penetration depth, perfect conductor versus supercond.
Energy gap, exitations,

Superconducting elements, compounds and alloys
Low Tc, A-15, HiTc, Heavy Fermions, MgB2

Thermal Properties:
Specific heat, thermal conductivity, thermo-electric effects
Two fluid model of superconductivity

Type I versus Type II superconductors.

Review questions:
As above with questionmarks.
What are the most characteristic properties of a superconductor?
What is the behavior in electric and magnetic fields? For ideal and real sc?
What are the new concepts?
What are the most useful properties of a superconductor?

Literature:
J R Waldram, Superconductivity of Metals and Cuprates, p 1-31
T Claeson, Supraledning, föreläsn ant, p 1-29
E A Lynton, Superconductivity, Methuen & Co, London 1964, p 1-54
A C Rose-Innes and E H Rhoderick, Introduction to Superconductivity, Pergamon, Bath 1978, p 3-81, 101-4
D R Tilley & J Tilley, Superfluidity and Superconductivity, Ch. 1.2, 5.1-5.4, p.294-303
M. Tinkham: Introduction to Superconductivity, Ch.1

Tyrckfel, förel.ant.:
s 14 o 15: Stryk 2 i nämnare i 3 uttryck för S och C
s15, 5 fr bot: dt->dT; s16, r 6&7: m /m -> m*/m
s20: Ginzburg-Landaus teori
s 24, r1: $m_o l_L^2 J + A = 0$ s 34 r 14: $b(T) = m_o H_c^2(T)$
s 27 slutet: fås att D = 1/2 då fältet.. s 37: Londons penetrationsdjup
s 31 r 11: vid ett fält $H_{c1} < H_c$ $l_L^2(0) = m/m_o e^2 n$
s31 r 18: , störningar av flödet av l. s 37 r 5 fr botten: $l = l_L(T)$
s31 r 6 fr botten: ferromagnetiska s 37 r1 fr botten: $l \approx (l_L^2 x_o)^{1/3}$
s 34 r 2: g_s med avseende på s 43-44 r 1 fr botten: ..= (e^2/16...
s 34 r7: = - $(1/2) m_o H_c^2$
s 34 r 9: I Londons teori ..

History

Kamerling Onnes 1911. Helium was liquefied 1908.
Mercury Tc=4.15 K, impurities did not affect Tc.

No resistance

R=0 below a critical temperature Tc., R(T)-graph.

Periodic table

Rapidly many new elements were tested.
Which are the good superconductors, Nb highest 9.2K.
Which elements are not superconducting, Alkali , rare earth magnetic, and coin metals.

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 $\partial B/\partial t = 0$. Infact not only $\partial B/\partial t = 0$ but also *B=0*.
Perfect dia magnetism Screening currents
B=μo(H+M) =μo(1+c)H

Maximum Magnetic field Hc related to some extent to Tc
Critical current related to Hc, Silsbee rule
$I_C = \frac{2\pi}{\mu_0} r H_C$, good exercise
T,H,I surface.

Themal Properties

Heat capacity graph, T^3, jump indicates phase transition
Heat conductivity graph, note perfect electrical conductor very poor thermal conductor.
Energy gap for excitations, Δ=1.76 kT
As if there was two fluids, one carrying current without resistance and without entropy and one which was more "normal" carrying entropy and being subject to scattering.
Relation to superfluid Helium
Absence of electric field also leads to absence of thermoelectric effects.

Type I and type II superconductors

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

Unusual Superconductors

Alloys often Type II allows high field e.g. NbTi
A15 Compounds NbSn3, Tc≈23K
Heavy Fermions, UBe13, UPt3 magnetic interaction f electrons => renormalized e-mass.

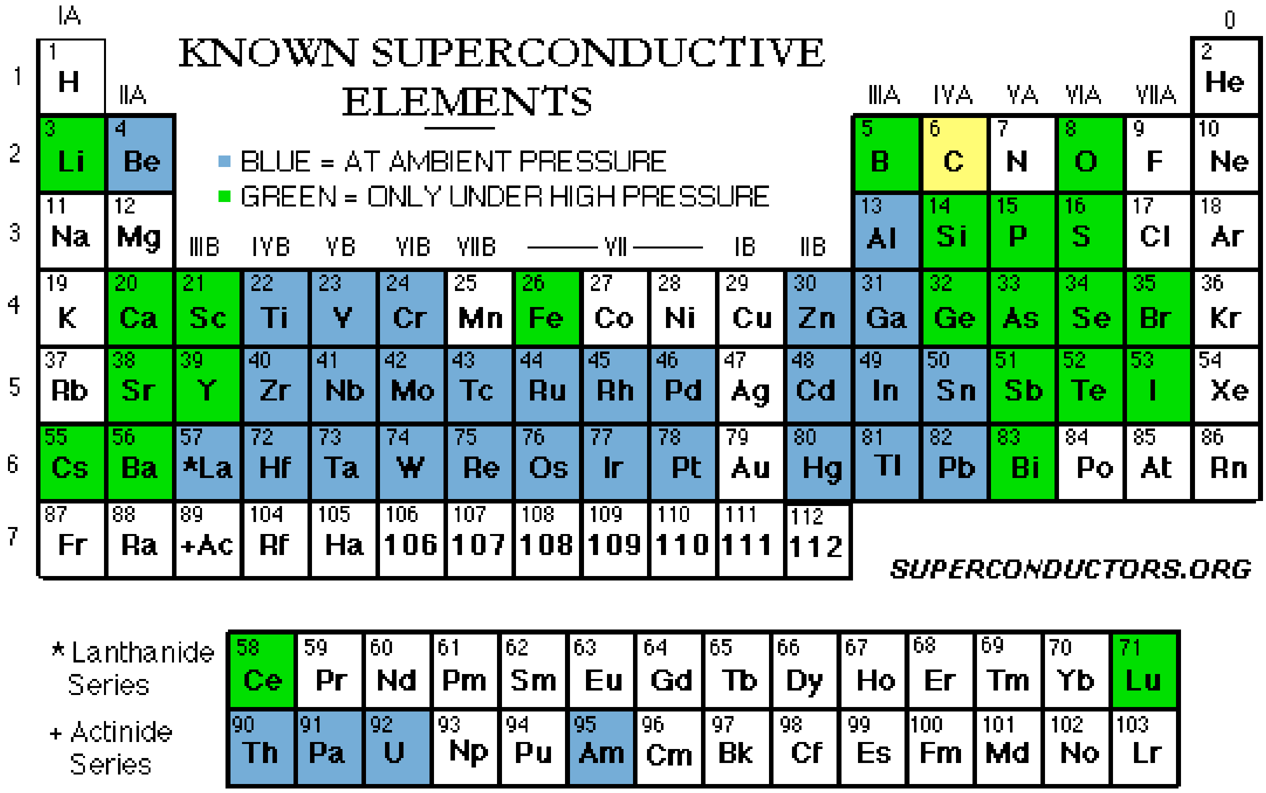
Organic superconductors, fullerenes, nanotubes
High Tc, Cuprates, YBCO, BiSCO, max 135 K somewhat higher under pressure
Anisotropic stucture and anisotropic gap.

Parameters

	Tc	Density	λ	ξ	κ	Δ	Hc	Θ Debey	γ
	K	kg/l	nm	nm		meV	Gauss	K	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

Summary

R=0
B=0
Energy gap $\Delta = 1.76\ kT$


KNOWN SUPERCONDUCTIVE ELEMENTS
BLUE = AT AMBIENT PRESSURE
GREEN = ONLY UNDER HIGH PRESSURE
IA
IIA
IIIB
IVB
VB
VIB
VIIB
VII
IB
IIB
IIIA
IVA
VA
VIA
VIIA
0
1
2
3
4
5
6
7
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 *La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 +Ac
104 Rf
105 Ha
106 106
107 107
108 108
109 109
110 110
111 111
112 112
SUPERCONDUCTORS.ORG
* Lanthanide Series
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
+ Actinide Series
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr