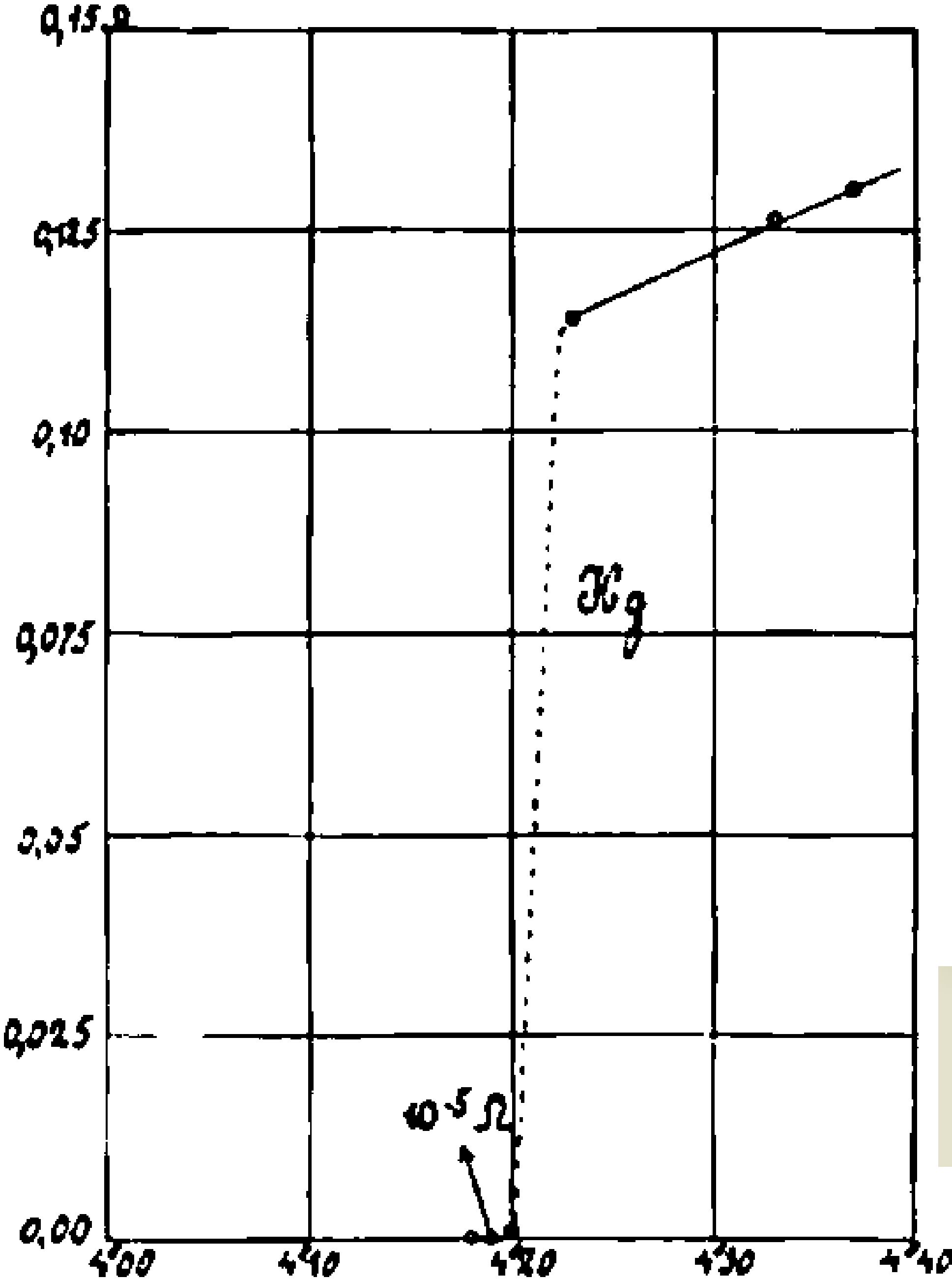
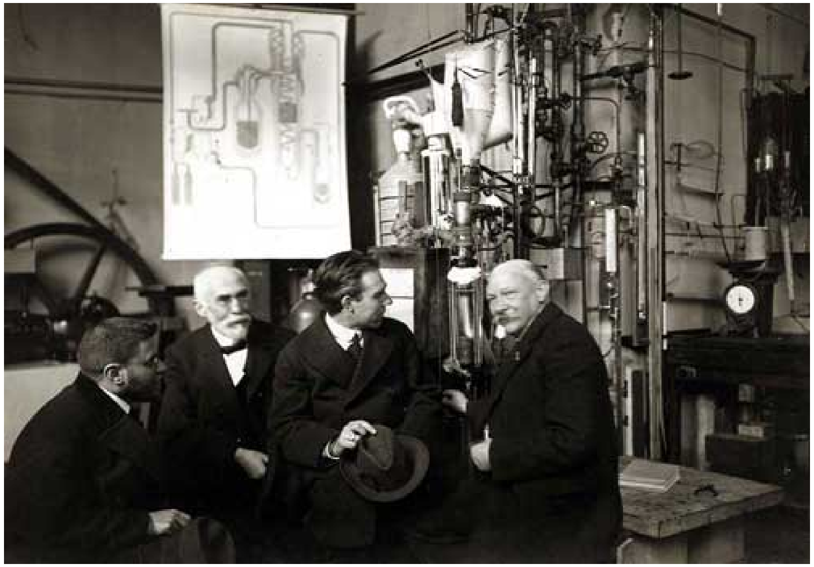
The zero resistance transition of Hg measured in 1911 by Kamerlingh Onnes.

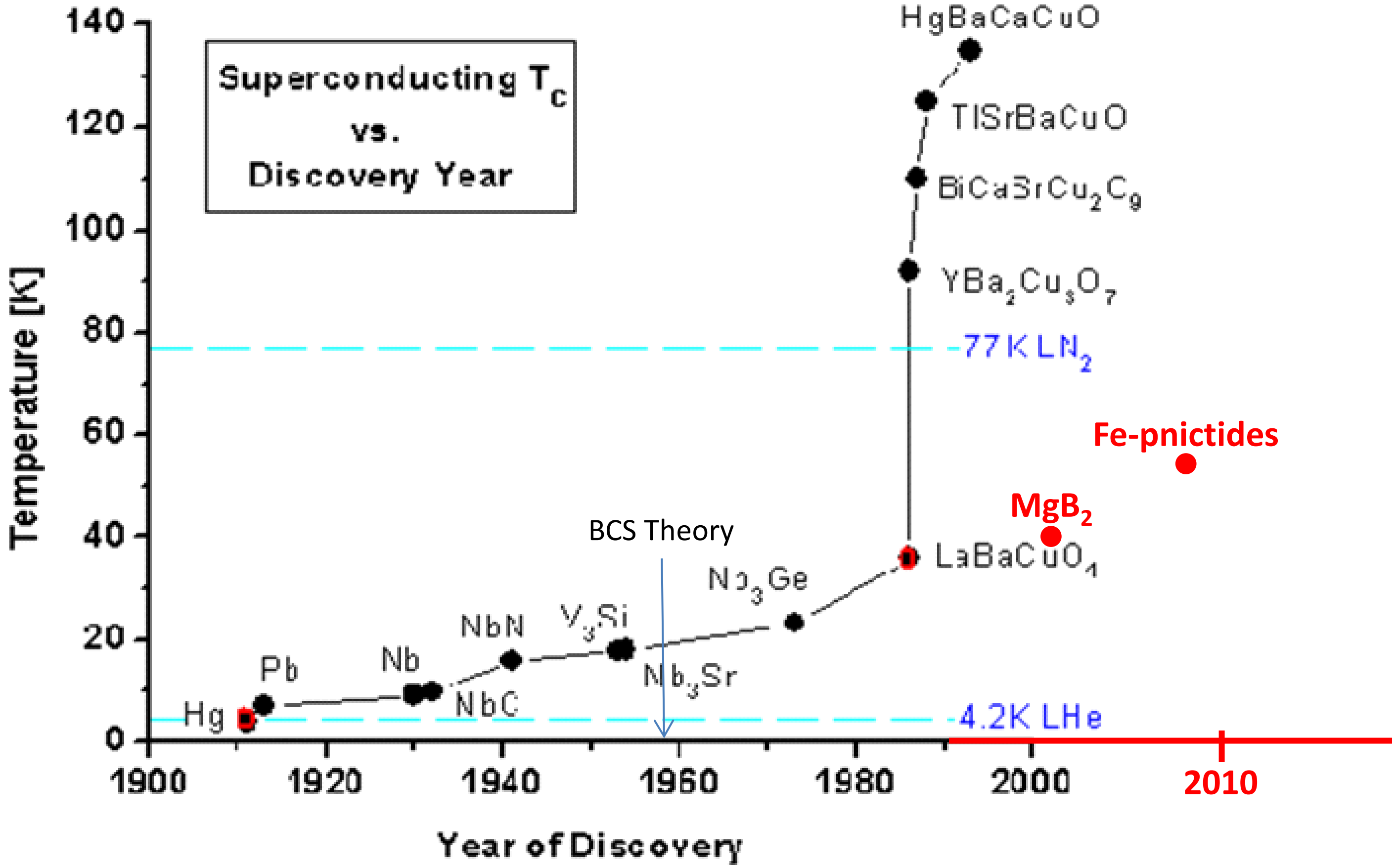




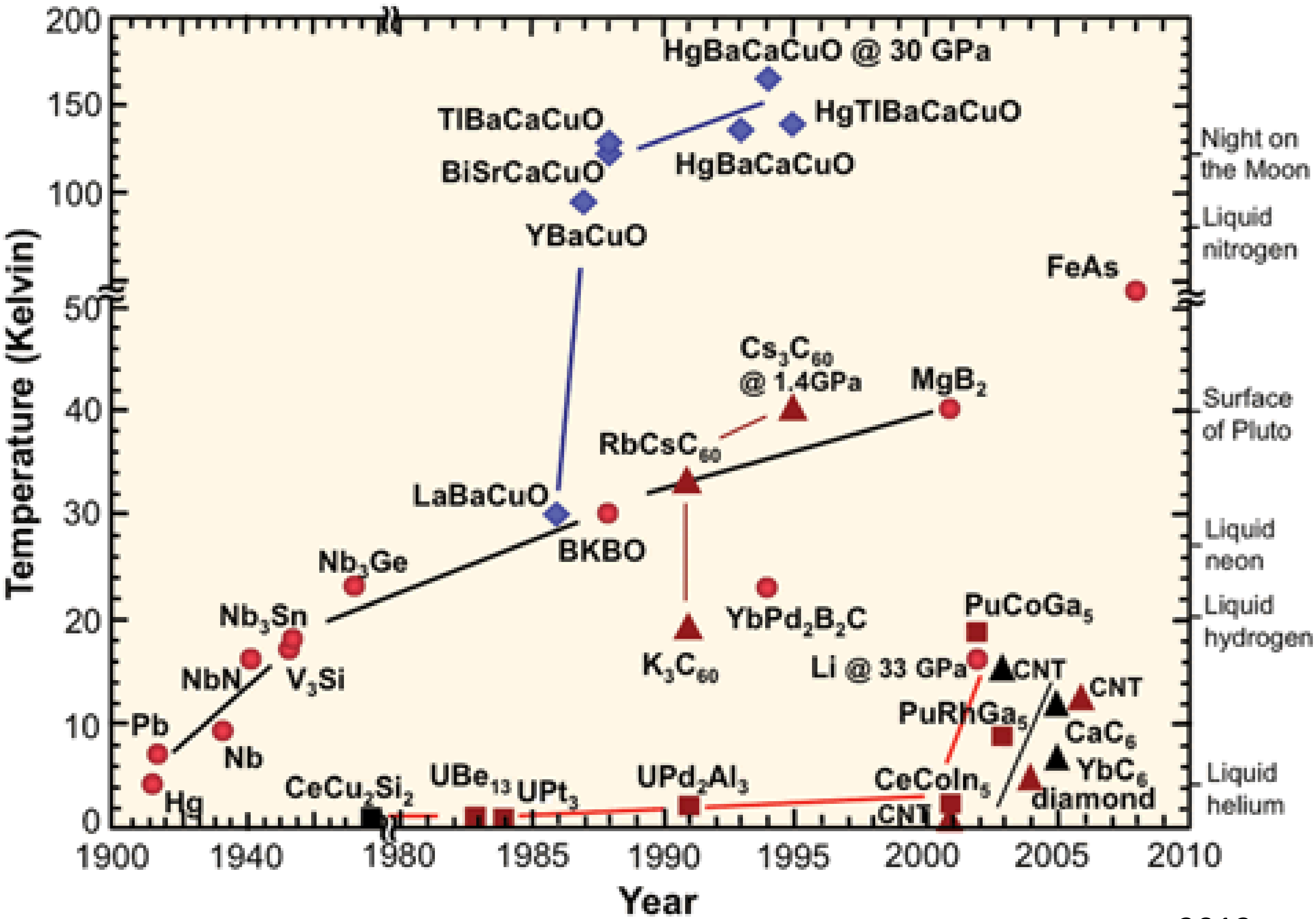
Heike Kamerlingh Onnes (right), the discoverer of superconductivity.
Paul Ehrenfest, Hendrik Lorentz, Niels Bohr stand to his left.

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.)

Look at the History of the "History of Superconductivity" ….

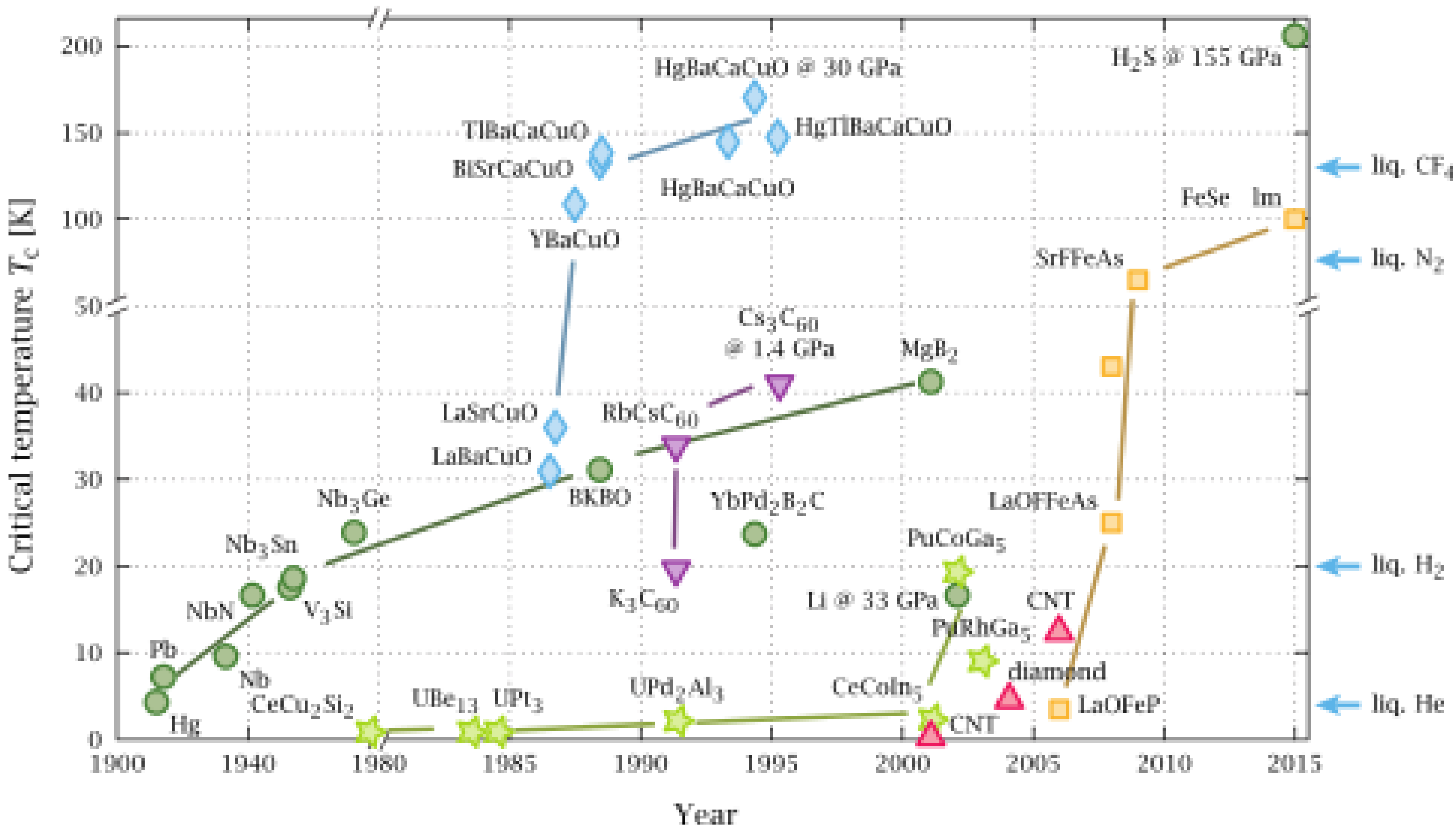


2006



2012

http://en.wikipedia.org/wiki/Superconductivity



2016

http://en.wikipedia.org/wiki/Superconductivity

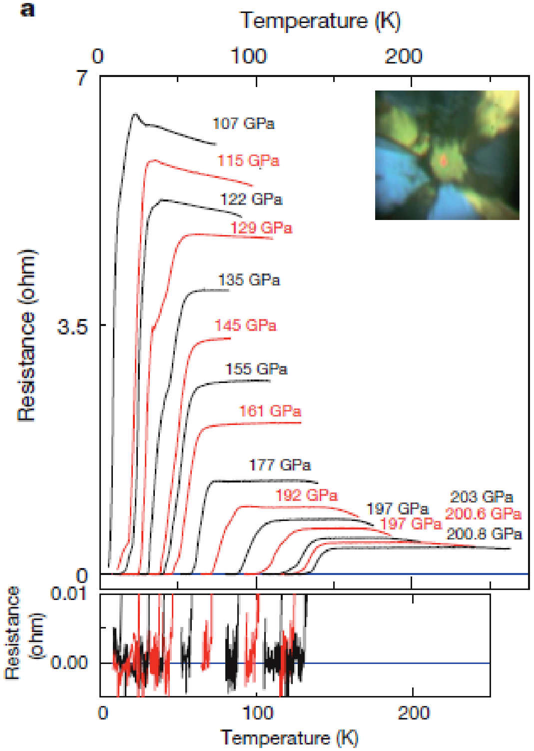
Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system

A. P. Drozdov[1]*, M. I. Eremets[1]*, I. A. Troyan[1], V. Ksenofontov[2] & S. I. Shylin[2]

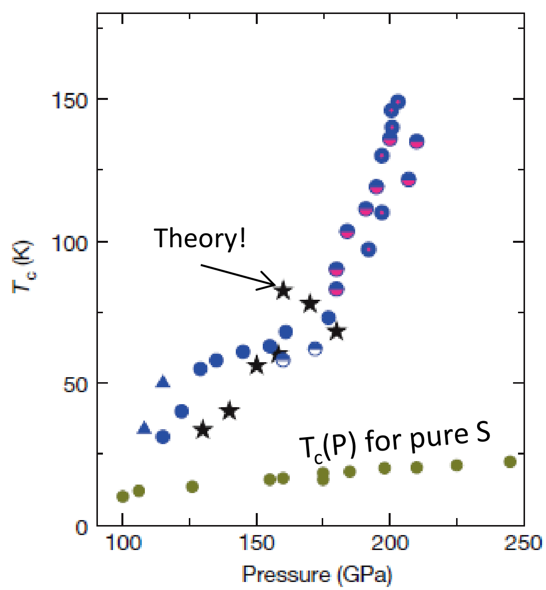
Nature 525, 73–76 (03 September 2015) doi:10.1038/nature14964

Zero Resistance

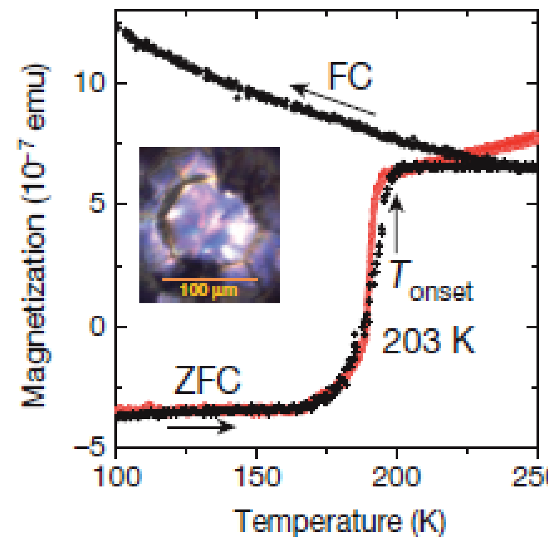
a

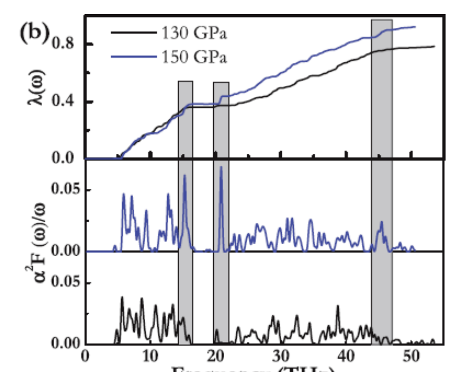


b



Meissner Screening

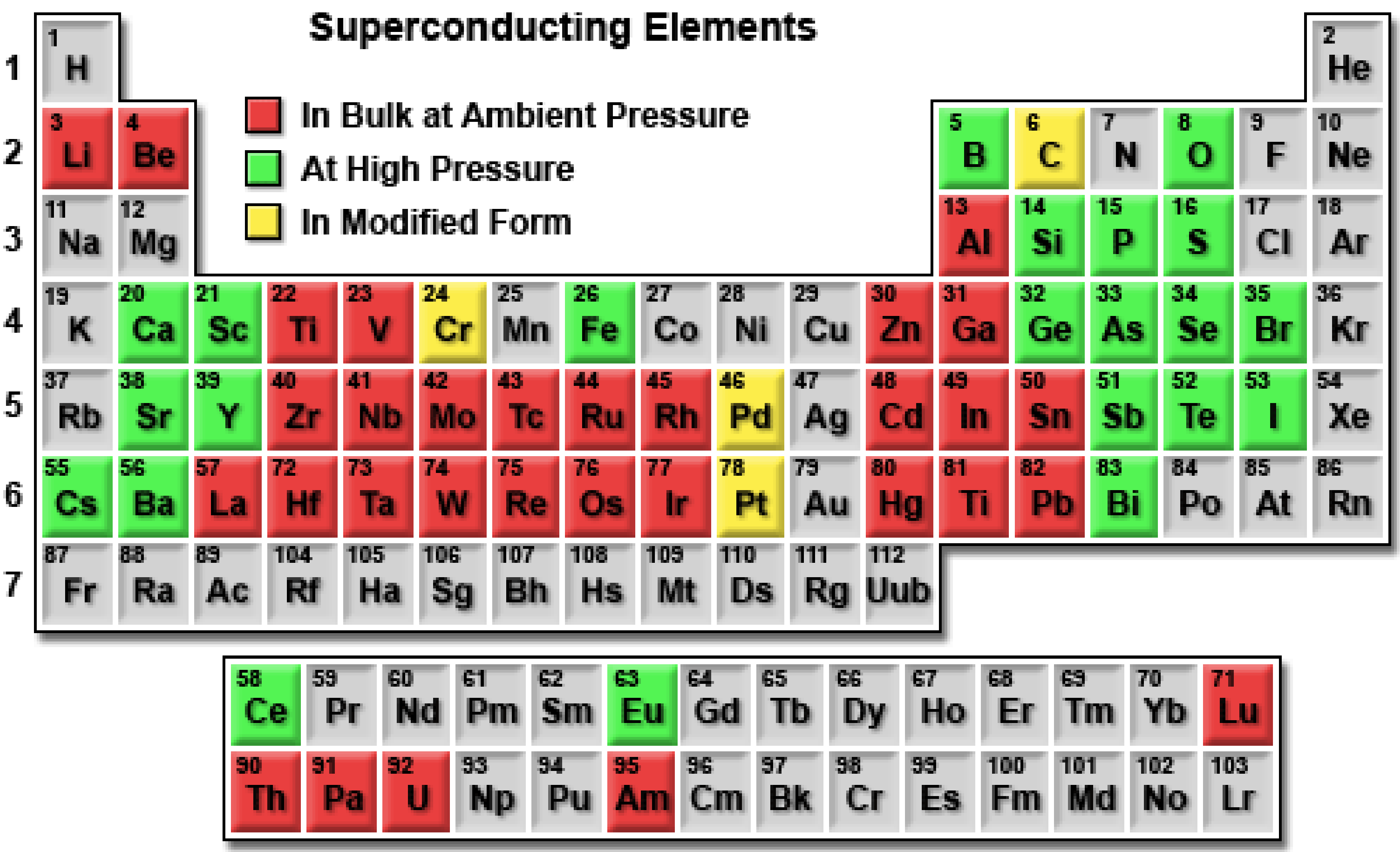




THE JOURNAL OF CHEMICAL PHYSICS 140, 174712 (2014)

The metallization and superconductivity of dense hydrogen sulfide

Yinwei Li,[1,a)] Jian Hao,[1] Hanyu Liu,[2] Yanling Li,[1] and Yanming Ma[3,b)]


Superconducting Elements
In Bulk at Ambient Pressure
At High Pressure
In Modified Form
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 Ti
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
104 Rf
105 Ha
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Uub
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
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cr
99 Es
100 Fm
101 Md
102 No
103 Lr

Classes of Superconductors

"Conventional" — 3D BCS s-wave

Nb, Al, Pb, Sn, Nb_3Sn, Nb-Ti, etc. — $T_c < 25$ K

A_3C_{60}, electronically-doped C_{60}, MgB_2 — $T_c < 40$ K

"Organic" — Quasi 1-D,2-D

$(TMTSF)_2X$, $(BEDT\text{-}TTF)_2X$ — $T_c < 12$ K

"Oxide"

$Ba(Pb\text{-}Bi)_3O$, Ba-K-Bi-O — $T_c < 30$ K

"Heavy Fermion" — Anisotropic (p- or d-wave)

UPt_3, UBe_{13}, $CeCu_2Si_2$ — $T_c < 2$ K

"Cuprates"

High-T_c:

- Hg-Ba-Ca-Cu-O — $T_c < 135$ K ($T_c \to 154$ K (under pressure))
- Tl-Ba-Ca-Cu-O — $T_c < 125$ K
- Bi-Sr-Ca-Cu-O — $T_c < 108$ K
- ☆ Y-Ba-Cu-O — $T_c < 93$ K

Low-T_c:

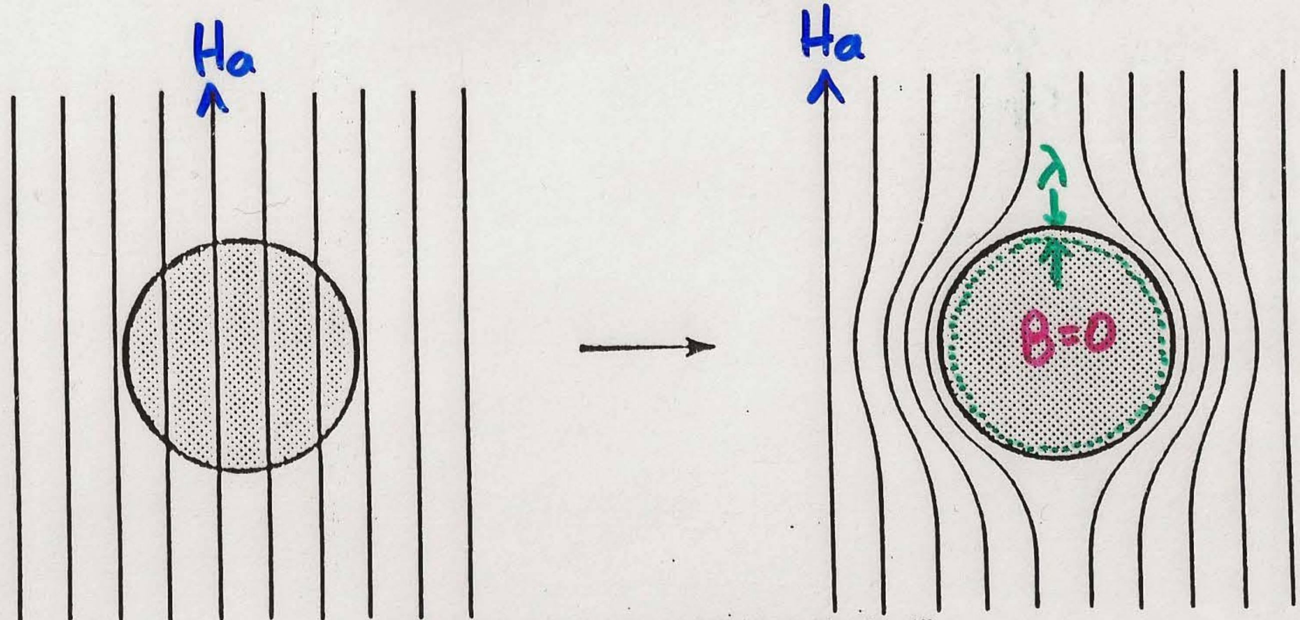
- La-Sr-Cu-O — $T_c < 36$ K
- ☆ Nd-Ce-Cu-O — $T_c < 25$ K

"Ruthenates" Sr-Ru-O (p-wave) $T_c < 1.5$ K

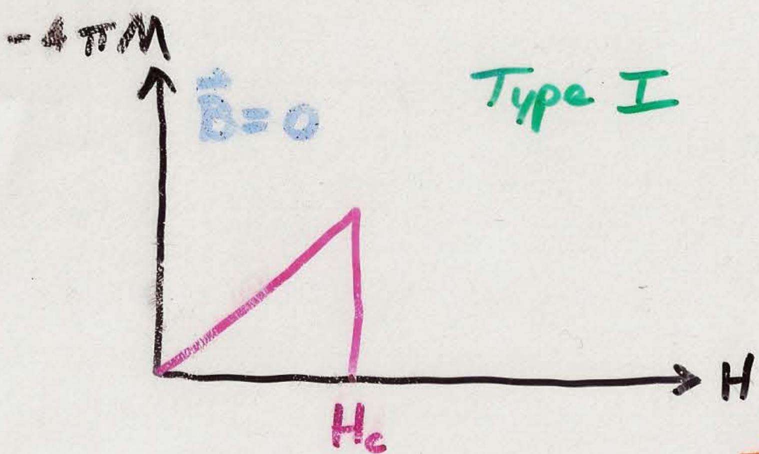
Superfluid ^4He -> Bose-Einstein condensate: $T_c \sim 2$ K

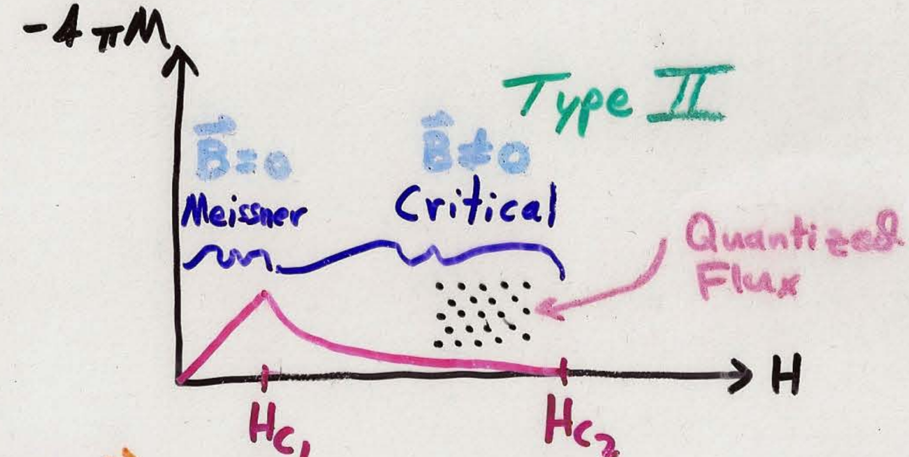
Superfluid ^3He -> S = 1 pairs, p-wave superfluid: $T_c \sim 10^{-3}$ K

Meissner Effect



From Kittel: Introduction to Solid State Physics, 4E

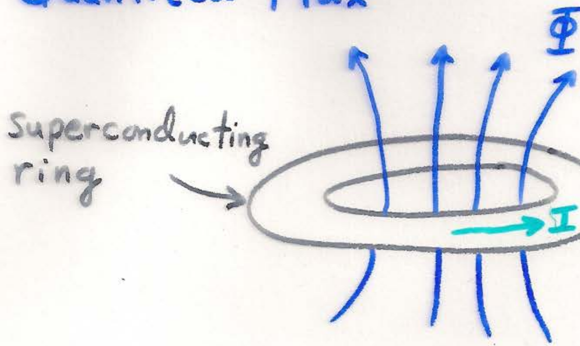




$$\vec{B} = \vec{H} + 4\pi\vec{M}$$

Macroscopic Quantum Phenomena

Quantized Flux



But

$$\Phi = n\Phi_0 = \frac{nh}{2e}$$

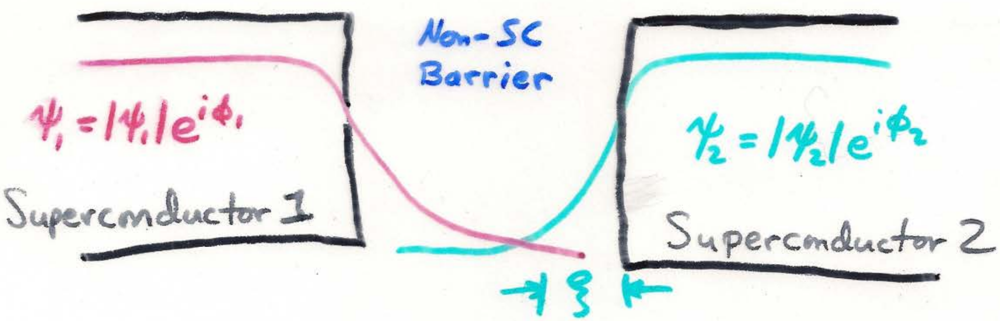
$n = 0, 1, 2, 3, \ldots$

$\Phi_0 = 2.07 \times 10^{-15}$ Wb

"Rigidity of the wave function"

WF is single-valued

Josephson Effect



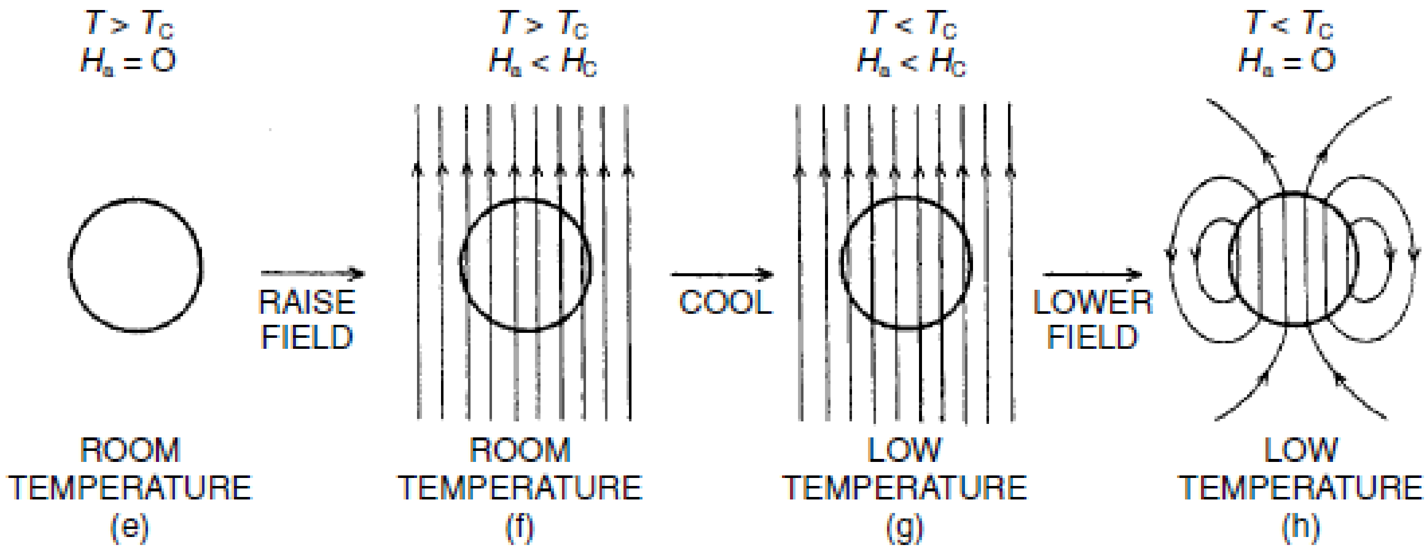
$$I = I_c \sin(\phi_2 - \phi_1) \quad (V_{DC} = 0)$$

$$\frac{\partial(\phi_2 - \phi_1)}{\partial t} = \frac{2e}{h} V_{DC}$$

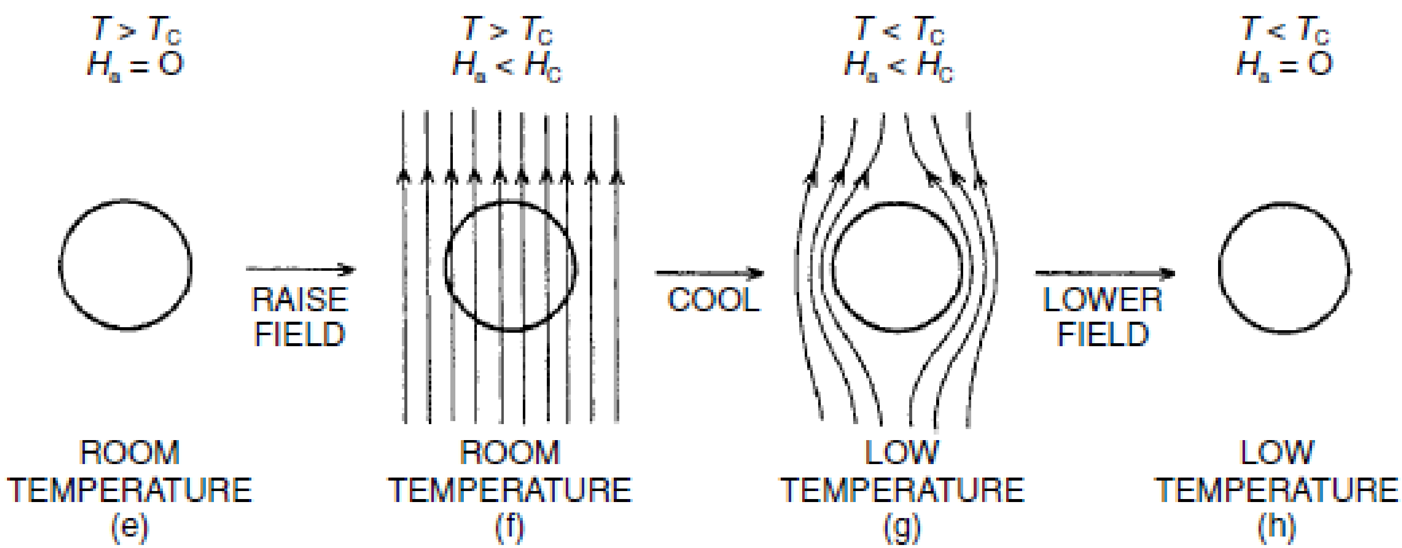
$$\frac{2e}{h} = 483 \text{ MHz}/\mu\text{V}$$

Perfect Conductor vs. Superconductor

Perfect Conductor

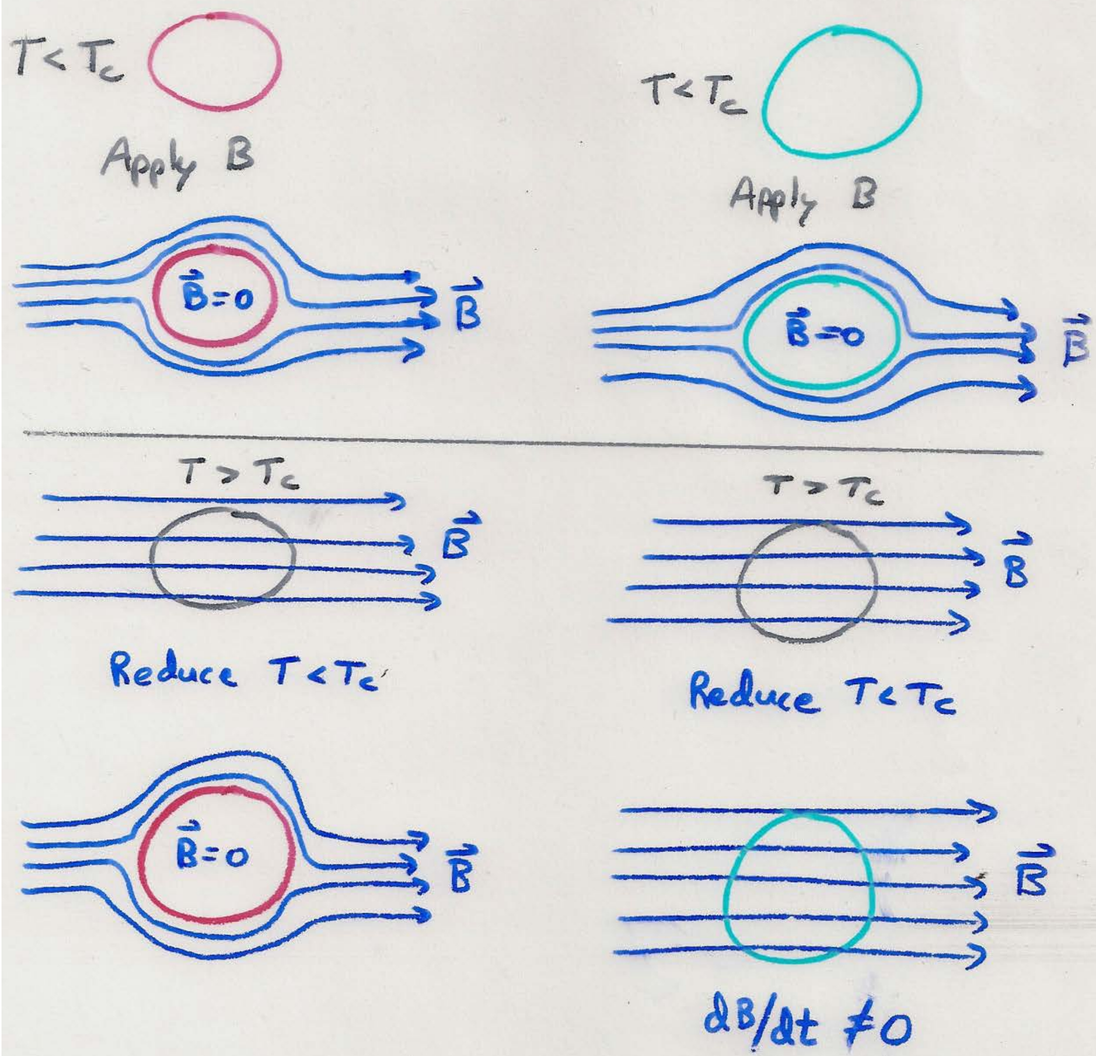


Super-Conductor



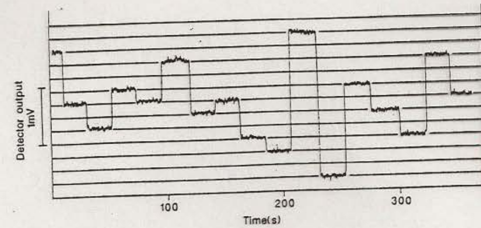
Zero Resistance and Perfect Diamagnetism

Superconductor vs **Perfect Conductor**



Flux Quantization in a High T_c SC

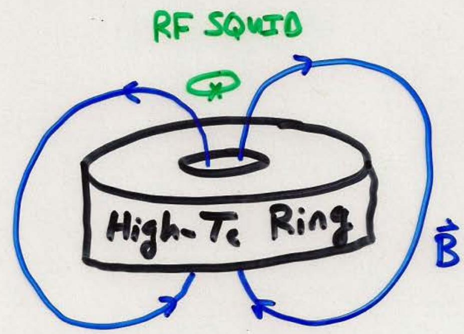
C. E. Gough, et al. Nature **326**, 855 (1987).



$$\pm\,\Phi_0 = \frac{h}{2e}$$

Fig. 2 Output of the r.f.-SQUID magnetometer showing small integral numbers of flux quanta jumping in and out of the ring.

$YBa_2Cu_3O_7$
ceramic
4.2 K



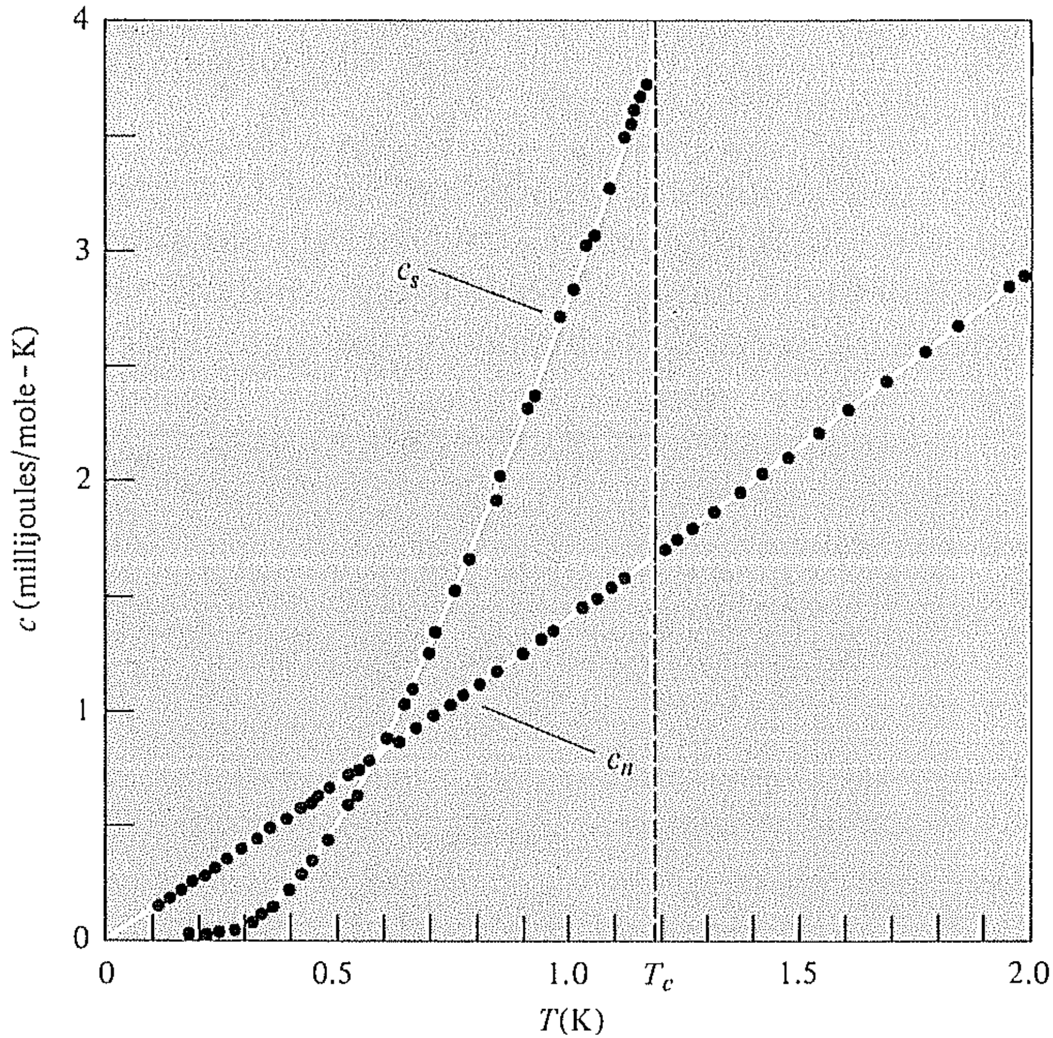
Experimental value for the flux quantum

$$\Phi_0 = 0.97 \pm 0.04\ \frac{h}{2e}$$

SQUID magnetometer output stable for 1000 s

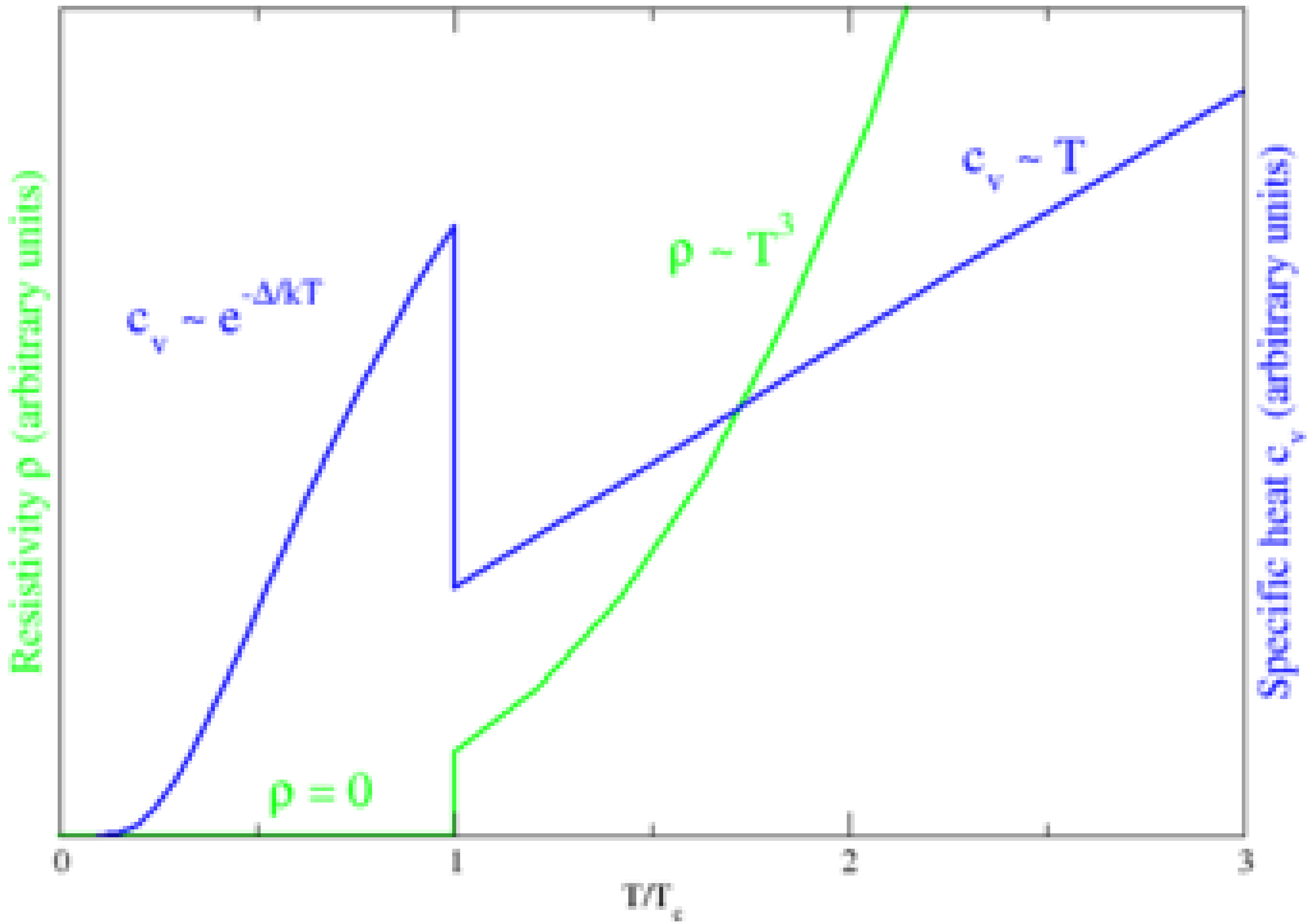
$\Rightarrow R_{ring} < 10^{-13}\,\Omega$

Low Temperature Specific Heat of Aluminum



Low-temperature specific heat of normal and superconducting aluminum. The normal phase is produced below T_c by application of a weak (300-gauss) magnetic field, which destroys the superconducting ordering but has otherwise negligible effect on the specific heat. The Debye temperature is quite high in aluminum, so the specific heat is dominated by the electronic contribution throughout this temperature range (as can be seen from the fact that the normal-state curve is quite close to being linear). The discontinuity at T_c agrees well with the theoretical prediction (34.22) $[c_s - c_n]/c_n = 1.43$. Well below T_c, c_s drops far below c_n, suggesting the existence of an energy gap. (N. E. Phillips, *Phys. Rev.* **114**, 676 (1959).)

Ashcroft and Mermin, p. 734



http://en.wikipedia.org/wiki/Superconductivity

MEASURED VALUES OF THE RATIO[a] $[(c_s - c_n)/c_n]_{T_c}$

ELEMENT	$\left[\frac{c_s - c_n}{c_n}\right]_{T_c}$
Al	1.4
Cd	1.4
Ga	1.4
Hg	2.4
In	1.7
La (HCP)	1.5
Nb	1.9
Pb	2.7
Sn	1.6
Ta	1.6
Tl	1.5
V	1.5
Zn	1.3

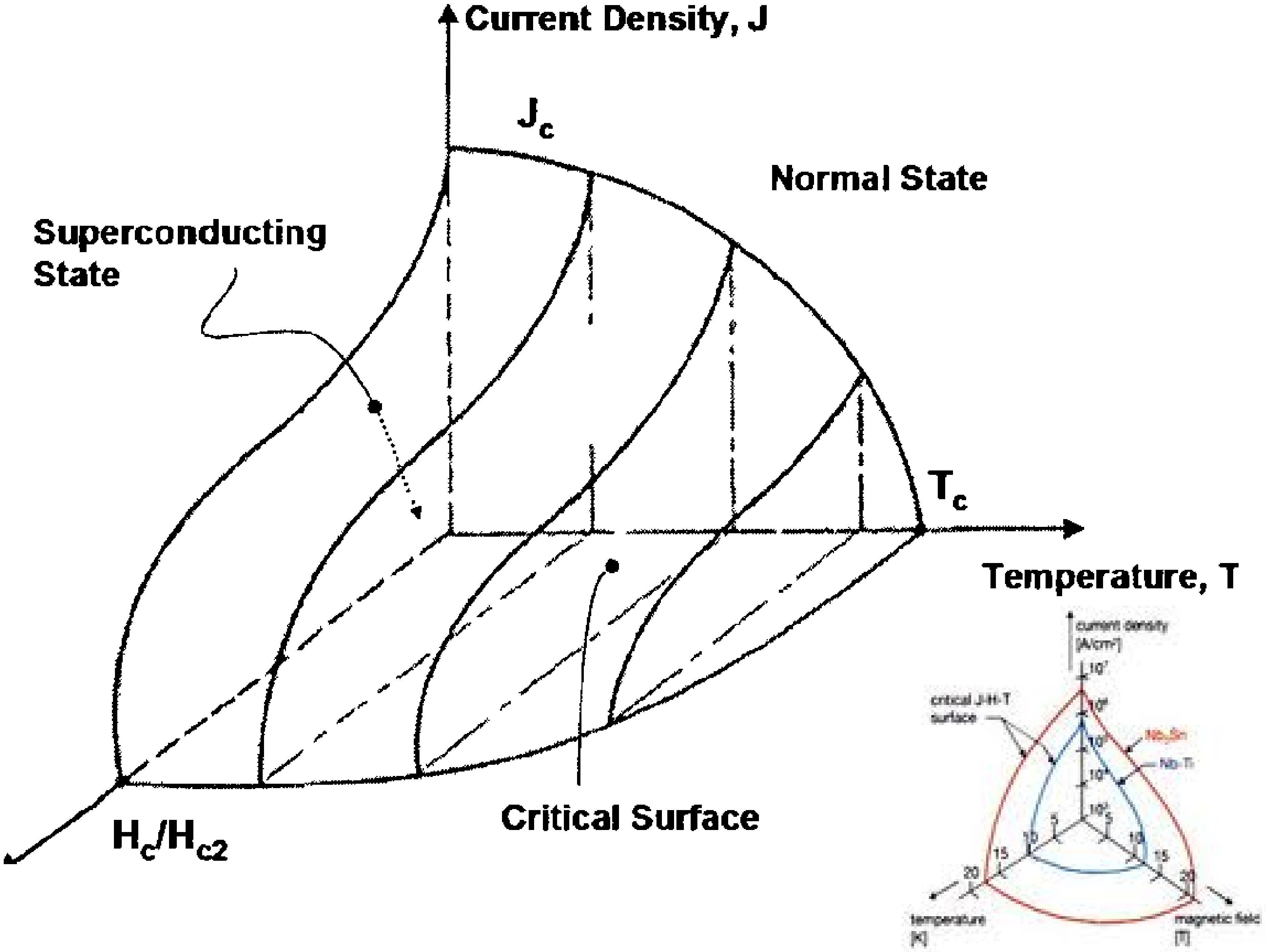
[a] The simple BCS prediction is $[(c_s - c_n)/c_n]_{T_c} = 1.43$.

Source: R. Mersevey and B. B. Schwartz, *Superconductivity*, R. D. Parks, ed., Dekker, New York, 1969.

The 'Universal' Heat Capacity Jump at T_c

The prediction holds for weak-coupled SCs

Ashcroft and Mermin, p. 747



Current Density, J
J_c
Normal State
Superconducting State
T_c
Temperature, T
H_c/H_{c2}
Critical Surface
current density
critical J-H-T surface
Nb-Ti
temperature
magnetic field