

SUPERCONDUCTIVITY WS 15-16

Monday 10:00-11:30

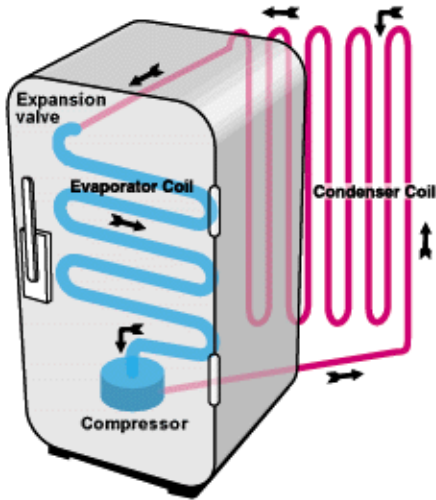
SR Exp. physics II

Prof. Paul H.M. van Loosdrecht

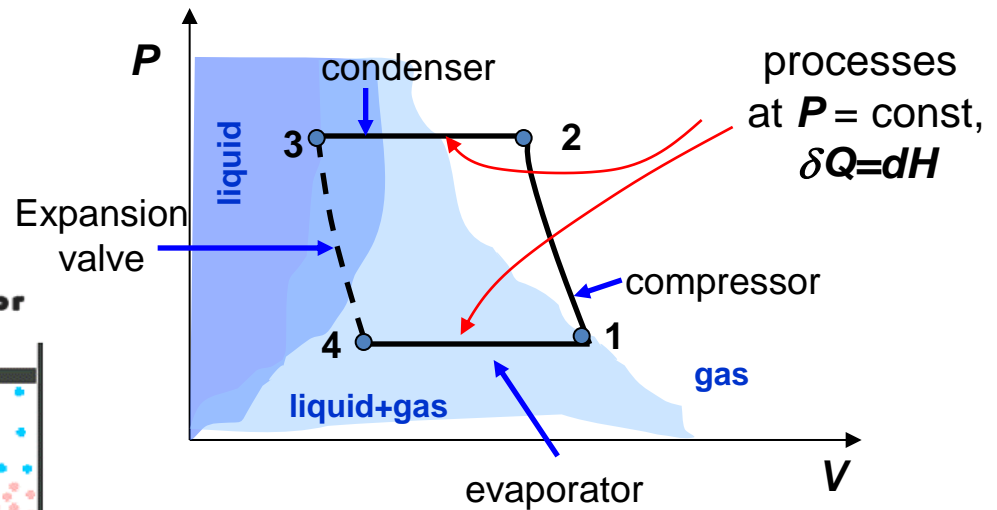
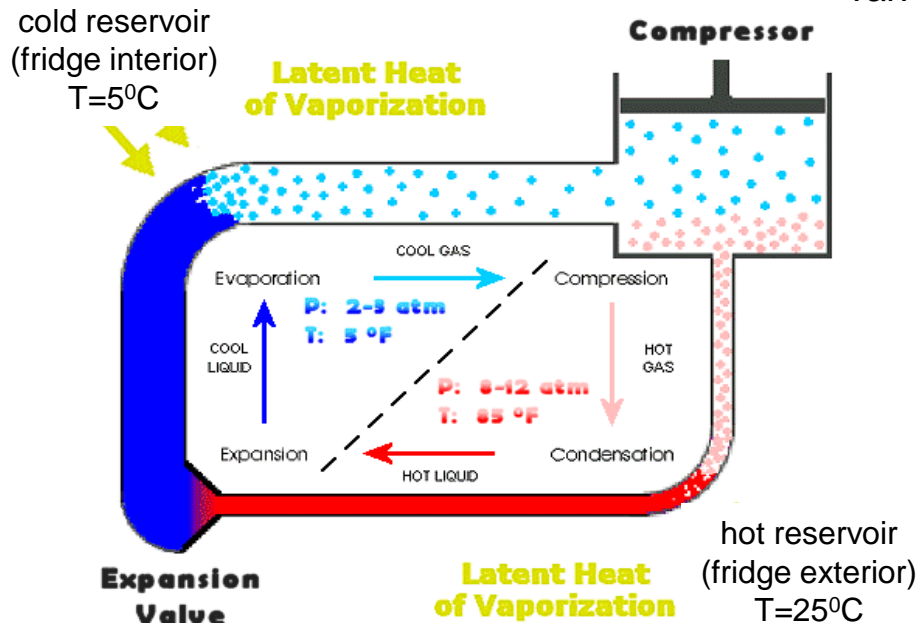
pvl@ph2.uni-koeln.de

www.loosdrecht.net

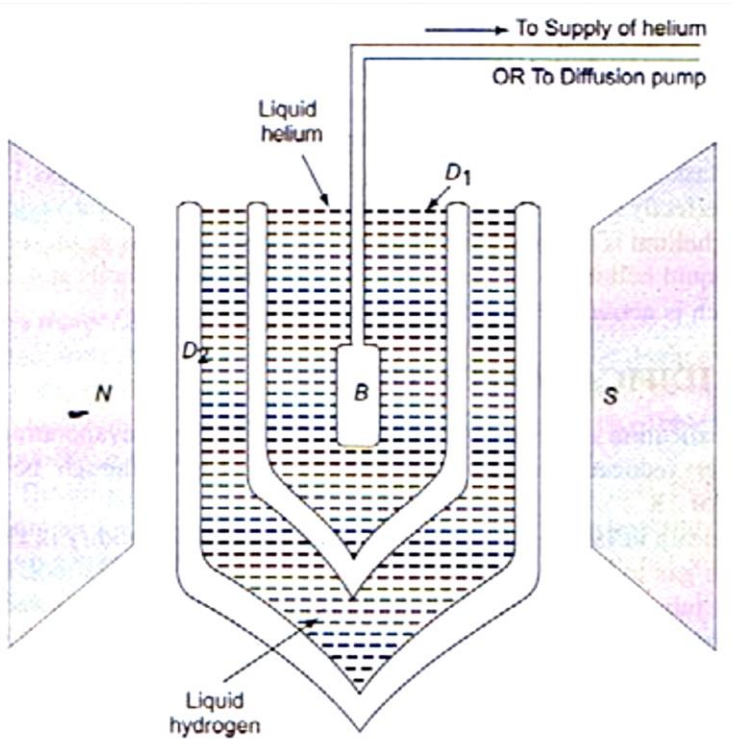
Kitchen refrigerator



The compressor pushes the liquid through the condenser coil at a high pressure (~ 10 atm). The liquid sprays through a throttling valve into the evaporation coil which is maintained by the compressor at a low pressure (~ 2 atm).



Adiabatic demagnetization



Sample in flask B

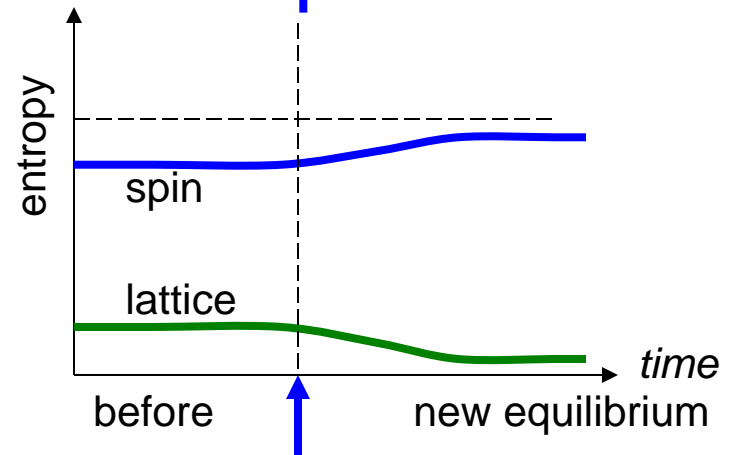
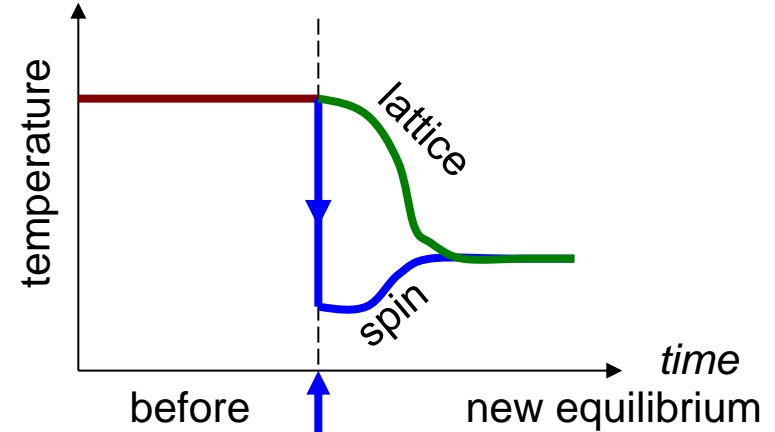
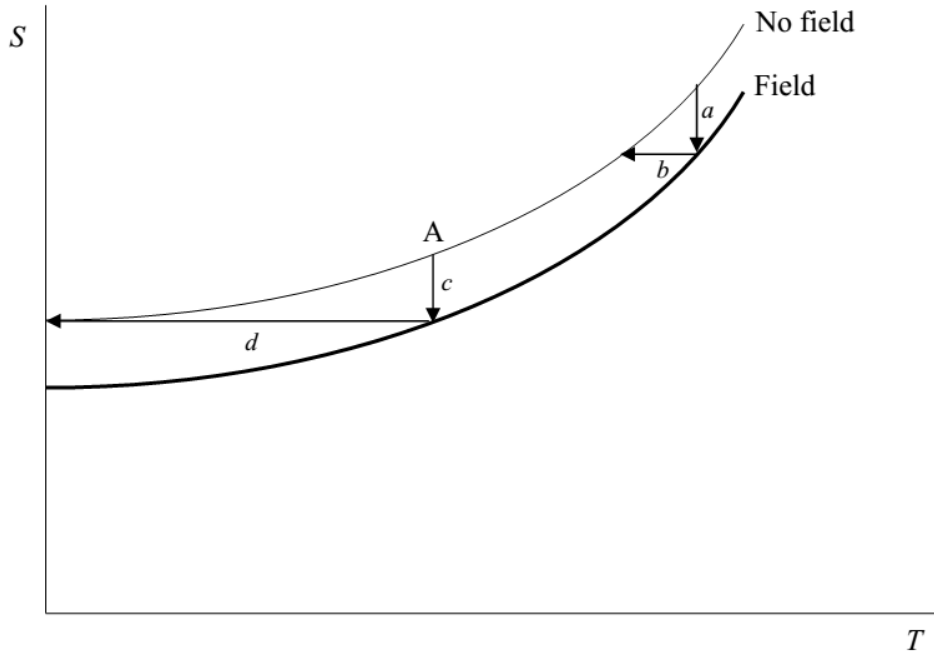
1. Thermal contact (B filled), Field on.
→ Xtal magnetized & cold
2. Thermal isolated (B pumped)
3. Field off
→ Xtal demagnetized adiabatically
→ Xtal cools down (entropy increases)

William F. Giauque (Nobel prize Chem. 1949)

"for his contributions in the field of chemical thermodynamics, particularly concerning the behaviour of substances at extremely low temperatures"



Adiabatic demagnetization



time at which
magnetic field
is removed

During adiabatic (better: isentropic) demagnetization the total entropy of the specimen is constant.

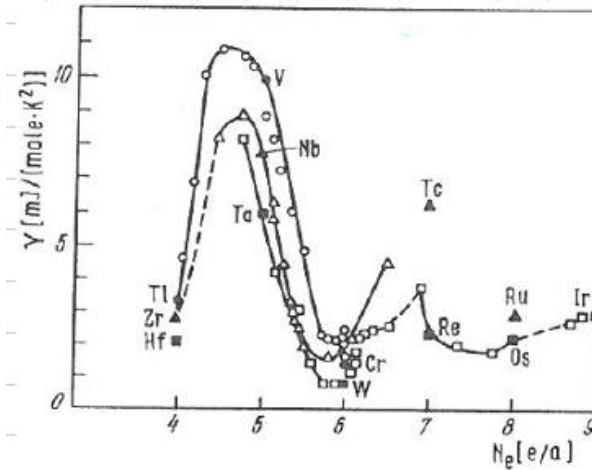
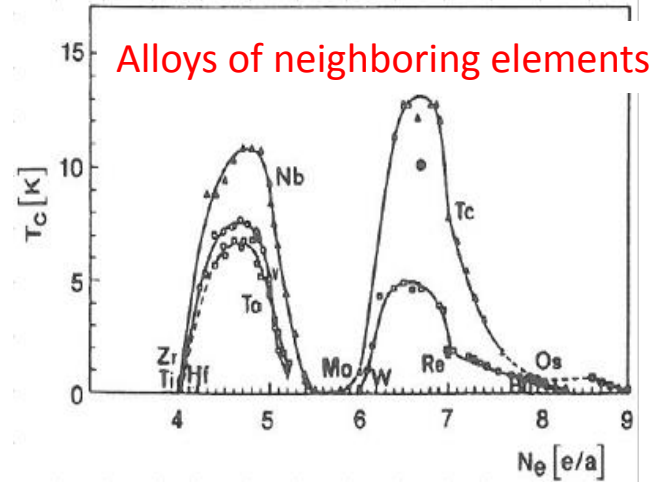
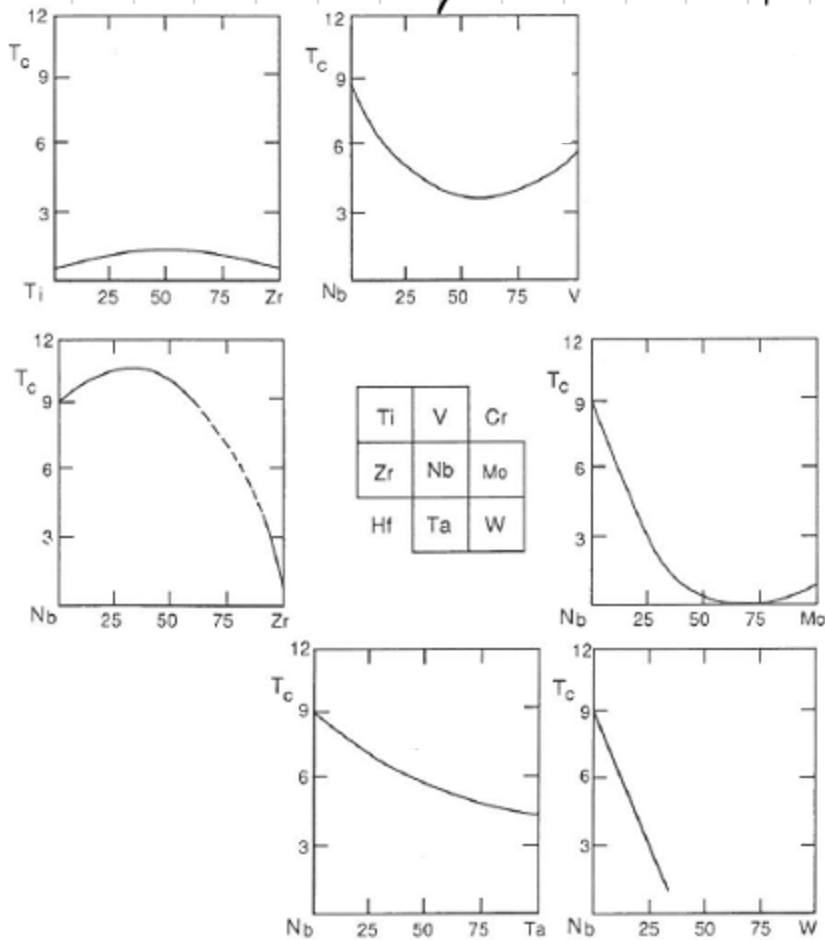
The entropy can flow into the spin system only from the system of lattice vibrations. The initial entropy of the lattice should be small in comparison with the entropy of the spin system in order to obtain significant cooling of the lattice – indeed, $S_{\text{lattice}} \ll S_{\text{spin}}$ holds in the mK range.

The heat capacity of the spins in the two-state paramagnetic is **large** at low T : 1 cm³ of iron ammonium salt at $T=50$ mK and $B \sim 0.05$ T has a heat capacity equal to 16 tons of lead (!) at the same T .

Temperatures attained:

- ~ **1 mK** with electronic paramagnetic systems and
- ~ **1 μ K** with nuclear paramagnetic systems.

Intermetallic alloys



Correlation sommerfeld coefficient & T_c
 → Again density of states Fermi level

Intermetallic compounds: The A15's

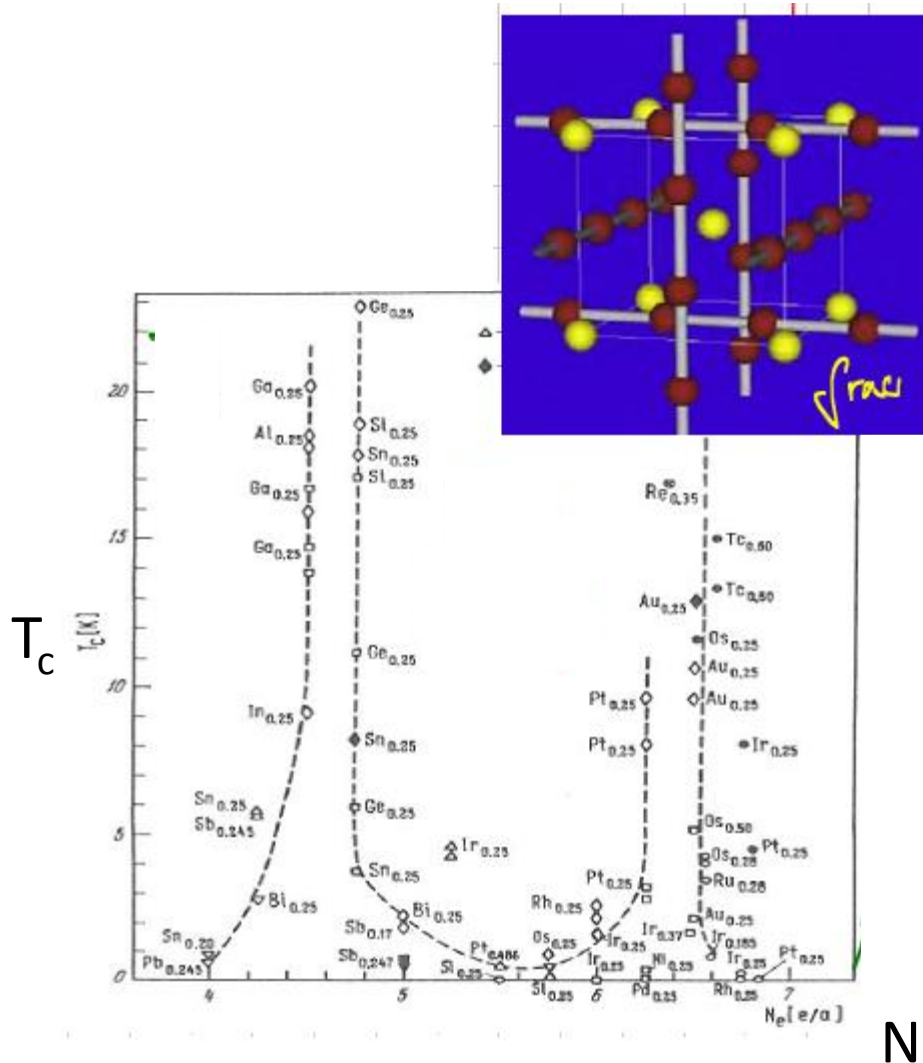
- A_3B with
 $A = \text{Ti, V, Cr, Zr, Nd, Mo, Ta, W}$ (transition metals)
 $B = \text{Sn, Ge, Ga, Si, ...}$
- Large number of SC's known (>60)
- Technologically relevant (superconducting magnets)

Tabelle 2.2 Supraleitende Verbindungen mit β -Wolframstruktur [5, 30].

• 110

Stoff	T_c in K	λ_L in nm	ξ_{GL} in nm	B_{c2} in T
V_3Ge	6,0	65		
V_3Ga^*	14,2–14,6	65	4	23
V_3Si	17,1	70	4	23
Nb_3Sn	18,0	80	4	24
<u>Nb_3Ge</u>	<u>23,2</u>	80	3	<u>38</u> <i>Incl</i>

Intermetallic compounds: The A15's



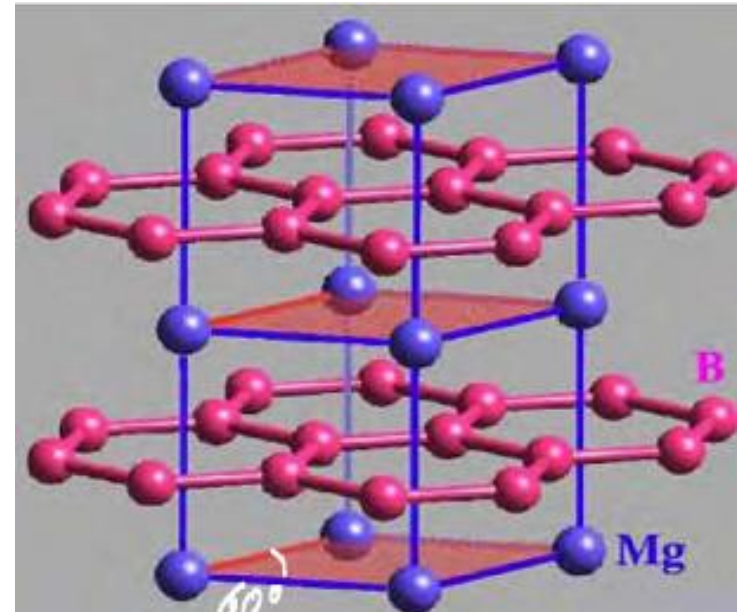
- Cubic crystal structure
- Like for alloys:
 - Max T_c for $N \sim 4.5$ & 6.5 e/a (Matthias rule)
- Again correlation with Sommerfeld parameter
Magn. Susceptibility
→ $D(E_F)$

N

Intermetallics: MgB_2

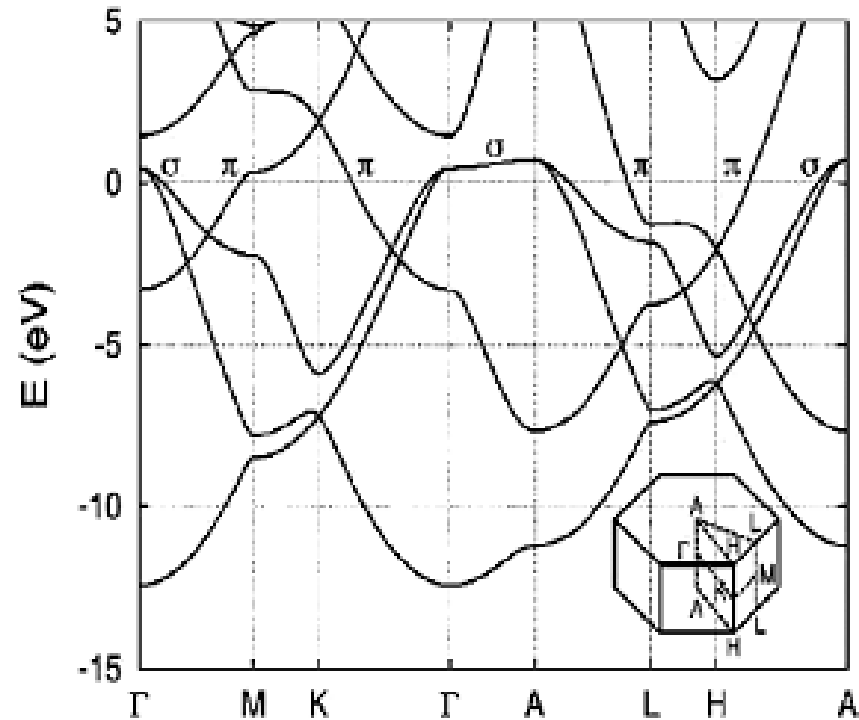
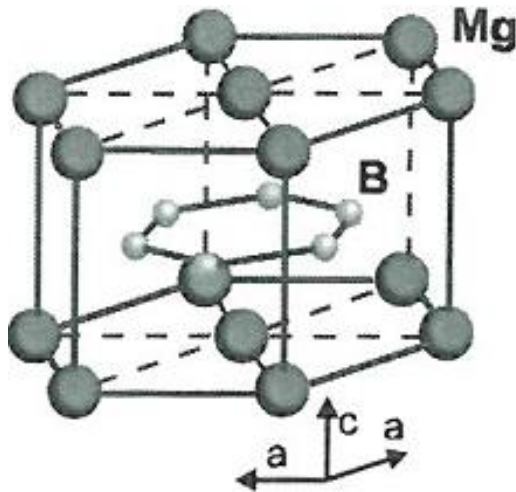
Nagamatsu, Akimitsu Nature 2001

- Highest T_c of conventional (e-ph) superconductors. 40 K
- Type II ($H_{c1}=2\text{T}$, $H_{c2}=15\text{-}20\text{T}$)
- Hexagonal crystal structure
- Material commercially available since 50's
- 2-band SC (2 bands cross E_F)



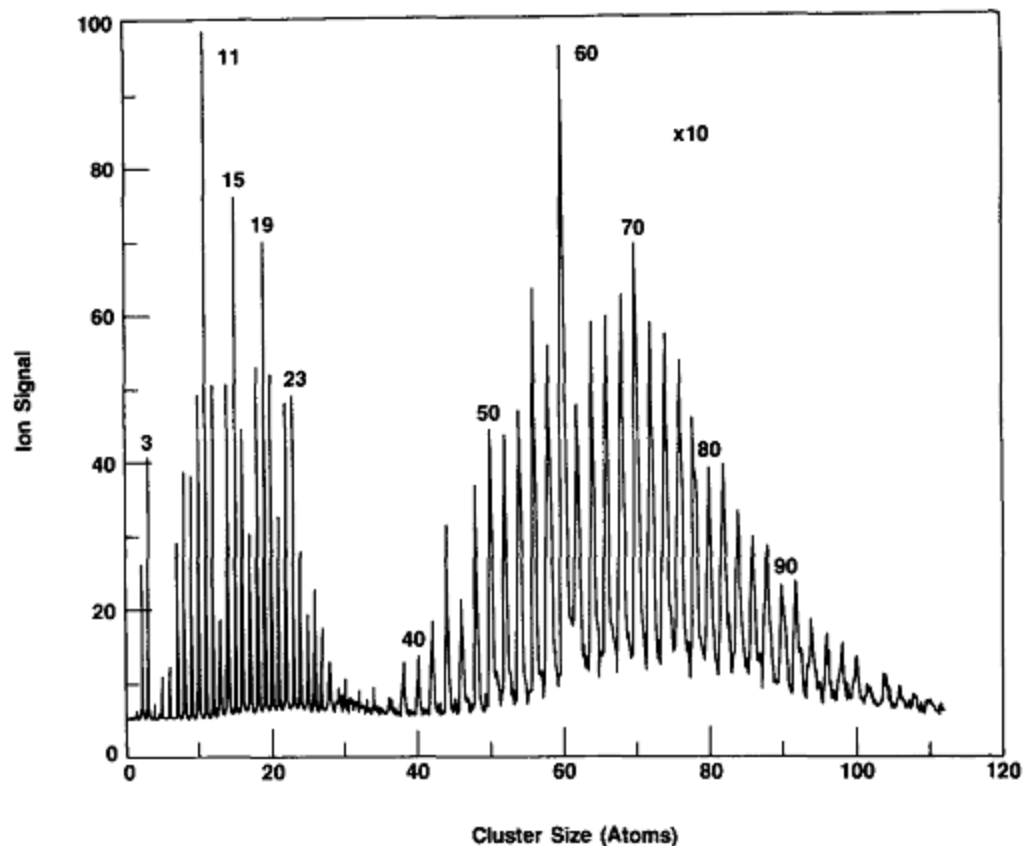
Intermetallics: MgB₂

- σ - and π -bands crossing E_F (Boron layer, analogy graphite)
- Two gaps!!
 - $2\Delta_\sigma = 7 \text{ meV}$
 - $2\Delta_\pi = 2\text{-}4 \text{ meV}$
- 2-band BCS-like theory



PRL 86 (4656) 2001

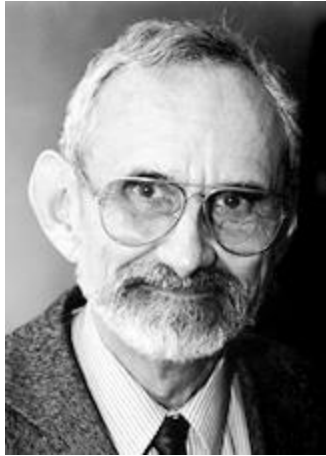
Fullerides



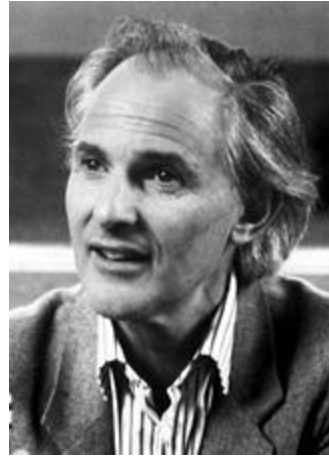
E. A. Rohlfing,^{a)} D. M. Cox, and A. Kaldor

J. Chem. Phys. **81** (7), 1 October 1984

Nobelprize (Chem.) Fullerenes 1996



Robert F.
Curl Jr



Sir Harold W.
Kroto



Richard E.
Smalley

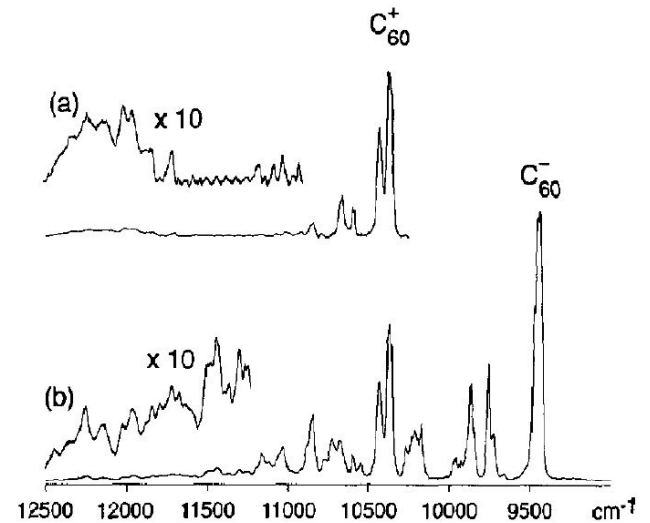
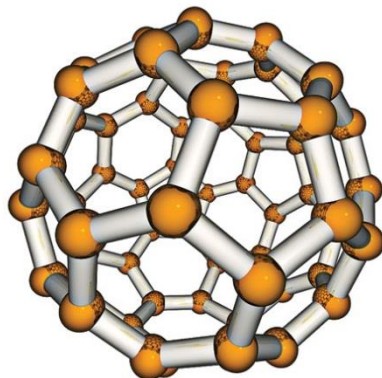


Fig. 1. Electronic absorption spectrum of: (a) C₆₀⁺ obtained by growing a neon matrix with a mass-selected ion beam; (b) C₆₀⁺ and C₆₀⁻ generated in a neon matrix upon NeI irradiation during deposition of C₆₀ with neon.

4.3 fullerenes

C_{60} : 1985 Kroto, Curl, Smalley; Nobel prize chemistry 1996

- fullerenes = molecular crystals of C_{60} ; fcc @ 300K
- doping via alkaline metals, $K_x C_{60}$, $x = 1..6$

$K_3 C_{60}$: $T_c \approx 20 K$ Hedard et al., Nature 350, 600 (91)

$Rb_3 C_{60}$: $T_c \approx 29.5 K$

$Cs_3 C_{60}$: $T_c \approx 40 K$ @ 1.5 GPa Palsha et al., Solid State Comm. 93, 327 (95)

increasing
lattice
constant

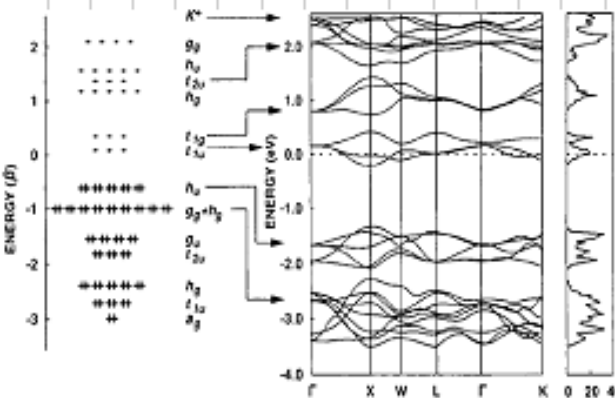
Highest T_c in non-organic material before 2008.

type II: $\lambda = 200-800 nm$, $\xi \sim 3 nm$ $J_{c2} \sim 50 T$

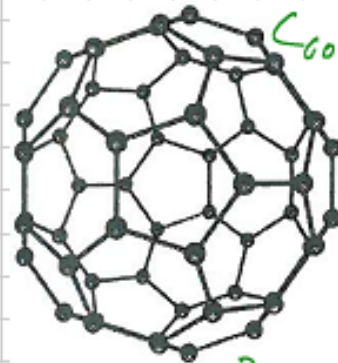
conventional electron-phonon, intramolecular vibrations

($\hbar\omega_{ph} \approx 0.2 eV$, very high)

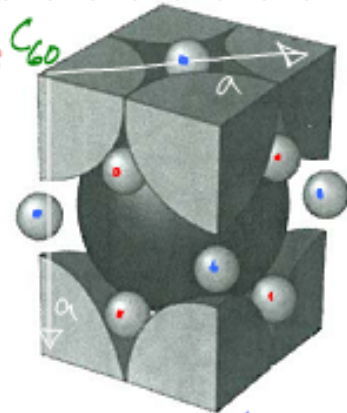
- weak intermolecular hopping \rightarrow flat bands
- energy scale of phonons, band width & "on-site" repulsion U comparable



Pennington & Steiner, Rev. Mod. Phys. 68, 855 (1996)

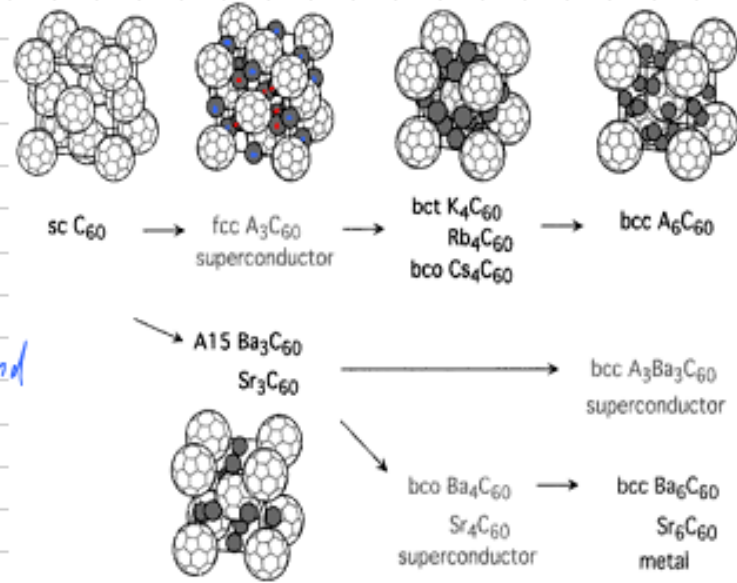


Dodecah



octahedral
tetrahedral

Fullerene-based materials: structures and properties
K. Prassides & H. Alloul



Derivation [edit]

An informal derivation follows. Suppose that $f(x, y, z) = 0$. Write z as a function of x and y . Thus the [total differential](#) dz is

$$dz = \left(\frac{\partial z}{\partial x} \right)_y dx + \left(\frac{\partial z}{\partial y} \right)_x dy$$

Suppose that we move along a curve with $dz = 0$, where the curve is parameterized by x . Thus y can be written in terms of x , so on this curve

$$dy = \left(\frac{\partial y}{\partial x} \right)_z dx$$

Therefore the equation for $dz = 0$ becomes

$$0 = \left(\frac{\partial z}{\partial x} \right)_y dx + \left(\frac{\partial z}{\partial y} \right)_x \left(\frac{\partial y}{\partial x} \right)_z dx$$

Since this must be true for all dx , rearranging terms gives

$$\left(\frac{\partial z}{\partial x} \right)_y = - \left(\frac{\partial z}{\partial y} \right)_x \left(\frac{\partial y}{\partial x} \right)_z$$

Dividing by the derivatives on the right hand side gives the triple product rule

$$\left(\frac{\partial x}{\partial y} \right)_z \left(\frac{\partial y}{\partial z} \right)_x \left(\frac{\partial z}{\partial x} \right)_y = -1$$

Note that this proof makes many implicit assumptions regarding the existence of partial derivatives, the existence of the [exact differential](#) dz , the ability to construct a curve in some [neighborhood](#) with $dz = 0$, and the nonzero value of partial derivatives and their reciprocals. A formal proof based on [mathematical analysis](#) would eliminate these potential ambiguities.