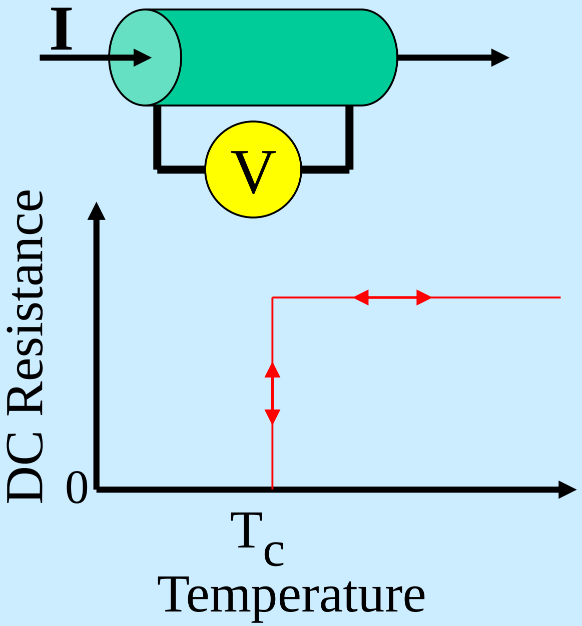
- Presented by
- Shivkumar P. Bias
- Asst. Prof.
- Department of Physics
- Dr. H.N.Sinha College Patur

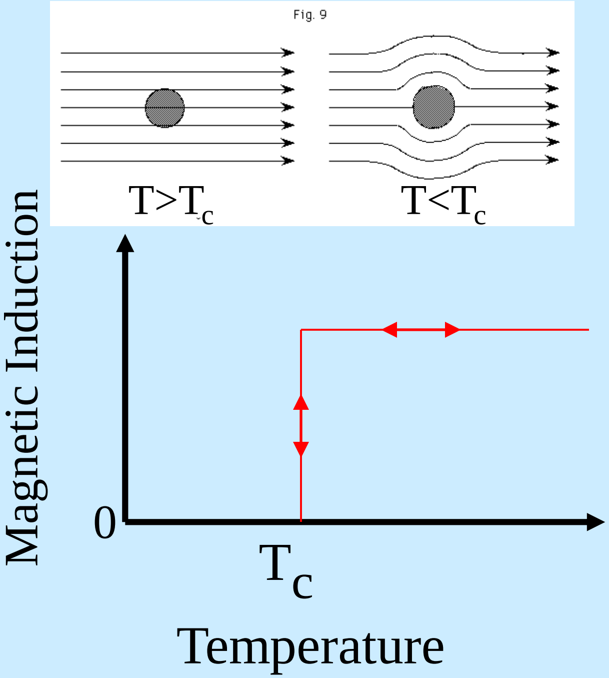
UNIVERSITY OF MARYLAND

The Three Hallmarks of Superconductivity

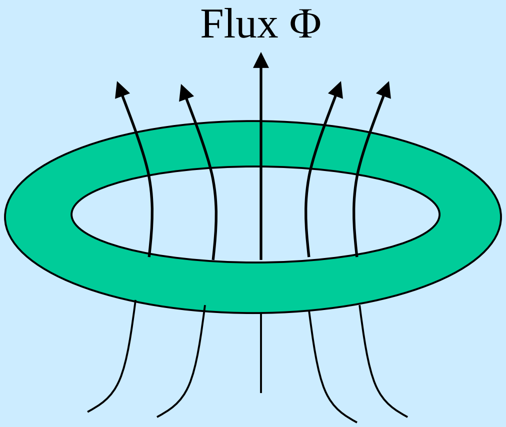
Zero Resistance



Complete Diamagnetism



Macroscopic Quantum Effects

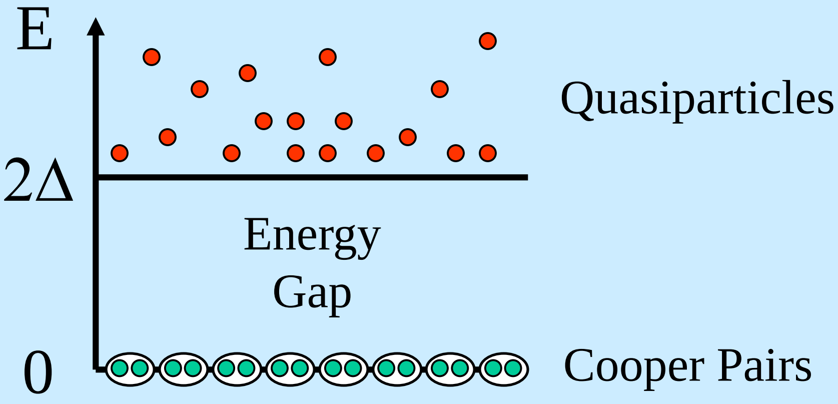


Flux quantization $\Phi = n\Phi_0$
Josephson Effects

Zero Resistance

R = 0 only at $\omega = 0$ (DC)

R > 0 for $\omega > 0$



E

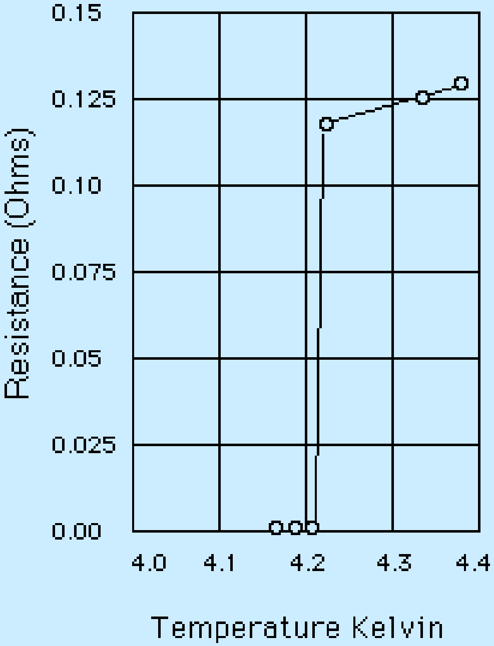
2Δ

Energy Gap

0

Quasiparticles

Cooper Pairs

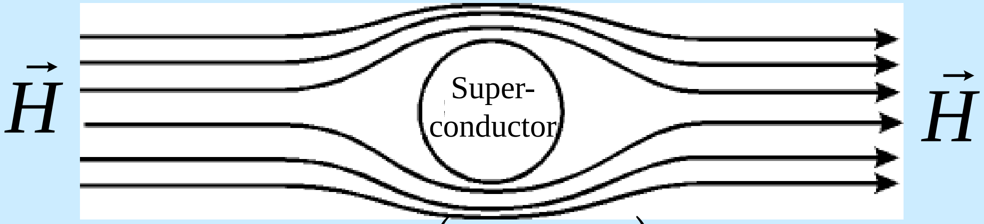


The Kamerlingh Onnes resistance measurement of mercury. At 4.15K the resistance suddenly dropped to zero

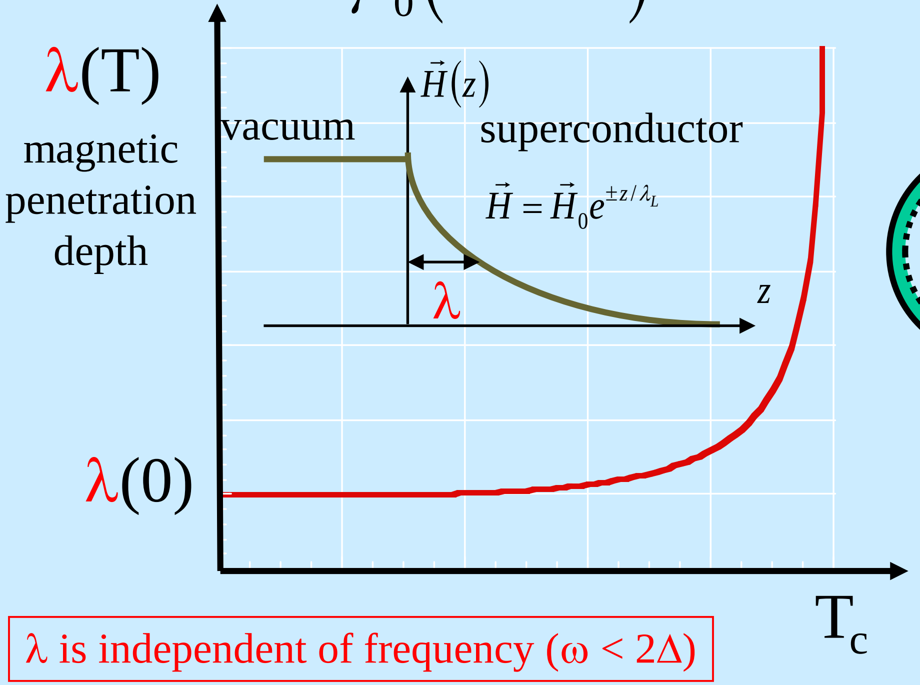
UNIVERSITY OF MARYLAND

Perfect Diamagnetism

Magnetic Fields and Superconductors are not generally compatible

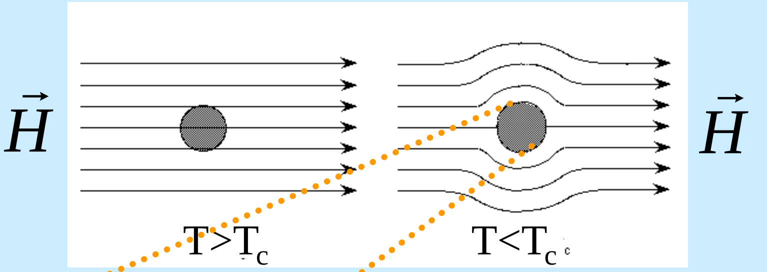


$$\vec{B} = \mu_0\left(\vec{H} + \vec{M}\right) = 0$$

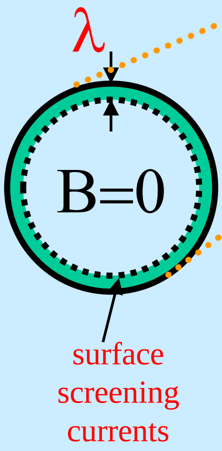


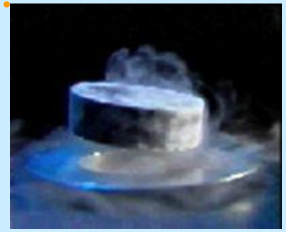
λ is independent of frequency (ω < 2Δ)

The Meissner Effect



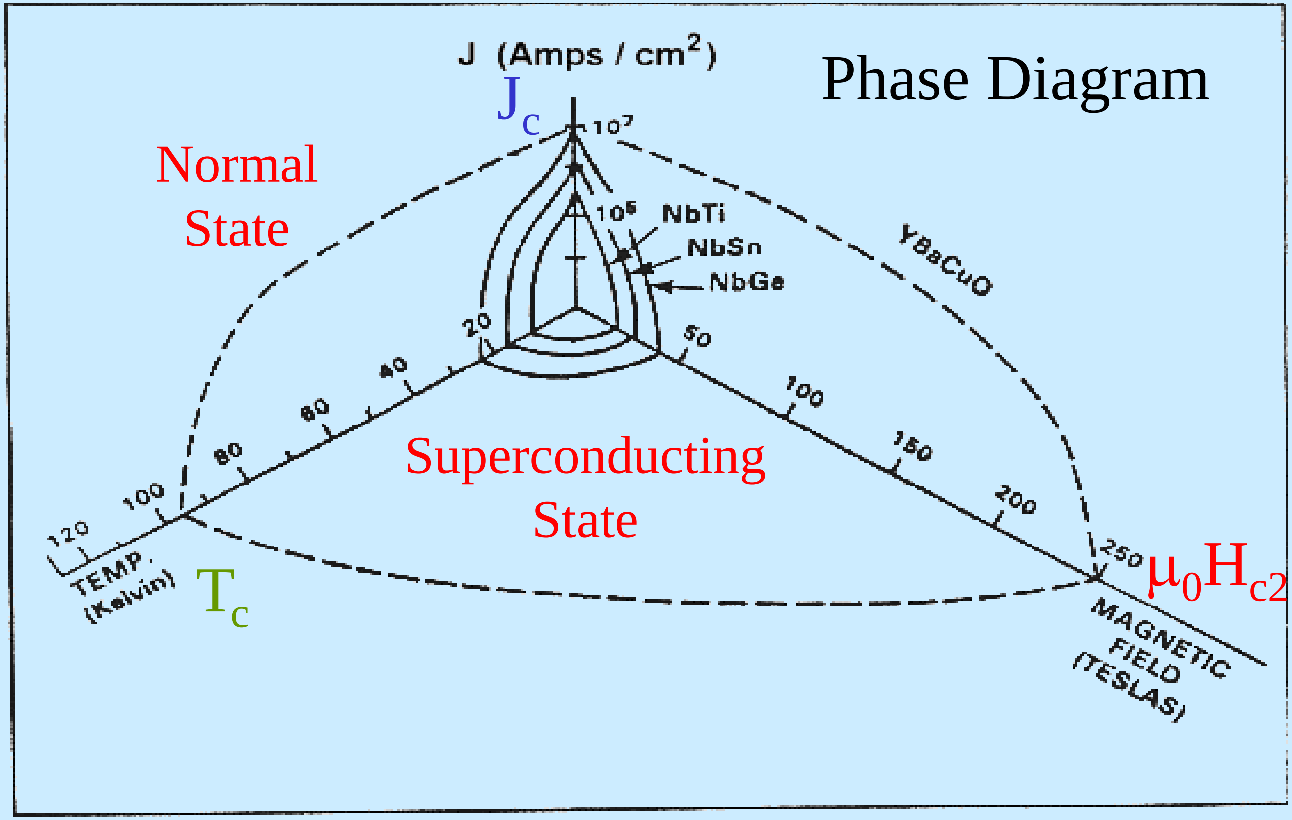
Spontaneous exclusion of magnetic flux





The Yamanashi MLX01 MagLev test vehicle achieved a speed of 343 mph (552 kph) on April 14, 1999

What are the Limits of Superconductivity?



$$f_{\text{super}} = f_{\text{normal}} + \alpha(T)|\psi|^2 + \frac{\beta(T)}{2}|\psi|^4 + \frac{1}{2m^*}\left|\left(\frac{\hbar}{i}\vec{\nabla} - e^*\vec{A}\right)\psi\right|^2 + \frac{\mu_0 h^2}{2}$$

Ginzburg-Landau
free energy density

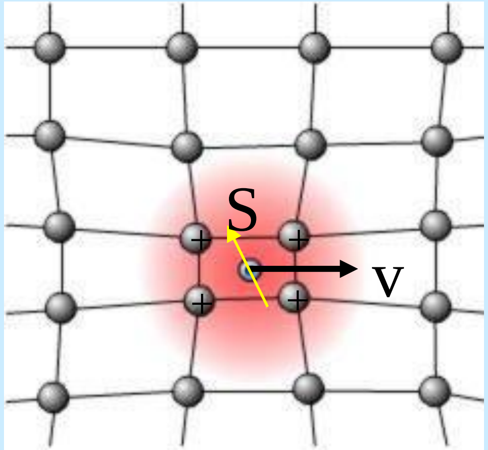
Temperature dependence

Currents

Applied magnetic field

BCS Theory of Superconductivity

Bardeen-Cooper-Schrieffer (BCS)

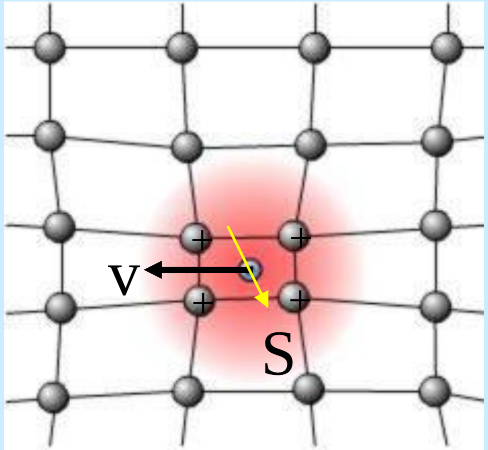


First electron polarizes the lattice

Cooper Pair

s-wave ($\ell = 0$) pairing

Spin singlet pair



Second electron is attracted to the concentration of positive charges left behind by the first electron

$$T_c \cong \Omega_{Debye}\, e^{-1/NV}$$

Ω_{Debye} is the characteristic phonon (lattice vibration) frequency
N is the electronic density of states at the Fermi Energy
V is the attractive electron-electron interaction

A many-electron quantum wavefunction Ψ made up of Cooper pairs is constructed with these properties:

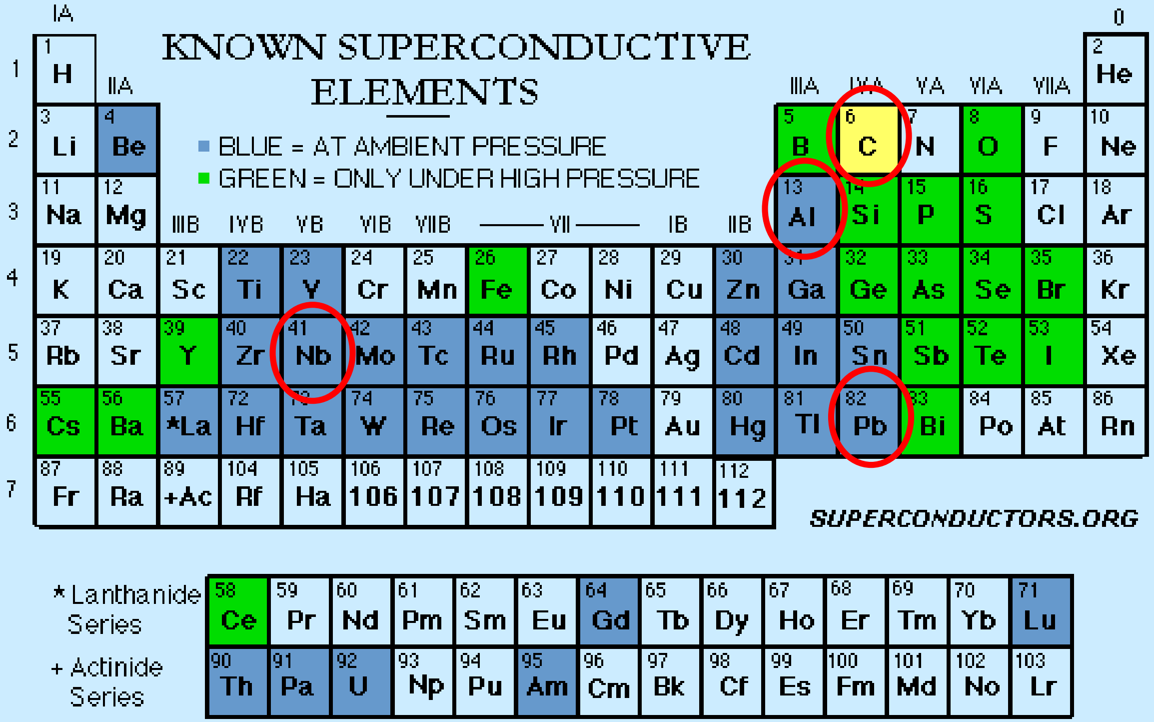
An energy $2\Delta(T)$ is required to break a Cooper pair into two quasiparticles (roughly speaking)

Cooper pair size: $\xi = v_F \cdot \dfrac{\hbar}{\Delta}$

UNIVERSITY OF MARYLAND

http://www.chemsoc.org/exemplarchem/entries/igrant/hightctheory_noflash.html

Where do we find Superconductors?



KNOWN SUPERCONDUCTIVE ELEMENTS

🟦 BLUE = AT AMBIENT PRESSURE
🟩 GREEN = ONLY UNDER HIGH PRESSURE

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be 🟦											5 B 🟩	6 C 🟨	7 N	8 O 🟩	9 F	10 Ne
3	11 Na	12 Mg											13 Al 🟦	14 Si 🟩	15 P 🟩	16 S 🟩	17 Cl	18 Ar
4	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
5	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
6	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
7	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

Also:

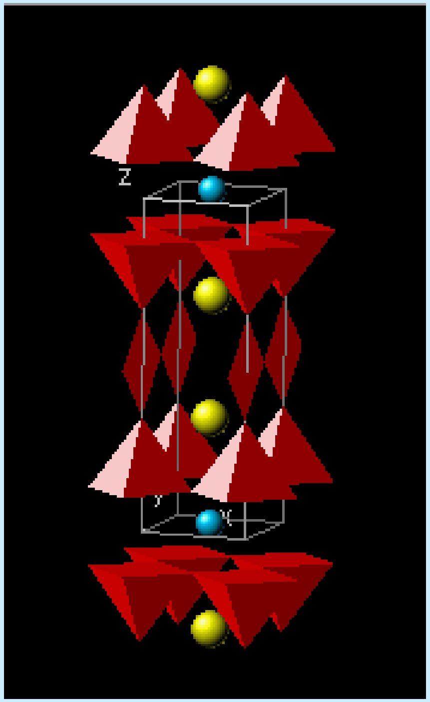
Nb-Ti, Nb_3Sn, A_3C_{60}, NbN, MgB_2, Organic Salts ($(TMTSF)_2X$, $(BEDT\text{-}TTF)_2X$), Oxides (Cu-O, Bi-O, Ru-O,…), Heavy Fermion (UPt_3, $CeCu_2Si_2$,…), Electric Field-Effect Superconductivity (C_{60}, $[CaCu_2O_3]_4$, plastic), …

Most of these materials, and their compounds, display spin-singlet pairing

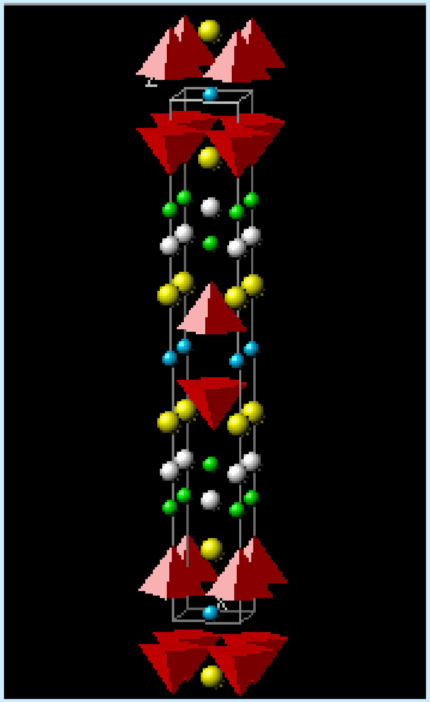
The High-T_c Cuprate Superconductors

Layered structure – quasi-two-dimensional
Anisotropic physical properties
Ceramic materials (brittle, poor ductility, etc.)
Oxygen content is critical for superconductivity

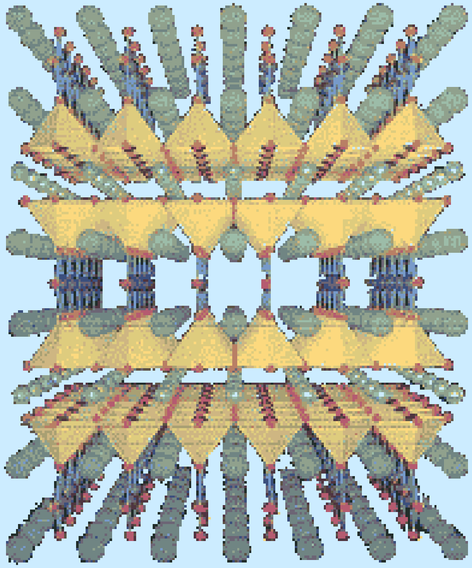
Spin singlet pairing
d-wave ($\ell = 2$) pairing



$YBa_2Cu_3O_{7-\delta}$



$Tl_2Ba_2CaCu_2O_8$



Two of the most widely-used HTS materials in applications

UNIVERSITY OF MARYLAND