Matéria Condensada

Supercondutividade

Michael Faraday (22/09/1791 – 25/08/1867)

- Eletromagnetismo

Sir Humphry Davy descobriu o cloro (gás) em 1810.

Em 1823, Faraday liquefez o cloro, tornando-se a primeira pessoa a liquefazer um gás.

NH_3, H_2S, NO_2 e SO_2 foram liquefeitos na mesma época.

Gases permanentes: Hidrogênio, nitrogênio, oxigênio, ..., hélio.

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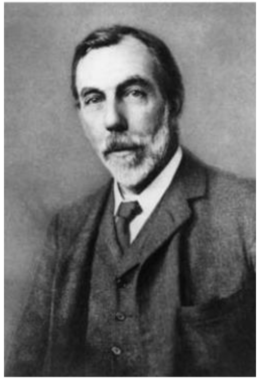
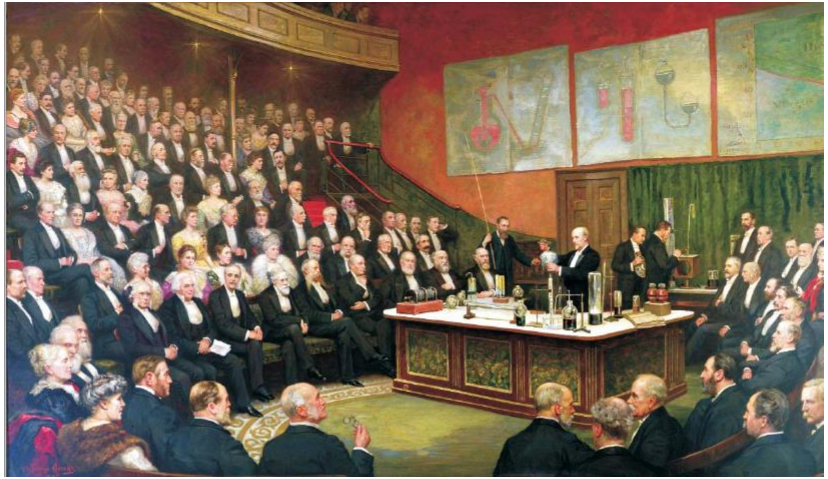


William Ramsay (02/10/1852 – 23/07/1916), Royal Institution

1895 – Descoberta do hélio na Terra >> Prêmio Nobel de Química (1904).

Corrida para liquefação de gases

Vários cientistas participaram desta corrida, incluindo pessoas ilustres como James Joule e William Thomson (Lord Kelvin).



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sucessor do Faraday na Royal Institution.

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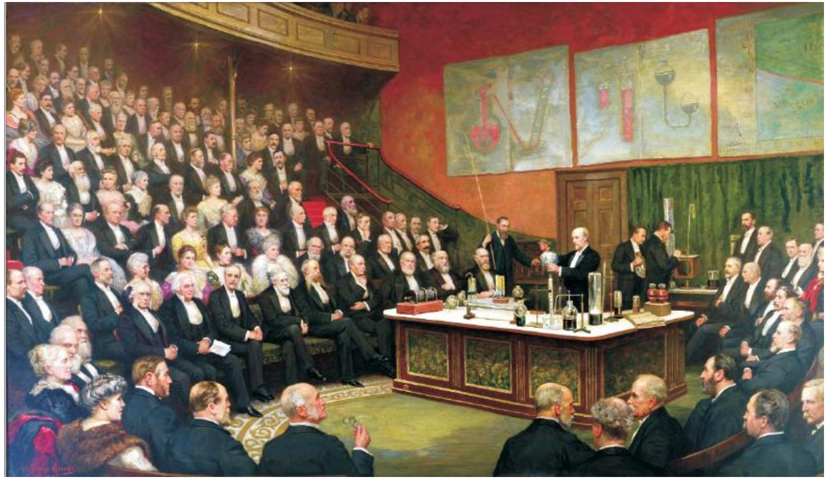

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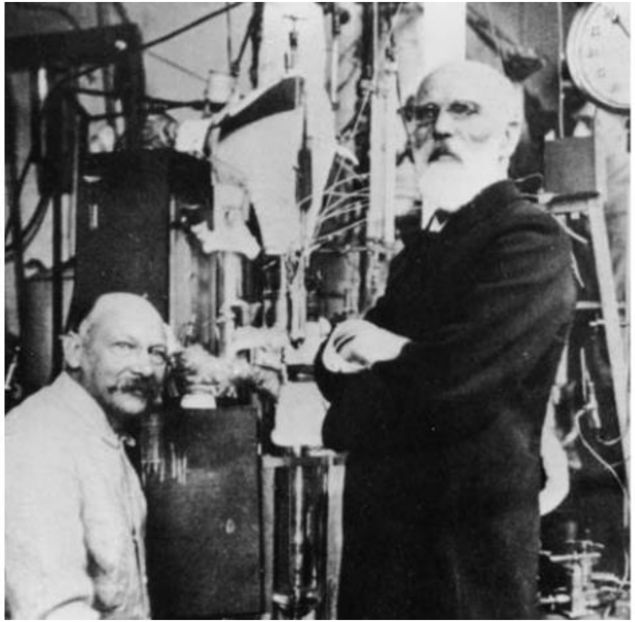
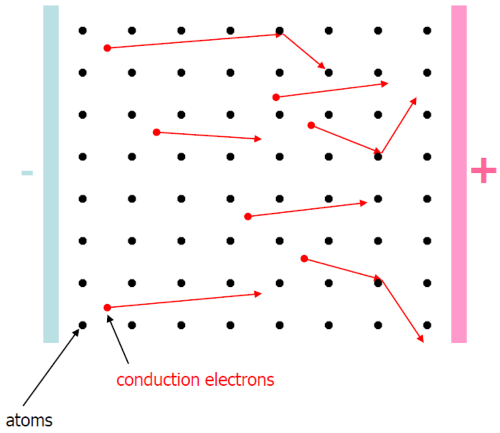
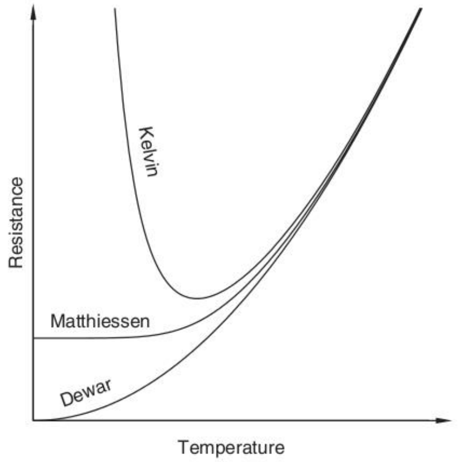
Heike Kamerlingh Onnes

1908 – Liquefação do hélio (~4 K).



1911 - Supercondutividade





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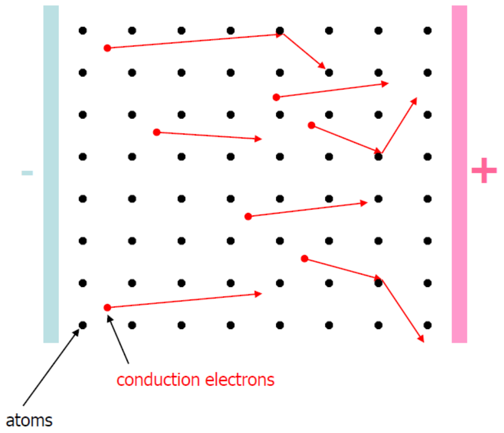

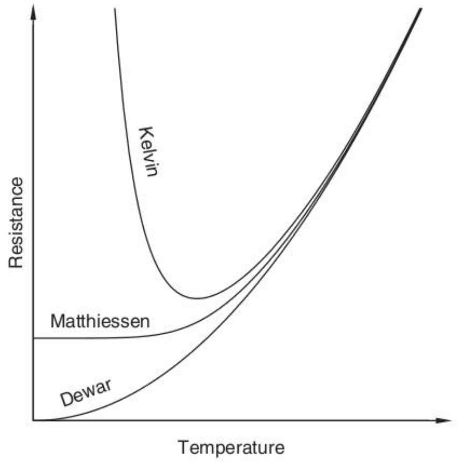

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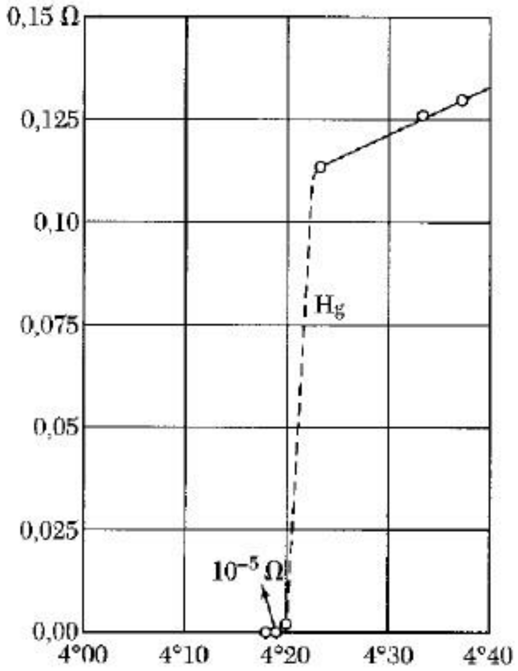

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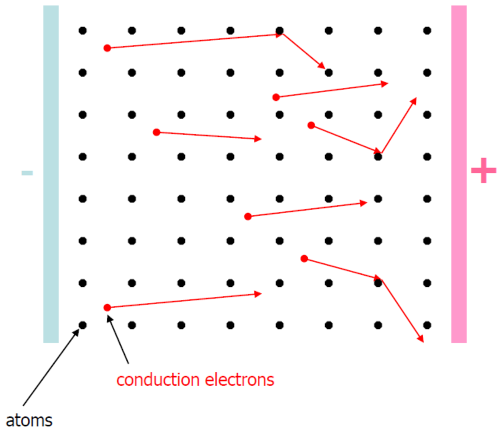

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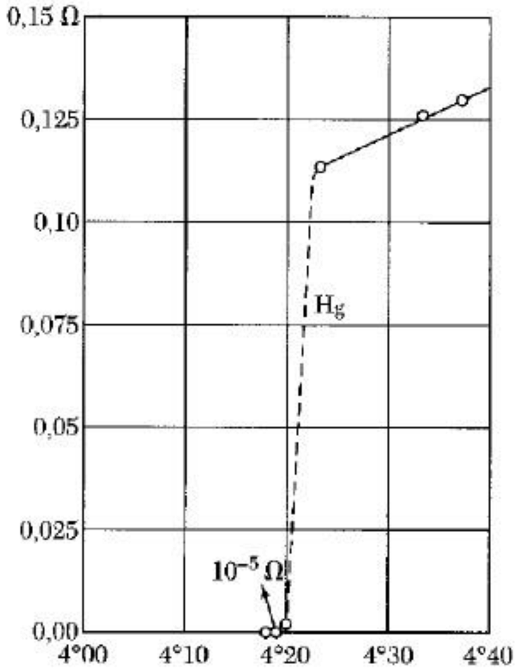
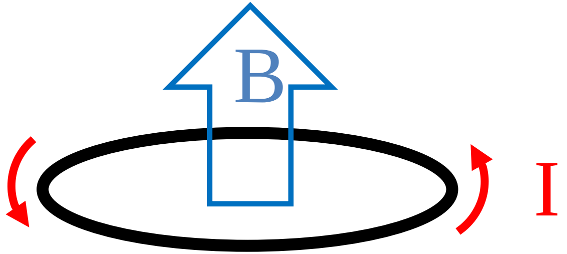
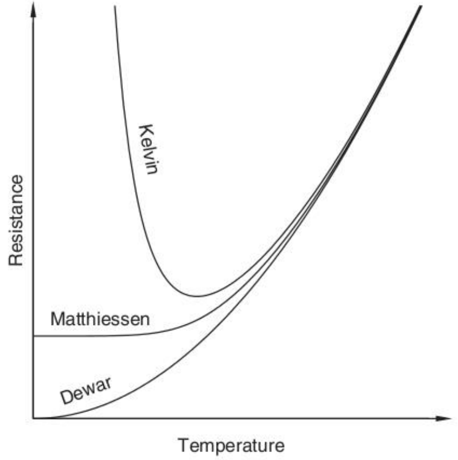
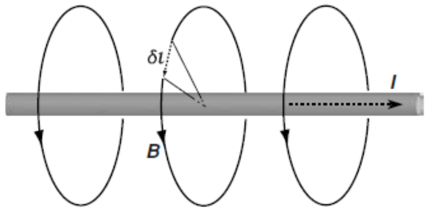


Corrente fluindo sem perda de energia!!







"It has become more and more clear that a change in the whole theory of electrons is necessary. Theoretical work in this direction has already been begun by a number of research workers, particularly by Planck and Einstein."

Supercondutor ou condutor perfeito?

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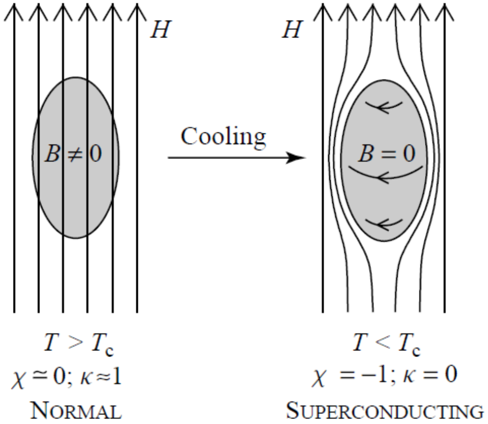
Walther Meissner



Criação de correntes superficiais que cancelam o campo magnético externo, de modo que B=0 no interior da amostra (no estado supercondutor).

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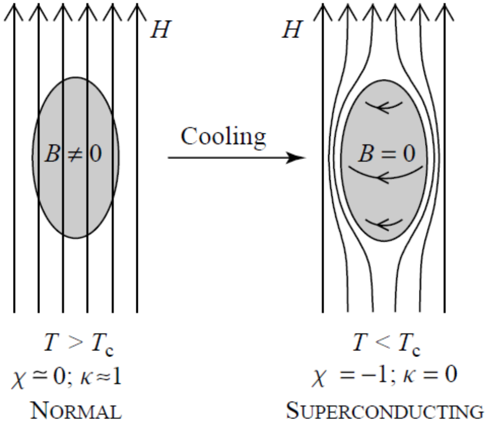

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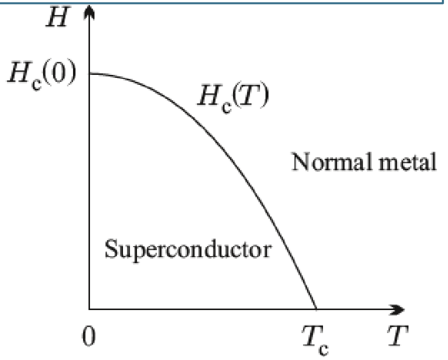
Diamagneto perfeito

condutor perfeito ≠ Supercondutor



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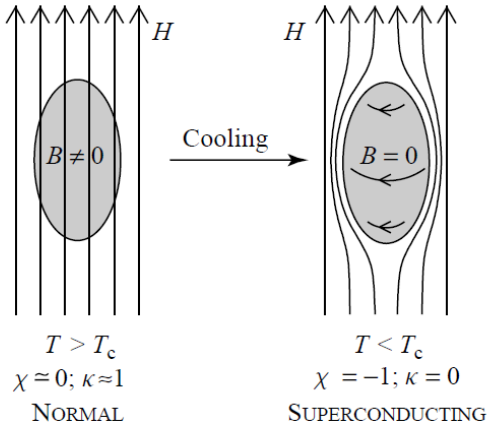

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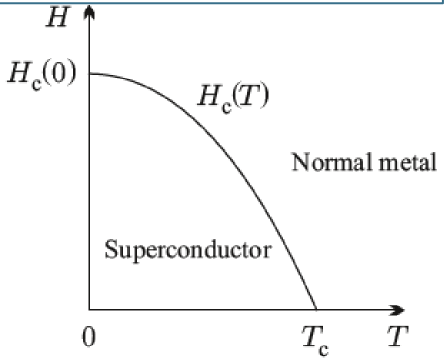
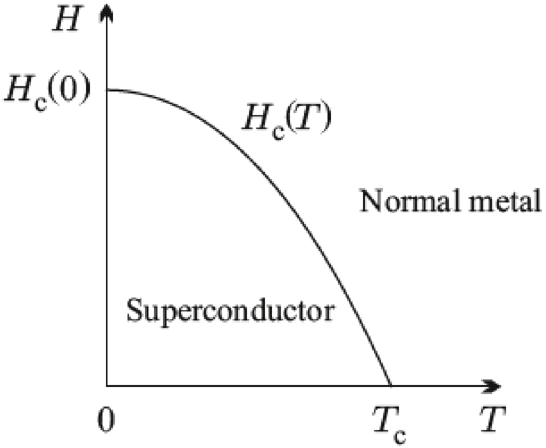
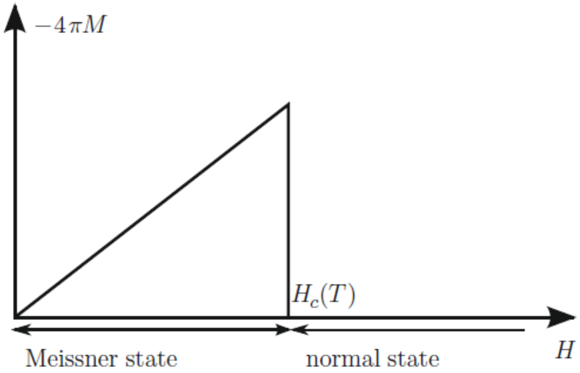


142 kg sumotori + 60 kg magnetized disk = 202 kg lévitated

Supercondutores tipo I





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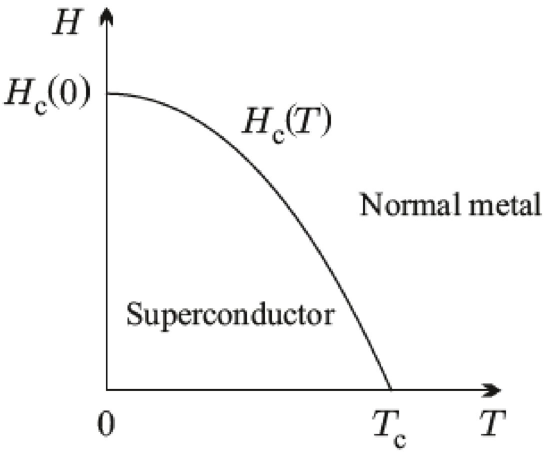
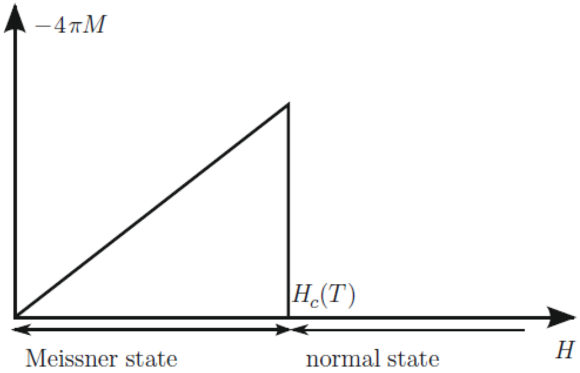
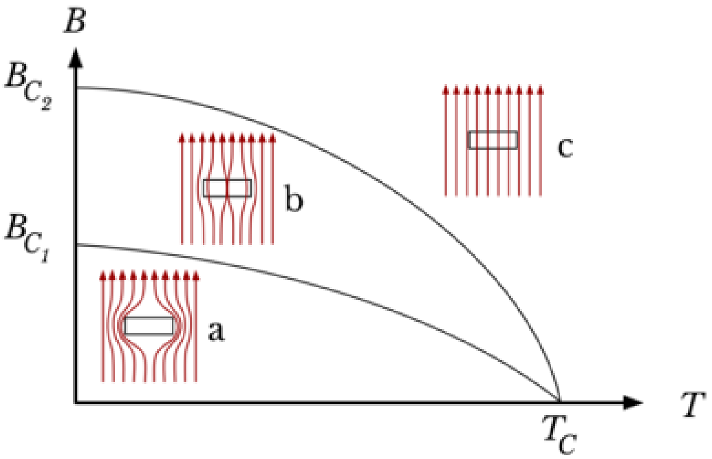
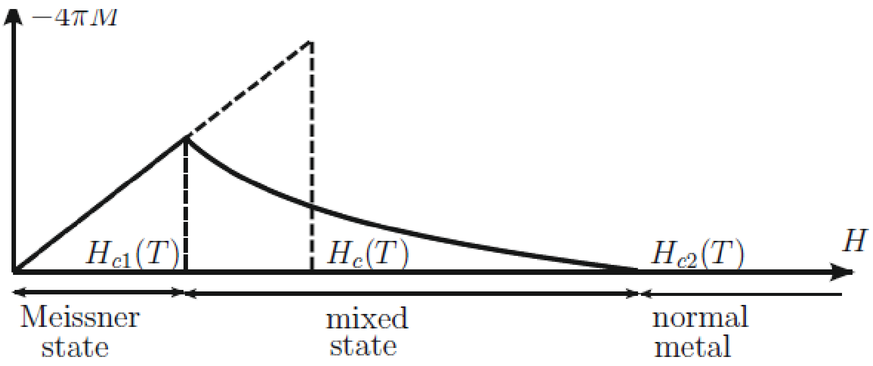




Supercondutores tipo II





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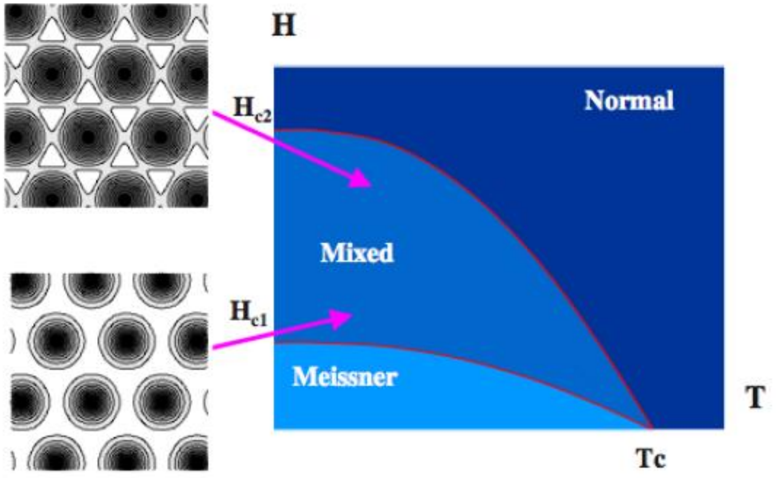
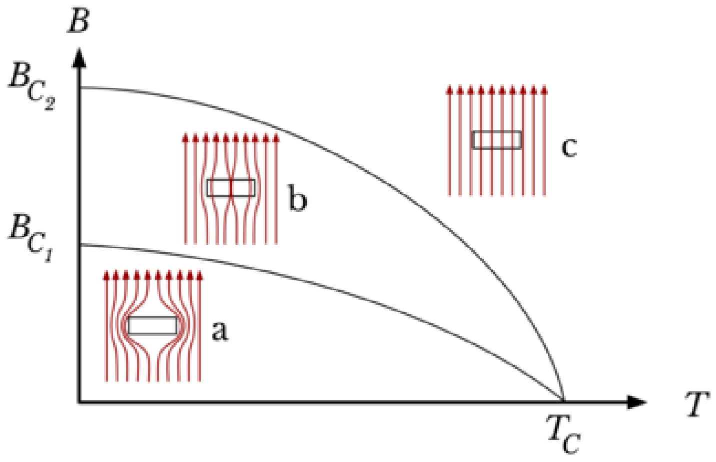
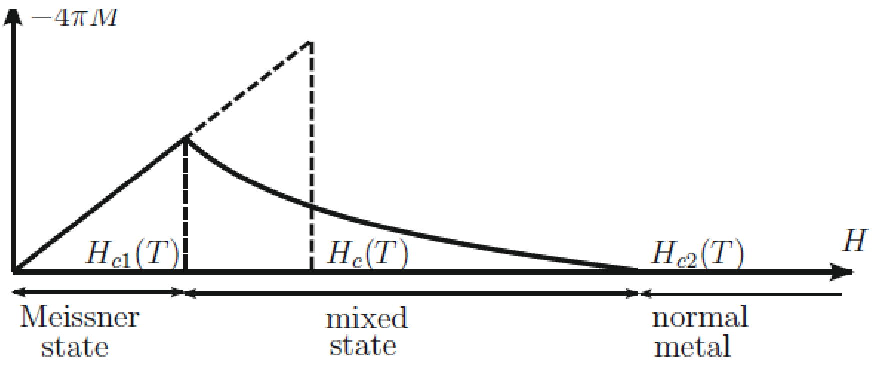
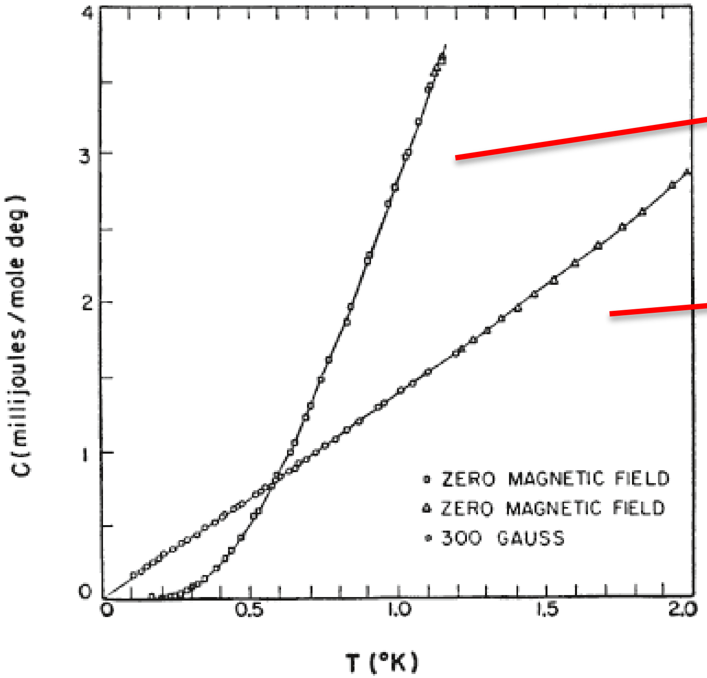






Calor específico



$$C_{\rm s} \sim \exp\left(-\frac{\Delta}{k_{\rm B}T}\right)$$

$$C_{\rm n} = \gamma T + AT^3$$

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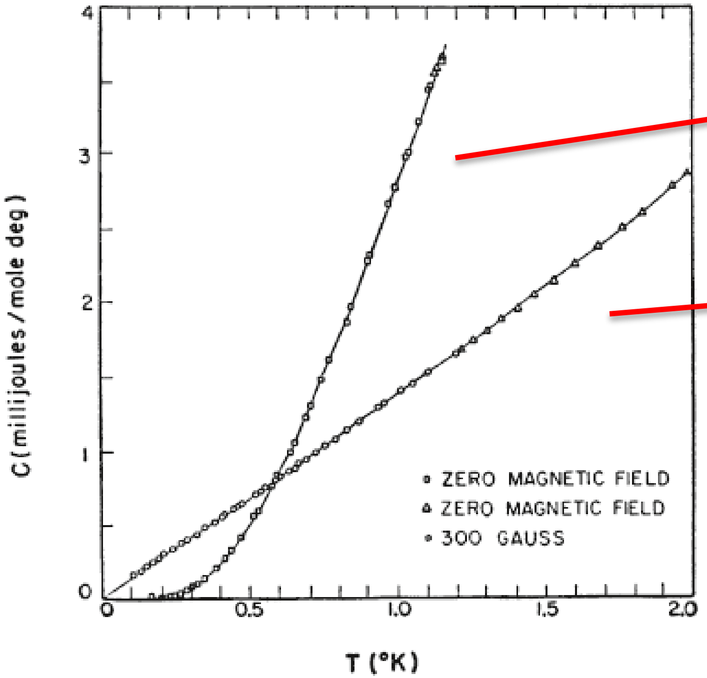

$$C_s \sim \exp\left(-\frac{\Delta}{k_B T}\right) \Rightarrow \Delta \sim k_B T_c$$

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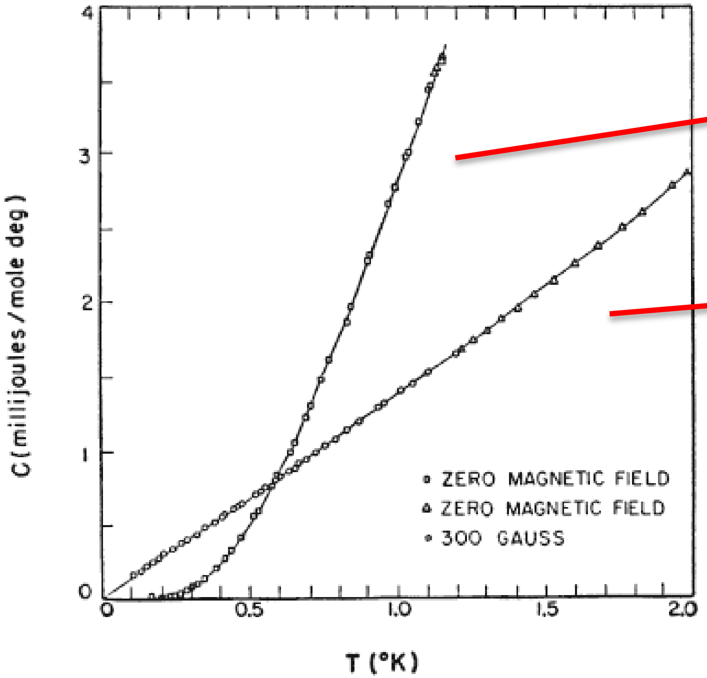

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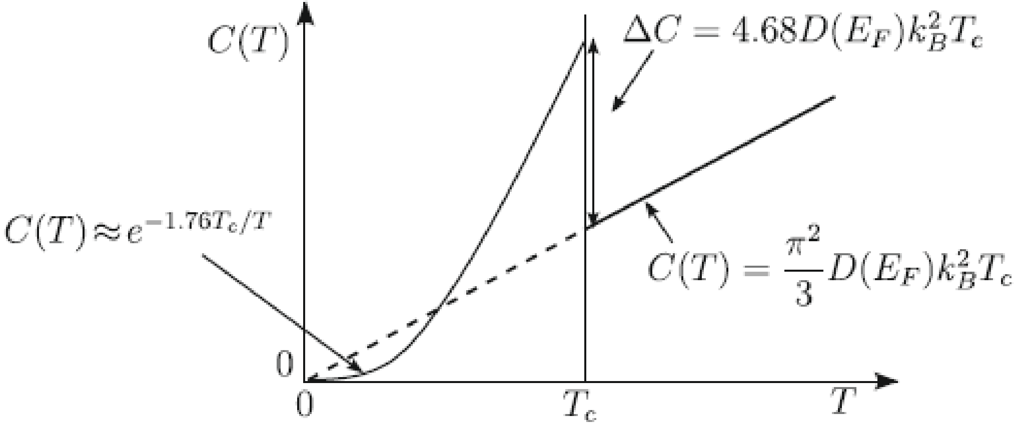
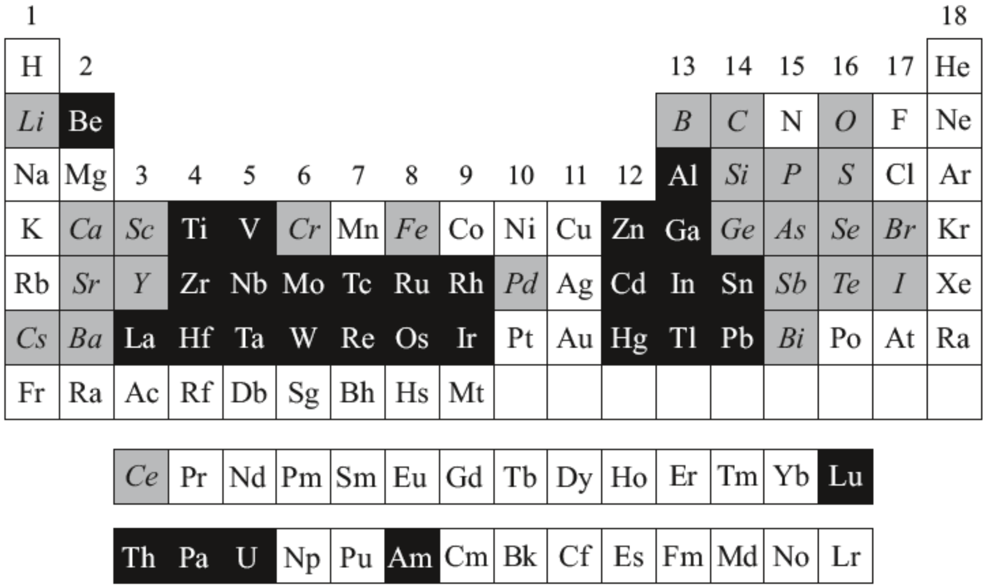
Element	Relative jump
Al	1.45
Cd	1.36
Nb	1.93
Pb	2.71





Element	T_c (K)	B_c (mT)	Element	T_c (K)	B_c (mT)
Al	1.18	10.5	Pa	1.4	
Am	0.6		Pb	7.20	80.3
Be	0.03	9.9	Re	1.70	20.1
Cd	0.52	2.8	Rh	3.2×10^{-4}	5×10^{-3}
Ga	1.08	5.9	Ru	0.49	6.9
Hf	0.13	1.3	Sn	3.72	30.5
α-Hg	4.15	41.1	Ta	4.47	82.9
β-Hg	3.95	33.9	Tc	7.8	141
In	3.41	28.2	Th	1.37	16.0
Ir	0.11	1.6	Ti	0.40	5.6
α-La	4.87	80	Tl	2.38	17.6
β-La	6.06	110	U	0.68	10.0
Lu	0.1	35.0	V	5.46	140
Mo	0.92	9.7	W	0.01	0.1
Nb	9.25	206	Zn	0.86	5.4
Os	0.66	7.0	Zr	0.63	4.7

Qual é a origem microscópica de supercondutividade?

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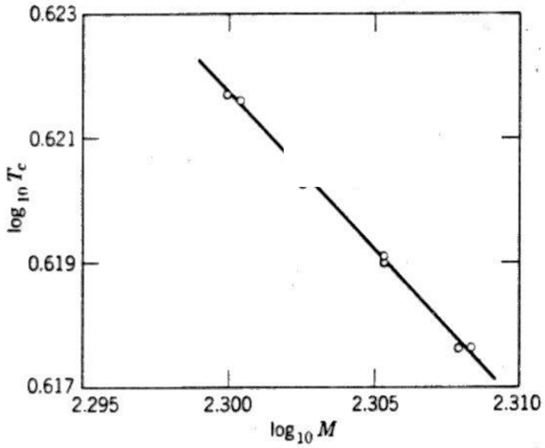
Efeito isotópico



$$T_c \propto M^{-\alpha}$$

Vibrações da rede cristalina (fônons)

	Cd	Hg	Mo	Os	Pb	Re	Ru	Sn	Tl	Zn	Zr
α	0.5	0.50	0.37	0.21	0.48	0.36	0.0	0.47	0.5	0.45	0.0

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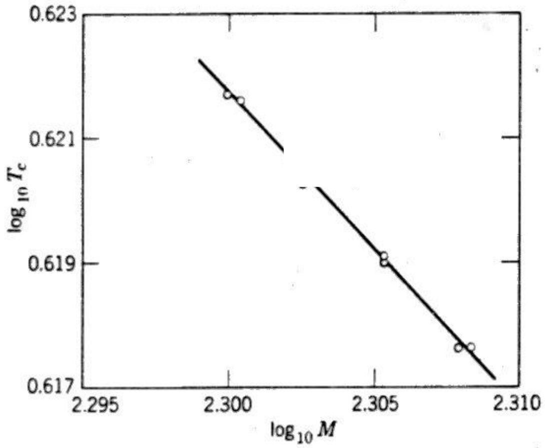

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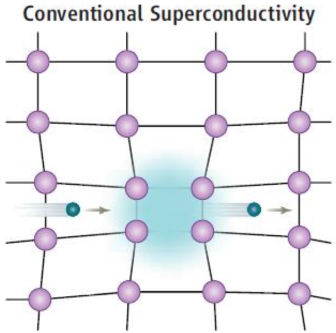

A interação elétron-fônon pode induzir uma atração efetiva entre elétrons, levando a formação de **pares.**

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Fröhlich Hamiltonian

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$$\mathcal{H} = \underbrace{\sum_{\mathbf{k}} \mathcal{E}_{\mathbf{k}} c^{\dagger}_{\mathbf{k}} c_{\mathbf{k}} + \sum_{\mathbf{q}} \hbar\omega_{\mathbf{q}} a^{\dagger}_{\mathbf{q}} a_{\mathbf{q}}}_{H_0} + \underbrace{\sum_{\mathbf{kq}} M_{\mathbf{q}} (a^{\dagger}_{-\mathbf{q}} + a_{\mathbf{q}}) c^{\dagger}_{\mathbf{k}+\mathbf{q}} c_{\mathbf{k}}}_{H_1}$$

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A Canonical Transformation

$$H = H_0 + H_1.$$

$$H_1 \longrightarrow \lambda H_1$$

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$$\widetilde{H} = e^{-S} H \, e^{S} \longrightarrow$$ Operador anti-Hermitiano $S^{\dagger} = -S$

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$U = \exp S$ é um operador unitário

(i.e., preserva a norma dos estados e seus autovalores)

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$$S \longrightarrow \lambda S$$

$$\widetilde{H} = H + [H, S] + \frac{1}{2!}[[H, S], S] + \frac{1}{3!}[[[H, S], S], S] + \cdots$$

$$\widetilde{H} = H_0 + H_1 + [H_0, S] + [H_1, S] + \frac{1}{2}[[H_0, S], S] + \cdots$$

$$\widetilde{H} = H_0 + H_{\mathrm{indirect}}$$

??

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$$H_1 + [H_0, S] = 0.$$

$$\langle n|S|m\rangle = \frac{\langle n|H_1|m\rangle}{E_m - E_n}$$

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O(λ²)

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&= \frac{1}{2}\sum_{\alpha}\langle f|H_1|\alpha\rangle\langle\alpha|H_1|i\rangle\left[\frac{1}{E_i - E_\alpha} + \frac{1}{E_f - E_\alpha}\right].
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$$\langle f | H_{\text{indirect}} | i \rangle = \frac{1}{2} \sum_{\alpha} \langle f | H_1 | \alpha \rangle \langle \alpha | H_1 | i \rangle \left[\frac{1}{E_i - E_\alpha} + \frac{1}{E_f - E_\alpha} \right].$$

$|i\rangle = |\boldsymbol{k}_1, \boldsymbol{k}_2, 0\rangle \qquad E_i = E(\boldsymbol{k}_1) + E(\boldsymbol{k}_2)$

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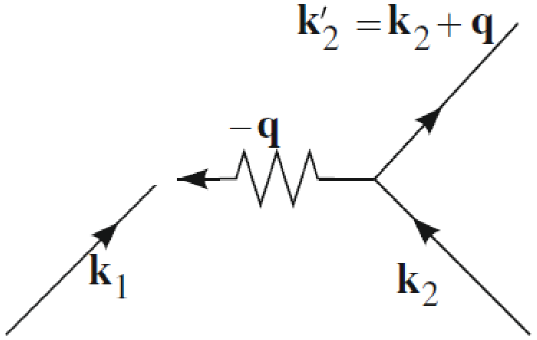

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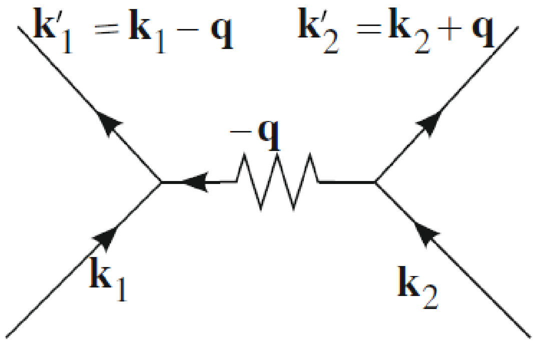
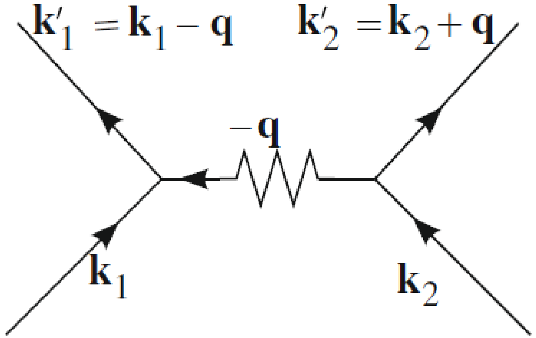


$$\langle f|H_{\text{indirect}}|i\rangle = \frac{1}{2}\sum_\alpha \langle f|H_1|\alpha\rangle\langle\alpha|H_1|i\rangle\left[\frac{1}{E_i - E_\alpha} + \frac{1}{E_f - E_\alpha}\right].$$

$|i\rangle = |\boldsymbol{k}_1, \boldsymbol{k}_2, 0\rangle \qquad E_i = E(\boldsymbol{k}_1) + E(\boldsymbol{k}_2)$

$|\alpha\rangle = |\boldsymbol{k}_1, \boldsymbol{k}'_2, 1_{-\boldsymbol{q}}\rangle \qquad E_\alpha = E(\boldsymbol{k}_1) + E(\boldsymbol{k}'_2) + \hbar\omega_{-\boldsymbol{q}}$

$|f\rangle = |\boldsymbol{k}'_1, \boldsymbol{k}'_2, 0\rangle \qquad E_f = E(\boldsymbol{k}'_1) + E(\boldsymbol{k}'_2)$



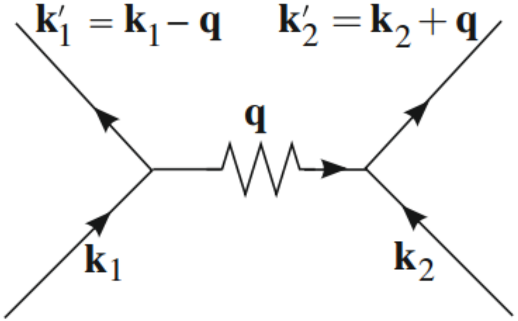
$$\langle f|H_{\mathrm{indirect}}|i\rangle = \frac{1}{2}\sum_\alpha \langle f|H_1|\alpha\rangle\langle\alpha|H_1|i\rangle\left[\frac{1}{E_i - E_\alpha} + \frac{1}{E_f - E_\alpha}\right].$$

$$\langle f|H_{\mathrm{indirect}}|i\rangle = \frac{1}{2}|M_{\mathbf{q}}|^2\left(\frac{1}{E(\boldsymbol{k}_2) - E(\boldsymbol{k}'_2) - \hbar\omega_{-\boldsymbol{q}}} + \frac{1}{E(\boldsymbol{k}'_1) - E(\boldsymbol{k}_1) - \hbar\omega_{-\boldsymbol{q}}}\right)$$

$$|i\rangle = |\boldsymbol{k}_1, \boldsymbol{k}_2, 0\rangle \qquad E_i = E(\boldsymbol{k}_1) + E(\boldsymbol{k}_2)$$

$$|\alpha\rangle = \left|\boldsymbol{k}_1, \boldsymbol{k'}_2, 1_{-\boldsymbol{q}}\right\rangle \qquad E_\alpha = E(\boldsymbol{k'}_1) + E(\boldsymbol{k}_2) + \hbar\omega_{\boldsymbol{q}}$$

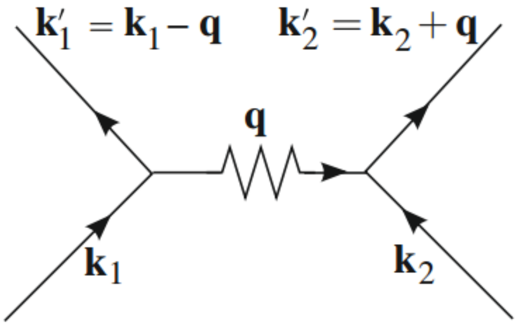
$$|f\rangle = |\boldsymbol{k'}_1, \boldsymbol{k'}_2, 0\rangle \qquad E_f = E(\boldsymbol{k'}_1) + E(\boldsymbol{k'}_2)$$



$$|i\rangle = |\boldsymbol{k}_1, \boldsymbol{k}_2, 0\rangle \qquad E_i = E(\boldsymbol{k}_1) + E(\boldsymbol{k}_2)$$

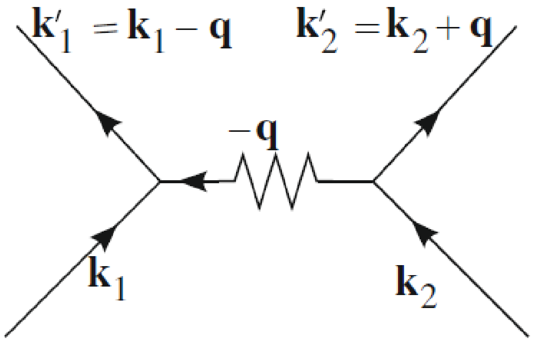
$$|\alpha\rangle = |\boldsymbol{k}_1, \boldsymbol{k}'_2, 1_{-\boldsymbol{q}}\rangle \qquad E_\alpha = E(\boldsymbol{k}'_1) + E(\boldsymbol{k}_2) + \hbar\omega_{\boldsymbol{q}}$$

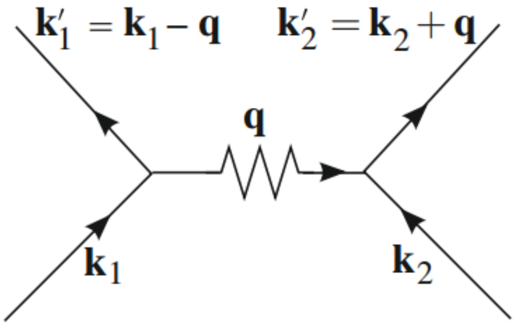
$$|f\rangle = |\boldsymbol{k}'_1, \boldsymbol{k}'_2, 0\rangle \qquad E_f = E(\boldsymbol{k}'_1) + E(\boldsymbol{k}'_2)$$



$$\langle f|H_{\text{indirect}}|i\rangle = \frac{1}{2}\sum_\alpha \langle f|H_1|\alpha\rangle\langle\alpha|H_1|i\rangle \left[\frac{1}{E_i - E_\alpha} + \frac{1}{E_f - E_\alpha}\right].$$

$$\langle f|H_{\text{indirect}}|i\rangle = \frac{1}{2}|M_{\mathbf{q}}|^2 \left(\frac{1}{E(\boldsymbol{k}_1) - E(\boldsymbol{k}'_1) - \hbar\omega_{\boldsymbol{q}}} + \frac{1}{E(\boldsymbol{k}'_2) - E(\boldsymbol{k}_2) - \hbar\omega_{\boldsymbol{q}}} \right)$$





$$\langle f|H_{\text{indirect}}|i\rangle = \frac{1}{2}|M_{\mathbf{q}}|^2 \left[\frac{1}{E(\boldsymbol{k}_1) - E(\boldsymbol{k'}_1) - \hbar\omega_{\boldsymbol{q}}} + \frac{1}{E(\boldsymbol{k'}_2) - E(\boldsymbol{k}_2) - \hbar\omega_{\boldsymbol{q}}} + \frac{1}{E(\boldsymbol{k}_2) - E(\boldsymbol{k'}_2) - \hbar\omega_{-\boldsymbol{q}}} + \frac{1}{E(\boldsymbol{k'}_1) - E(\boldsymbol{k}_1) - \hbar\omega_{-\boldsymbol{q}}} \right]$$

Sendo $\omega_{-\boldsymbol{q}} = \omega_{\boldsymbol{q}}$

$$\langle f|H_{\text{indirect}}|i\rangle = |M_{\mathbf{q}}|^2 \left[\frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}_1) - E(\mathbf{k}'_1)]^2 - \hbar^2\omega_{\mathbf{q}}^2} + \frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}'_2) - E(\mathbf{k}_2)]^2 - \hbar^2\omega_{\mathbf{q}}^2} \right]$$

Sendo $\omega_{-\boldsymbol{q}} = \omega_{\boldsymbol{q}}$

$$\langle f|H_{\text{indirect}}|i\rangle = |M_{\mathbf{q}}|^2 \left[\frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}_1) - E(\mathbf{k}_1')]^2 - \hbar^2\omega_{\mathbf{q}}^2} + \frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}_2') - E(\mathbf{k}_2)]^2 - \hbar^2\omega_{\mathbf{q}}^2} \right]$$

Para o caso de $\boldsymbol{k}_1 = -\boldsymbol{k}_2 = \boldsymbol{k}$ e $\boldsymbol{k'}_1 = -\boldsymbol{k'}_2 = \boldsymbol{k'}$

$$V_{\mathbf{k}\mathbf{k}'} = |M_{\mathbf{q}}|^2 \frac{2\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}) - E(\mathbf{k}')]^2 - \hbar^2\omega_{\mathbf{q}}^2}$$

Sendo $\omega_{-\boldsymbol{q}} = \omega_{\boldsymbol{q}}$

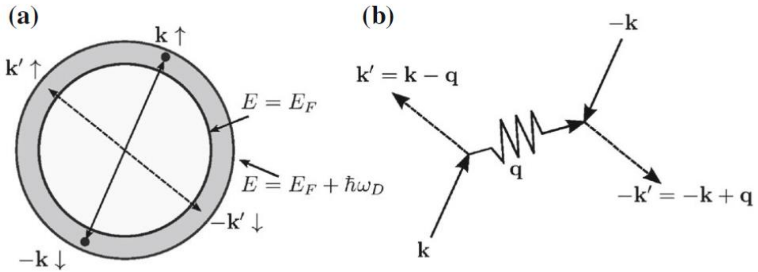
$$\langle f|H_{\text{indirect}}|i\rangle = |M_{\mathbf{q}}|^2 \left[\frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}_1) - E(\mathbf{k}_1')]^2 - \hbar^2\omega_{\mathbf{q}}^2} + \frac{\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}_2') - E(\mathbf{k}_2)]^2 - \hbar^2\omega_{\mathbf{q}}^2} \right]$$

Para o caso de $\boldsymbol{k}_1 = -\boldsymbol{k}_2 = \boldsymbol{k}$ e $\boldsymbol{k}'_1 = -\boldsymbol{k}'_2 = \boldsymbol{k}'$

$$V_{\mathbf{k}\mathbf{k}'} = |M_{\mathbf{q}}|^2 \frac{2\hbar\omega_{\mathbf{q}}}{[E(\mathbf{k}) - E(\mathbf{k}')]^2 - \hbar^2\omega_{\mathbf{q}}^2} < 0 \text{ (Atrativo)} \quad \text{se} \quad |E(\boldsymbol{k}) - E(\boldsymbol{k}')| < \hbar\omega_{\boldsymbol{D}}$$

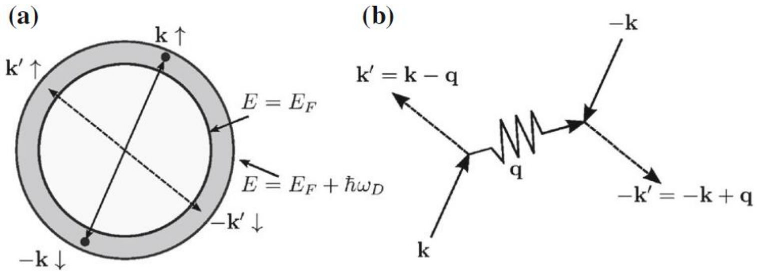
Pares de Cooper

$$\left[\frac{\mathbf{p}_1^2}{2m} + \frac{\mathbf{p}_2^2}{2m} + U(\mathbf{r}_1,\mathbf{r}_2)\right]\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2) = E\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)$$



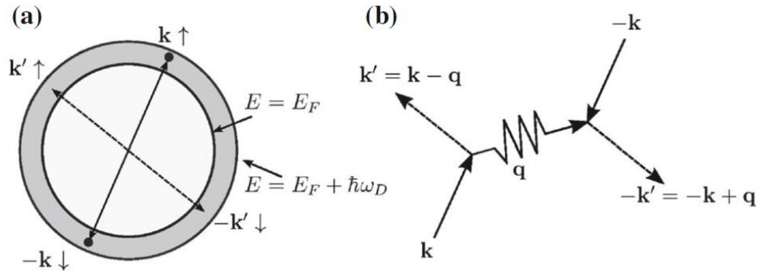
Pares de Cooper

$$\left[\frac{\mathbf{p}_1^2}{2m}+\frac{\mathbf{p}_2^2}{2m}+U(\mathbf{r}_1,\mathbf{r}_2)\right]\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)=E\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)$$



$$\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)=\phi(\mathbf{r}_1,\mathbf{r}_2)\chi(\sigma_1,\sigma_2)\,.$$

Pares de Cooper



$$\left[\frac{\mathbf{p}_1^2}{2m} + \frac{\mathbf{p}_2^2}{2m} + U(\mathbf{r}_1,\mathbf{r}_2)\right]\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2) = E\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)$$

$$\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2) = \phi(\mathbf{r}_1,\mathbf{r}_2)\chi(\sigma_1,\sigma_2).$$

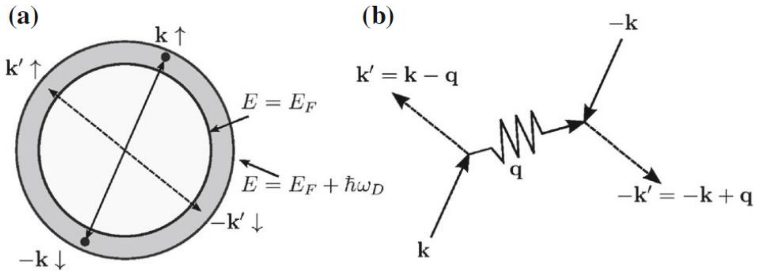
singlet

$$\chi^{(S=0)} = \frac{1}{\sqrt{2}}[\alpha(1)\beta(2) - \beta(1)\alpha(2)],$$

triplet

$$\chi^{(S=1)} = \begin{cases} \alpha(1)\alpha(2), \\ \frac{1}{\sqrt{2}}[\alpha(1)\beta(2) + \beta(1)\alpha(2)], \\ \beta(1)\beta(2), \end{cases}$$

Pares de Cooper



$$\left[\frac{\mathbf{p}_1^2}{2m}+\frac{\mathbf{p}_2^2}{2m}+U(\mathbf{r}_1,\mathbf{r}_2)\right]\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)=E\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)$$

$$\psi(\mathbf{r}_1\sigma_1,\mathbf{r}_2\sigma_2)=\phi(\mathbf{r}_1,\mathbf{r}_2)\chi(\sigma_1,\sigma_2).$$

singlet

$$\chi^{(S=0)}=\frac{1}{\sqrt{2}}[\alpha(1)\beta(2)-\beta(1)\alpha(2)],$$

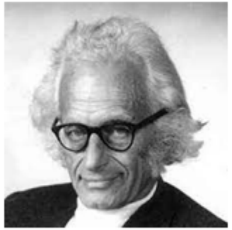
triplet

$$\chi^{(S=1)}=\begin{cases}\alpha(1)\alpha(2),\\ \frac{1}{\sqrt{2}}[\alpha(1)\beta(2)+\beta(1)\alpha(2)],\\ \beta(1)\beta(2),\end{cases}$$

$$\Delta_b=2\hbar\omega_D\exp[-2/U_0n_0].$$

Formação de pares ligados para **qualquer** acoplamento atrativo!!

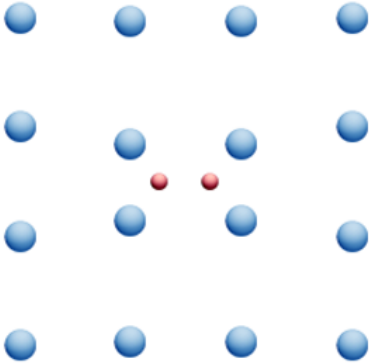
The Bardeen-Cooper-Schrieffer (BCS) theory

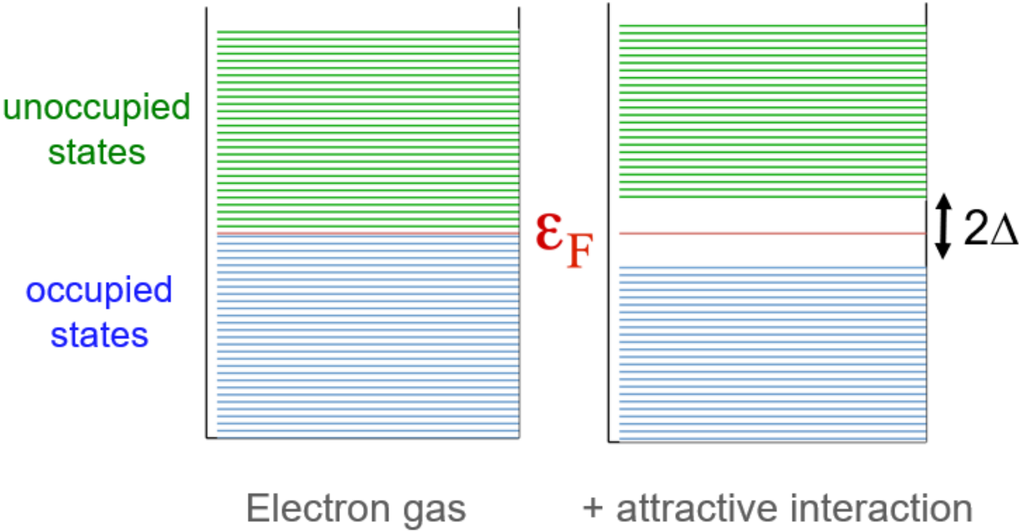


Frölich (1951): e⁻-phonon coupling may lead to an effective attractive e⁻-e⁻ interaction

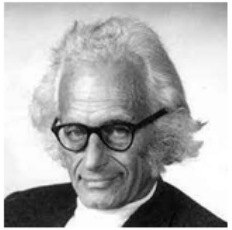
BCS (1957): electrons pair in bound state: Cooper pairs

k-space





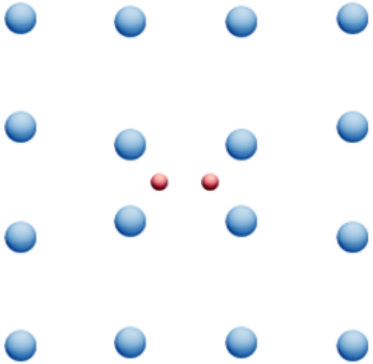
The Bardeen-Cooper-Schrieffer (BCS) theory

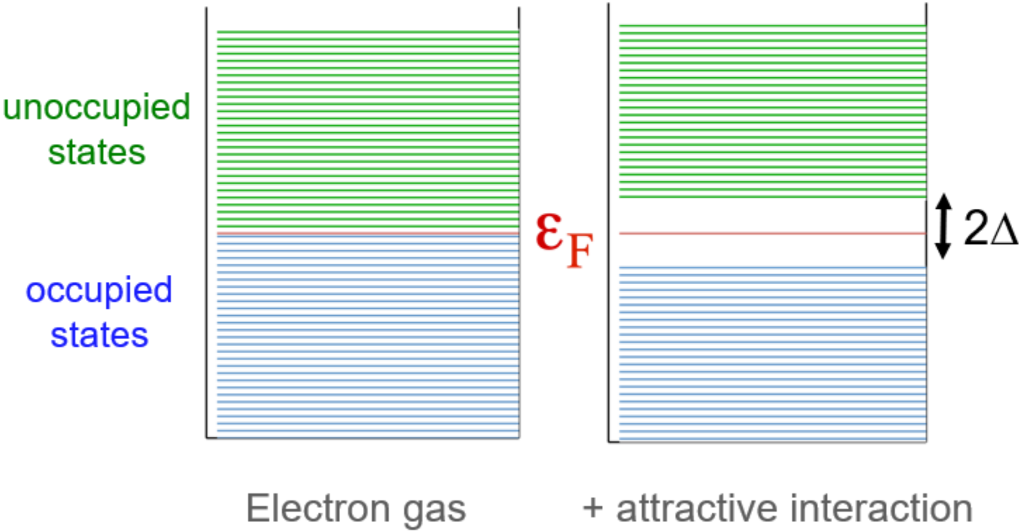


Frölich (1951): e^--phonon coupling may lead to an effective attractive e^--e^- interaction

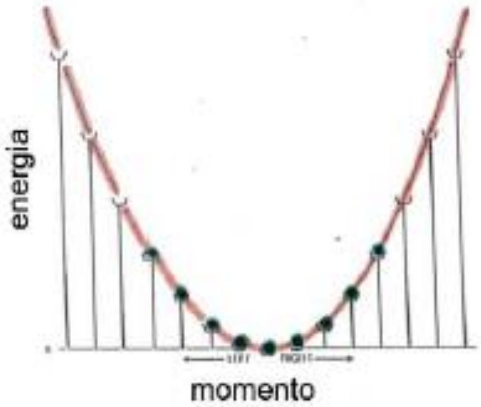
BCS (1957): electrons pair in bound state: Cooper pairs

k-space

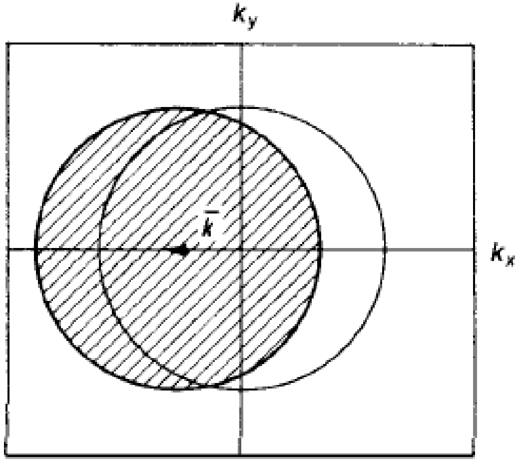


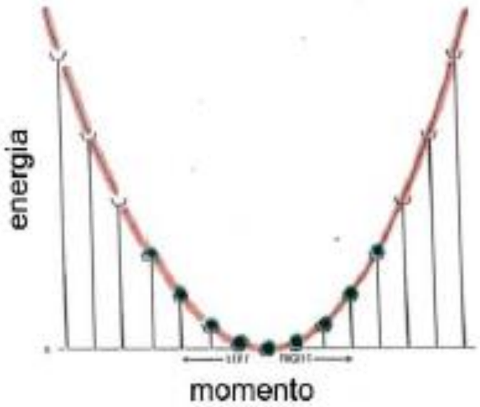


$$H_{\mathrm{BCS}} = \sum_{\mathbf{k}} \varepsilon_{\mathbf{k}} \left(c^\dagger_{\mathbf{k}\uparrow} c_{\mathbf{k}\uparrow} + c^\dagger_{-\mathbf{k}\uparrow} c_{-\mathbf{k}\uparrow} \right) + \sum_{\mathbf{k}\mathbf{k}'} U_{\mathbf{k}\mathbf{k}'} c^\dagger_{\mathbf{k}\uparrow} c^\dagger_{-\mathbf{k}\downarrow} c_{-\mathbf{k}'\downarrow} c_{\mathbf{k}'\uparrow}$$

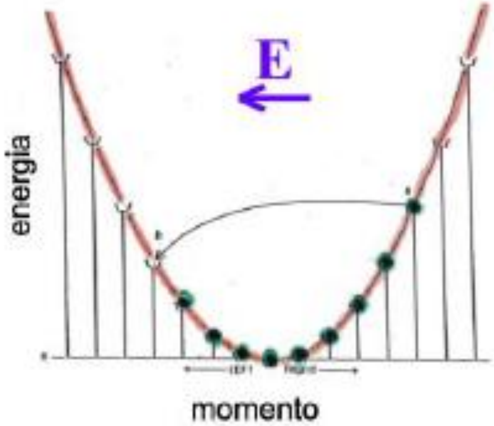


$$\sum_i \vec{k}_i = \vec{0}$$

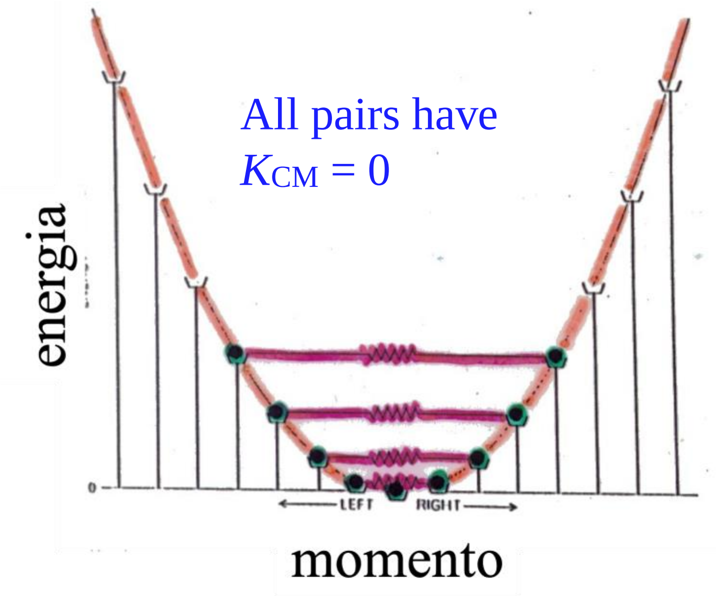




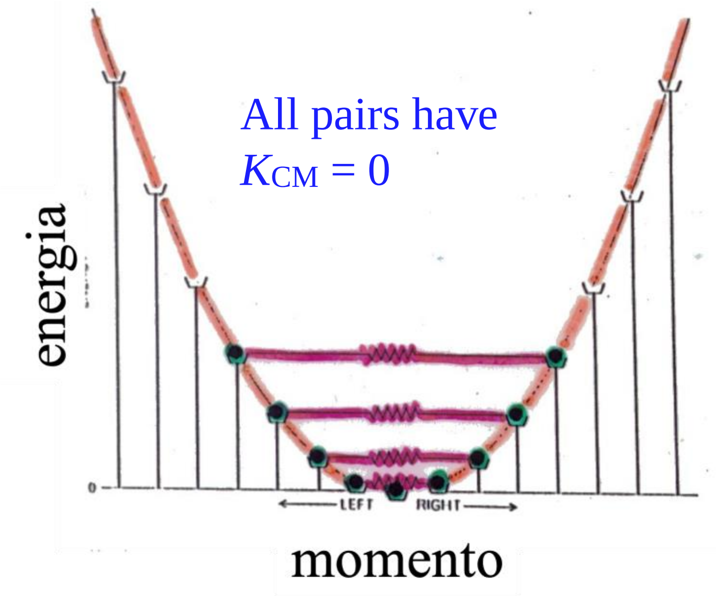
$$\sum_i \vec{k}_i = \vec{0}$$

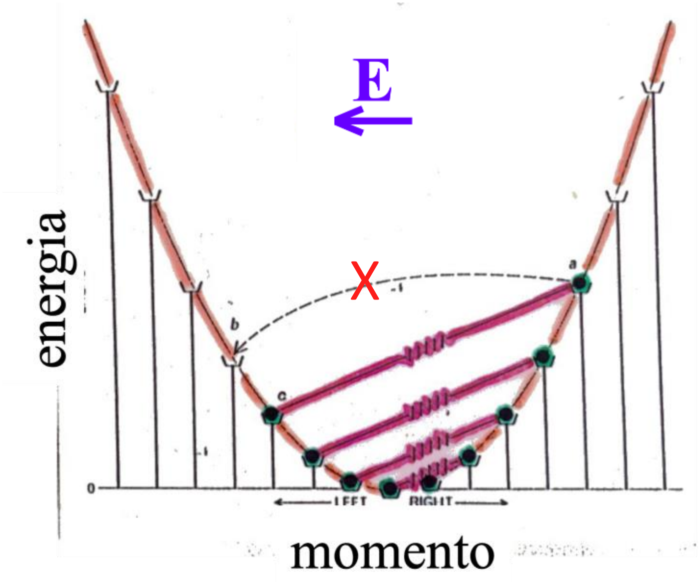


$$\sum_i \vec{k}_i \neq \vec{0} \Rightarrow \vec{J} \neq \vec{0}$$

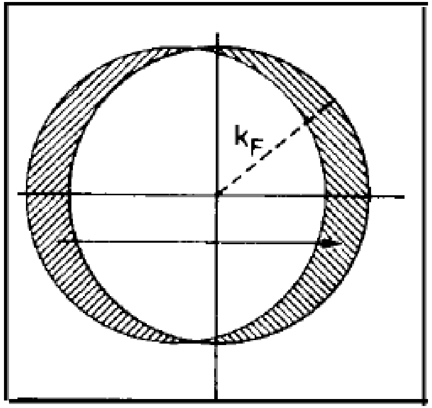


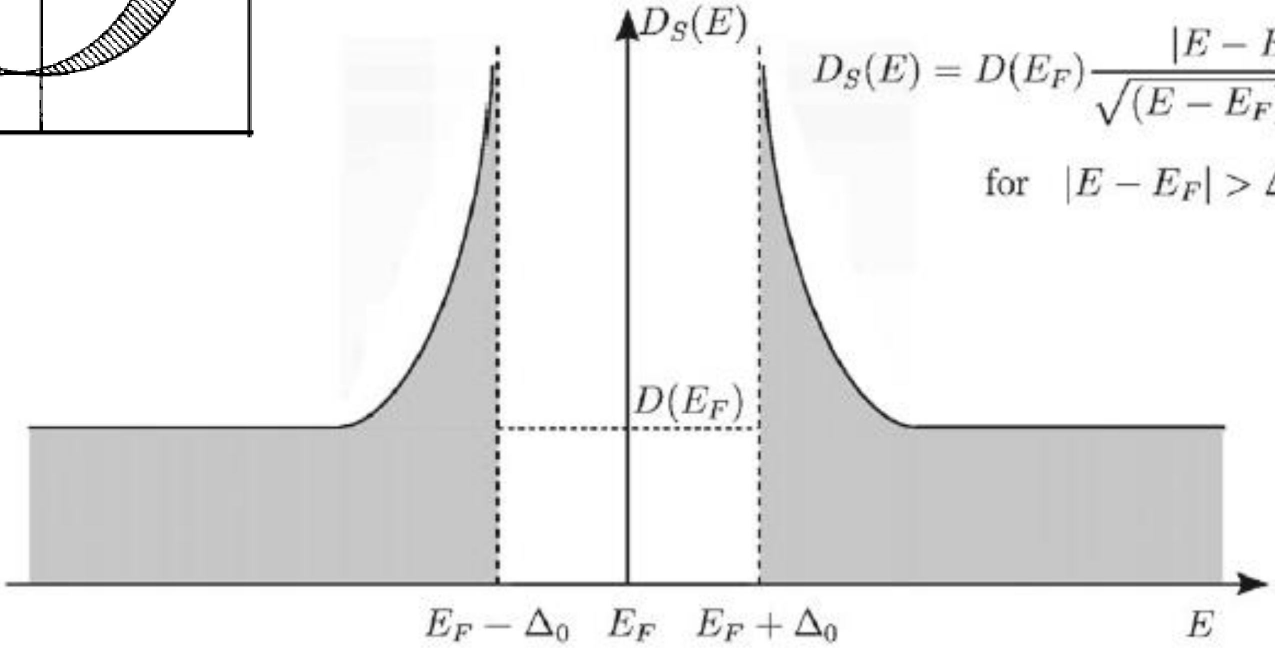
All pairs have
$K_{CM} = 0$
energia
0
LEFT
RIGHT
momento





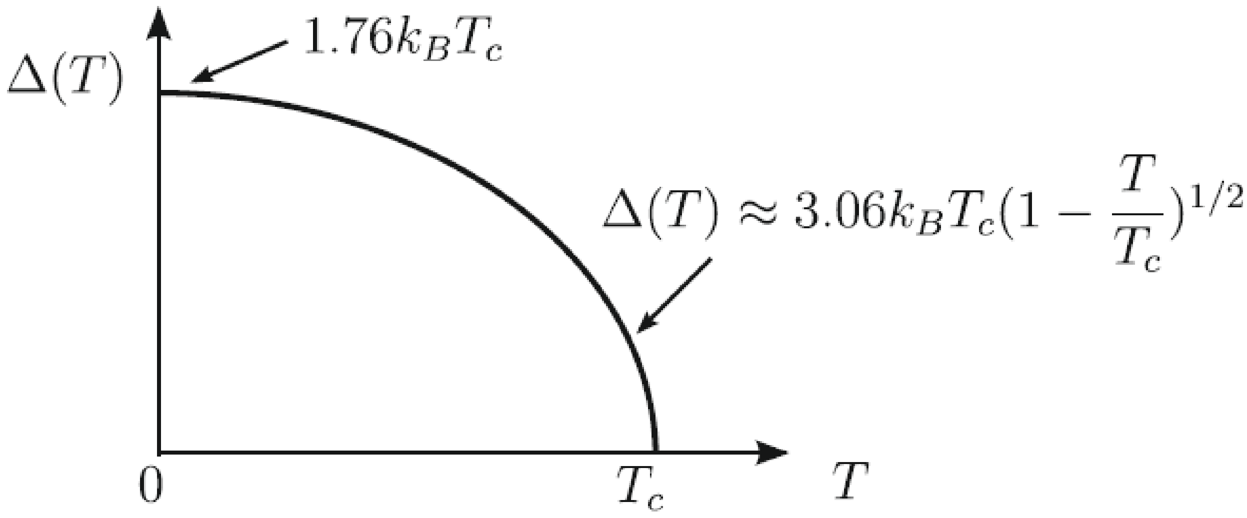
By forming pairs, electrons become imune to dissipative processes
$\Longrightarrow$ no resistance





$$D_S(E) = D(E_F)\frac{|E - E_F|}{\sqrt{(E - E_F)^2 - \Delta_0^2}}$$

for $|E - E_F| > \Delta_0$



$\Delta(T)$
$1.76 k_B T_c$
$\Delta(T) \approx 3.06 k_B T_c (1 - \frac{T}{T_c})^{1/2}$
0
T_c
T

Um pouco mais de história antes ...

The Nobel Prize in Physics

1913
Heike Kamerlingh Onnes "for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium"

1972
John Bardeen, Leon Neil Cooper and John Robert Schrieffer "for their jointly developed theory of superconductivity, usually called the BCS-theory"

1973
Leo Esaki and **Ivar Giaever** "for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively"
Brian David Josephson "for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects"

1987
J. Georg Bednorz and **K. Alexander Müller** "for their important break-through in the discovery of superconductivity in ceramic materials"

1996
David M. Lee, Douglas D. Osheroff and Robert C. Richardson "for their discovery of superfluidity in helium-3"

2003
Alexei A. Abrikosov, Vitaly L. Ginzburg and Anthony J. Leggett "for pioneering contributions to the theory of superconductors and superfluids"

The Nobel Prize in Physics

J. Georg Bednorz

K. Alexander Müller

19
H ... nes ... on the properties of matter at low temperatures which led, inter alia, to the production
of

19
Jo ... eil ... ert Schrieffer “for their jointly developed theory of superconductivity, usually called the
B

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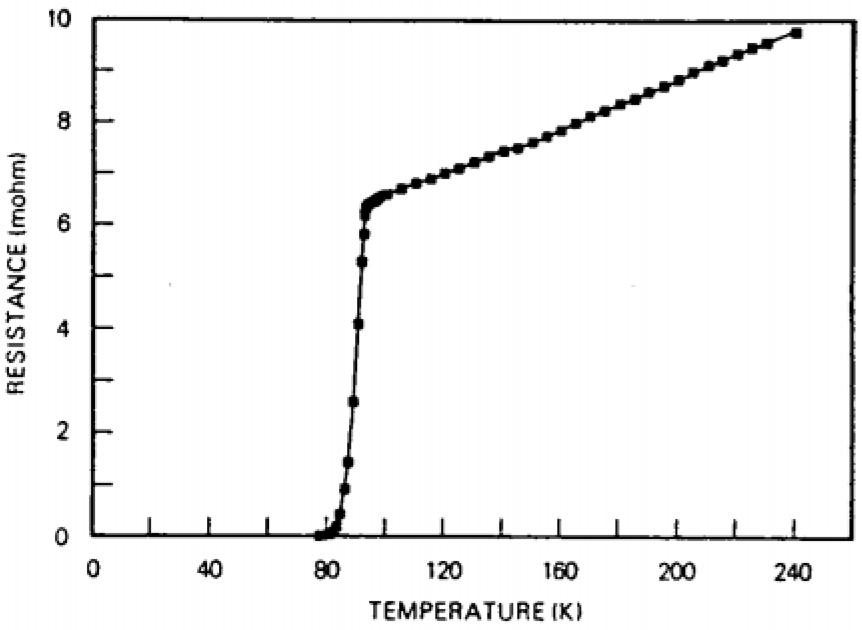

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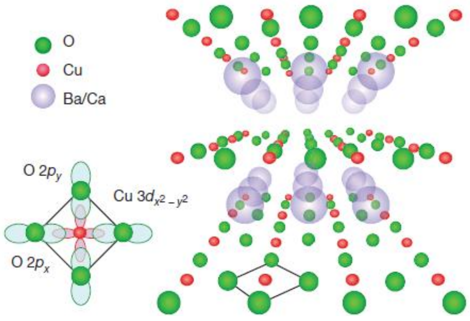
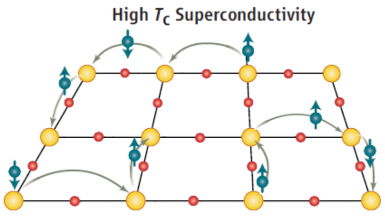
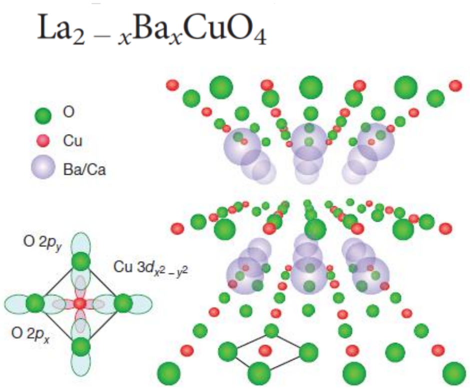
Supercondutores de alta temperatura

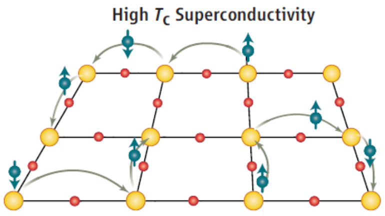
$La_{2-x}Ba_xCuO_4$

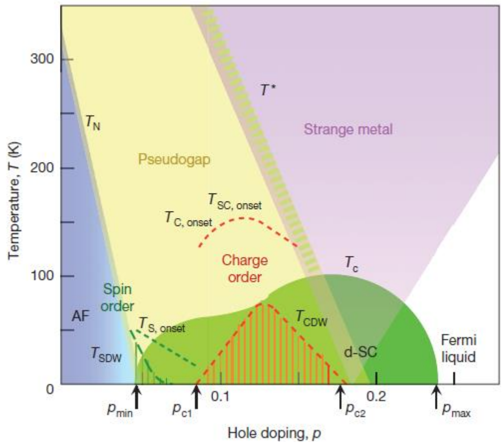




Supercondutores de alta temperatura







Supercondutores de alta temperatura

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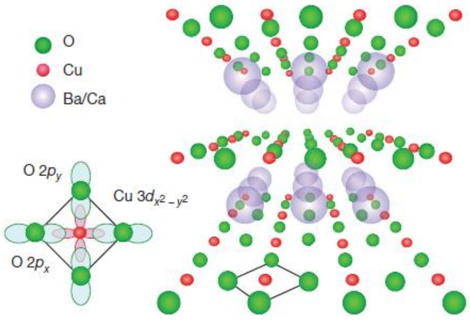
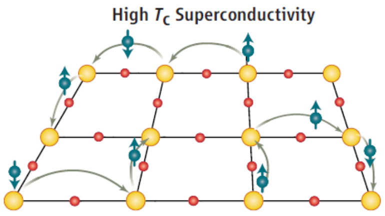
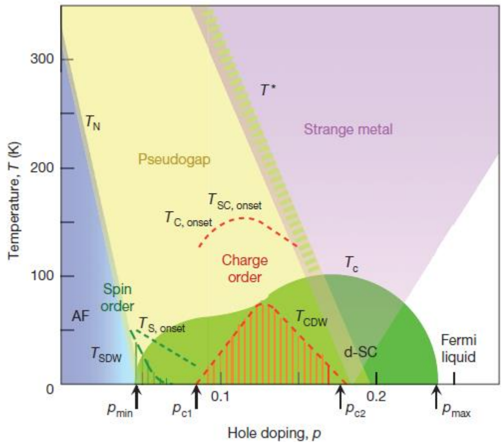
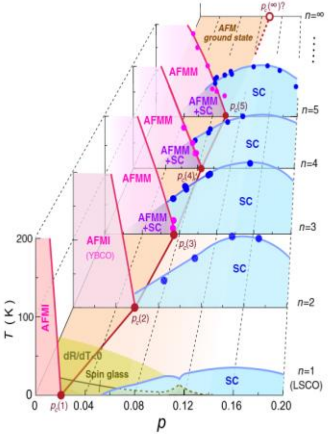
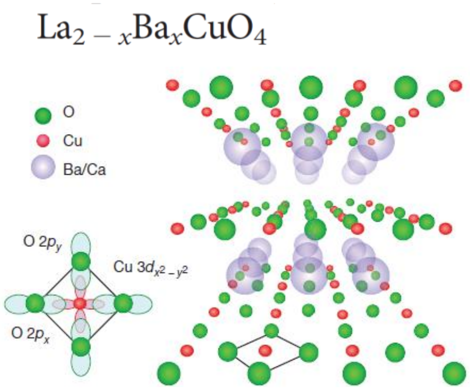


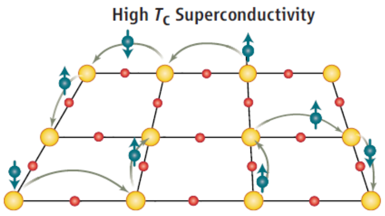


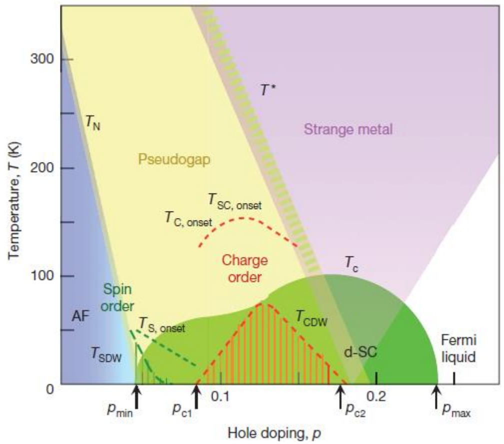


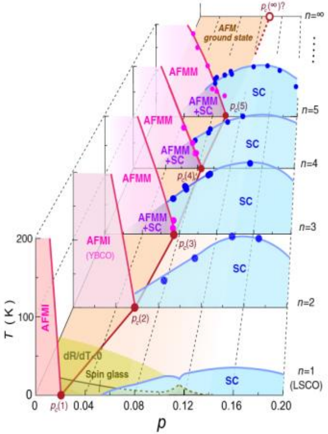


Supercondutores de alta temperatura

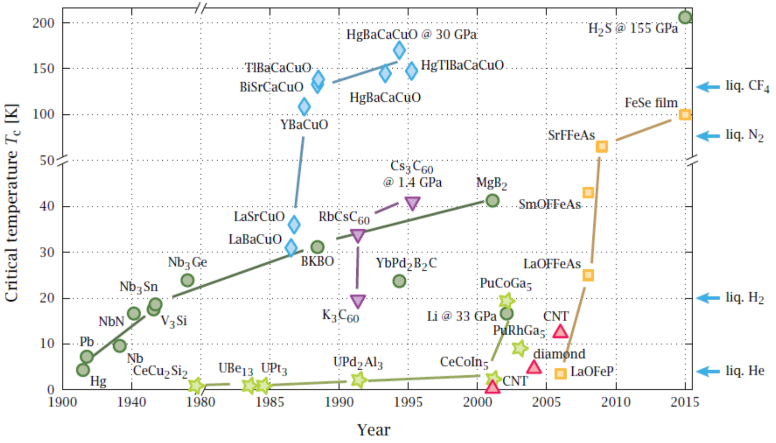






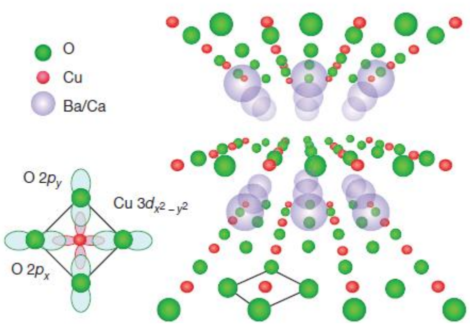


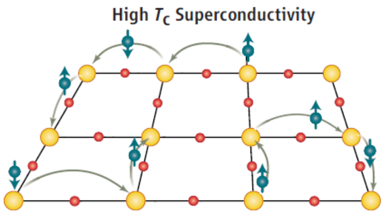
“Corrida” para aumentar Tc

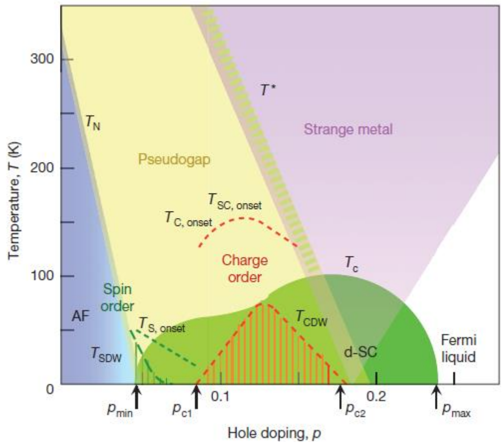


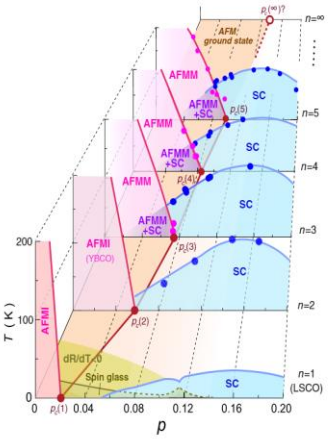
Supercondutores de alta temperatura

$La_{2-x}Ba_xCuO_4$









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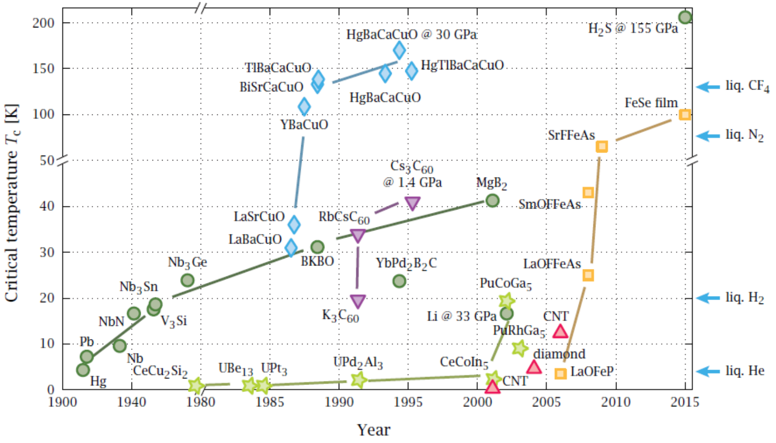
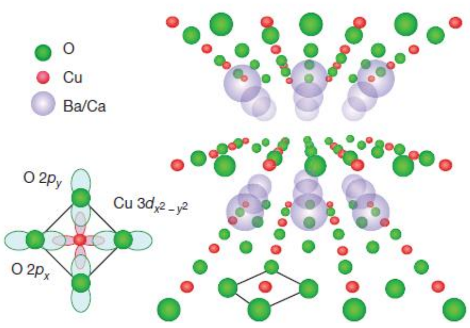
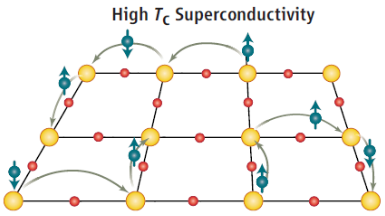


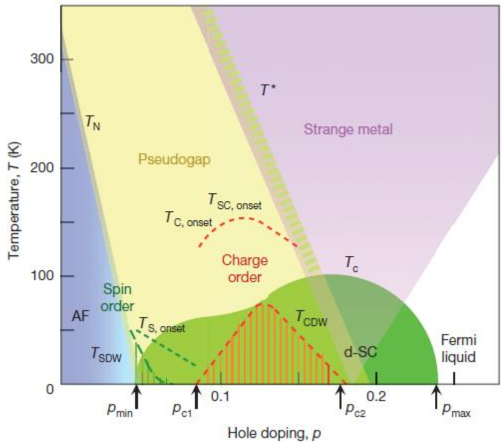
Qual é a origem microscópica de supercondutividade de altas temperaturas?

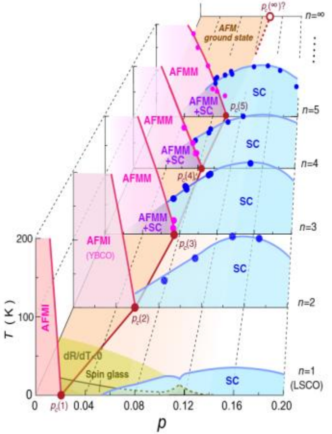
Supercondutores de alta temperatura

$La_{2-x}Ba_xCuO_4$

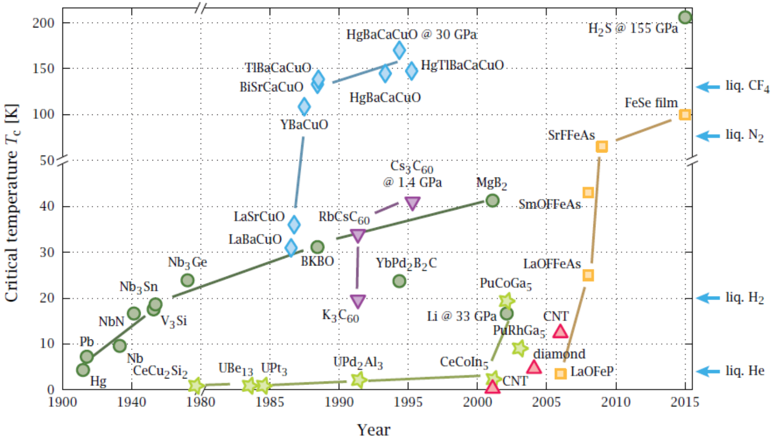








“Corrida” para aumentar Tc

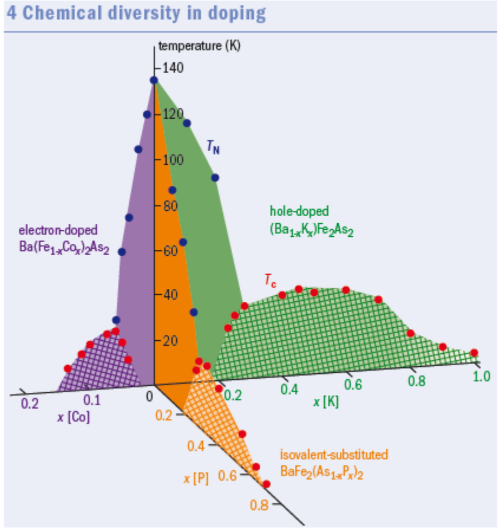


Qual é a origem microscópica de supercondutividade de altas temperaturas?

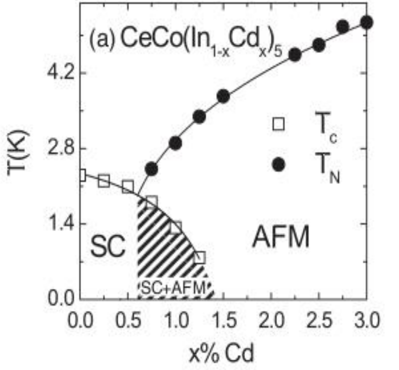
Passados 35 anos, ainda não há uma resposta para essa pergunta!!

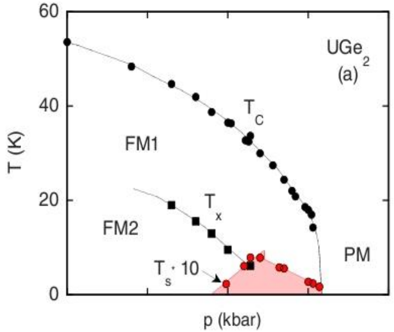
- Estados de ligação de valência
- Emparelhamento por flutuações magnéticas

Pnictides de Ferro

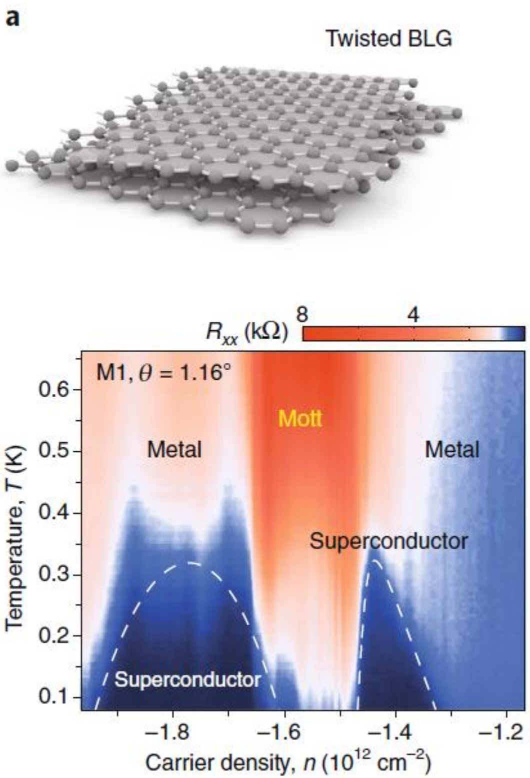


Materiais tipo Fermions pesados





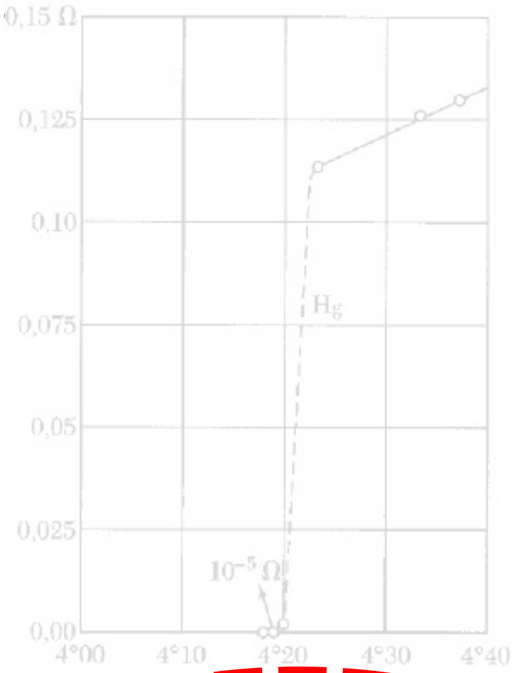
Bicamadas de Grafeno



1911 - Supercondutividade

The Nobel Prize in Physics 1913 was awarded to Heike Kamerlingh Onnes *"for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium"*.

Corrente fluindo sem perda de energia!!



"It has become more and more clear that a change in the whole theory of electrons is necessary. Theoretical work in this direction has already been begun by a number of research workers, particularly by Planck and Einstein."

‘Novos’ materiais

A compreensão microscópica da natureza de fenômenos em ‘novos’ materiais é necessária para eventuais aplicações em tecnologia.