Effetti quantistici alla basse temperature: dalla superconduttività alla superfluidità

Claudio Giannetti

Dipartimento di Matematica e Fisica, Università Cattolica, Brescia, Italy

Interdisciplinary laboratories for advanced materials physics (I-LAMP)

PROGETTO DI ECCELLENZA 2014

PERCORSI INNOVATIVI
in Matematica e in Fisica

Conferenze

UNIVERSITÀ CATTOLICA del Sacro Cuore

FONDAZIONE DELLA COMUNITÀ BRESCIANA ONLUS

Effetti quantistici alla basse temperature: dalla superconduttività alla superfluidità

- Condensazione di Bose-Einstein
- Superfluidità
- Superconduttività

meccanica quantistica
nel mondo macroscopico!

Nobel Prizes in Physics

Nobelprize.org
The Official Web Site of the Nobel Prize

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

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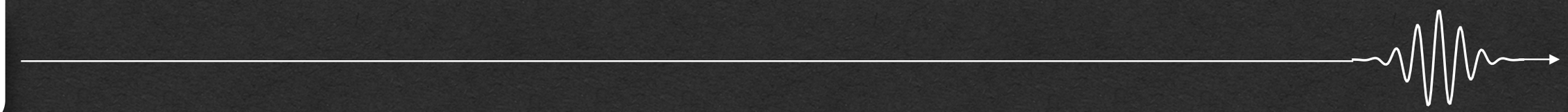

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"for their jointly developed theory of superconductivity, usually called the BCS-theory”

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•2003: A.A. Abrikosov, V.L. Ginzburg, A.J. Leggett
"for pioneering contributions to the theory of superconductors and superfluids"

•2001: E.A. Cornell, W.Ketterle, C.E. Wieman
"for the achievement of Bose-Einstein condensation in dilute gases of alkali atoms, and for early fundamental studies of the properties of the condensates”

•1997: S. Chu, C. Cohen-Tannoudji, W.D. Phillips
"for development of methods to cool and trap atoms with laser light"

•1996: D.M. Lee, D.D. Osheroff, R.C. Richardson
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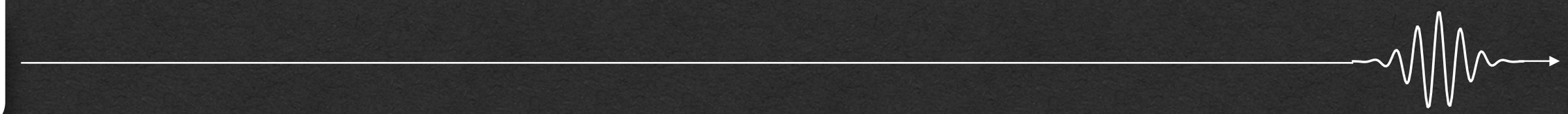
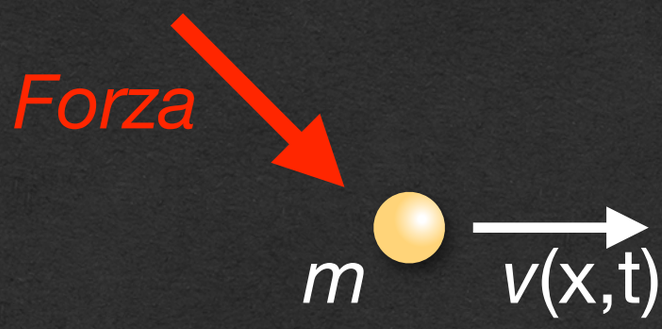


fisica classica



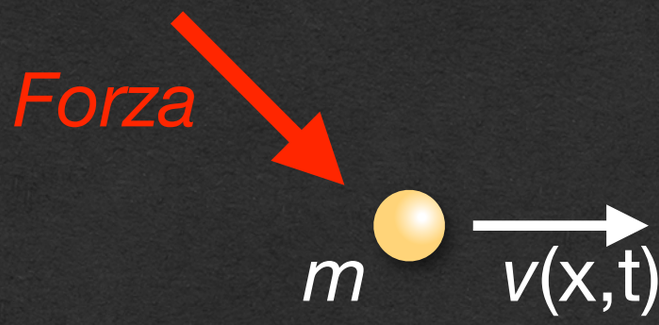
equazione del moto:

$$\vec{F} = m\,\vec{a}$$

accelerazione $\vec{a} = \dfrac{d\vec{v}}{dt}$

il mondo quantistico

fisica classica



equazione del moto:

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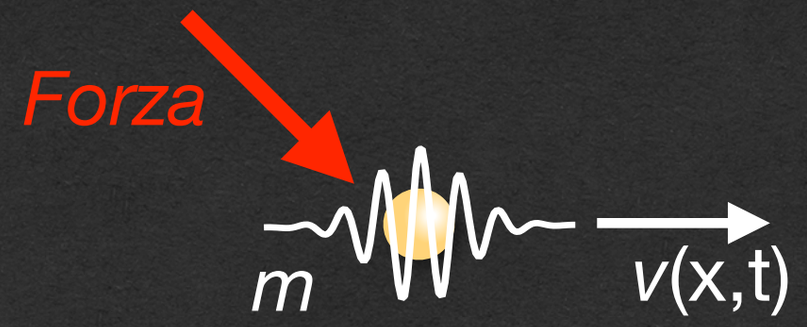
meccanica quantistica



onda $\Psi(x,t)$

equazione di Schroedinger:

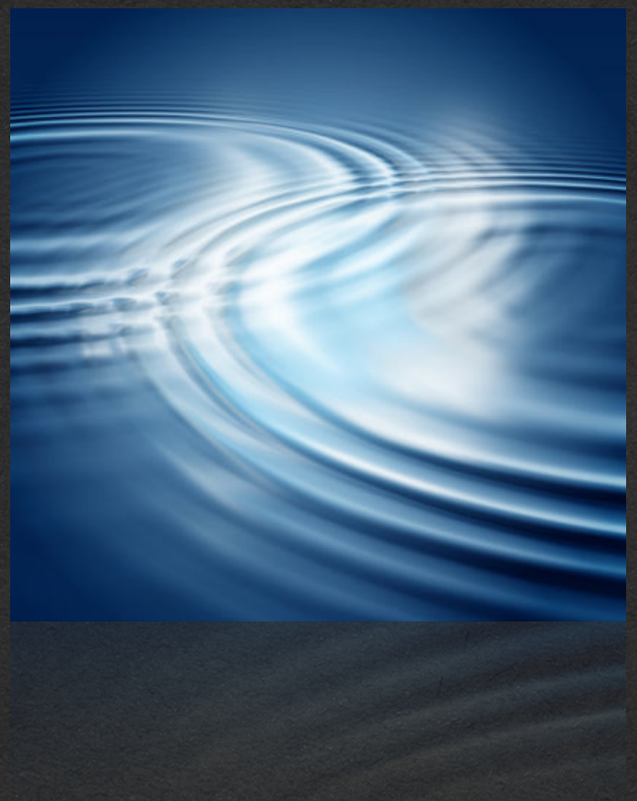
$$-\frac{\hbar^2}{2m}\frac{d^2\Psi}{dx^2} + V\Psi = E\Psi$$

forze esterne

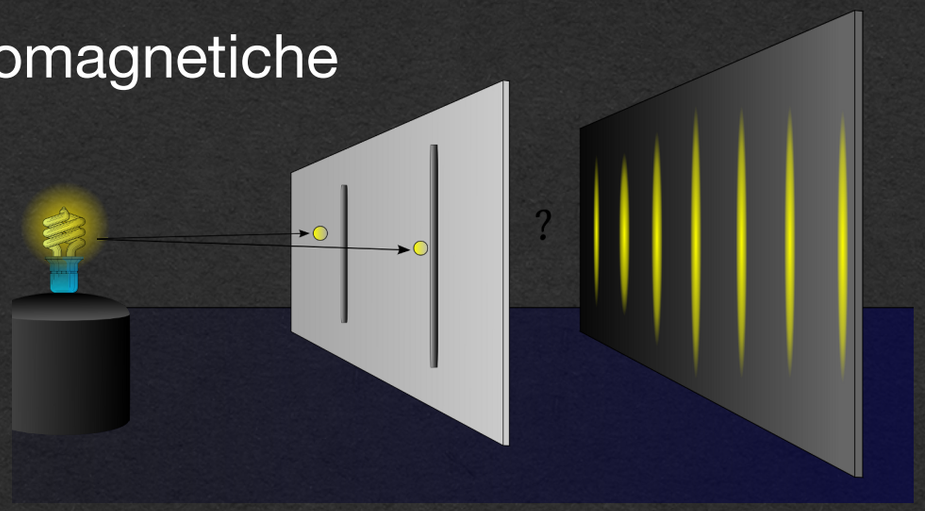
energia

il mondo quantistico

interferenza tra onde



onde
elettromagnetiche



il mondo quantistico

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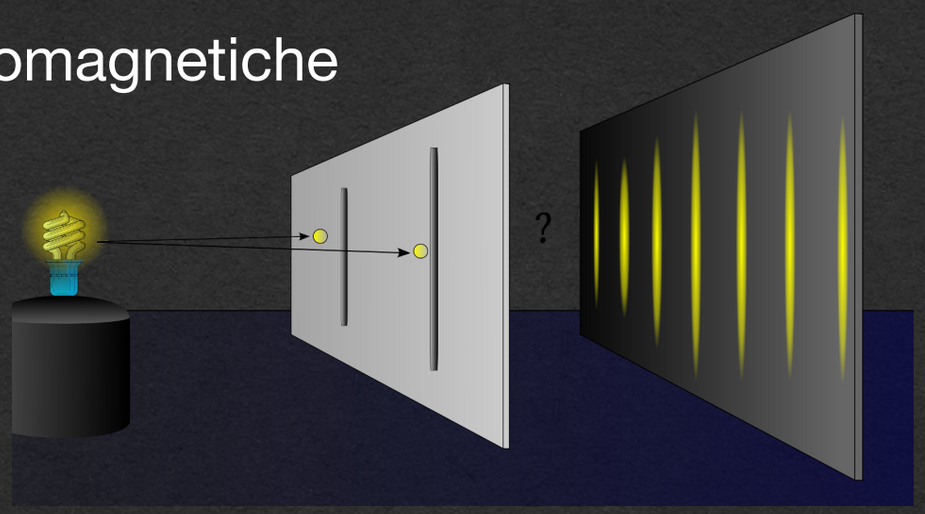
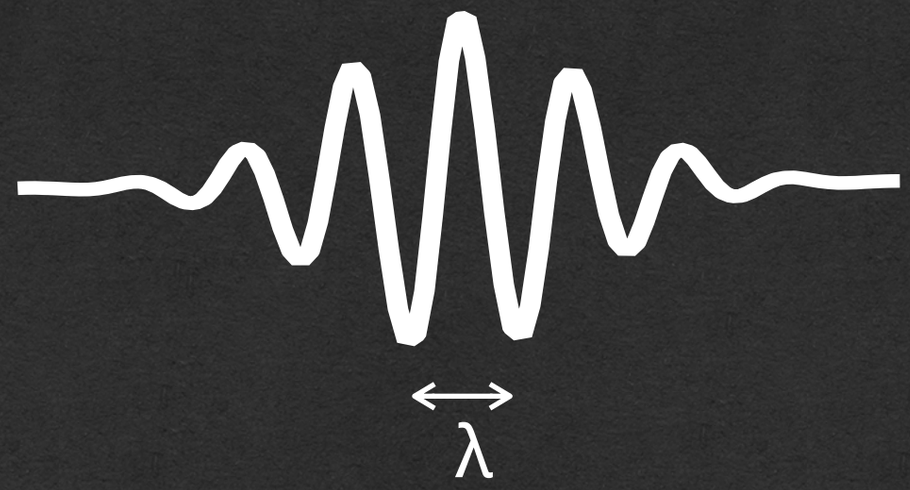


onda di materia



lunghezza d'onda
di De Broglie:

costante di Planck

$$\lambda_{DB} = \frac{h}{mv}$$

λ_{DB}= ~1 nm @ elettrone con v=5000 Km/s

~10^{-14} nm @ massa ad 1 mg con v=5000 Km/s

- Condensazione di Bose-Einstein
(predetta nel 1925→scoperta in atomi alkalini nel 1995)

- Superfluidità

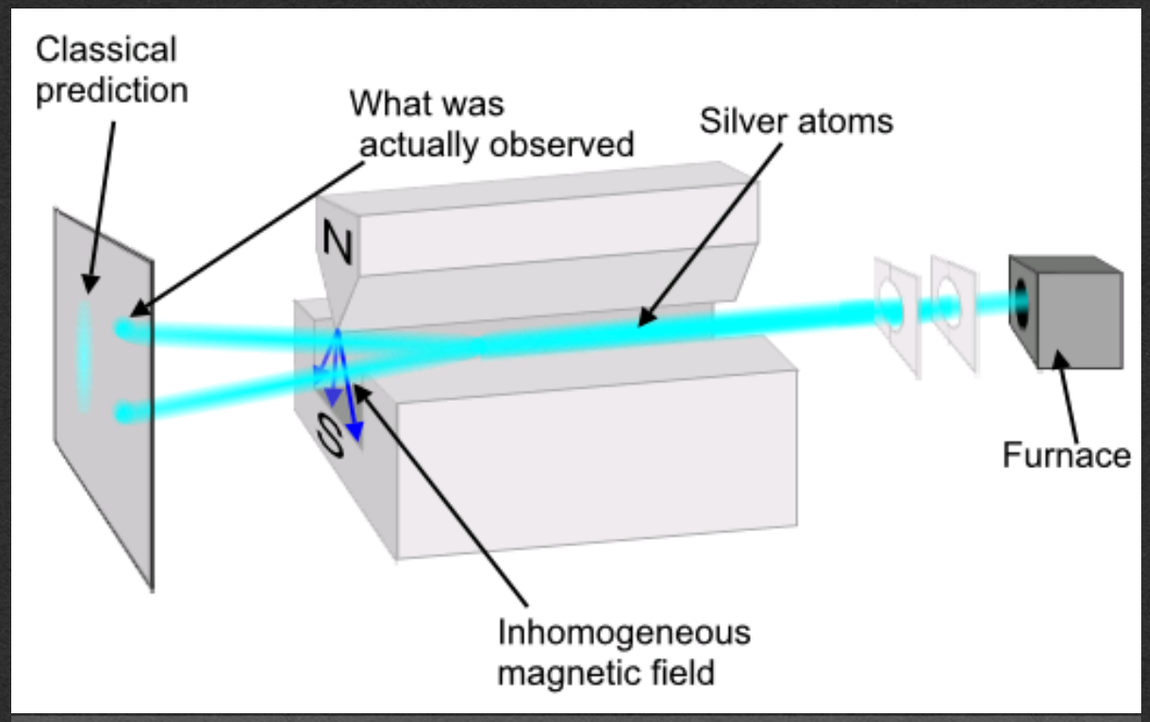
- Superconduttività

effetto macroscopico della statistica di Bose-Einstein

BOSONE = particella spin intero (fotone, fonone, atomi alkalini, bosone di Higgs, ecc.)

FERMIONE = particella spin semi-intero (elettrone, protone, ecc.)

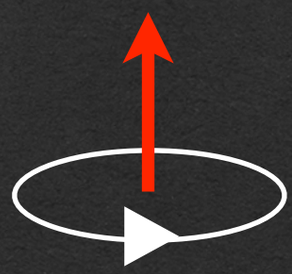
esperimento di Stern-Gerlach (1922)



particella quantistica

- elettrone: S=1/2
- atomi: J_{tot} (momento magnetico totale)

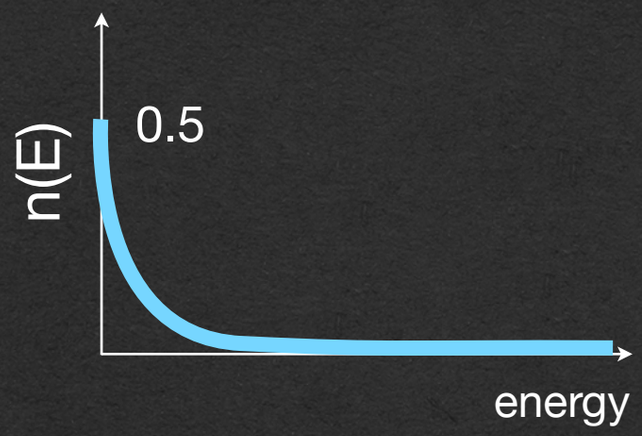
analogo classico



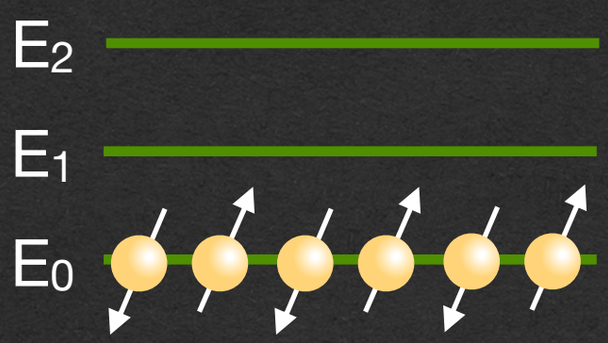
momento magnetico di un circuito percorso da corrente

statistiche quantistiche

Bose-Einstein distribution

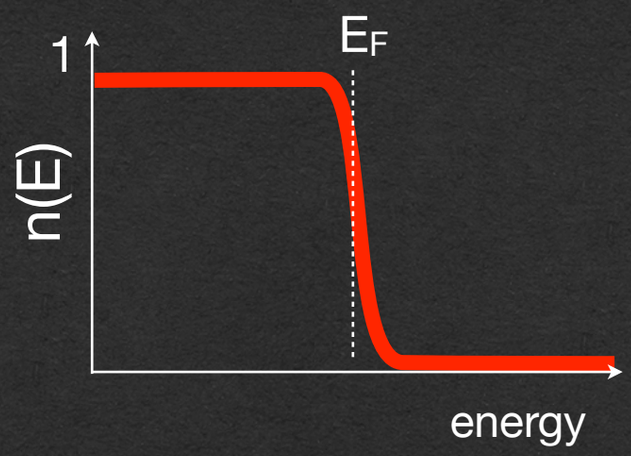


bosoni

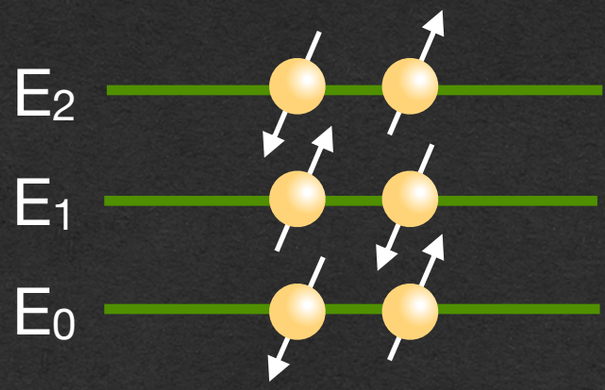


Condensazione di Bose-Einstein
predetta nel 1925 da A. Einstein

Fermi-Dirac distribution

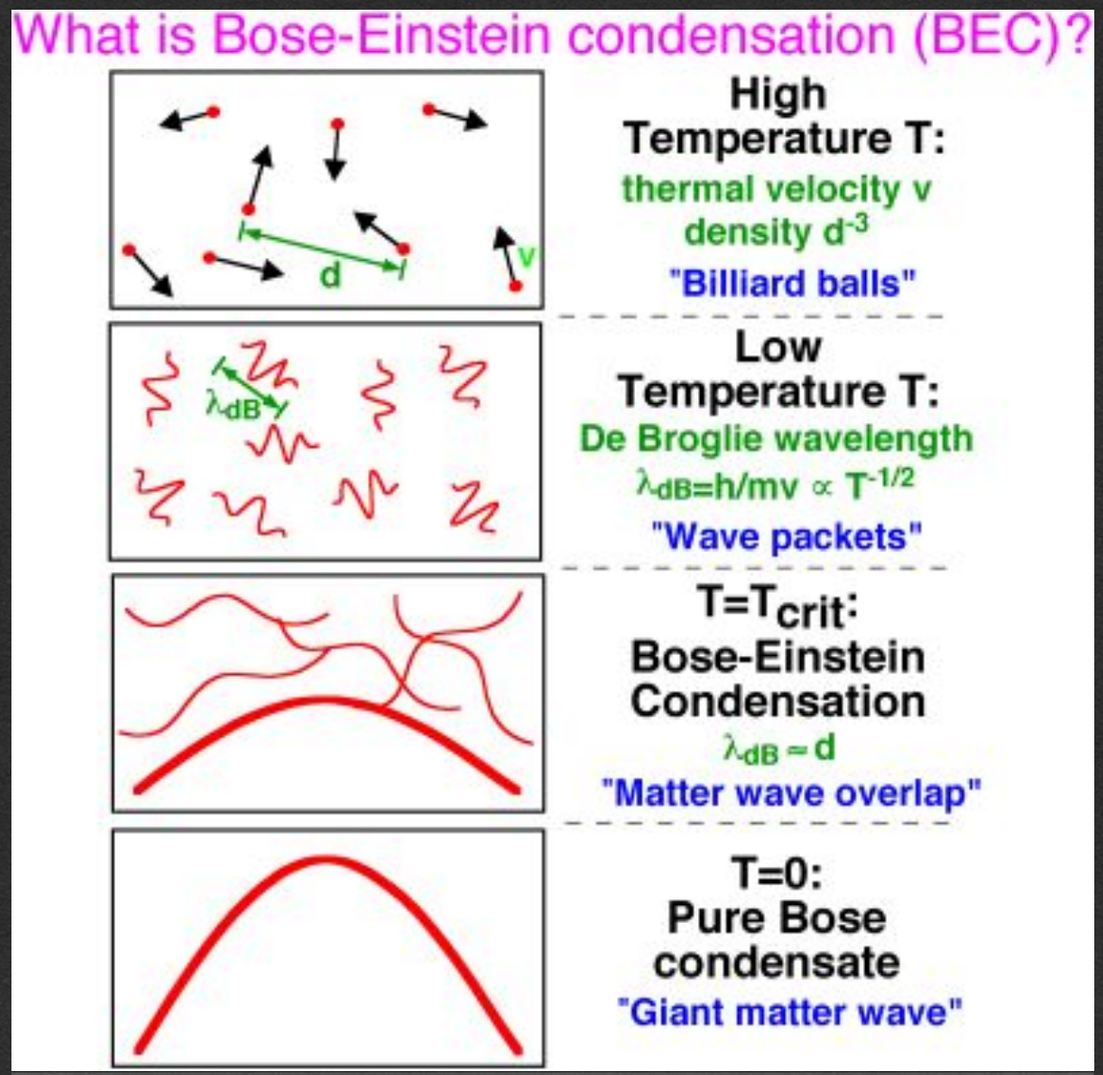


fermioni



condensazione di Bose-Einstein

W. Ketterle Nobel Lecture 2001



classicamente:

energia cinetica particella

$$\frac{1}{2}mv^2 = \frac{3}{2}K_B T$$

energia termica

condensazione di Bose-Einstein

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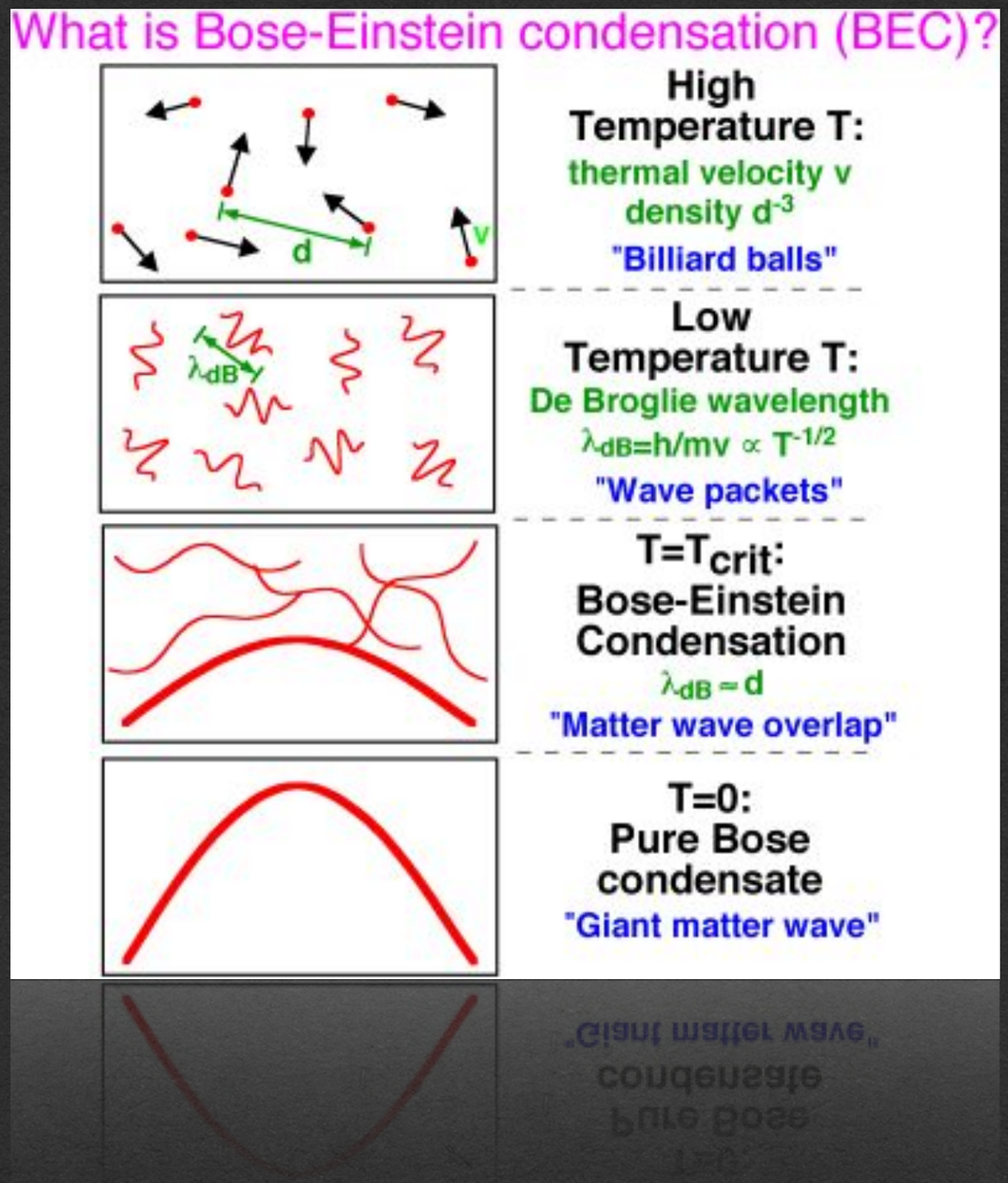

classicamente:

energia cinetica particella $\frac{1}{2}mv^2 = \frac{3}{2}K_B T$ energia termica

lunghezza d'onda di de Broglie:

cost. Planck

$$\lambda_{DB} = \frac{h}{mv} \propto \frac{1}{\sqrt{T}}$$

condensazione di Bose-Einstein

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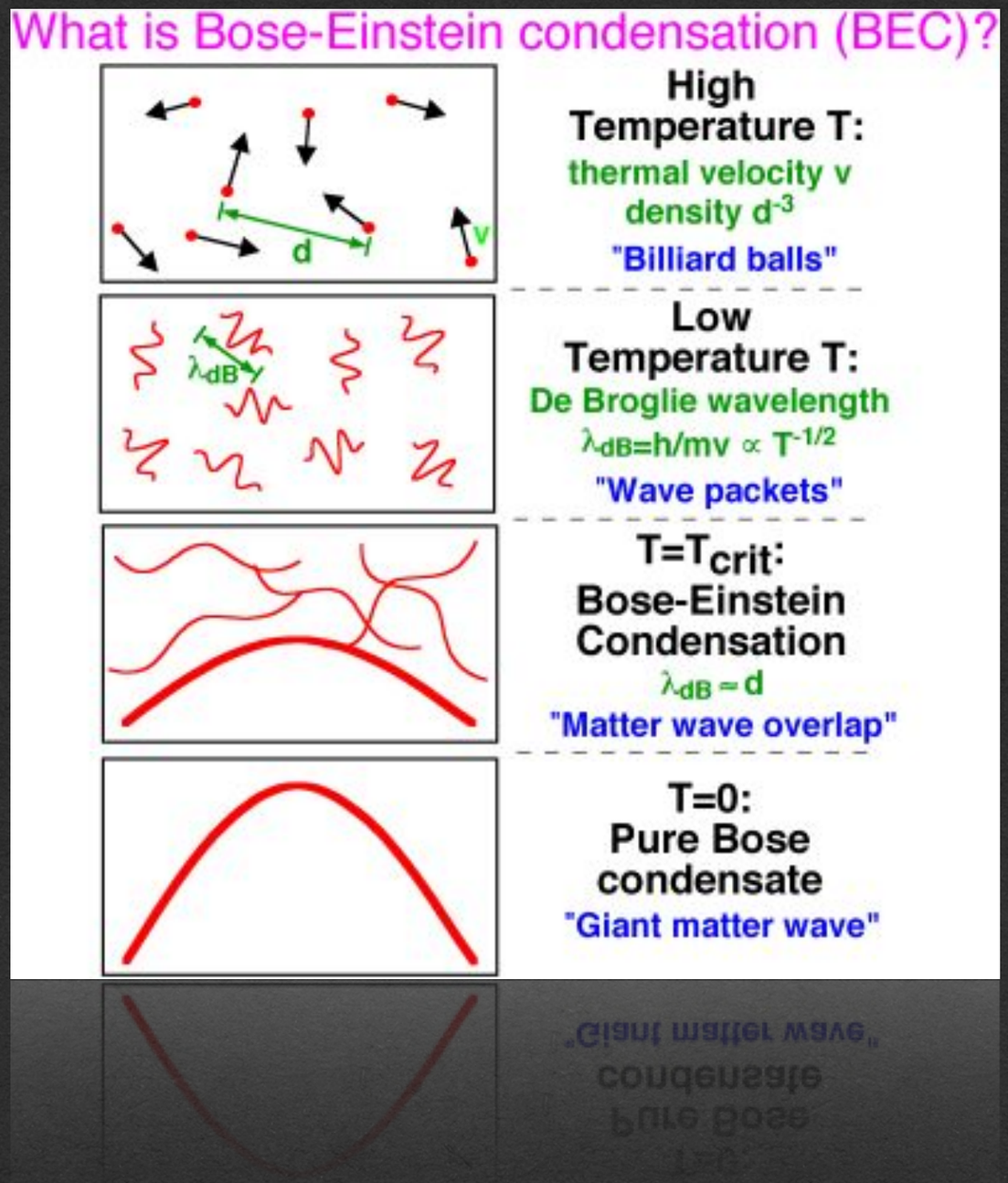

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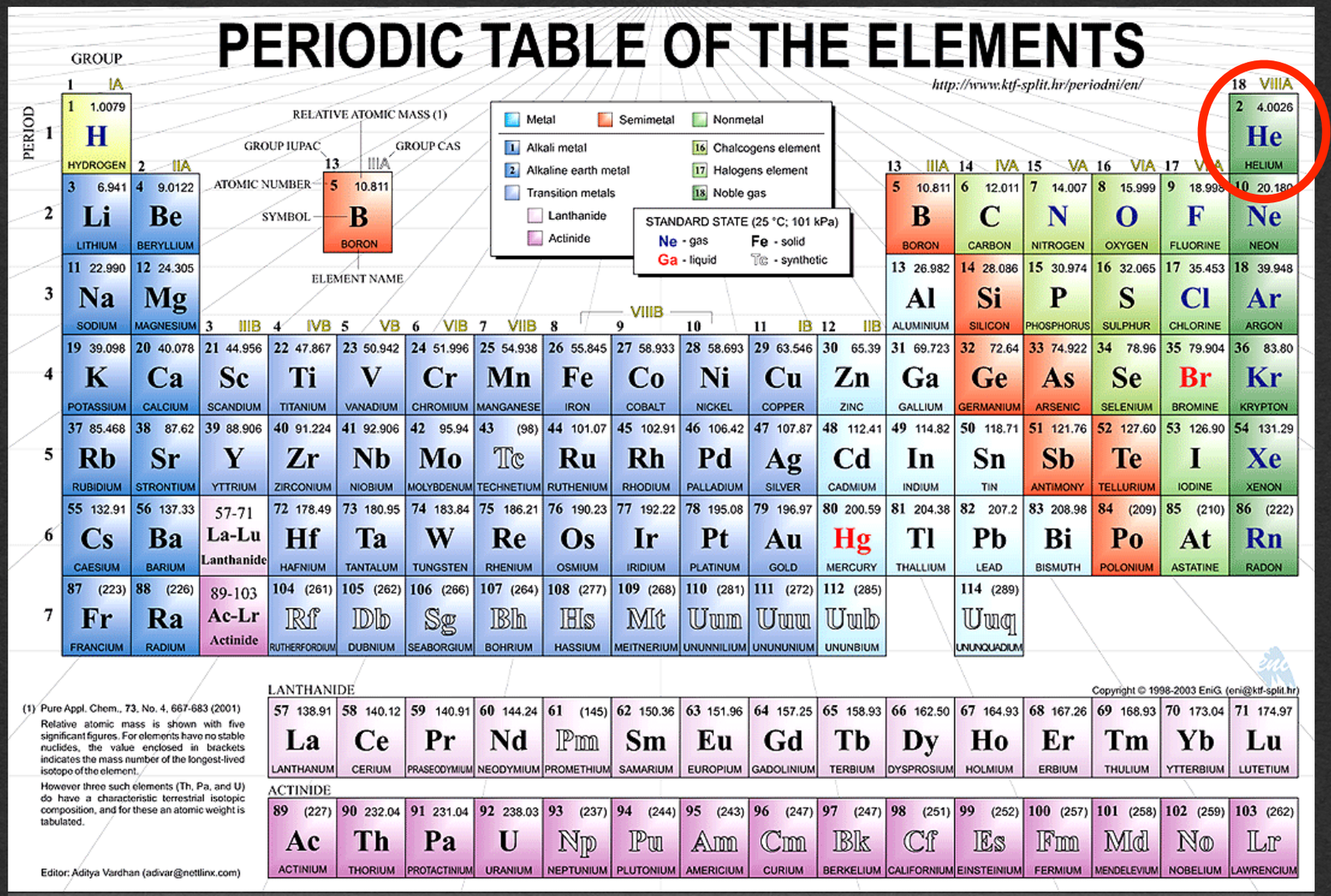
temperatura di condensazione:

densità

$$T_c = \frac{2\pi\hbar^2}{k_B m}\left(\frac{n}{2.6}\right)^{2/3}$$

massa della particella

bosoni nella tavola degli elementi



^{4}He → J=0

T_c=3.1 K

in 1913 liquefazione di ^{4}He a T≈4 K
K. Onnes (Nobel Prize)

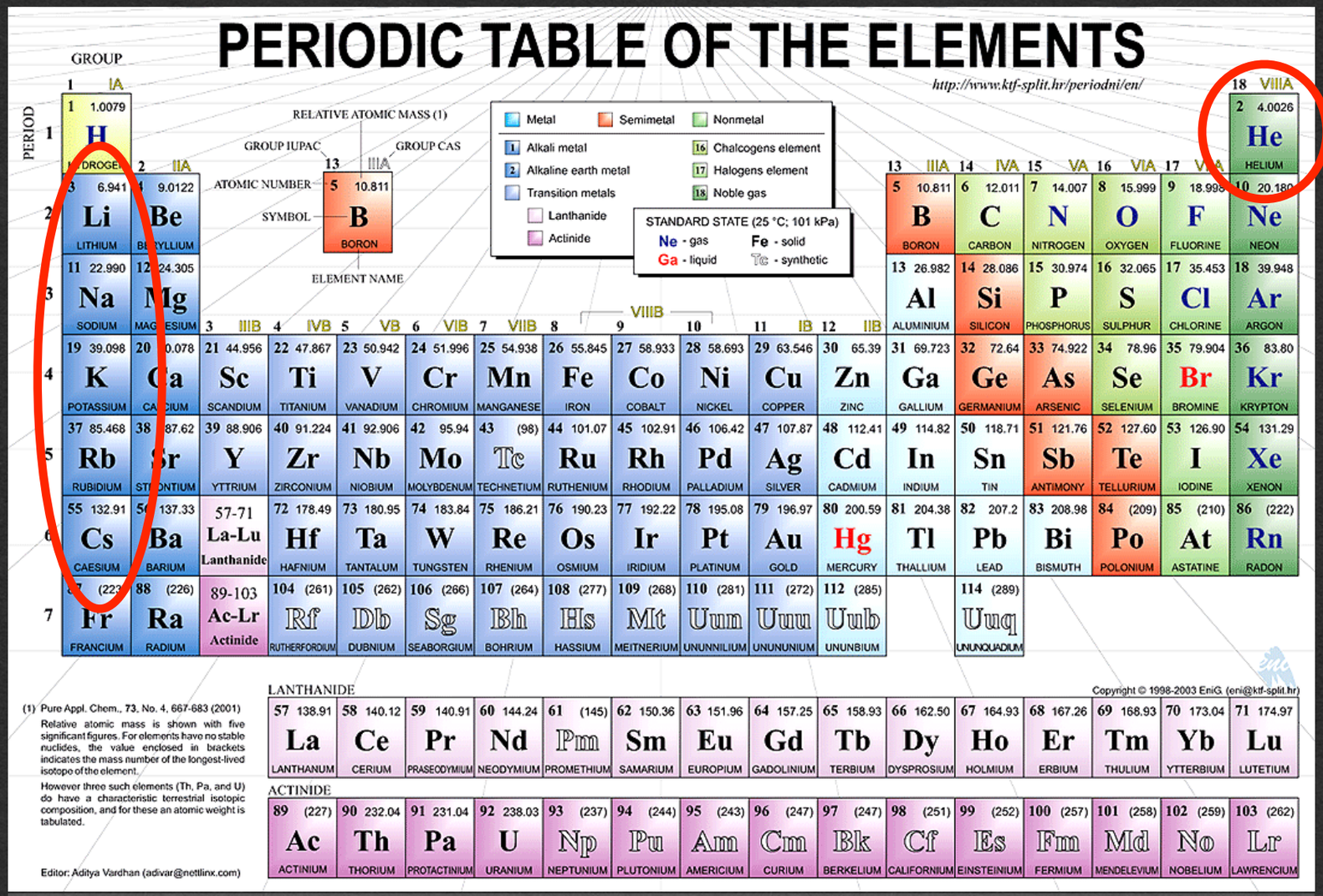
ma atomi fortemente interagenti!!

bosoni nella tavola degli elementi

atomi alkalini

T_c=10 nK-1 μK

ma atomi debolmente interagenti!!



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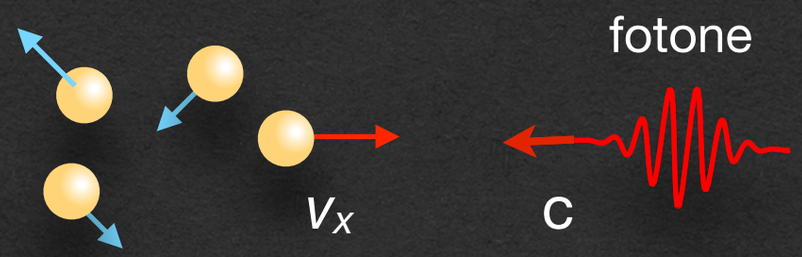
vicini allo zero assoluto!

laser cooling
(effetto Doppler) $\nu' = \nu(1 + \frac{v_x}{c})$



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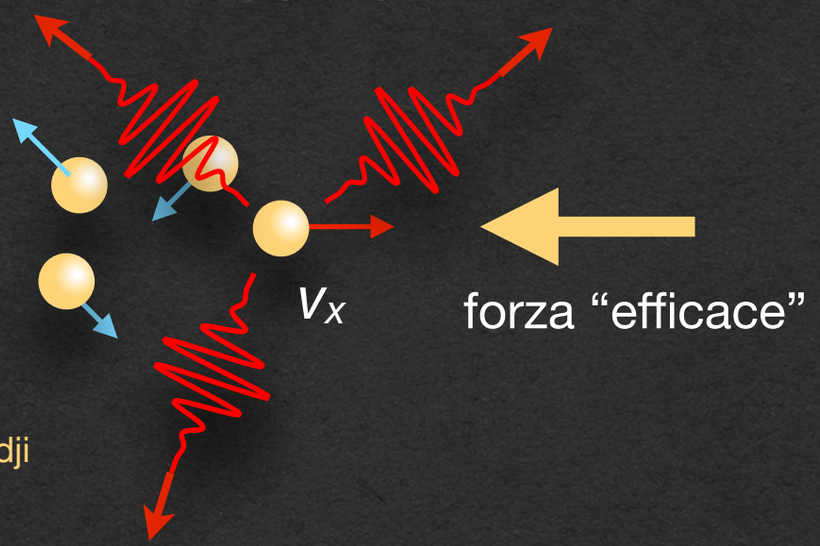
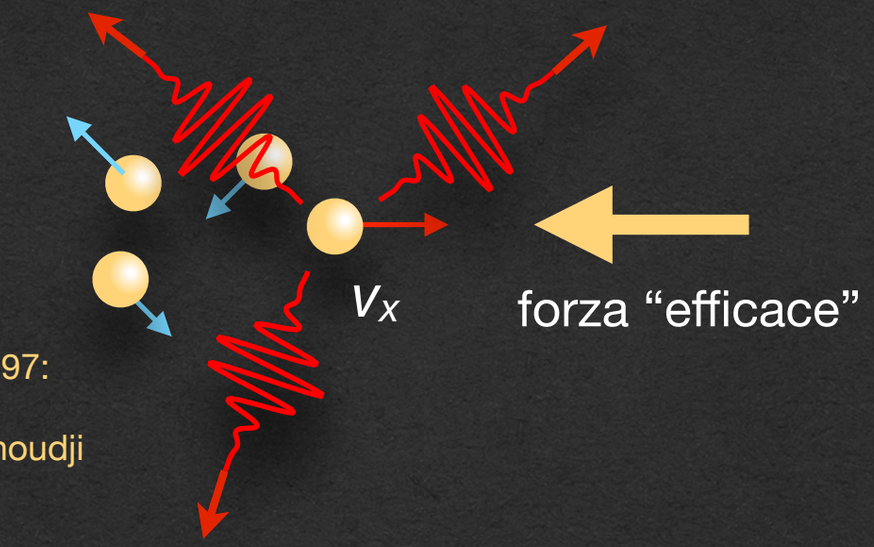


Nobel Prize 1997:
S. Chu
C. Cohen-Tannoudji
W.D. Phillips

fino a <100 μK
(0.0001 K)

vicini allo zero assoluto!

laser cooling
(effetto Doppler)



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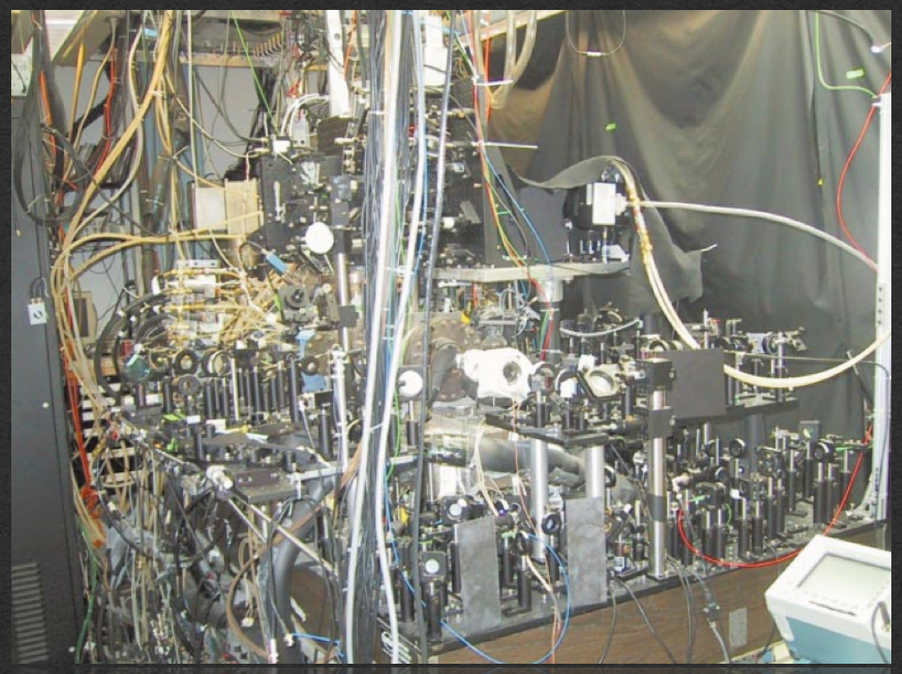

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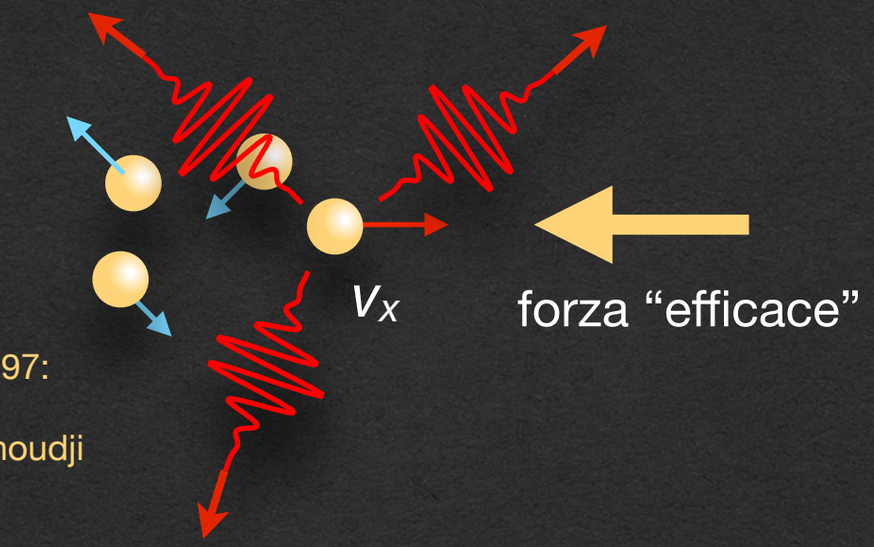

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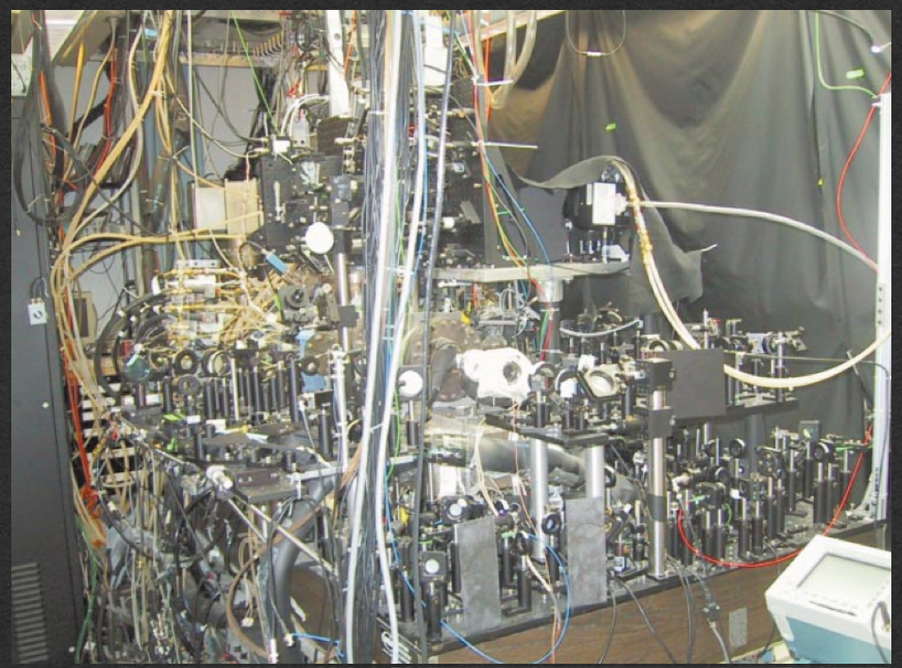
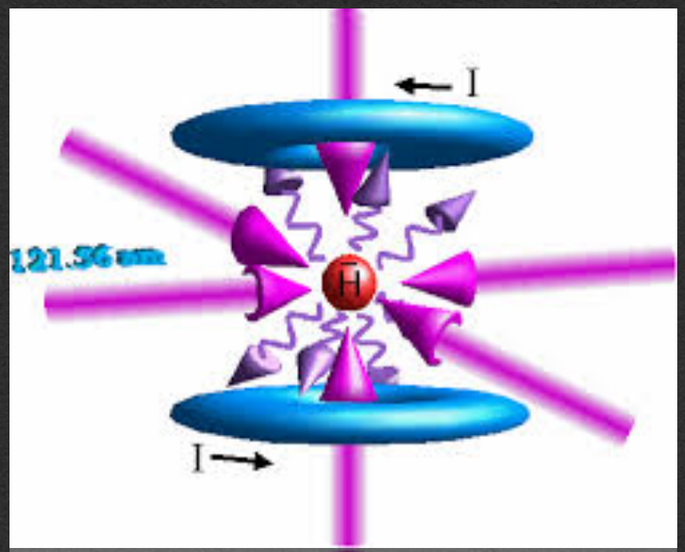
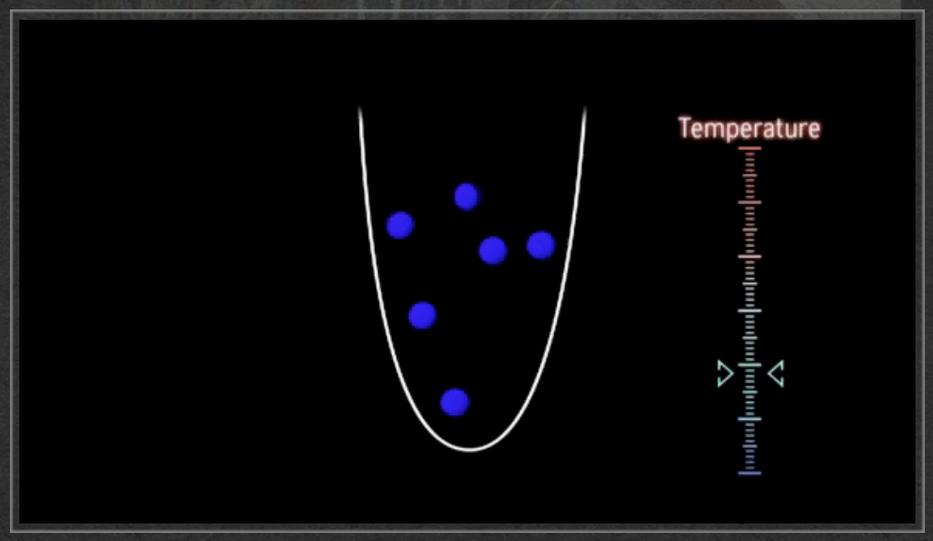


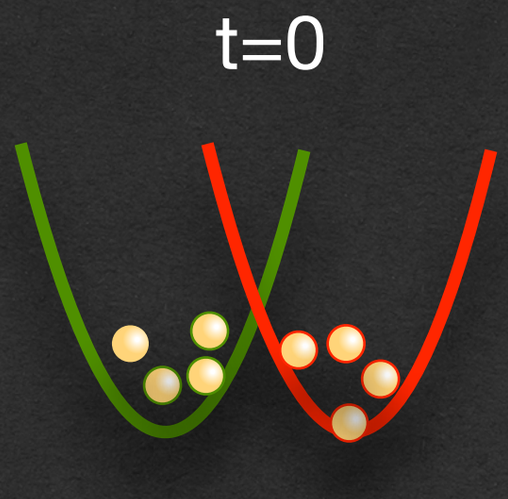
trappola magnetica e evaporazione

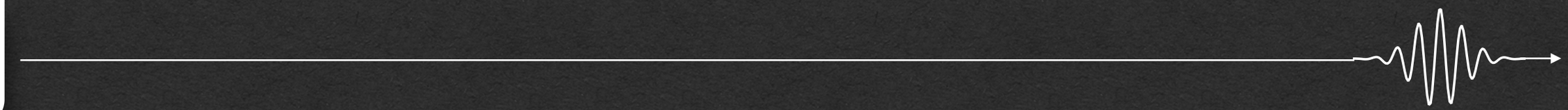


fino a <1 μK
(0.000001 K)



materia come onde





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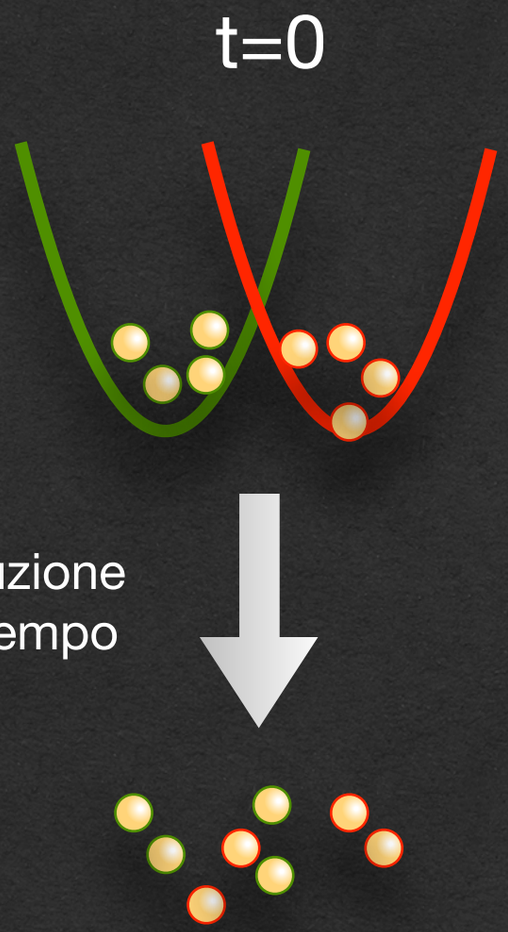
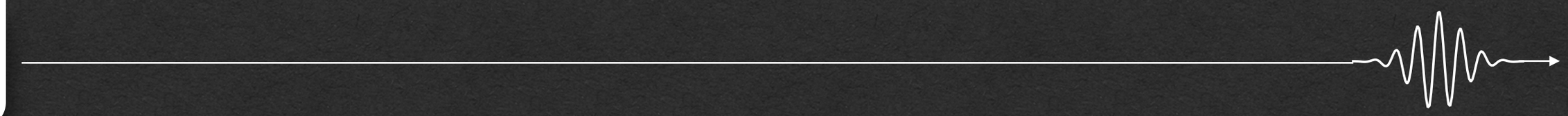
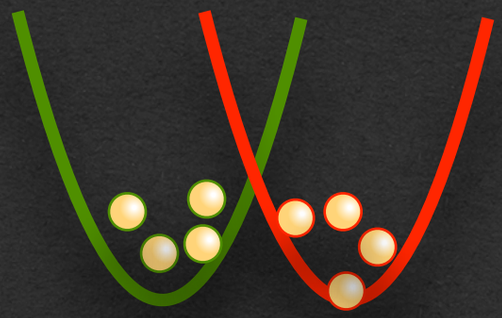


onde o particelle?



materia come onde

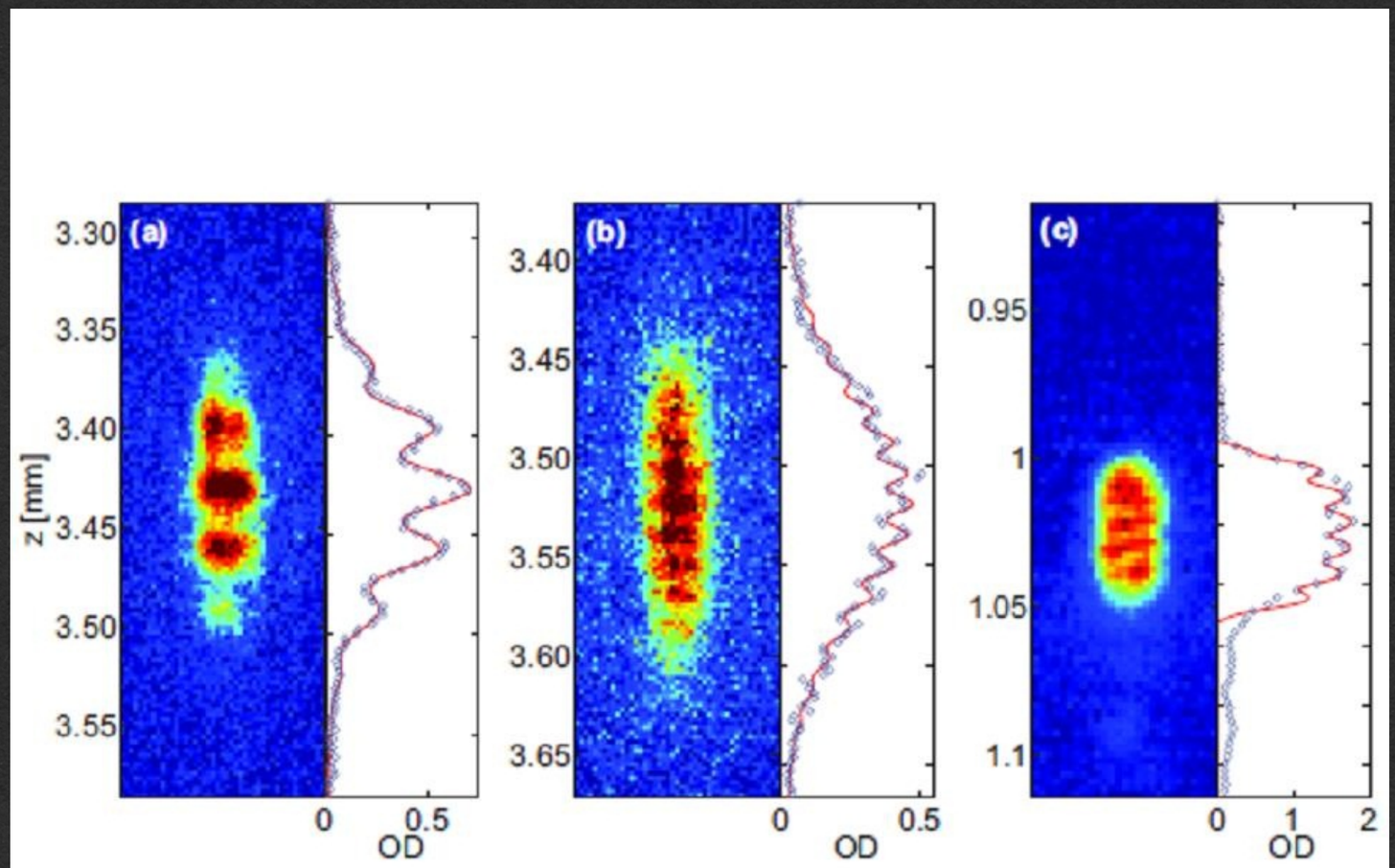
t=0



evoluzione
nel tempo

onde o particelle?

interferenza di materia!!



Ben Gurion University 2012

vortici di materia

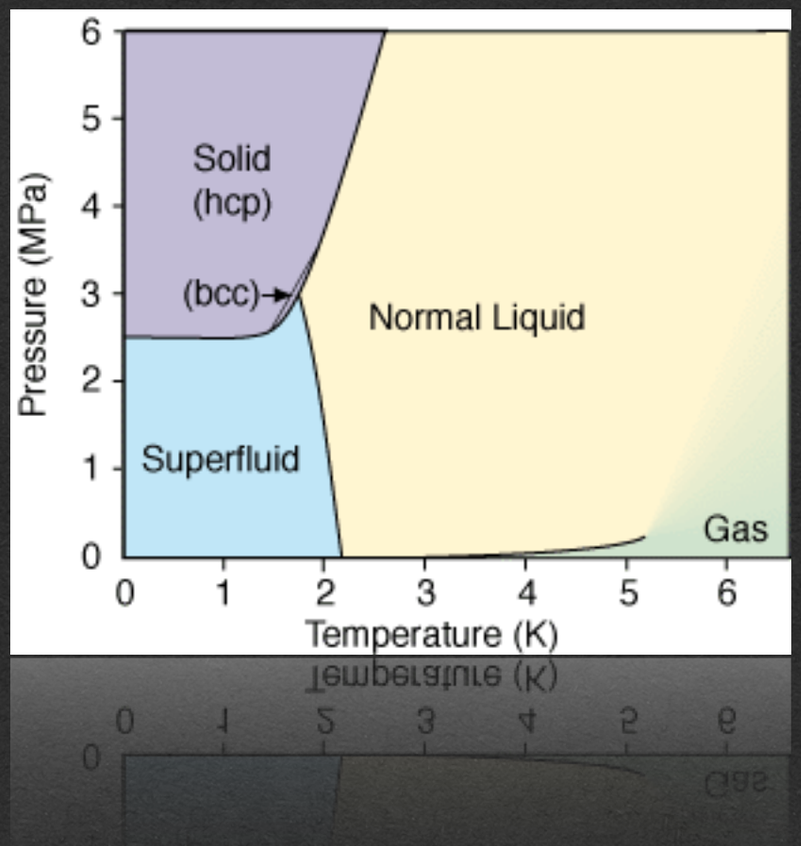
Nobel Prize 2003:
A.A. Abrikosov
V.L. Ginzburg
A.J. Leggett

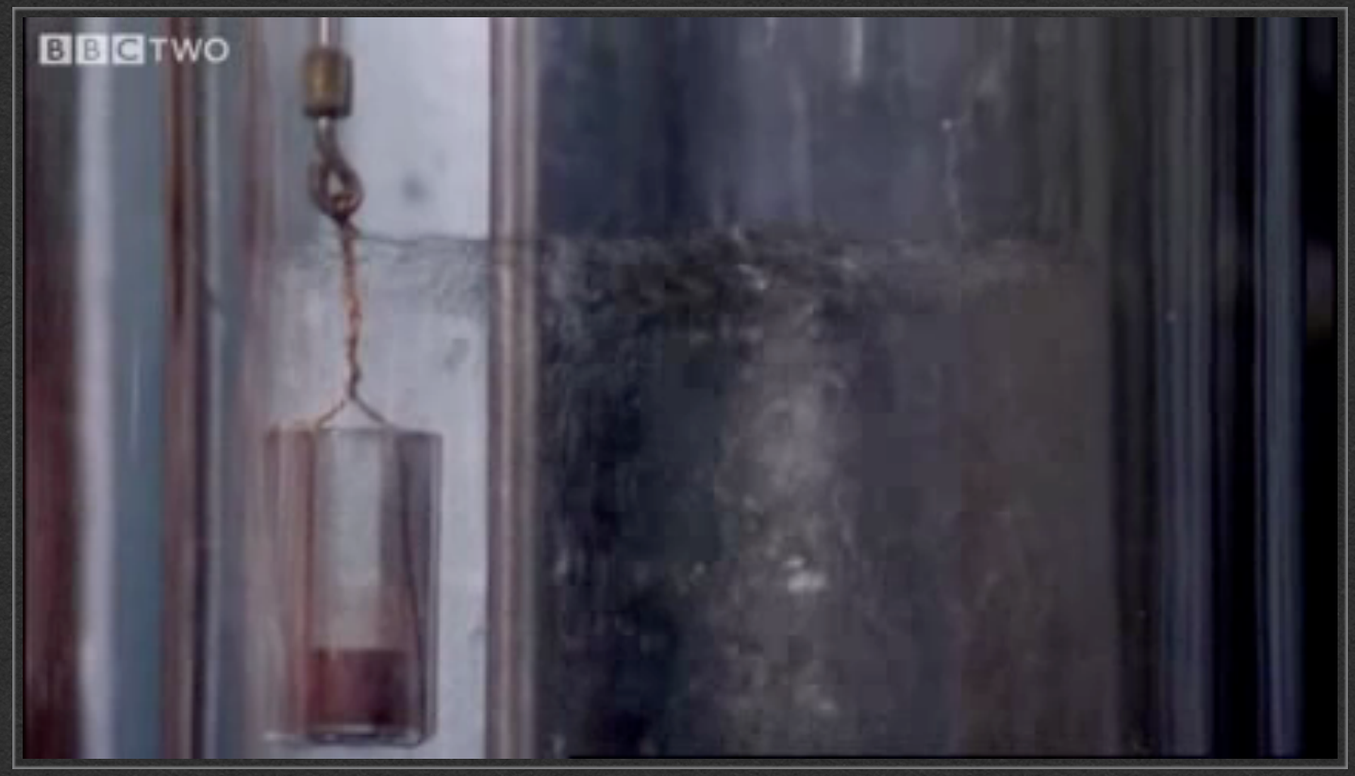
reticoli di vortici di materia in condensati

- Condensazione di Bose-Einstein
- Superfluidità
  (scoperta negli anni ’30 da Kapitza, Nobel Prize 1978)
- Superconduttività

^{4}He superfluido

diagramma delle fasi di ^{4}He:
l'unico liquido quantistico!





superfluidità a $T<T_c=2.17$ K

- no viscosità
- singolo stato quantistico
- vortici

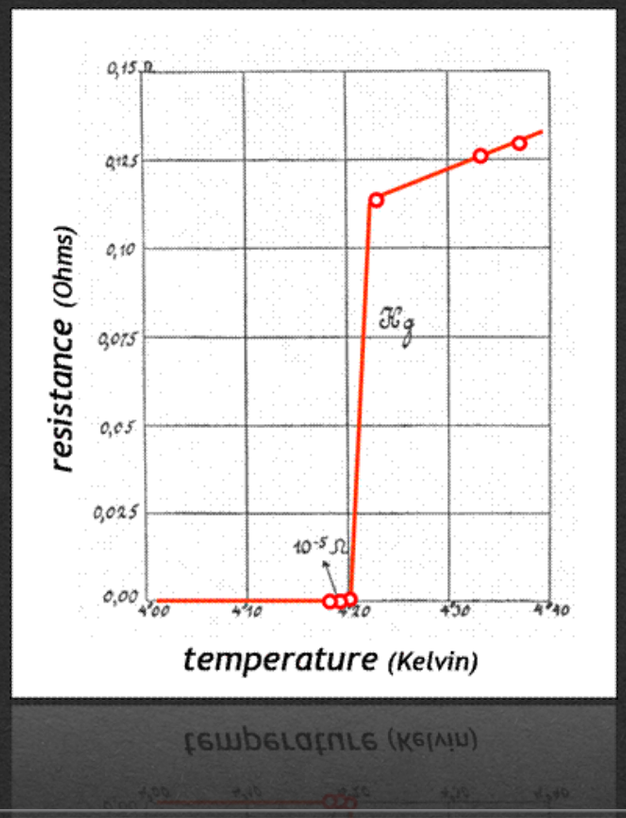
•Condensazione di Bose-Einstein
(predetta nel 1925→scoperta in atomi alkalini nel 1995)

•Superfluidità

•Superconduttività
(scoperta nel 1911→ capita nel 1972 (BCS)
→ superconduttività ad alta temperatura 1986)

superconduttività

resistenza nulla

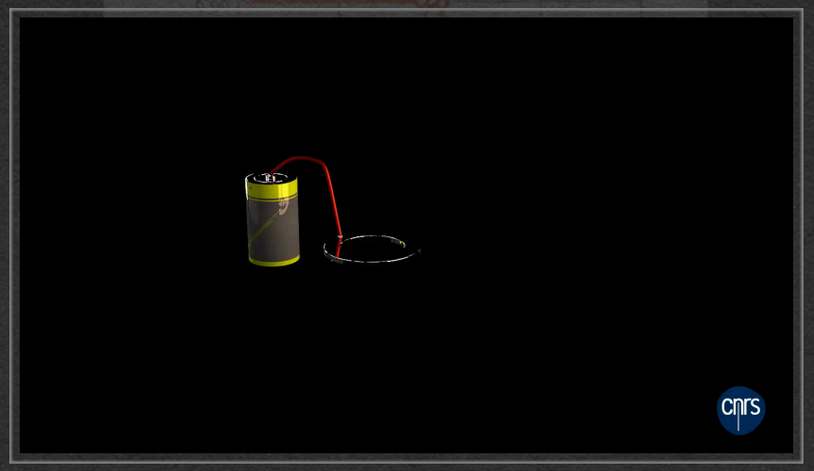


Nobel Prize
1913:
K. Onnes

diff. potenziale

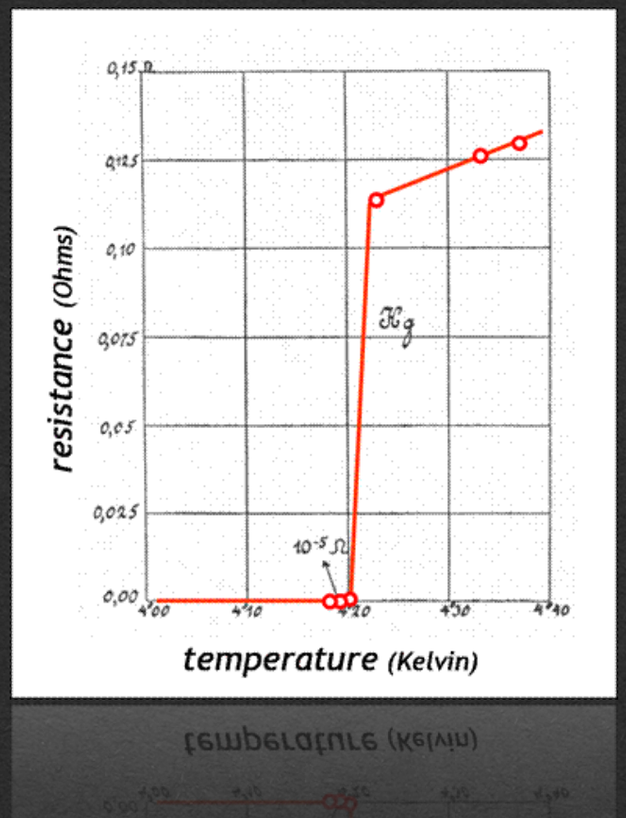
$V=R \cdot I$

corrente



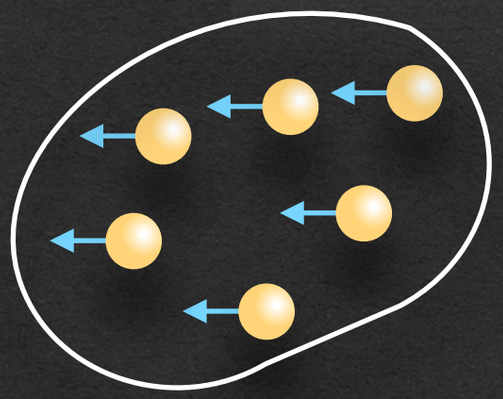
superconduttività

resistenza nulla

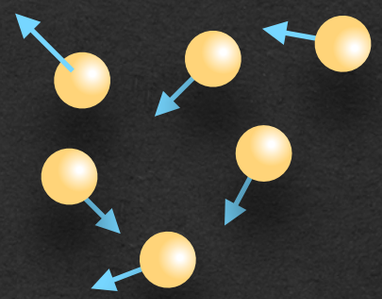


Nobel Prize
1913:
K. Onnes

moto collettivo



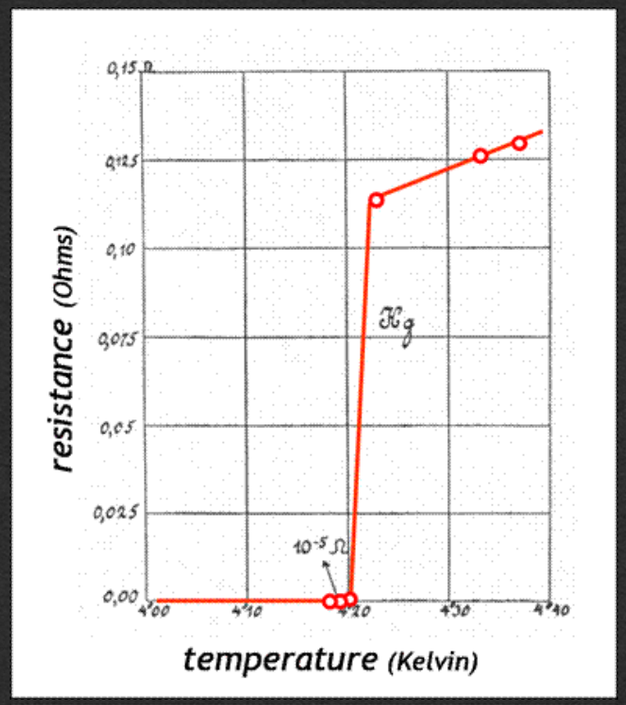
moto casuale e urti



T_c=4.2 K @ Hg

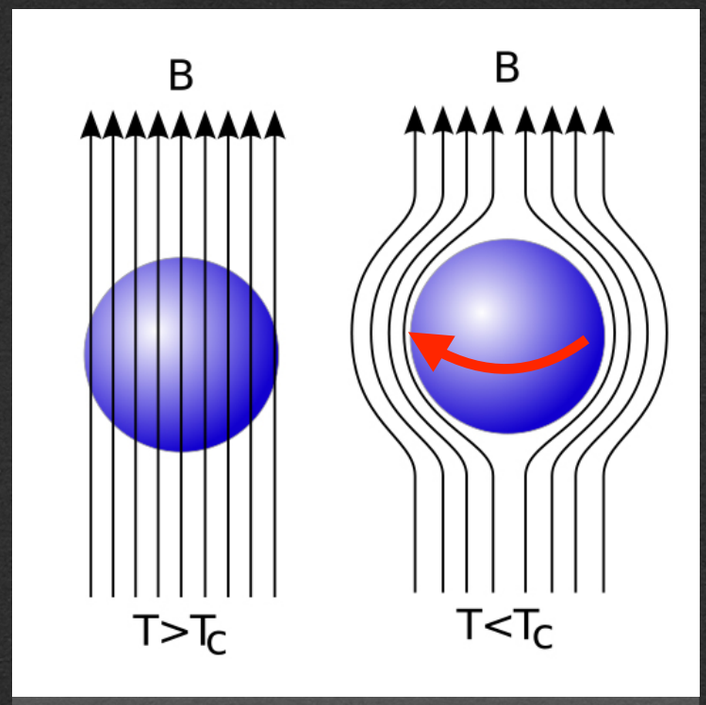
superconduttività

resistenza nulla



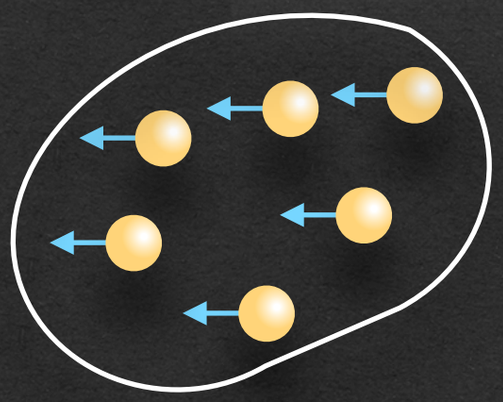
Nobel Prize
1913:
K. Onnes

repulsione di campi magnetici

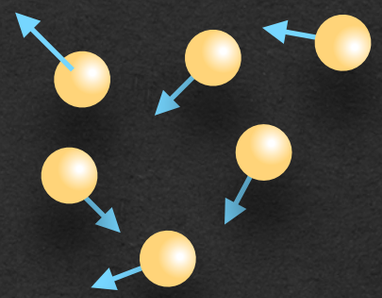


supercorrenti

moto collettivo



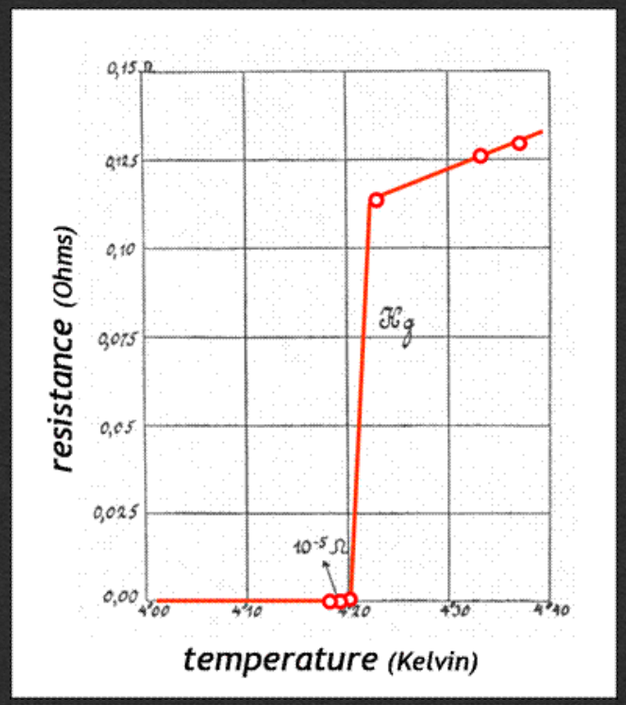
moto casuale e urti



T_c=4.2 K @ Hg

superconduttività

resistenza nulla



Nobel Prize
1913:
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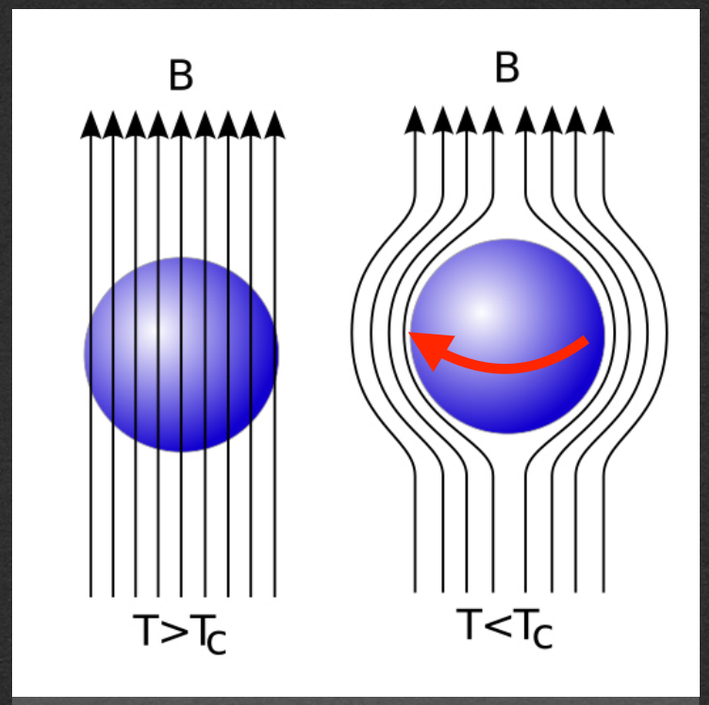
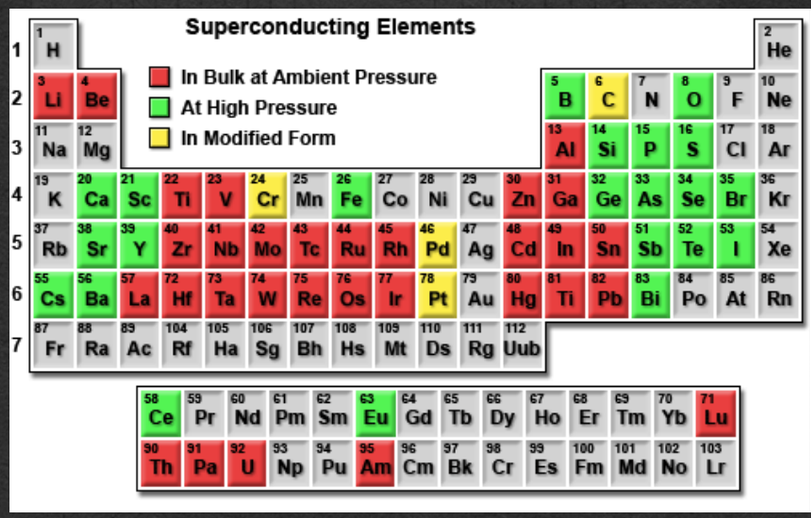
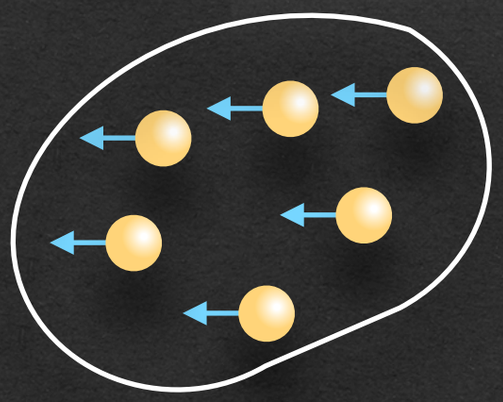


supercorrenti

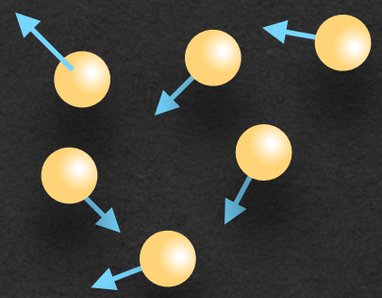
fenomeno universale!



moto collettivo



moto casuale e urti

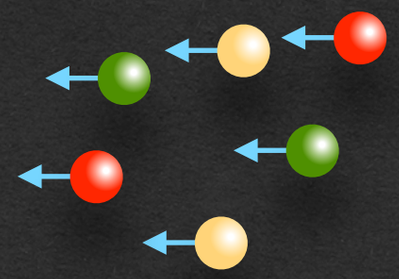


T_c=4.2 K @ Hg

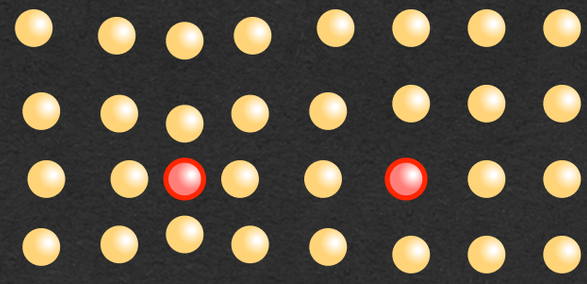
superconduttività

teoria BCS
(Nobel Prize 1972)

formazione di coppie di e^-
(bosoni) e condensazione

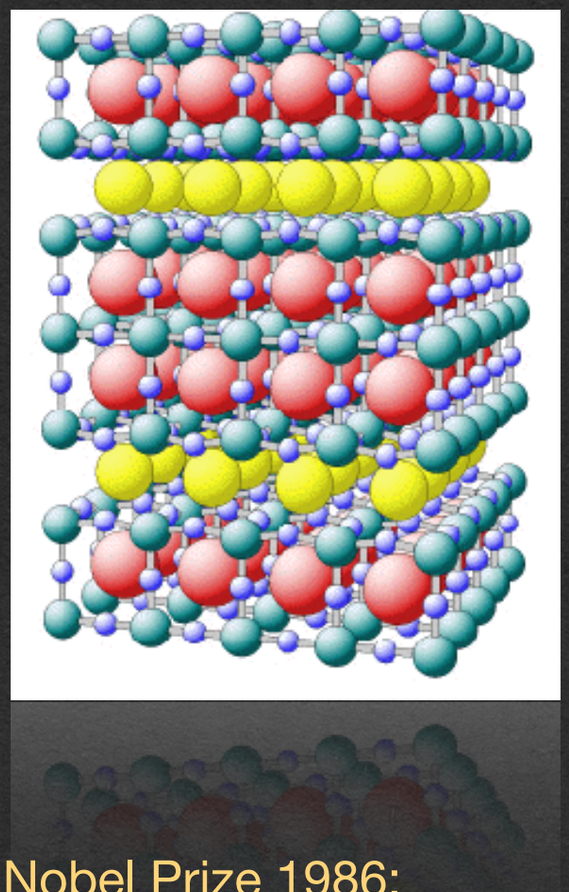


distorsione del
reticolo cristallino



superconduttività ad alta temperatura

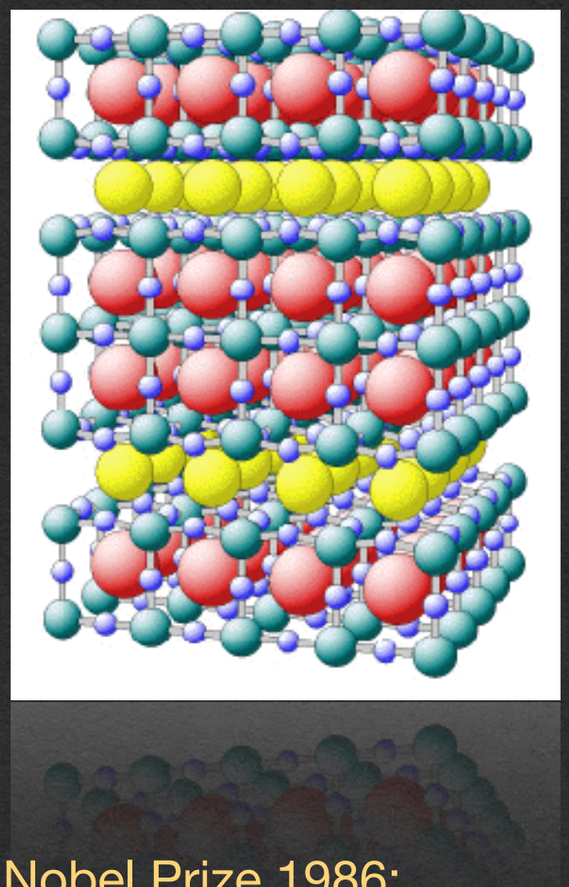
ossidi di metalli di transizione (Cu) bidimensionali



Nobel Prize 1986:
J.G. Bednorz, K.A. Müller

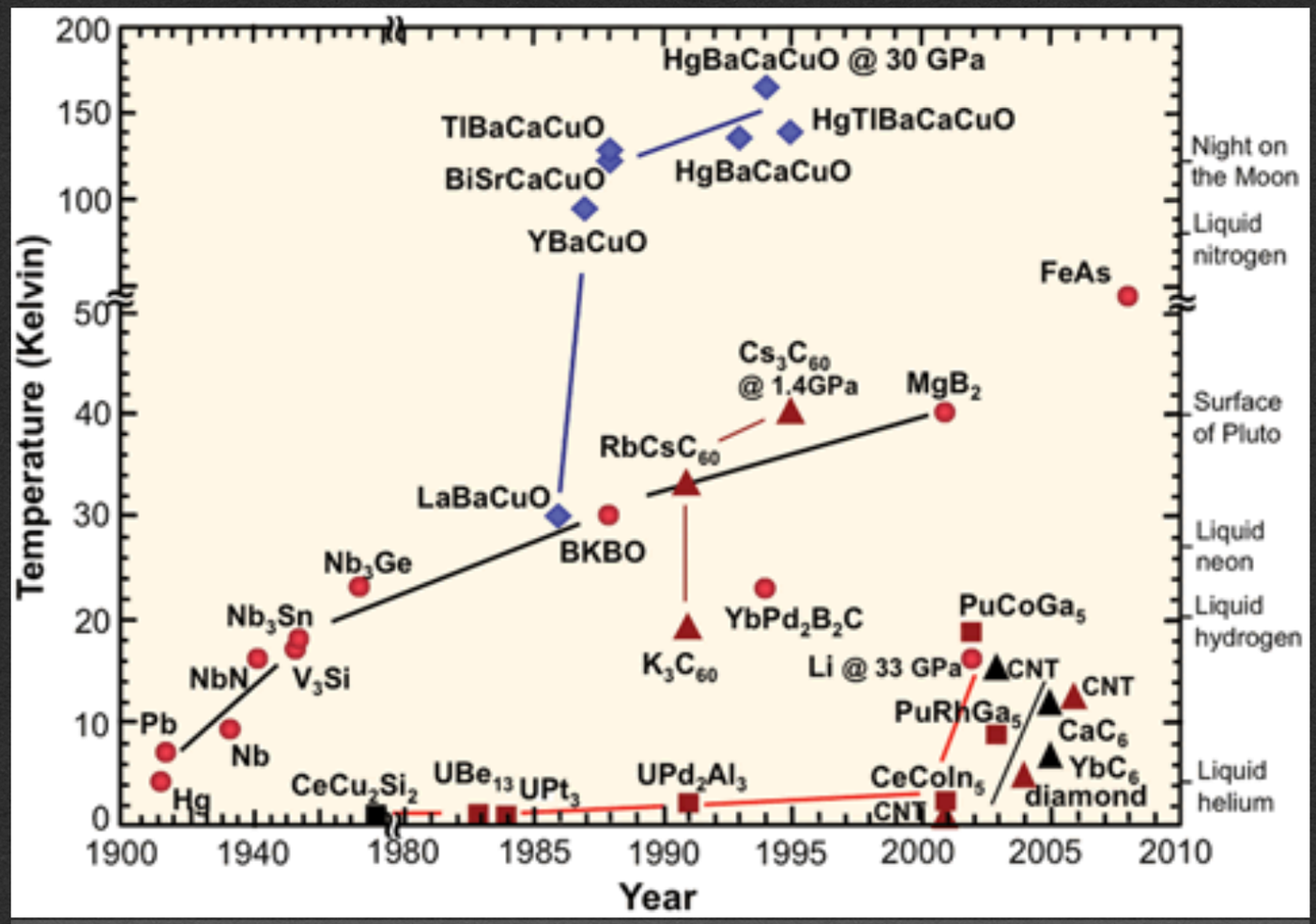
superconduttività ad alta temperatura

ossidi di metalli di transizione (Cu) bidimensionali



Nobel Prize 1986:
J.G. Bednorz, K.A. Müller

T_c fino a 160 K !!

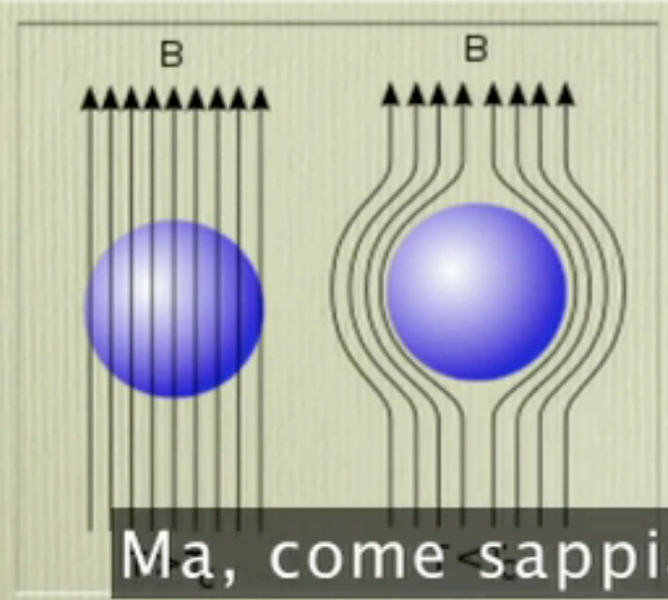


superconduttività ad alta temperatura

What defines a SUPERCONDUCTOR?

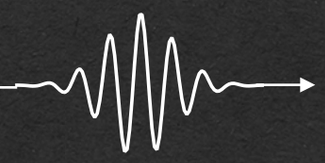
SUPERCONDUCTOR will have both :

expulsion of magnetic fields

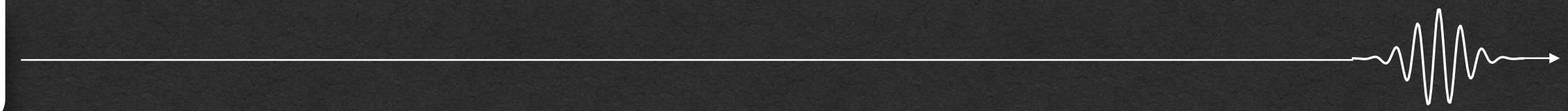


Zero electrical resistance.

Ma, come sappiamo, nulla è perfetto



cosa facciamo noi?



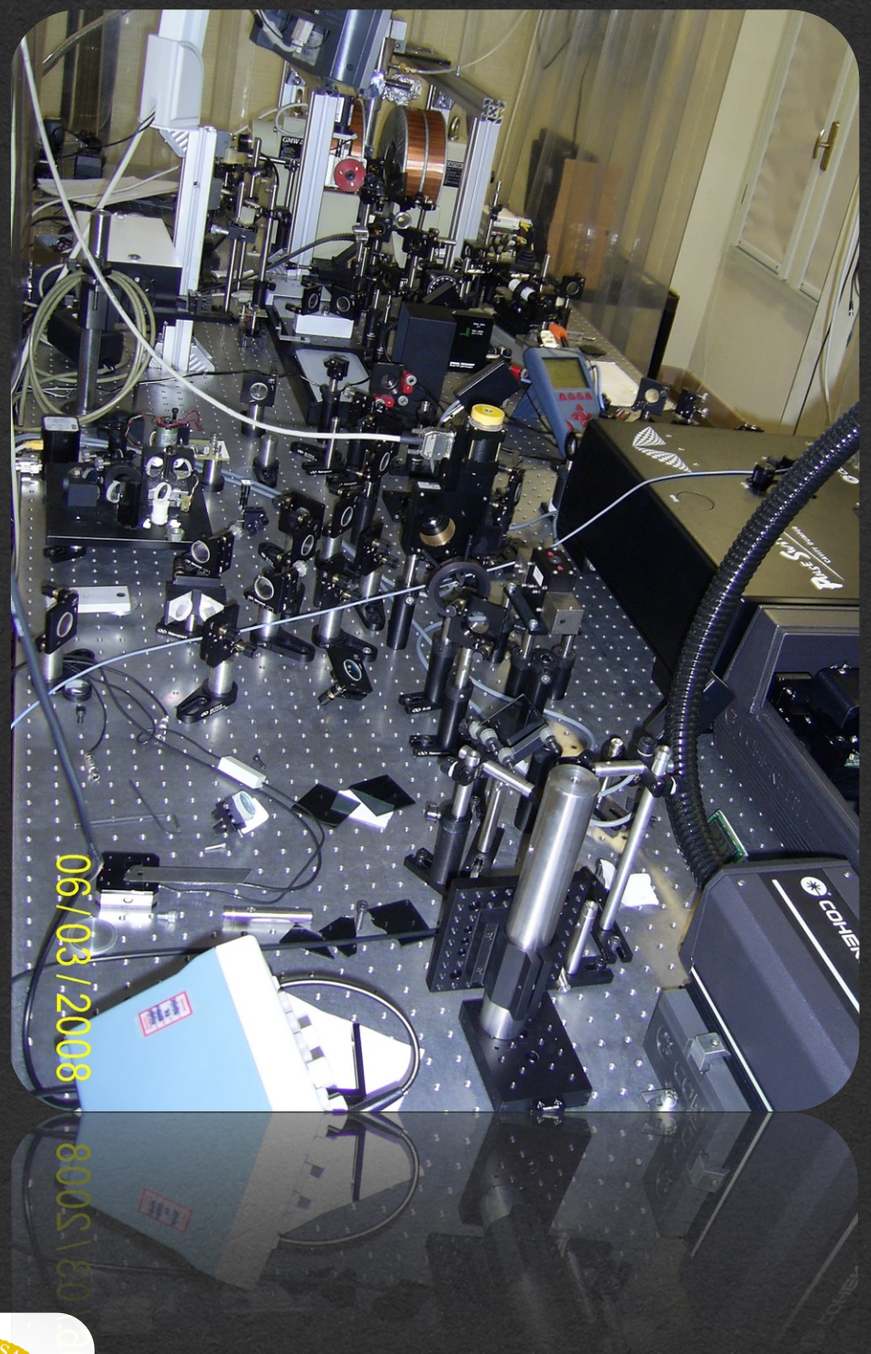
ottica ultraveloce

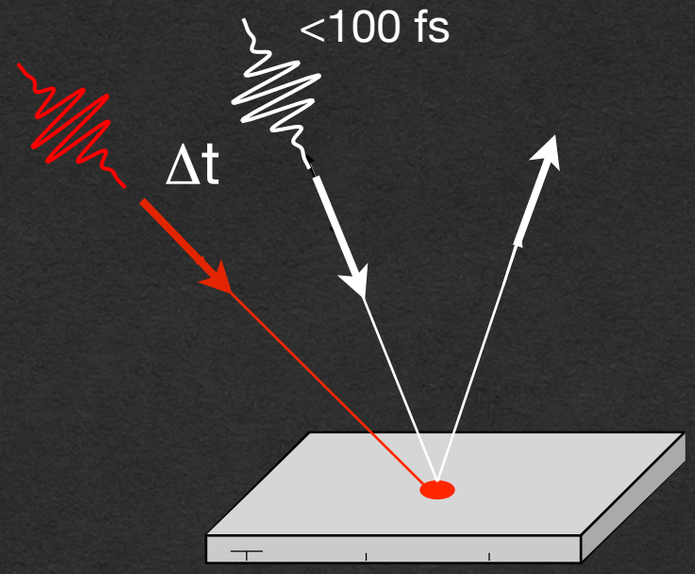
Fotografia stroboscopica ad alta velocità E. Muybridge (1872, San Francisco)

Nobel Lecture by A. Zewail (1999)

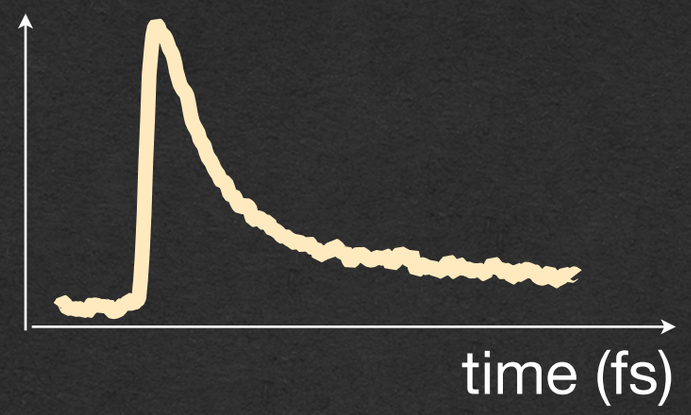
shutter ultraveloce?

Time-resolved optical spectroscopy



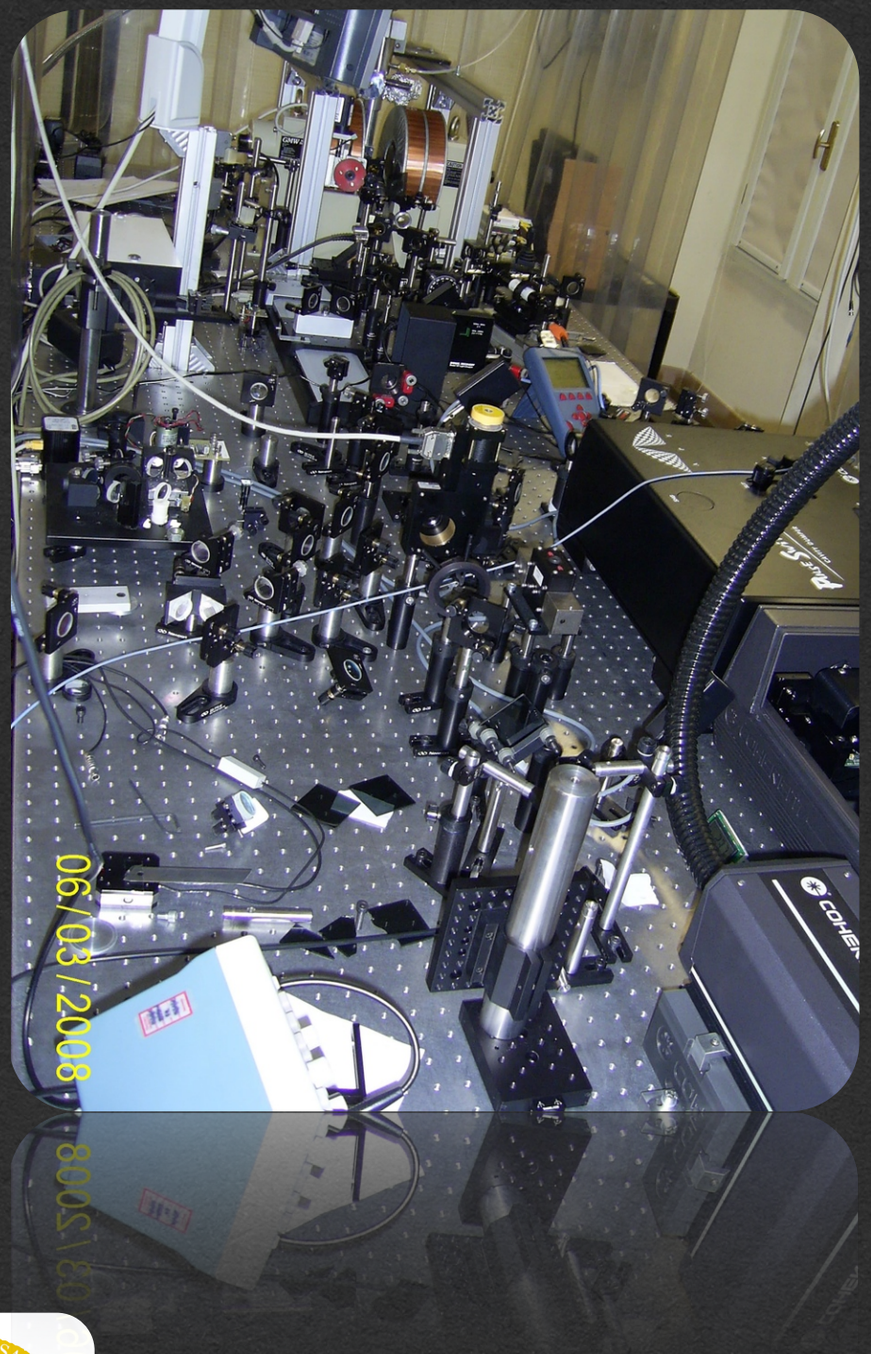


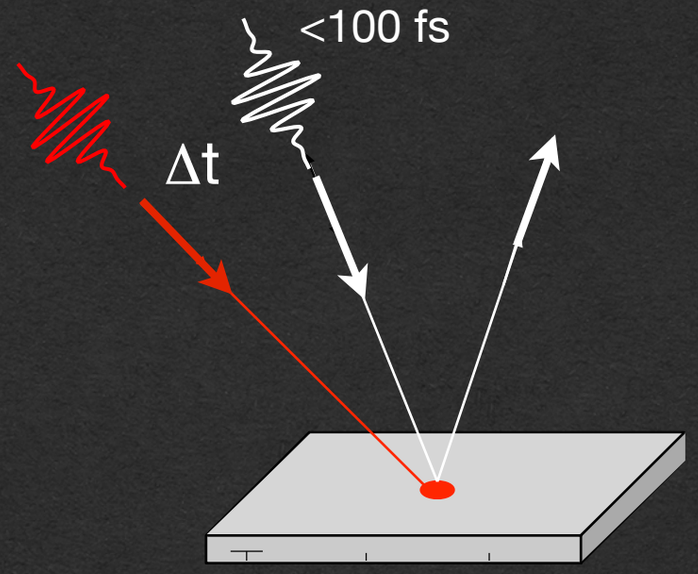
superconduttore



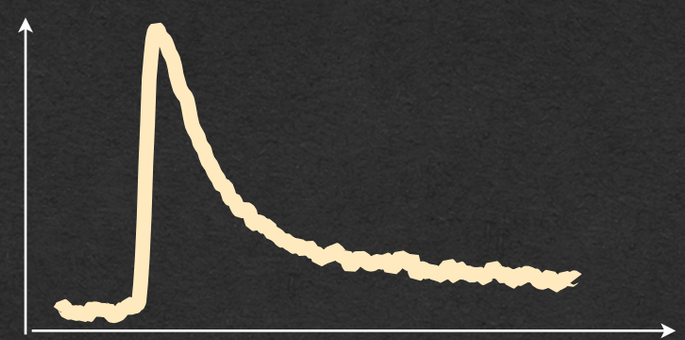
1 femtosecondo = 10^{-15} s

Time-resolved optical spectroscopy

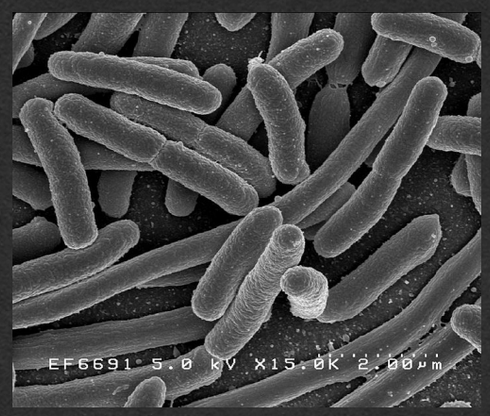




superconduttore



1 femtosecondo = 10^{-15} s



batterio

terra-luna

sei interessato?

Interdisciplinary laboratories for advanced materials physics (I-LAMP)

http://centridiricerca.unicatt.it/ilamp