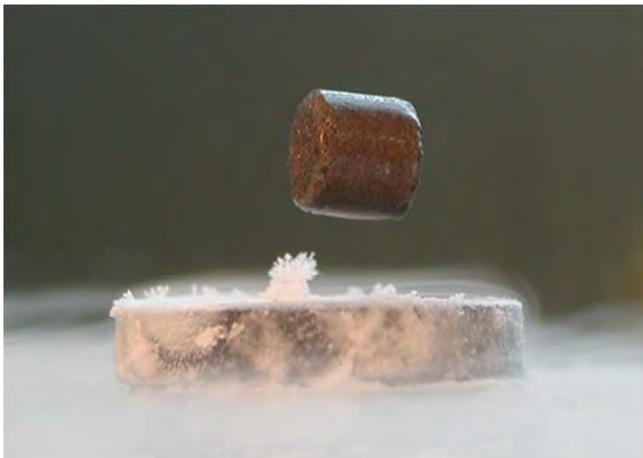


Supraconductivité: La magie du monde quantique devant vos yeux.

André-Marie Tremblay

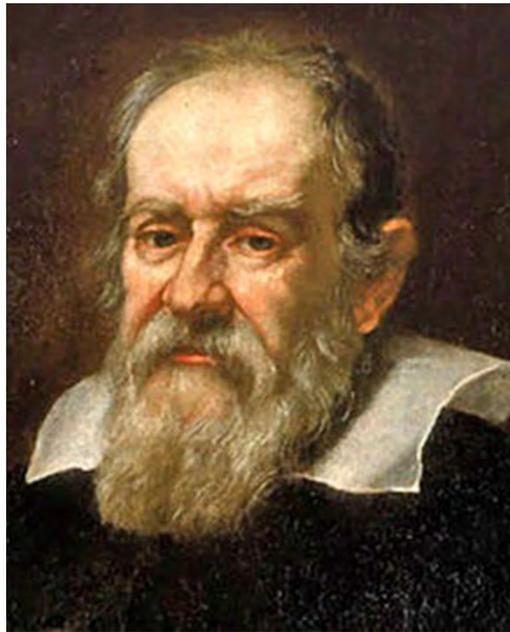


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Galileo Galilei



1564-1642

Richard Feynman



1918-1988



Quelle serait la phrase qui contiendrait le plus d'information dans le moins de mots?



Atomes - température

La course vers la température zéro



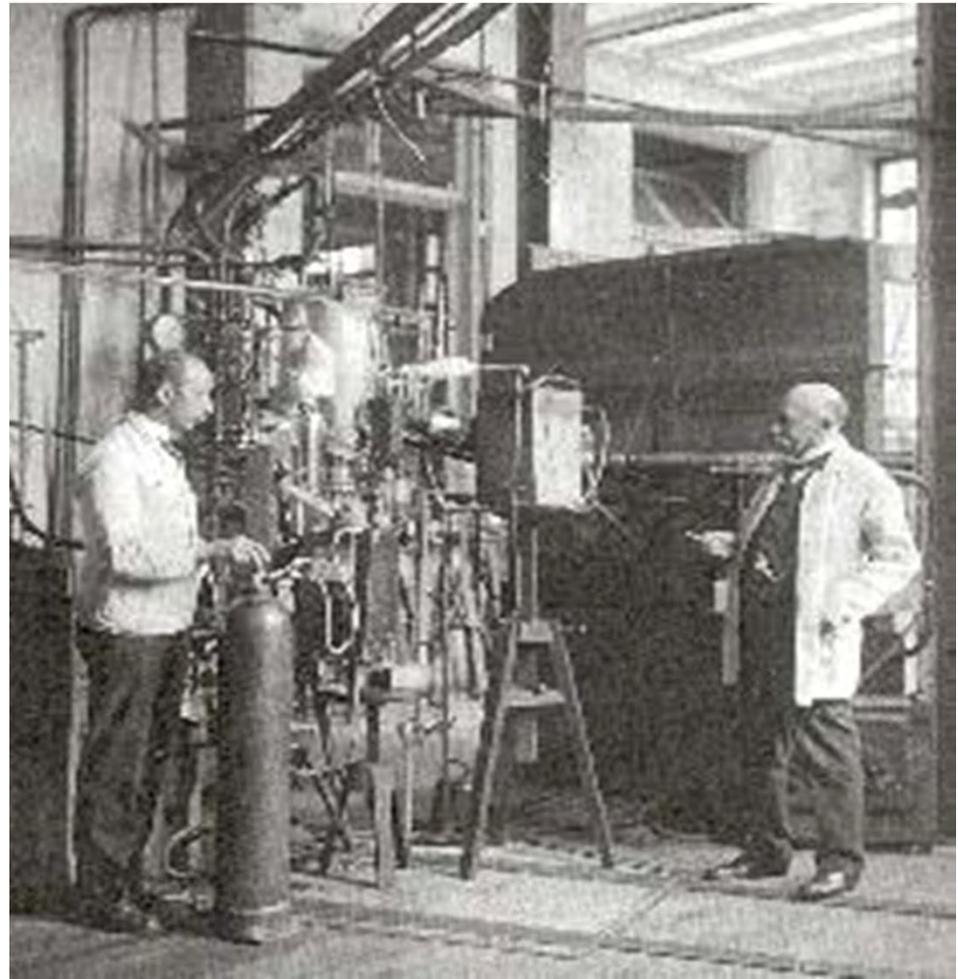
Un pas important vers $T = 0$

- Heike Kamerlingh Onnes
(Leiden) (1853/1926)



Les débuts du travail d'équipe en recherche

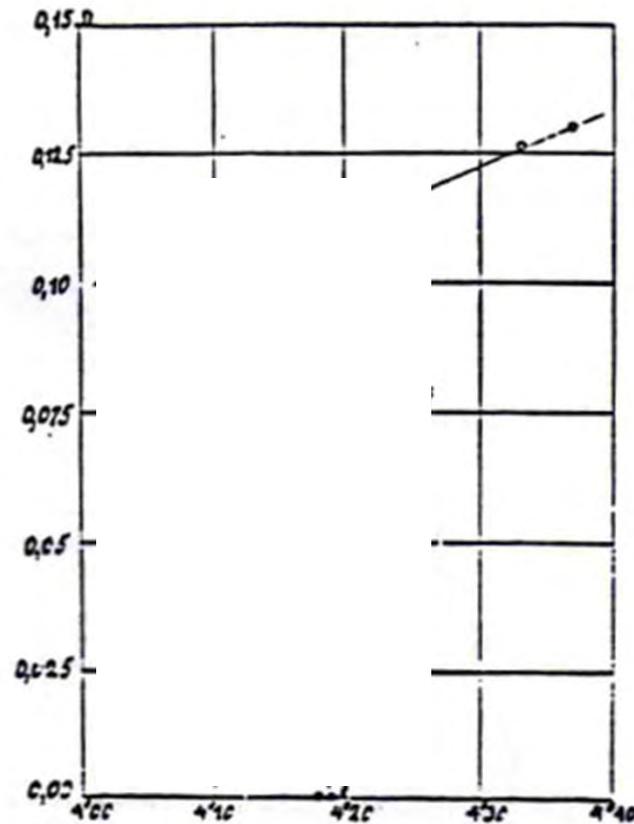
J.G.. Flim, cryogénie
G. Dorsma: thermométrie
G. Holst: électronique
Souffleur de verre



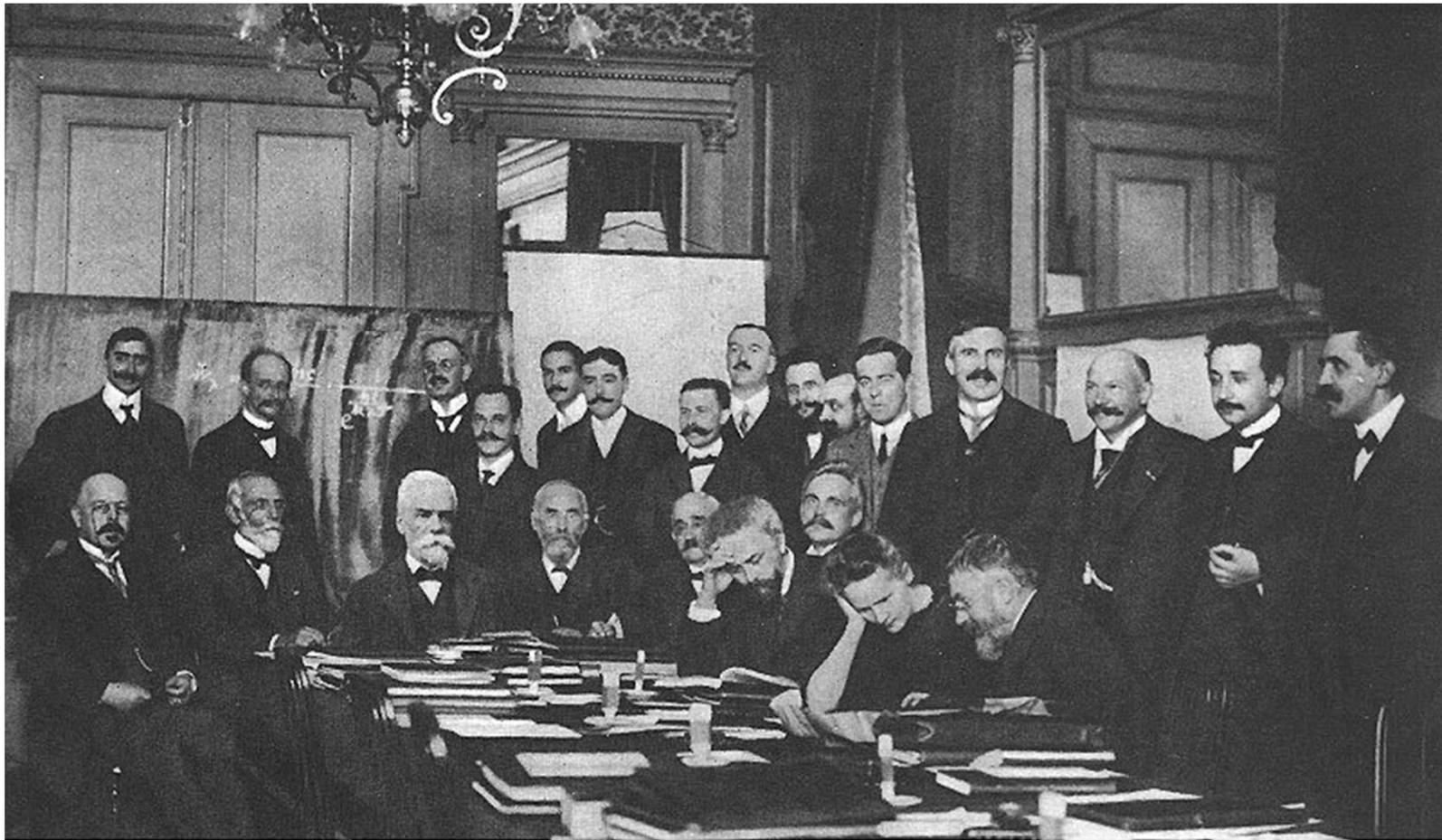
Et alors?

- Qu'arrive-t-il à la résistance électrique?

8 avril 1911



Congrès Solvay, 1911



GOLDSCHMIDT
NERNST

PLANCK
BRILLOUIN

RUBENS
SOMMERFELD

LINDEMANN
M. DE BROGLIE

SOLVAY

LORENTZ

HASENOHRL
HCSTELET

KNUDSEN
WARBURG

PERRIN

HERZEN
WIEN

JEANS
Madame CURIE

RUTHERFORD

POINCARÉ

KAMERLINGH ONNES

EINSTEIN

LANGEVIN

DE BROOKE

Et le gagnant est...

- Heike Kamerlingh Onnes
(Leiden) (1853/1926)



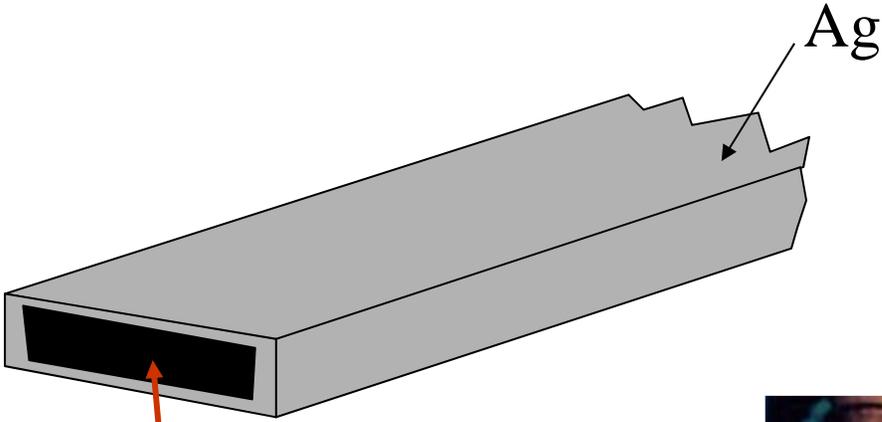
<http://www.nobel.se>

1913: Prix Nobel de physique

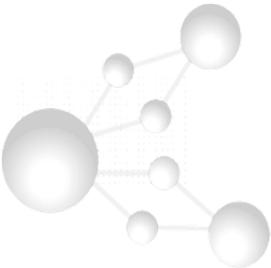
Au Professeur H. Kamerlingh Onnes de Leiden, pour ses expériences sur les propriétés de la matière à basse température qui ont conduit, concomitamment à la production de l'hélium liquide.

Transmission de l'électricité

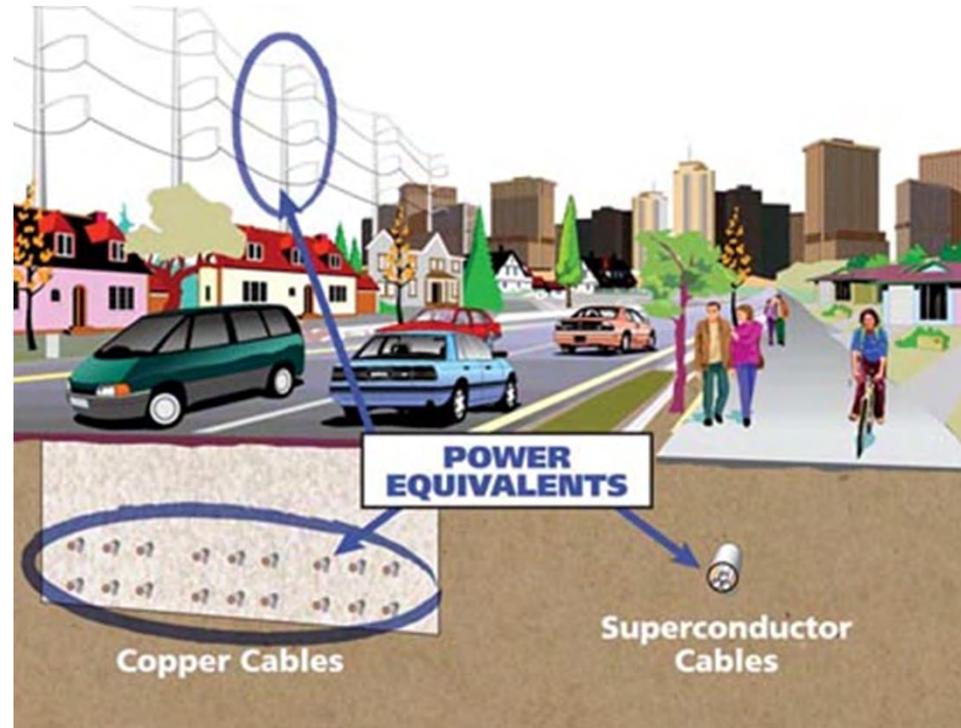
Câbles



BiSrCaCuO



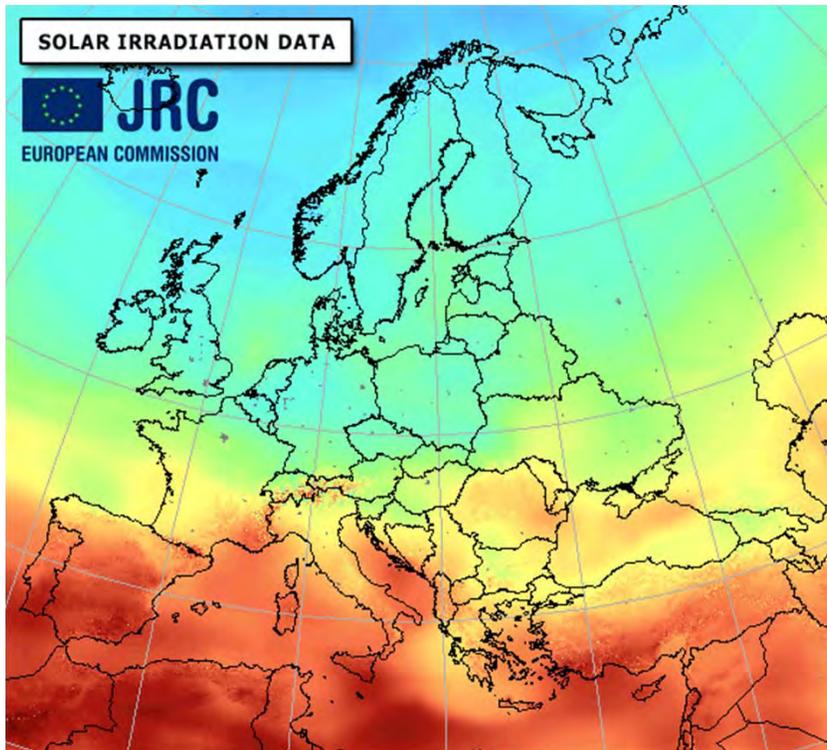
7 octobre 2010, American Superconductors



3,000 km de câbles pour la Corée du sud



Production et besoin



Tourner en rond tout en faisant quelque chose d'utile



André-Marie Ampère



1775 - 1836



Le premier aimant supraconducteur



Martin

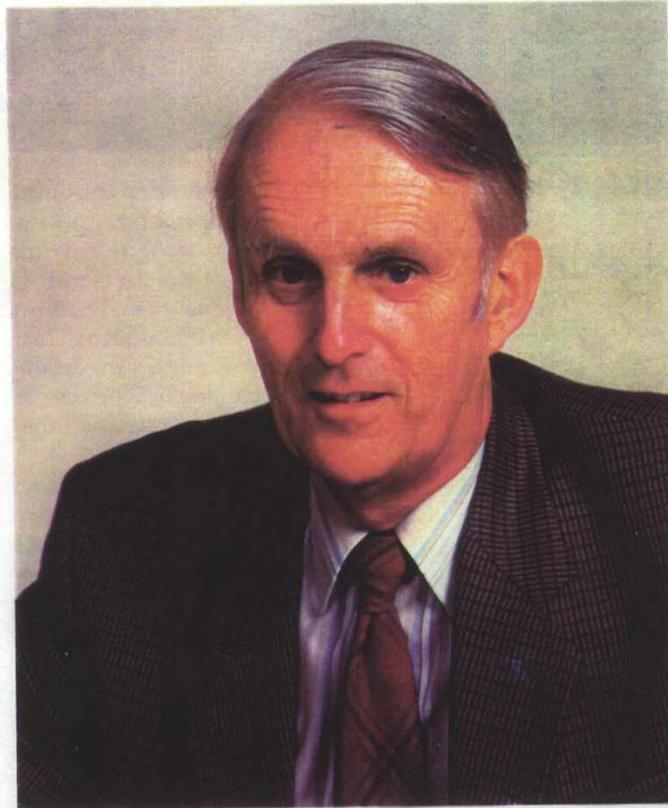
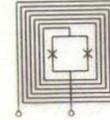
Wood, 1962



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Supercurrents

The Superconductivity Magazine



Sir Martin Wood
Founder, Oxford Instruments



Transport des personnes

Maglev, aéroport de Shanghai



350 km/h (220 mph) en 2 minutes,
Vitesse maximale 431 km/h (268 mph).
Record 12 novembre 2006, 501 km/h (311 mph).



Test, train à lévitation magnétique, Japan Rail

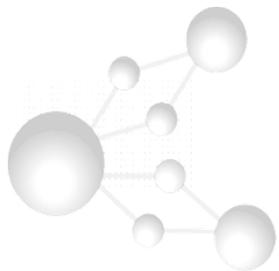
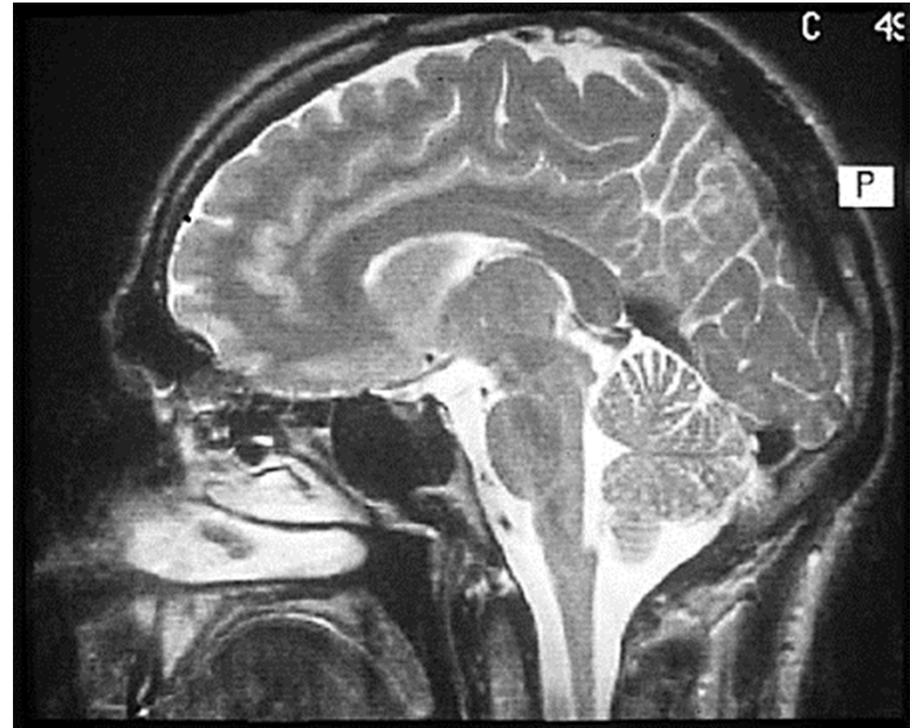


JR-MLX01 maglev train at [Yamanashi](#) test track



En médecine

Imagerie par résonance magnétique



Et là où vous l'attendez le moins



De retour à la lévitation

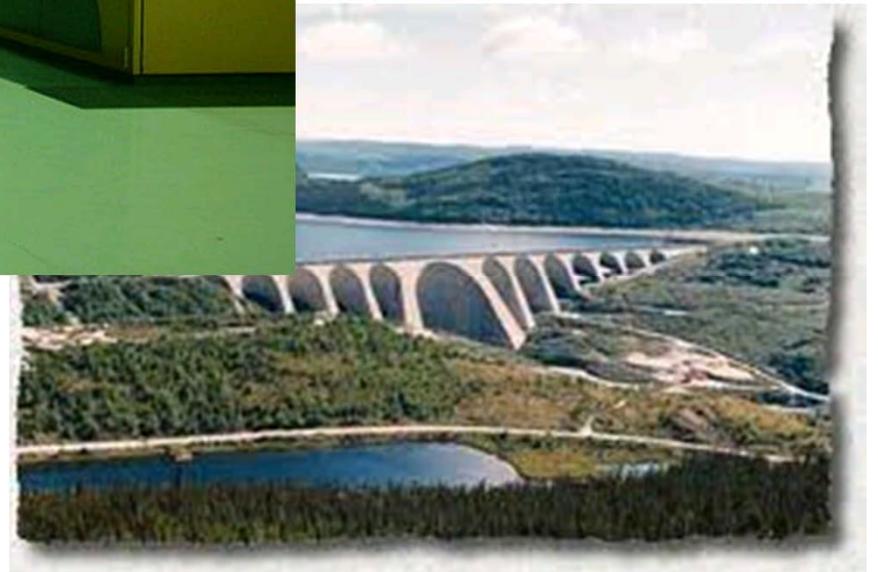


Michael Faraday



1791-1867

Induction

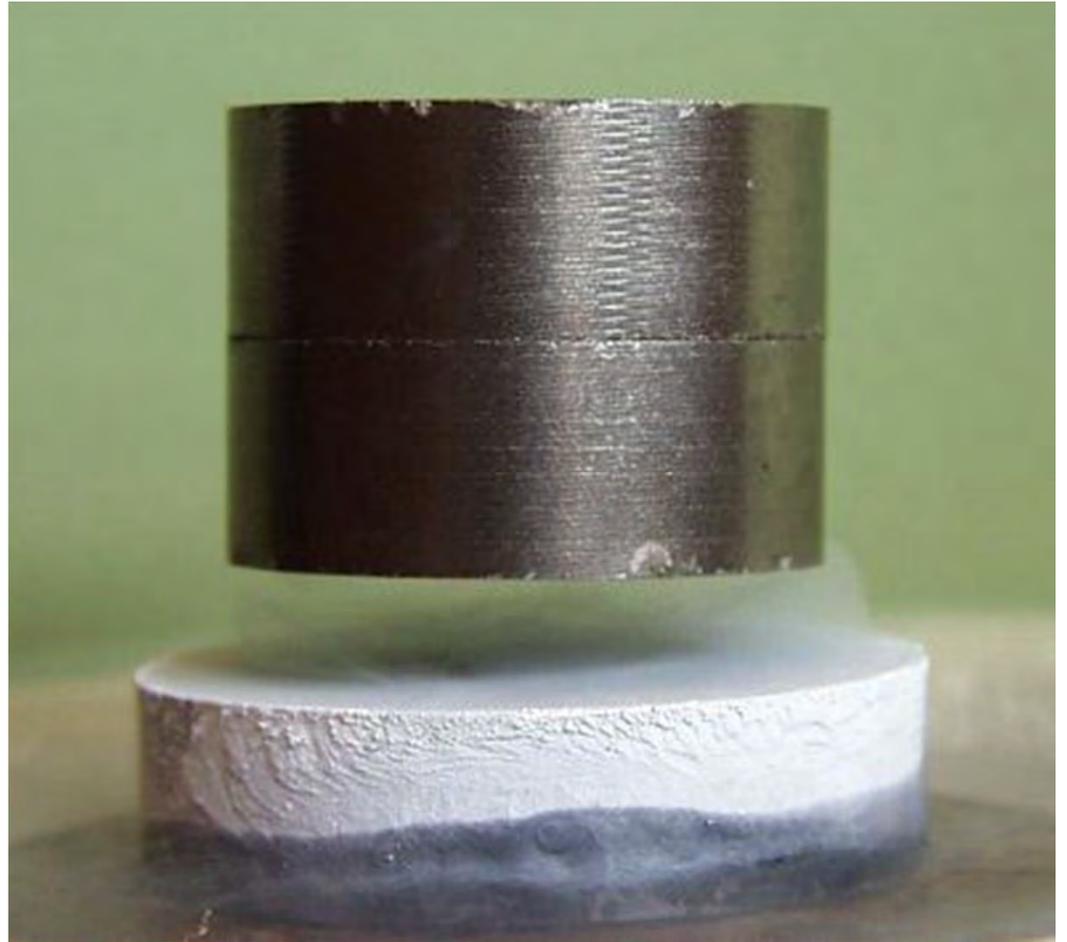




Walther Meissner
(1882-1974)

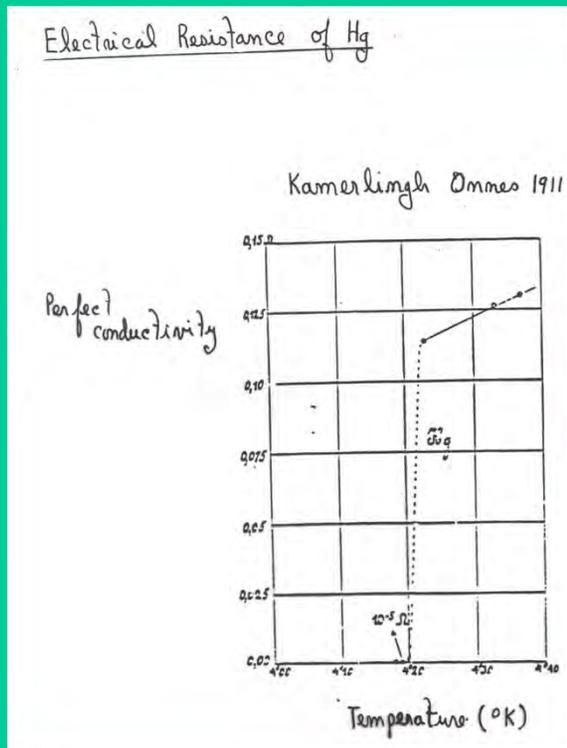


R. Ochsenfeld (1900-1992)



Deux propriétés importantes

1. Zero resistance (if $\mathbf{B}=0$)



2. Diamagnetism



Comment explique-t-on la supraconductivité?



Théorème de Bloch, 1930

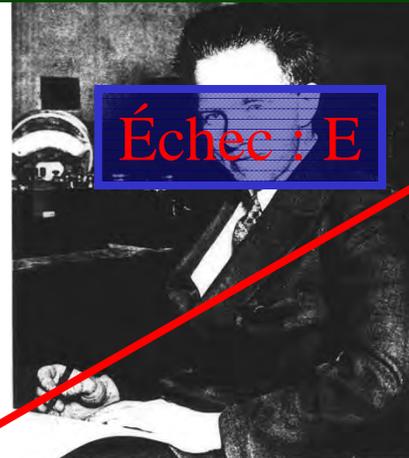
- On peut prouver que toutes les théories de la supraconductivité sont fausses.
- Feynman: personne n'est assez brillant pour trouver la solution.



Quelques essais infructueux



Feynman



Heisenberg

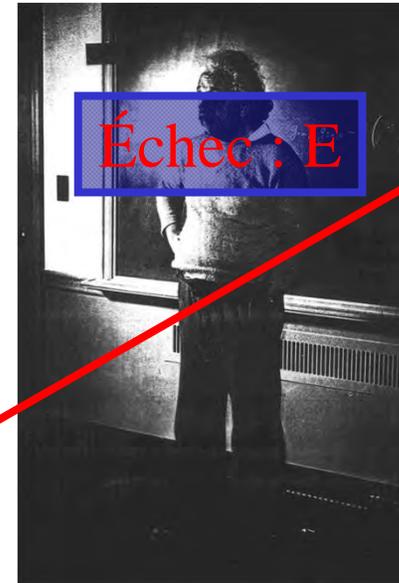
WERNER HEISENBERG (1901-) introduced matrix mechanics, which, like the Sch

Bohr



NIELS BOHR (1885-1962) introduced the idea that the electron moved about the nucleus in well-defined orbits. This photograph was made in 1922, nine years after the publication of his paper

Einstein



Une analogie

- Symétrie brisée
- Rigidité

BCS 1957

Comportement quantique à l'échelle macroscopique

Leon Cooper



Prix Nobel : 1972

John Bardeen*

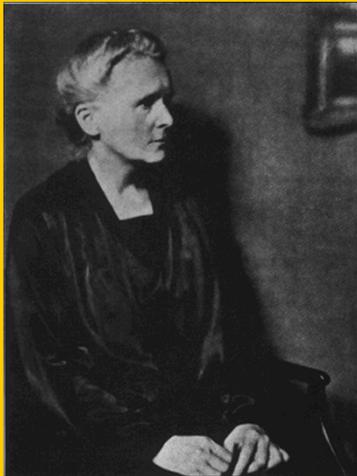
Robert Schrieffer

- John Bardeen :
- Le seul à avoir obtenu deux prix Nobel en physique!!!



Invention : TRANSISTOR!

W. Shockley, J. Bardeen, W.H. Brattain



Marie Curie:

1903 Physique with H.A. Becquerel

1911 Chimie (seule)



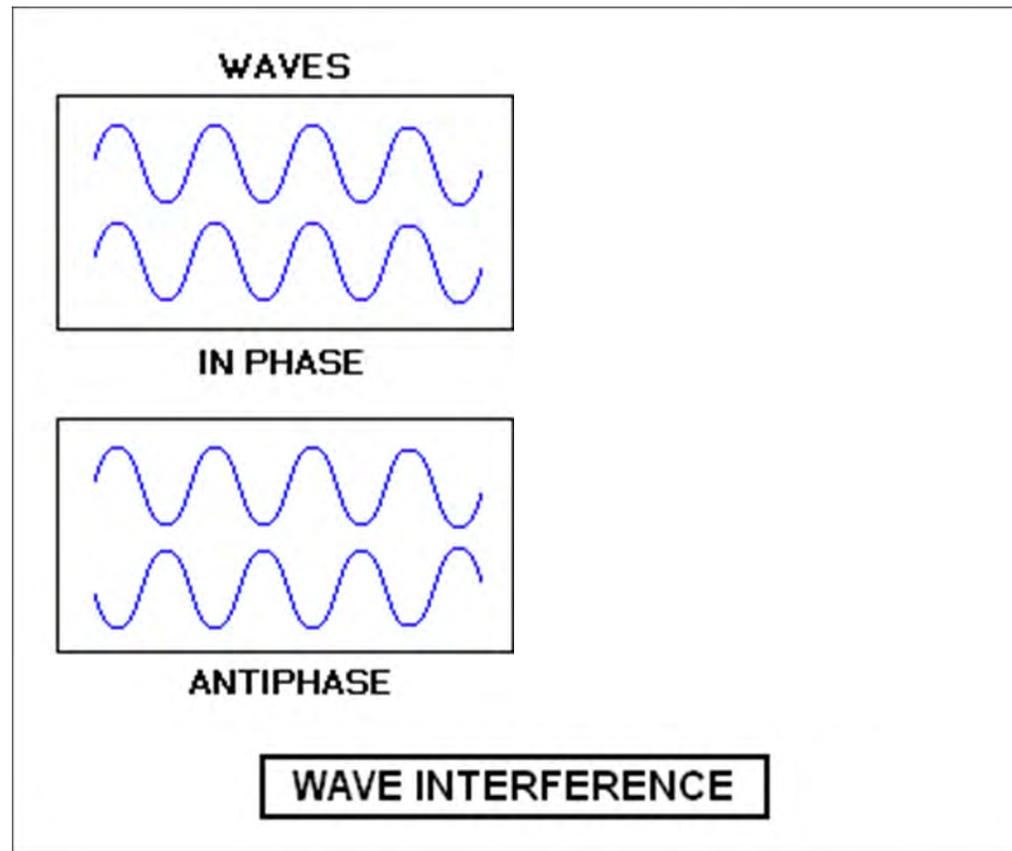
Ce qui était connu

- La résistance s'annule
- L'effet Meissner
- Transparent aux microondes basse fréquence
- Effet isotopique

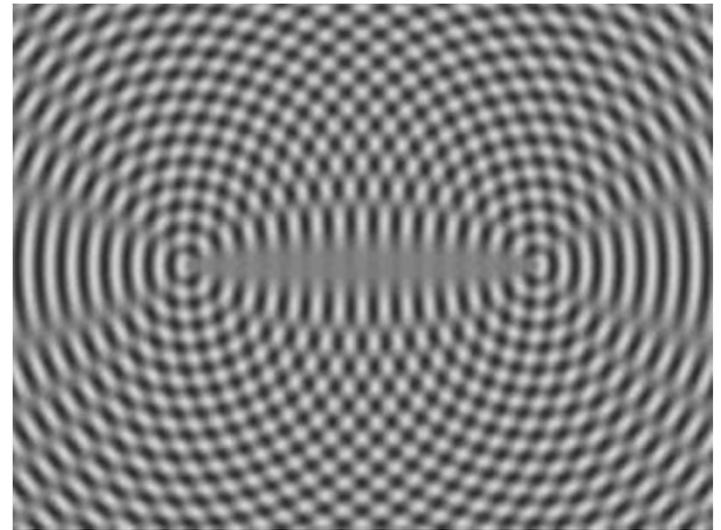


Mécanisme d'attraction dans l'état métallique

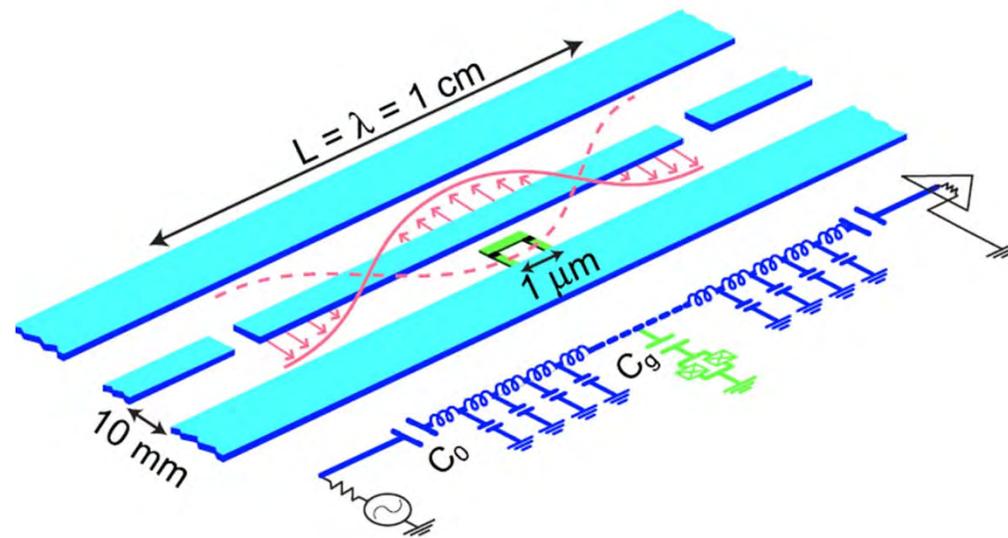
Ondes



Interférence



L'ordinateur quantique



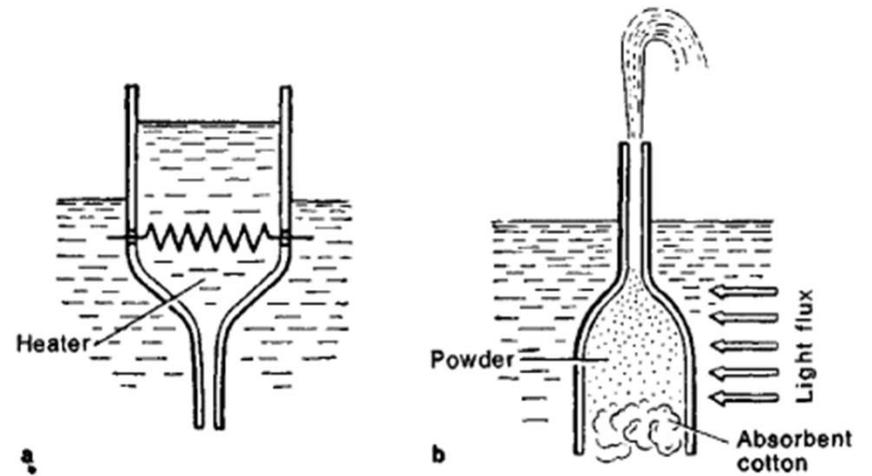
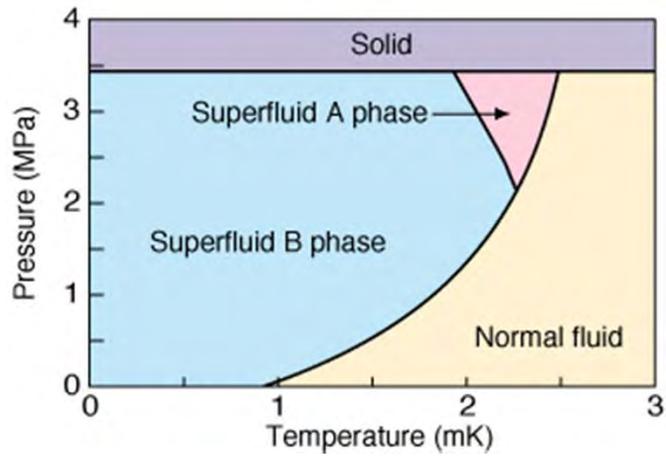
Alexandre Blais, et al. Phys. Rev. A **69**, 062320 (2004)



La supraconductivité partout



^3He superfluid



Le noyau des atomes (Rutherford 1911)

PHYSICAL REVIEW

VOLUME 110, NUMBER 4

MAY 15, 1958

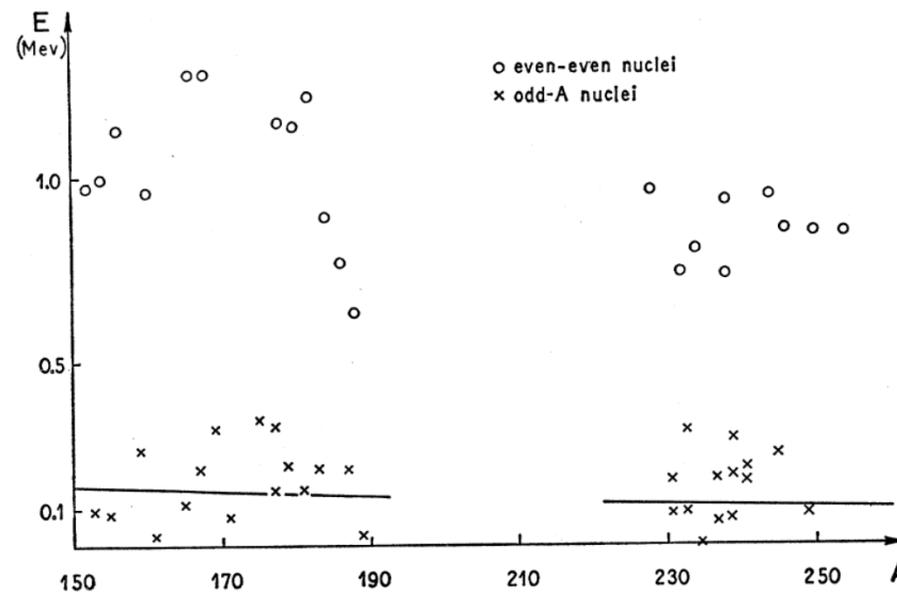
Possible Analogy between the Excitation Spectra of Nuclei and Those of the Superconducting Metallic State

A. BOHR, B. R. MOTTELSON, AND D. PINES*

Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark, and Nordisk Institut for Teoretisk Atomfysik, Copenhagen, Denmark

(Received January 7, 1958)

The evidence for an energy gap in the intrinsic excitation spectrum of nuclei is reviewed. A possible analogy between this effect and the energy gap observed in the electronic excitation of a superconducting metal is suggested.



Les étoiles à neutron



La nébuleuse du crabe (4 juillet 1054) en bleu et blanc
Credit & Copyright: Jay Gallagher (U. Wisc.), WIYN,
AURA, NOAO, NSF

Les atomes ultra-froids

Vol 443 | 26 October 2006 | doi:10.1038/nature05224

nature

LETTERS

Evidence for superfluidity of ultracold fermions in an optical lattice

J. K. Chin¹, D. E. Miller¹, Y. Liu¹, C. Stan¹†, W. Setiawan¹, C. Sanner¹, K. Xu¹ & W. Ketterle¹



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Le modèle standard des particules élémentaires (unification des interactions électro-faibles)

$$SU(2) \otimes U(1) \rightarrow U(1)$$

$$\begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix} \rightarrow \begin{pmatrix} 0 \\ \nu \end{pmatrix}$$

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (Quantum Chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	<1·10 ⁻⁶	0	u up	0.003	2/3
e^- electron	0.000511	-1	d down	0.006	-1/3
μ^- muon	<0.0002	0	c charm	1.3	2/3
τ^- tauon	1.7771	-1	s strange	0.1	-1/3
ν_μ muon neutrino	<0.02	0	t top	175	2/3
ν_τ tau neutrino	<0.02	0	b bottom	4.2	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = 1.054 \times 10^{-34}$ J·s and $\hbar = 6.582 \times 10^{-16}$ eV·s.

Electric charge is given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy of particles given in the table above is in electronvolts (eV). The energy gained by one electron in crossing a potential difference of one volt is called a "electron volt" (eV). Conversion: 1 eV = 1.602 × 10⁻¹⁹ J. Conversion: 1 GeV = 10⁹ eV = 1.602 × 10⁻¹⁰ J. The mass of the proton is 938 GeV/c² = 1.67 × 10⁻²⁷ kg.

Structure within the Atom

Size ~ 10⁻¹⁶ m: Quark
Size ~ 10⁻¹⁴ m: Nucleus
Size ~ 10⁻¹⁸ m: Electron
Size ~ 10⁻¹⁰ m: Atom

If the proton and neutron in this picture were 10 m across, then the quark and electron would be less than 1 μm across. One of the most amazing facts about the atom is that the mass of the atom would still be about the same.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W^\pm	80.4	-1			
Z^0	91.1876	0			

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges need nothing to do with the color of visible light. There are eight possible types of color charge for quarks, but only three colors are observed in nature. The color charges are carried by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (confinement) results from the exchange of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy of the color force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see Figure below). The quarks and antiquarks then combine into hadrons. Hence, as the particles begin to emerge, new types of hadrons have been observed to appear (mesons $q\bar{q}$ and baryons qqq).

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color charge constituents. It is similar to the residual intermolecular interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property	Interaction	Gravitational		Weak		Electromagnetic		Strong	
		Acts on	Mass-Energy	Flavor	Electric Charge	Color Charge	Residual		
Particles experiencing:	All	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons			
Particles mediating:	Graviton	$W^+ W^- Z^0$	γ	Gluons	Hadrons				
Strength (compared to gravity)	10 ⁻⁴¹ to 10 ⁻⁴⁹	10 ⁻⁴¹	10 ⁻¹⁷	1	25	Not applicable to quarks			
Range (compared to gravity)	10 ⁻¹⁷ m	10 ⁻¹⁷ m	10 ⁻¹⁷ m	Not applicable to hadrons	10 ⁻¹⁵ m				
Is force prohibitive for molecules?	Yes	No	No	No	No	No	No	No	

Matter and Antimatter

For every particle there is a corresponding antiparticle type, denoted by a bar over the particle symbol (antimatter = $\bar{\psi}$ = charge is opposite). Particles and antiparticles have identical mass and spin but opposite charges. Some electrically neutral bosons (γ , Z^0 , π^0 , η , and η' , but not π^\pm or η') are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are not exact and they do not represent a full, Green shaded area represents the cloud of gluons or the gluon field, and red lines the quark paths.

$n + p + e^- \rightarrow \gamma + \nu_e$

The electron and proton annihilate each other, producing a photon and a neutrino. The neutrino is an electrically neutral cloud (hadron) of gluons. This is a common β^- decay.

$p + \bar{p} \rightarrow Z^0 + g$

Two protons colliding at high energy can produce various baryons and mesons that have been observed, such as a Z boson, baryons such as mesons, baryons or combinations thereof, and mesons.

The Particle Adventure

Visit the award-winning web feature The Particle Adventure at <http://www.feynman.com>.

This chart has been made possible by the generous support of:
 U.S. Department of Energy
 Lawrence Berkeley National Laboratory
 Stanford Linear Accelerator, University of California
 National Science Foundation, Division of Particle and Field Studies
 BNL, ILL, INEL, FNAL, etc.

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Retour à l'histoire



Heureusement que tout n'était pas connu

- Résistance nulle (sauf s'il y a un aimant proche)
- L'effet Meissner (pas parfait)
- Parfois pas transparent aux micro-ondes
- Effet isotopique (parfois en direction opposée)



La théorie la mieux comprise

- En 1969, R.D. Parks deux volumes
« Superconductivity »
- D'un des auteurs: « *C'est le dernier clou dans le cercueil de la supraconductivité* »



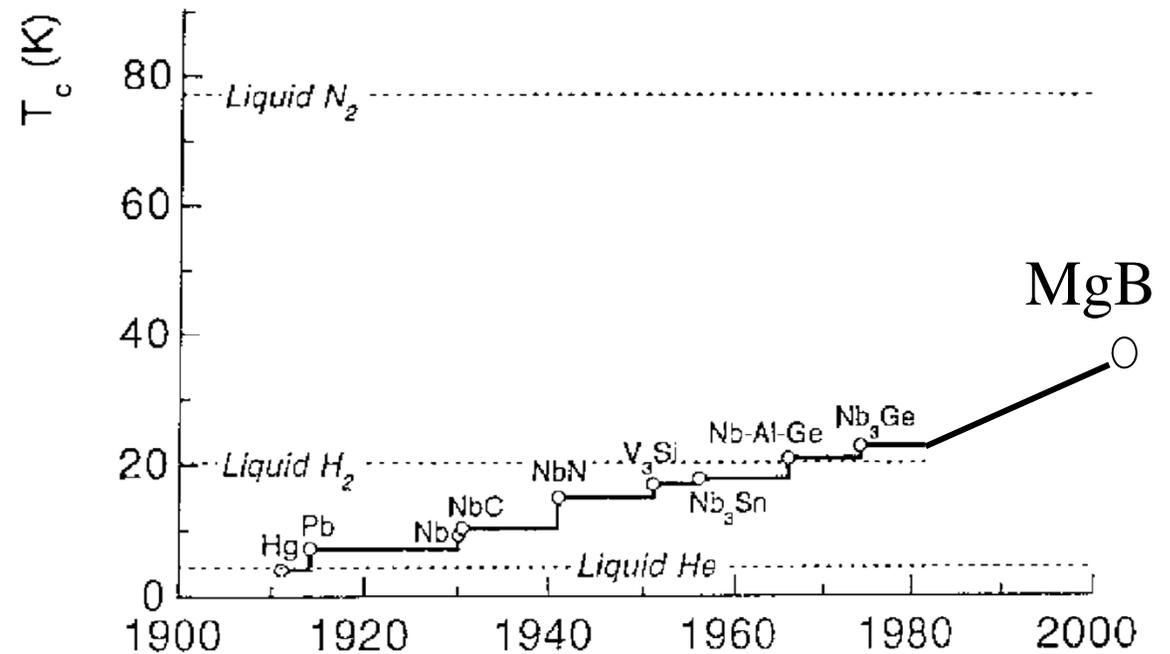
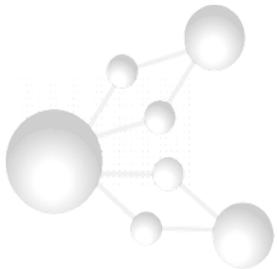
La quête de nouveaux matériaux

Le but: la température de l'azote
liquide!

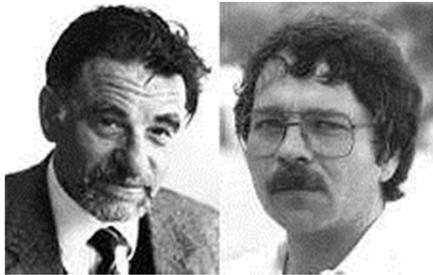


On croyait généralement que (1952)

- Métaux de transition (pas Cu,Au,Fe)
- Cubique
- Ne pas s'approcher de
 - 0
 - Aimants
 - Isolants



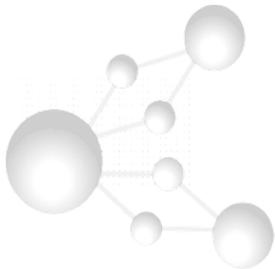
Janvier 1986



OSNI

1986 : Bednorz et Muëller, IBM
Zurich
La-Ba-Cu-O $T_c \sim 30-40K$

Effet Meissner ?



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Ça va vite...

- Boston, "Materials Research Society"
Décembre 1986
 - Koitchi Kitazawa et Shoji Tanaka Tokyo convainquent tout le monde.
- 16 février 1987, Houston:
 - Conférence de presse par **Paul Chu** pour annoncer la découverte de *Y-Ba-Cu-O*
 - $T_c = 93\text{ K}$ (vs 77 K)



March meeting APS, 1987

- Titre du New York Times le lendemain:
"The Woodstock of Physics"

- 3000 personnes jusqu'à 3 heures du matin

"They began lining up outside the New York Hilton Sutton Ballroom at 5:30PM for an evening session that would last until 3:00 AM"





The "Woodstock of physics." On March 18, 1987, thousands of physicists crammed a ballroom at the New York Hilton to celebrate the coming of the age of superconductivity.

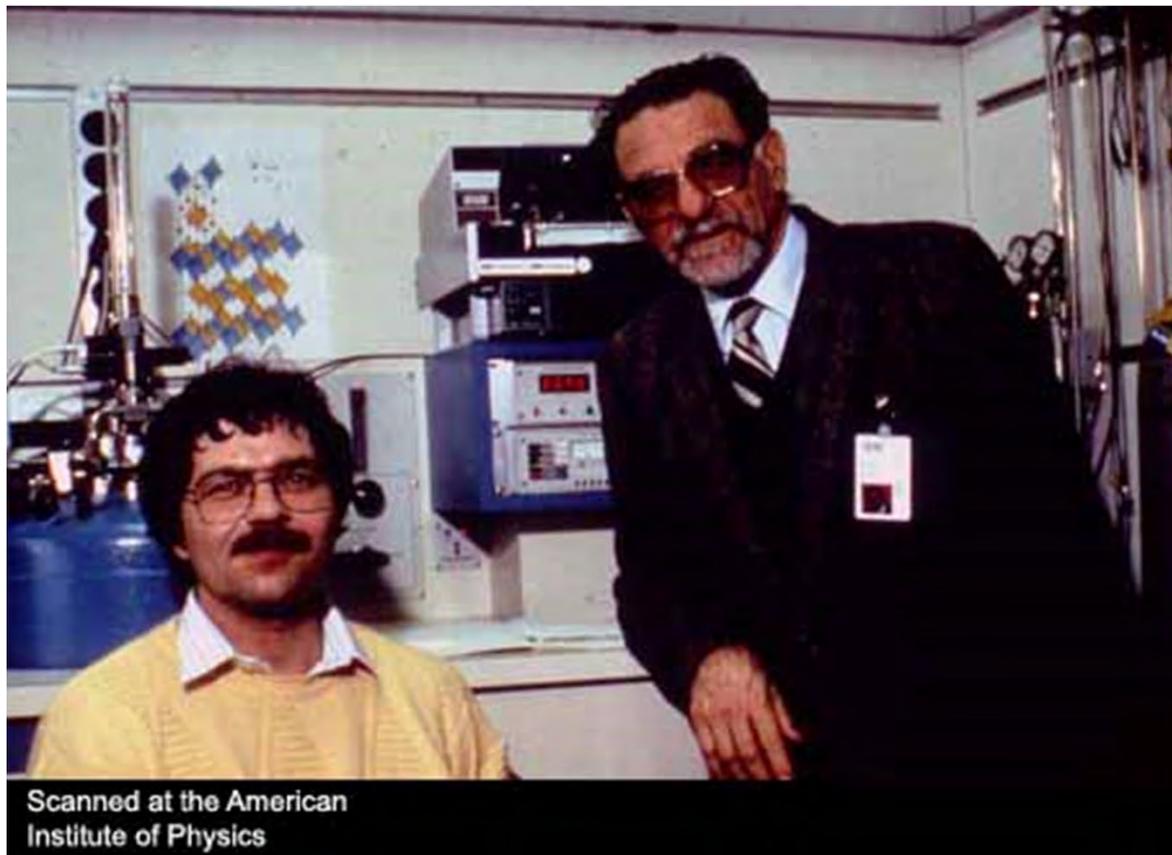
AMERICAN INSTITUTE OF PHYSICS

(right) Alex Müller, Paul Chu, and Shoji Tanaka, answering questions at the "Woodstock" meeting. Tanaka and Koichi Kitazawa were the first to confirm Bednorz and Müller's discovery, launching a worldwide race to find still better superconductors.

AMERICAN INSTITUTE OF PHYSICS







Ce qu'il y a de particulier avec ces supraconducteurs

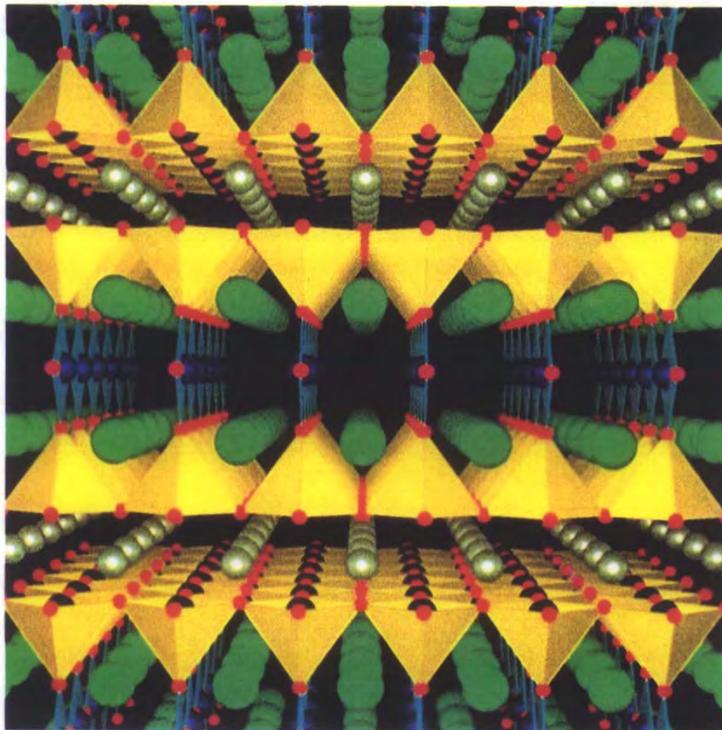


Structure atomique

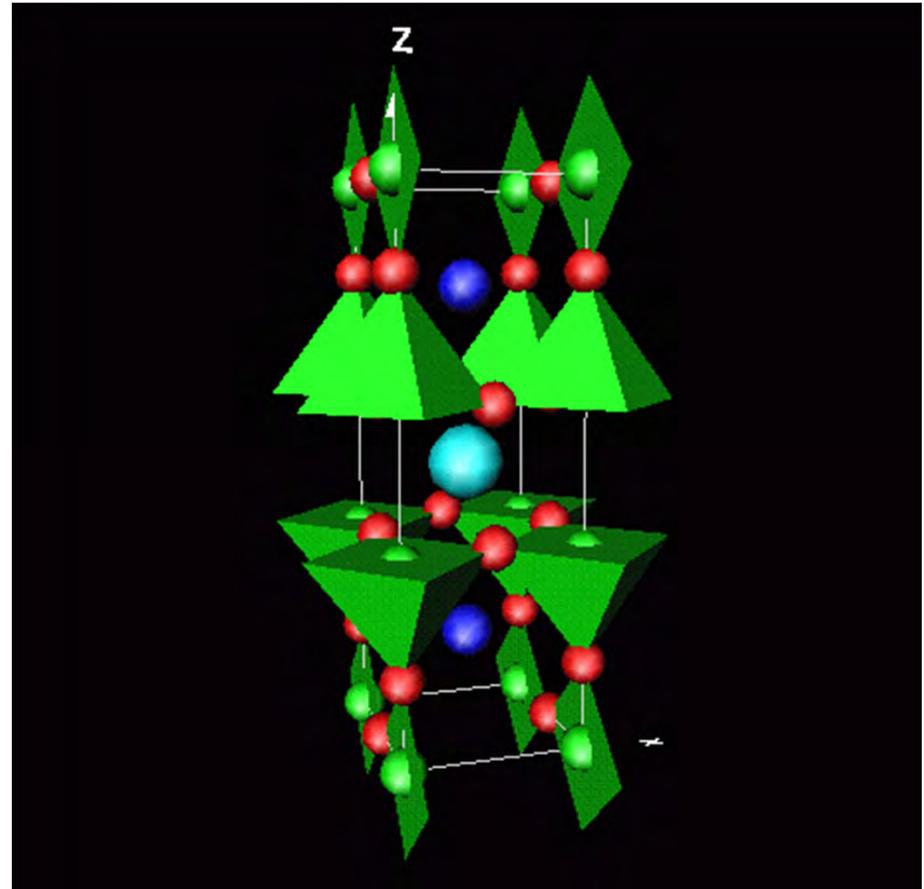
SCIENTIFIC AMERICAN

JUNE 1988
\$3.50

How nonsense is deleted from genetic messages.
R& for economic growth: aggressive use of new technology.
Can particle physics test cosmology?



High-Temperature Superconductor belongs to a family of materials that exhibit exotic electronic properties.
 $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ 92-37



Ce qu'il y a de particulier

- Métaux de transition
- Cubique
- S'éloigner de
 - O
 - Aimants
 - Isolants
- Cu
- En couche
- Près de
 - O
 - Aimants
 - Isolants

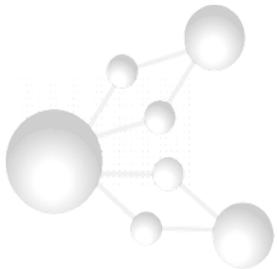
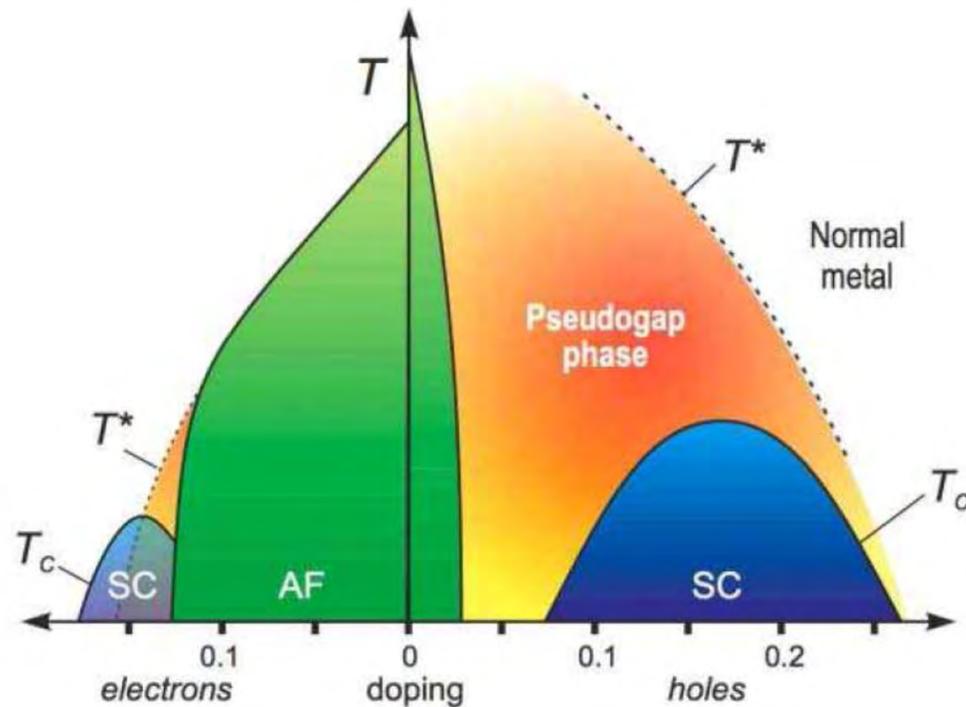


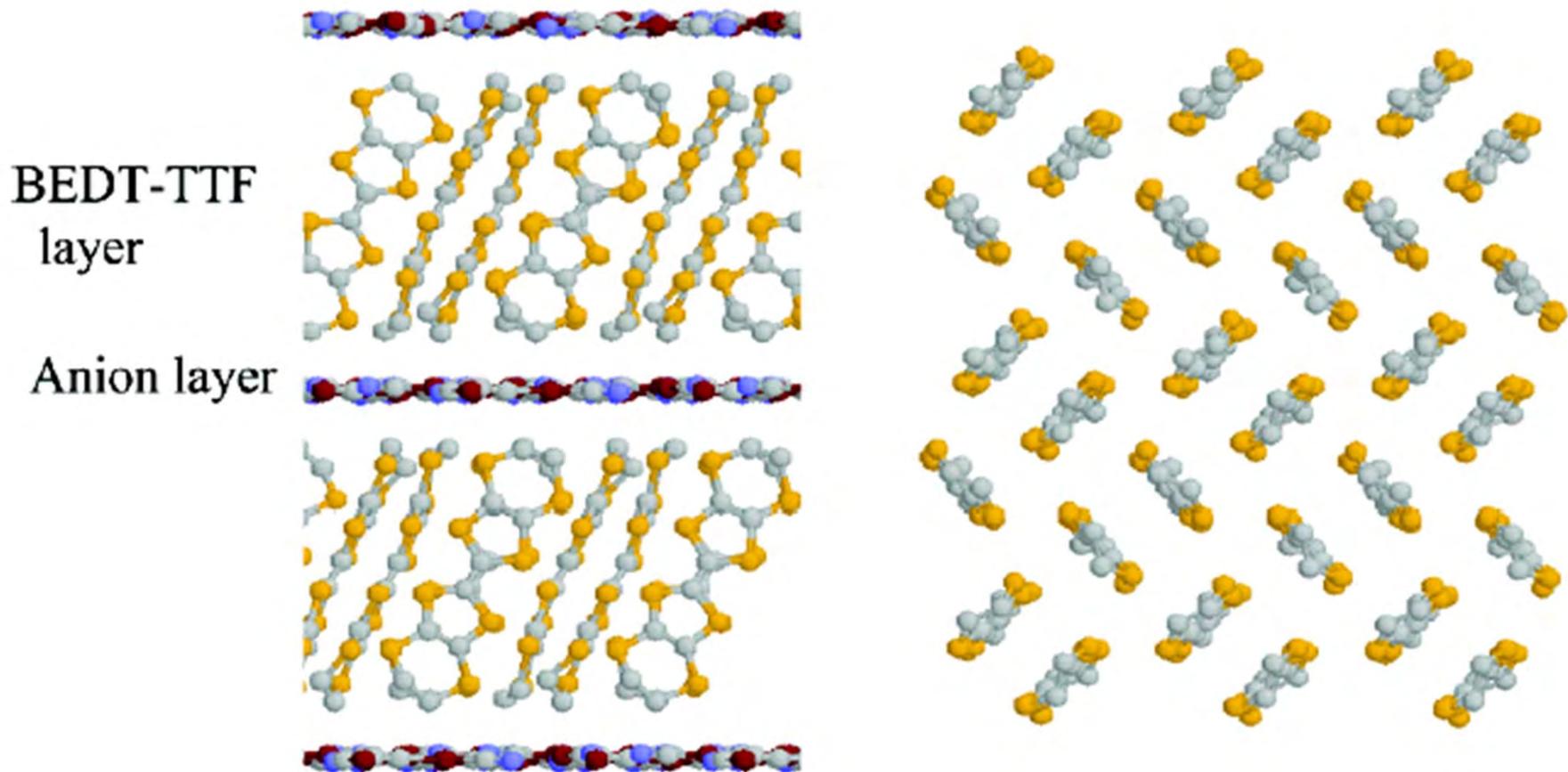
Diagramme de phase



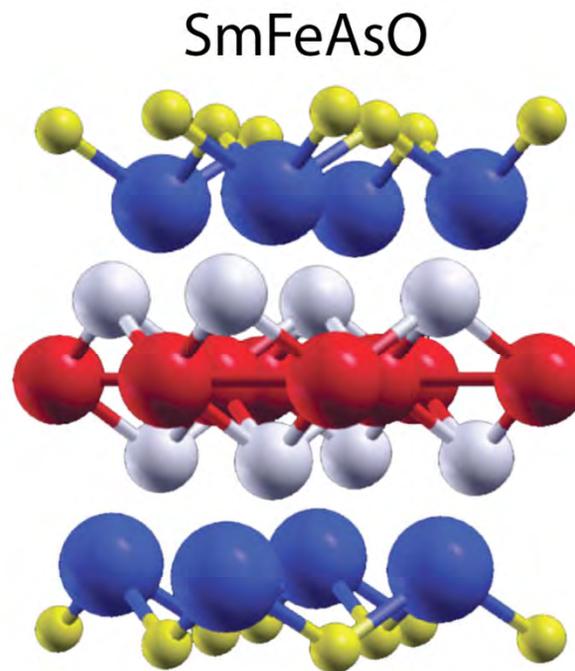
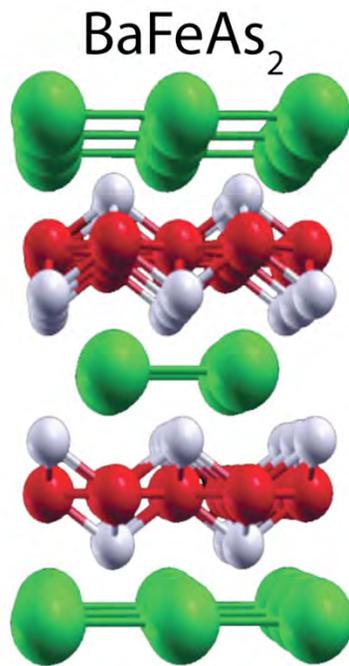
Fischer et al. Rev. Mod. Phys. 79, 353 (2007)



Conducteurs organiques en couches (κ -BEDT-X)



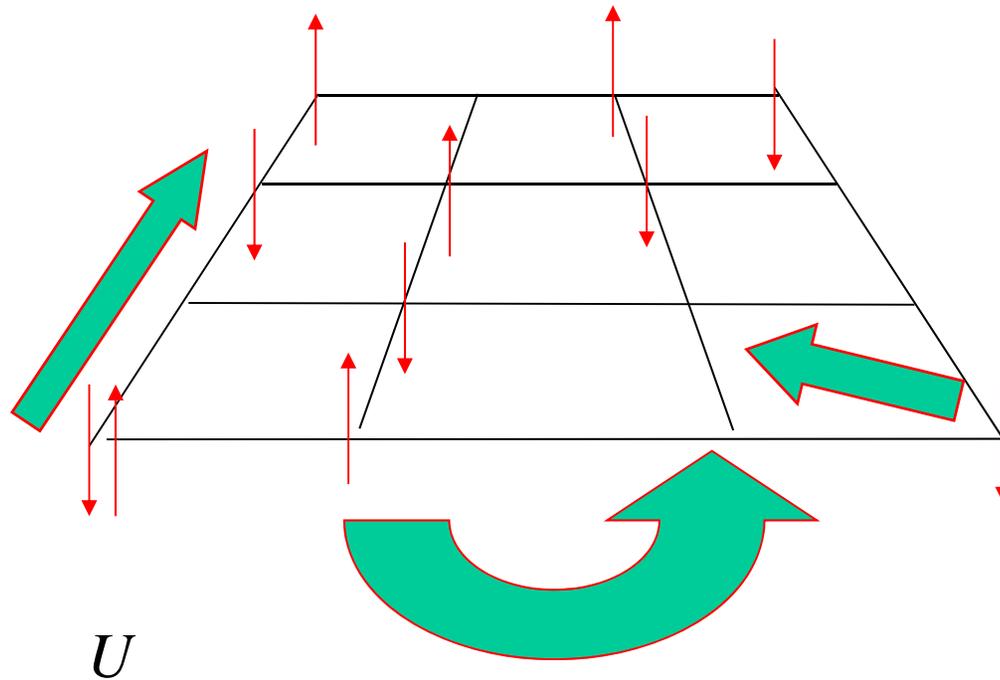
Pnictures (2008)



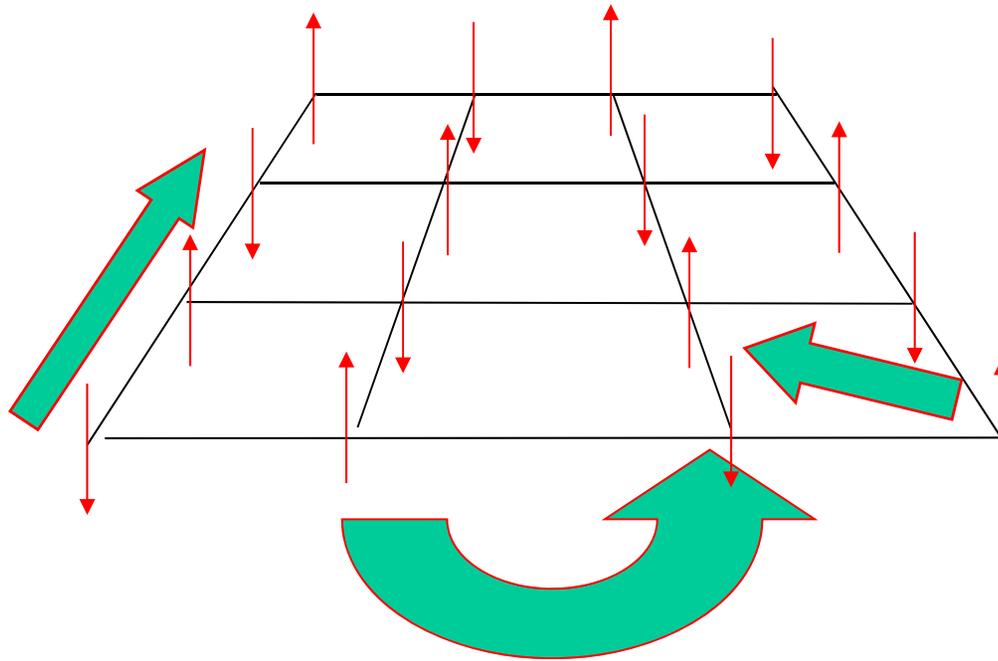
http://www.stanford.edu/~tpd/research_hightc.html



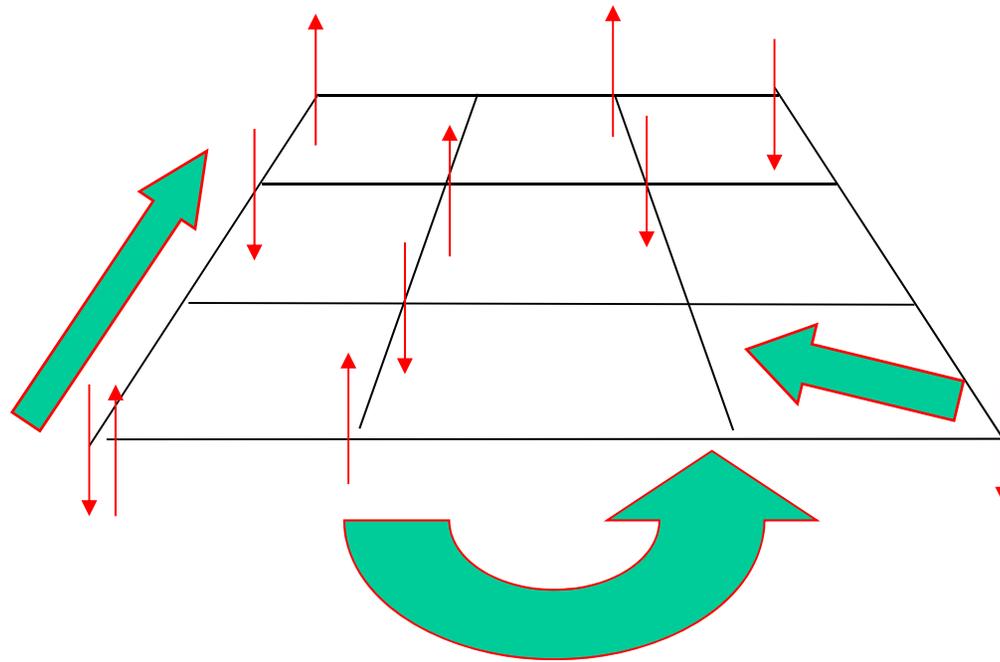
Pourquoi est-ce si difficile à comprendre?



Isolant

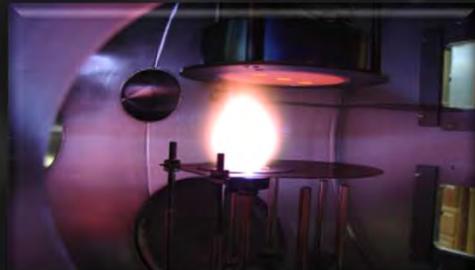
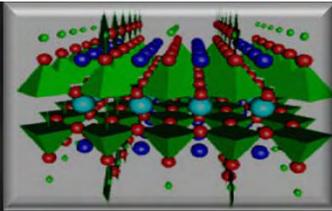


Pourquoi est-ce si difficile à comprendre?



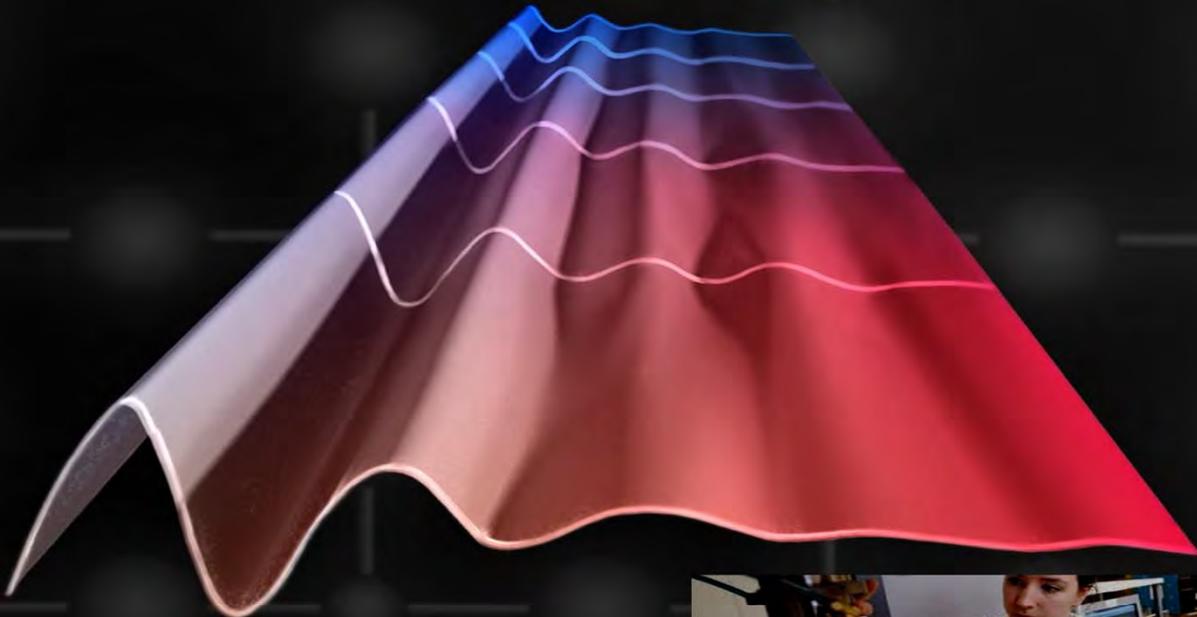


Scanned at the American Institute of Physics



$$H(t) = - \sum_{ij\sigma} t_{ij} c_{i\sigma}^\dagger c_{j\sigma} e^{-i \int_i^j d\mathbf{r}_{ij} \cdot \mathbf{A}(\mathbf{r}, t)} + U \sum_i n_{i\uparrow} n_{i\downarrow}$$

$$\Delta_{\mathbf{p}} = \frac{1}{V} \sum_{\mathbf{p}'} U(\mathbf{p} - \mathbf{p}') \langle c_{-\mathbf{p}'\downarrow} c_{\mathbf{p}'\uparrow} \rangle$$



$$|BCS(\theta)\rangle = \dots + e^{iN\theta} |N\rangle + e^{i(N+2)\theta} |N+2\rangle + \dots$$



Conclusion

Le rêve



room-temperature superconductors

They would transform the grid—if they can exist at all By Michael Moyer

You can build a coal-fired power plant just about anywhere. Renewables, on the other hand, are finicky. The strongest winds blow across the high plains. The sun shines brightest on the desert. Transporting that energy into cities hundreds of kilometers away will be one of the great challenges of the switch to renewable energy. The most advanced superconducting cable can move those megawatts thousands of kilometers with losses of only a few percent. Yet there is a catch: the cable must be kept in a bath of liquid nitrogen at 77 kelvins (or -196 degrees Celsius). This kind of deployment, in turn, requires pumps

and refrigeration units every kilometer or so, greatly increasing the cost and complexity of superconducting cable projects. Superconductors that work at ordinary temperatures and pressures would enable a truly global energy supply. The Saharan sun could power western Europe via superconducting cables strung across the floor of the Mediterranean Sea. Yet the trick to making a room-temperature superconductor is just as much of a mystery today as it was in 1986, when researchers constructed the first superconducting materials that worked at the relatively high temperatures of liquid nitrogen (pre-

vious substances needed to be chilled down to 23 kelvins or less). Two years ago the discovery of an entirely new class of superconductor—one based on iron—raised hopes that theorists might be able to divine the mechanism at work in high-temperature superconductors [see “An Iron Key to High-Temperature Superconductivity?” by Graham P. Collins; SCIENTIFIC AMERICAN, August 2009]. With such insights in hand, perhaps a path toward room-temperature superconductors would come into view. But progress has remained slow. The winds of change don't always blow on cue.

www.ScientificAmerican.com

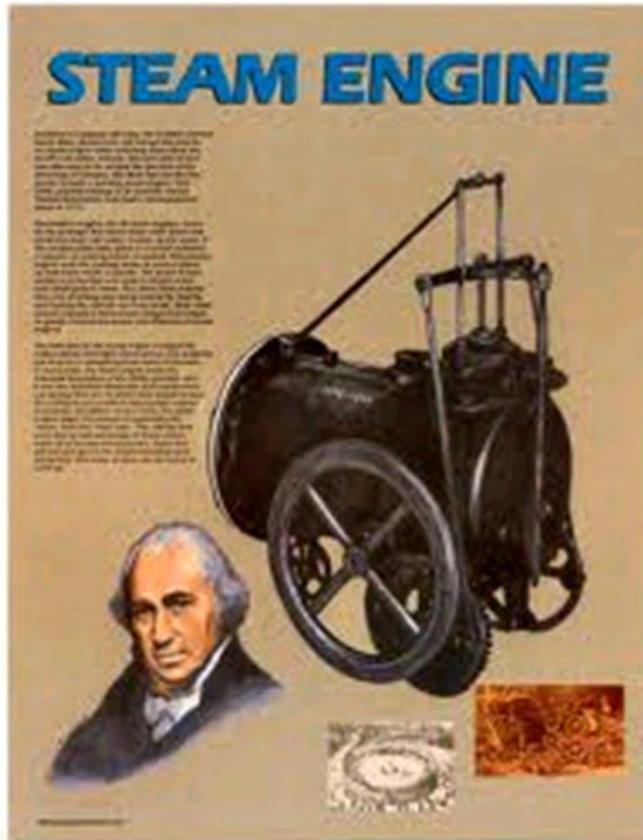
<http://www.physique.usherbrooke.ca/taillefer/Vulgarisation.html>



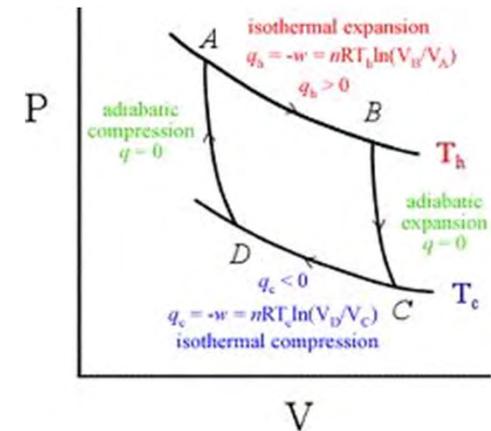
Science et technologie, main dans la main



Machine à vapeur et thermodynamique



Watts 1765



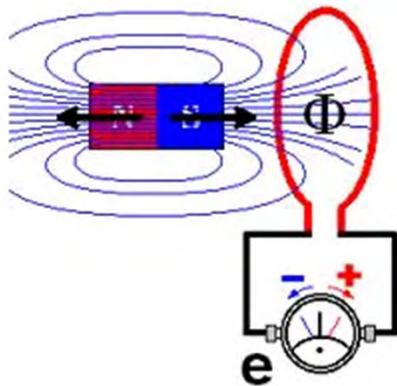
Carnot 1824



Induction et le moteur électrique



Induction, Faraday (1831)



Moteur électrique, Tesla(1880)



Induction



Électron and television



Thomson, 1897



Télévision, 1940



Mécanique quantique et le transistor



Prof. Dr. Erwin Schrödinger
reçoit le prestigieux Nobel pour la Physique. Prof. Schrödinger
enseignait jusqu'à son départ en Allemagne, mais il fut invité à
venir à Oxford. — Il a fait le célèbre Atome modèle
représenté par un «Schwinger»-Modell.
Phot. Robertson, Berlin

Schrödinger



Heisenberg

Mécanique quantique 1926

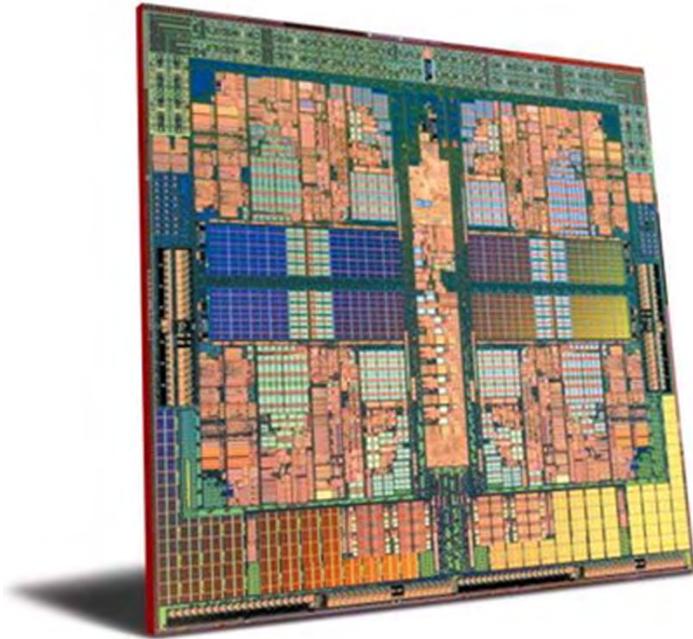
The first point contact transistor
William Shockley, John Bardeen, and Walter Brattain
Bell Laboratories, Murray Hill, New Jersey (1947)



Transistor 1947



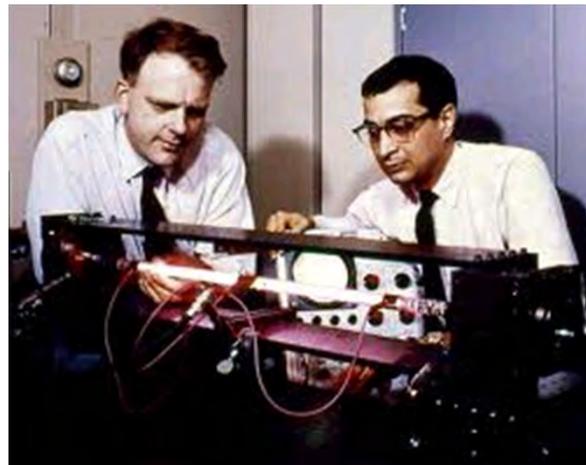
Mécanique quantique et le transistor



Laser et CD-ROM



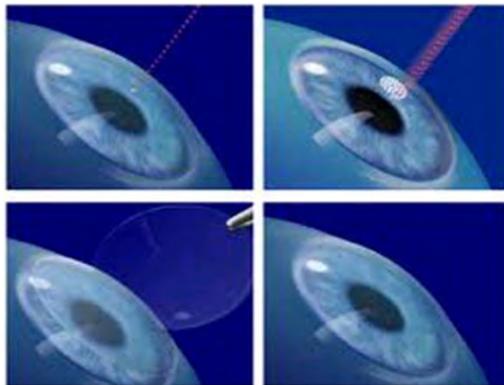
Stimulated emission 1925



Laser 1960



CD-ROM (1980-90)



Chirurgie oculaire



Edward Bellamy (USA) 1887

- Roman: « Looking backward » 2000-1887
- Si nous pouvions inventer un dispositif pour offrir à tous de la musique dans leur maison, qui serait de qualité parfaite, de quantité illimitée, pour toutes les humeurs et qui commencerait et s'arrêterait lorsqu'on voudrait, alors nous aurions atteint la limite du bonheur pour l'humanité et nous pourrions cesser de chercher des améliorations.



Merci



<http://sweetladiesbakery.com/gallery/female-cakes/>