



CIFAR
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for ADVANCED RESEARCH



Fondation canadienne pour l'innovation

Fonds de recherche
Nature et
technologies

Québec

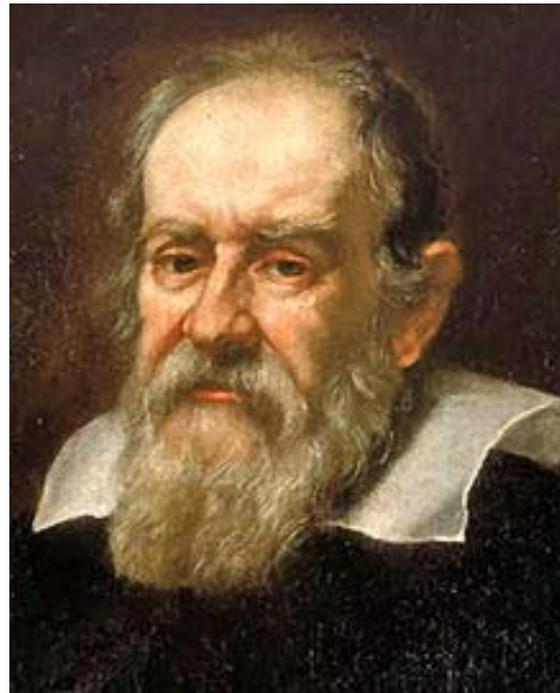


Supraconductivité: La mécanique quantique devant vos yeux.

André-Marie Tremblay



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 $T = 0$



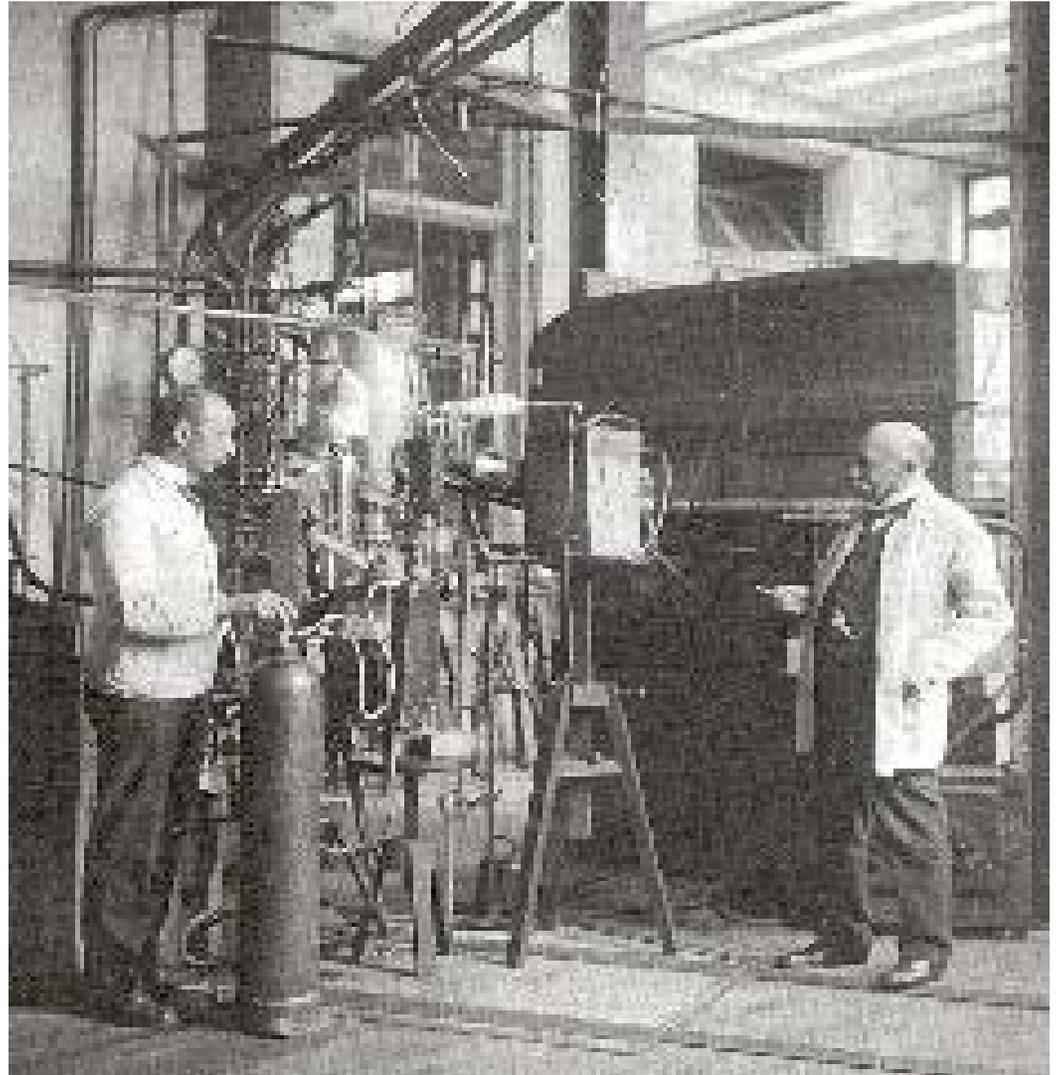
- Heike Kamerlingh Onnes
(Leiden) (1853/1926)



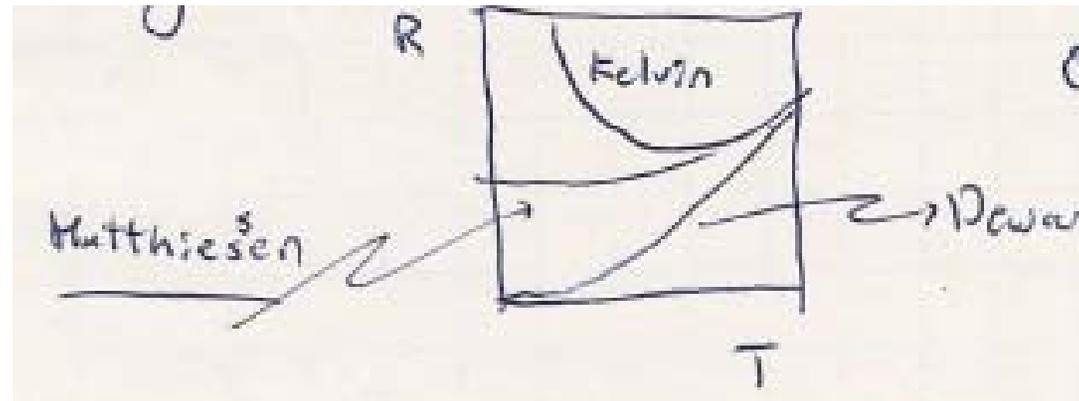
Les débuts du travail d'équipe en recherche



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



Et quoi encore?

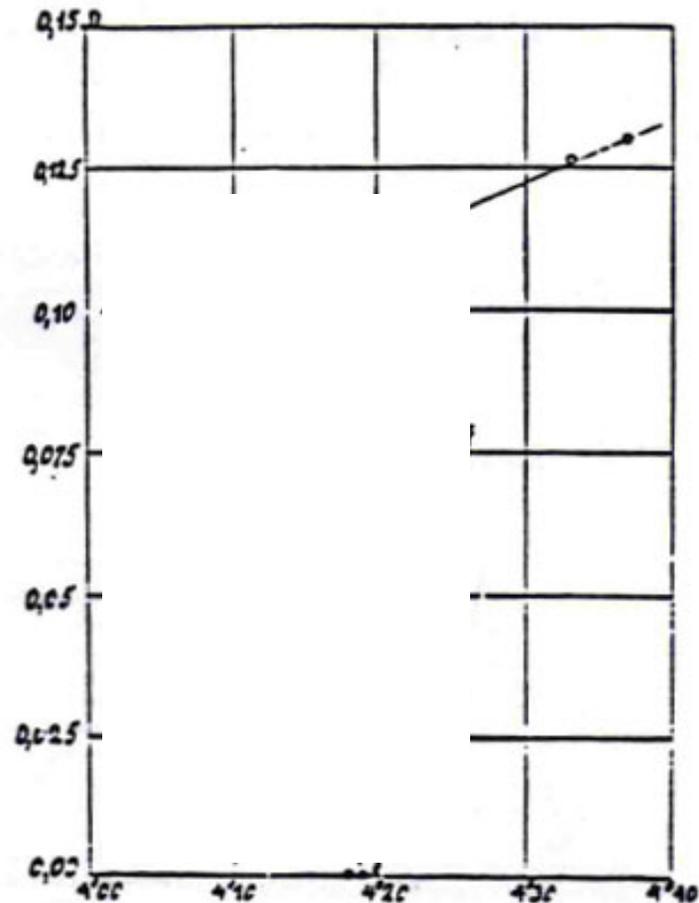


Et alors?



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

8 avril 1911



Congrès Solvay, 1911



GOLDSCHMIDT
NERNST

PLANCK
BRILLOUIN

RUBENS
SOMMERFELD
SOLVAY

LINDEMANN
M. DE BROGLIE
LORENTZ

HASENDRHL
HOSTELET

KNUDSEN
WARBURG
PERRIN

HERZEN
WIEN

JEANS
Madame CURIE

RUTHERFORD
POINCARÉ

KAMERLINGH ONNES

EINSTEIN

LANGEVIN

Et le gagnant est...



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



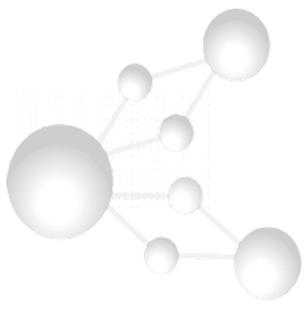
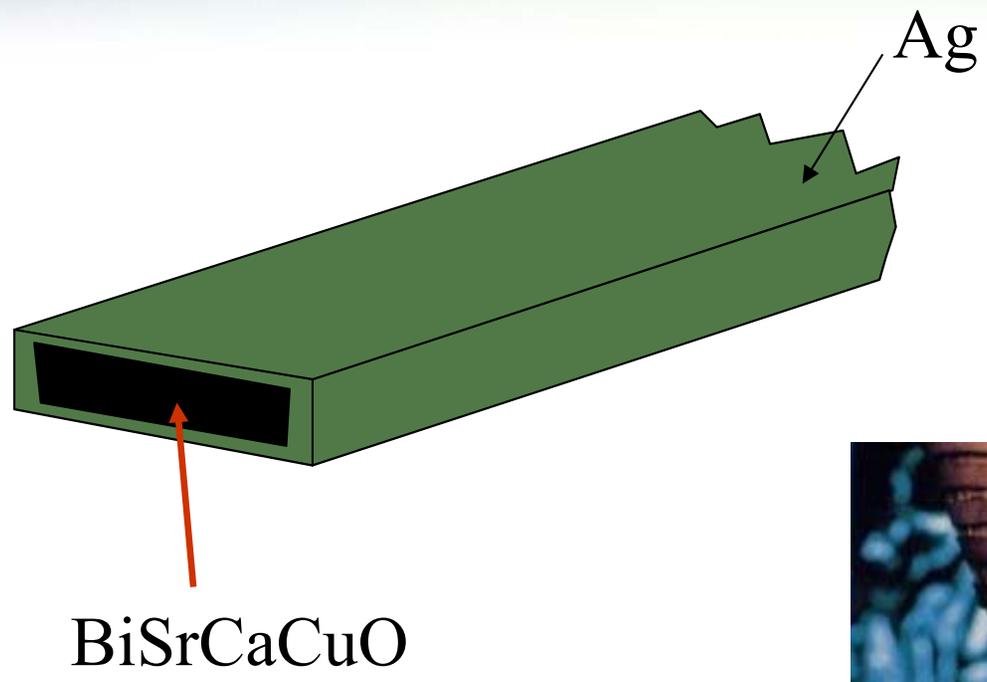
<http://www.nobel.se>

1913: Prix Nobel de physique

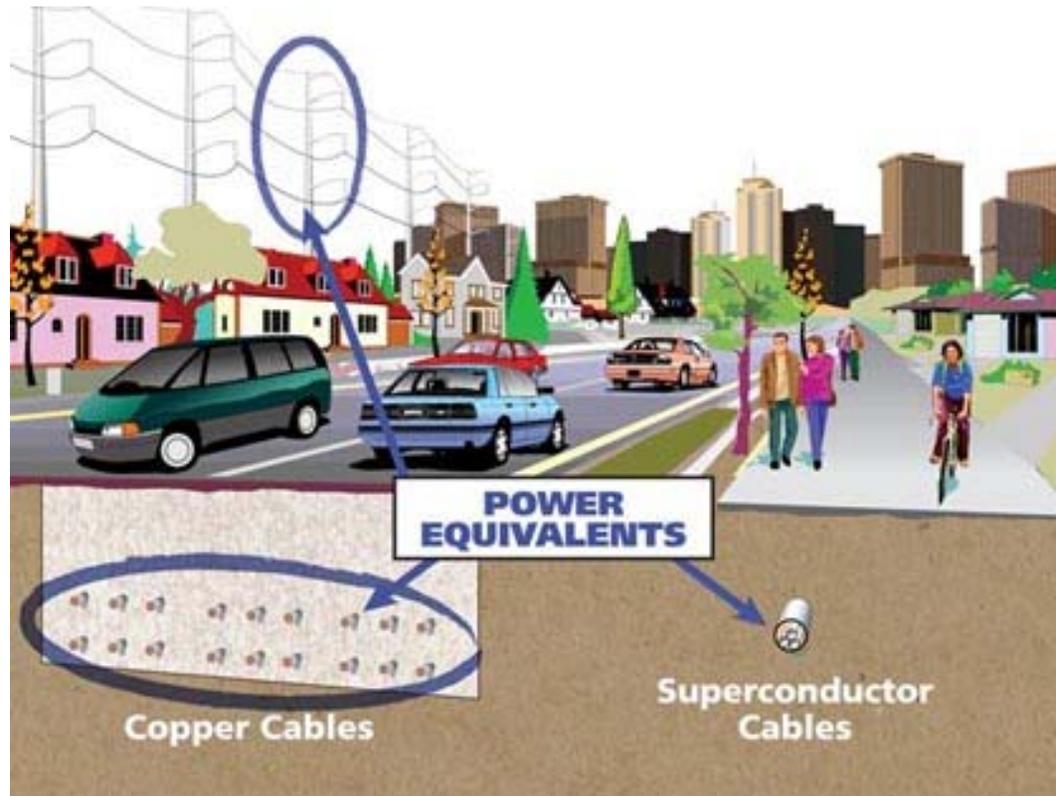
Au Professeur H. Kamerlingh Onnes de Leiden, pour ses expériences sur les propriétés de la matière à basse température qui ont conduit, concomitamment à la production de l'hélium liquide.

Transmission de l'électricité

Câbles

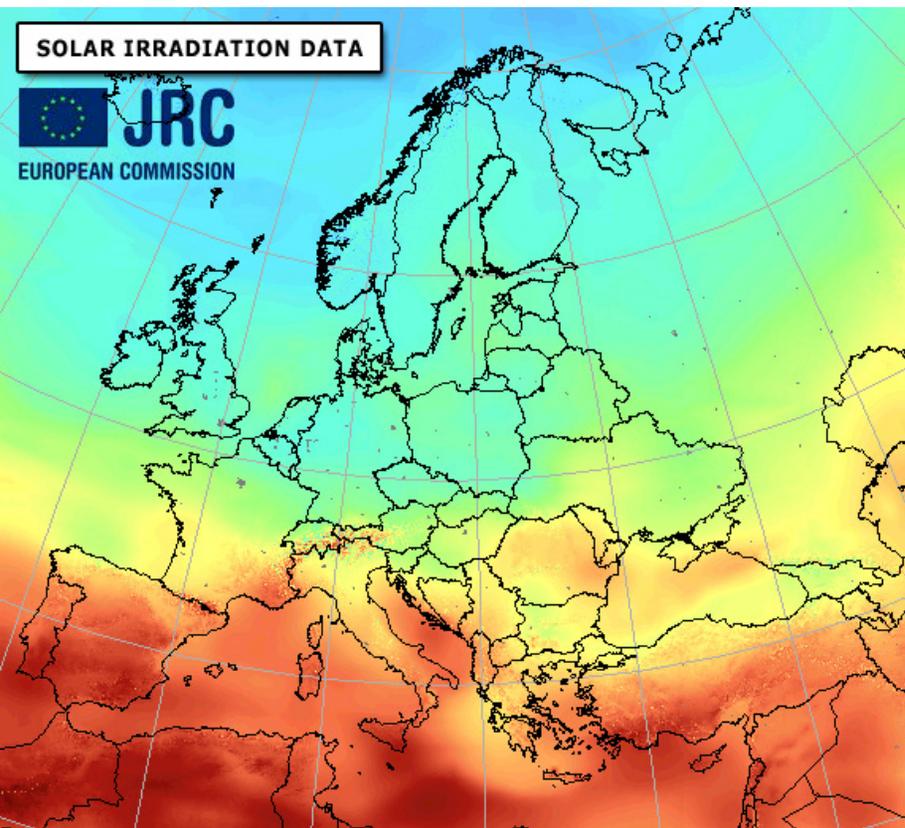


7 octobre 2010, American Superconductors



3,000 km de câbles pour la Corée du sud

Production et besoin



[Regional Agenda](#) | [SDG 07: Affordable and Clean Energy](#) | [Electricity](#) | [Oil and Gas](#)

Could the Sahara turn Africa into a solar superpower?



A promising theory, but could it work in reality?

Image: Unsplash/Nicolas Jehly

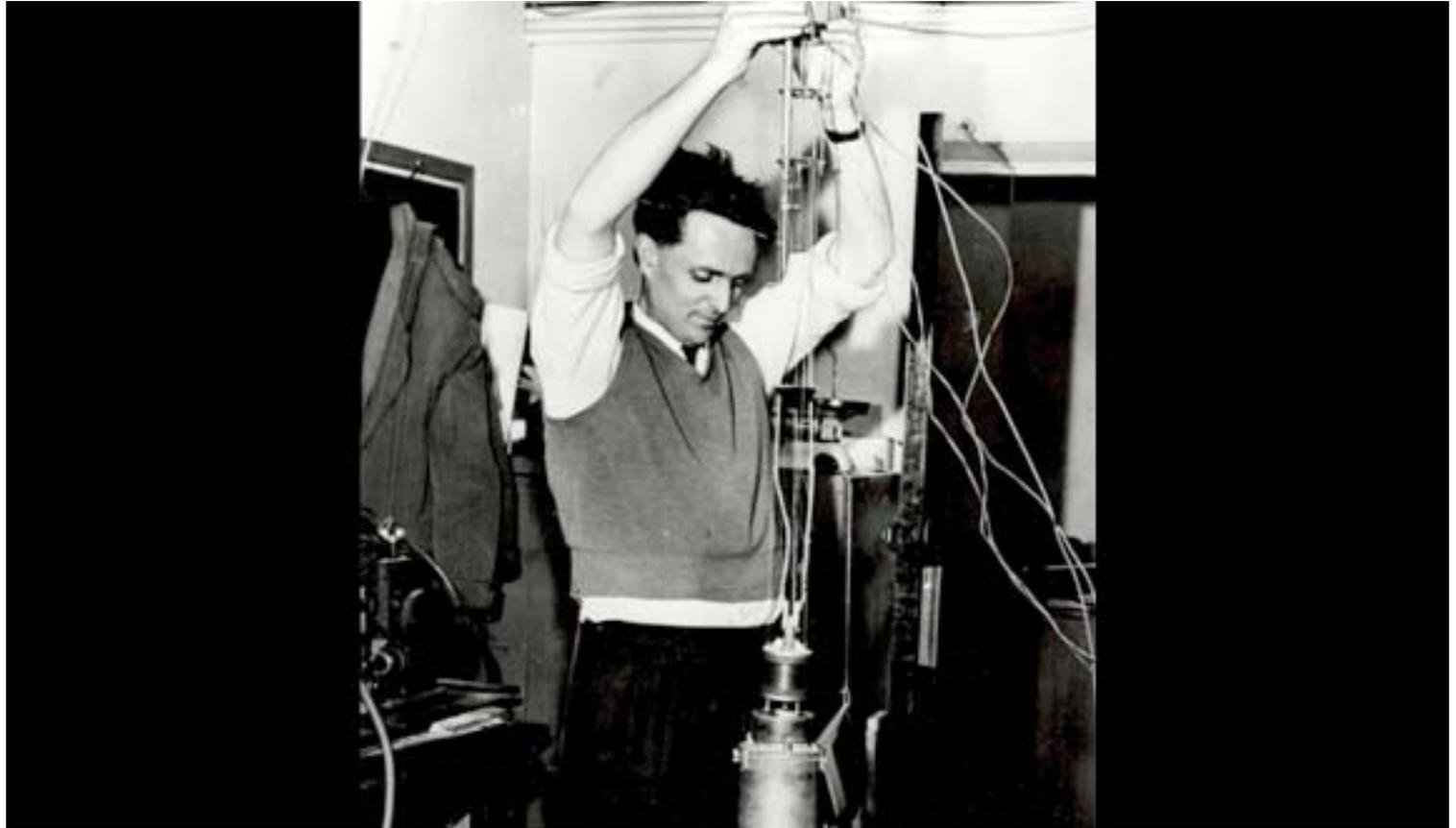
Tourner en rond tout en
faisant quelque chose
d'utile

André-Marie Ampère



1775 - 1836

Le premier aimant supraconducteur

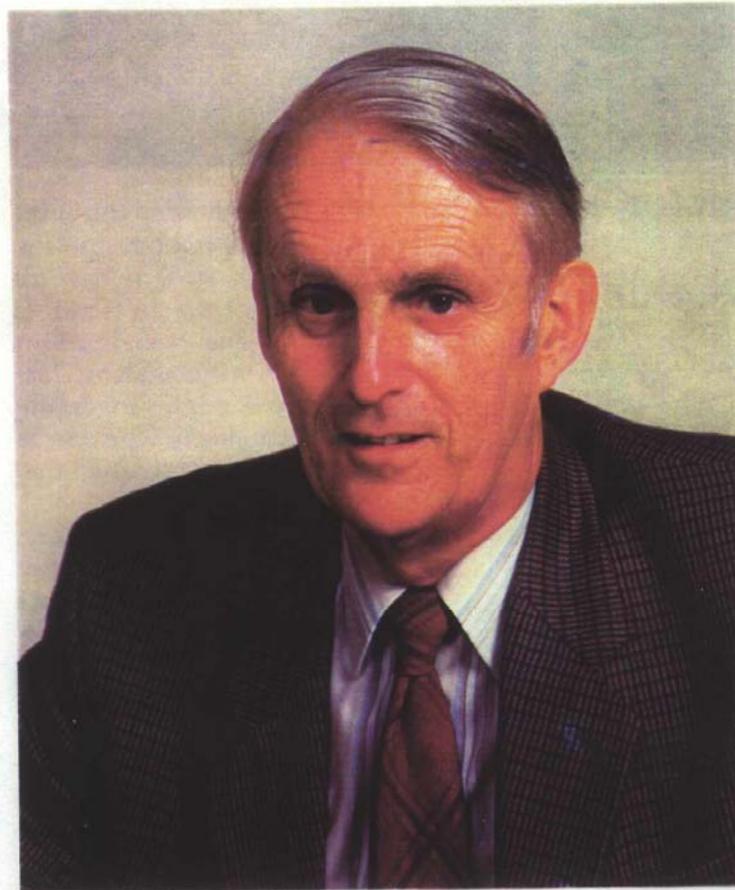
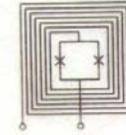


Martin

Wood, 1962

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).

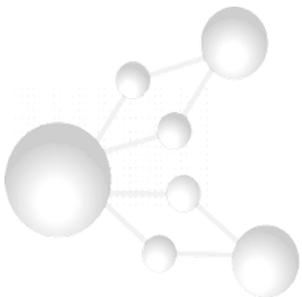
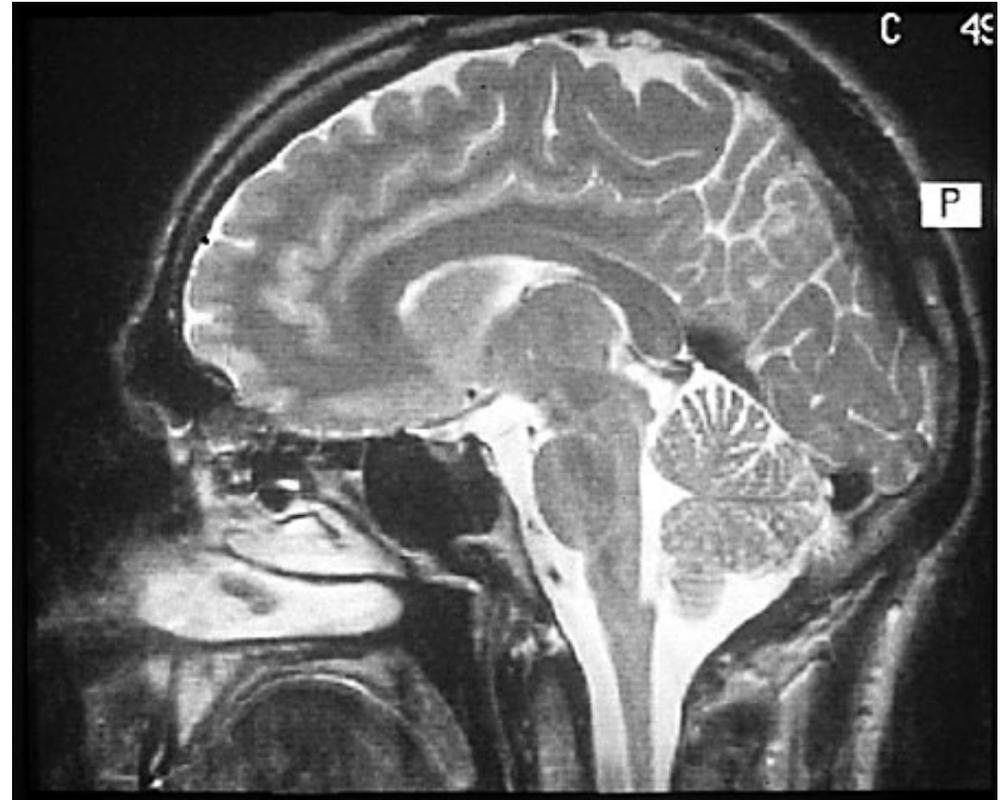
Test, train à lévitation magnétique, Japan Rail



JR-MLX01 maglev train at [Yamanashi](#) test track (630 km/h 2015)

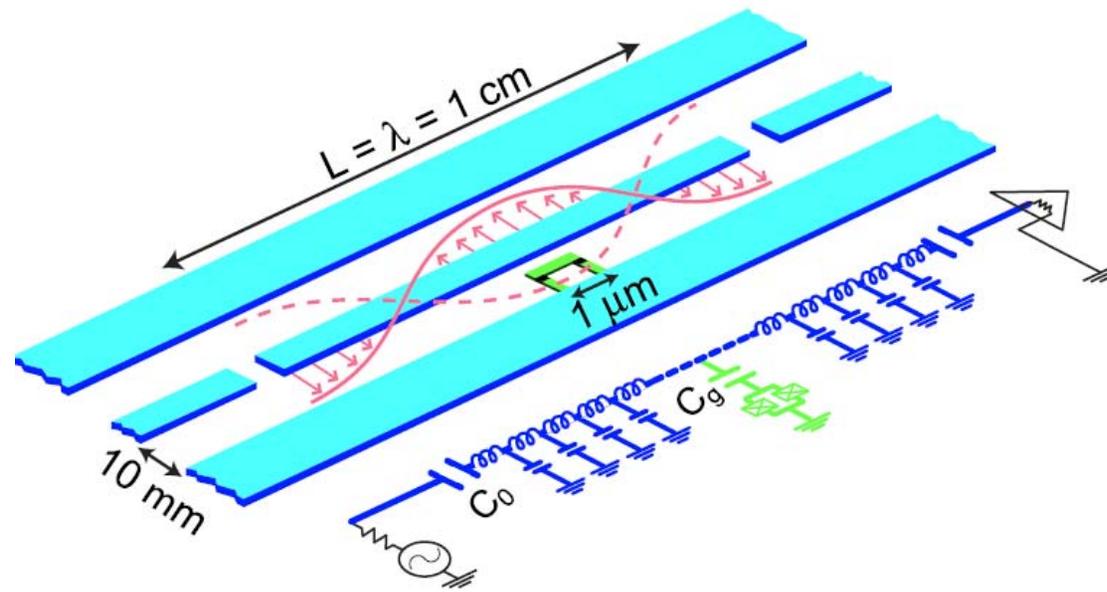
En médecine

Imagerie par résonance magnétique

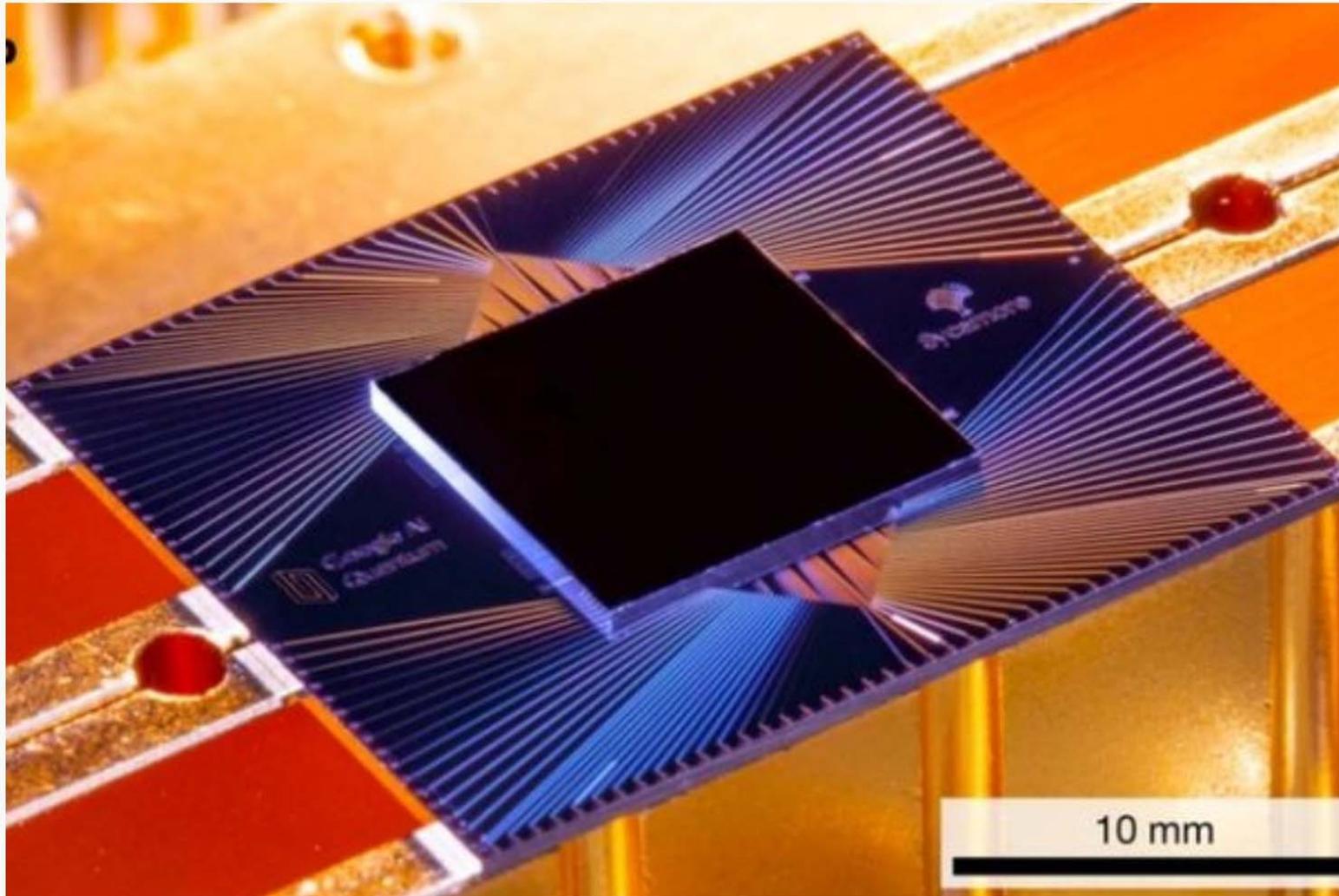


Et là où vous l'attendez
le moins

L'ordinateur quantique



Google franchit un cap vers la «suprématie quantique»



GOOGLE

Le processeur Sycamore parvient à réaliser un calcul en 200 secondes, là où un supercalculateur «classique» aurait mis «environ 10 000 ans».

De retour à la lévitation

Michael Faraday



1791-1867

Induction

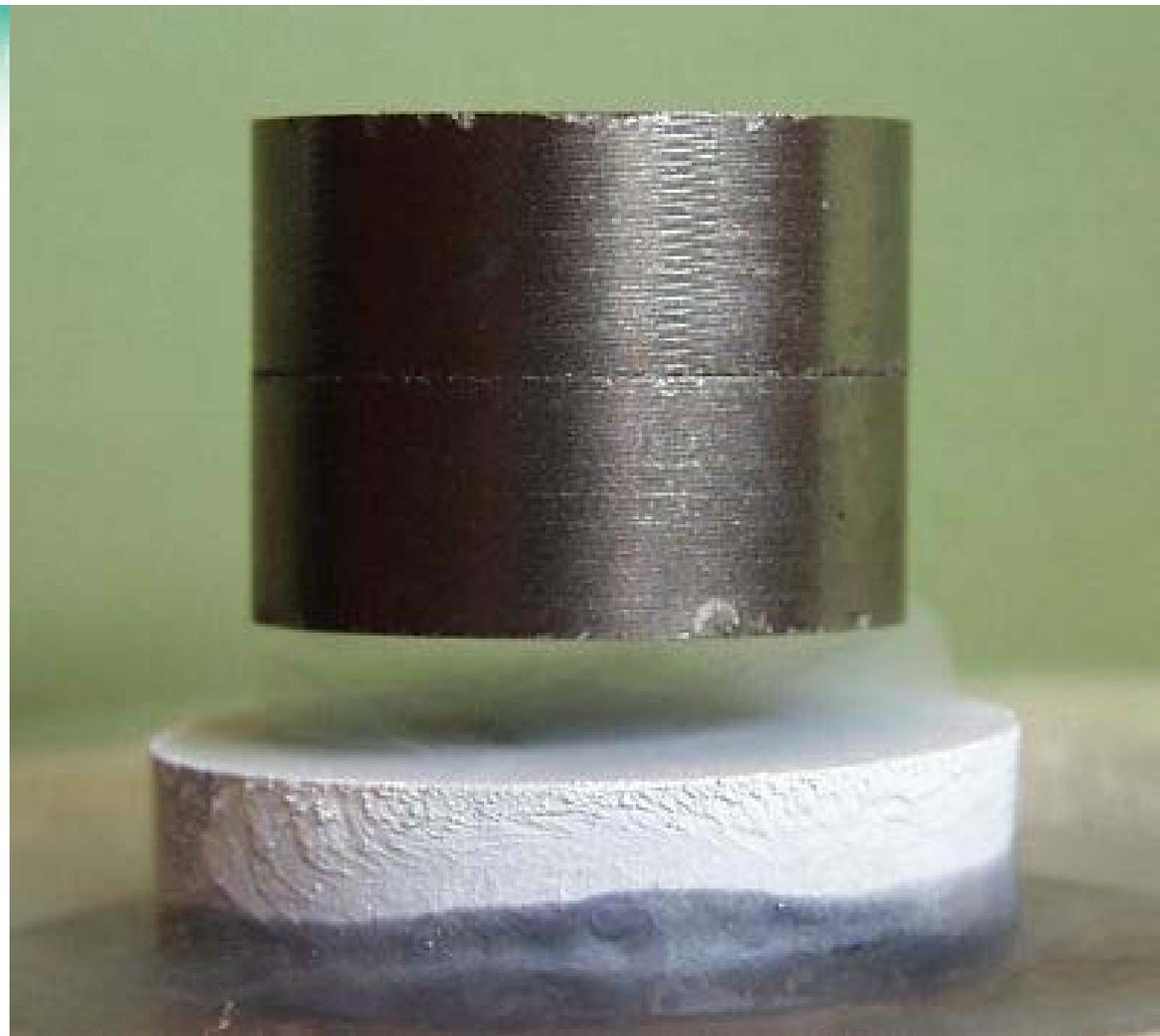




**Walther Meissner
(1882-1974)**



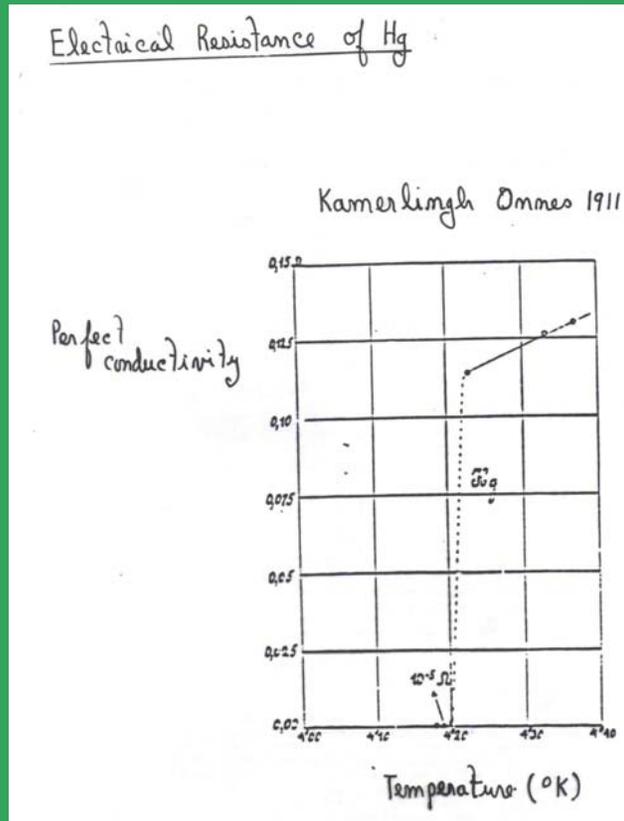
R. Ochsenfeld (1900-1992)



Deux propriétés importantes



1. Résistance zéro (si $\mathbf{B=0}$)



2. Diamagnetism



Un état de la matière



par Alexis Reymbaut, 2014

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



Échec : E

Feynman

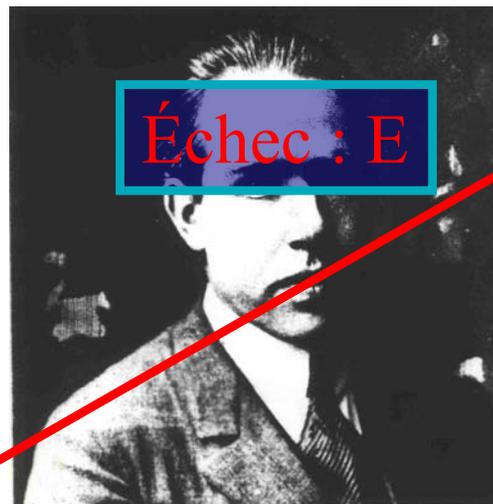


Échec : E

Heisenberg

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

Bohr



Échec : E

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



Échec : E

Comportement quantique à l'échelle macroscopique

Leon Cooper



Prix Nobel : 1972

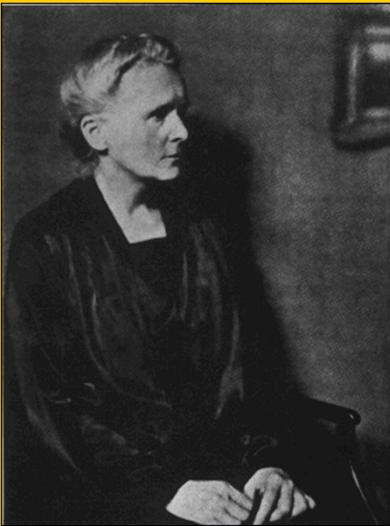
John Bardeen*

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

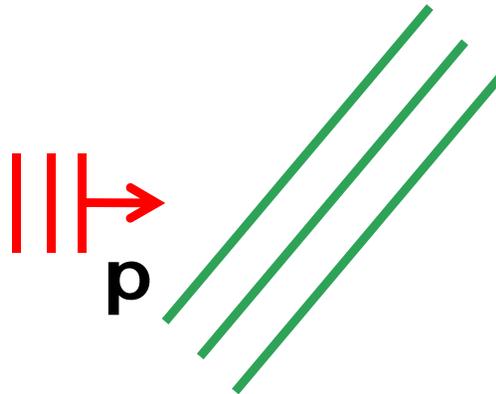
1911 Chimie (seule)

Ce qui était connu

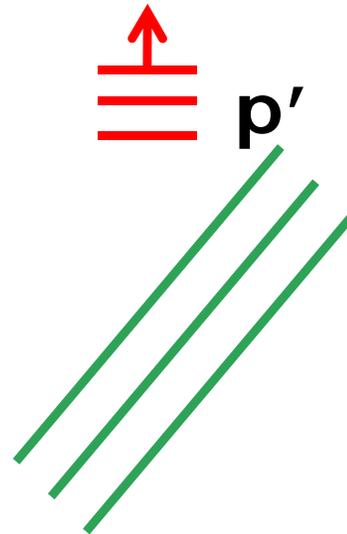
- La résistance s'annule
- L'effet Meissner
- Transparent aux microondes basse fréquence
- Effet isotopique

L'explication:
Un premier
phénomène: les
électrons peuvent
s'attirer

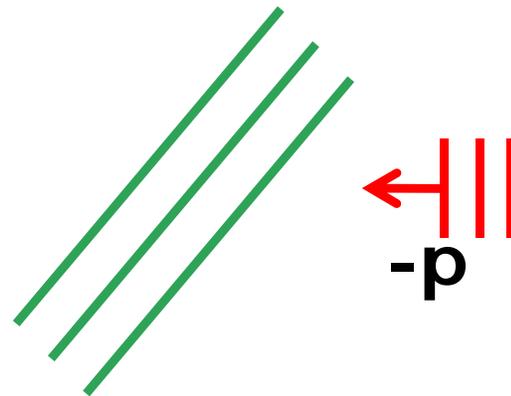
Mécanisme d'attraction dans l'état métallique



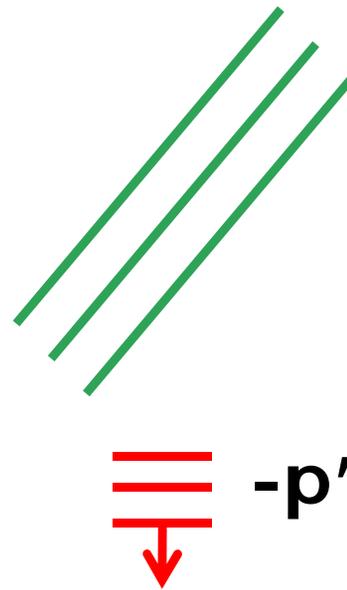
Mécanisme d'attraction dans l'état métallique



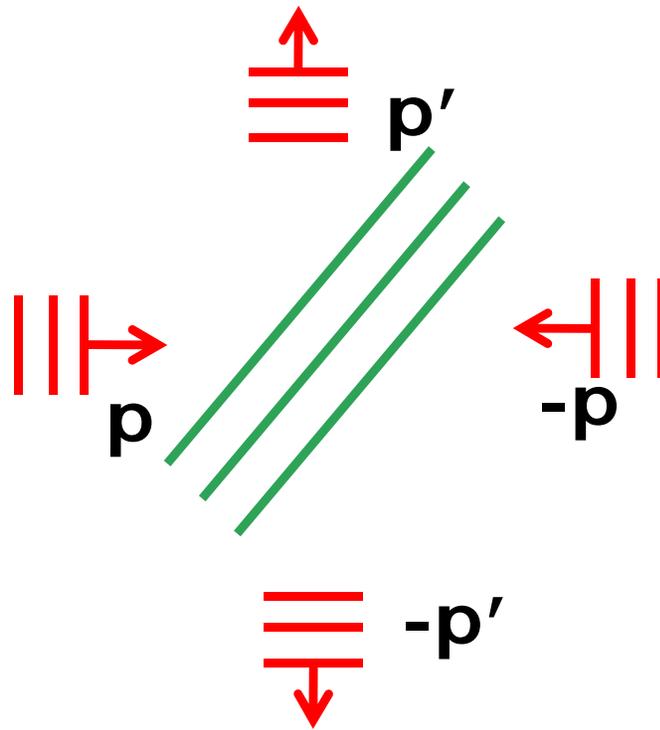
Mécanisme d'attraction dans l'état métallique



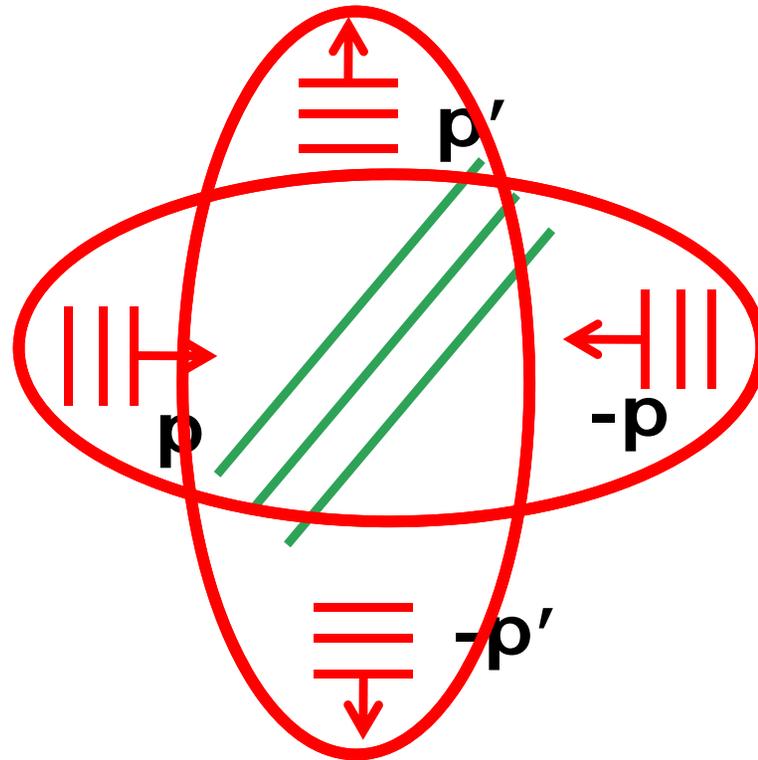
Mécanisme d'attraction dans l'état métallique



Mécanisme d'attraction dans l'état métallique



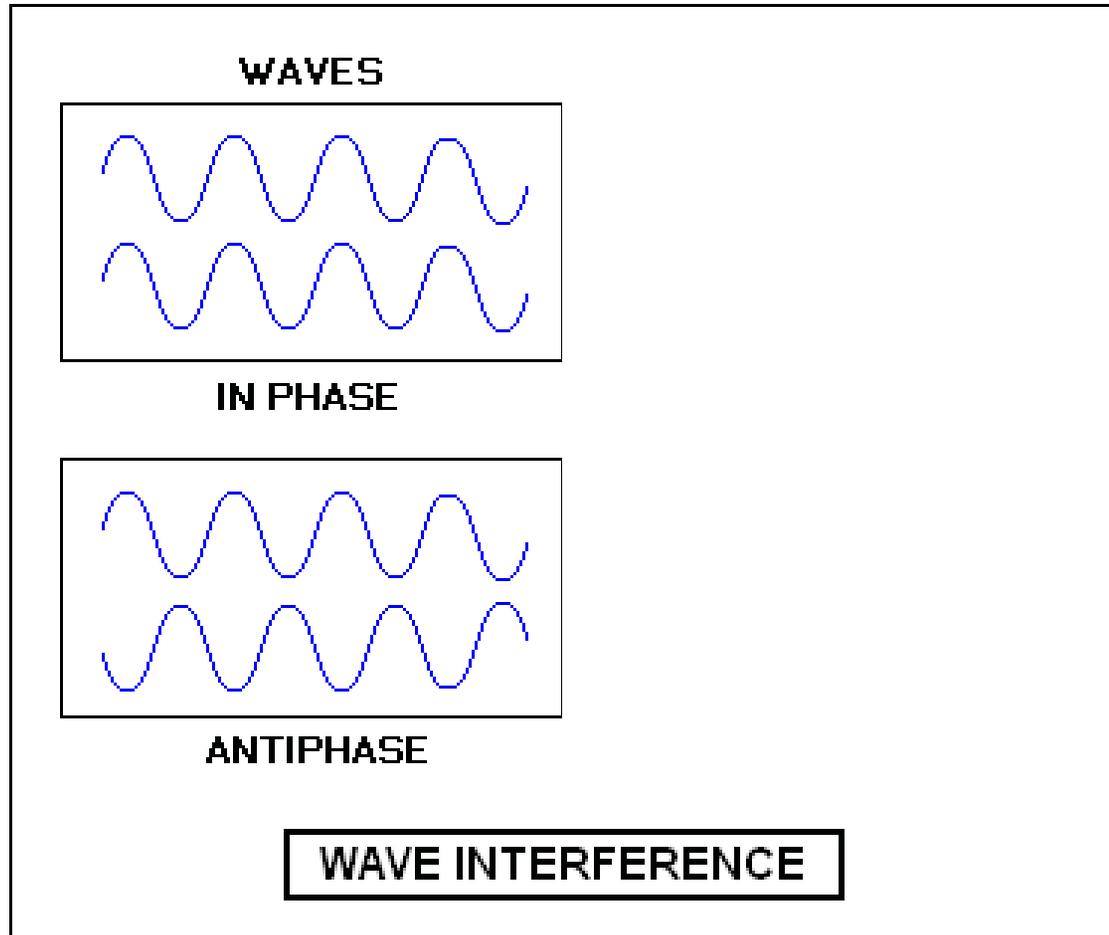
Mécanisme d'attraction dans l'état métallique



Paires de Cooper

Un deuxième
phénomène, la
cohérence

Ondes



Une analogie

- Symétrie brisée
- Rigidité

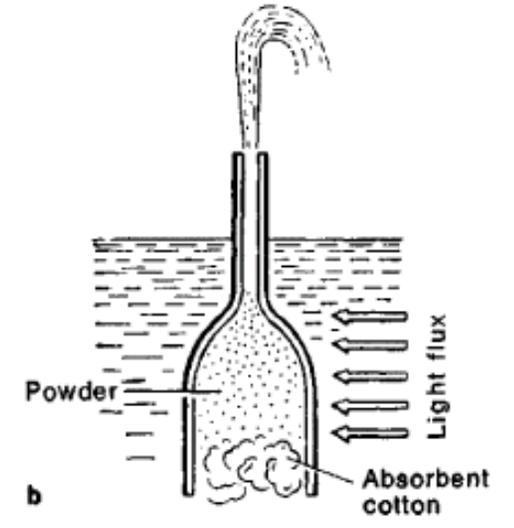
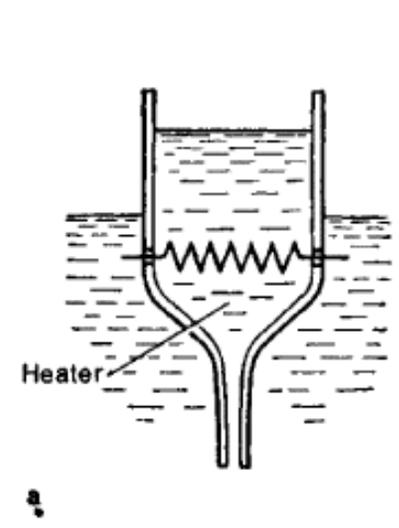
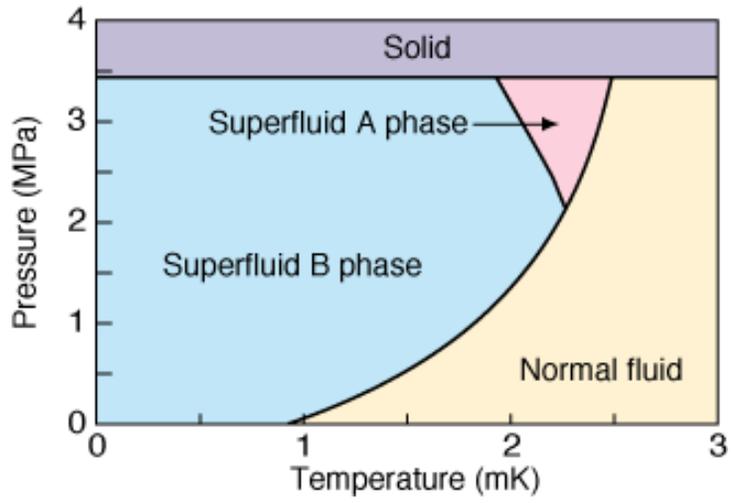


Rigidité de phase, état cohérent

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

La supraconductivité partout

^3He superfluid



Le noyau des atomes (Rutherford 1911)



PHYSICAL REVIEW

VOLUME 110, NUMBER 4

MAY 15, 1958

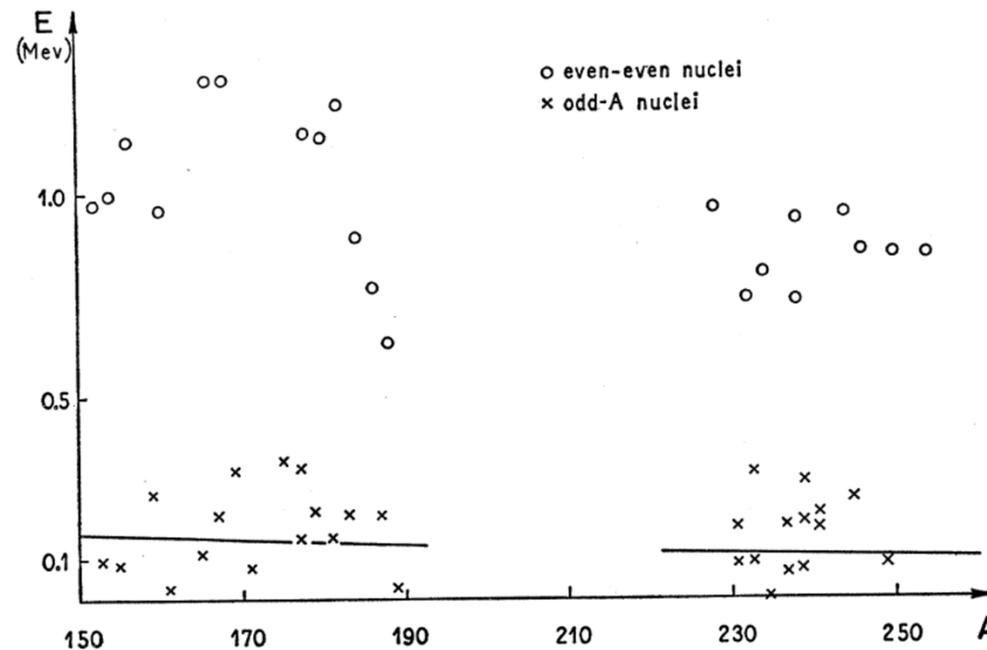
Possible Analogy between the Excitation Spectra of Nuclei and Those of the Superconducting Metallic State

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

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

Leptons spin = 1/2

Flavor	Mass GeV/c ²	Electric charge
e ⁻ electron	<1·10 ⁻⁸	0
ν _e electron neutrino	0.000511	-1
μ ⁻ muon	<0.0002	0
ν _μ muon neutrino	0.106	-1
τ ⁻ tau	<0.02	0
ν _τ tau neutrino	1.7771	-1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3

BOSONS

Unified Electroweak spin = 1

Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W ⁺	80.4	-1
W ⁻	80.4	+1
Z ⁰	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c ²	Electric charge
g gluon	0	0

PROPERTIES OF THE INTERACTIONS

Property	Gravitational		Weak		Electromagnetic		Strong	
	Mass - Energy	Flavor	Electric Charge	Color Charge	Residual	Residual	Residual	
Acts on:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons	Mesons		
Particels mediating:	Graviton (not yet identified)	W ⁺ W ⁻ Z ⁰	γ	Gluons				
Strength (compared to electromagnetism):	10 ⁻⁴¹	10 ⁻⁶	1	1	25	Not applicable to quarks	60	
Range:	10 ⁻¹⁶ m	10 ⁻¹⁶ m	∞	∞	∞	∞	∞	

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (antimatter = opposite charge to matter). Particle and antiparticle have identical mass and spin but opposite charge. Some electrically neutral bosons (e.g., Z⁰, γ, and η⁰, etc.) are their own antiparticles.

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. As a result, lully-charged particles interact by exchanging gluons. In strong interactions color-charged particles interact 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 (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color force field between them increases. The energy eventually is converted into additional quark-antiquark pairs (see Figure below). The quarks and antiquarks then combine into hadrons, and the particles appear to emerge. Two types of hadrons have been observed in nature: mesons (q anti-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-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

The Particle Adventure
 With the great scientists who feature The Particle Adventure at <http://ParticleAdventure.org>
 This chart has been made possible by the generous support of:
 U.S. Department of Energy
 U.S. National Science Foundation
 Lawrence Berkeley National Laboratory
 Stanford Linear Accelerator Center
 American Physical Society, Division of Particles and Fields
 DUMPLER INDUSTRIES, INC.
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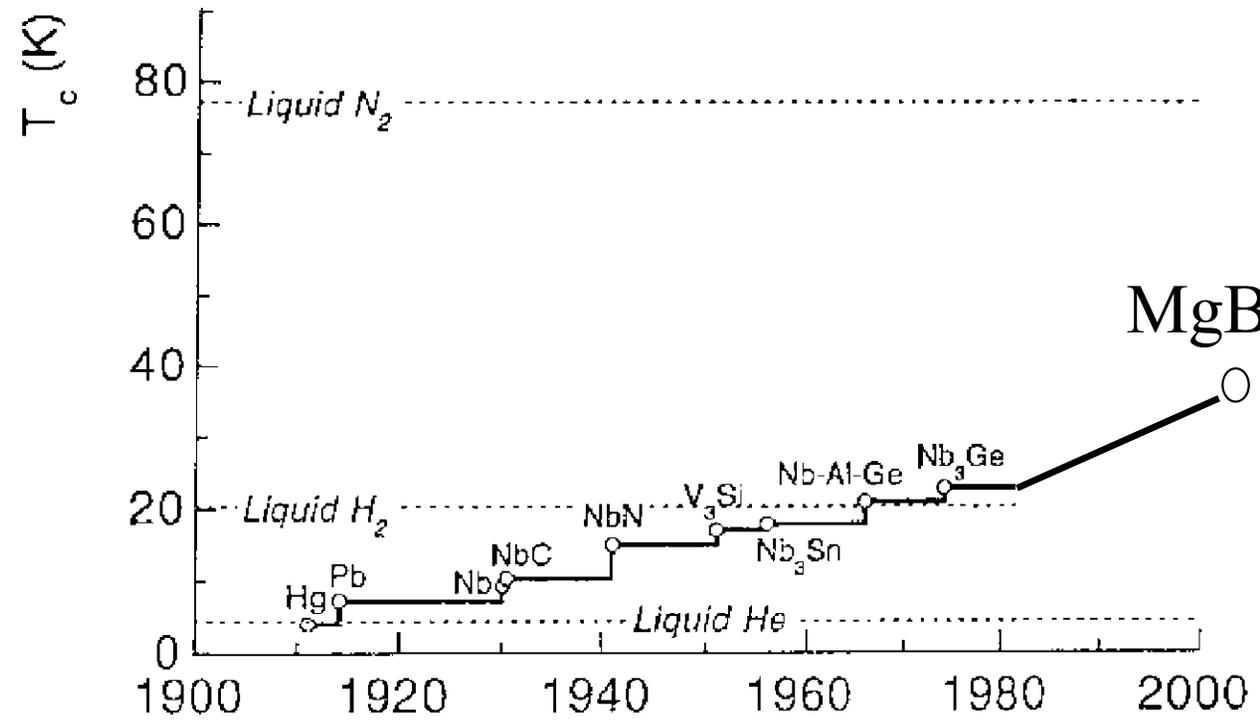
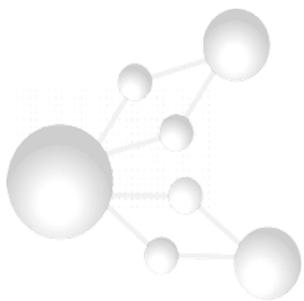
La quête de nouveaux matériaux

- 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



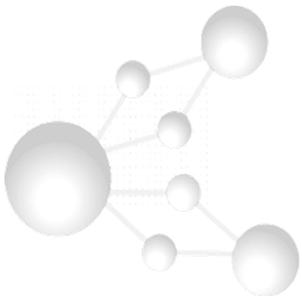
OSNI

1986 : Bednorz et Müller, IBM

Zurich

La-Ba-Cu-O $T_c \sim 30-40K$

Effet Meissner ?



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)

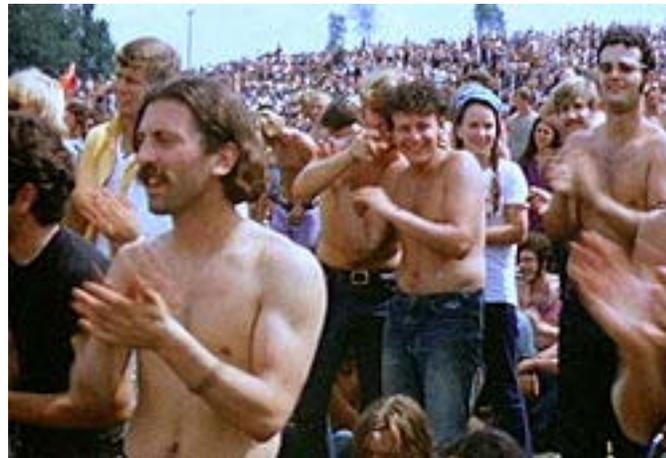
March meeting APS, 1987



- 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"



15-18 Aug. 1969
500,000 participants



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



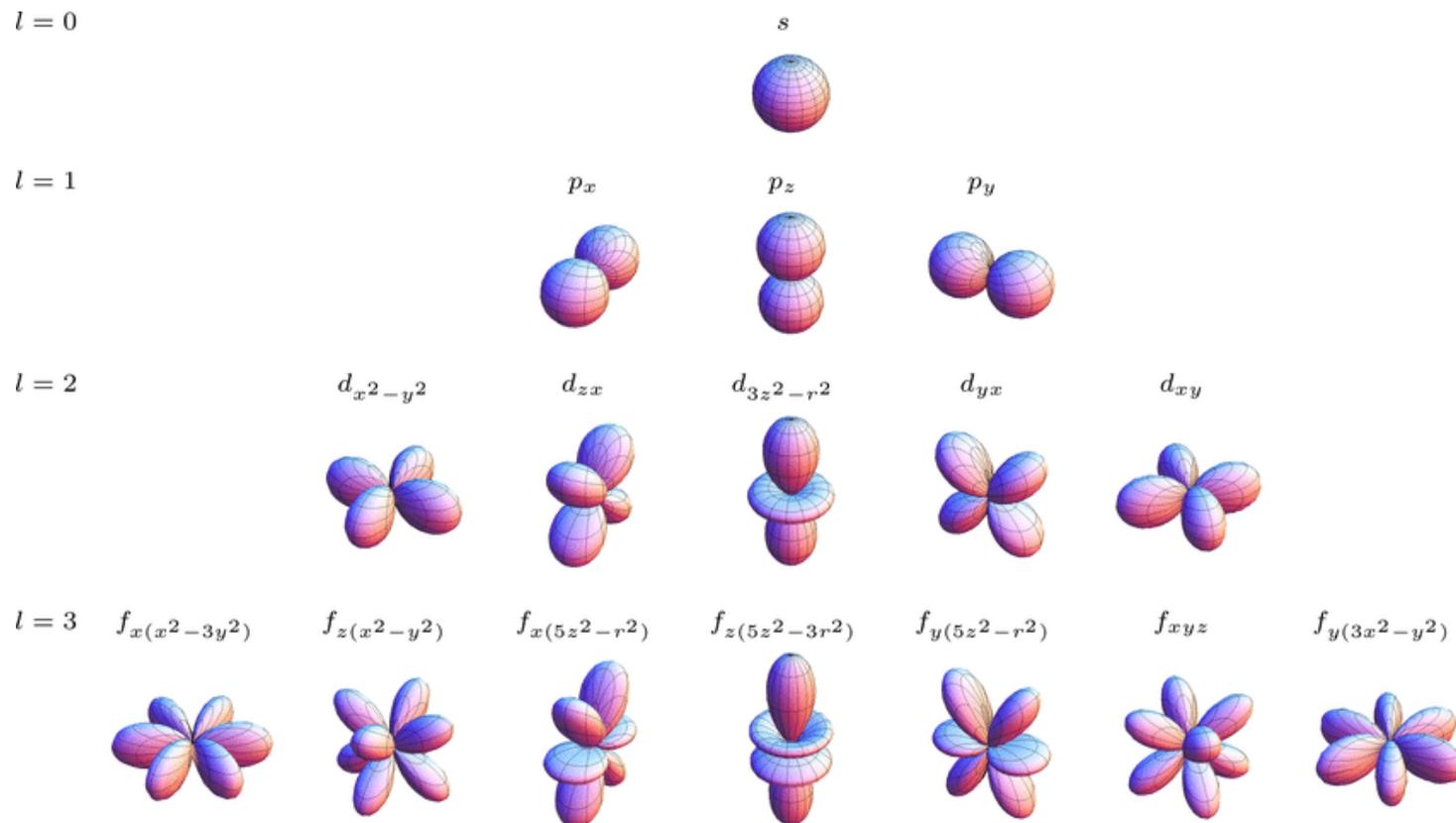


Ce qu'il y a de
particulier avec ces
supraconducteurs:

Ce qu'il y a de particulier



- Il y a des paires de Cooper, mais les vibrations cristallines n'expliquent pas leur présence.
- Les paires sont dans un état « d »



Structure atomique



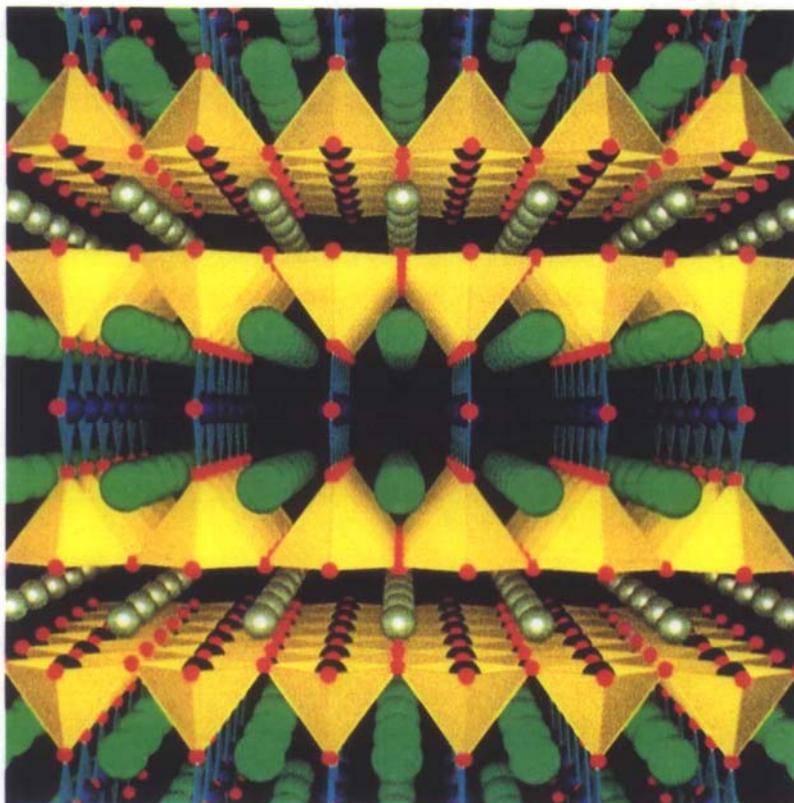
SCIENTIFIC AMERICAN

JUNE 1988
\$3.50

How nonsense is deleted from genetic messages.

R₁ for economic growth: aggressive use of new technology.

Can particle physics test cosmology?



High-Temperature Superconductor belongs to a family of

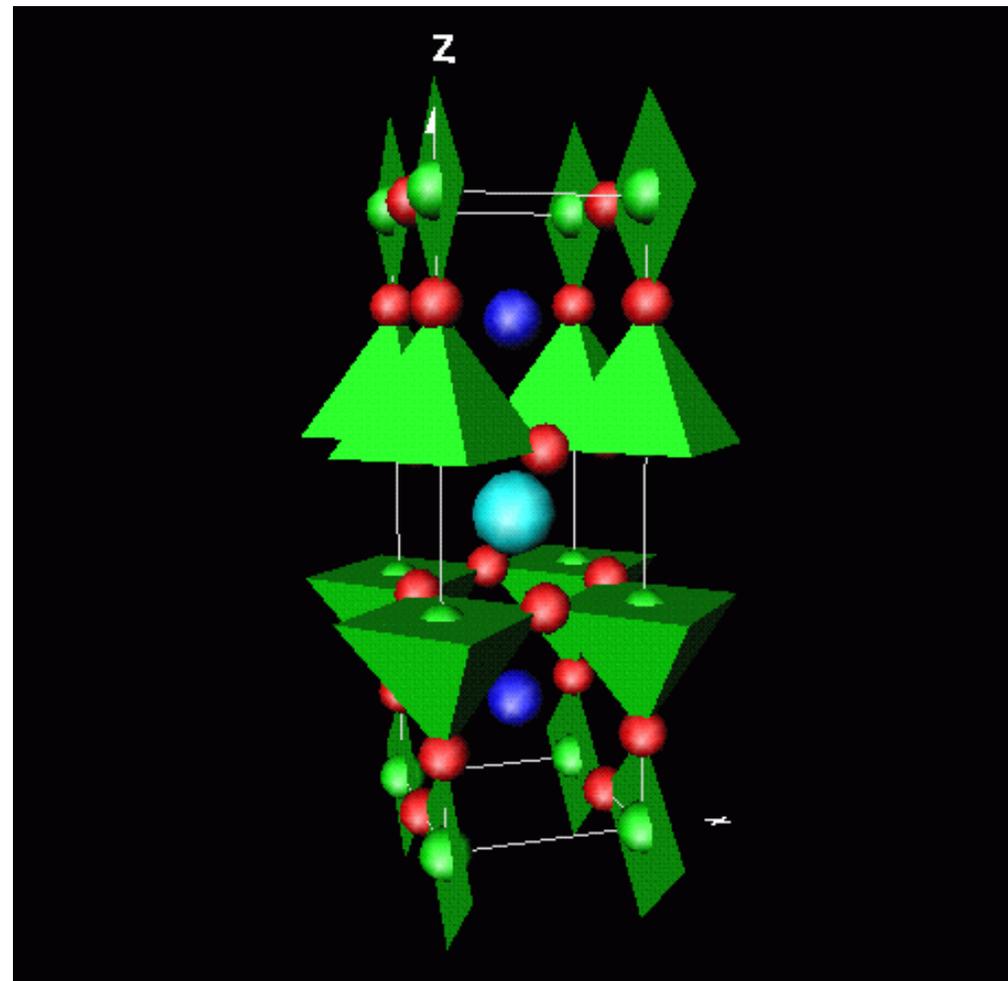
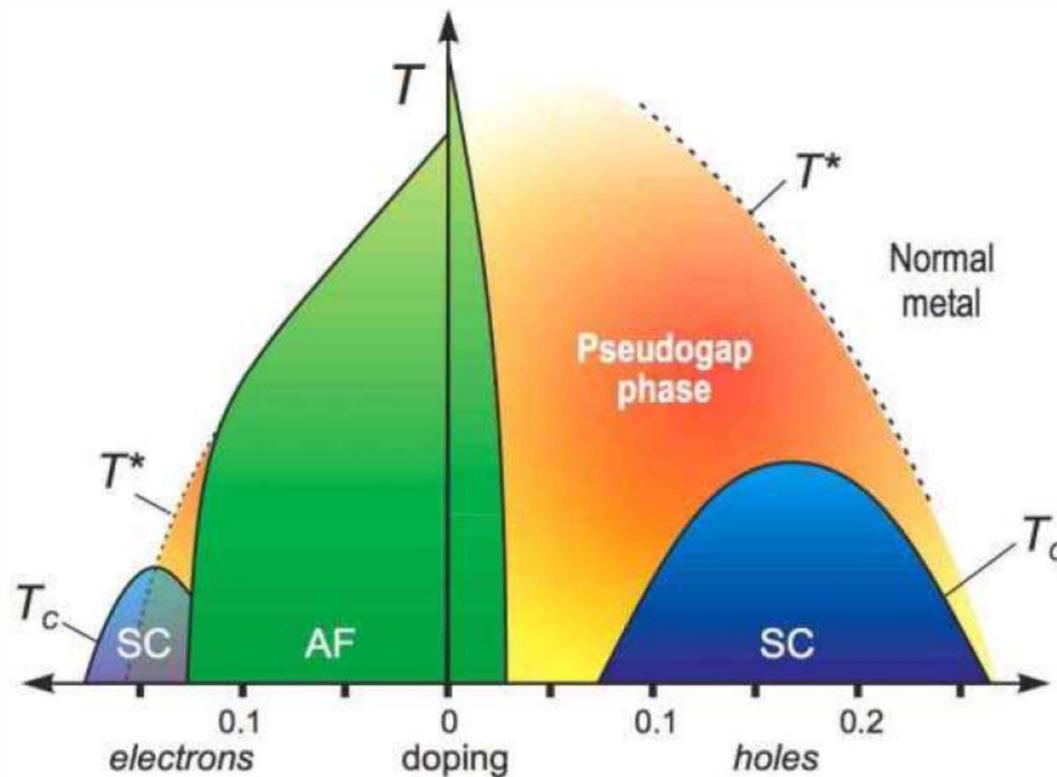


Diagramme de phase

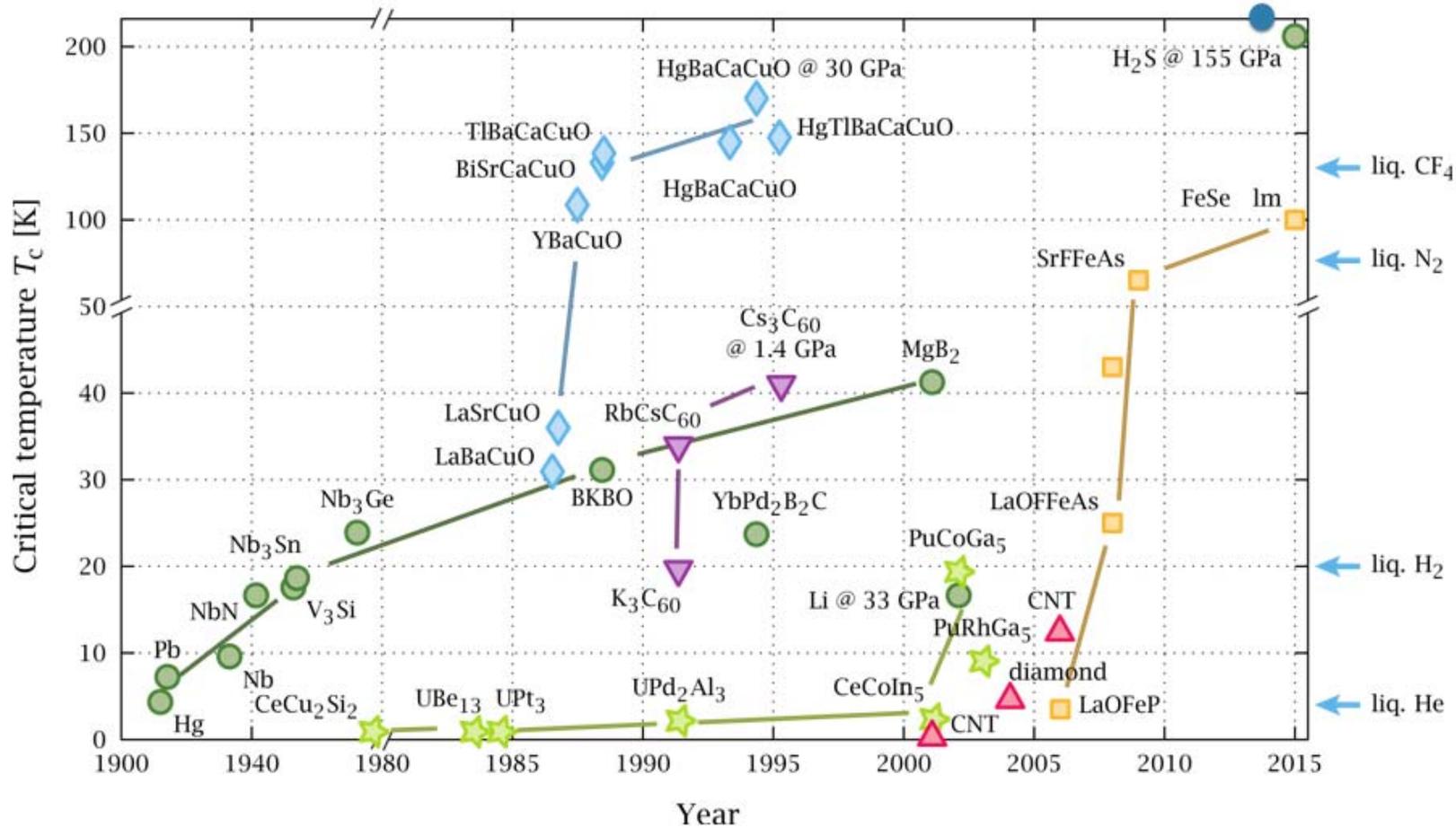


Fischer et al. Rev. Mod. Phys. 79, 353 (2007)

Température critique en fonction de l'année



LaH₁₀ T_c=250K @155GPa (2019)



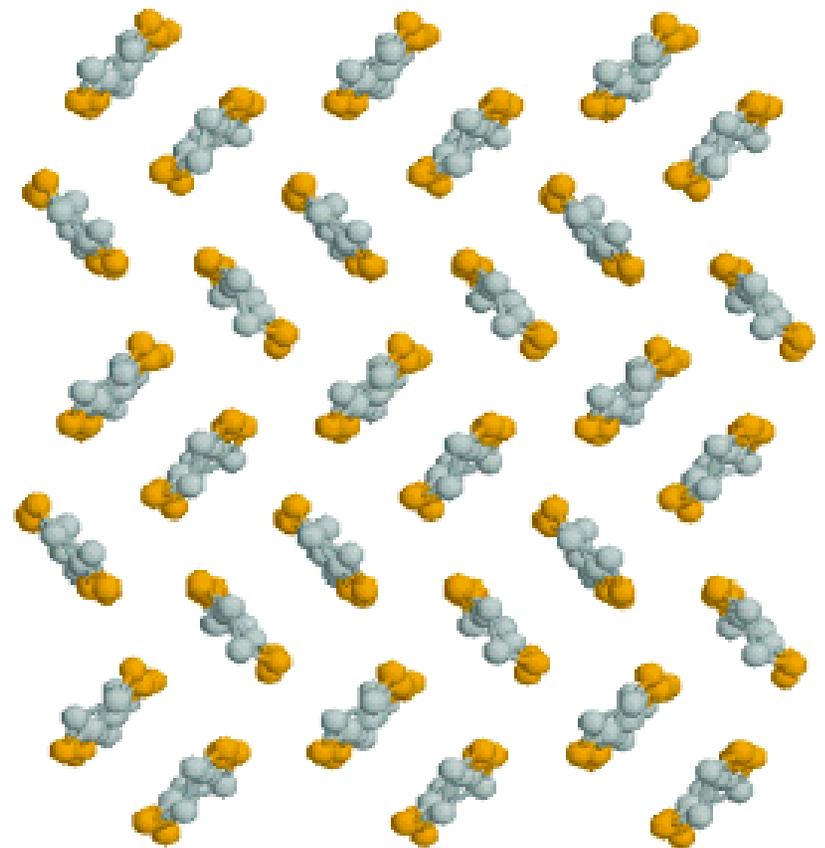
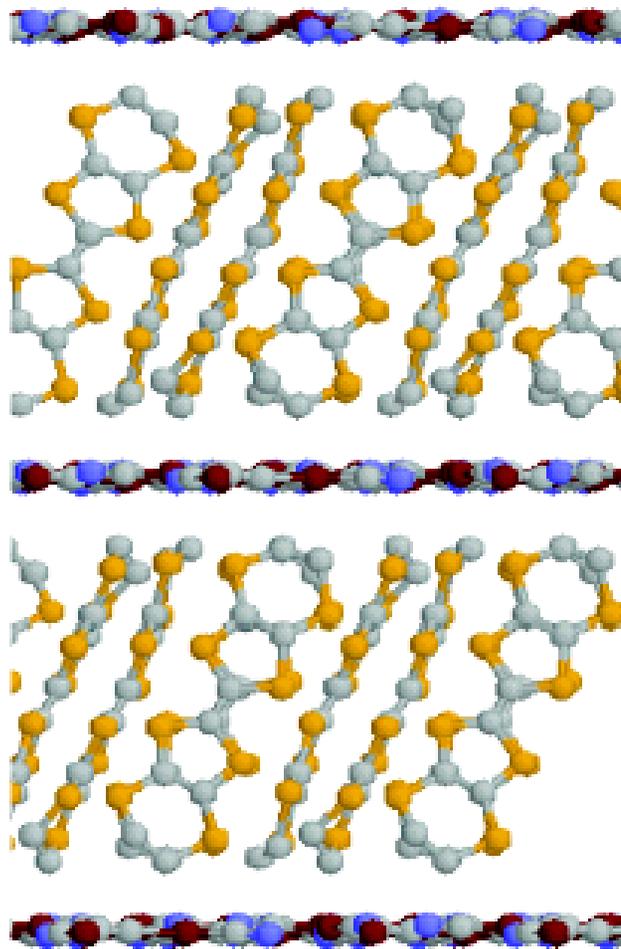
Pia Jensen Ray, Mémoire de Maîtrise

Conducteurs organiques en couches (κ -BEDT-X)

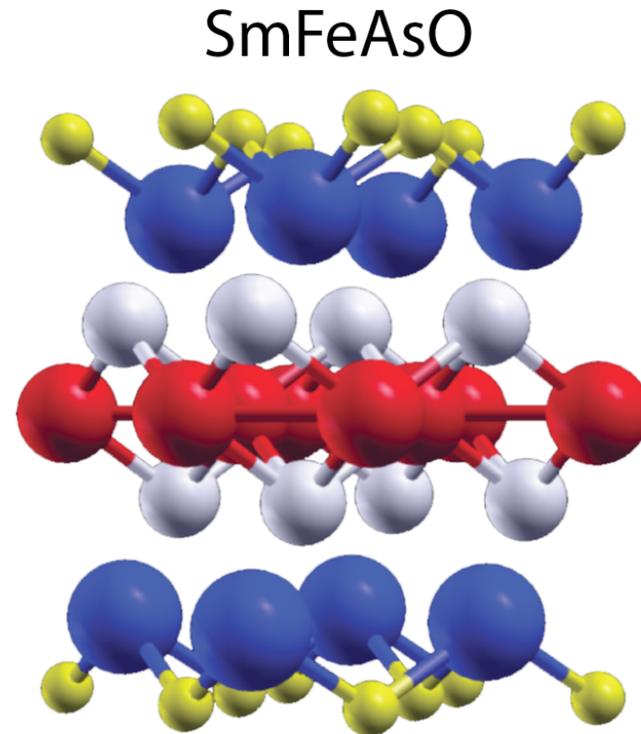
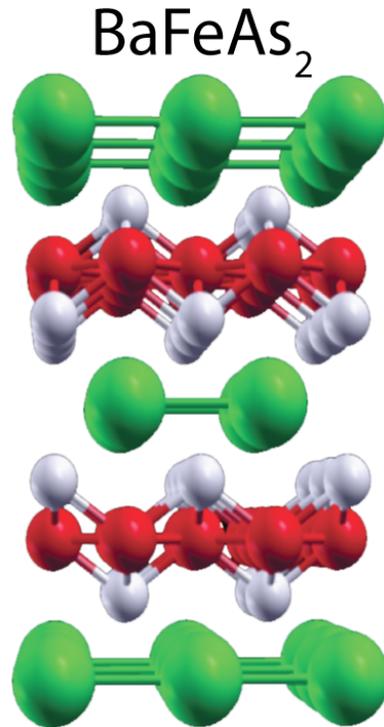


BEDT-TTF
layer

Anion layer



Pnictures (2008)



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

Couches de graphène à l'angle magique

nature

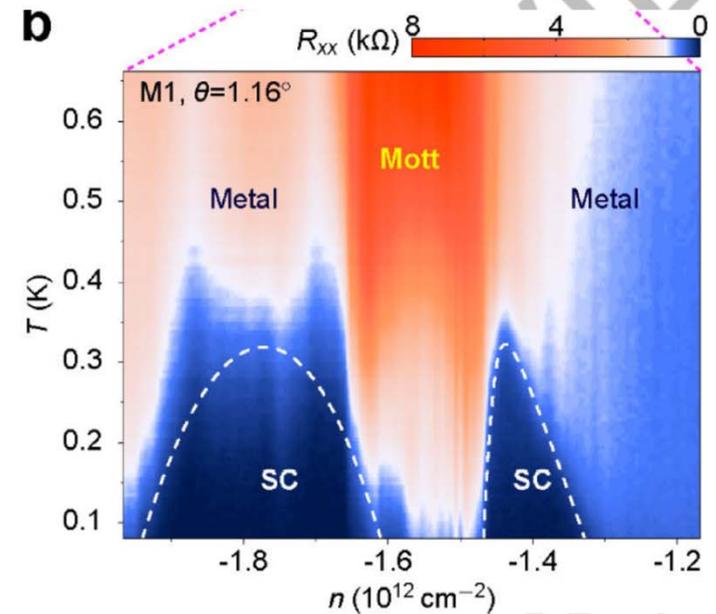
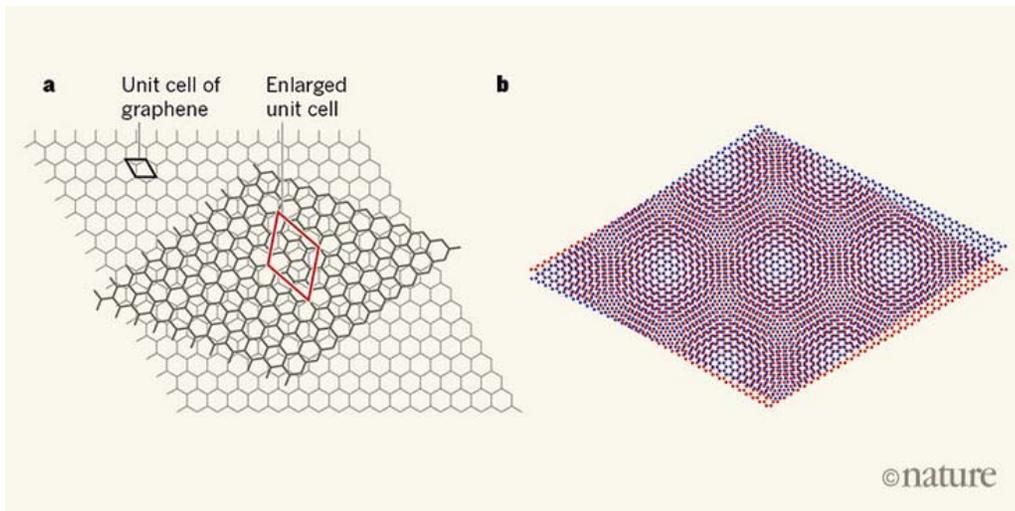
Accelerated Article Preview

ARTICLE

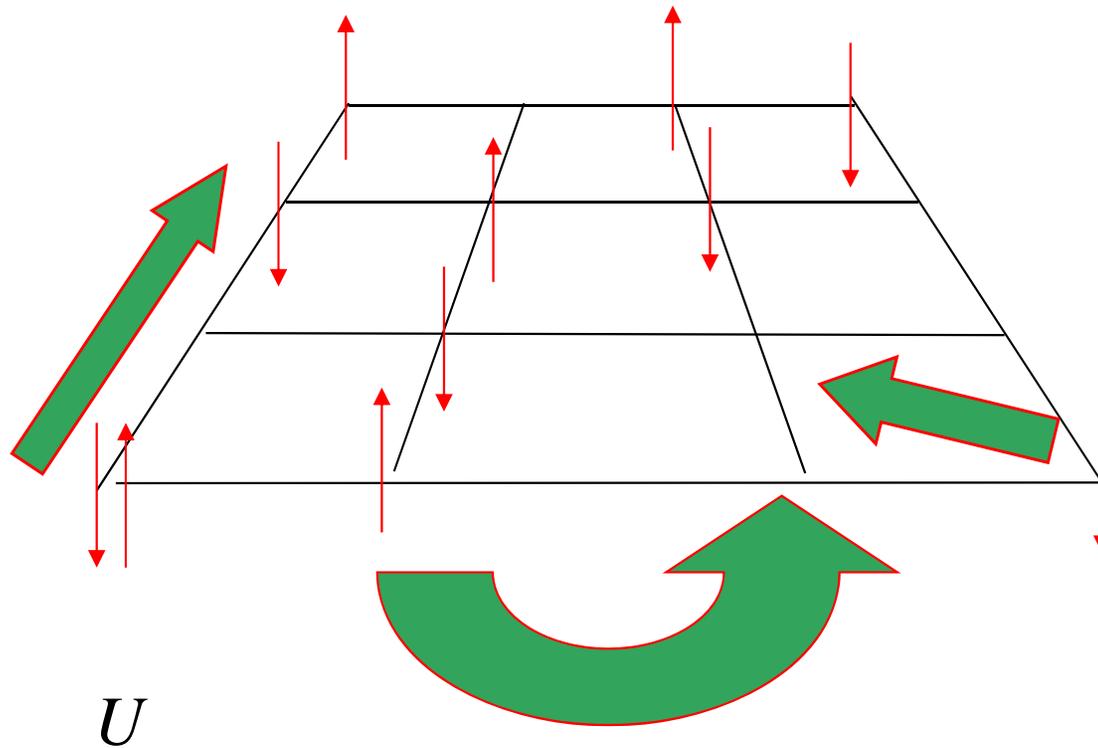
doi:10.1038/nature26160

Unconventional superconductivity in magic-angle graphene superlattices

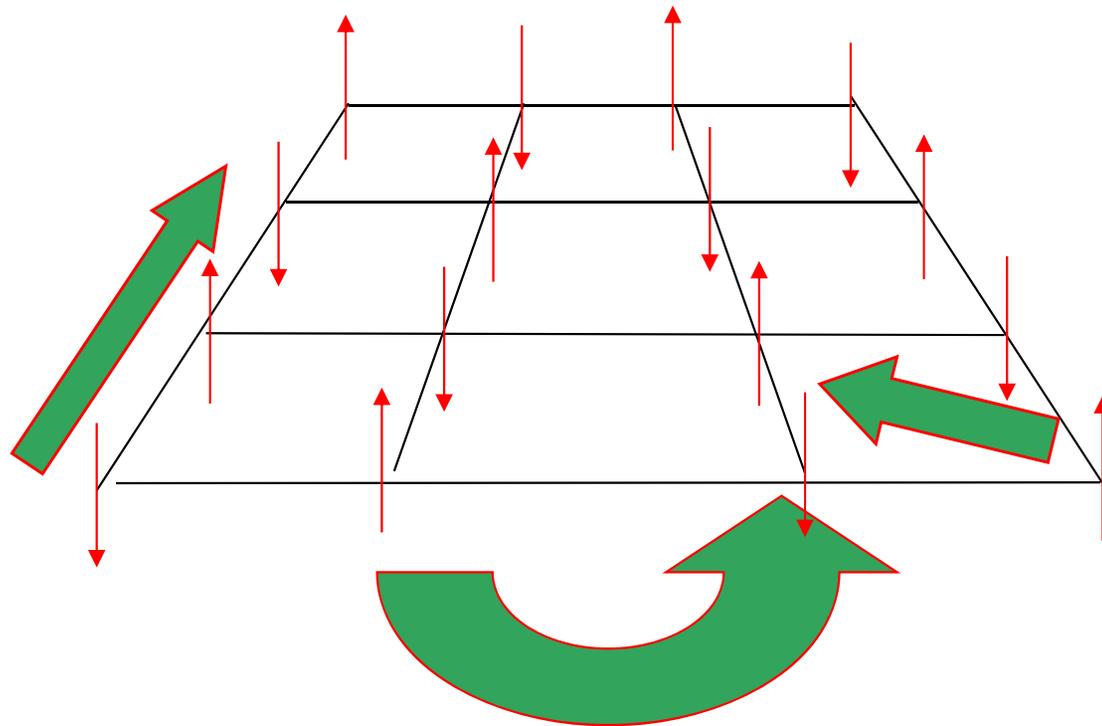
Yuan Cao, Valla Fatemi, Shiang Fang, Kenji Watanabe, Takashi Taniguchi, Efthimios Kaxiras & Pablo Jarillo-Herrero



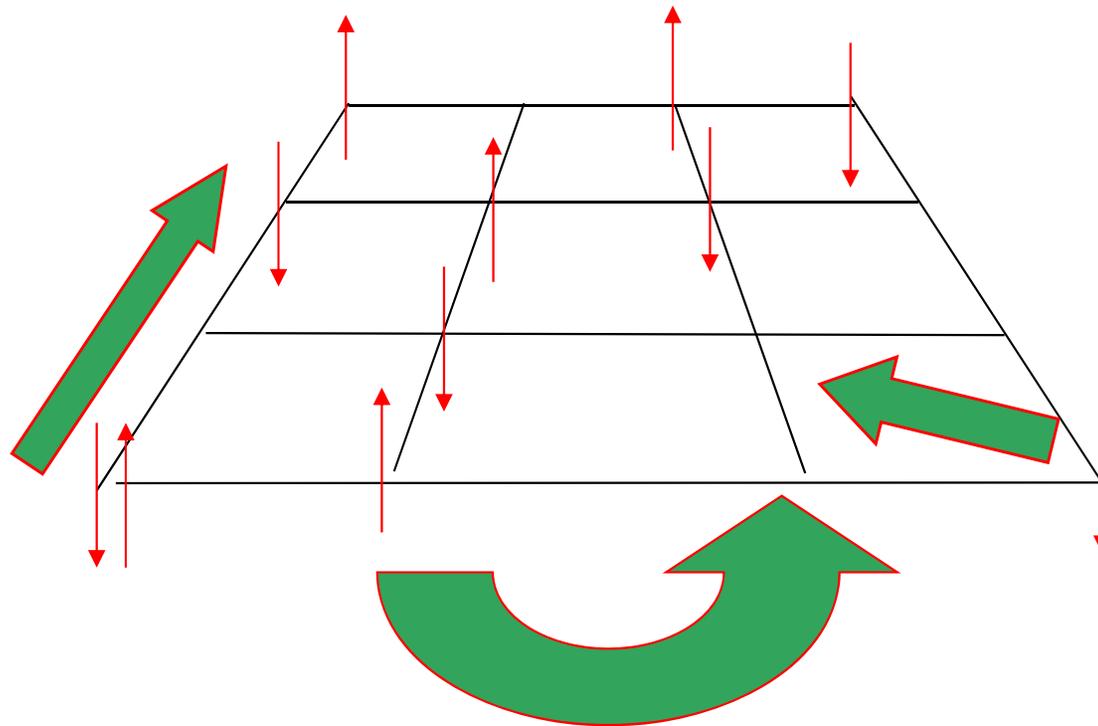
Pourquoi est-ce si difficile à comprendre?



Isolant



Pourquoi est-ce si difficile à comprendre?



Quoi faire?

Quoi faire?



Tableau périodique des éléments

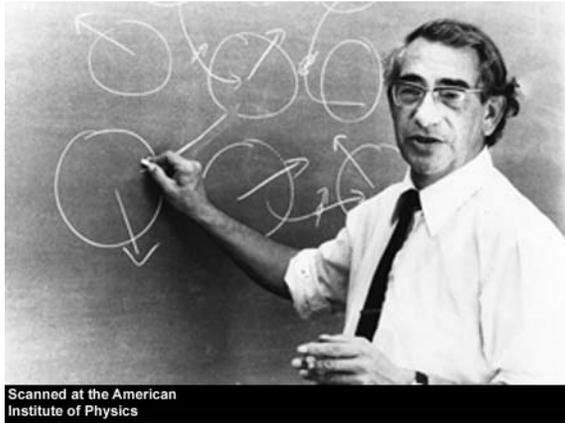
<p>Numéro atomique: 6 Symbole de l'élément: C Masse atomique: 12,011</p> <p>Principaux nombres d'oxydation: (Le plus fréquent est en gras) Electronégativité:</p> <p>Nom: Carbone</p> <p>(2c): deux électrons célibataires (3p): trois paires d'électrons</p>																																																																																																																																																													
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<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td>58</td><td>59</td><td>60</td><td>61</td><td>*62</td><td>63</td><td>64</td><td>65</td><td>66</td><td>67</td><td>68</td><td>69</td><td>70</td><td>71</td> </tr> <tr> <td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+2</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+2</td><td>+2</td><td>+3</td> </tr> <tr> <td>Ce</td><td>Pr</td><td>Nd</td><td>Pm</td><td>Sm</td><td>Eu</td><td>Gd</td><td>Tb</td><td>Dy</td><td>Ho</td><td>Er</td><td>Tm</td><td>Yb</td><td>Lu</td> </tr> <tr> <td>140,12</td><td>140,91</td><td>144,24</td><td>[145]</td><td>150,36</td><td>151,96</td><td>157,25</td><td>158,93</td><td>162,50</td><td>164,93</td><td>167,26</td><td>168,93</td><td>173,04</td><td>174,97</td> </tr> <tr> <td>Cérium</td><td>Praséodyme</td><td>Néodyme</td><td>Prométhium</td><td>Samarium</td><td>Europium</td><td>Gadolinium</td><td>Terbium</td><td>Dysprosium</td><td>Holmium</td><td>Erbium</td><td>Thulium</td><td>Ytterbium</td><td>Lutétium</td> </tr> <tr> <td>90</td><td>*91</td><td>*92</td><td>*93</td><td>*94</td><td>*95</td><td>*96</td><td>*97</td><td>*98</td><td>*99</td><td>*100</td><td>*101</td><td>*102</td><td>*103</td> </tr> <tr> <td>+4</td><td>+4</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td><td>+3</td> </tr> <tr> <td>Th</td><td>Pa</td><td>U</td><td>Np</td><td>Pu</td><td>Am</td><td>Cm</td><td>Bk</td><td>Cf</td><td>Es</td><td>Fm</td><td>Md</td><td>No</td><td>Lr</td> </tr> <tr> <td>232,04</td><td>231,04</td><td>238,03</td><td>[237]</td><td>[244]</td><td>[243]</td><td>[247]</td><td>[247]</td><td>[251]</td><td>[252]</td><td>[257]</td><td>[258]</td><td>[259]</td><td>[262]</td> </tr> <tr> <td>Thorium</td><td>Protactinium</td><td>Uranium</td><td>Neptunium</td><td>Plutonium</td><td>Américium</td><td>Curium</td><td>Berkélium</td><td>Californium</td><td>Einsteinium</td><td>Fermium</td><td>Mendélévium</td><td>Nobélium</td><td>Lawrencium</td> </tr> </table>																		58	59	60	61	*62	63	64	65	66	67	68	69	70	71	+3	+3	+3	+3	+3	+2	+3	+3	+3	+3	+3	+2	+2	+3	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	140,12	140,91	144,24	[145]	150,36	151,96	157,25	158,93	162,50	164,93	167,26	168,93	173,04	174,97	Cérium	Praséodyme	Néodyme	Prométhium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutétium	90	*91	*92	*93	*94	*95	*96	*97	*98	*99	*100	*101	*102	*103	+4	+4	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	232,04	231,04	238,03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]	[262]	Thorium	Protactinium	Uranium	Neptunium	Plutonium	Américium	Curium	Berkélium	Californium	Einsteinium	Fermium	Mendélévium	Nobélium	Lawrencium
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Métaux	Métaux de transition	Non métaux	Gaz rares et inertes
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Éléments artificiels

* Signifie élément radioactif (instable)

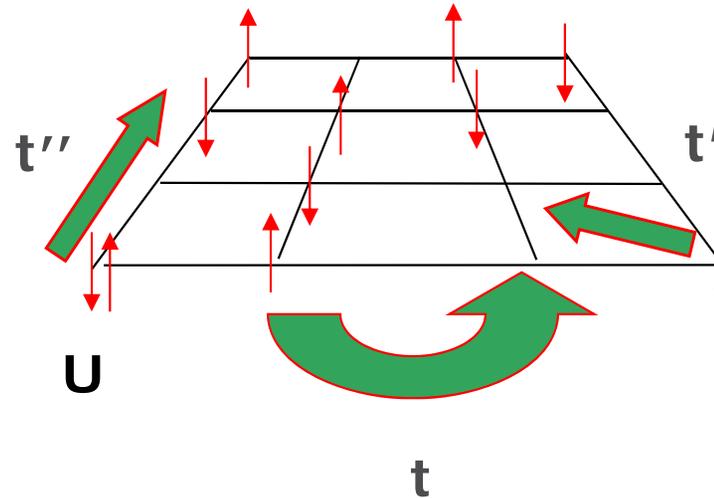
Le modèle de Hubbard



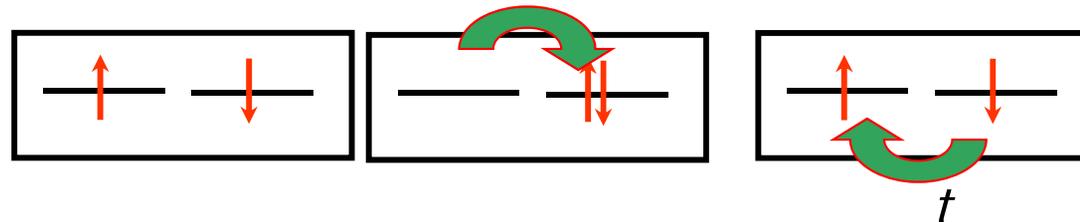
Scanned at the American Institute of Physics

1931-1980

μ



$$H = - \sum_{\langle ij \rangle \sigma} t_{i,j} (c_{i\sigma}^\dagger c_{j\sigma} + c_{j\sigma}^\dagger c_{i\sigma}) + U \sum_i n_{i\uparrow} n_{i\downarrow}$$



Modèle effectif, Heisenberg: $J = 4t^2 / U$

Attn: Isolant à transfert de charge

Méthode

- Théorie de champ moyen dynamique
 - amas
- Concept: corrélations atomiques localisées, cohérentes avec les aspects délocalisés

REVUES

Maier, Jarrell et al., RMP. (2005)

Kotliar *et al.* RMP (2006)

AMST *et al.* LTP (2006)

Hettler *et al.*, PRB 1998

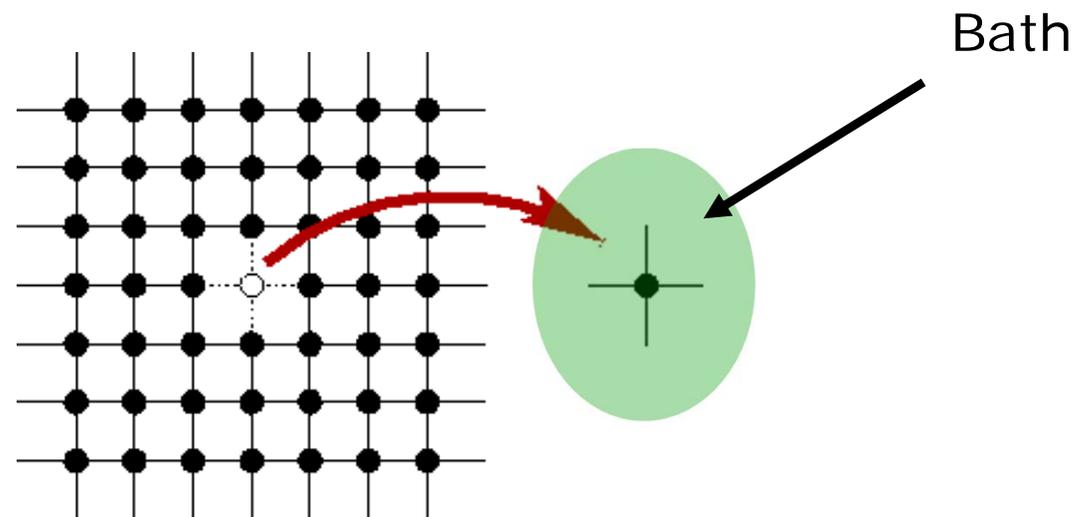
Lichtenstein *et al.*, PRB 2000

Kotliar *et al.*, PRB 2000

M. Potthoff, EJP 2003

Théorie de champ moyen dynamique

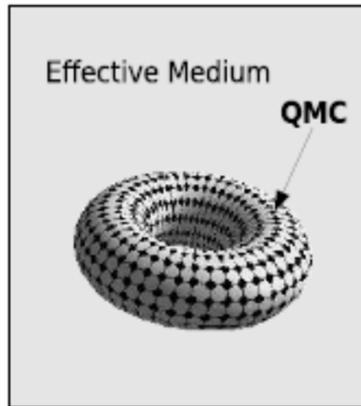
Les débuts en $d = \textit{infini}$



W. Metzner and D. Vollhardt, PRL (1989)
A. Georges and G. Kotliar, PRB (1992)
M. Jarrell PRB (1992)

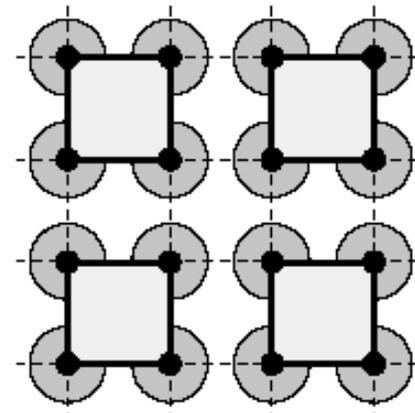
DMFT, ($d = 3$)

2d Hubbard: Amas quantiques

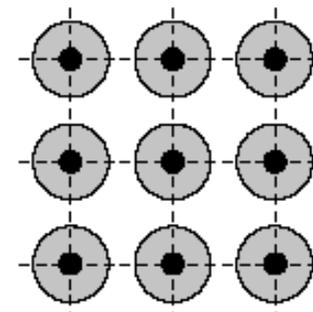


DCA

C-DMFT



DMFT



Hettler ...Jarrell...Krishnamurty PRB **58** (1998)

Kotliar et al. PRL **87** (2001)

M. Potthoff *et al.* PRL **91**, 206402 (2003).

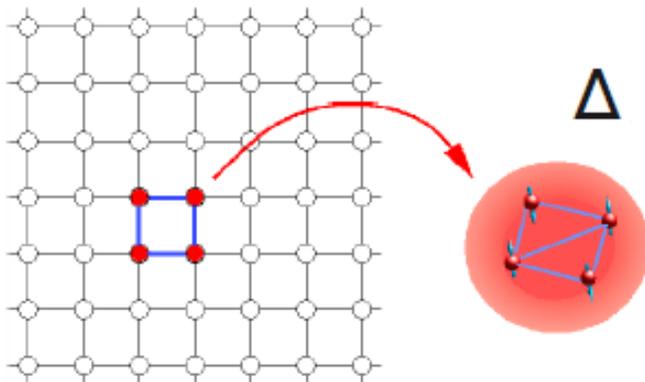
REVIEWS

Maier, Jarrell et al., RMP. (2005)

Kotliar *et al.* RMP (2006)

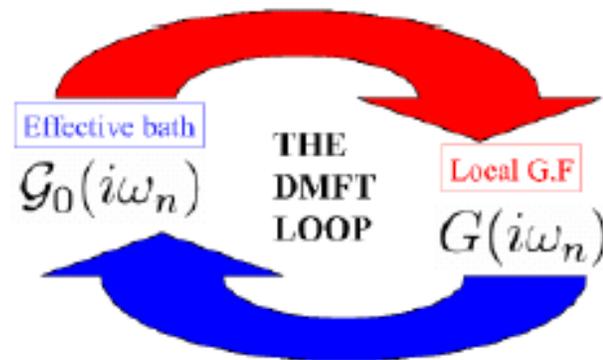
AMST *et al.* LTP (2006)

Solutionneur



$$Z = \int \mathcal{D}[\psi^\dagger, \psi] e^{-S_c - \int_0^\beta d\tau \int_0^\beta d\tau' \sum_{\mathbf{K}} \psi_{\mathbf{K}}^\dagger(\tau) \Delta_{\mathbf{K}}(\tau, \tau') \psi_{\mathbf{K}}(\tau')}$$

EFFECTIVE LOCAL IMPURITY PROBLEM



SELF-CONSISTENCY CONDITION

Mean-field is not a trivial problem! Many impurity solvers.

Here: continuous time QMC

P. Werner, PRL 2006

P. Werner, PRB 2007

K. Haule, PRB 2007

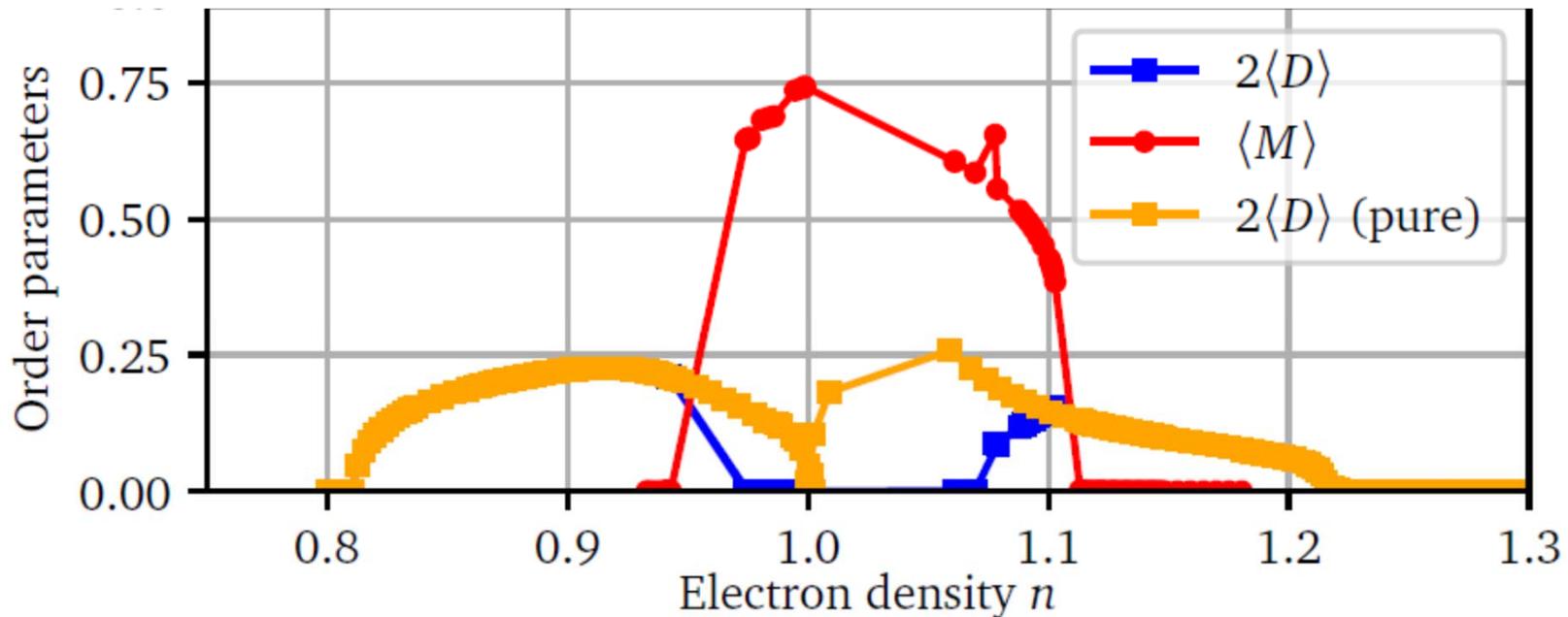
$$\Delta(i\omega_n) = i\omega_n + \mu - \Sigma_c(i\omega_n)$$

$$= \left[\sum_{\tilde{\mathbf{k}}} \frac{1}{i\omega_n + \mu - t_c(\tilde{\mathbf{k}}) - \Sigma_c(i\omega_n)} \right]^{-1}$$

Diagramme de phase, $T = 0$

Diagramme de phase $T = 0$

$$U = 8t, t' = -0.3t, t'' = 0.2t$$



- A. Foley *et al.* Phys. Rev. B **99**, 184510 (2019)
S. S. Kancharla, *et al.* Phys. Rev. B **77**, 184516 (2008)
D. Sénéchal, *et al.* Phys. Rev. Lett. **94**, (2005)
M. Jarrell *et al.* EPL **56** 563, (2001)

CDMFT 4 sites



D. Sénéchal



Bumsoo Kyung

La colle

Kyung, Sénéchal, Tremblay, Phys. Rev. B **80**, 205109 (2009)

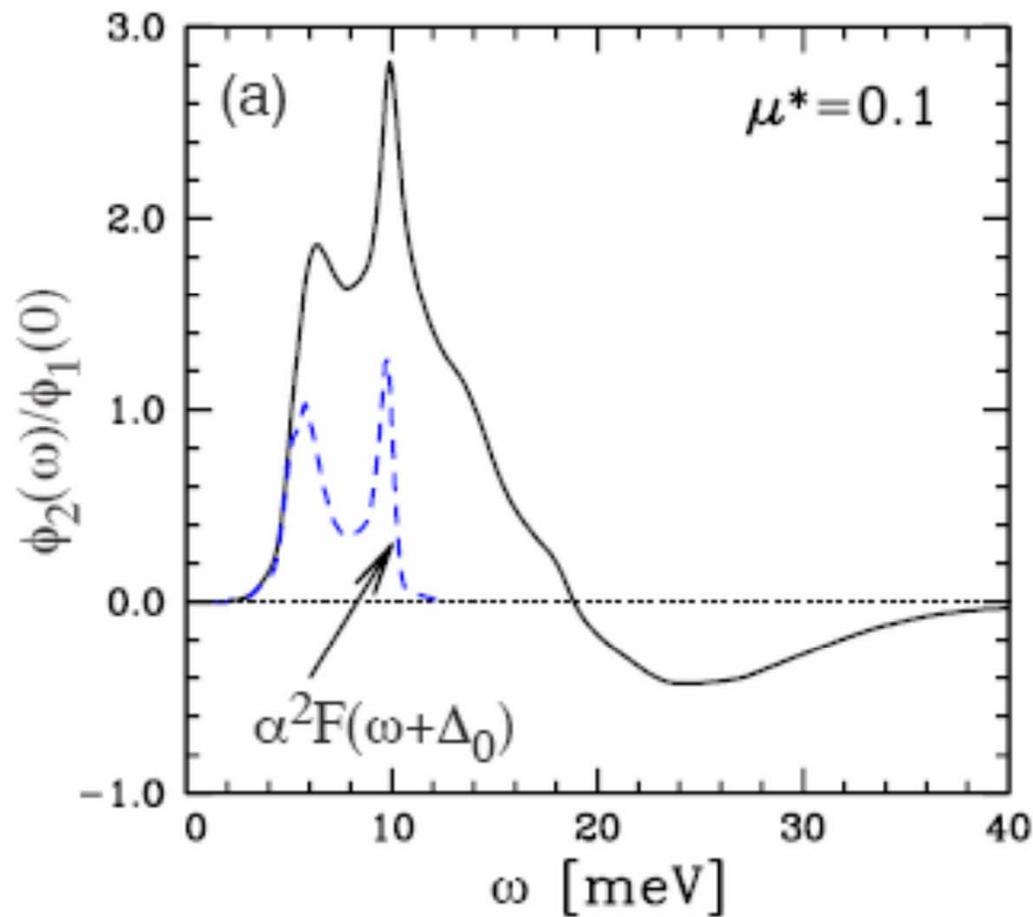
Sénéchal, Day, Bouliane, AMST, Phys. Rev. B **87**, 075123 (2013)

A. Reymbaut *et al.* PRB **94** 155146 (2016)

$\text{Im } \Sigma_{an}$ électron-phonon dans Pb



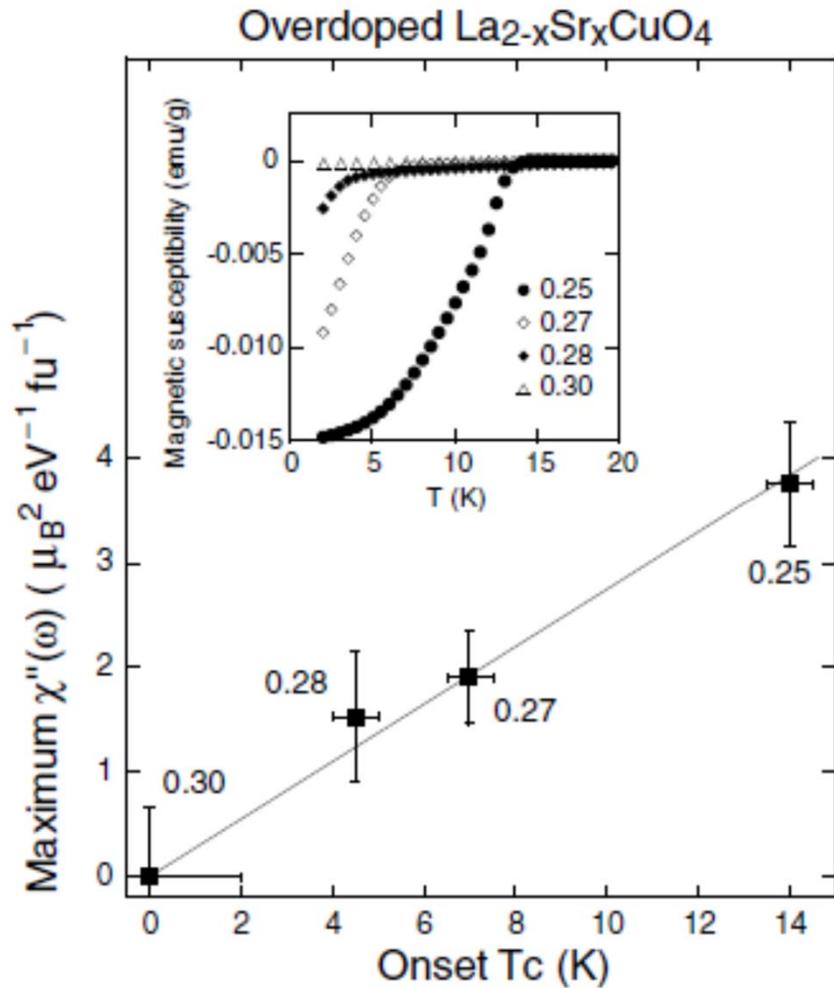
Maier, Poilblanc, Scalapino, PRL (2008)



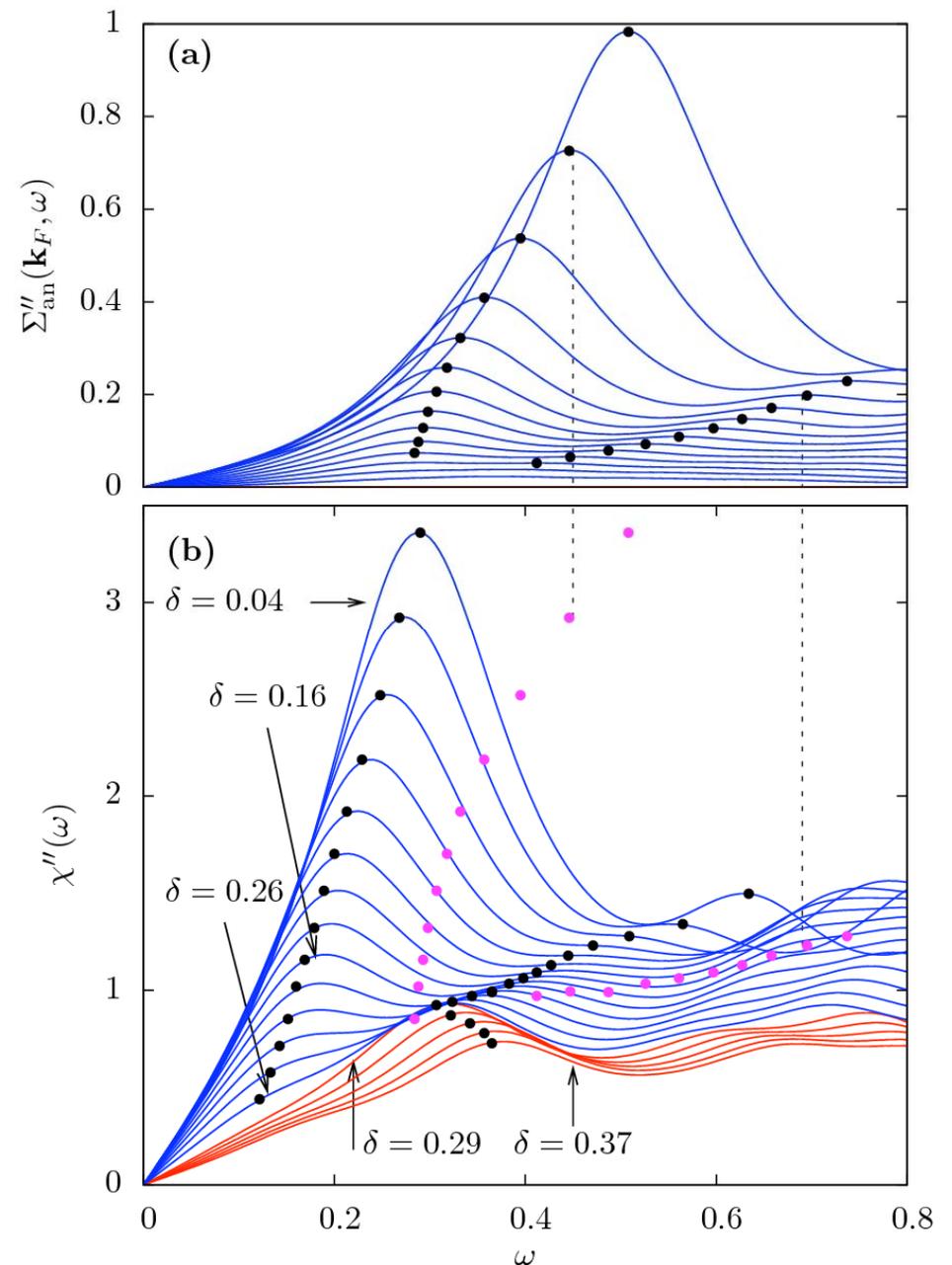
La colle



Kyung, S en echal, Tremblay, Phys. Rev. B **80**, 205109 (2009)



Wakimoto ... Birgeneau
PRL (2004)



La colle et les neutrons

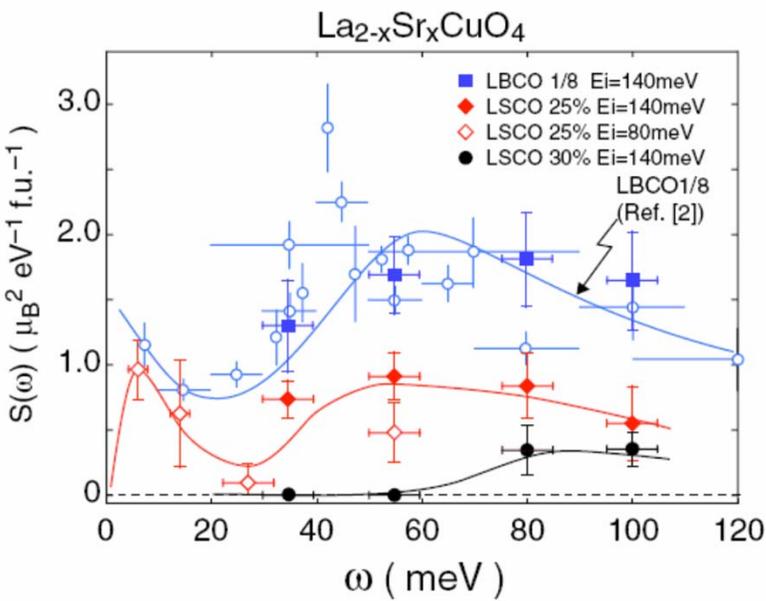
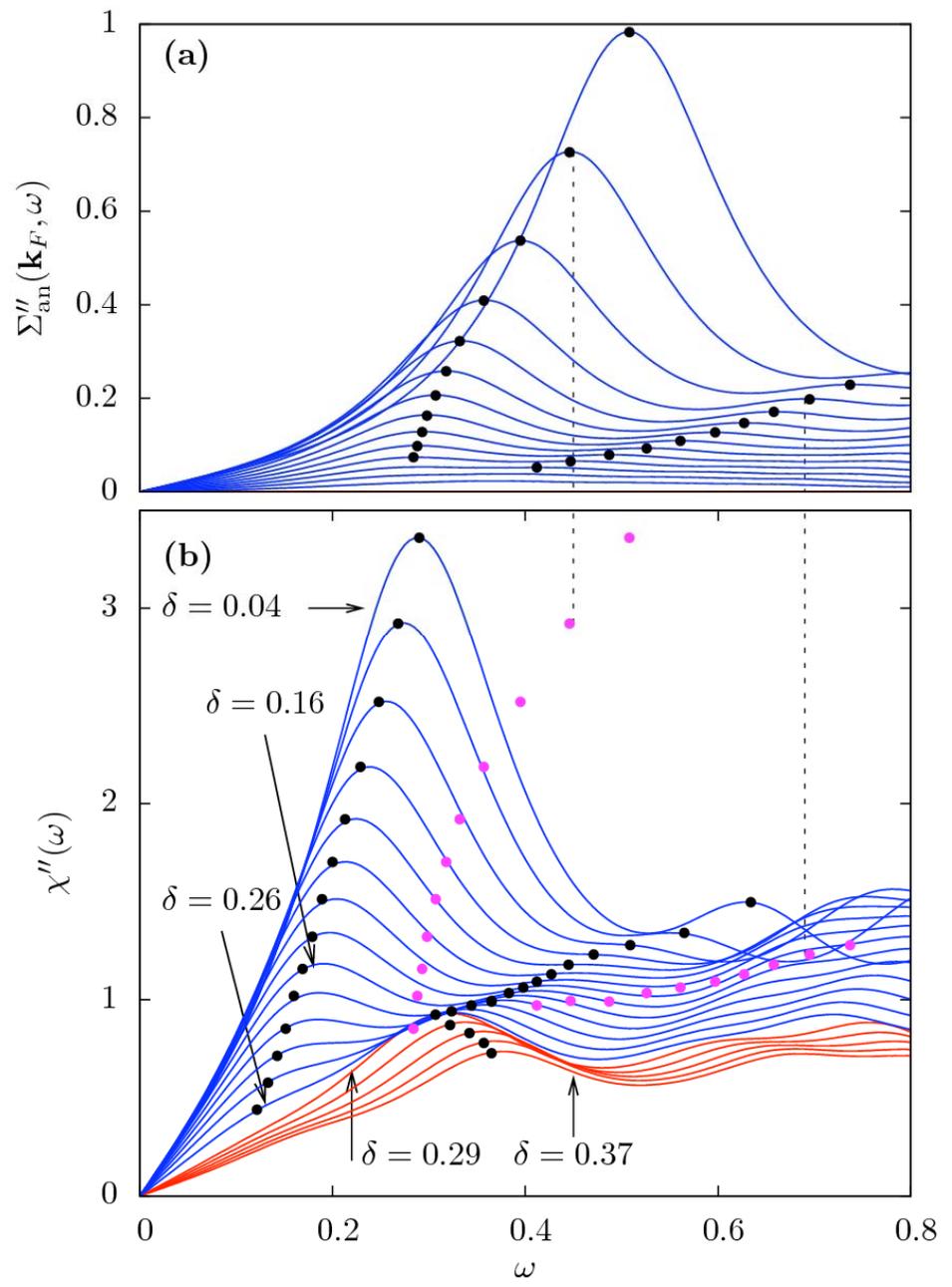


FIG. 3 (color online). \mathbf{Q} -integrated dynamic structure factor $S(\omega)$ which is derived from the wide- H integrated profiles for LBCO 1/8 (squares), LSCO $x = 0.25$ (diamonds; filled for $E_i = 140 \text{ meV}$, open for $E_i = 80 \text{ meV}$), and $x = 0.30$ (filled circles) plotted over $S(\omega)$ for LBCO 1/8 (open circles) from [2]. The solid lines following data of LSCO $x = 0.25$ and 0.30 are guides to the eyes.

Wakimoto ... Birgeneau PRL (2007)
PRL (2004)



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 deserts. 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.

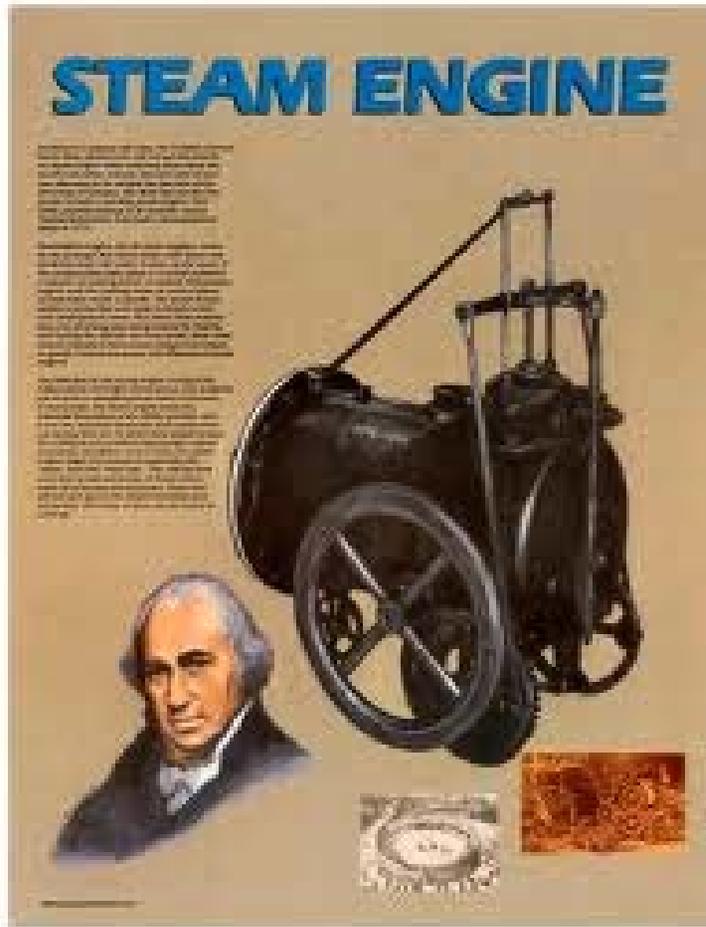
www.ScientificAmerican.com

SCIENTIFIC AMERICAN 43

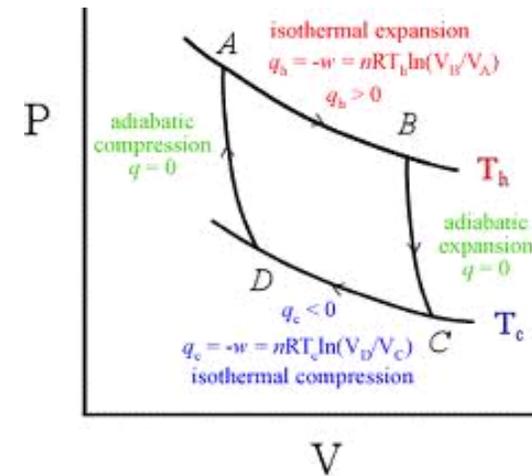
<http://www.physique.usherbrooke.ca/taillefer/Vulgarisation.html>

Science et technologie,
main dans la main

Machine à vapeur et thermodynamique



Watts 1765

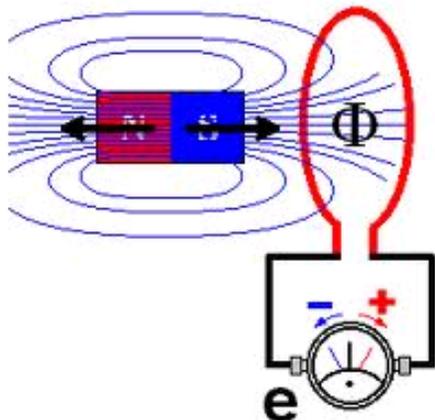


Carnot 1824

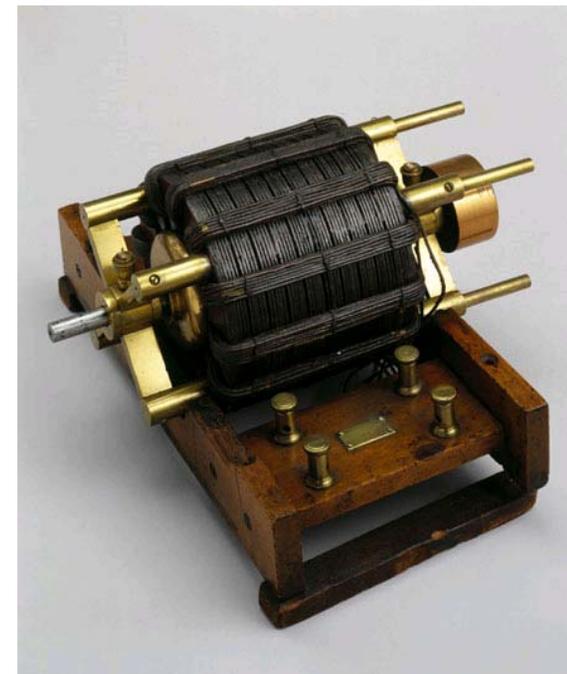
Induction et le moteur électrique



Induction, Faraday (1831)



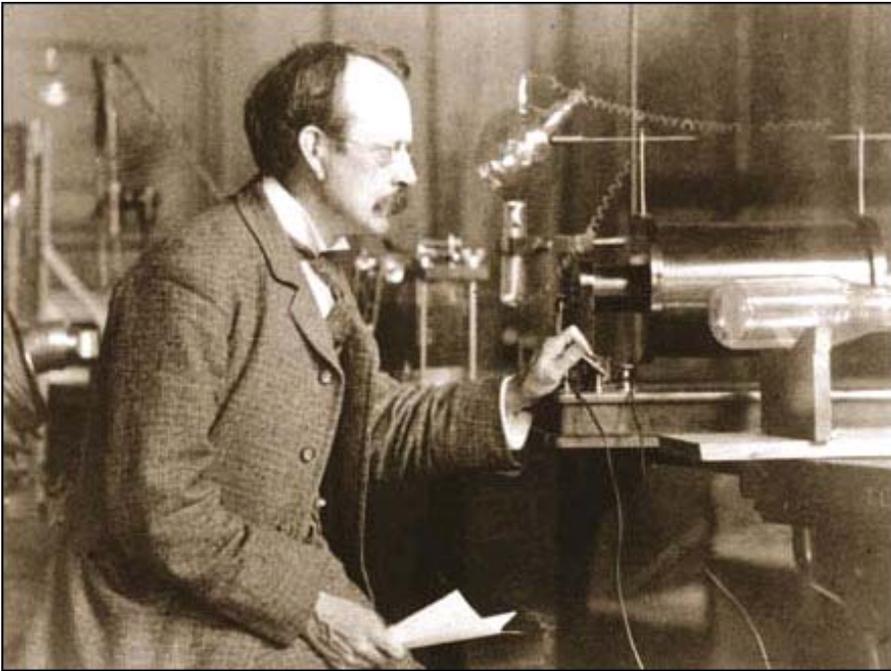
Moteur électrique, Tesla(1880)



Induction



Électron and television



Thomson, 1897



Télévision, 1940

Mécanique quantique et le transistor



Prof. Dr. Erwin Schrödinger
erhielt den diesjährigen Nobelpreis für Physik. Prof. Schrödinger lehrte bis vor kurzem in Berlin, folgte aber dann einem Ruf nach Oxford. — Er hat das Bohrsche Atommodell umgestaltet zu einem „Schwingungs“-Modell.
Phot. Robertus, Berlin

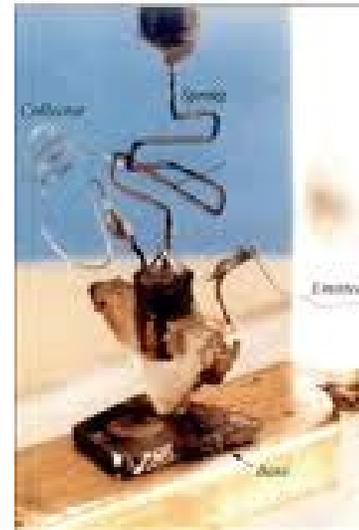
Schrödinger



Heisenberg

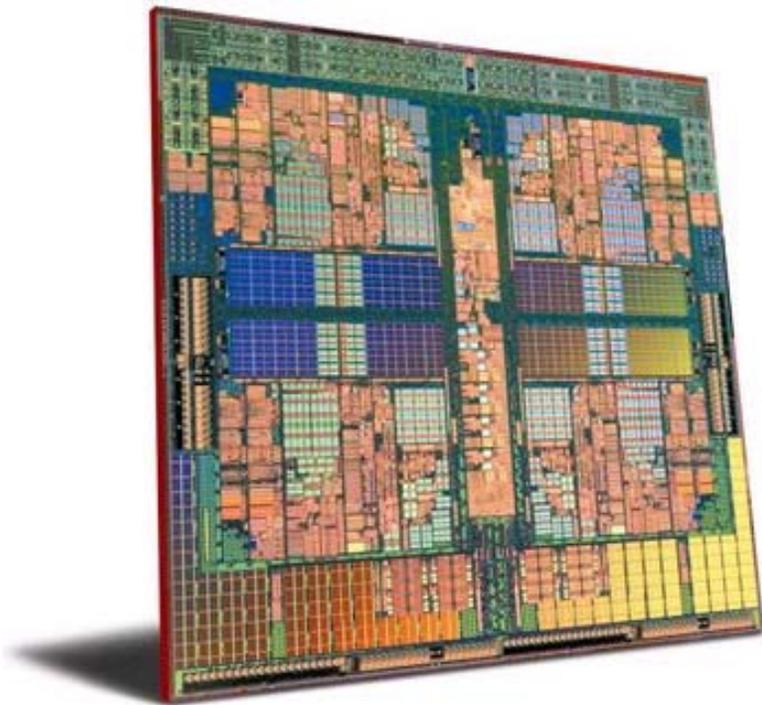
Mécanique quantique 1926

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

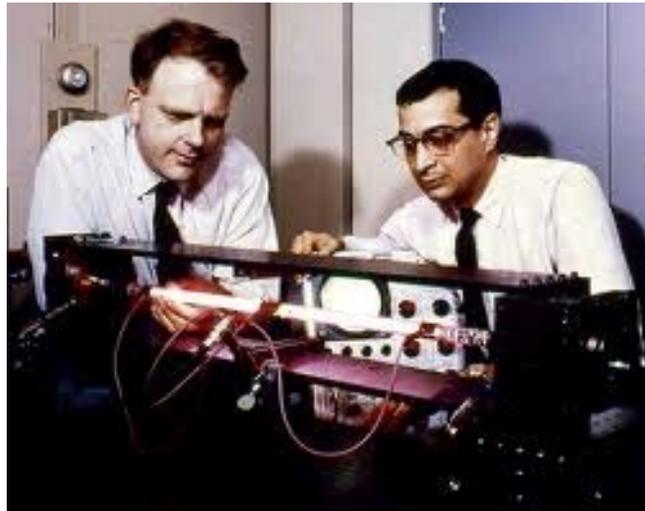


Transistor 1947

Mécanique quantique et le transistor



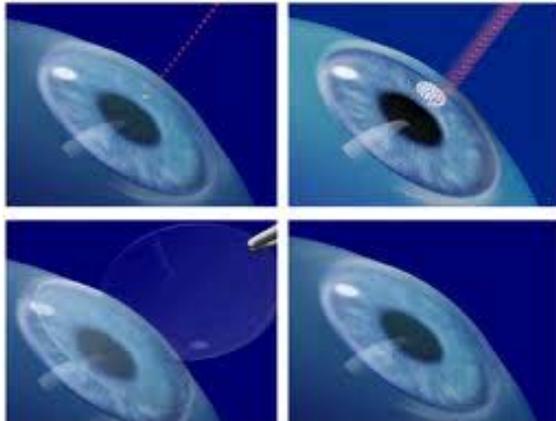
Laser et CD-ROM



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