

Markus Braden

II. Physikalisches Institut

Experimentelle Festkörperphysik

Übungen :

Dr. E. Benckiser

A.C Komarek

Organisatorisches :

Verschiebung der Mi-Vorlesung auf Mi 8:30 – 10:00 HS III ? ? ?

Übungen : Freitags 2 Gruppen im Seminarraum II. Physik

12:00 – 12:45 Uhr und 13:00 – 13:45 Uhr

Einteilung am Fr. den 18.4.2007 nach der Vorlesung

10 Übungsblätter davon 50% notwendig zur Zulassung zur Klausur  
plus eine Sonderübung

Klausur am 16.07.2008 !



# Was ist Festkörperphysik ?

- **Untersuchungen von allem „FESTEN“**
  - a) **kristalline Materialien**
  - b) **amorphe Substanzen**
  - c) **Gläser**
- bis hin zu *zähen* Flüssigkeiten**
- **der breiteste Zweig der modernen Physik**

# Wieso studiert man Festkörper?

## 1) Anwendungen

**Konstruktion (Stahl, ...)**

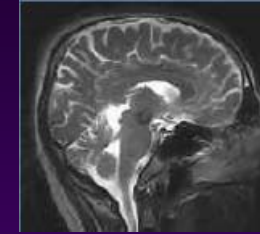
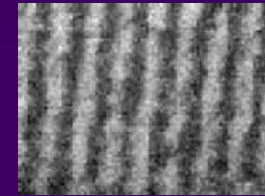
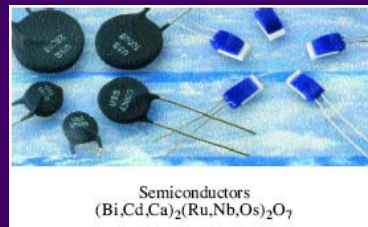
**Supraleiter (Energieübertragung, Medizin, ...)**

**Magnetismus in Speichermedien**

**wiederaufladbare Batterien**

**Mikrochips**

...



## 2) Fundamentale Fragestellungen :

**Wie verhält sich eine große Anzahl von Teilchen ?**

**Wie entstehen daraus makroskopische Eigenschaften?**

# Bedeutung der Festkörperphysik?

- 1913 Kammerling-Onnes Supraleitung
- 1914 Max von Laue für X-ray Beugung
- 1915 Bragg (Vater und Sohn) für x-ray Strukturbestimmung
- 1956 Shockley, Bardeen, Brattain für den Transistor
- 1970 L. Neel für antiferromagnetische Ordnung
- 1972 Bardeen, Cooper, Schrieffer für die BCS Theorie zur Supraleitung
- 1973 Josephson Tunnel-Effekte in Supraleitern  
Esaki und Gieaver für Halb-Supraleiter- Tunneln
- 1977 Andersen, Fleck, Mott Magnetismus
- 1982 K. Willson kritische Phänomene
- 1985 K. v. Klitzing Quanten-Hall-Effekt
- 1986 Ruska, Binning, Rohrer Elektronenmikroskop, STM
- 1987 Bednorz und Müller Hoch-Tc-Supraleiter
- 1991 P.G. de Gennes Ordnungsprozesse in Flüssigkristallen, Magneten...
- 1994 Brockhouse und Shull, Neutronenstreuung
- 1996 Lee, Oseeroff, Richardson He<sup>3</sup>
- 1998 Kohn Dichte-Funktional-Theorie (Chemie)
- 1998 Laughlin, Kroemer, Tsui Fraktionaler Quanten-Hall-Effekt
- 2000 Alferov, Kroemer, Kilby Integrierte Bausteine
- 2001 Cornell, Ketterle, Wiemann BEC in verdünnten Gasen
- 2003 Abrikosov, Ginzburg, Legget, Theorie zu Supraleitern und –flüssigkeiten
- 2007 Grünberg, Fert, Gigantischer Magnetwiderstand

# Wie baut sich ein Festkörper auf ?

Atom : Größe  $1-2 \cdot 10^{-10} \text{m} = 0.000\ 000\ 000\ 1 \text{ m}$

→ in einem Würfel von 1cm Kantenlängen befinden sich  $\sim 10^{23}$  Atome

also  $10^{23}$  Kerne und  $Z \cdot 10^{23}$  Elektronen

→ Festkörperphysik ist Vielteilchenphysik

zum Glück :  
regelmäßige Anordnung



# Regelmäßige Anordnung von Atomen

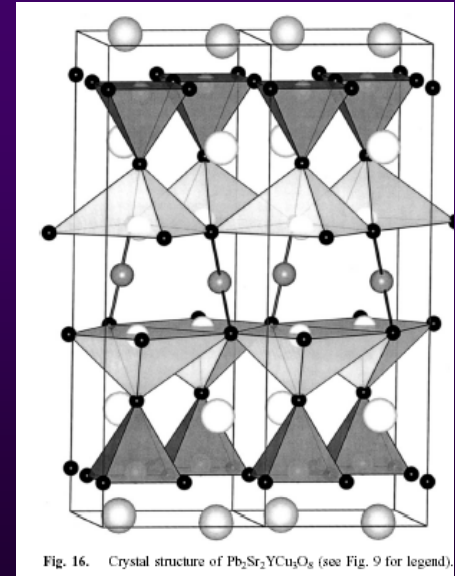
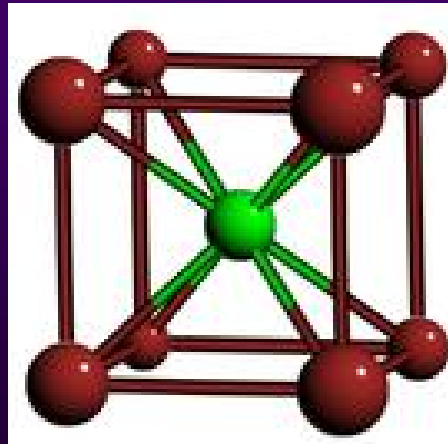
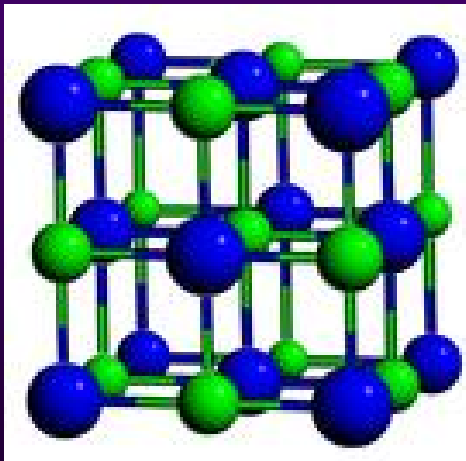
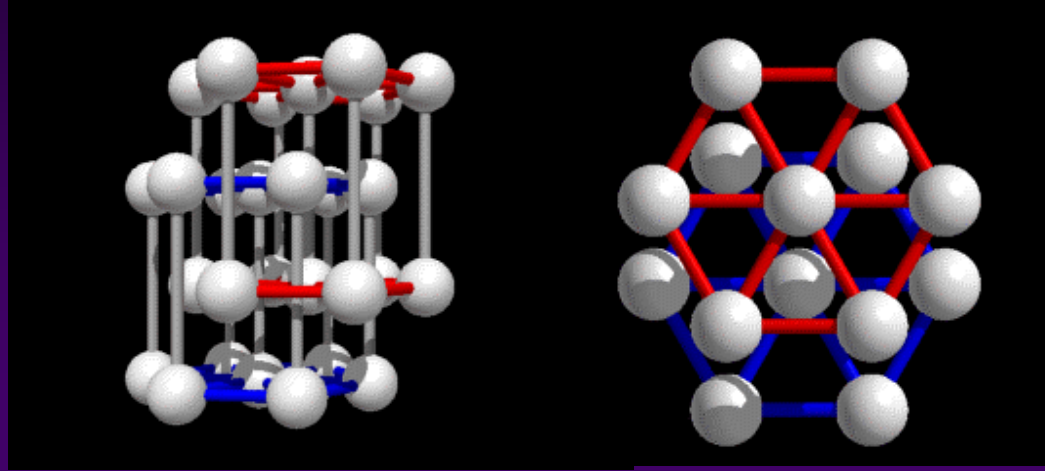
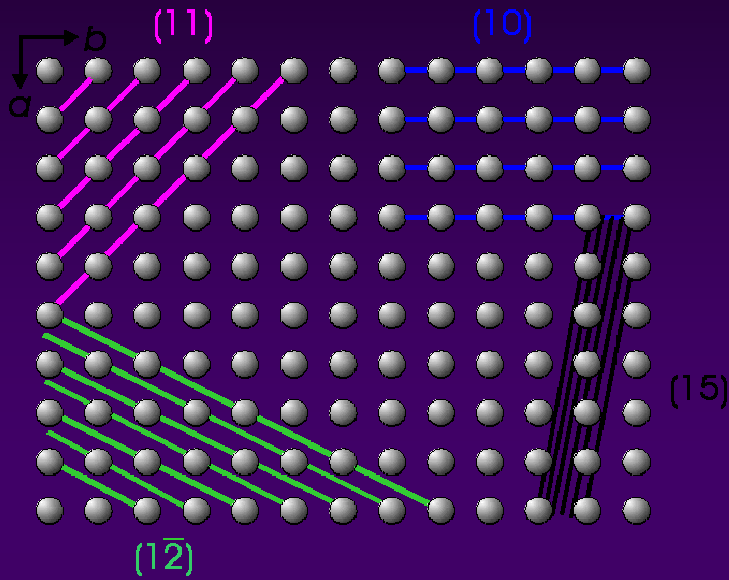
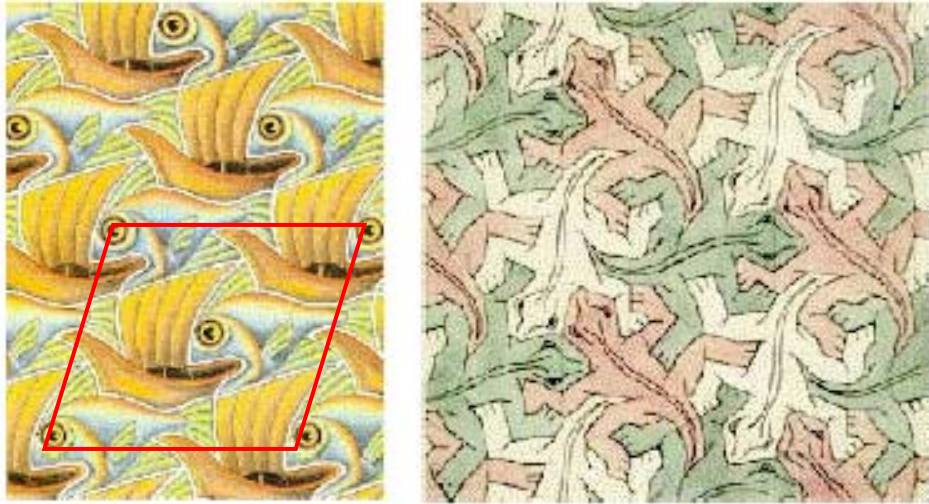
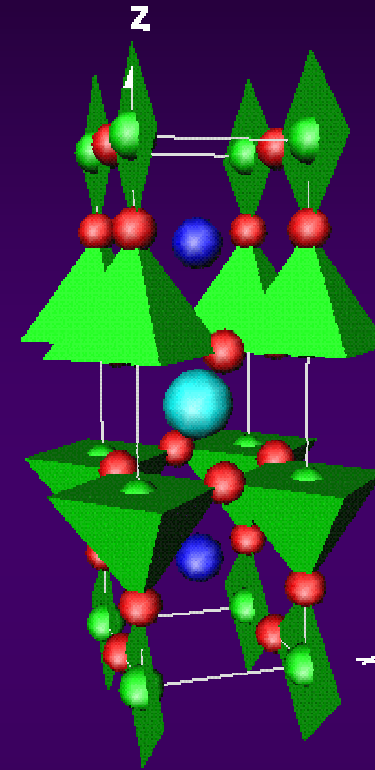


Fig. 16. Crystal structure of  $\text{Pb}_2\text{Sr}_2\text{YCu}_3\text{O}_8$  (see Fig. 9 for legend).

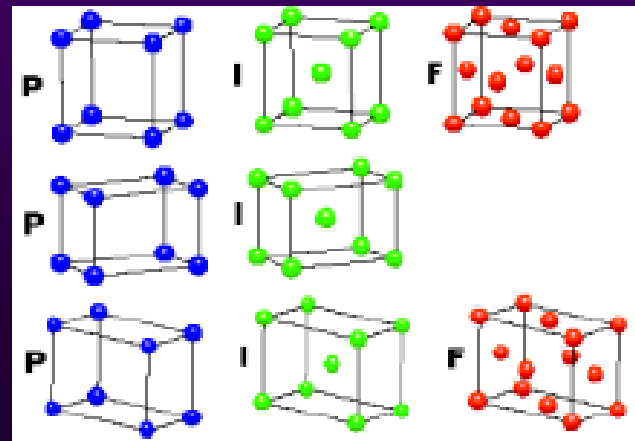
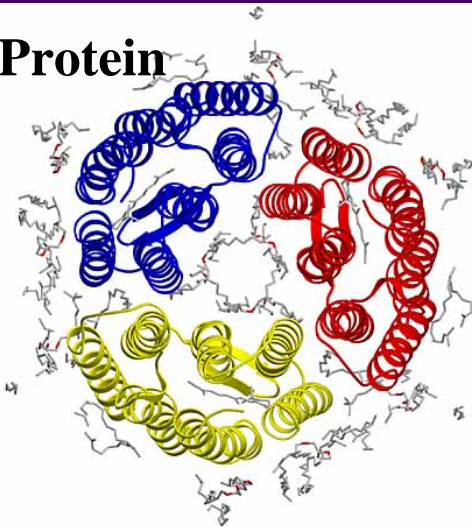
# Kristall : Muster und Wiederholung



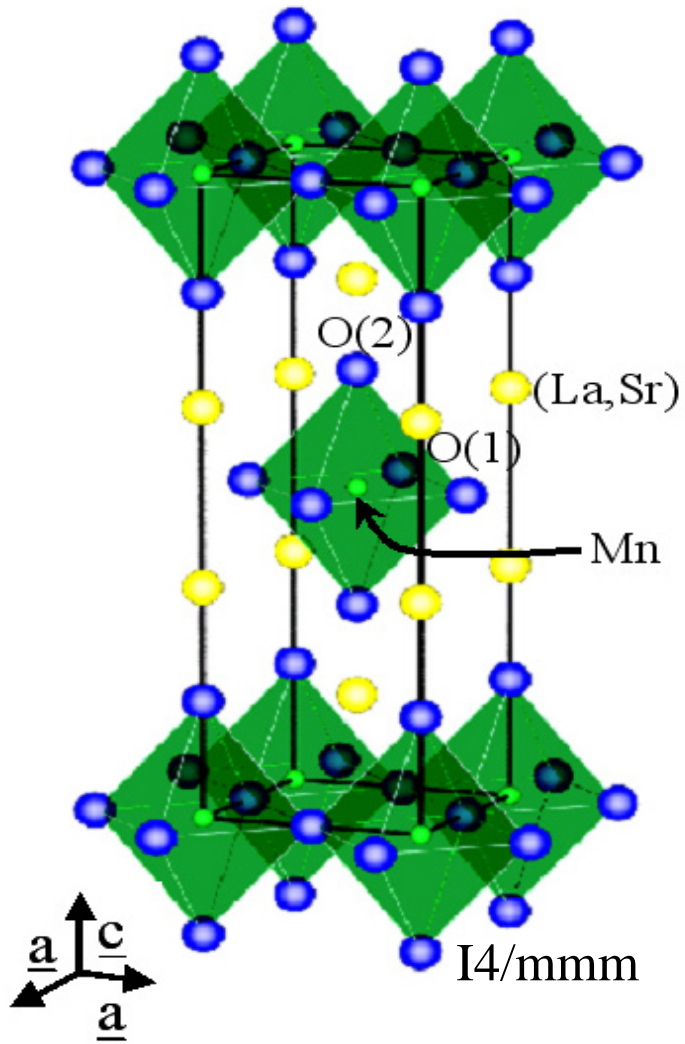
(M. C. Escher)



## Protein



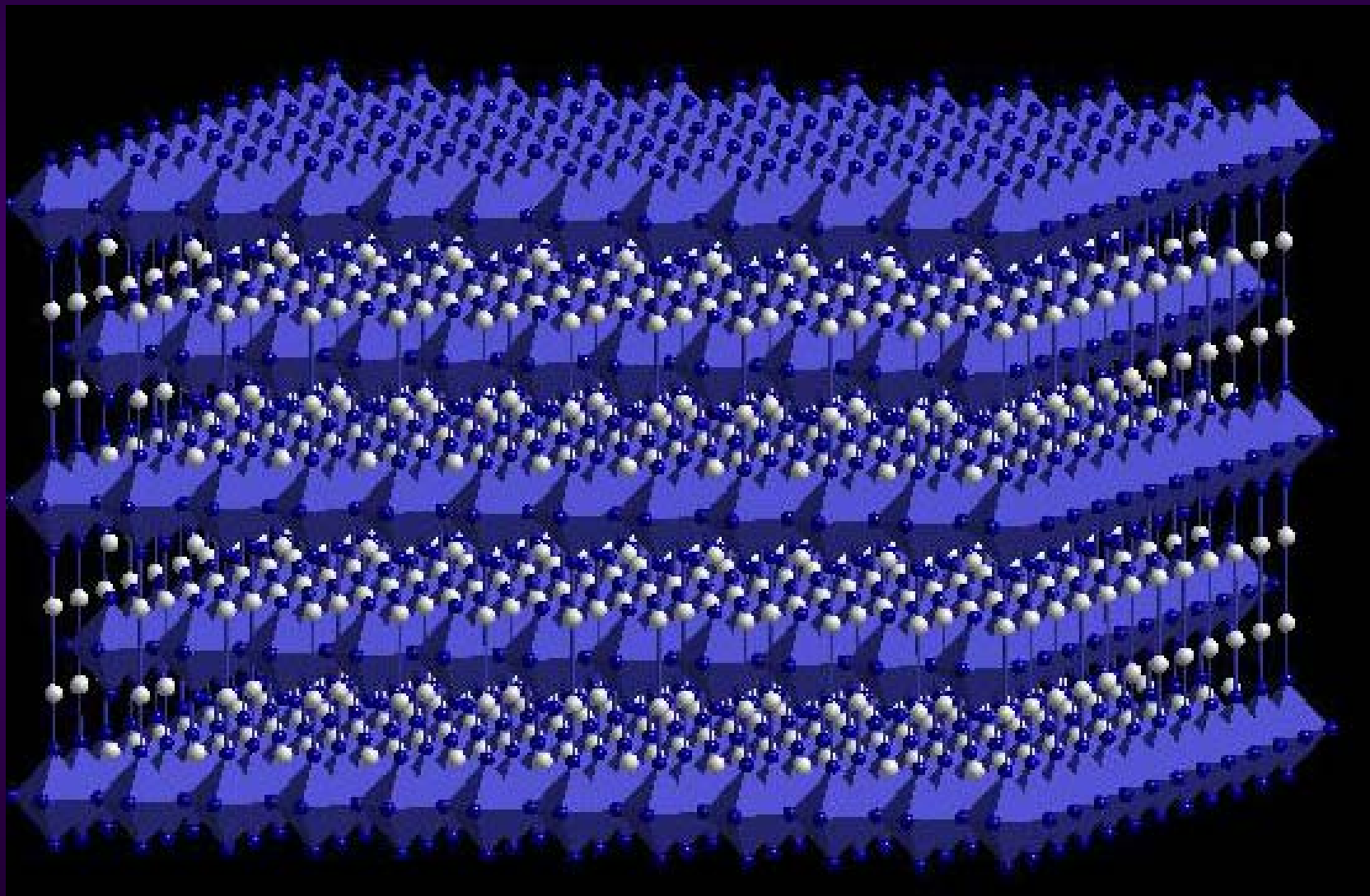




- Strukturtyp  $K_2NiF_4$   
 Cuprate, Manganate, . . .

Perovskit-artig

# Kristall : Muster und Wiederholung



# Kristalle und deren Spaltung

Hexagonal beryl



Monoclinic gypsum

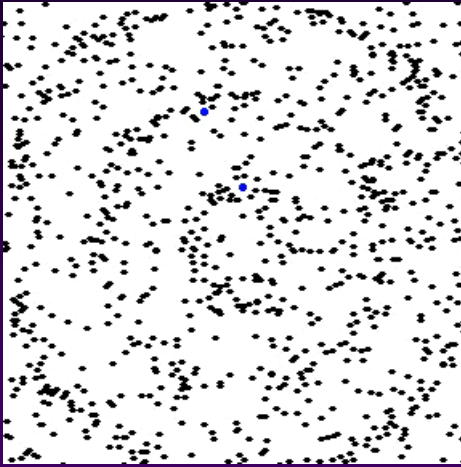


Trigonal quartz

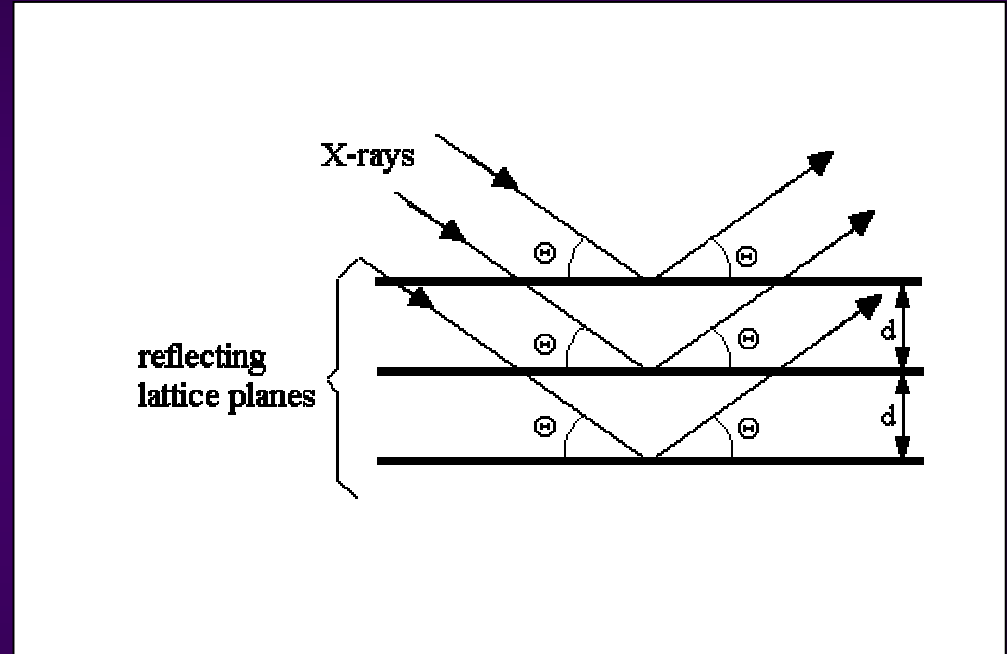
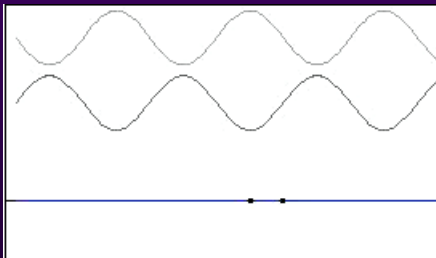
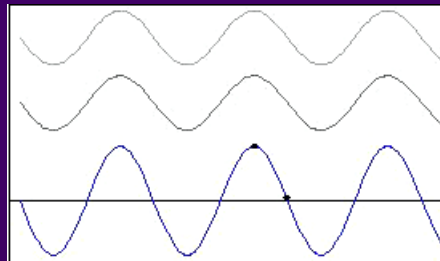


Amorphous amber  
(no underlying  
crystal symmetry)





# Wellen machen es einfacher !



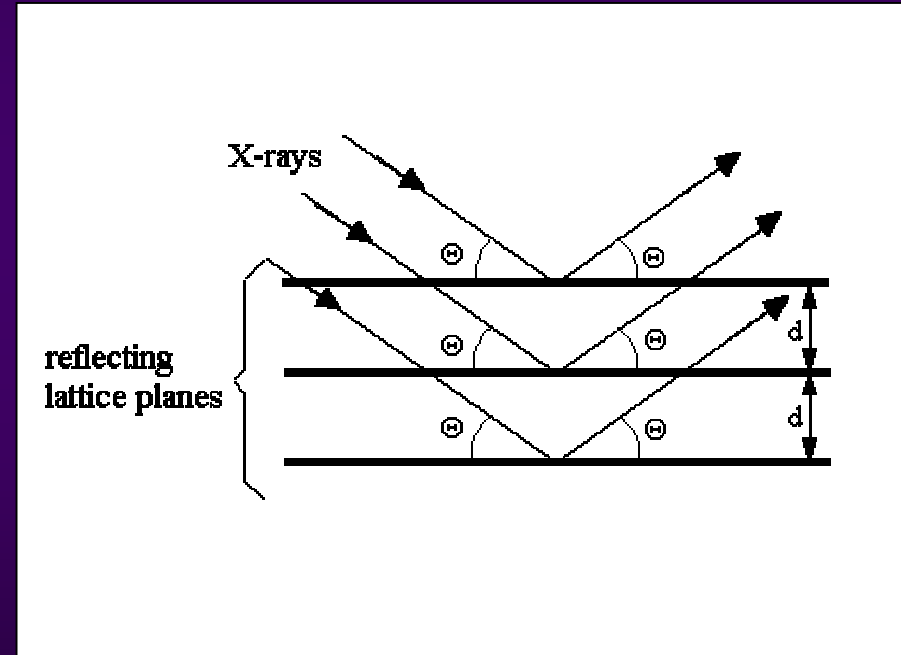
- **Licht ist eine elektromagnetische Welle**
- **Gitterschwingungen sind Wellen (Phononen)**
- **auch Elektronen verhalten sich wie Wellen**

Festkörperphysik  $\leftrightarrow$  Fourier-Transformation, --Zerlegung ...

# Wie sieht man kleine Dinge?



# Röntgen-Anlage zur Erforschung von Festkörpern



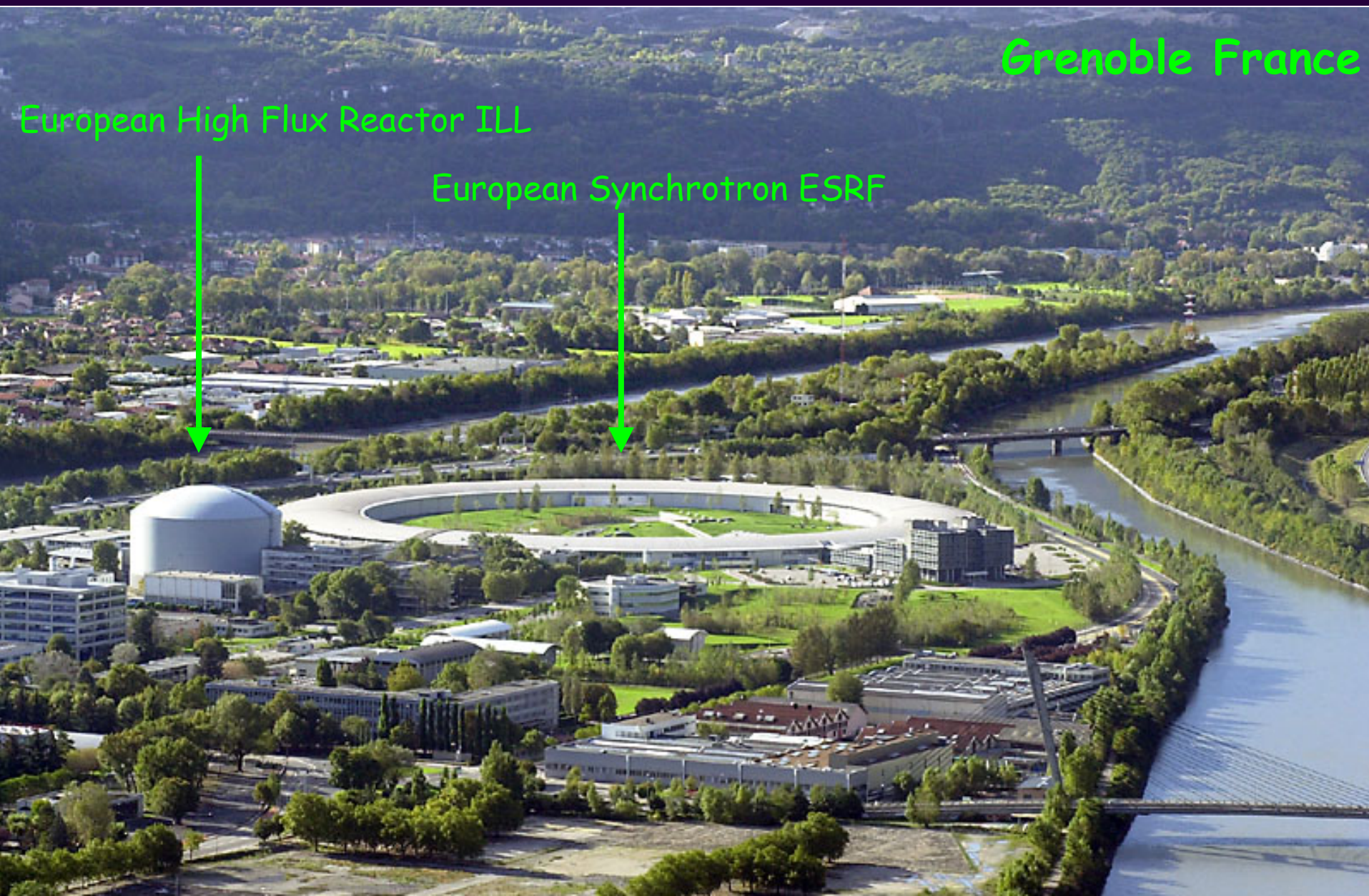
# Großanlagen zur Erforschung von Festkörpern

Grenoble France

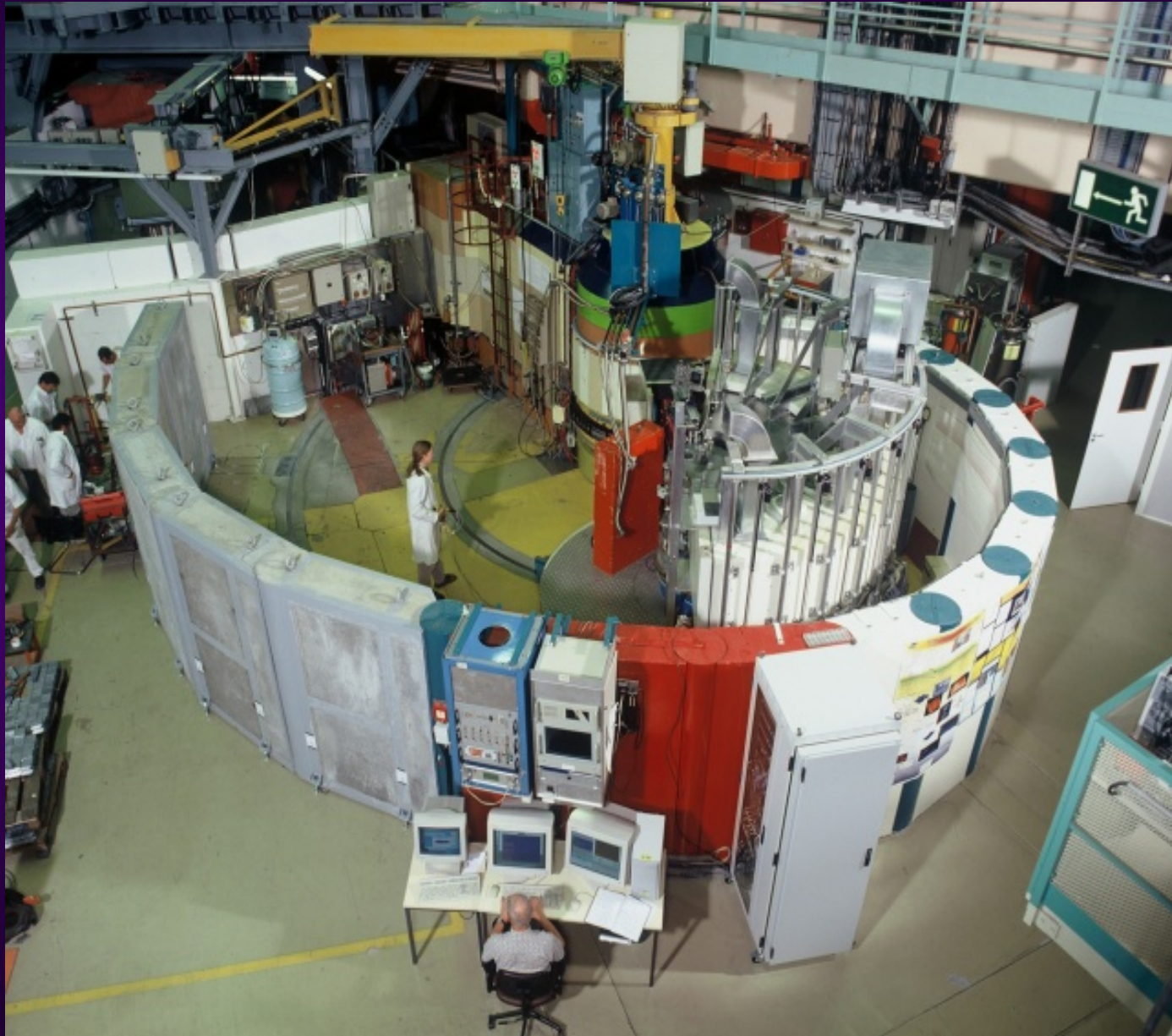
European High Flux Reactor ILL



European Synchrotron ESRF



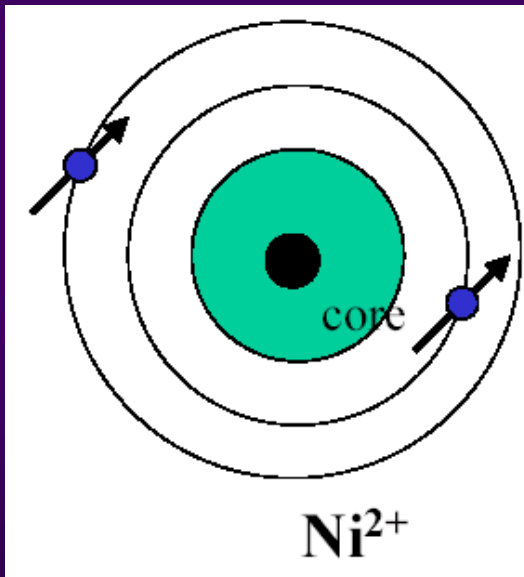
# D20 HF/HR diffractometer



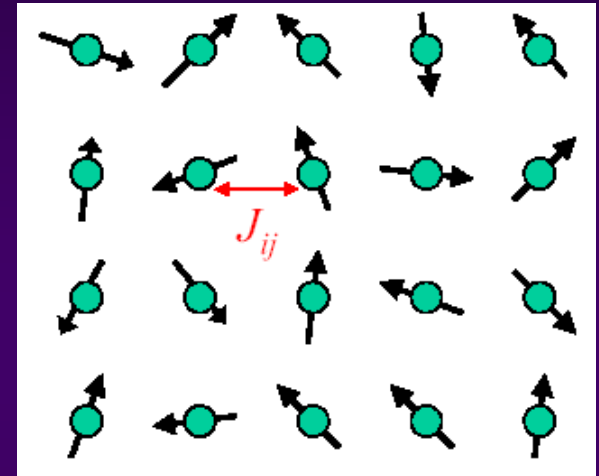


# Magnetismus

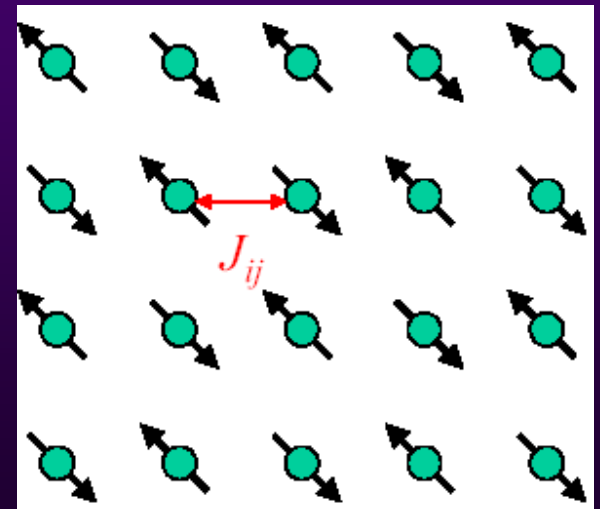
- manche Atome verhalten sich wie kleine Permanentmagnete



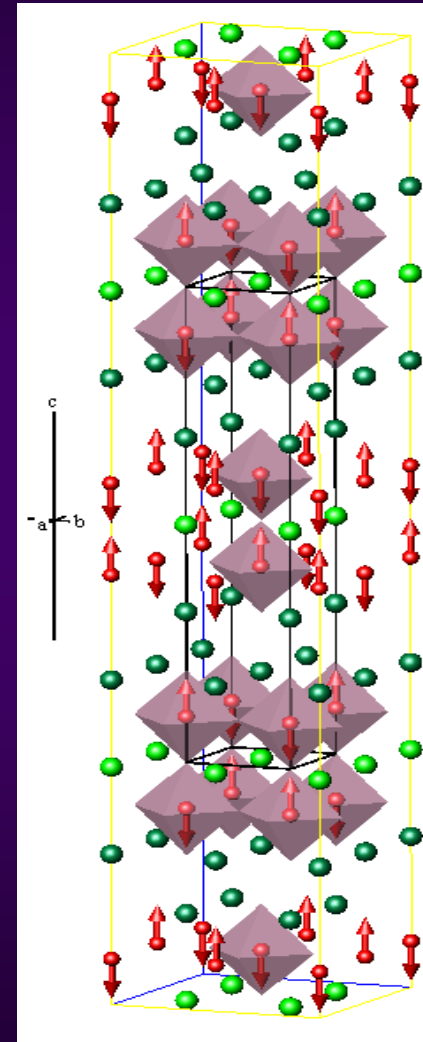
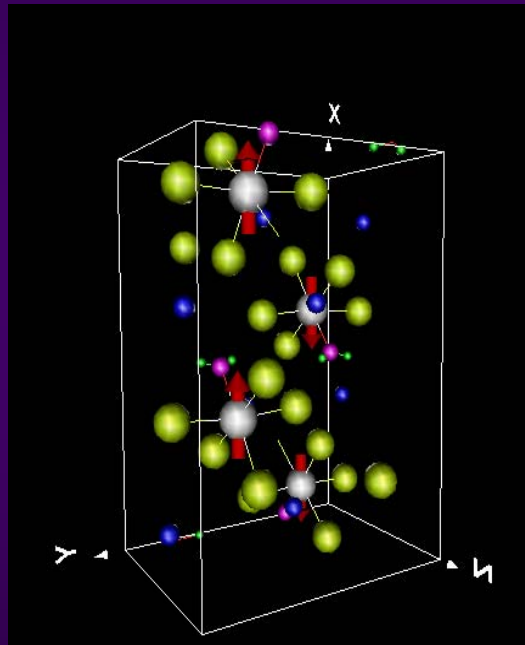
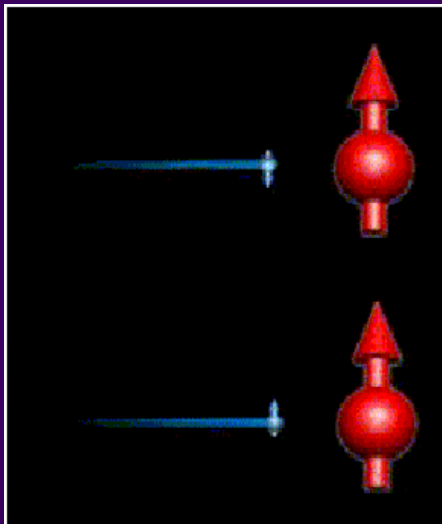
ungeordnet :



geordnet :



# Magnetische Eigenschaften



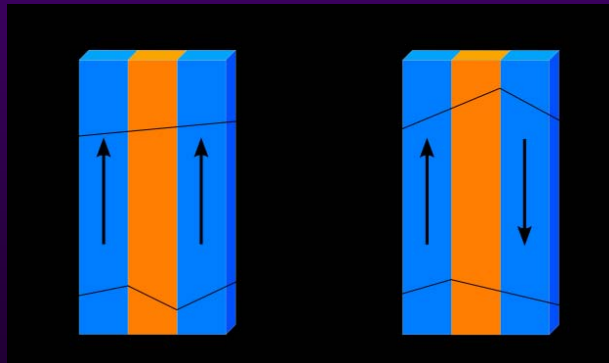
AFM(G)

# Nobel-Preis für Physik 2007

Prof. Peter Grünberg

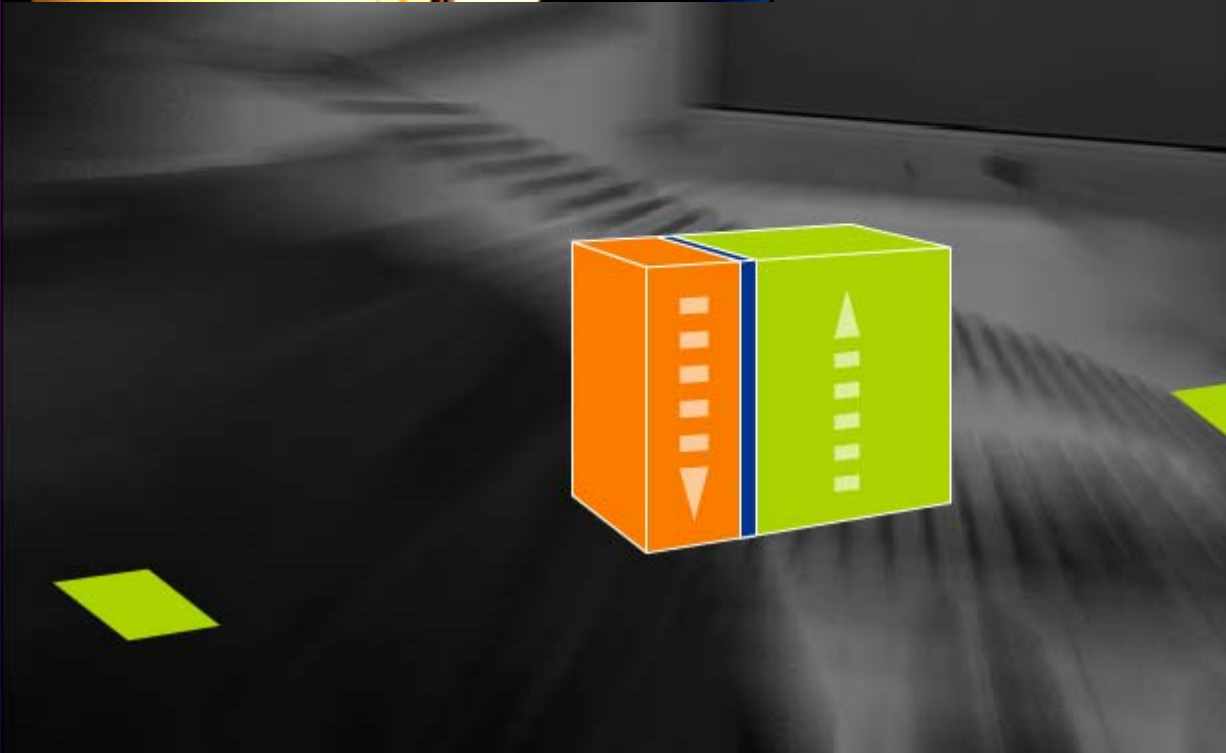
Forschungszentrum Jülich

Prof. an der Univ. zu Köln

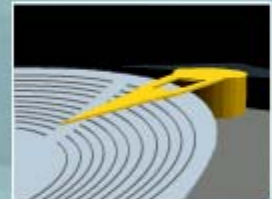
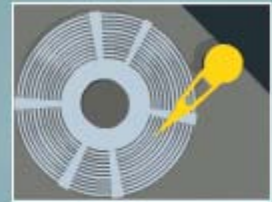


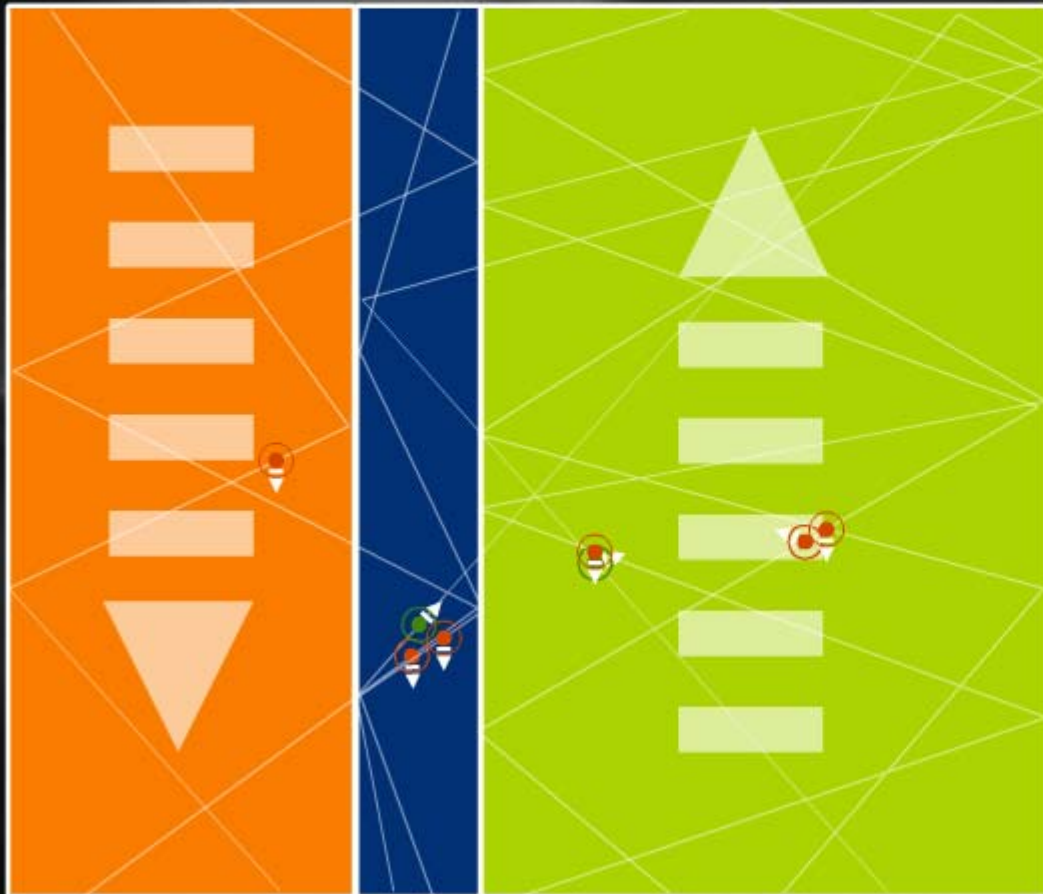


IBM Deutschland GmbH



## Der GMR-Effekt





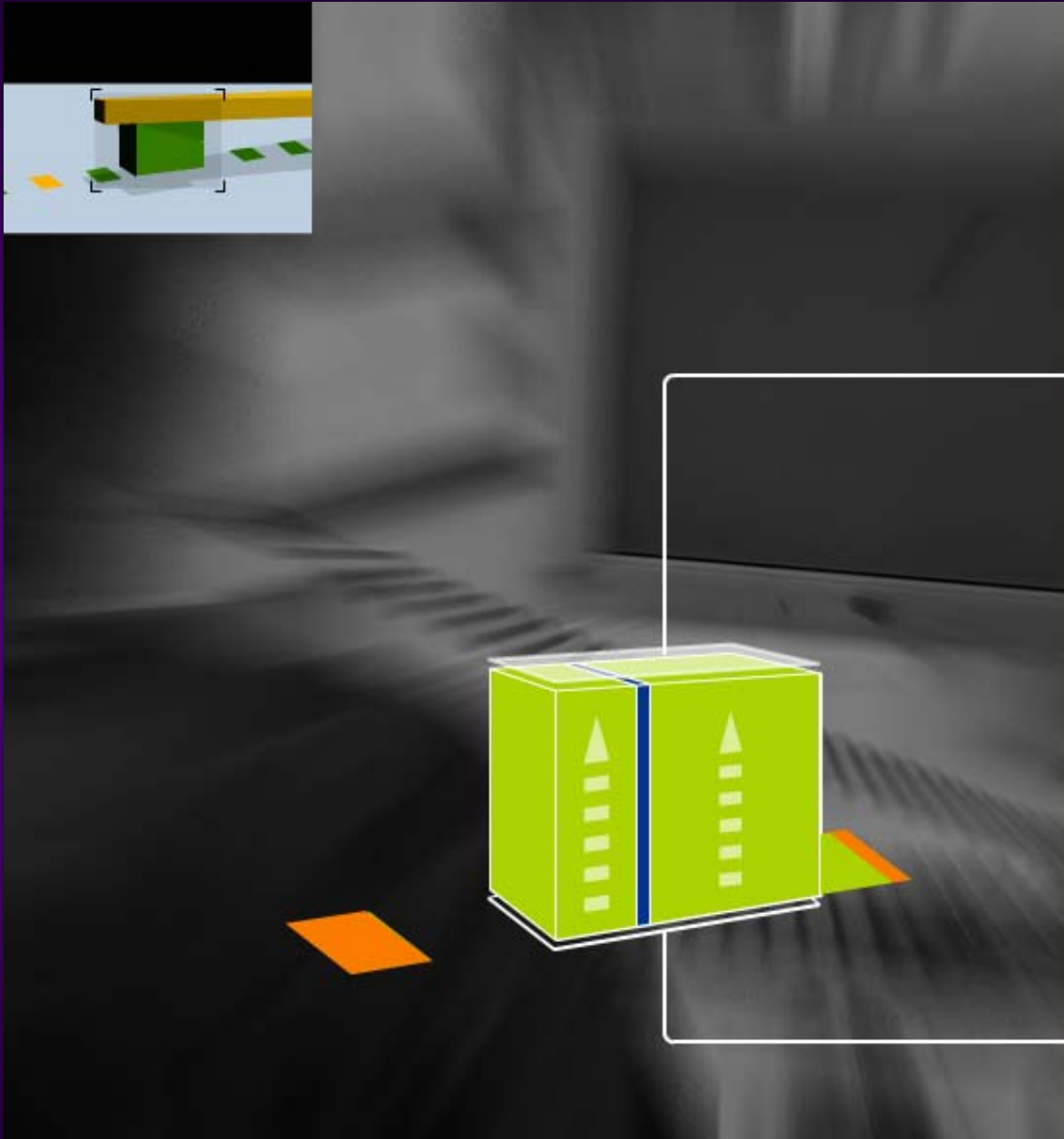
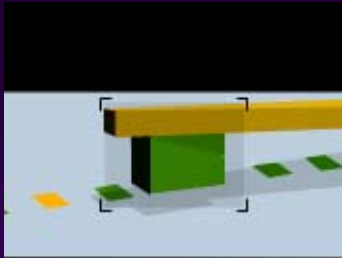
**SpinUp**

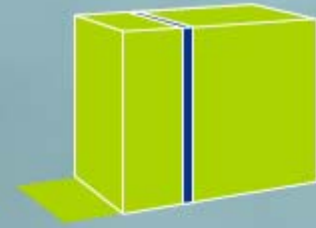
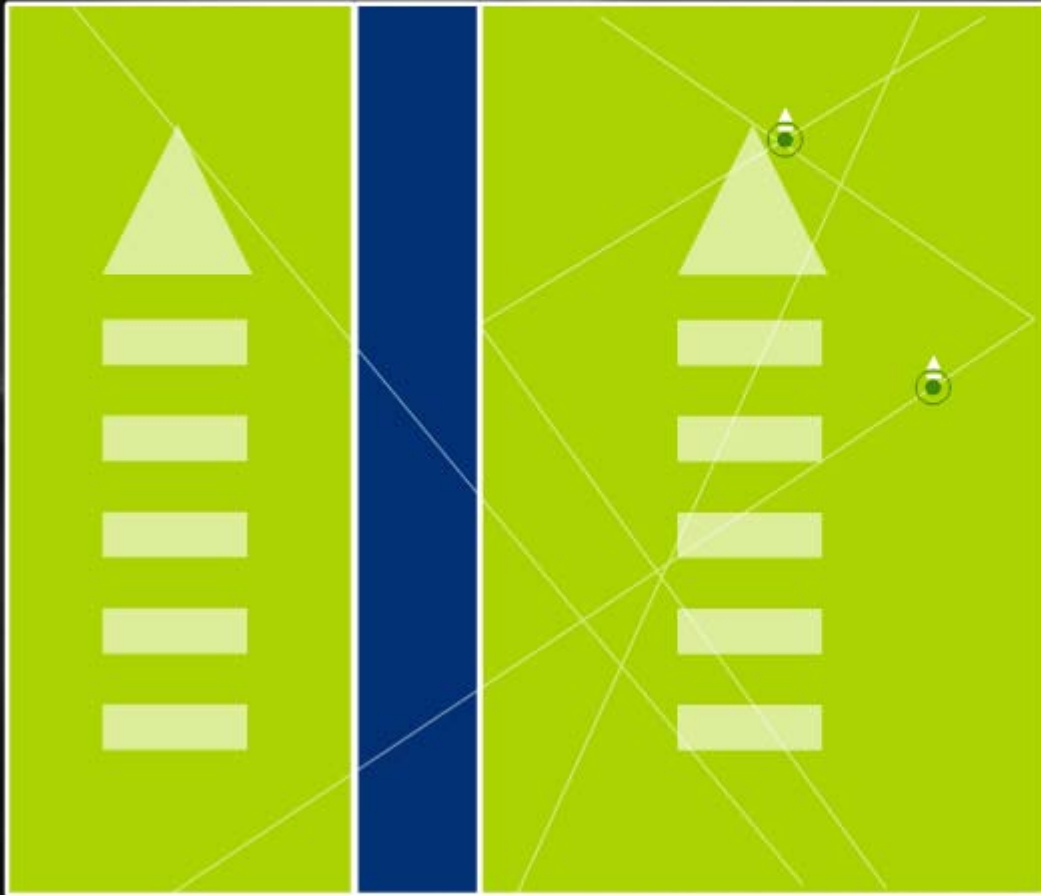


**SpinDown**

**Stromstärke**







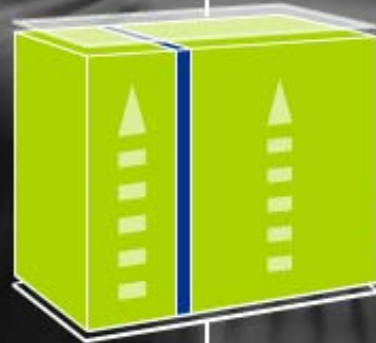
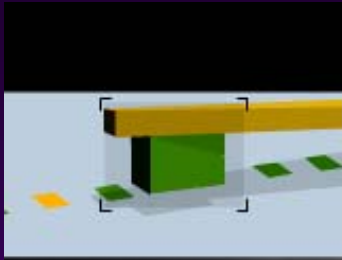
**SpinUp**



SpinDown

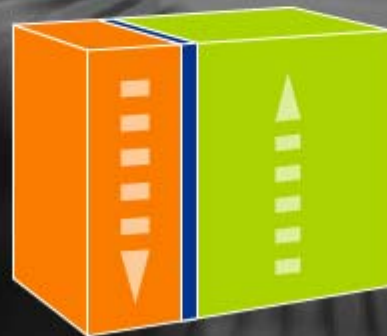
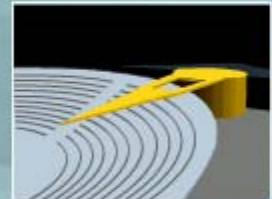
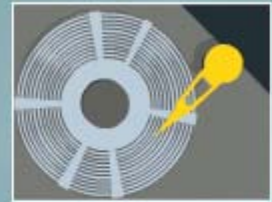
**Stromstärke**





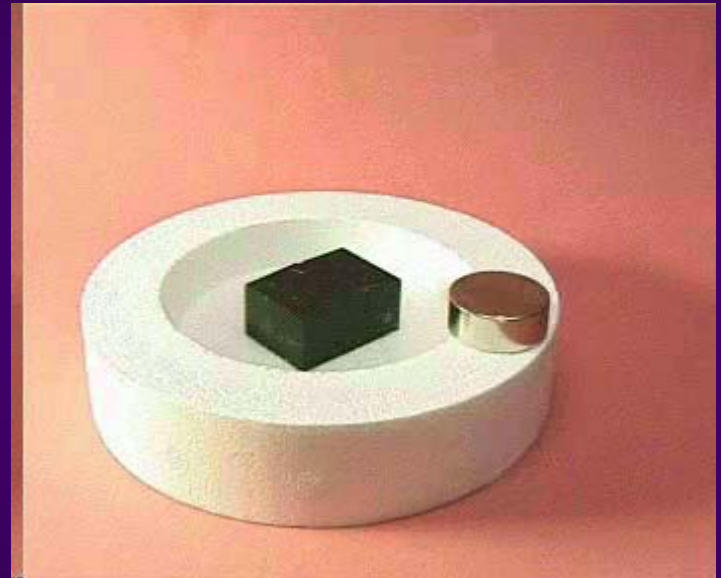


## Der GMR-Effekt



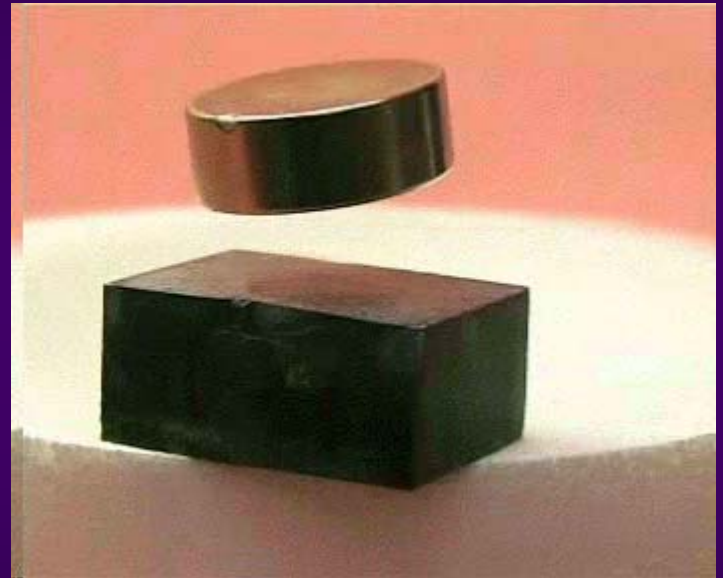
# Aktuelle Forschung I : Hoch- $T_c$ -Supraleitung

- Elektronen : Pauli-Prinzip  
meiden sich
- hier : Elektronen-Paare
- stabile Phase von Materie

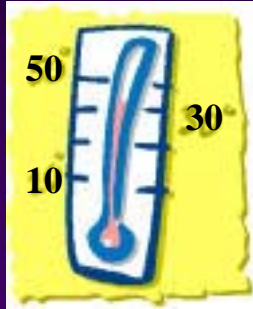


# Supraleitung

- Elektronen : Pauli-Prinzip  
meiden sich
- hier : Elektronen-Paare
- stabile Phase von Materie



# Supraleitung : Basis-Wissen

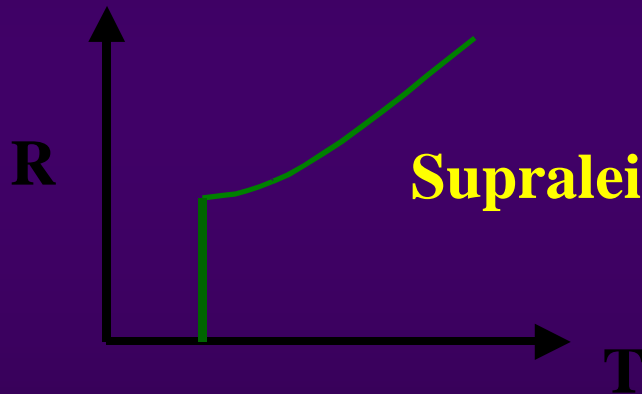


**Supraleitung tritt bei tiefen Temperaturen auf**

**Strom + Widerstand  $\rightarrow$  Verlust**

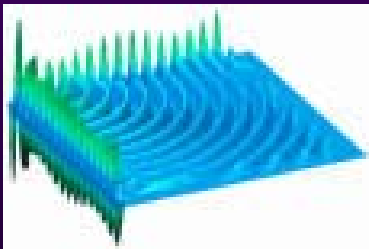
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**Supraleiter haben keinen elektrischen Widerstand**



**Supraleiter stoßen das magnetische Feld aus**

**zwei Elektronen bilden ein Cooper-Paar**





John Bardeen



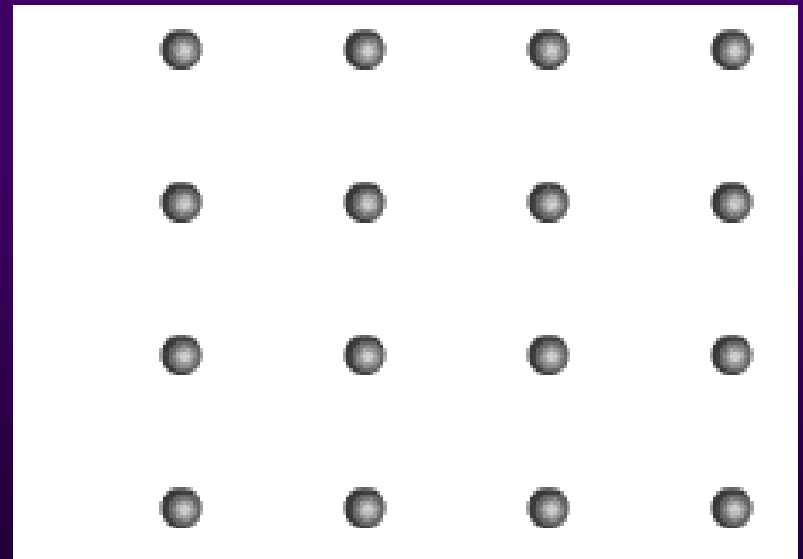
Leon Cooper



Bob Schrieffer

# Konventionelle Supraleitung

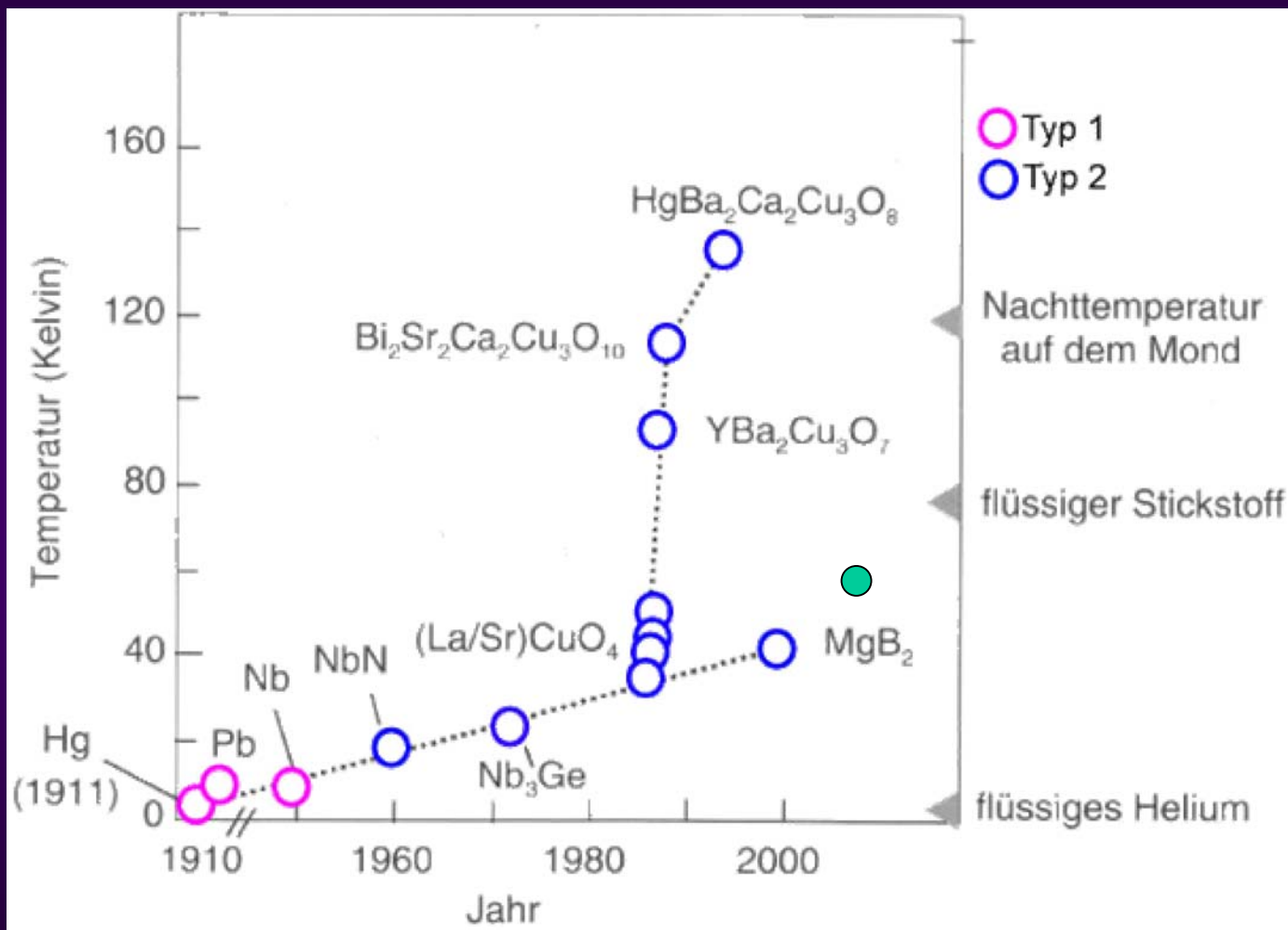
- BCS Theorie
- *metallischer*
- *Zustand wird instabil*



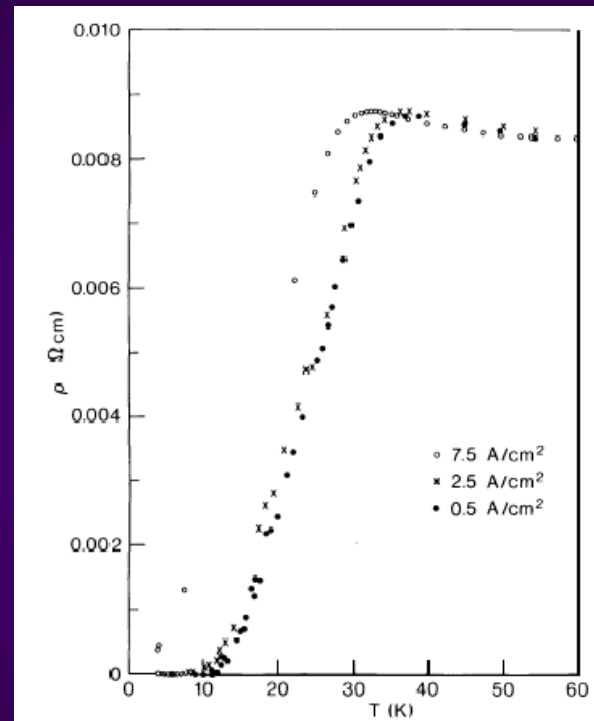
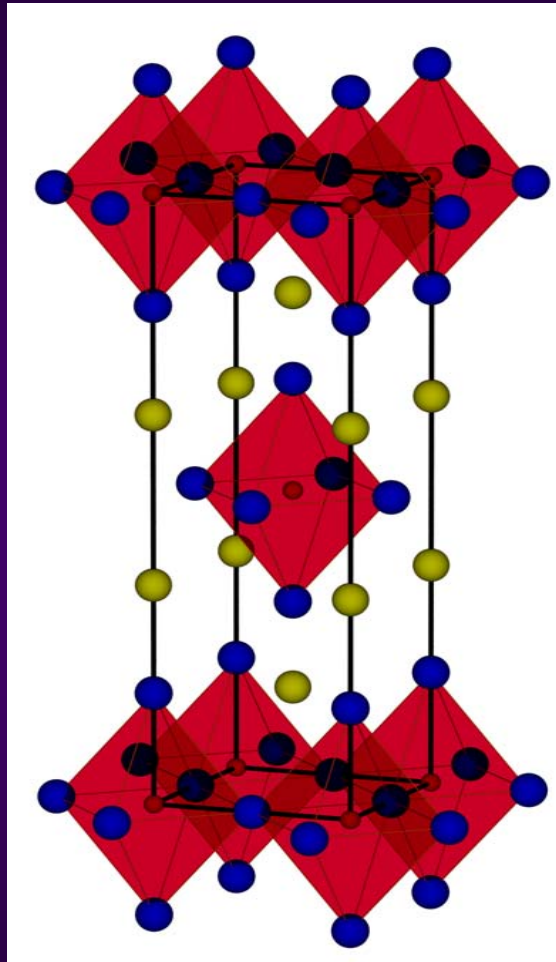
# Oxidische Supraleiter

ohne Kuprate !!! :

	$T_c$	
- $\text{SrTi}_{1-x}\text{Nb}_x\text{O}_3$	<0.5 K	(1964 ...)
- W-Bronzen	7 K	(1964 ...)
- NbO	~1.5 K	(70er)
- TiO	~1.0K	(70er)
- Spinel $\text{LiTi}_2\text{O}_4$	13 K	(1973)
- $\text{BaPb}_{1-x}\text{Bi}_x\text{O}_3$	13 K	(1975)
- $\text{Ba}_{1-x}\text{K}_x\text{BiO}_3$	35 K	(1988)
- $\text{Sr}_2\text{RuO}_4$	1.45 K	(1994)
- $\text{Cd}_2\text{Re}_2\text{O}_7$	1.5 K	(2001)
- $\text{Na}_x\text{CoO}_2 \cdot \text{H}_2\text{O}$	3-4 K	(2003)
- $\text{KOs}_2\text{O}_6$	10 K	(2004)
$\text{RbOs}_2\text{O}_6$	6.3 K	(2004)



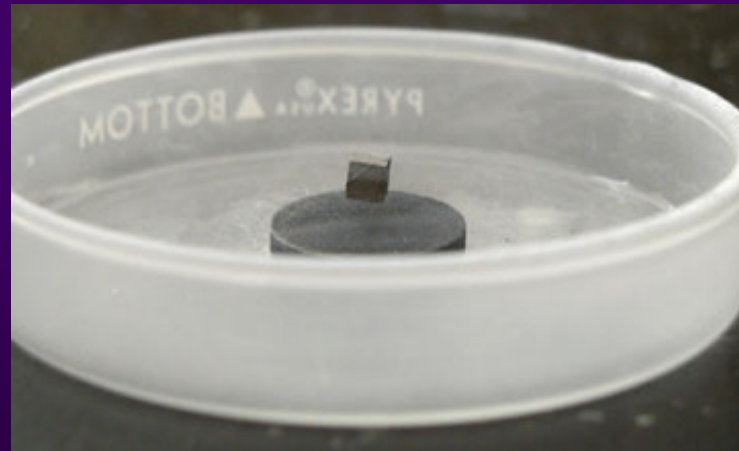
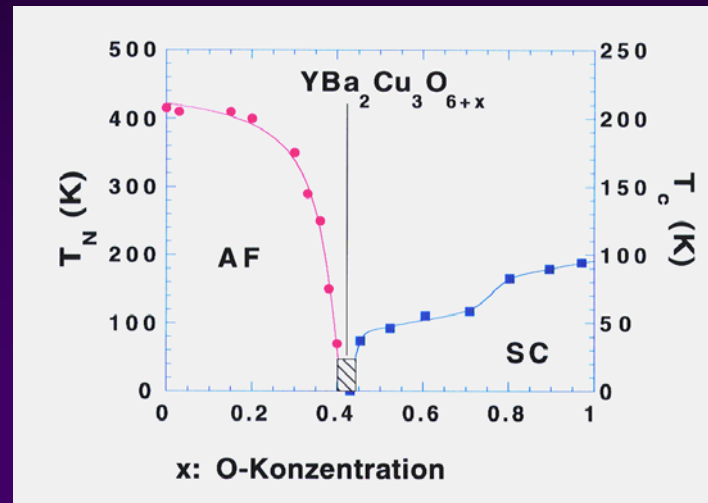
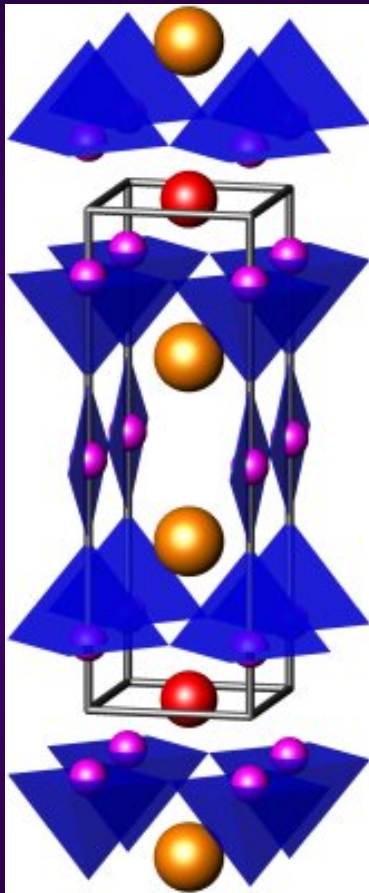
# Bednorz und Müller 1986



**1986 30K**  $\text{La}_{1.85}\text{Ba}_{0.15}\text{CuO}_4$  J. G. Bednorz, K. A. Müller  
*Zeitschrift für Physik B*. Vol. 64: 189-193.



# Modifizierte Phase : $\text{YBa}_2\text{Cu}_3\text{O}_{6+x}$



**1987 90K**  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (liquid nitrogen barrier broken) Wu et al., *Physical Review Letters*. 58 (1987): 908-910.

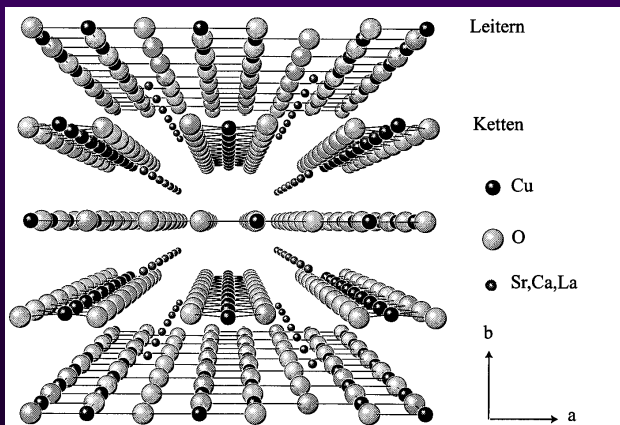
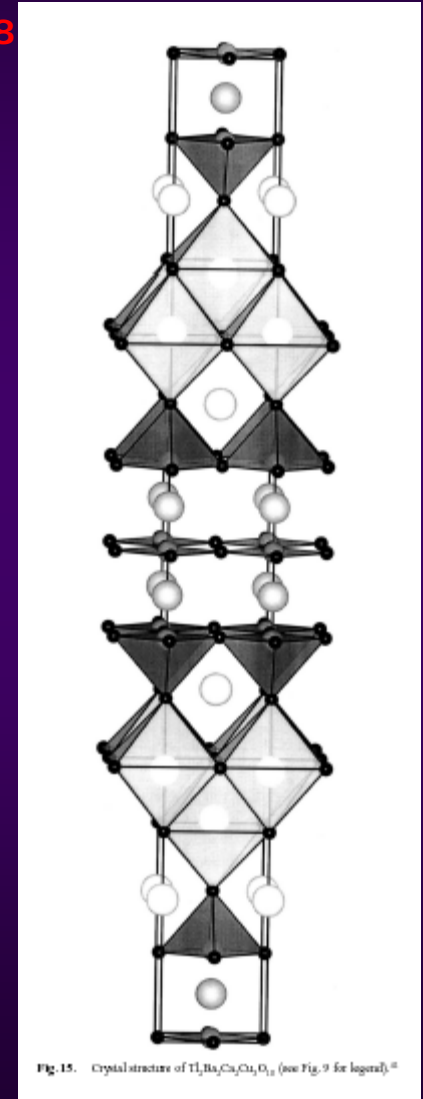
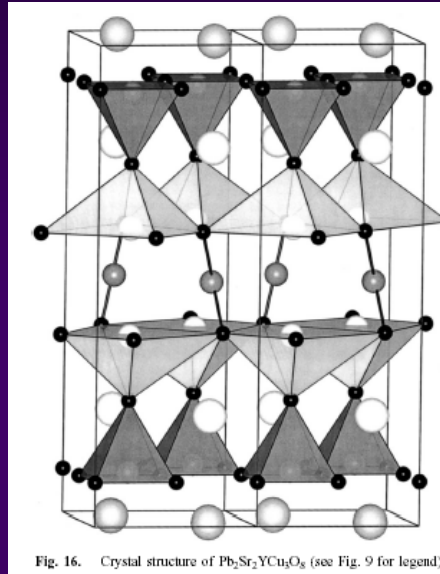
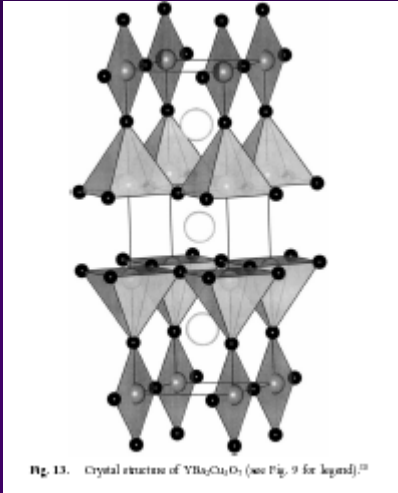
# Hoch- $T_c$ -Kuprat-Supraleiter

year	$T_c$ [K]	
1986	30	$\text{La}_{1.85}\text{Ba}_{0.15}\text{CuO}_4$ J. G. Bednorz, K. A. Müller <i>Zeitschrift für Physik B</i> . Vol. 64: 189-193.
1987	90	$\text{YBa}_2\text{Cu}_3\text{O}_7$ (liquid nitrogen barrier broken) Wu et al., <i>Physical Review Letters</i> . 58 (1987): 908-910.
1988	115	$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ H. Maeda et al <i>Jap. J. of Appl. Physics</i> . Vol. 27 (1988): 209.
1988	125	$\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ Z. Z. Sheng, A. M. Hermann <i>Nature</i> . Vol. 332 (1988): 138.
1993	133	$\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_8$ A. Schilling et al. <i>Nature</i> . Vol. 363 (1993): 56-58.
1995	<b>138</b>	$\text{Hg}_{0.8}\text{Tl}_{0.2}\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{8.33}$ P. Dai et al., (highest critical temperature of any material) <i>Physica C</i> . 243 No. 3&4 (1995): 201-206.
1994	164	$\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_8$ (under 30 GPa pressure) Gao et al., <i>Physical Review B</i> . Vol. 50 (1994): 4260-4263.

# Hoch- $T_c$ -Kuprat-Supraleiter

$(La,M)_2CuO_4$	1986	$TlBa_2(Eu,Ce)_2Cu_2O_9$	1992
$La_2CuO_{4+x}$	1988		
$La_2CuO_4F_x$	1988	(Tl,Pb)SrCaCu variants of Tl, Ba, Ca compounds	1988
$(Nd,Sr,Ce)_2CuO_4$	1989		
$(Nd,Ce)_2CuO_4$	1989		
$Nd_2CuO_{4-x}F_x$	1989	$GaSr_2(Y,Ca)Cu_2O_7$	1991
$Sr_2CuO_{3+x}$	1993	$GaSr_2Ca_{n-1}Cu_nO_x$	1994
$Sr_2CuO_2F_{2+x}$	1994	$n = 3, 4$	
$(Ca,Na)_2CuO_2Cl_2$	1994	$AuSr_2CaCu_2O_7$	1997
$(Ca,Na)_3Cu_2O_4Cl_2$	1995	$NbSr_2(Nd,Ce)_2Cu_2O_{10}$	1992
(Sr,K) versions of previous two also are superconducting		$RuSr_2(Nd,Ce)_2Cu_2O_{10}$	1996
		and others in "1222" type with a mix of Cu and M on first Cu site (e.g., Ti, V, Cr) also known	
$(La,Sr)_2CaCu_2O_6$	1990		
$(Sr,Ca)_2(Sr,Ca)_{n-1}Cu_nO_x$	1993	$Cu(Eu,Ce)_2(Eu,Sr)_2Cu_2O_9$	1989
$(n = 2, 3, 4)$		and others in this type with a mix of Cu and M on first Cu site (e.g., Pb, Ga) also known	
$PbBaSr(Y,Ca)Cu_3O_x$	1990		
$Sr_{1-x}Nd_xCuO_2$	1991		
$YBa_2Cu_3O_7$	1987		
$YBa_2Cu_4O_8$	1988	$HgBa_2Ca_{n-1}Cu_nO_{2n+2}$	1993
$Y_2Ba_4Cu_7O_{15}$	1988	$n = 1, 2, 3, 4, 5, 6$	
$(Cu,M)Sr_2(Y,Ca)Cu_2O_7$	1988	$Hg_2Ba_2(Y,Ca)Cu_2O_8$	1994
M stabilized Sr 123		$(Hg_{0.5}Cr_{0.5})Sr_2CuO_5$	1995
M = Pb, Ga, Fe, B, $SO_4$ , $CO_3$ , Al, (Bi + Cd)		$(Hg_{0.5}Cr_{0.5})Sr_4Cu_2O_7CO_3$	1995
		$(Ba,Sr)_2Cu_{1+x}(CO_2)_{1-x}O_y$	1992
$Pb_2Sr_2(Y,Ca)Cu_3O_8$	1988	$(Cu_{1-x}(CO_2)_x)_m(Ba,Sr)_2Ca_{n-1}Cu_nO_y$	1994
$Pb_2(Sr,La)_2Cu_2O_6$	1988	$m = 1; n = 2, 3, 4, 5; x \neq 0 \text{ or } x = 0$	
		$m = 2; n = 3, 4, 5; x \neq 0$	
" $Bi_2Sr_2CuO_6$ "	1987		
$Bi_2Sr_2CaCu_2O_8$	1988	$Bi_2Sr_4Cu_2O_8CO_3$	1993
$Bi_2Sr_2Ca_2Cu_3O_{10}$	1988	$Bi_2Sr_2Cu_3O_{10}(CO_3)_2$	1994
$Bi_2Sr_2(Ln,Ce)_2Cu_2O_{10}$	1990	(Tl,Pb)Sr <sub>4</sub> Cu <sub>2</sub> O <sub>7</sub> CO <sub>3</sub>	1993
$Tl_2Ba_2Ca_{n-1}Cu_nO_{2n+4}$	1988	$Ca_{13.5}Sr_{0.5}Cu_{24}O_{41}$	1996
$n = 1, 2, 3, 4$		(60 kbar (6 MPa) applied pressure only)	
$TlBa_2Ca_{n-1}Cu_nO_{2n+3}$	1988		
$n = 1, 2, 3$			

# Einige Kristallstrukturen



# Schema der Kristallstrukturen: ein wenig Chemie

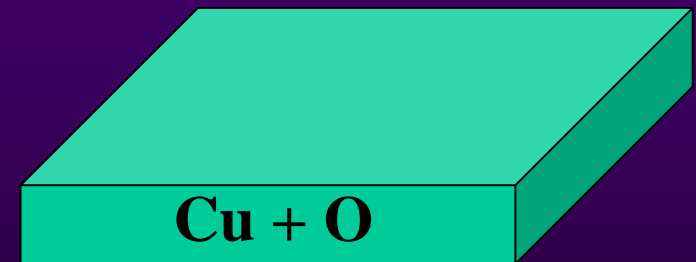
## Hoch-Temperatur-Supraleiter Formeln



**Cu = Copper**

**O = Oxygen**

**CuO = CopperOxide**



# Schema der Kristallstrukturen: ein wenig Chemie

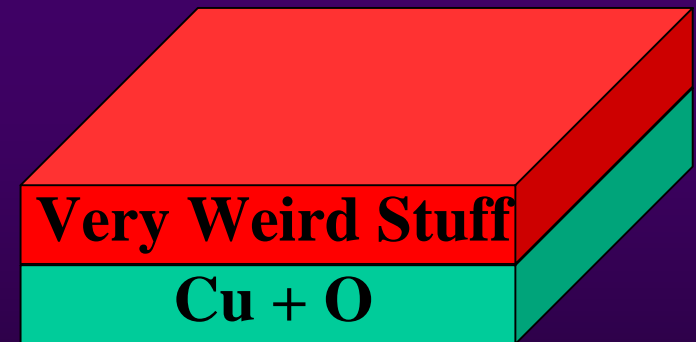
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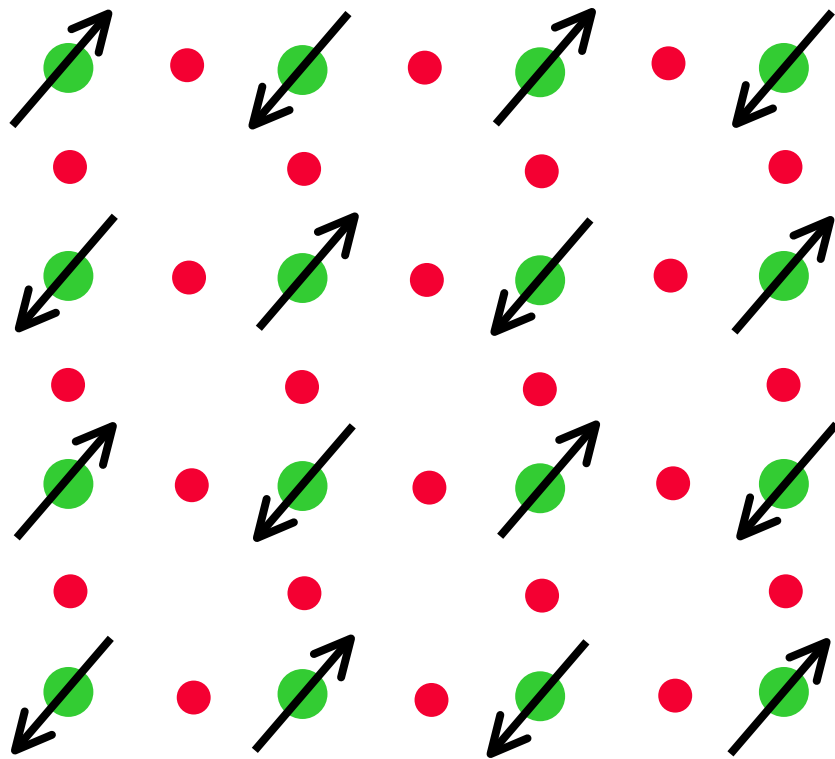


Supraleitung ist hier !!!

auch wichtig!

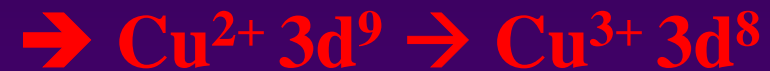


# Eine $\text{CuO}_2$ -Ebene

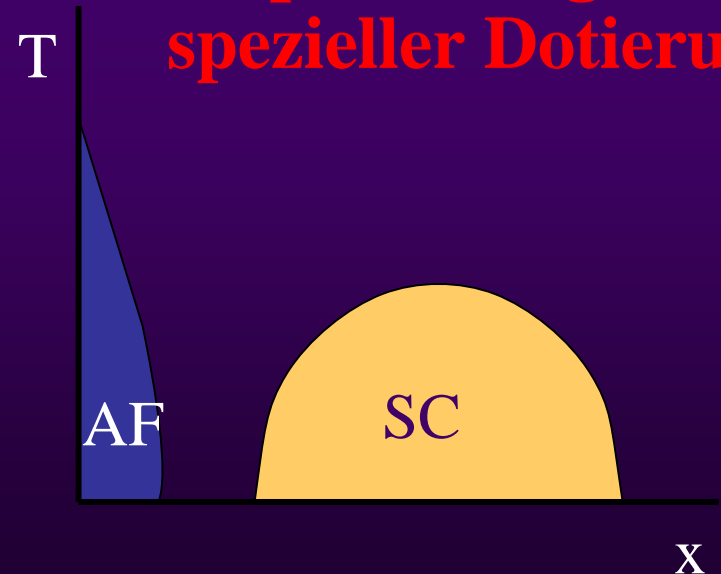


● Oxygen ● Cu

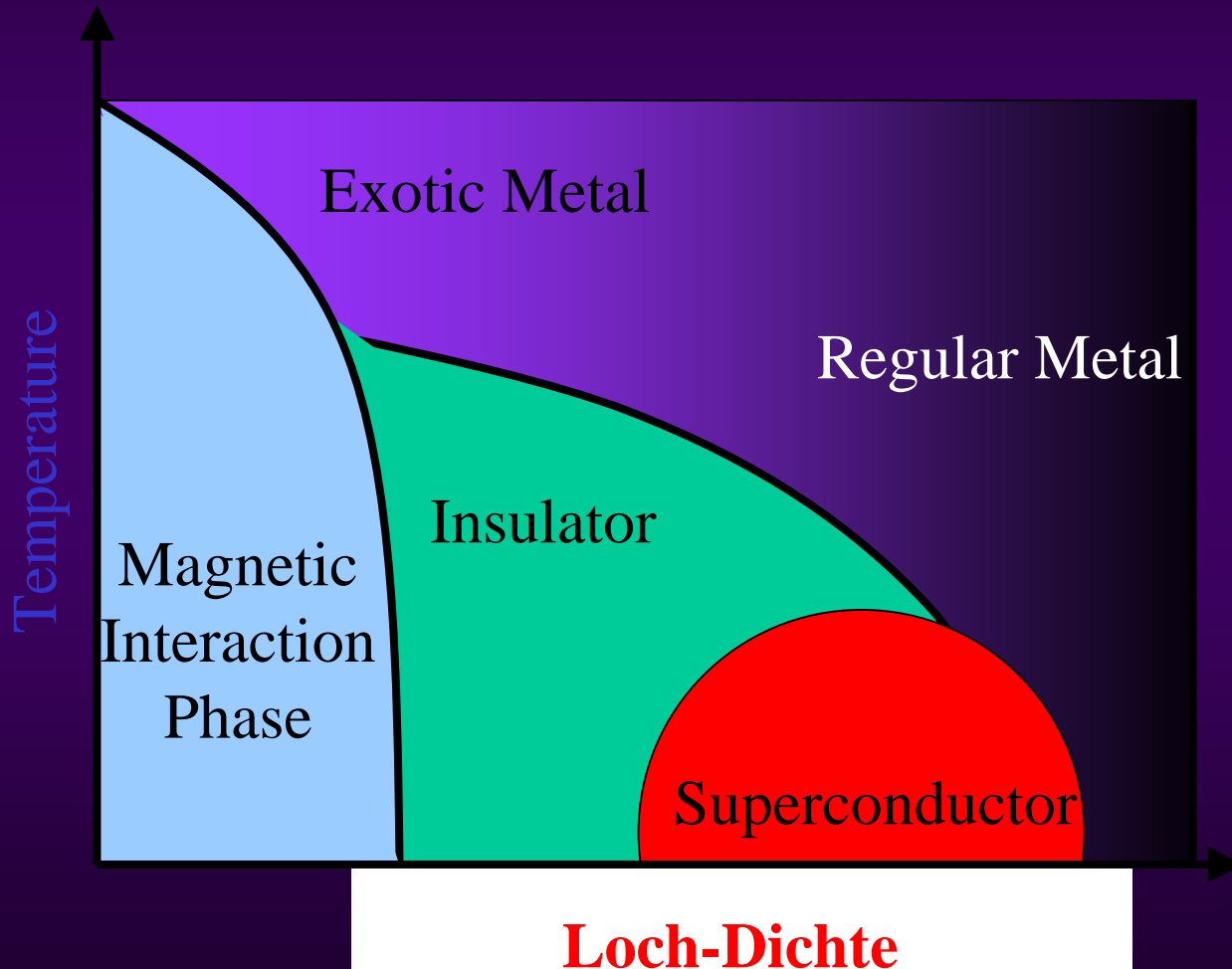
**Dotierung mit Löchern**



**Supraleitung bei spezieller Dotierung**



# Generelles Phasendiagramm?





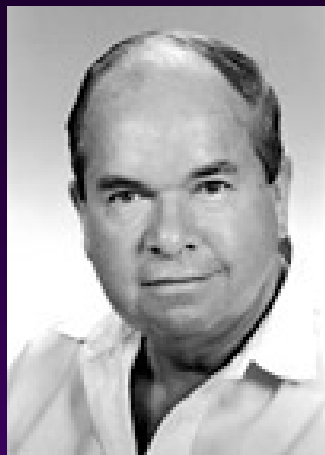
# Mechanism I ?

Superconductivity in High  $T_c$  Cuprates: The Cause is No Longer A Mystery

Philip W. Anderson  
*Joseph Henry Laboratories of Physics*  
*Princeton University, Princeton, NJ 08544*

(2001)

**I discuss various direct calculations of the properties of the one-band Hubbard model on a square lattice and conclude that these properties sufficiently resemble those of the cuprate superconductors that no more complicated interactions are necessary to cause high  $T_c$  superconductivity. In particular, I discuss phonon effects and conclude that these may be effective in reducing  $T_c$  and the gap in electron-doped materials.**



# Mechanism II ?

## Theory of High-T<sub>c</sub> Superconducting Cuprates Based on Experimental Evidence

A.A. Abrikosov

*Materials Science Division, Argonne National Laboratory  
9700 South Cass Avenue, Argonne, Illinois 60439, USA  
(January 8, 2004)*

**A model of superconductivity in layered high-temperature superconducting cuprates is proposed, based on the extended saddle point singularities in the electron spectrum, weak screening of the Coulomb interaction and **phonon-mediated interaction between electrons** plus a small short -range repulsion of Hund's, or spin-fluctuation, origin. This permits to explain the large values of T<sub>c</sub> ....**

# Mechanismus ..... ?

-Was versteht man :

„normale“ Metalle : Erweiterung freies Elektronengas  
lokalisierte Elektronen : Magnetismus

-Was versteht man nicht : den Übergang !

**Supraleiter** : ohne Dotierung  $\leftrightarrow$  lokalisierter Magnetismus  
hohe Dotierung  $\leftrightarrow$  normales Metall  
mittlere Dotierung  $\leftrightarrow$  starke Korrelationen ???

**Konzepte** : quantenkritische Punkte  
Streifenphasen  
sehr exotisch : orbitale Ströme ...



**TOSANOUMI**  
(Sumo Wrestler)

Height of Tosanoumi 186cm  
Weight of Tosanoumi 142kg  
Weight of disk 60kg  
Total weight 202kg

As of February '95

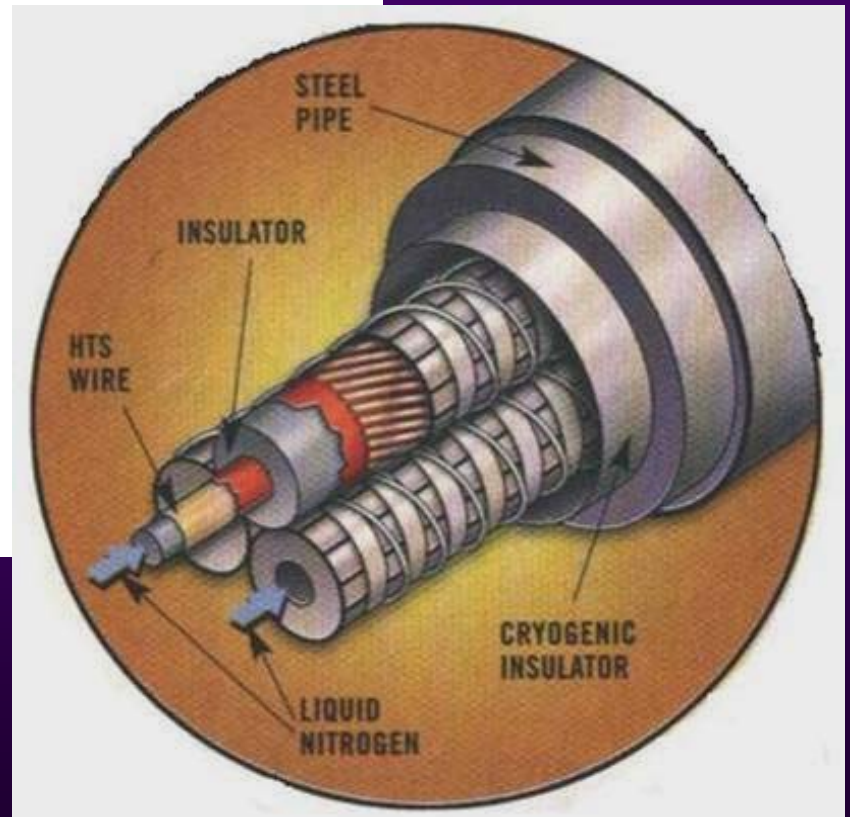
浮いた  
土佐ノ海

Es geht auch  
ohne  
Theo-rie/retiker

# HTS Kabel



Fig. 2-10: A HTSC cable from Sumitomo HTS, 50 m long, 23 mm diameter. It can carry 2.900 A dc at 77K and 2.200 A ac in current transmission.

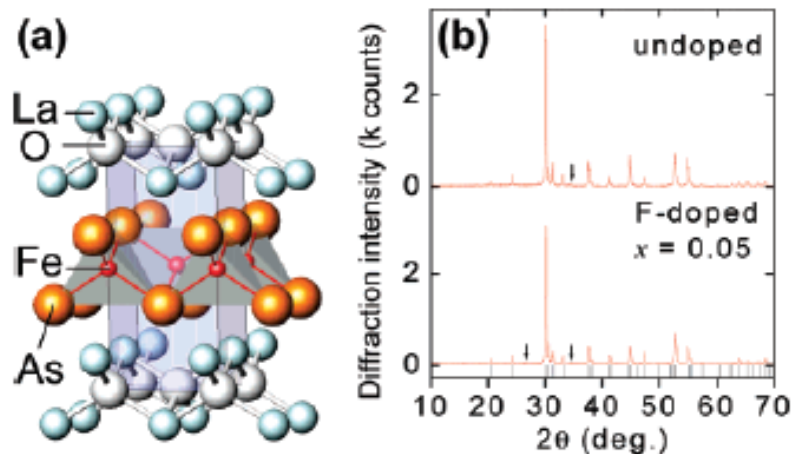


## Iron-Based Layered Superconductor $\text{La}[\text{O}_{1-x}\text{F}_x]\text{FeAs}$ ( $x = 0.05\text{--}0.12$ ) with $T_c = 26$ K

Yoichi Kamihara,<sup>\*†</sup> Takumi Watanabe,<sup>‡</sup> Masahiro Hirano,<sup>†§</sup> and Hideo Hosono<sup>†‡§</sup>

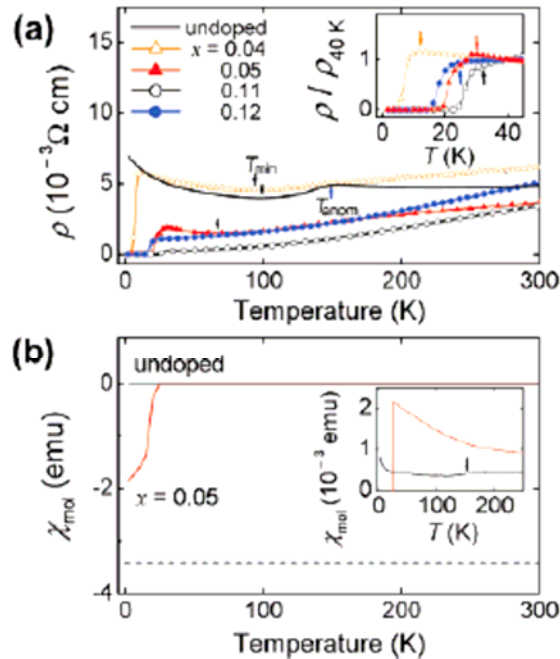
*ERATO-SORST, JST, Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, Materials and Structures Laboratory, Tokyo Institute of Technology, Mail Box R3-1, and Frontier Research Center, Tokyo Institute of Technology, Mail Box S2-13, 4259 Nagatsuta, Midori-ku, Yokohama 226-8503, Japan*

Received January 9, 2008; E-mail: hosono@msl.titech.ac.jp

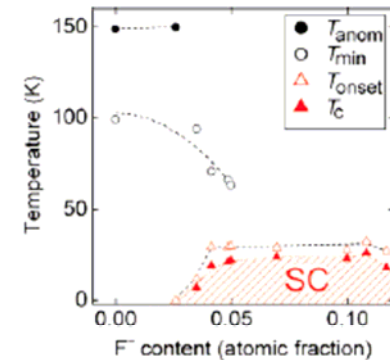


**Figure 1.** (a) Crystal structure of  $\text{LaOFeAs}$ . (b) Powder XRD patterns of undoped  $\text{LaOFeAs}$  and  $\text{La}[\text{O}_{1-x}\text{F}_x]\text{FeAs}$ :  $x = 0.05$ . Black bars at bottom show calculated Bragg diffraction positions of  $\text{LaOFeAs}$ . Arrows denote peaks due to impurity phases,  $\text{FeAs}$  (helimagnetic),<sup>13</sup> and  $\text{LaOF}$ .





**Figure 2.** (a) Electrical resistivity ( $\rho$ ) versus temperature ( $T$ ) for undoped and  $\text{La}[\text{O}_{1-x}\text{F}_x]\text{FeAs}$ :  $x = 0.04, 0.05, 0.11,$  and  $0.12$ . Inset shows expanded  $\rho$ - $T$  curves for  $x = 0.04, 0.05, 0.11,$  and  $0.12$ . Arrows show onset transition temperatures. (b) Molar susceptibility ( $\chi_{\text{mol}}$ ) versus  $T$  for undoped and  $\text{La}[\text{O}_{1-x}\text{F}_x]\text{FeAs}$ :  $x = 0.05$ . The dotted line denotes perfect diamagnetism for the sample. Inset shows expanded  $\chi_{\text{mol}}$ - $T$  curves at  $10^3$  times magnification of the vertical axis. An arrow shows  $T_{\text{anom}}$  in part a.

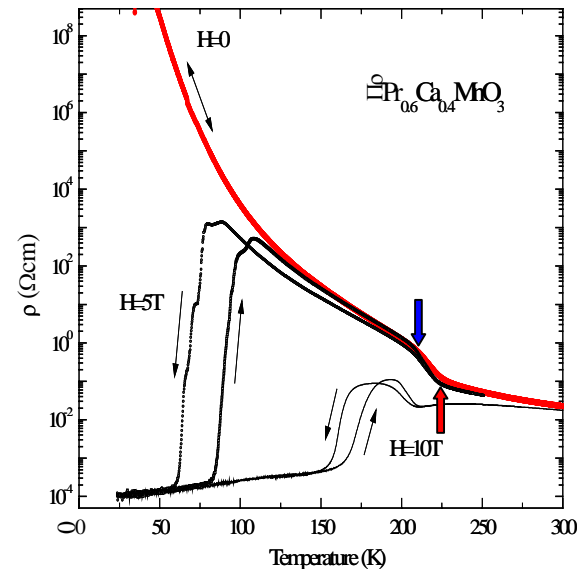
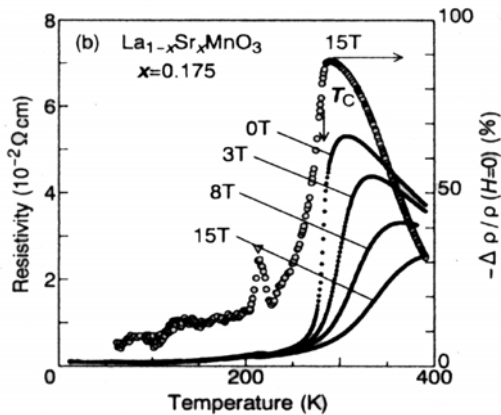
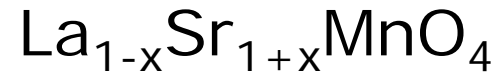
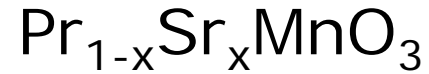
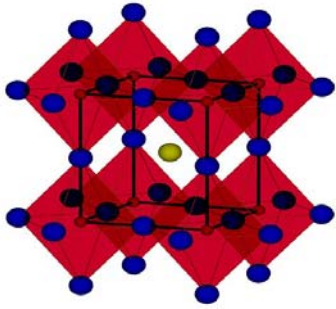


**Figure 3.**  $T_c, T_{\text{onset}},$  and  $T_{\text{min}}$  in the  $\rho$ - $T$  curves as a function of  $\text{F}^-$  content ( $x$ ) for  $\text{La}[\text{O}_{1-x}\text{F}_x]\text{FeAs}$ .  $T_c$  is defined as the temperature where the  $\rho$  value becomes half of that at  $T_{\text{onset}}$ .  $T_{\text{anom}}$  values for the undoped and  $\text{LaO}_{0.97}\text{F}_{0.03}$ - $\text{FeAs}$  are also shown. Dotted curves are guides for eyes.

- Inzwischen  $T_c \sim 52\text{K}$  wenn La durch Pr oder Nd ersetzt wird !

# Aktuelle Forschung II

## Kolossaler Magnetwiderstand in Manganaten



$$MR = - \frac{R(H) - R(0)}{R(H)} = - \frac{\Delta R}{R(H)}$$

# Colossal Magneto Resistivity – CMR Was ist das?

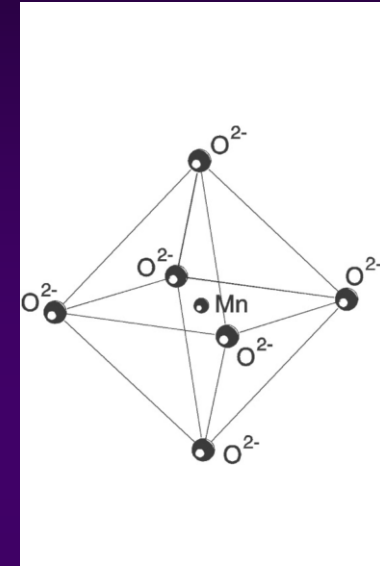
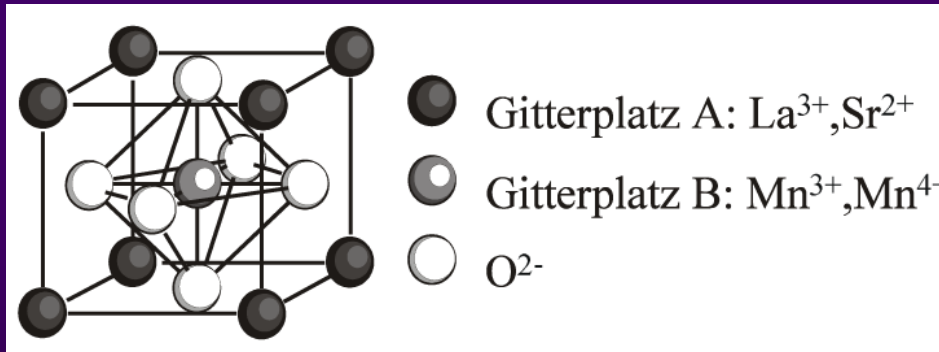
- Messung des elektrischen Widerstandes am Kristall für verschiedene äußere Magnetfelder und Temperaturen
- CMR: Starke Abnahme des elektrischen Widerstandes bei Erhöhung des äußeren Magnetfeldes
- Entdeckt in den 50er Jahren von Jonker und van Santen, aber Tragweite nicht erkannt.
- Starke Forschungsaktivität erst seit den Arbeiten von Kusters (1989) und von Helmholt (1993)

# CMR – Wofür ist das gut?

- Anwendung: Magnetfeldsonden, Lesen von Daten-Speichern (Festplatten)
- Probleme bei technischer Umsetzung: Effekt tritt nur in einem kleinen Intervall nahe der Curietemperatur auf, außerdem werden große Magnetfelder benötigt.

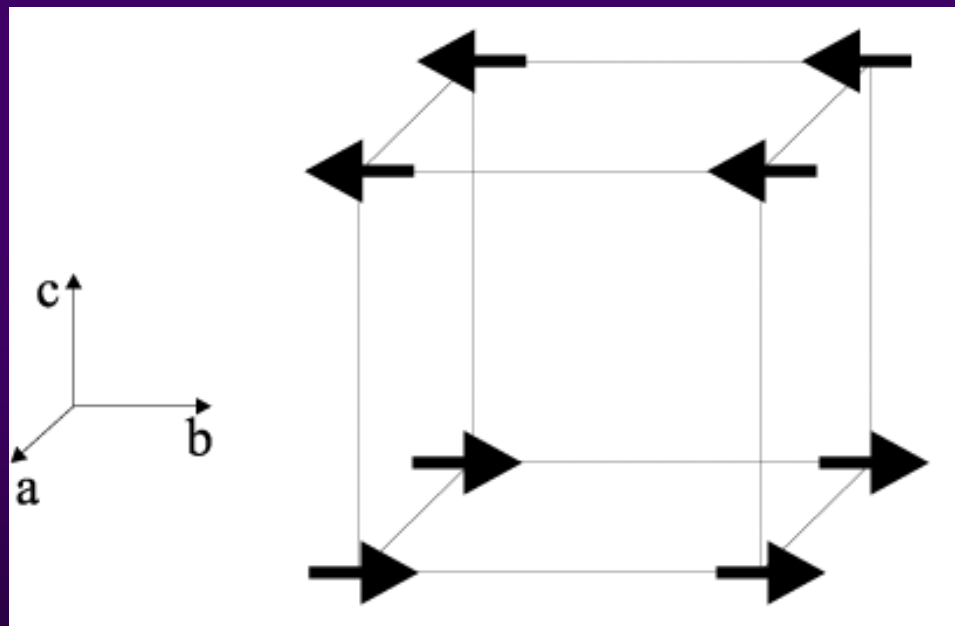
# Perowskit-Struktur

Manganate kristallisieren in der Perowskit-Struktur:



# Magnetische Struktur von $\text{LaMnO}_3$

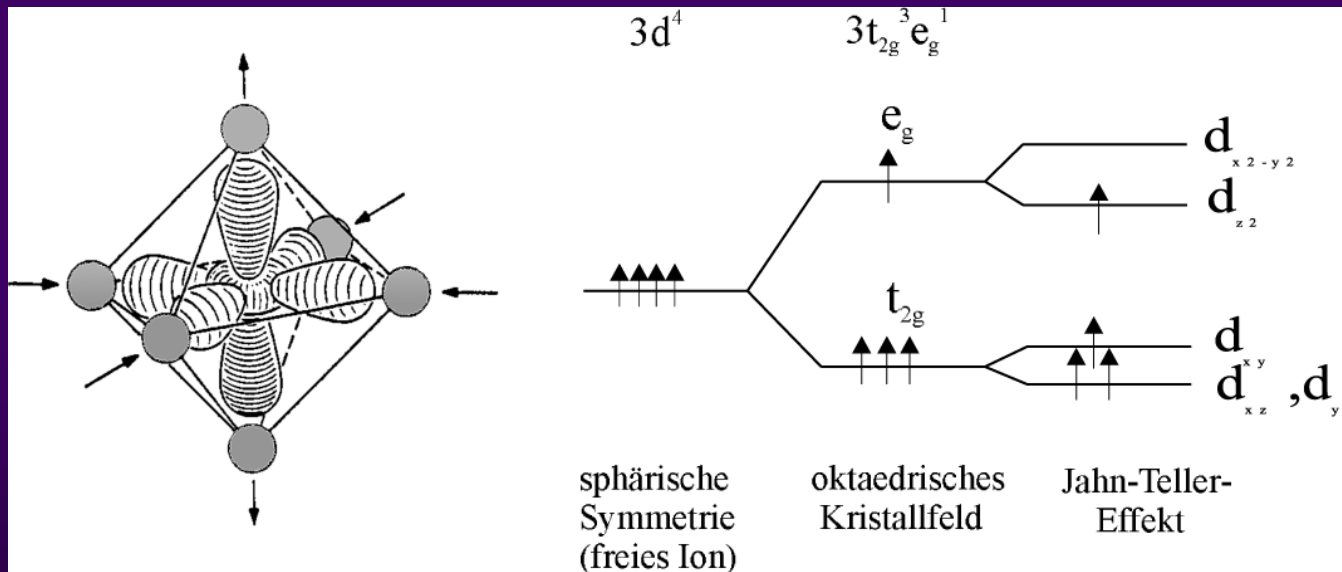
$\text{LaMnO}_3$  ist ein Antiferromagnet und Isolator



Wollan et. al. 1955

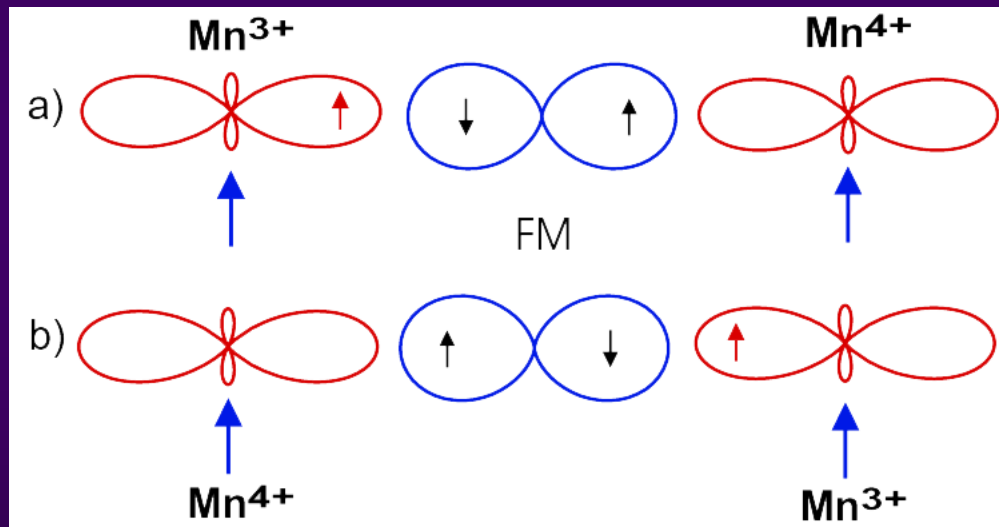
# Elektronische Struktur

Elektronen in Manganaten besetzen bestimmte Orbitale



# Atomphysik : elektronische Struktur

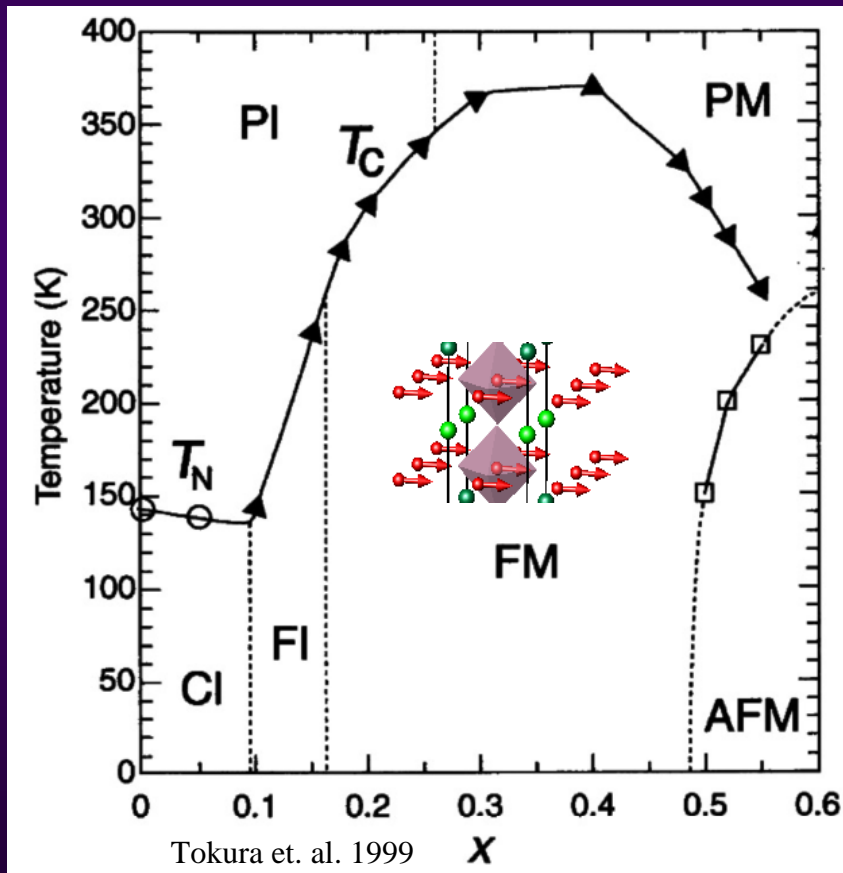
## Doppelaustausch



Gute elektrische Leitfähigkeit geht einher mit ferromagnetischer Spinordnung !!!



## Phasendiagramm für $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$



Mit der Dotierung kommen Ladungsträger (Löcher) in das Gitter.

Tendenz zum → Ferromagneten

→ Geringer Widerstand

→ Magnetfeld stabilisiert ferromagnetische Ordnung

→ Aber unzureichend !!!

# Halb-Dotierte Manganate ( $x=0.5$ )

## Ladungs-Ordnung

Commensurable ratio  $\text{Mn}^{3+}:\text{Mn}^{4+} = 1:1 \Rightarrow$  **Schachbrettordnung**

## Orbitale Ordnung

$\text{Mn}^{3+}$ -occupation coupled to orbital degree of freedom

$\Rightarrow$  **Orbitale Ordnung von  $e_g$ -Elektronen**

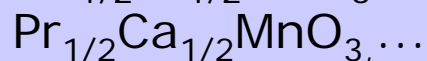
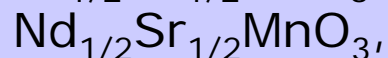
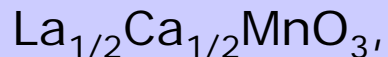
## Magnetische Ordnung

Orbital occupation closely connected to magnetism

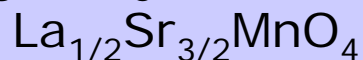
$\Rightarrow$  **CE-Typ Magnetismus**

## CE-type Ordnung tritt in allen Manganaten auf

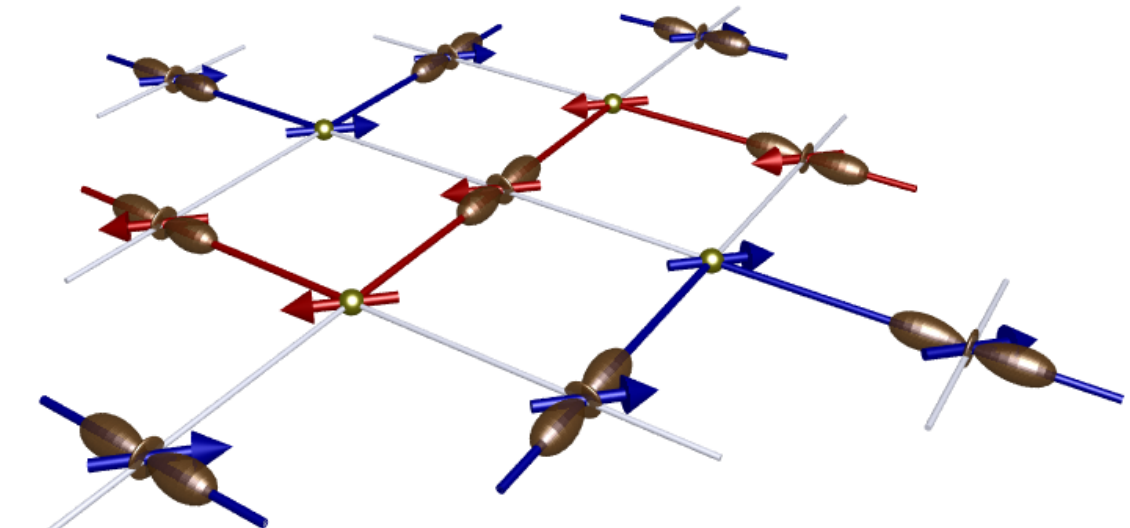
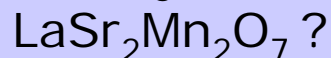
Perovskite-Manganites:



Single-Layered :



Double-Layered :



E.O.Wollan and W.C. Koehler, Phys. Rev. 100,545 (1955).

J.B. Goodenough, Phys. Rev. 100, 564 (1955)

## Offene Probleme :

- quantitatives Verständnis des CMR
- wieso kann ein Feld von  $\sim 10\text{T}=10\text{K}$  einen Phasenübergang von  $T_S=230\text{K}$  unterdrücken ???
- Kopplung der unterschiedlichen Ordnungen

**Technisch** : Effekt bei zu tiefen Temperaturen

# Aktuelle Themen in der Festkörperphysik

- neue Substanzen
- Halbleiterphysik
- dünne Schichten (Grenzflächen)
- Miniaturisierung (Nanotechnik)
- Magnetismus (Supraleitung)
- Ionenleiter . . . .

**Bauelemente**  
**Sensoren**  
**Energietechnik**  
**Datenverarbeitung**  
...  
**Quantencomputer**  
**H-Speicher**  
...