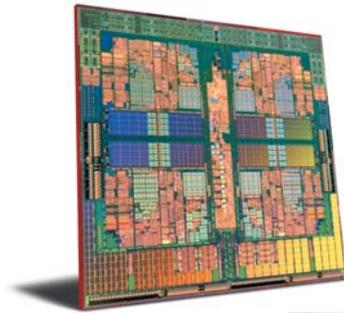
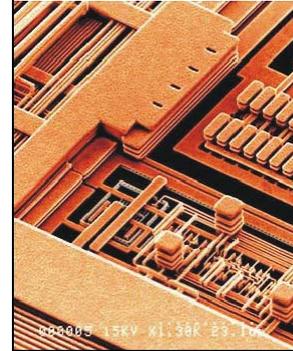
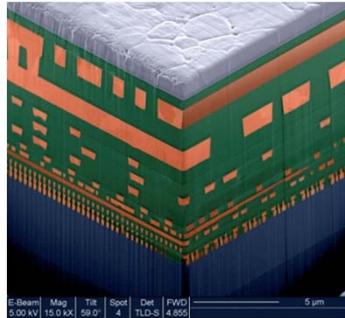


1 / 3

## Anwendungen von Festkörperphysik



Elektronik/Optoelektronik

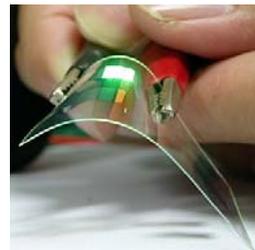


1 / 4

## Anwendungen von Festkörperphysik



Selbstreinigende  
Oberflächen

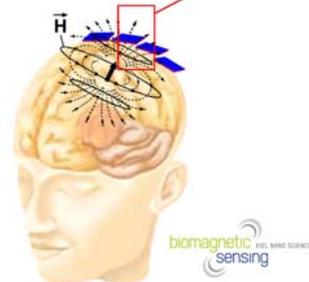
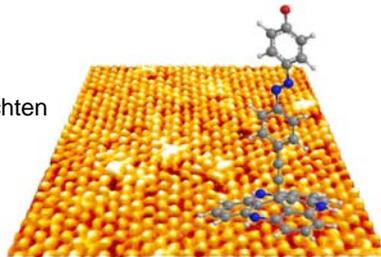


Organische (Opto-)elektronik

Energietechnologie



## „intelligente“ Materialien

Schaltbare  
MolekülschichtenMagnetoelektrische Sensoren  
„Brain-Maschine-Interface“

## 1 / 6 Nobelpreise für Physik zu festkörperphysikalischen Themen

1913	Heike Kamerlingh Onnes
1914	Max von Laue
1915	William Henry Bragg, William Lawrence Bragg
1920	Charles Edouard Guillaume
1921	Albert Einstein
1923	Robert Andrews Millikan
1924	Karl Manne Siegbahn
1926	Jean Baptiste Perrin
1937	Clinton Davisson, George Paget
1946	Percy W. Bridgman
1956	William B. Shockley, John Bardeen und Walter H. Brattain
1961	Rudolf Mößbauer
1962	Lev Landau
1971	Louis Néel
1972	John Bardeen, Leon Neil Cooper, Robert Schrieffer
1973	Leo Esaki, Ivar Giaever, Brian Davon Josephson
1977	Philip W. Anderson, Nevill F. Mott, John H. van Vleck
1978	Pjotr Kapiza
1982	Kenneth G. Wilson
1985	Klaus von Klitzing
1986	Ernst Ruska, Gerd Binnig, Heinrich Rohrer
1987	Johannes Georg Bednorz, Karl Alex Müller
1991	Pierre-Gilles de Gennes
1994	Bertram N. Brockhouse, Clifford Glenwood Shull
1996	David M. Lee, Douglas D. Osheroff, Robert C. Richardson
1998	Robert B. Laughlin, Horst Ludwig Störmer, Daniel Chee Tsui
2000	Schores Aljorow, Herbert Kroemer, Jack S. Kilby
2001	Eric A. Cornell, Wolfgang Ketterle, Carl E. Wieman
2003	Alexei Abrikossow, Witali Ginsburg, Anthony James Leggett
2007	Albert Fert, Peter Grünberg
2009	Charles Kao, Williard Boyle, Georg Smith
2010	Andre Geim, Konstantin Novoselov
2014	Isamu Akasaki, Hiroshi Amano, Shuji Nakamura

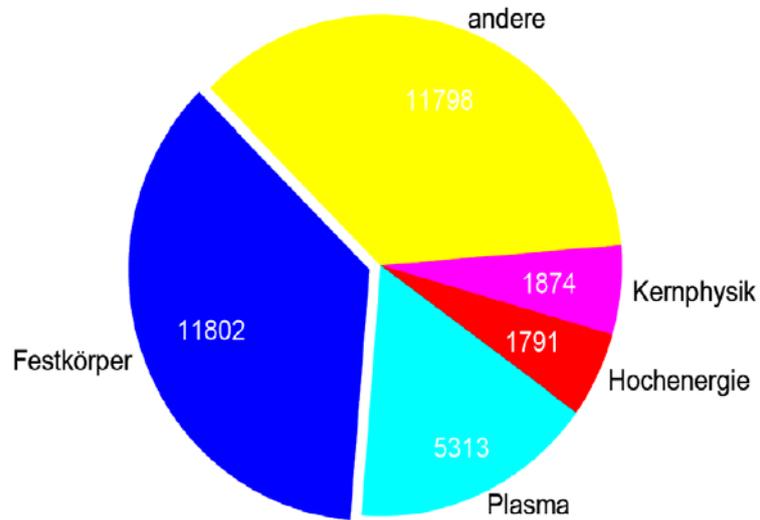
Details siehe  
<http://almaz.com/nobel/physics/physics.html>

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## Festkörperphysik in der DPG

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Mitglieder der Deutschen Physikalischen Gesellschaft



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## Experimentalphysik V: Themen

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- Struktur und Bindung
- Beugung und reziprokes Gitter
- Gitterdynamik
- Thermische Eigenschaften
- Elektronen im Festkörper
- Elektronischer Transport
- Halbleiter
- Supraleitung
- Magnetismus
- Optische Eigenschaften
- Dielektrische und ferroelektrische Eigenschaften
- Oberflächen- und Grenzflächen
- Nanostrukturen

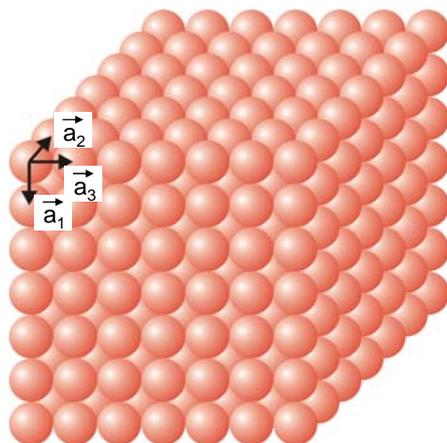
**Einführungen:**

- S. Hunklinger, „Festkörperphysik“, Oldenburg
- C. Kittel, „Introduction to Solid State Physics“, Wiley  
bzw. deutsche Ausgabe „Einführung in die Festkörperphysik“, Oldenburg
- N.W. Ashcroft, N.D. Mermin, „Solid State Physics“, Holt Saunders  
bzw. deutsche Ausgabe „Festkörperphysik“, Oldenburg
- W. Ibach, F. Lüth, „Festkörperphysik“, Springer
- K. Kopitzki, P. Herzog, „Einführung in die Festkörperphysik“, Vieweg/Teubner

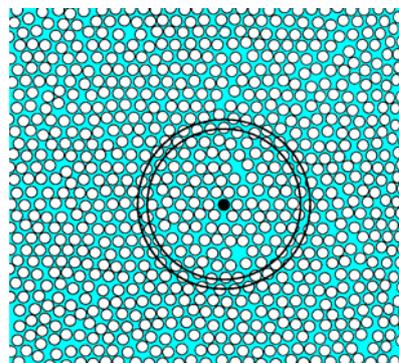
**Weiterführende Literatur:**

- M. P. Marder, „Condensed Matter Physics“, Wiley
- P.M. Chaikin, T.C. Lubensky, „Principles of Condensed Matter Physics“,  
Cambridge University Press
- S. Elliott, „The Physics and Chemistry of Solids“, Wiley

**Kristalline Festkörper:**  
langreichweitige Ordnung



**Flüssigkeiten und Gläser:**  
nur Nahordnung



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## Natürliche Kristalle

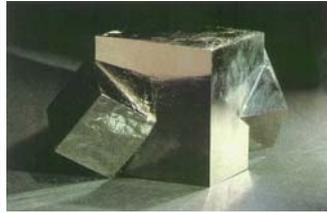


Quarz



Zinnober

siehe auch <http://webmineral.com>

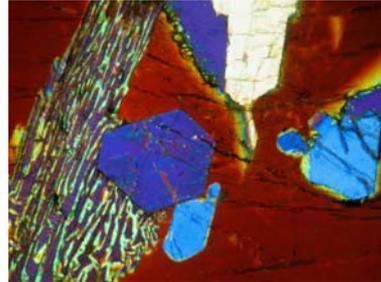


Pyrit



Eis

Labradorid Dünnschliff



[i106.photobucket.com/albums/m276/microklaus/800\\_IMG\\_0002-184.jpg](http://i106.photobucket.com/albums/m276/microklaus/800_IMG_0002-184.jpg)

1 / 12

## Hinweise auf kristalline Ordnung

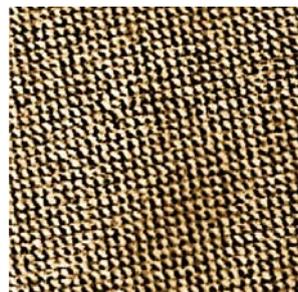
anisotrope Eigenschaften



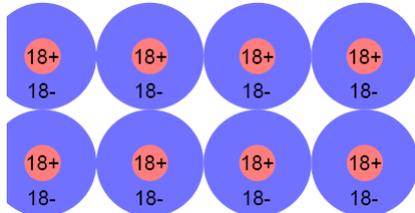
Beugungsexperimente



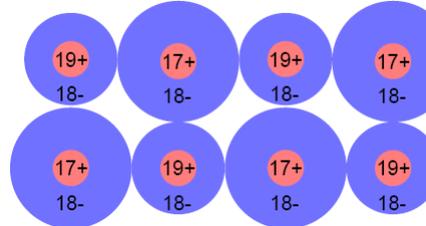
Mikroskopische Beobachtung



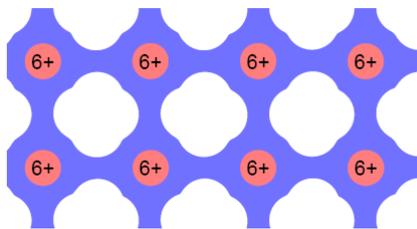
Van-der-Waals Kristall (z.B. Argon)



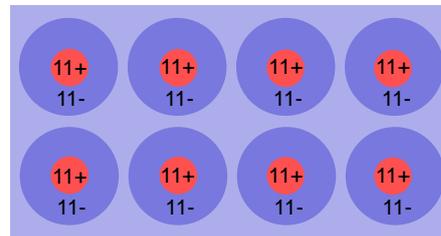
Ionenkristall (z.B. KCl)



kovalent geb. Kristall (z.B. Diamant)



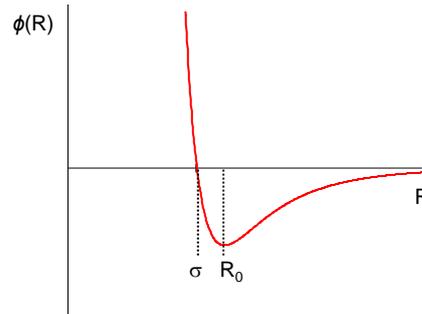
metallischer Kristall (z.B. Na)



Kristall mit Wasserstoffbrückenbindung (z.B. Eis)

- Lennard-Jones Potential

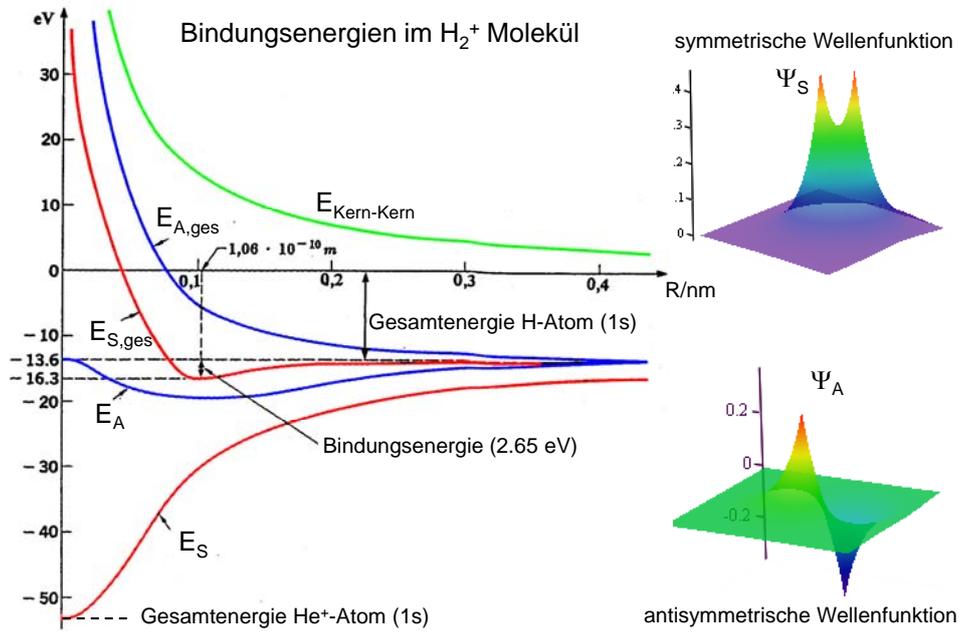
$$\phi(R) = 4\varepsilon \left[ \left( \frac{\sigma}{R} \right)^{12} - \left( \frac{\sigma}{R} \right)^6 \right]$$

 $\sigma \equiv$  vdW-Radius


Atom	He	Ne	Ar	Kr	Xe
$\sigma$ [Å]	2.56	2.74	3.40	3.65	3.98
$\varepsilon$ [ $10^{-23}$ J]	14	50	167	225	320

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### Kovalente Bindung: $H_2^+$

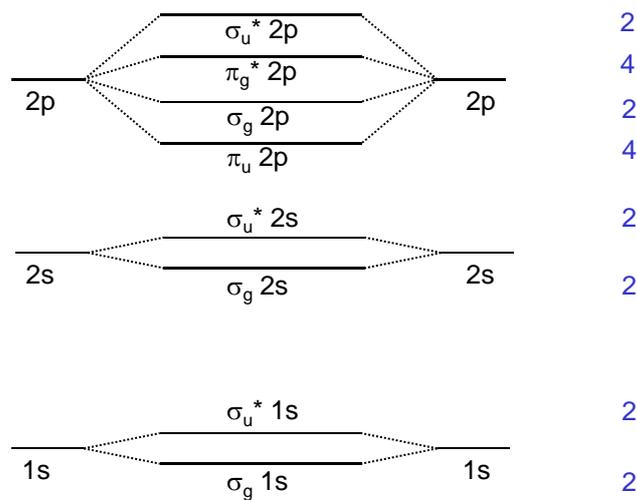


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### Kovalente Bindung: Energieniveaus

Schematischer Verlauf der Energieniveaus für  $H_2$  bis  $N_2$ :

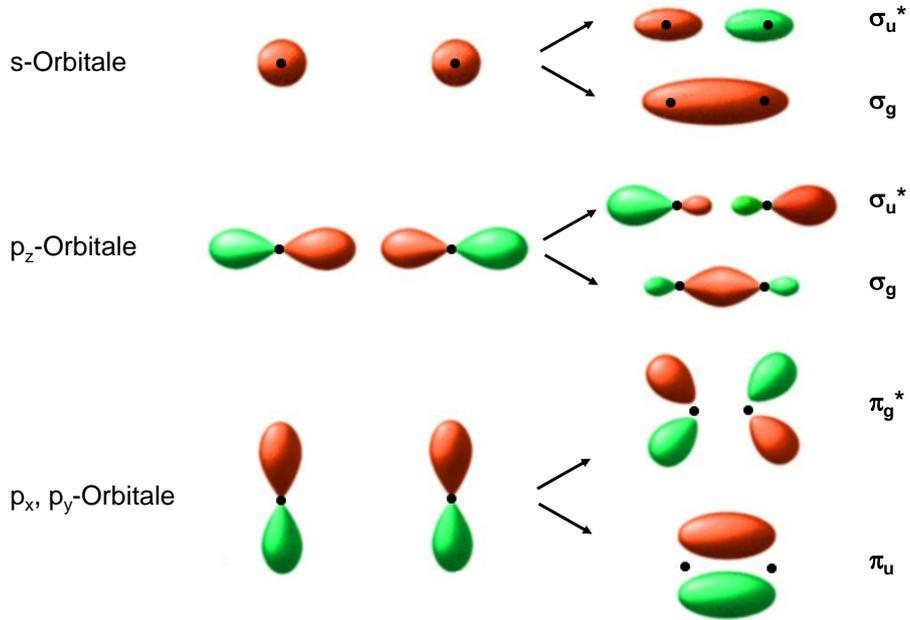
maximale Anzahl von Elektronen pro MO



Anmerkung: Abstand und Reihenfolge der MOs abhängig von Molekül

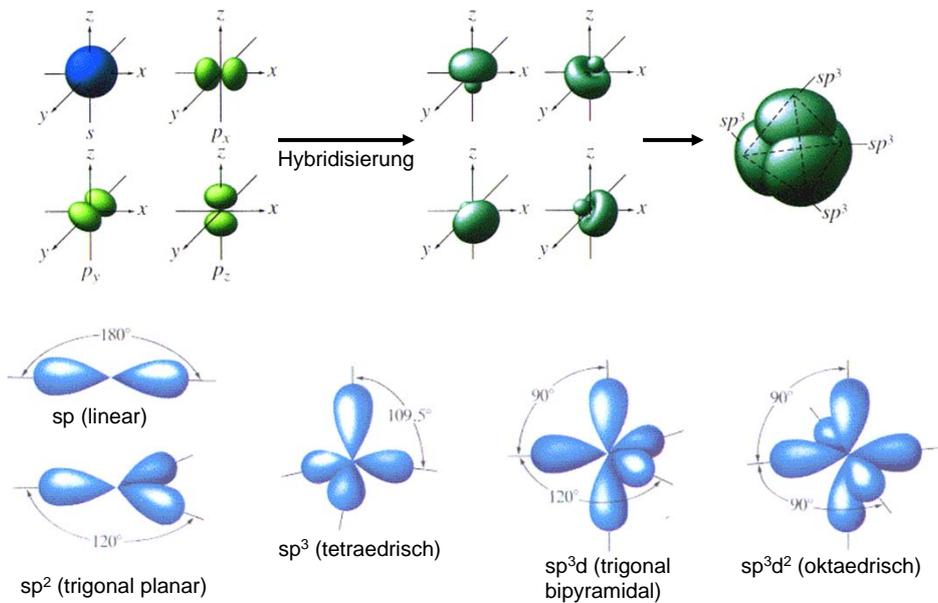
1 / 17

Kovalente Bindung: Molekülorbitale



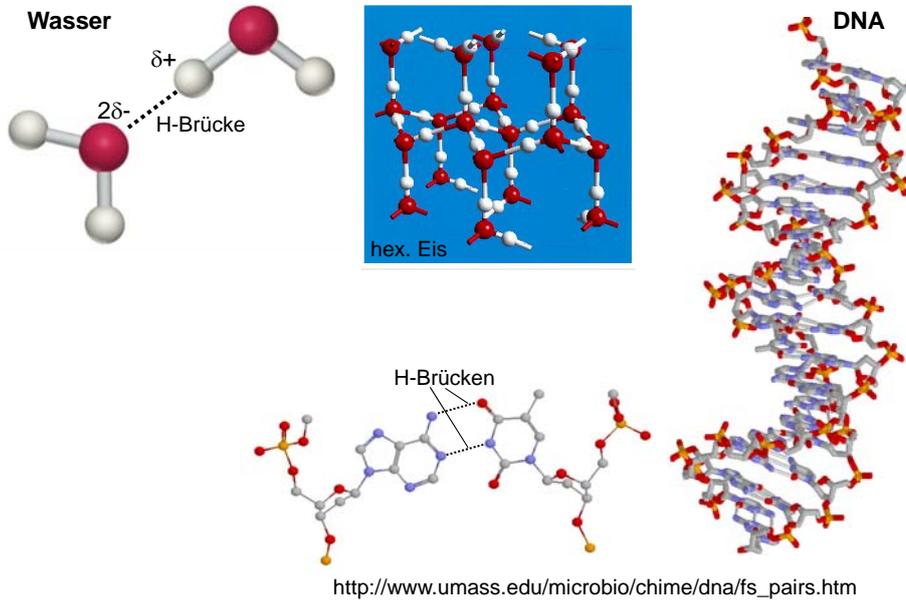
1 / 18

Kovalente Bindung: Hybridisierung



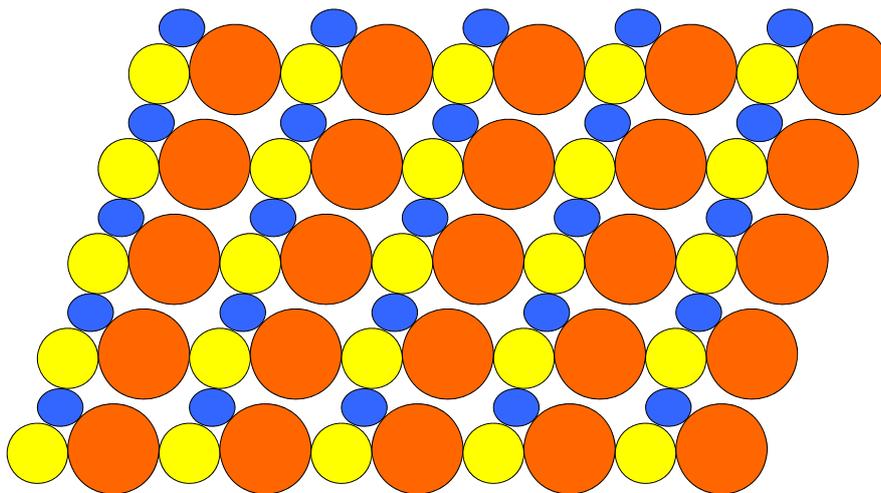
1 / 19

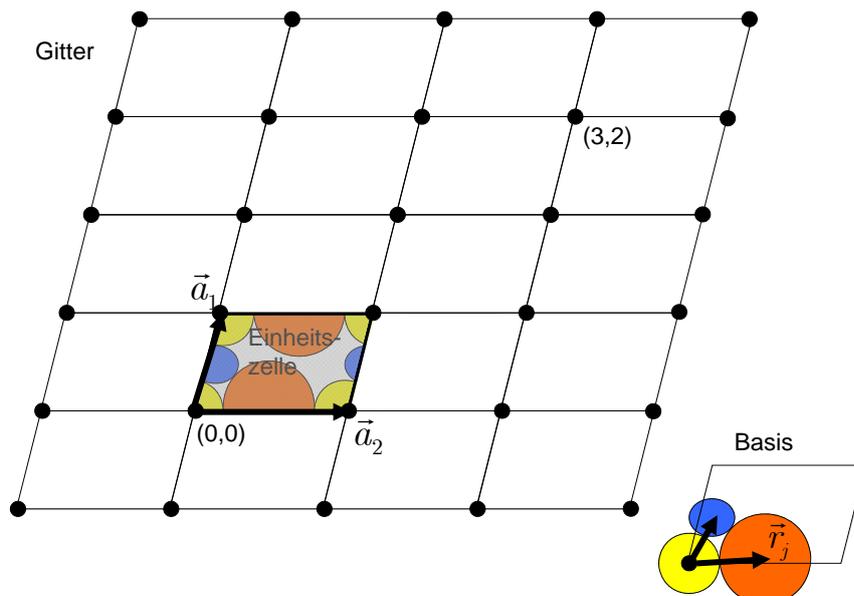
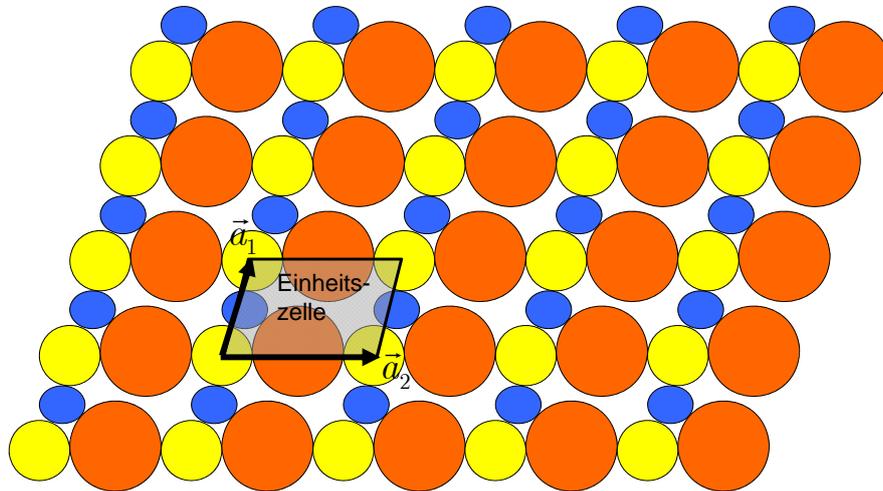
## Wasserstoffbrückenbindung



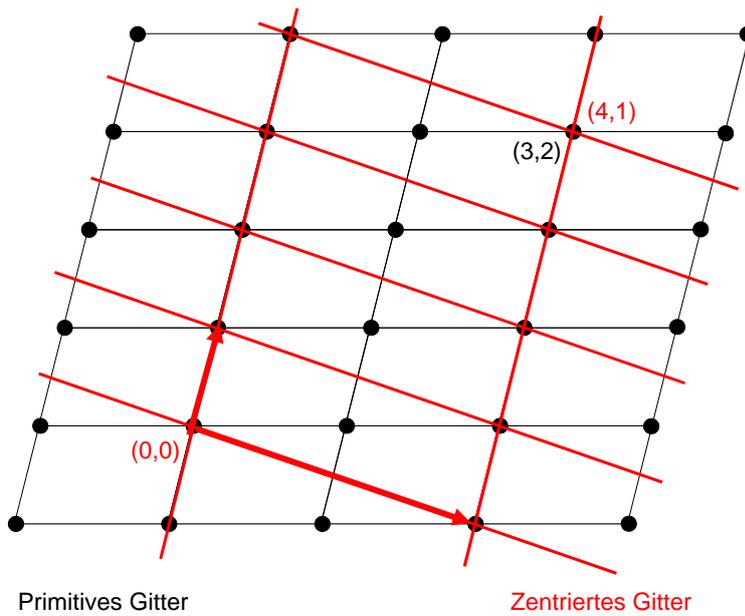
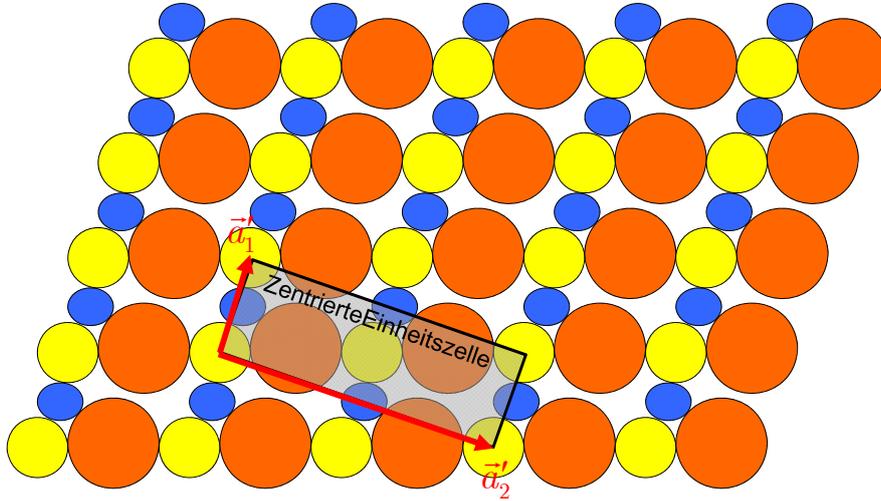
1 / 20

## Gitter mit Basis





Zentriertes Gitter



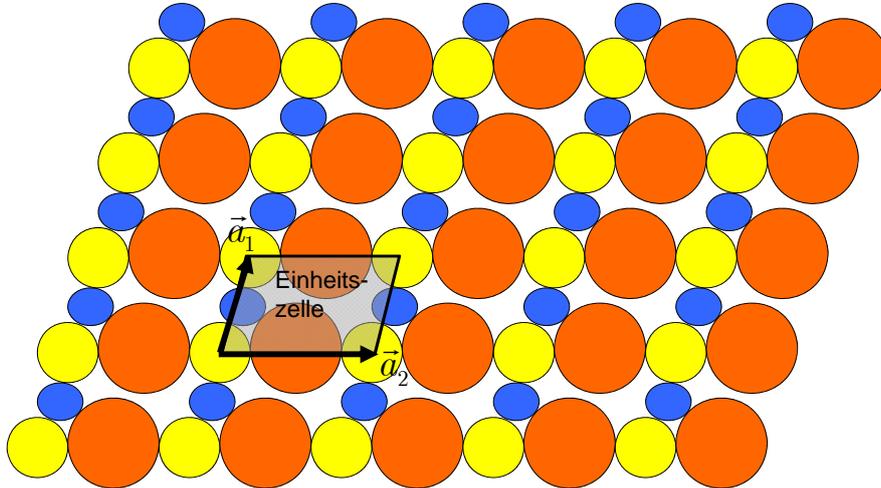
Primitives Gitter

Zentriertes Gitter

1 / 25

Gitter mit Basis

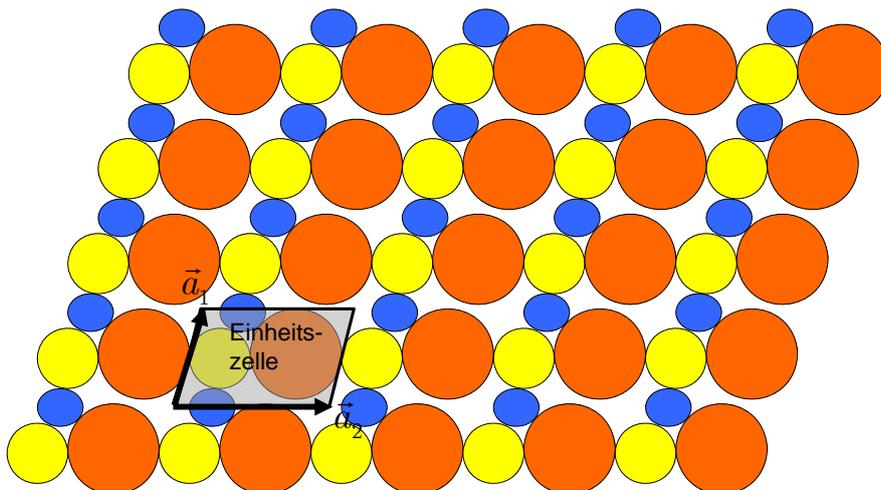
---



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Gitter mit Basis

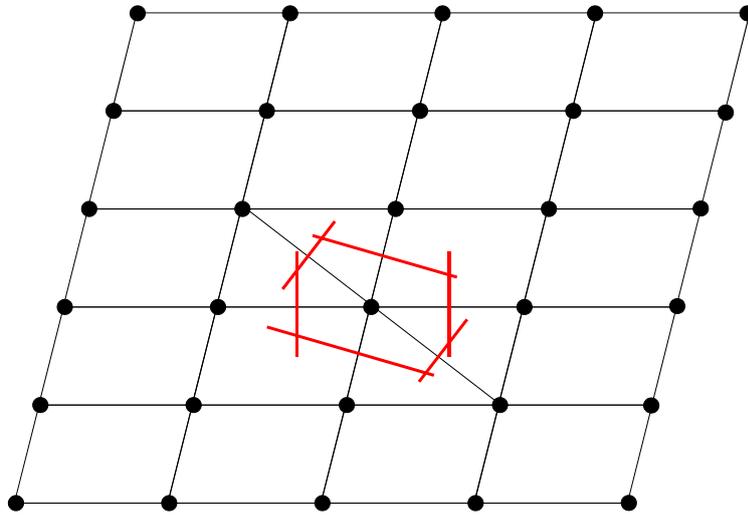
---



1 / 27

### Gitter mit Basis

---

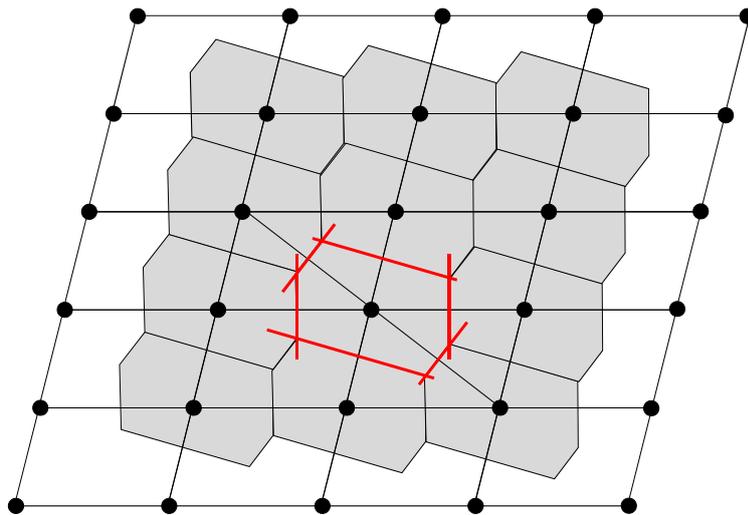


Wigner-Seitz Einheitszelle

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### Gitter mit Basis

---



Wigner-Seitz Einheitszelle

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### Punktsymmetrie

Rotationssymmetrie:

zweizählig

dreizählig

vierzählig

sechszählig

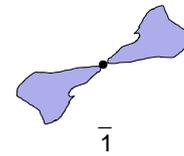
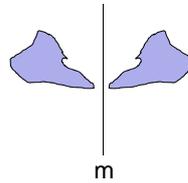


fünfzählig

siebenzählig

Spiegelung

Inversion



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### Punktsymmetrie

Rotationssymmetrie:

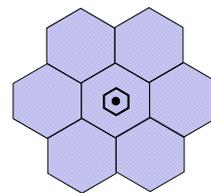
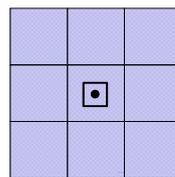
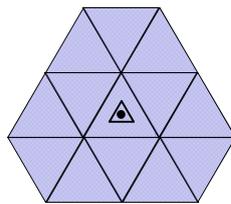
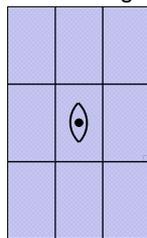
zweizählig

dreizählig

vierzählig

sechszählig

Symbol:



Bezeichnung: 2

3

4

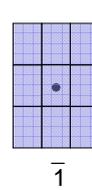
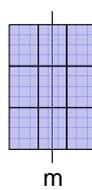
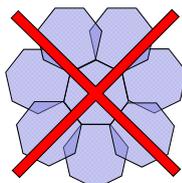
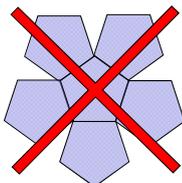
6

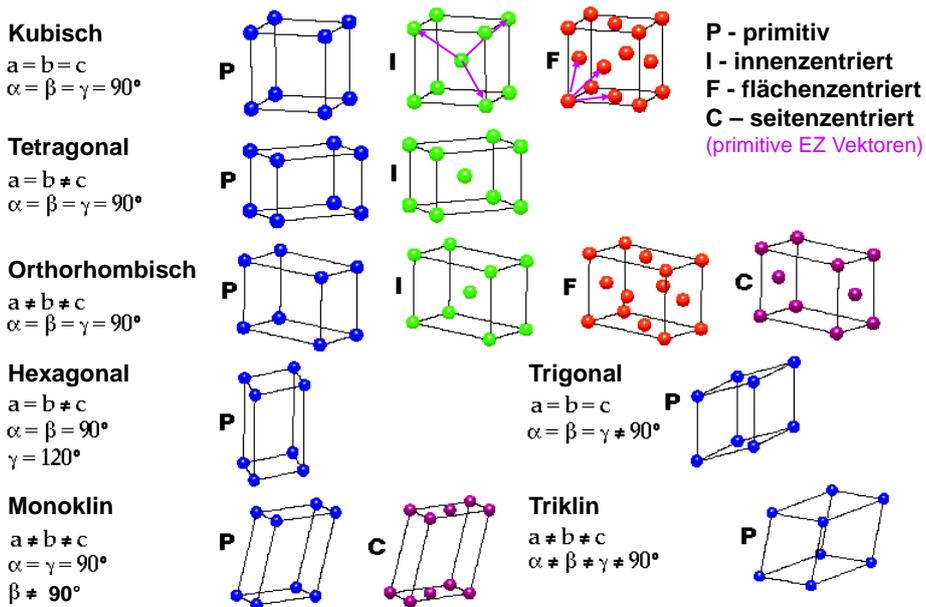
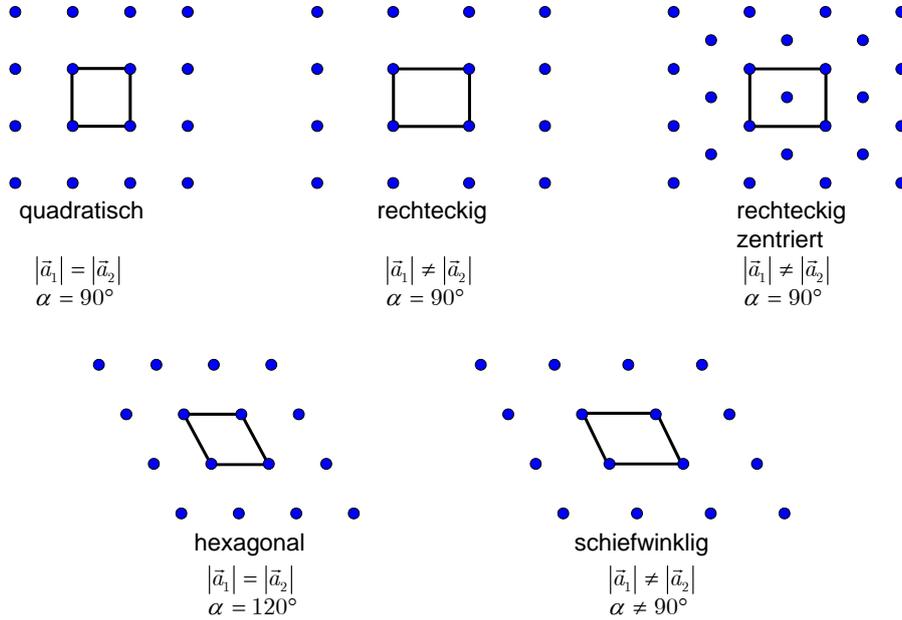
fünfzählig

siebenzählig

Spiegelung

Inversion

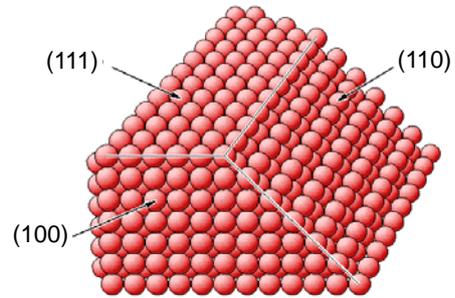
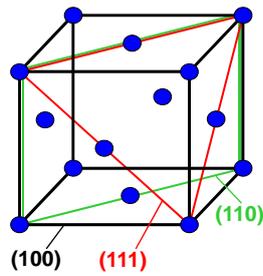




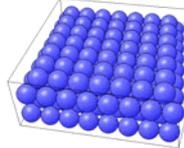
[http://ac16.uni-paderborn.de/lehveranstaltungen/\\_aac/vorles/skript/kap\\_5/bravais.html](http://ac16.uni-paderborn.de/lehveranstaltungen/_aac/vorles/skript/kap_5/bravais.html)

Schnittebene angegeben über Miller-Indizes (h,k,l)

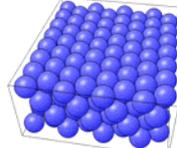
Beispiel: dichtgepackte, niederindizierte  
Oberflächen von fcc-Kristallen



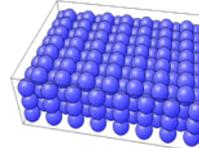
fcc(100)



fcc(111)

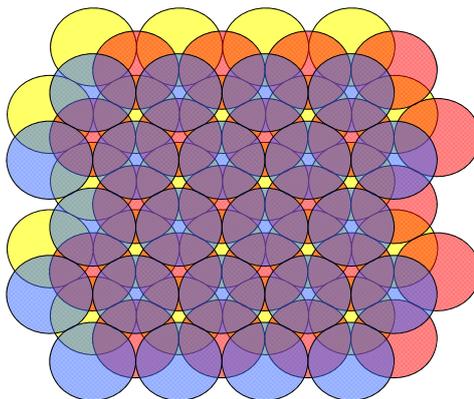


fcc(110)

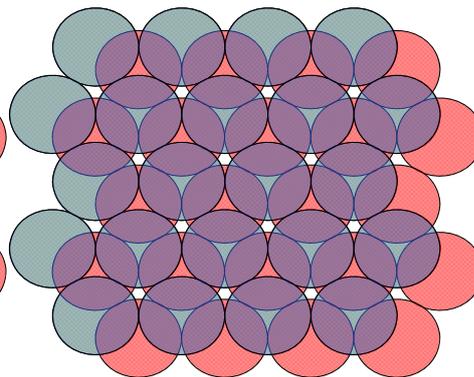


Modelle erzeugt mit surface explorer  
([w3.rz-berlin.mpg.de/~rammer/surfexp\\_prod/SXinput.html](http://w3.rz-berlin.mpg.de/~rammer/surfexp_prod/SXinput.html))

Kubisch-flächenzentriert (fcc)

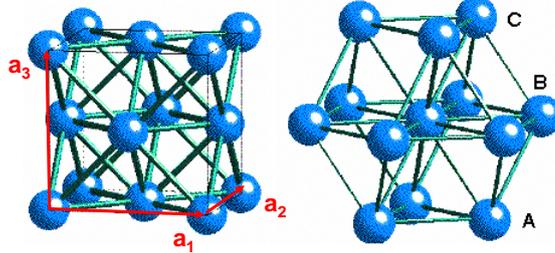


Hexagonal-dichtgepackt (hcp)

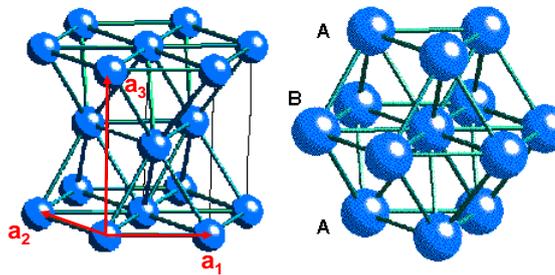


**Kubisch-flächenzentriert (fcc)**

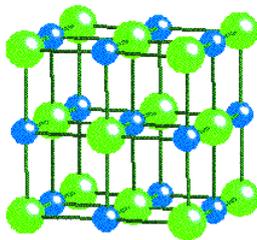
$$(x,y,z) = (0,0,0), (1/2,1/2,0) \\ (1/2,0,1/2), (0,1/2,1/2)$$

**Hexagonal-dichtgepackt (hcp)**

$$(x,y,z) = (0,0,0), (2/3,1/3,1/2)$$

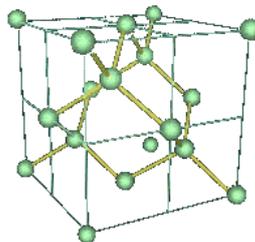


NaCl



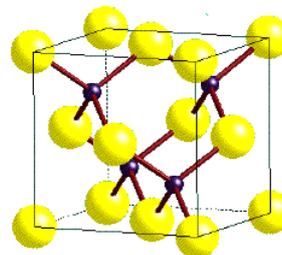
fcc  
Cl: (0,0,0)  
Na: (1/2,1/2,1/2)

Diamant



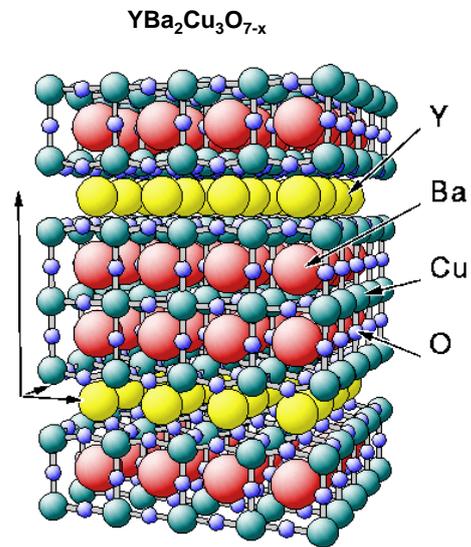
fcc  
(0,0,0), (1/4,1/4,1/4)

Zinkblende

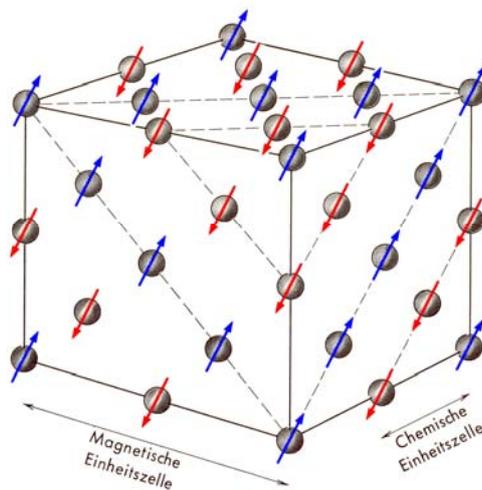


fcc  
S: (0,0,0)  
Zn: (1/4,1/4,1/4)

Interaktiv: <http://webmineral.com/>

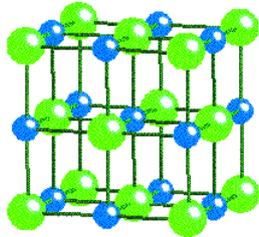


## MnO, antiferromagnetische Phase

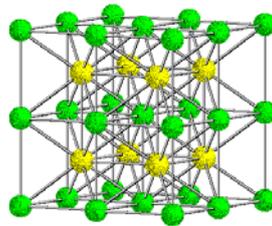


C. Kittel, Einführung in die Festkörperphysik,  
14. Auflage, Oldenbourg (2006)

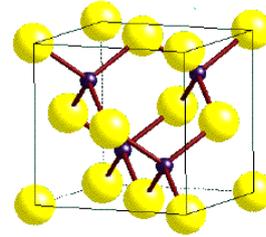
NaCl-Struktur



CsCl-Struktur



ZnS-Struktur



Madelung-Energie  $\alpha$  und Koordinationszahl Z:

$$\alpha = 1.747565$$

$$Z = 6$$

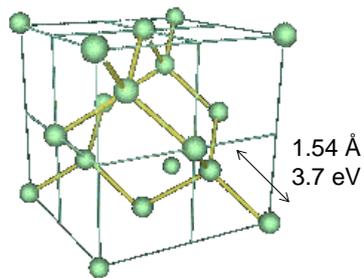
$$\alpha = 1.762675$$

$$Z = 8$$

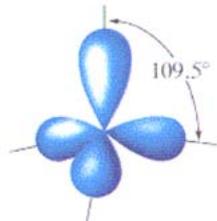
$$\alpha = 1.747565$$

$$Z = 4$$

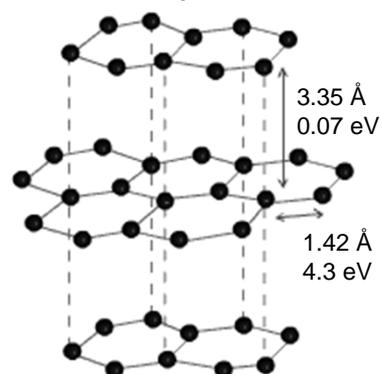
Diamant



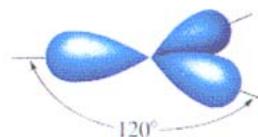
$sp^3$  (tetraedrische Koordination)



Graphit

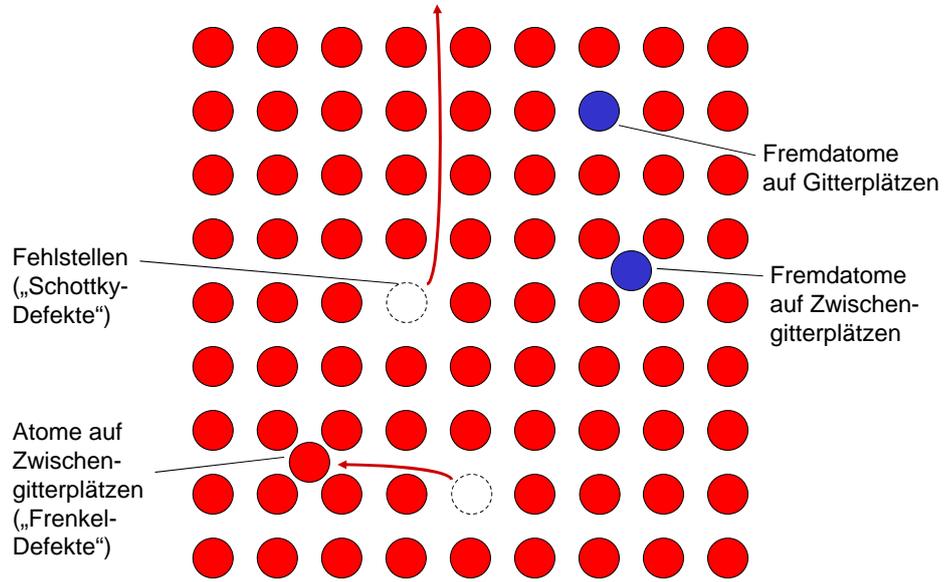


$sp^2$  (trigonal planare Koordination)



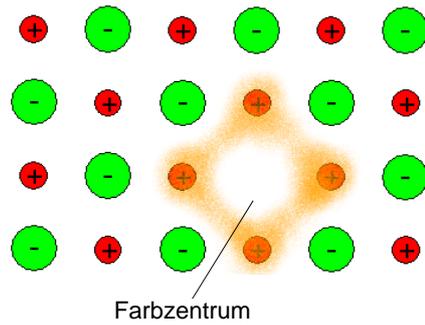
1 / 41

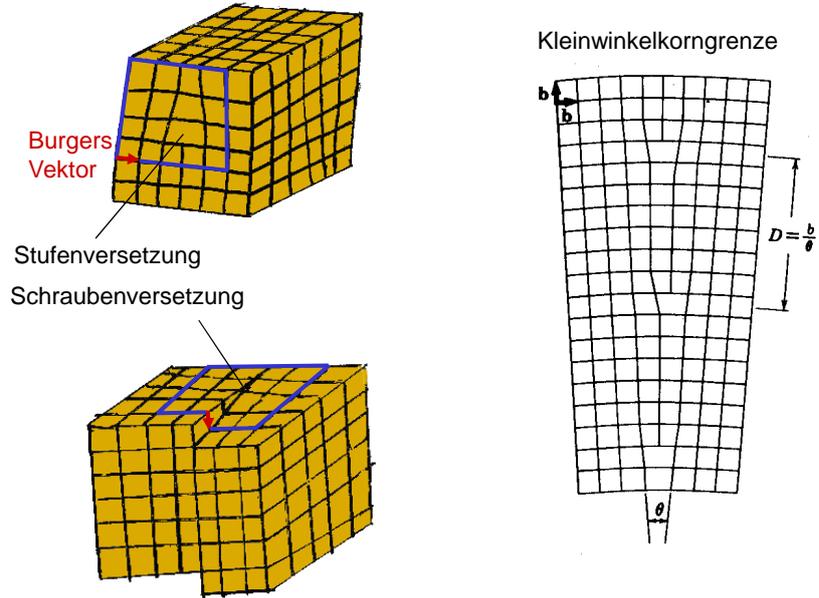
### Punktdefekte



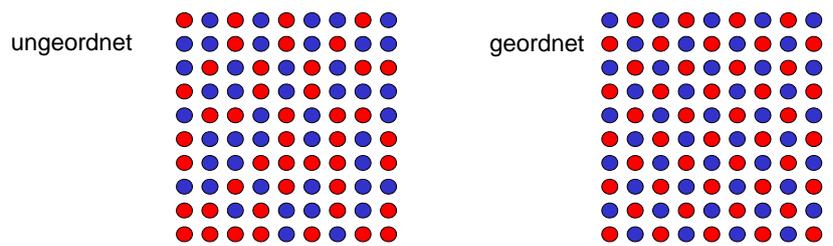
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### Punktdefekte

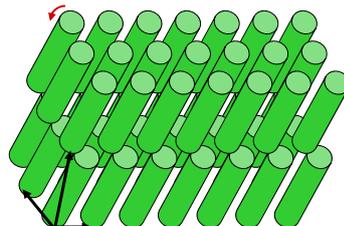




Besetzungsunordnung in binären Legierungen



Orientierungsunordnung z.B. Rotator-Phasen der Alkane

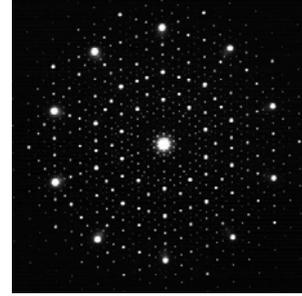


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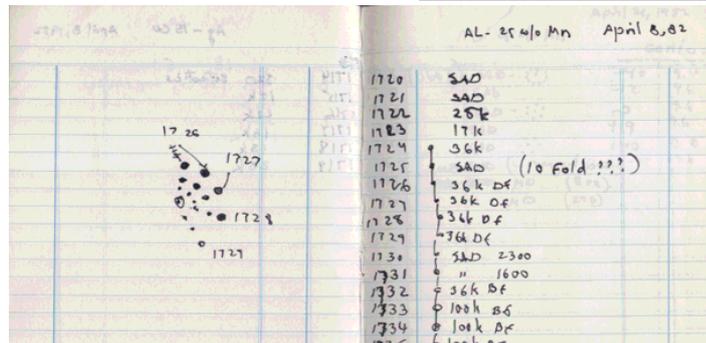
## Quasikristalle

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Elektronenbeugung  
an AlMn



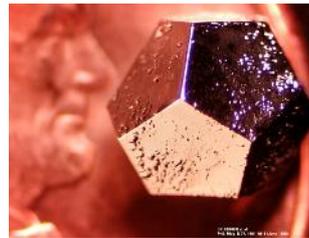
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