

Festkörperphysik

Prof. Andreas Schilling

Vorlesung: Di 13:00 - 14:45 Hörsaal Y16G05

Vorlesung/Anwendungen: Fr 8:15 -10:00 Hörsaal Y15G20

Vorlesungsbeginn: Di 17. September 2024

Inhalt der Vorlesung:

I. Anordnung von Atomen und Molekülen

Periodizität und Symmetrie, Bravais-Gitter, Symmetrieeigenschaften der Kristalle, Millersche Indizes, einfache Kristallstrukturen

II. Beugung am Kristallgitter

Reziprokes Gitter, Brillouin-Zonen, Laue-Gleichungen, Braggsche Reflexionsbedingung, Strukturamplitude, atomarer Streufaktor, Debye-Waller-Faktor, Röntgen- und Neutronenstreuung

III. Bindungen im Kristall

Ionenbindung, kovalente Bindung, metallische Bindung, Van-der-Waals-Bindung, Wasserstoff-Brücken-Bindung

IV. Phononen

Eigenschwingungen von Kristallgittern, Quantisierung von Gitterschwingungen (Phononen) Impuls der Phononen,

V. Thermische Eigenschaften von Isolatoren

Spezifische Wärme des Gitters, anharmonische Effekte (thermische Ausdehnung von Festkörpern, Wärmeleitung in Isolatoren)

VI. Elektronenzustände im Kristall

Fermi-Dirac-Verteilung, freies Elektronengas, spezifische Wärme und magnetische Suszeptibilität des Elektronengases, elektrische und thermische Leitfähigkeit von Metallen, Hall-Effekt, Zyklotronfrequenz, Landau-Zylinder, Bloch-Funktionen, Fermi-Körper, Bahnen im Magnetfeld

VII. Metalle, Halbleiter und Isolatoren

Metalle, Halbleiter, Isolatoren, Halbmetalle, Bandlücke, effektive Masse und Löcher, Eigenleitung und Störstellenleitung in Halbleitern

VIII. Magnetismus

Para- und Diamagnetismus, Curie Gesetz, Ferromagnetismus, Antiferromagnetismus, Bandmagnetismus

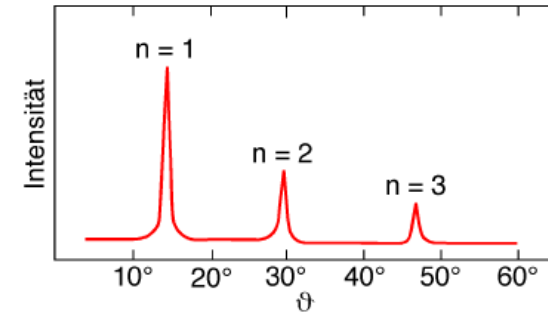
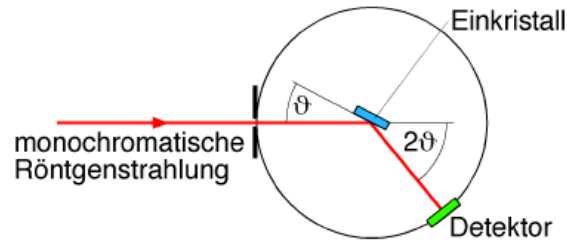
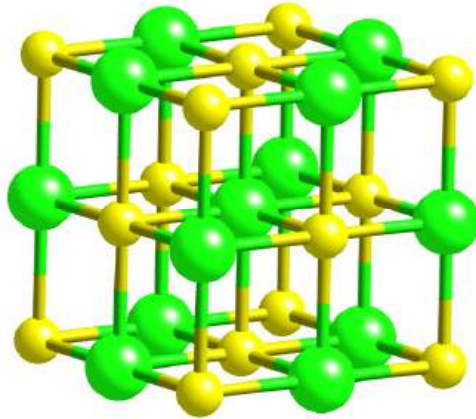
Literatur (kleine Auswahl)

- **Rudolf Gross, Achim Marx, *Festkörperphysik*, (Oldenbourg Verlag)**
<https://ezproxy.uzh.ch/login?url=https://www.degruyter.com/document/doi/10.1515/9783110782394/html>
- K. Kopitzki und P. Herzog, *Einführung in die Festkörperphysik*, (Teubner Studienbücher Physik)
<https://ezproxy.uzh.ch/login?url=https://link.springer.com/book/10.1007/978-3-662-53578-3>
- C. Kittel, *Einführung in die Festkörperphysik*, (Oldenbourg Verlag)
Nur als Hardcopy in der Bibliothek, dafür in Deutsch oder Englisch
https://uzb.swisscovery.slsp.ch/permalink/41SLSP_UZB/1d8t6qj/alma990113957980205508
- H. Ibach und H. Lüth, *Festkörperphysik*, (Springer-Verlag)
<https://ezproxy.uzh.ch/login?url=https://link.springer.com/book/10.1007/978-3-540-85795-2>



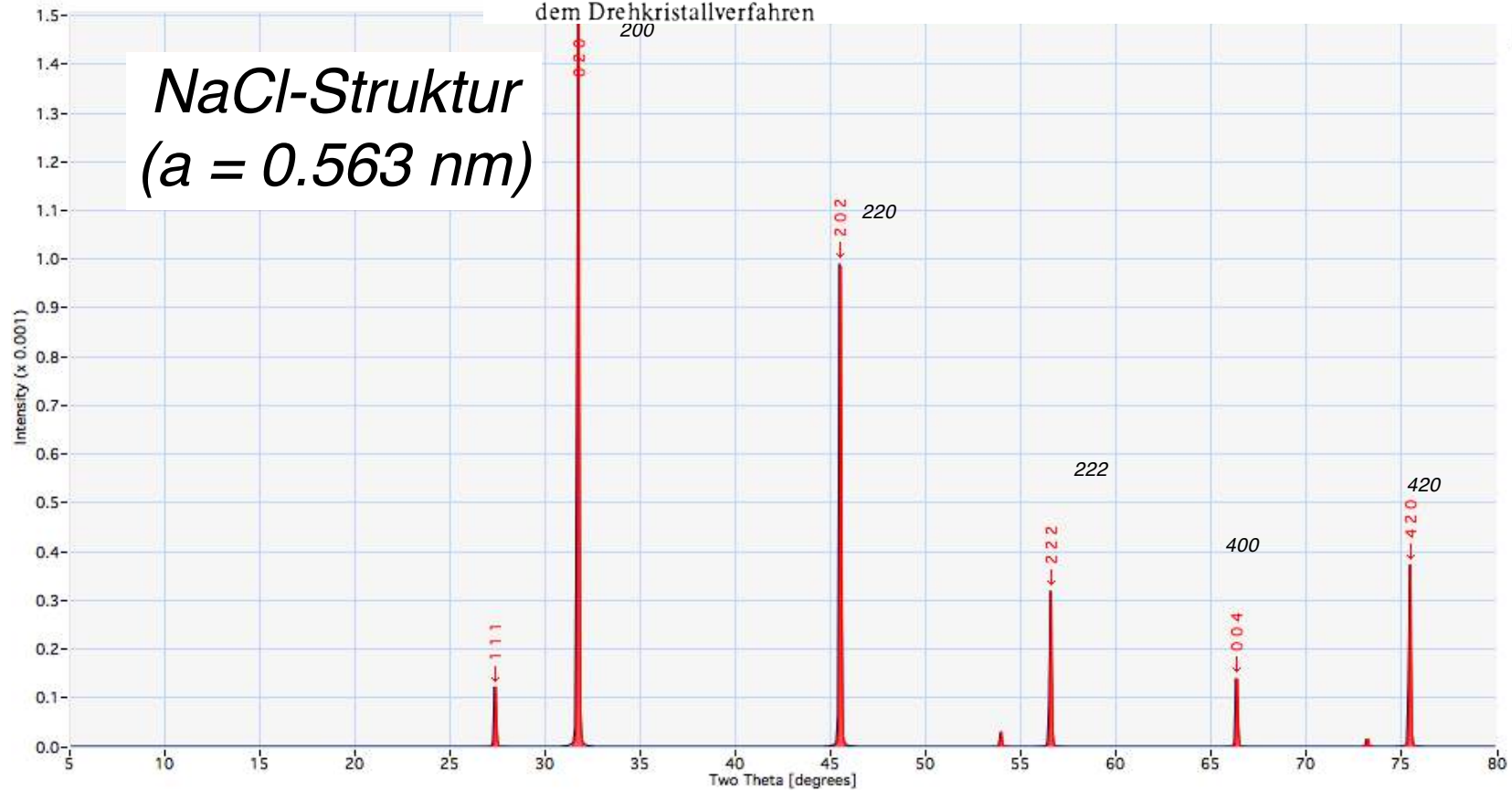
I. Anordnung von Atomen und Molekülen

Braggsches Drehkristall-Verfahren



Schema einer Vorrichtung zur Aufnahme eines Röntgenspektrums nach dem Drehkristallverfahren

Röntgenspektrum nach dem Drehkristallverfahren



Transmissions- Elektronenmikroskopische Aufnahme

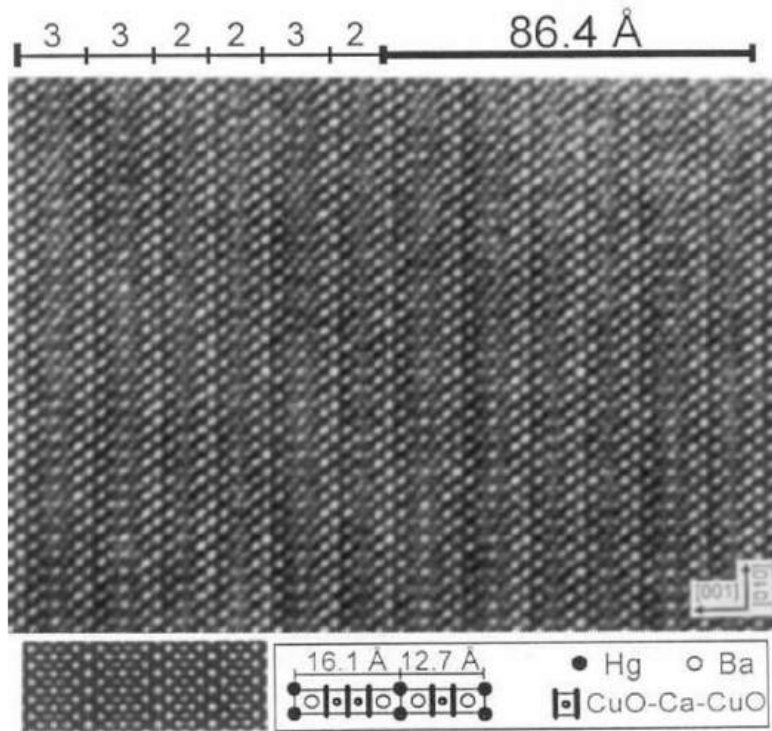


FIG. 1 HRTEM image of a grain in [100] orientation, containing layers of Hg-1212 and Hg-1223. Here, they are stacked in a periodic sequence forming a supercell with $c \approx 86.4 \text{ \AA}$ (see text). A contrast simulation ($c_s = 1.1 \text{ nm}$, $E = 300 \text{ keV}$, defocus -870 \AA , specimen thickness 23 \AA) is inserted. The stacking sequence in terms of the number of Cu-O planes and an enlarged schematic drawing of the involved unit cells are included.

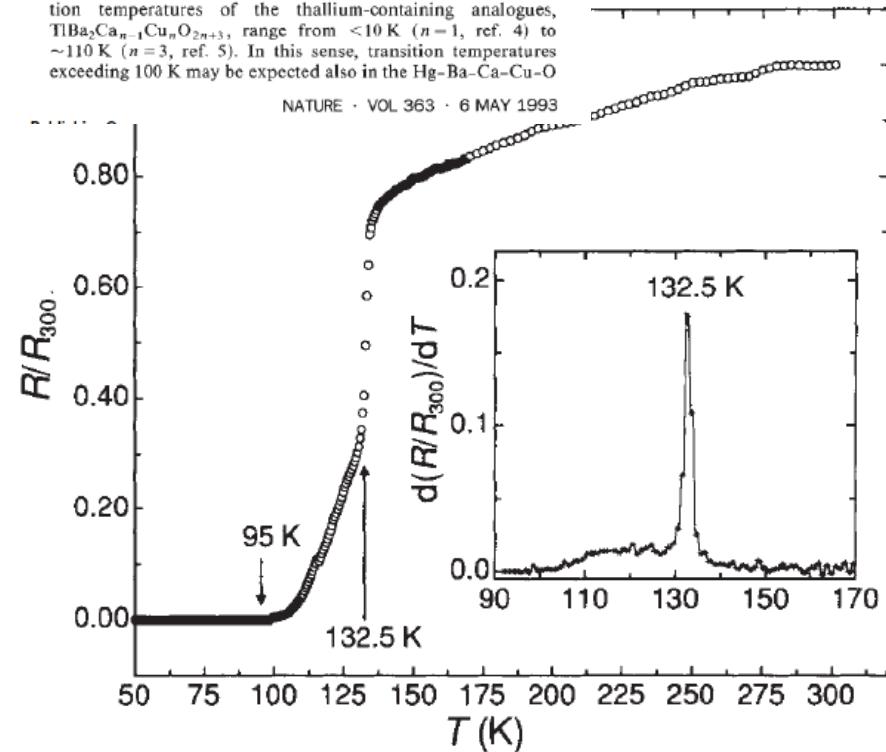
Superconductivity above 130 K in the Hg-Ba-Ca-Cu-O system

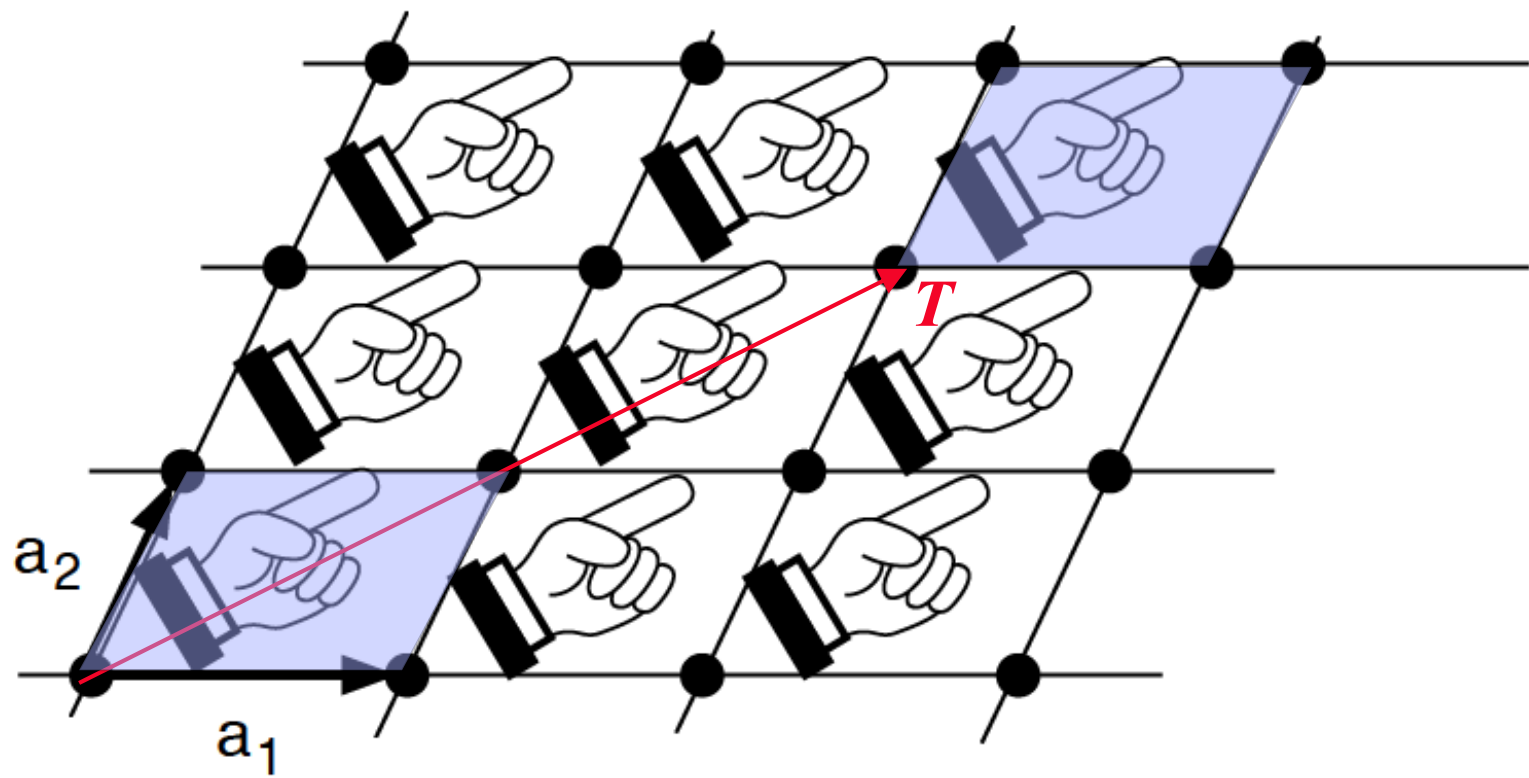
A. Schilling, M. Cantoni, J. D. Guo & H. R. Ott

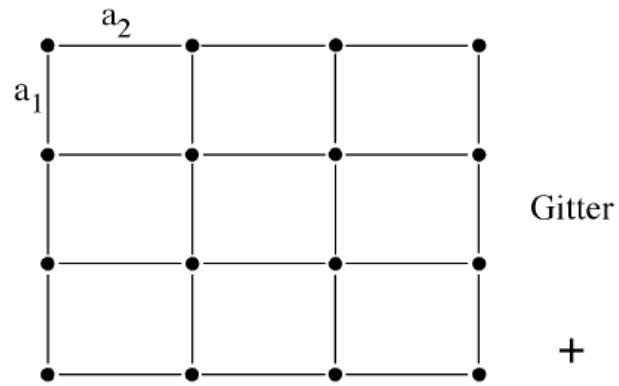
Laboratorium für Festkörperphysik, ETH Höggerberg, 8093 Zürich, Switzerland

THE recent discovery¹ of superconductivity below a transition temperature (T_c) of 94 K in $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+x}$ has extended the repertoire of high- T_c superconductors containing copper oxide planes embedded in suitably structured (layered) materials. Previous experience with similar compounds containing bismuth and thallium instead of mercury suggested that even higher transition temperatures might be achieved in mercury-based compounds with more than one CuO_2 layer per unit cell. Here we provide support for this conjecture, with the discovery of superconductivity above 130 K in a material containing $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{10+x}$ (with three CuO_2 layers per unit cell), $\text{HgBa}_2\text{CaCu}_2\text{O}_{6+x}$ (with two CuO_2 layers) and an ordered superstructure comprising a defined sequence of the unit cells of these phases. Both magnetic and resistivity measurements confirm a maximum transition temperature of $\sim 133 \text{ K}$, distinctly higher than the previous established record value of 125–127 K observed in $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (refs 2, 3).

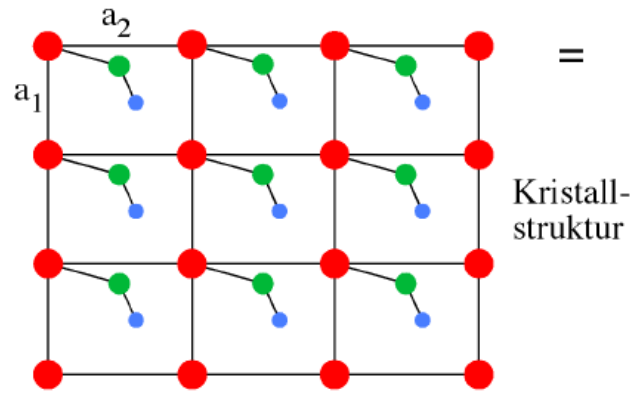
The structural similarity of $\text{HgBa}_2\text{CuO}_{4+\delta}$ (Hg-120; ref. 1) to a member of the thallium-containing family of copper oxides, $\text{TlBa}_2\text{CuO}_3$ (Tl-1201), suggests the existence of compounds with the general composition $\text{HgBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+2+\delta}$. The transition temperatures of the thallium-containing analogues, $\text{TlBa}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_{2n+3}$, range from $< 10 \text{ K}$ ($n=1$, ref. 4) to $\sim 110 \text{ K}$ ($n=3$, ref. 5). In this sense, transition temperatures exceeding 100 K may be expected also in the Hg-Ba-Ca-Cu-O





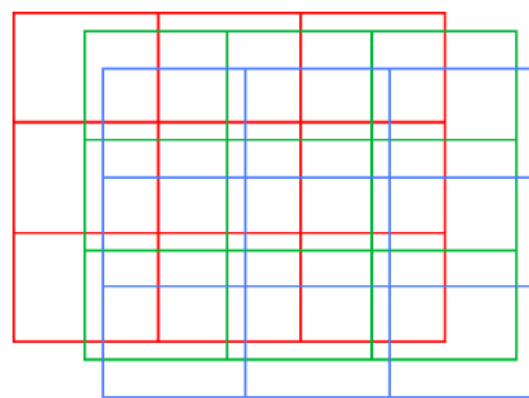


+

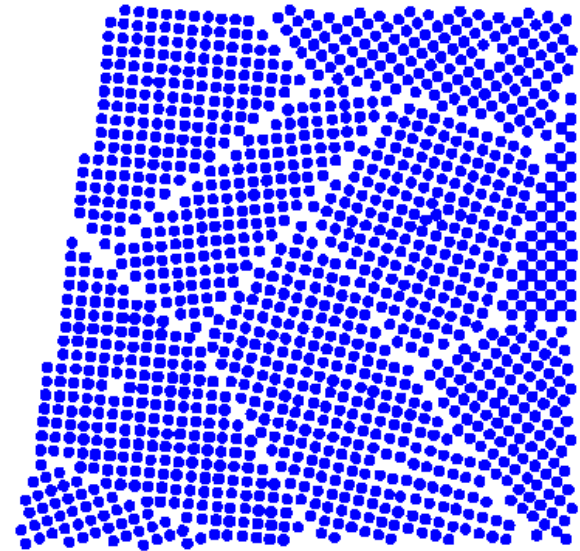


=

Beziehung von Gitter, Basis und Kristallstruktur zueinander; Gitter und Kristallstruktur sind Projektionen auf (001)

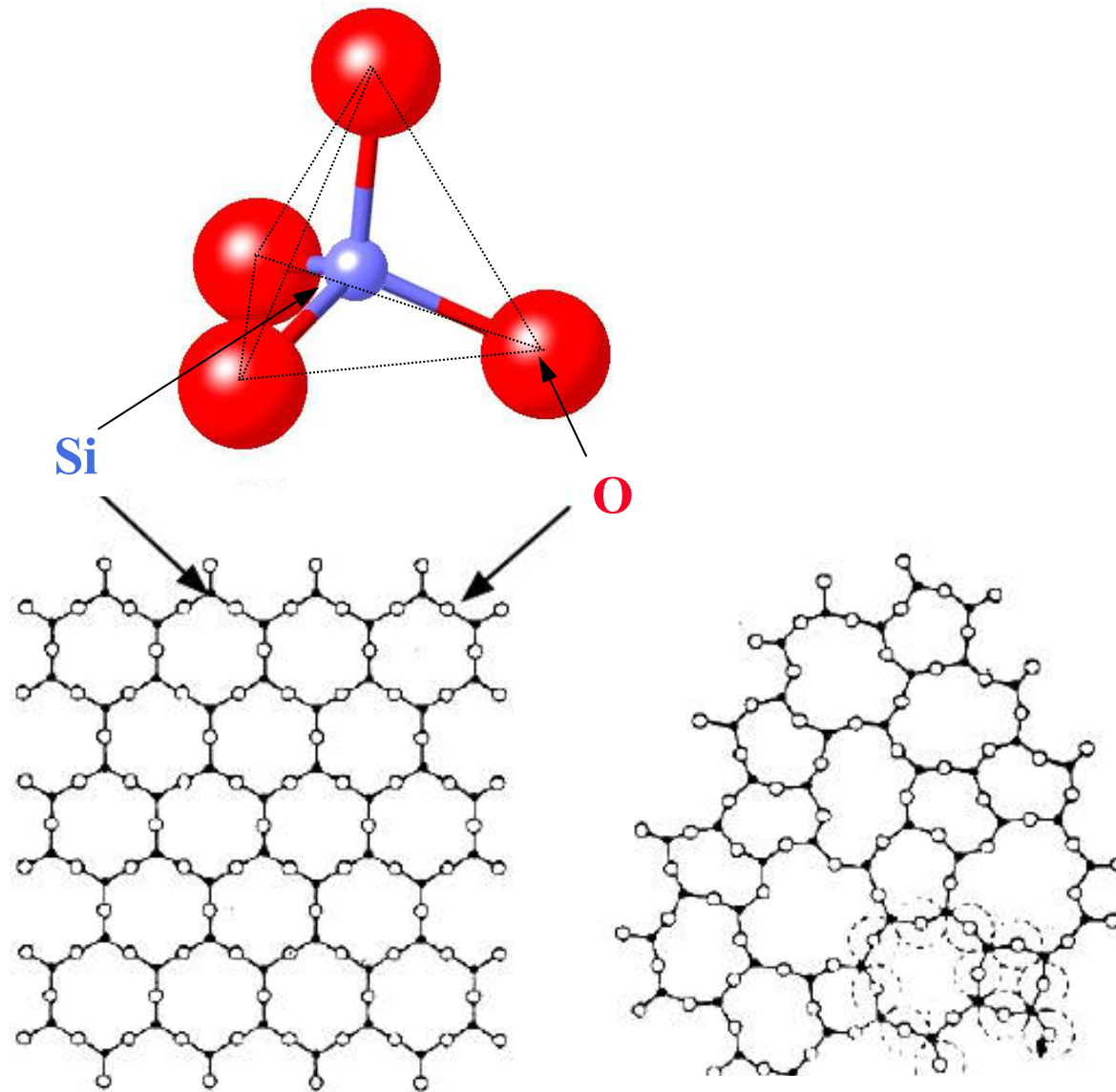


Alle Bausteine der in oben gezeigten Kristallstruktur liegen auf den Eckpunkten von kongruenten Gittern

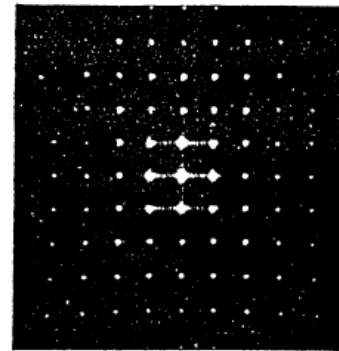
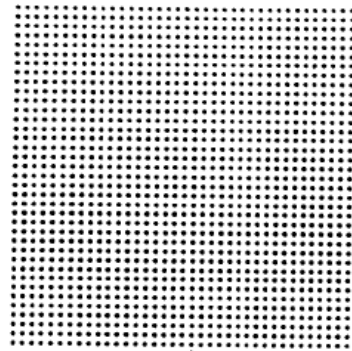


Stahl: polykristallin

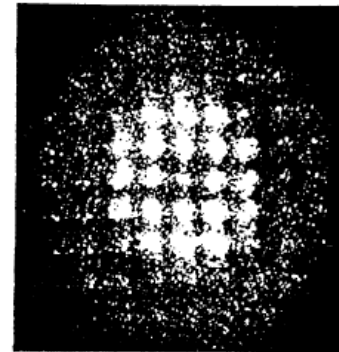
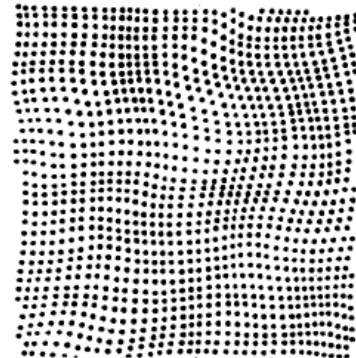
Struktur von kristallinem und amorphem Quarz



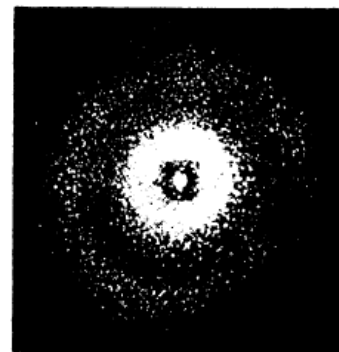
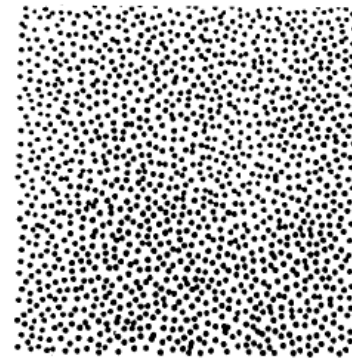
Amorphes GeSbTe als Farbdisplay



Modell und Beugungsbild einer kristallinen Struktur

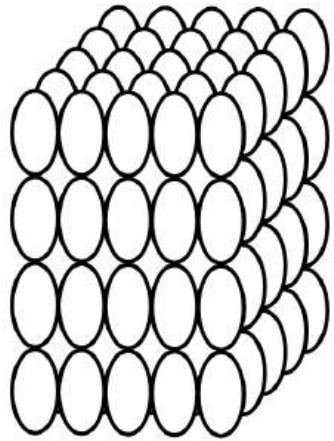


Modell und Beugungsbild einer parakristallinen Struktur

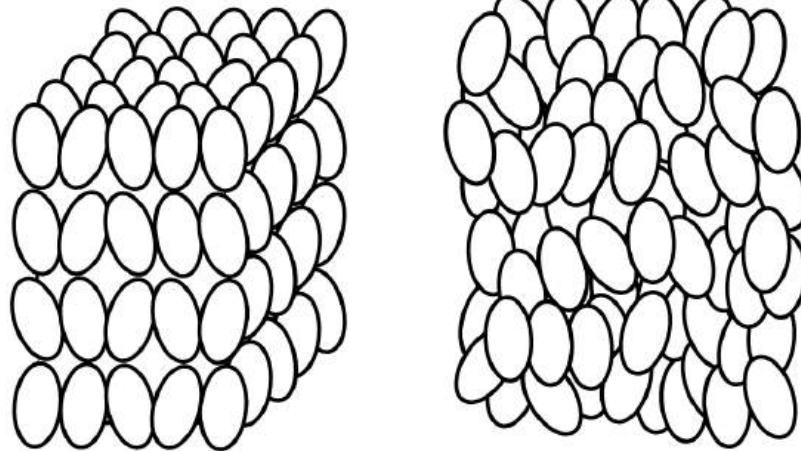


Modell und Beugungsbild einer amorphen Struktur

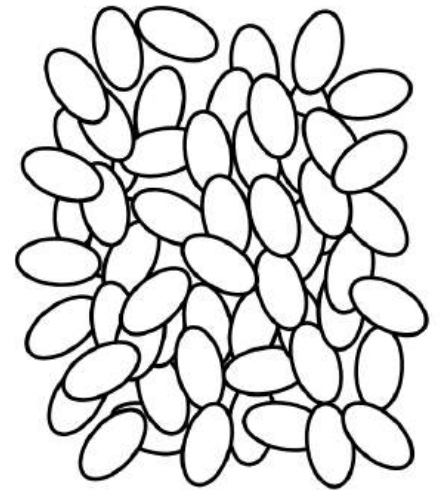
Solid



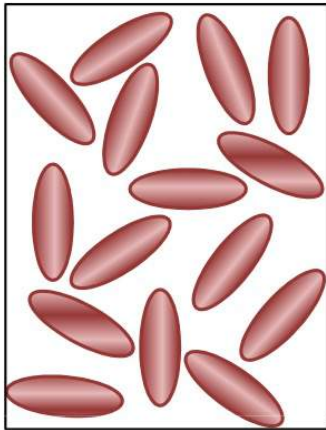
Mesophases



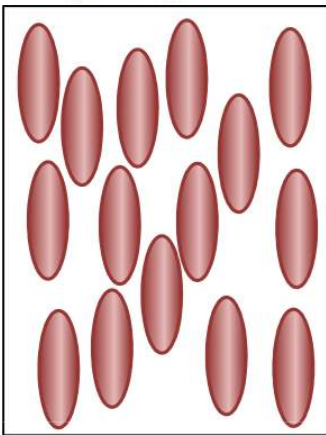
Liquid



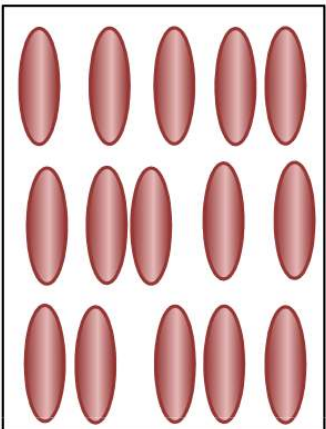
Flüssigkristalle



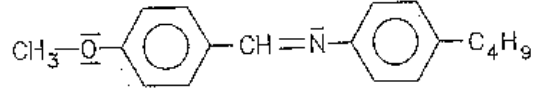
flüssig



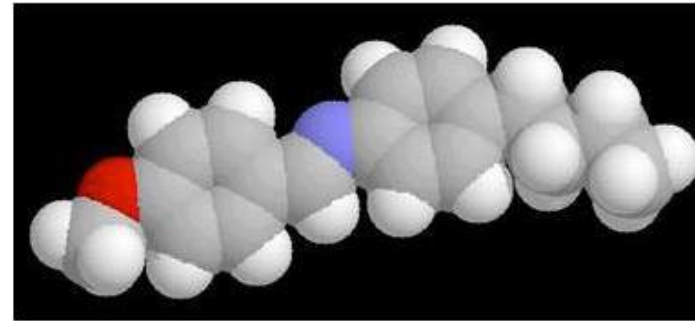
nematisch



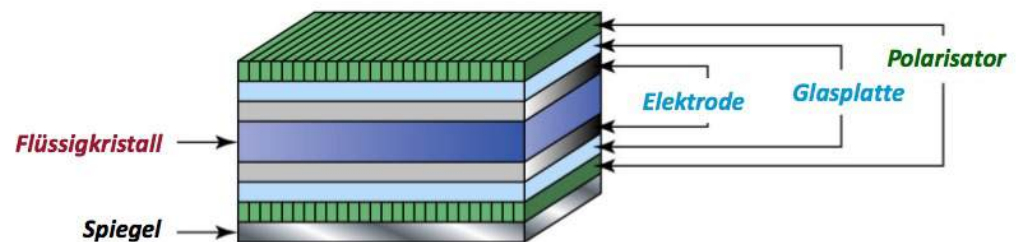
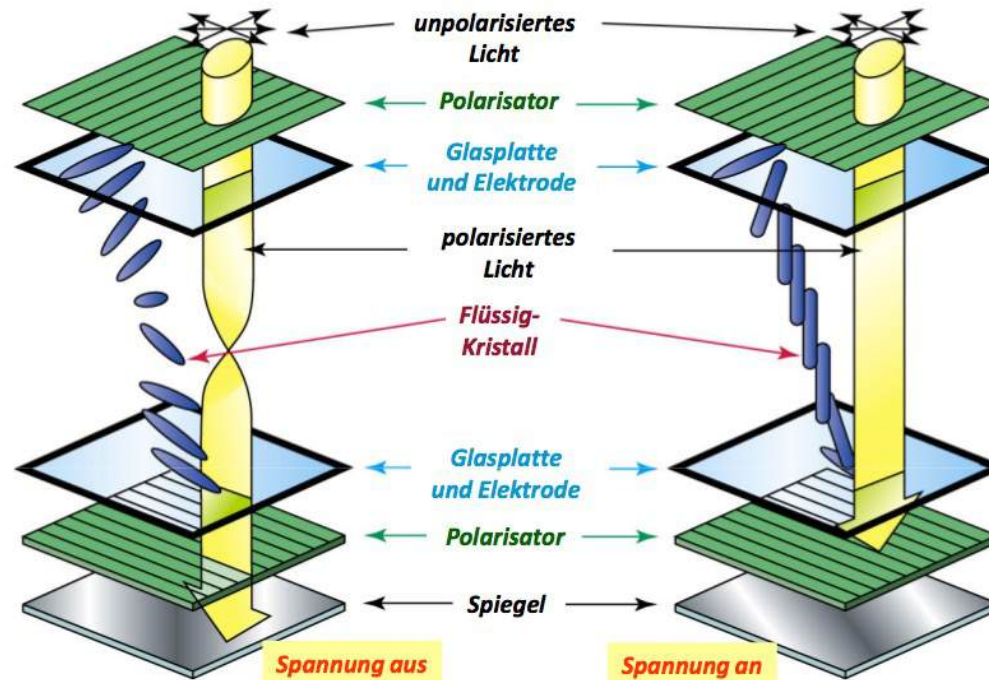
smektisch



Methoxybenzylidenbutylanilin (MBBA)

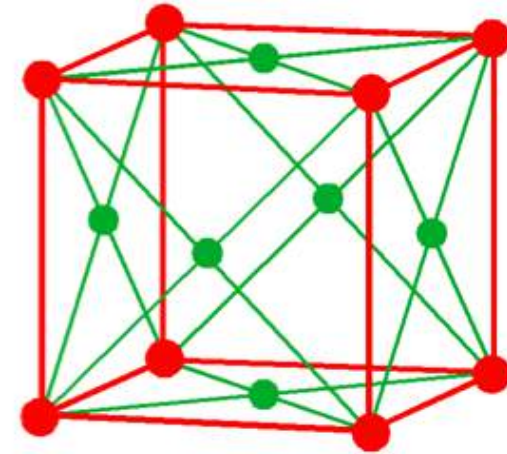


Schmelzpunkt: 22 °C
 Klärpunkt: 47 °C



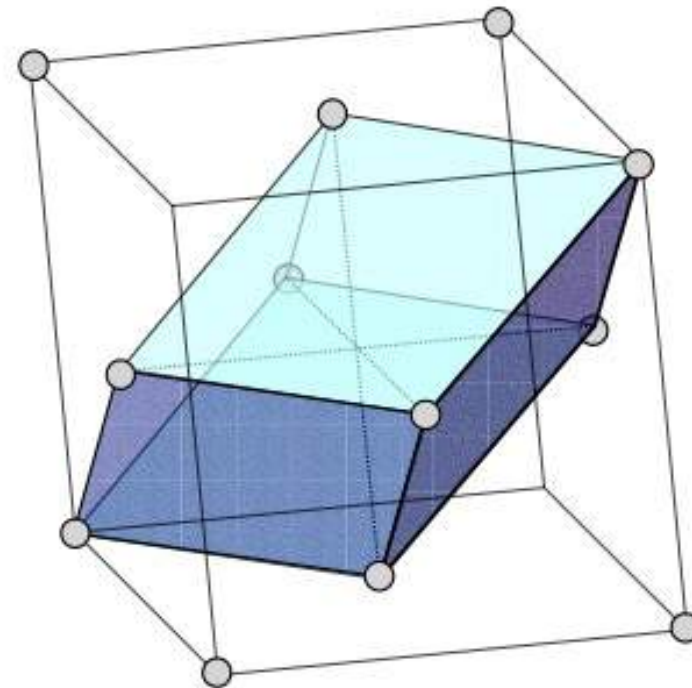
Zur prinzipiellen Funktionsweise von LCD-Anzeigen.

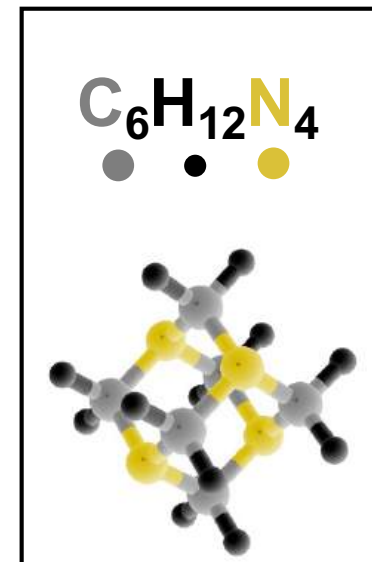
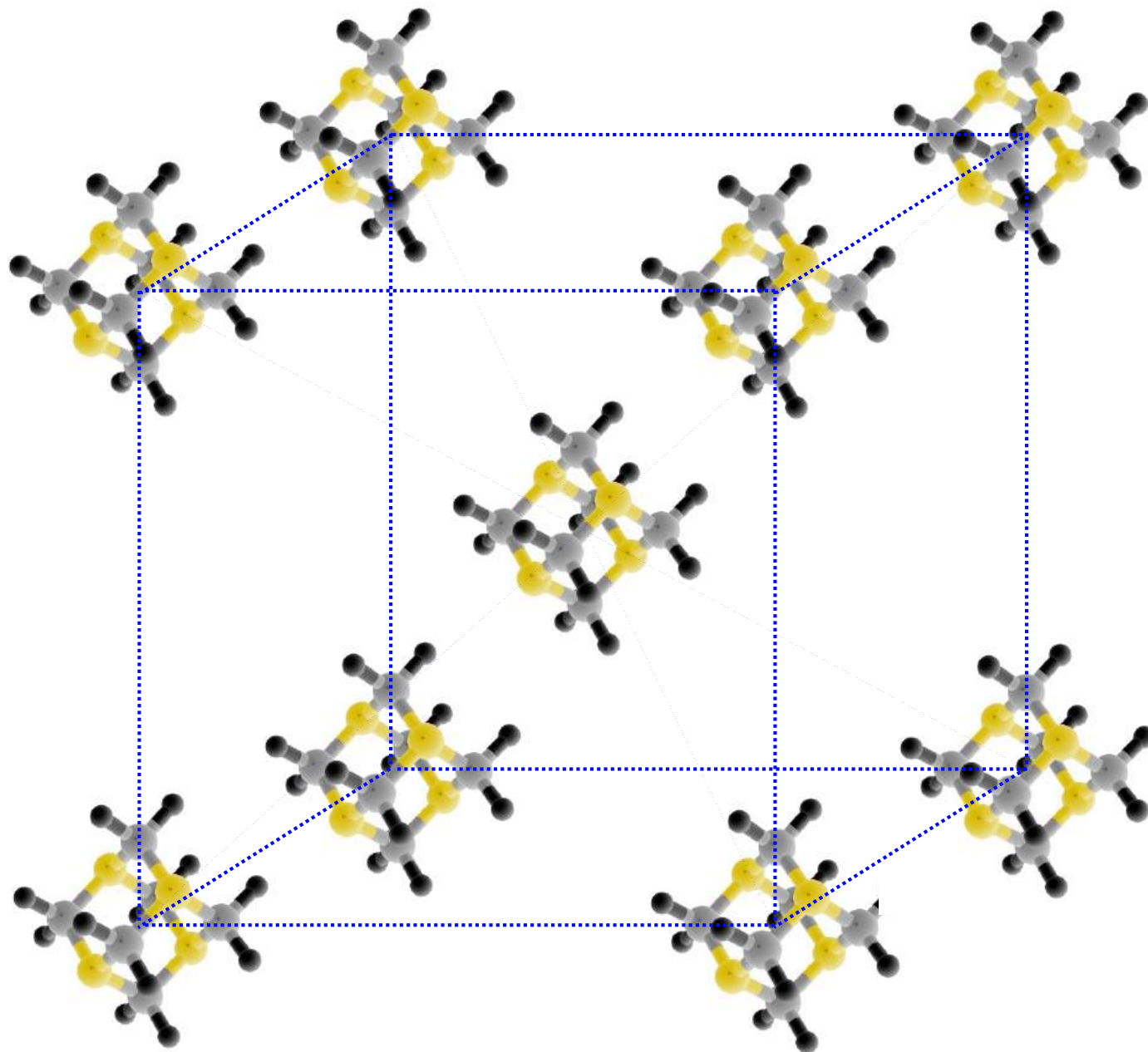
*Diese mehrfach primitive
Einheitszelle enthält vier (!)
Gitterpunkte*



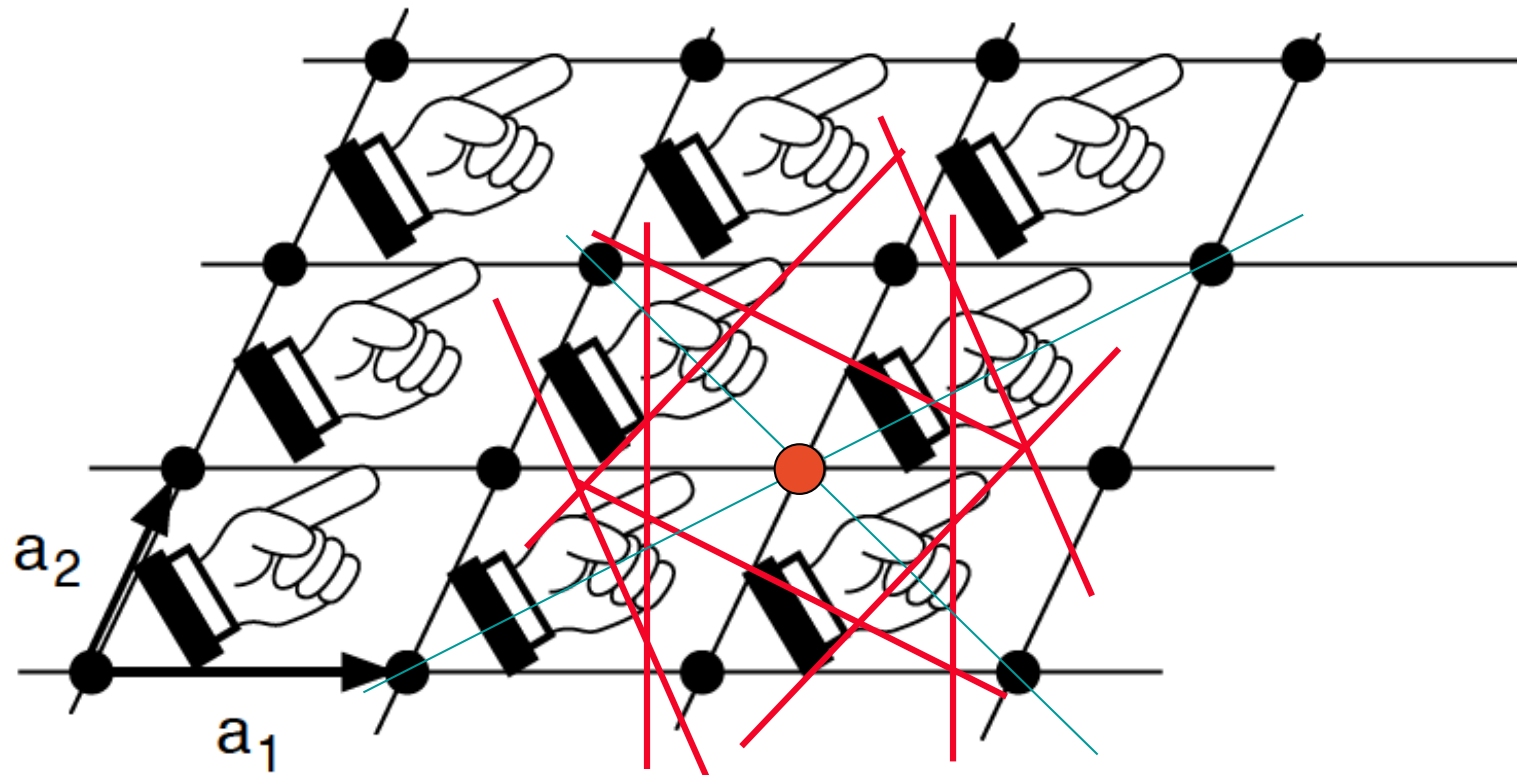
Kubisch F

*Die einfach primitive
Einheitszelle ist kein Würfel!*

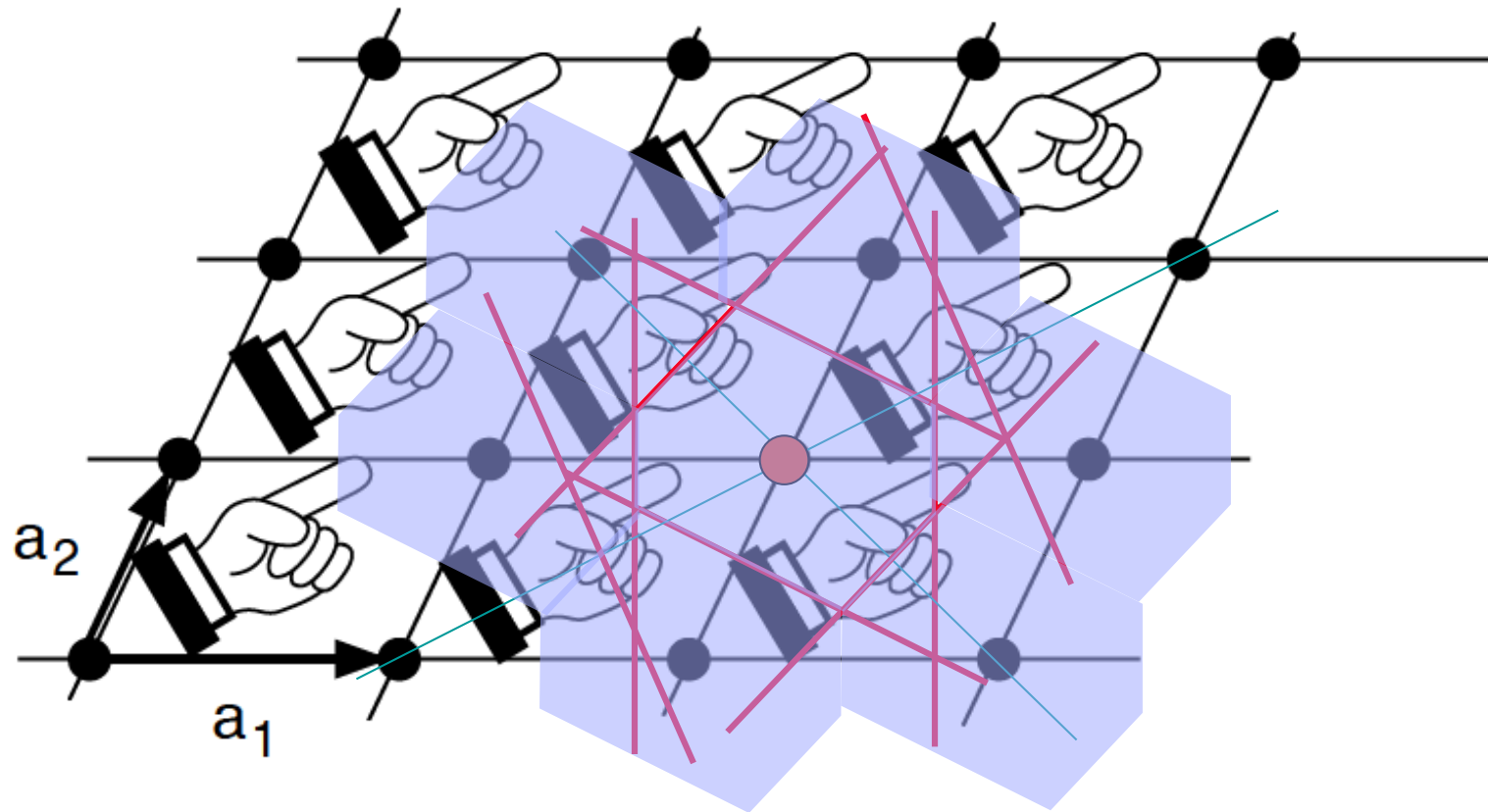




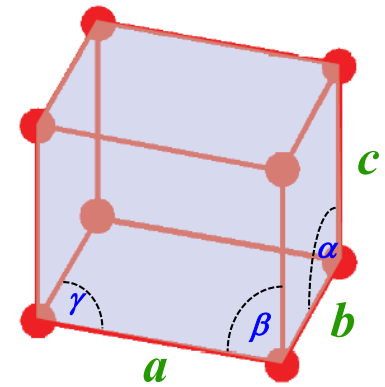
Wigner-Seitz-Zelle



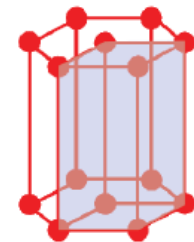
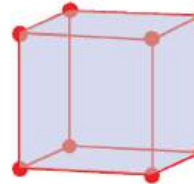
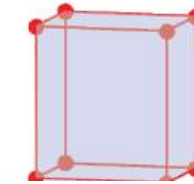
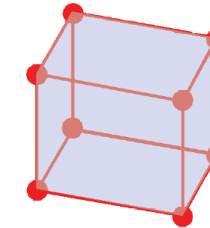
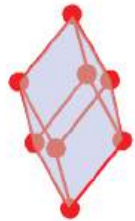
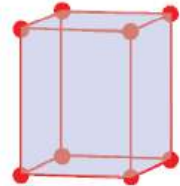
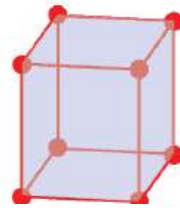
Wigner-Seitz-Zelle



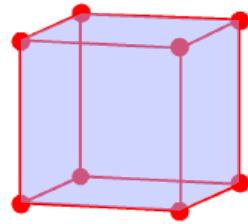
Die 7 einfachsten Kristallsysteme



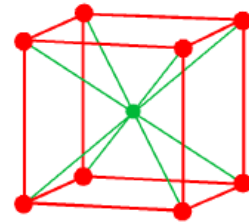
System	Einschränkungen bezüglich der Achsen und Winkel der gebräuchlichen Einheitszelle
Triklin	$a \neq b \neq c$ $\alpha \neq \beta \neq \gamma$
Monoklin	$a \neq b \neq c$ $\alpha = \gamma = 90^\circ \neq \beta$
Orthorhombisch	$a \neq b \neq c$ $\alpha = \beta = \gamma = 90^\circ$
Tetragonal	$a = b \neq c$ $\alpha = \beta = \gamma = 90^\circ$
Kubisch	$a = b = c$ $\alpha = \beta = \gamma = 90^\circ$
Rhomboedrisch (oder trigonal)	$a = b = c$ $\alpha = \beta = \gamma < 120^\circ, \neq 90^\circ$
Hexagonal	$a = b \neq c$ $\alpha = \beta = 90^\circ$ $\gamma = 120^\circ$



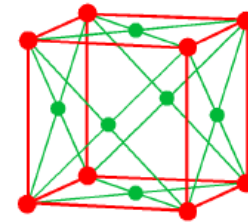
Die 14 Bravais-Gitter



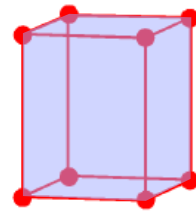
Kubisch *P*



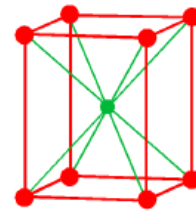
Kubisch *I*



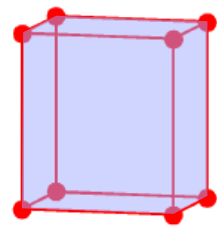
Kubisch *F*



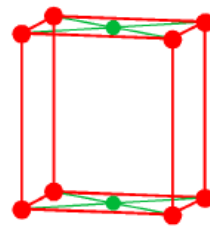
Tetragonal *P*



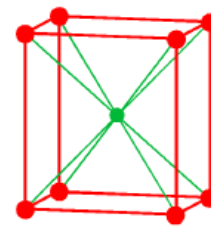
Tetragonal *I*



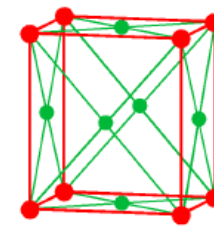
Orthorhombisch *P*



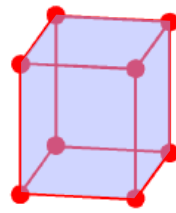
Orthorhombisch *C*



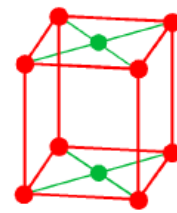
Orthorhombisch *I*



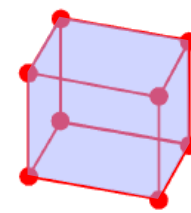
Orthorhombisch *F*



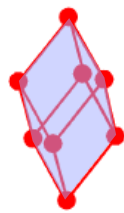
Monoklin *P*



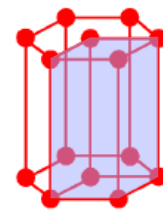
Monoklin *C*



Triklin

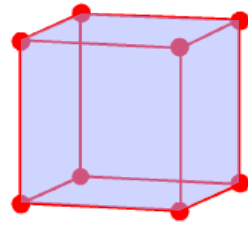


Rhombodrisch *R*

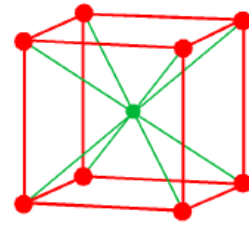


Hexagonal *P*

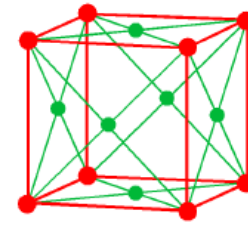
Die 14 Bravais-Gitter



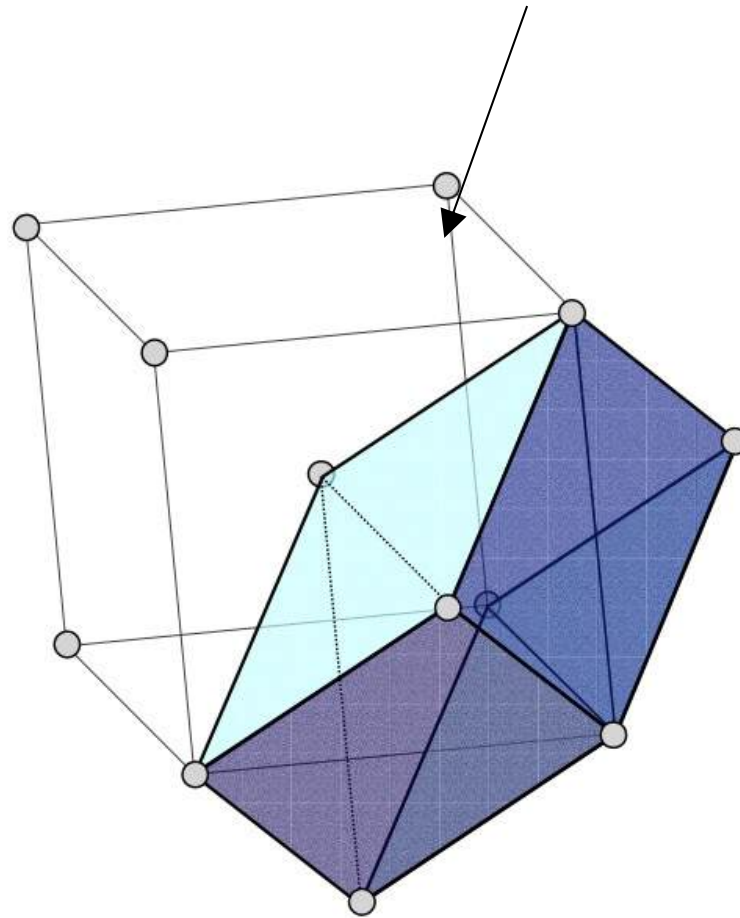
Kubisch *P*



Kubisch *I*

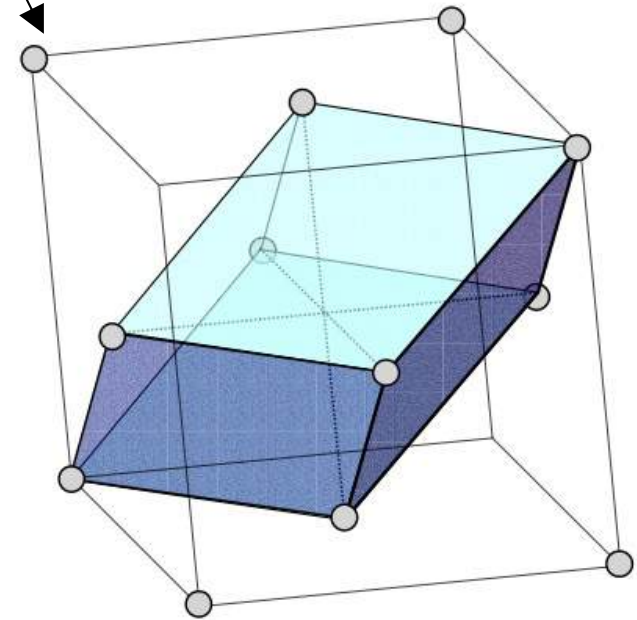


Kubisch *F*

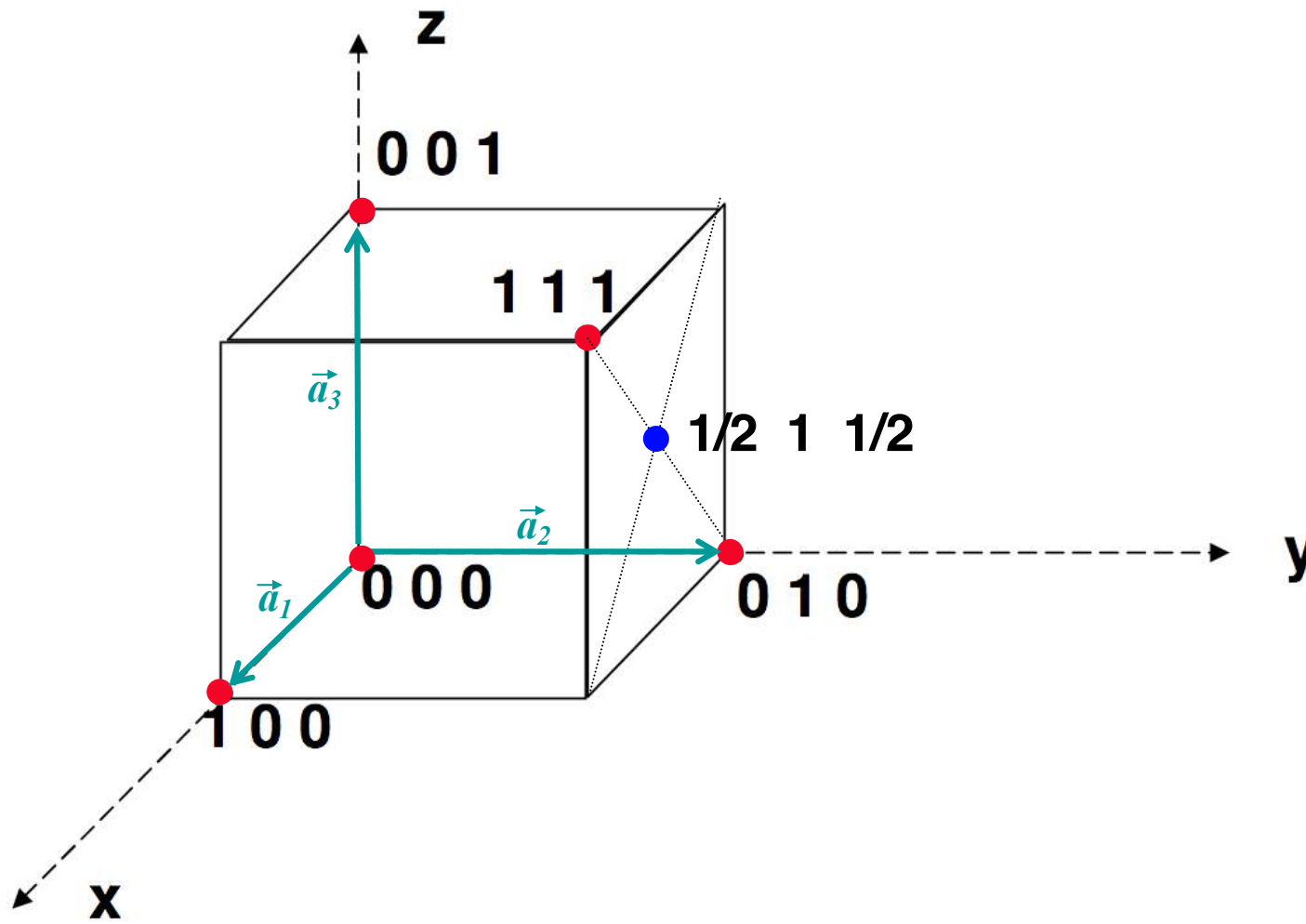


primitive Zelle bcc

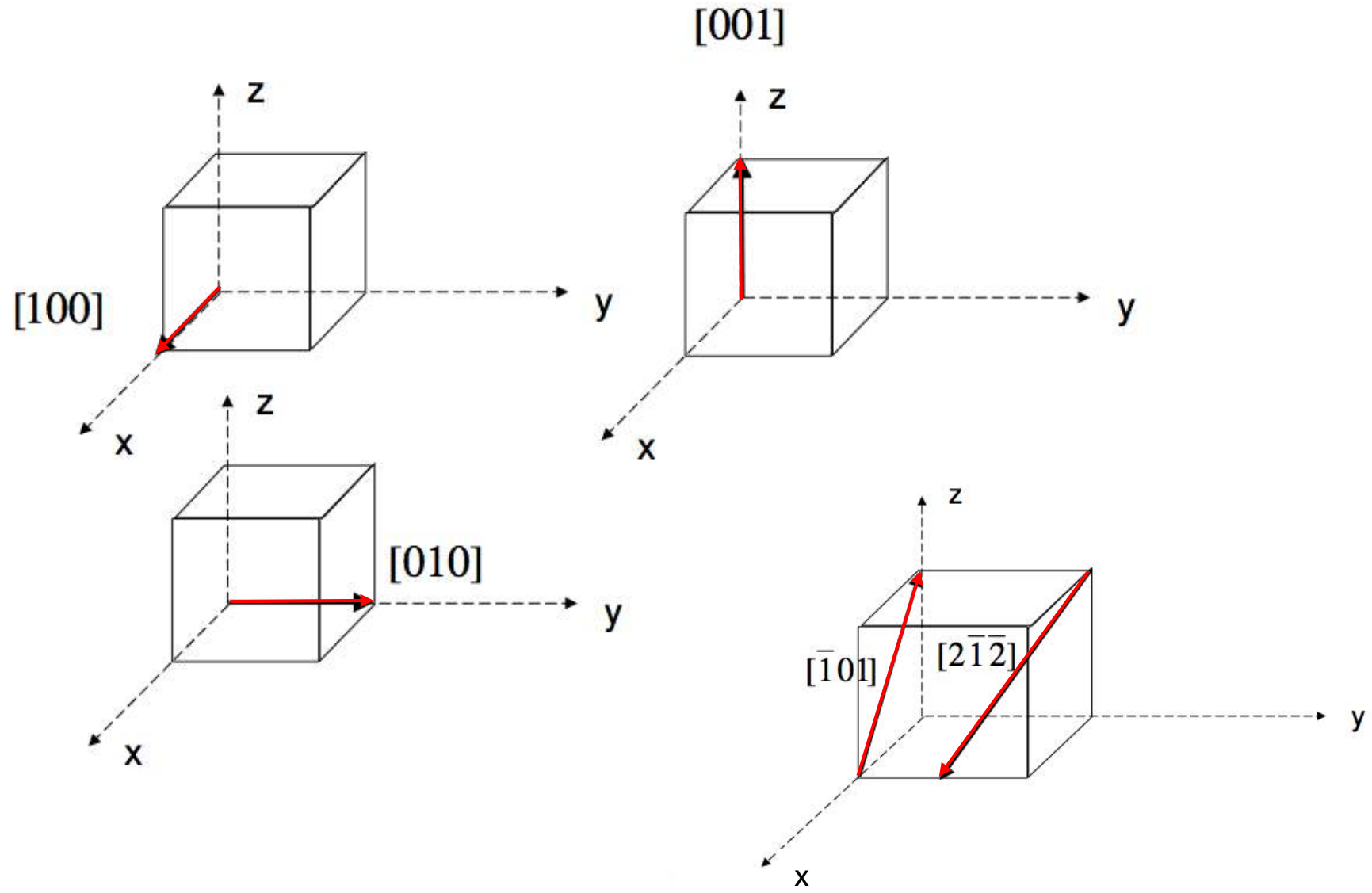
primitive Zelle fcc



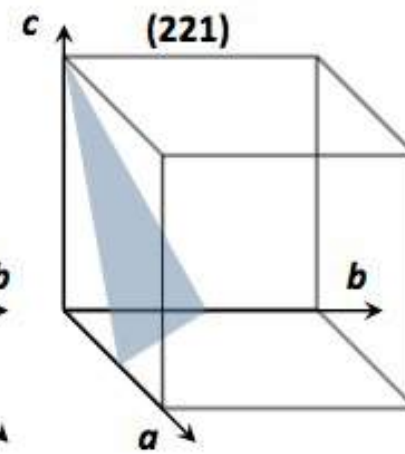
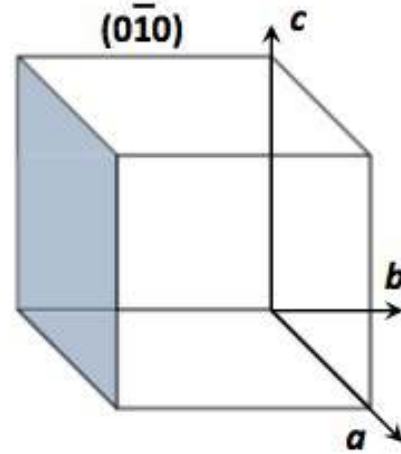
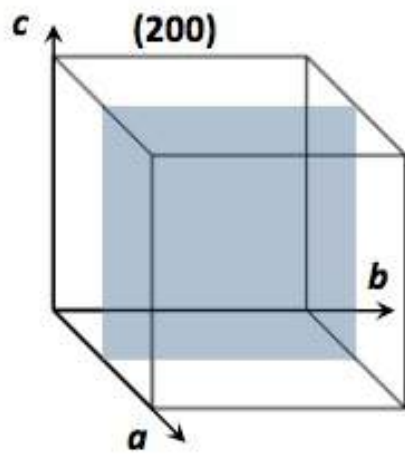
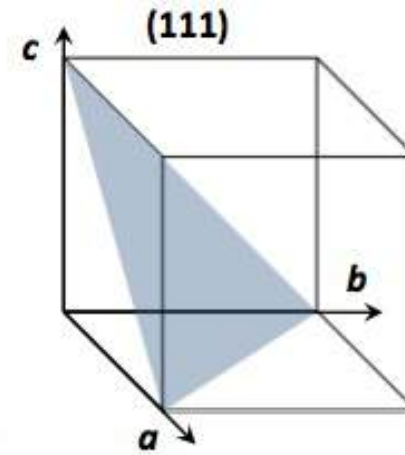
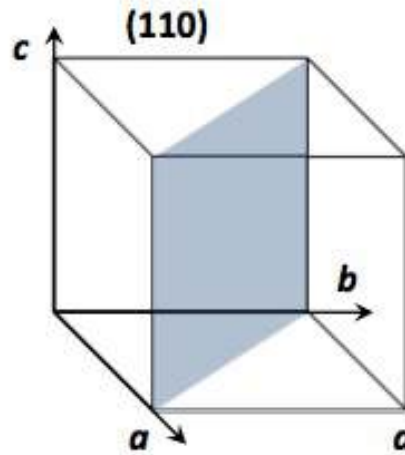
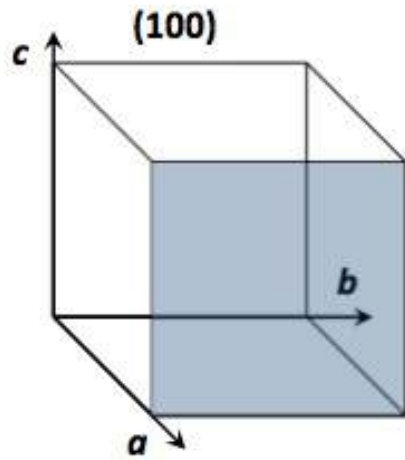
Atomkoordinaten

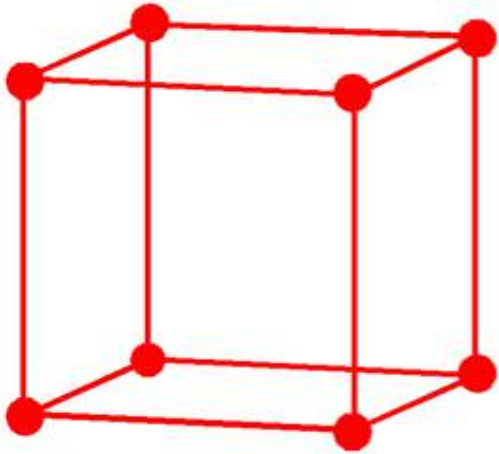


Richtungen im Kristall

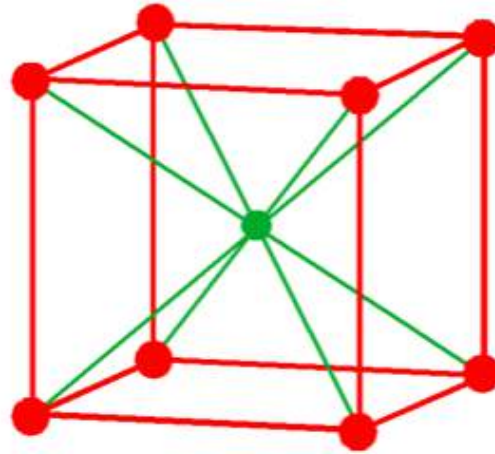


Netzebenen



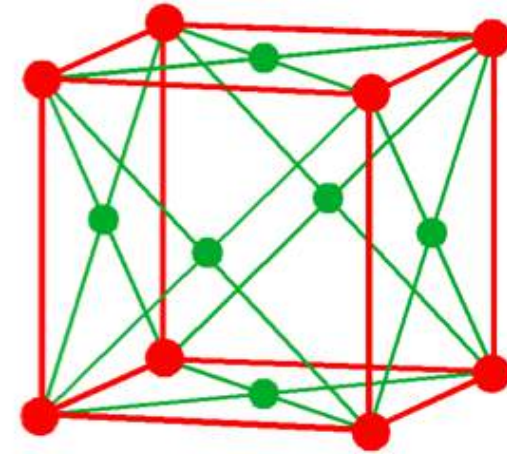


Kubisch *P*



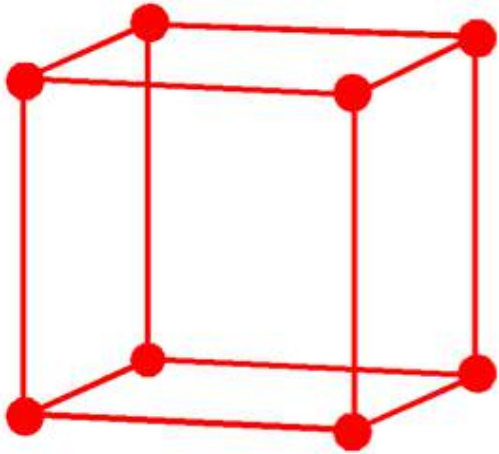
Kubisch *I*

bcc

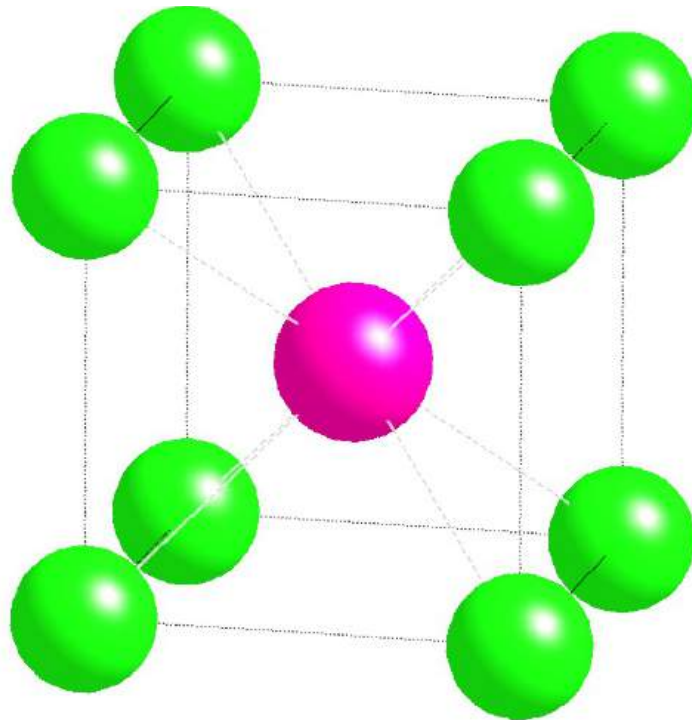


Kubisch *F*

fcc

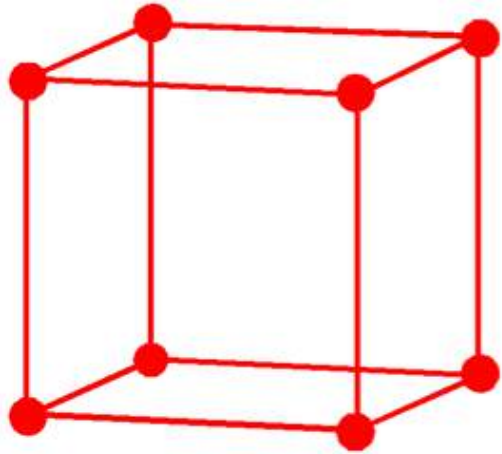


Kubisch *P*

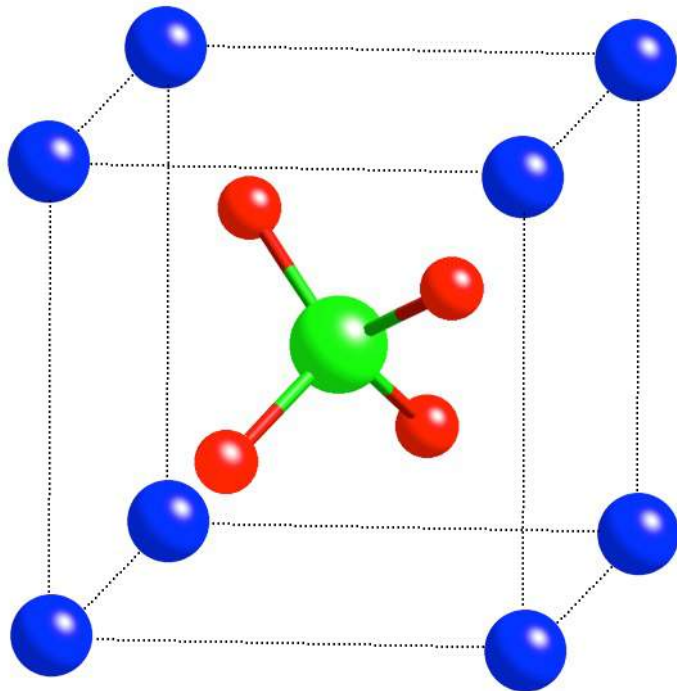


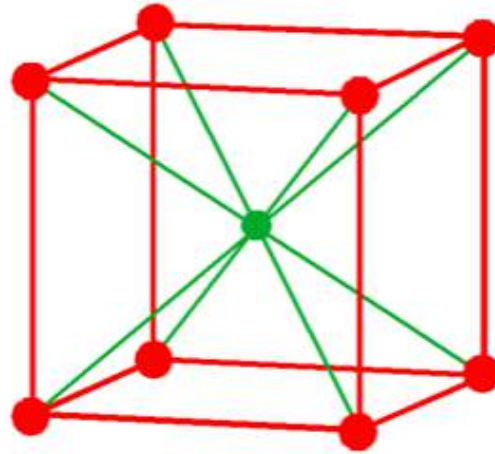
CsCl-Struktur





Kubisch *P*

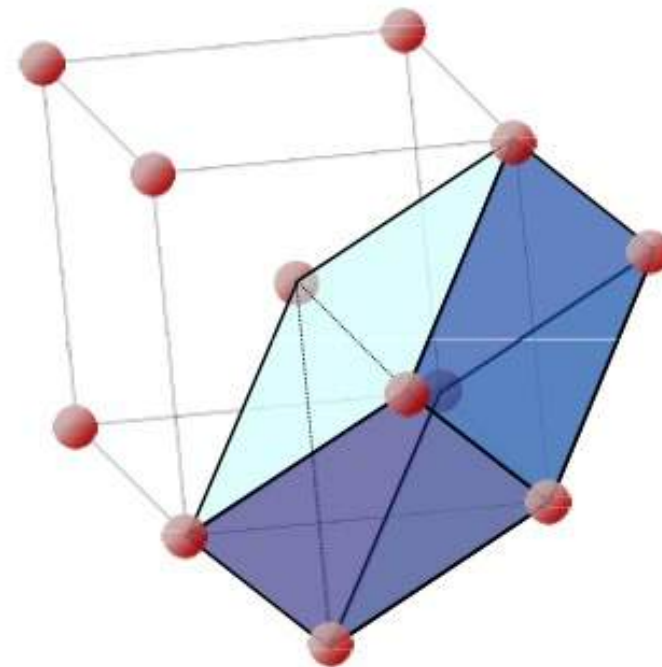




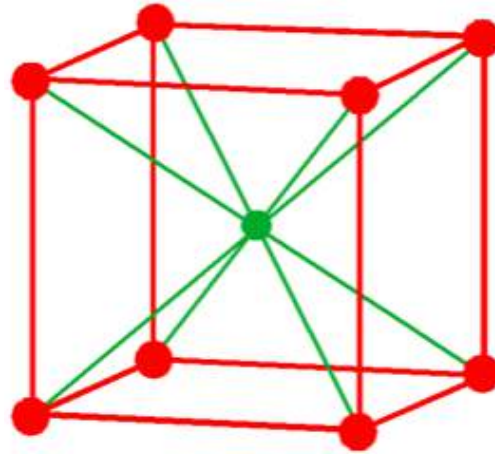
Kubisch I
bcc

Elemente Na, K, Rb, W,

*Achtung: primitive
Einheitszelle ist kein Würfel!*



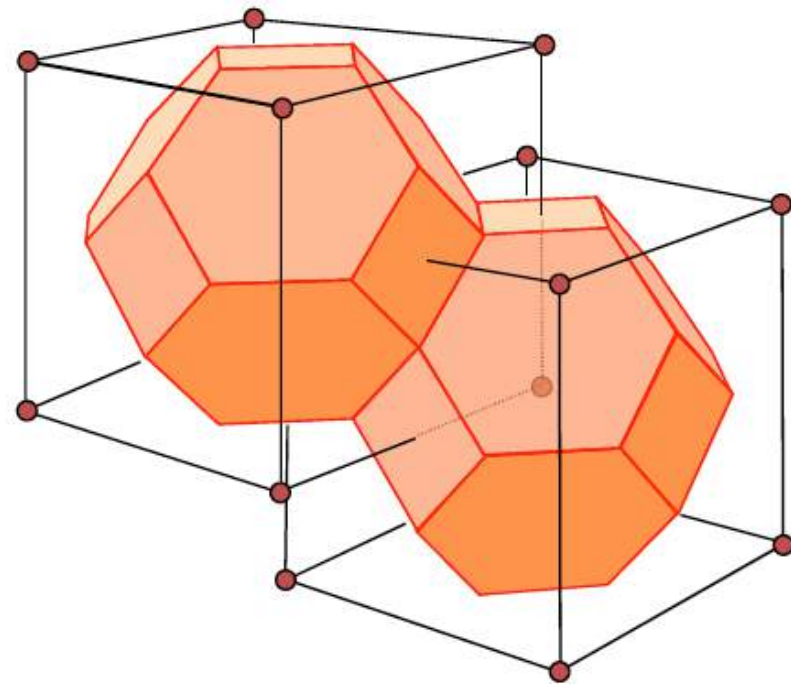
primitive Zelle bcc



Kubisch I

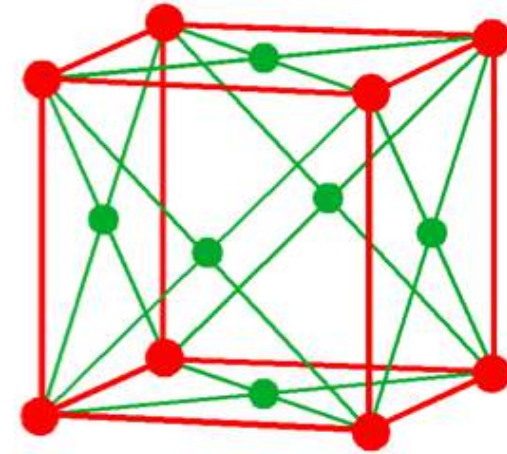
bcc

Wigner-Seitz Zelle für bcc



Elemente Na, K, Rb, W,

*Achtung: primitive
Einheitszelle ist kein Würfel!*



Kubisch F

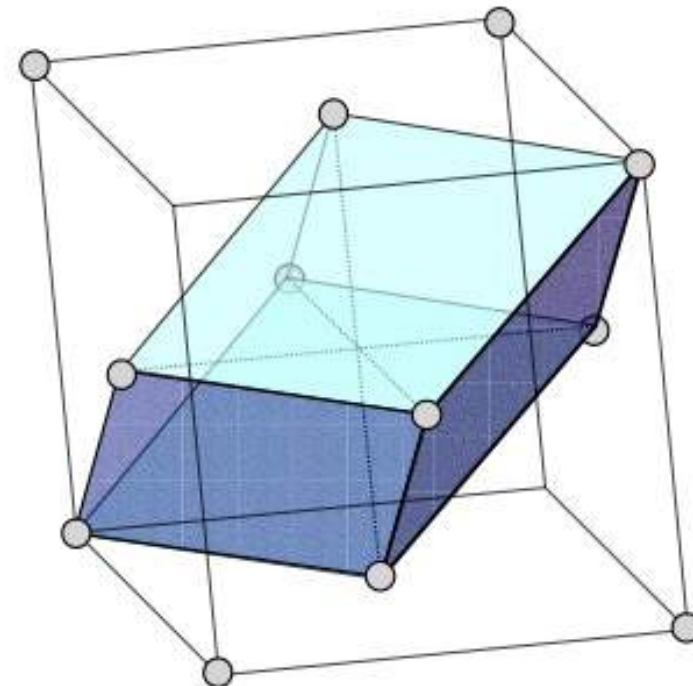
primitive Zelle fcc

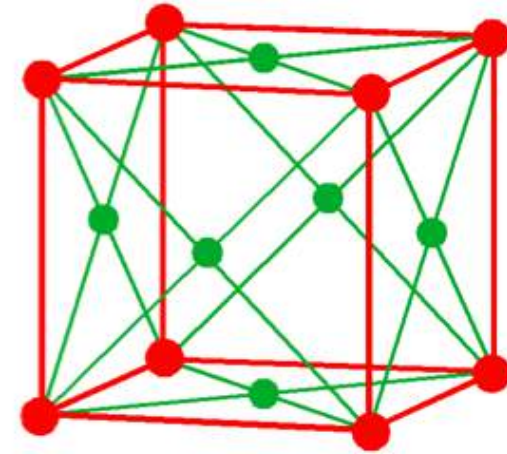
Mit einer Atomsorte:

Elemente Al, Cu, Ag, Au,

Achtung: primitive

Einheitszelle ist kein Würfel!





Kubisch F

fcc

NaCl Struktur

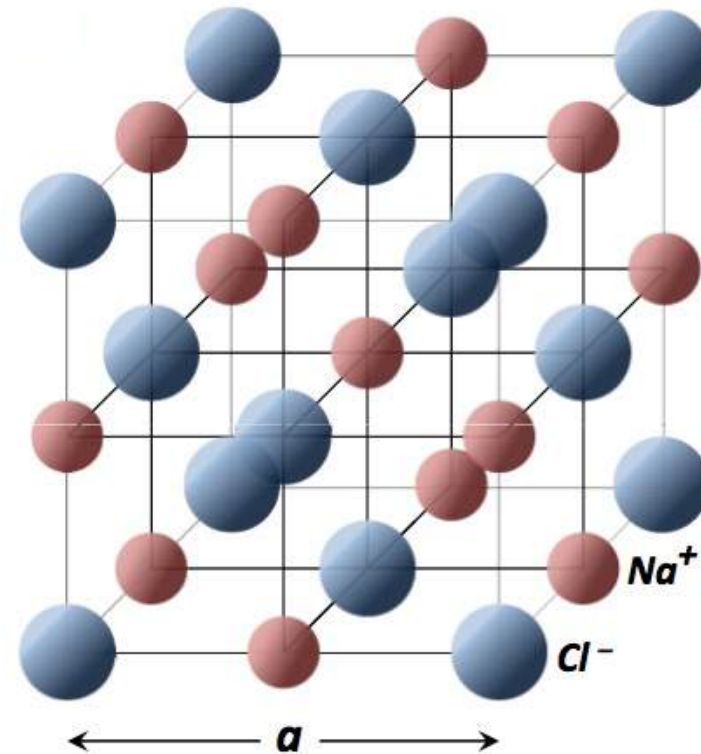
(KCl, LiF,)

Cl **0 0 0**

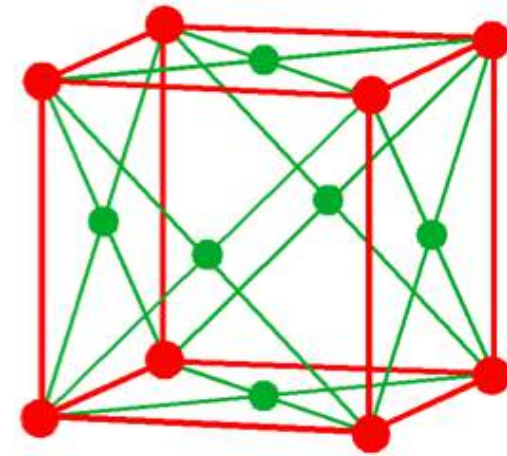
0 1/2 1/2 & zyklisch

Na **1/2 1/2 1/2**

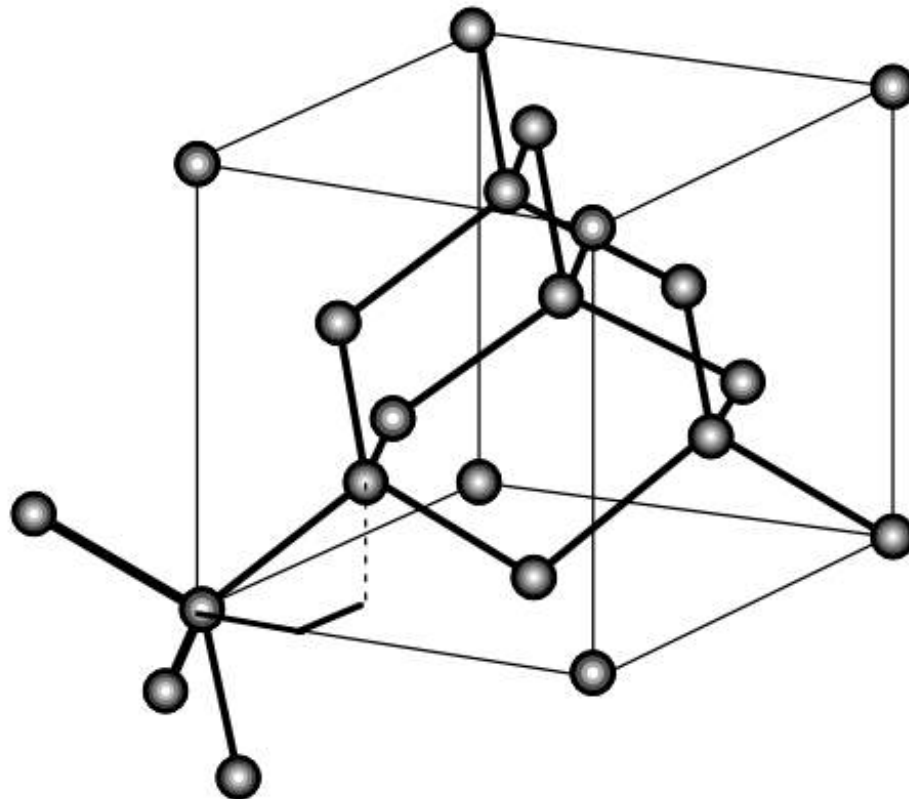
0 1/2 0 & zyklisch



Diamantstruktur (C, Si, Ge, ...)



Kubisch *F*
fcc



C

0 0 0

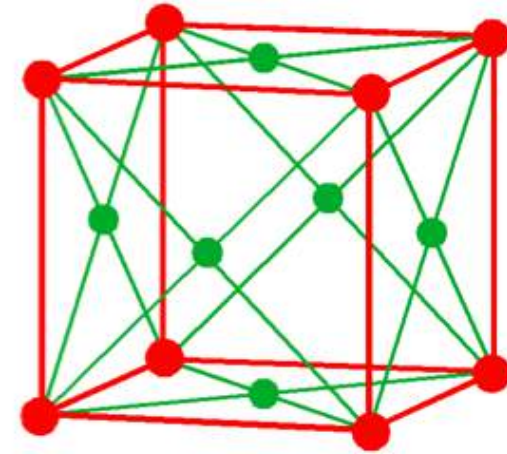
0 1/2 1/2 & zyklisch

1/4 1/4 1/4

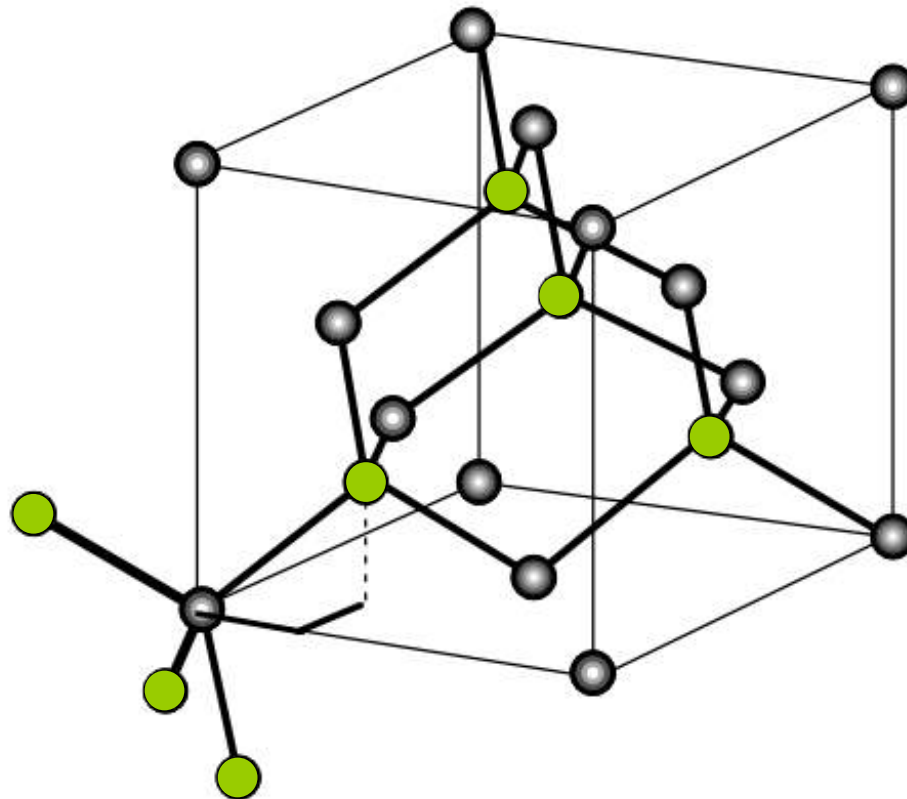
1/4 3/4 1/4

& zyklisch

Kubische ZnS-Struktur („Zinkblende“)
(CuF, AgJ, CdS, ZnS, ZnSb, SiC)

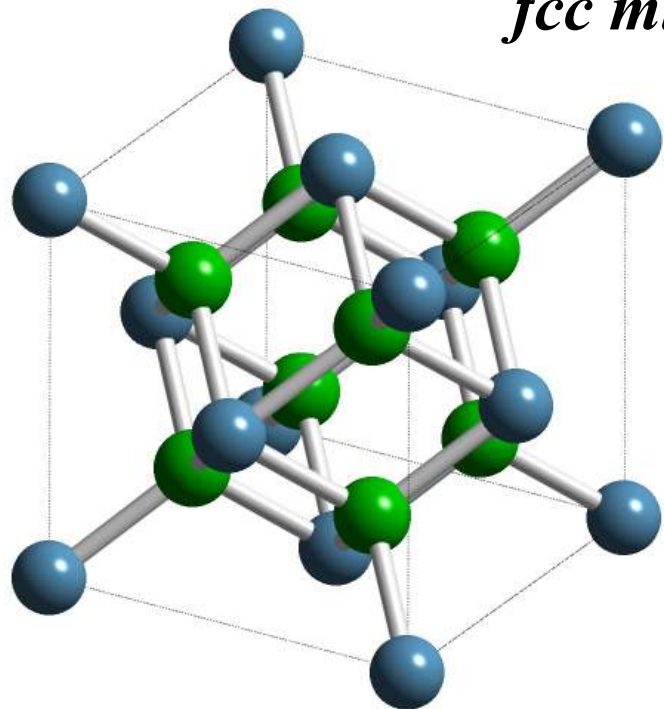


Kubisch *F*
fcc

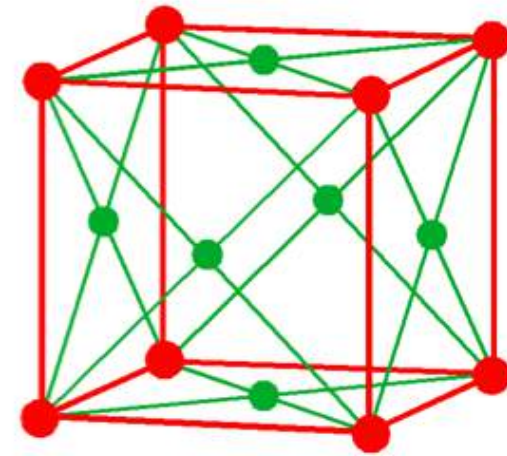
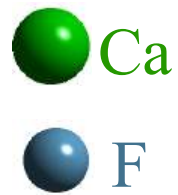


Zn	0 0 0
	0 1/2 1/2 & zyklisch
S	1/4 1/4 1/4
	1/4 3/4 1/4
	& zyklisch

Fluorit CaF_2



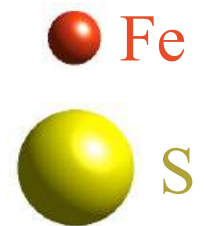
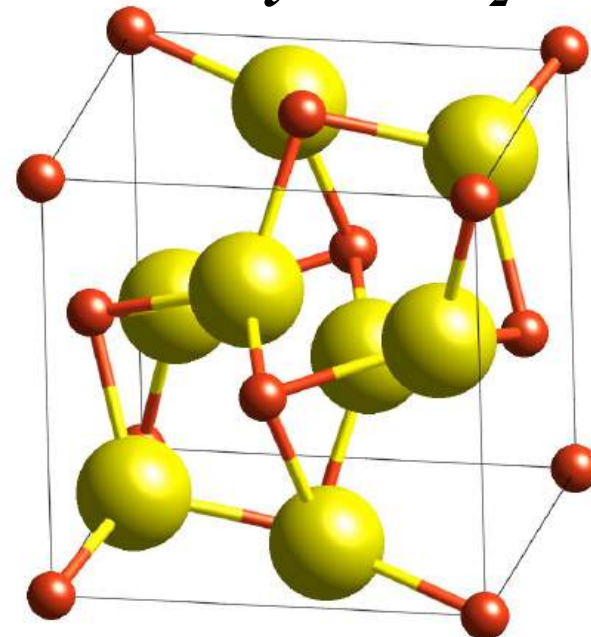
fcc mit 3-atomiger Basis

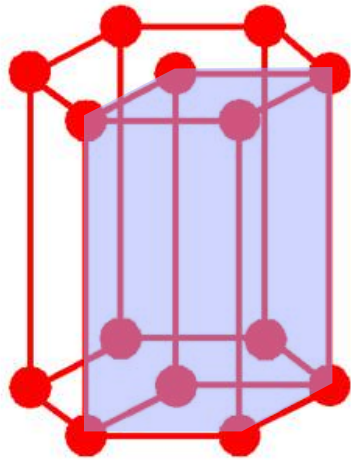


Kubisch F

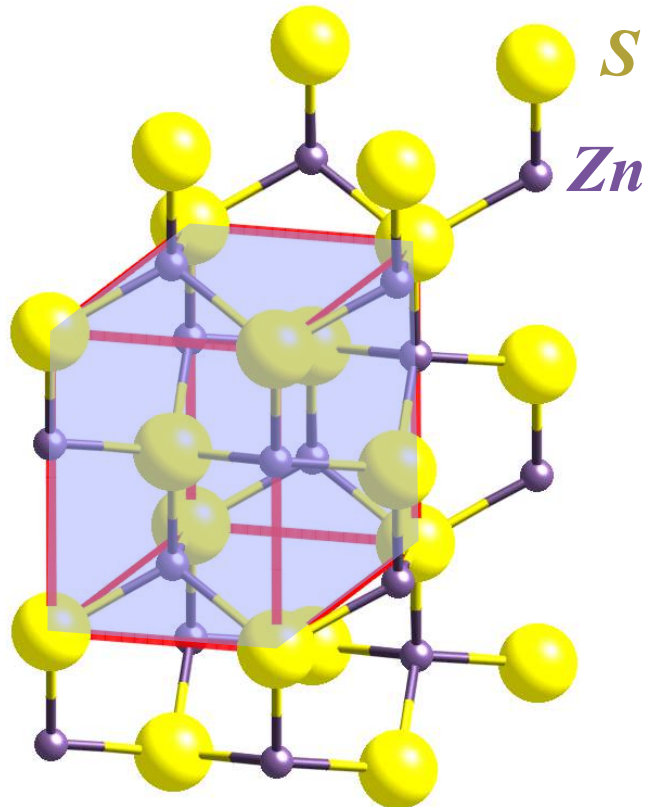
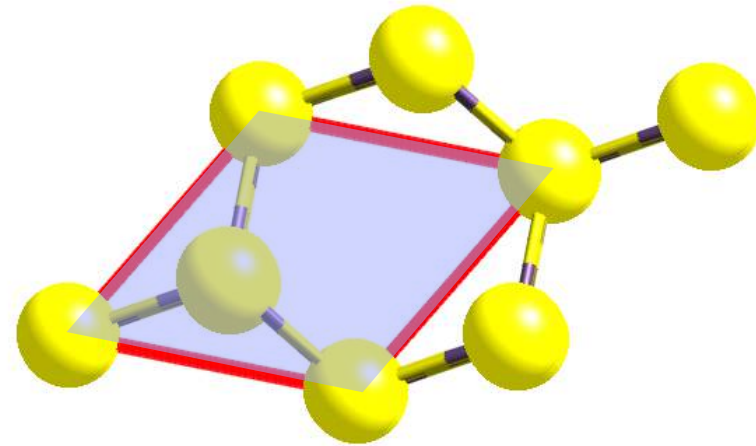
fcc

Pyrit FeS_2

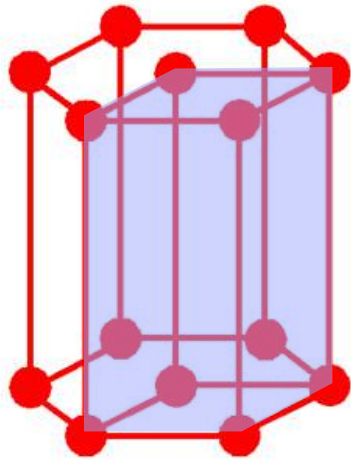




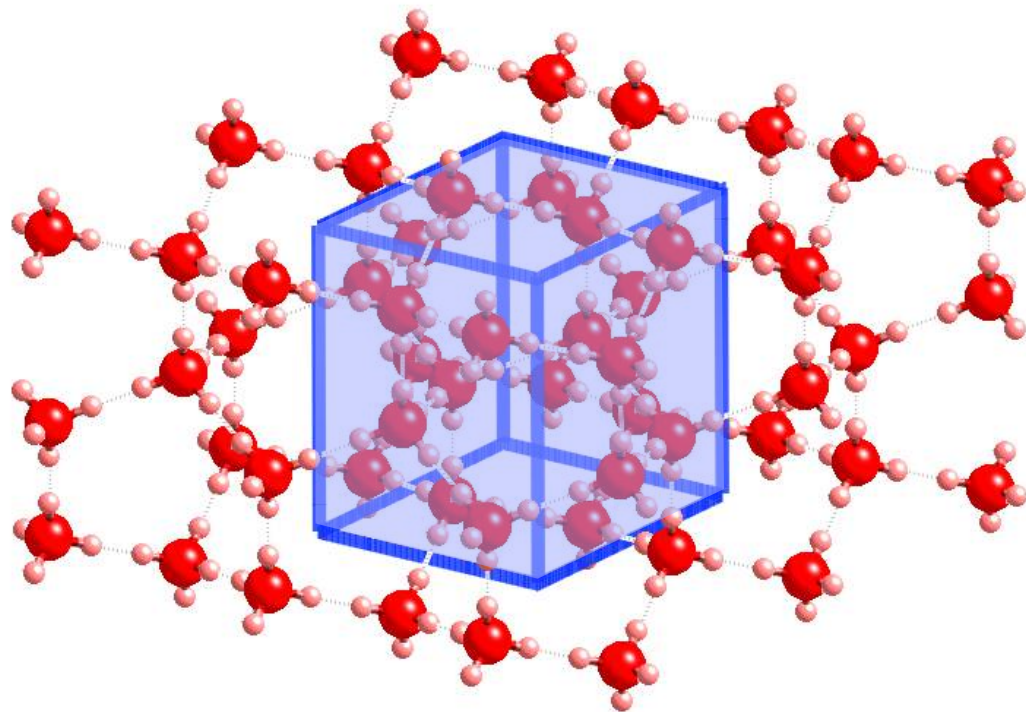
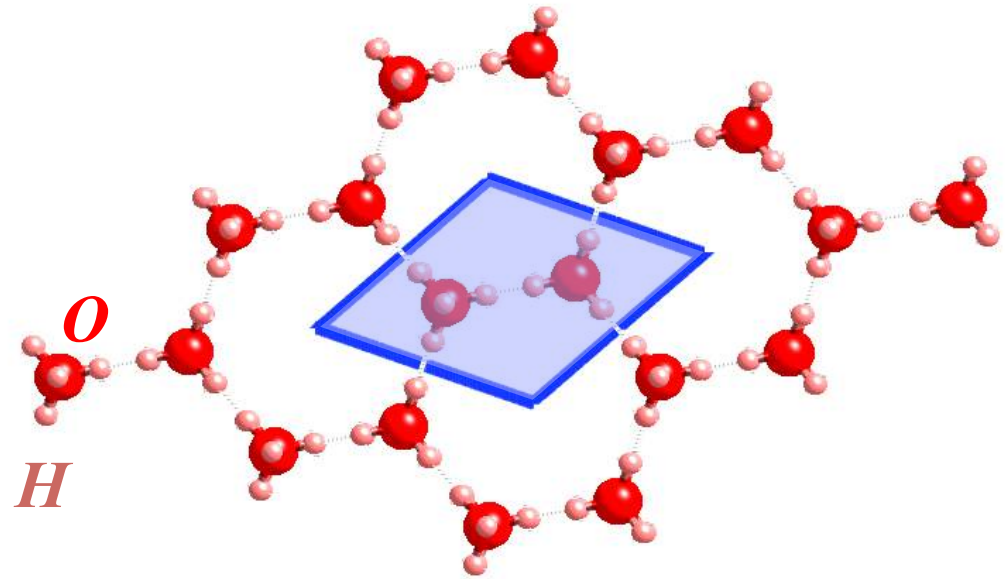
Hexagonal *P*



Wurtzit - hexagonales ZnS

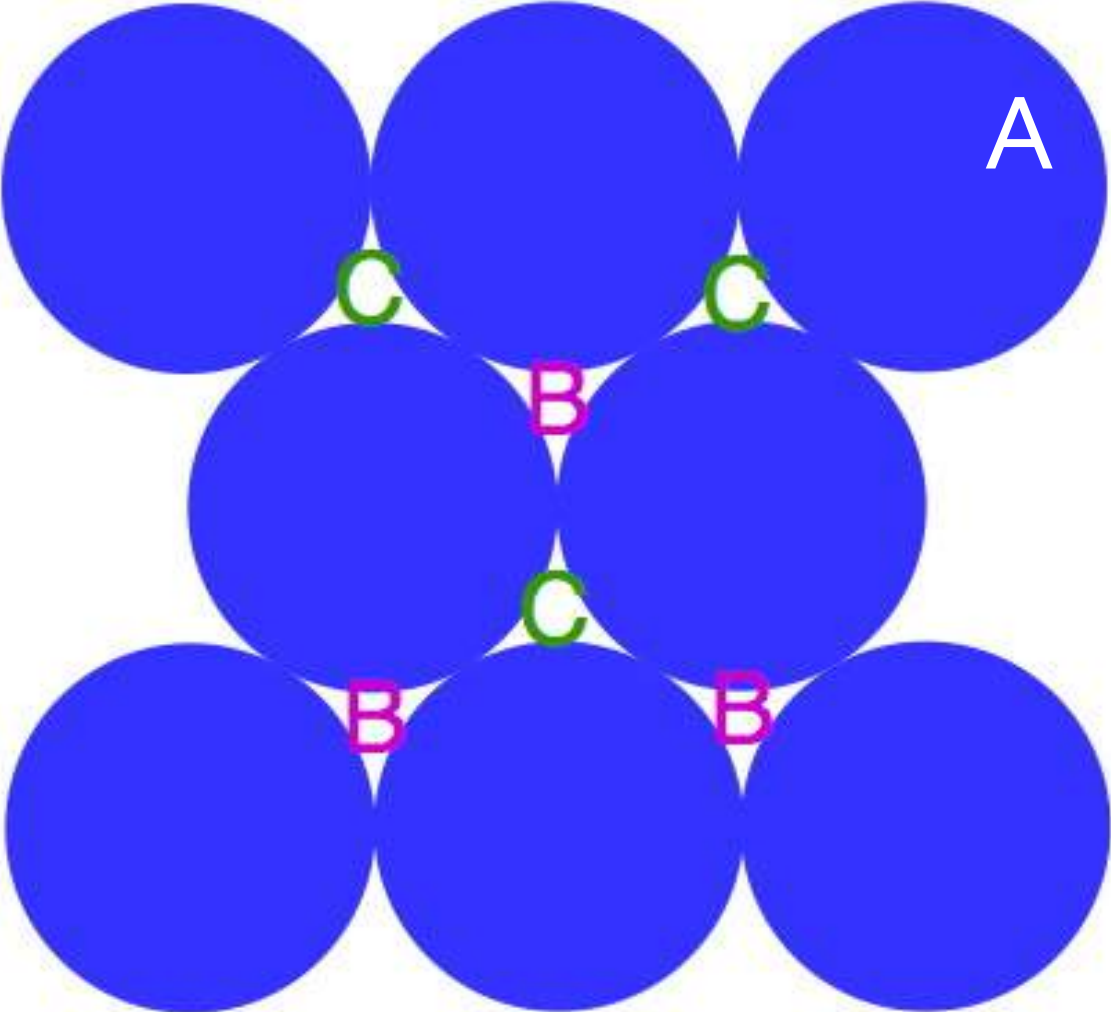


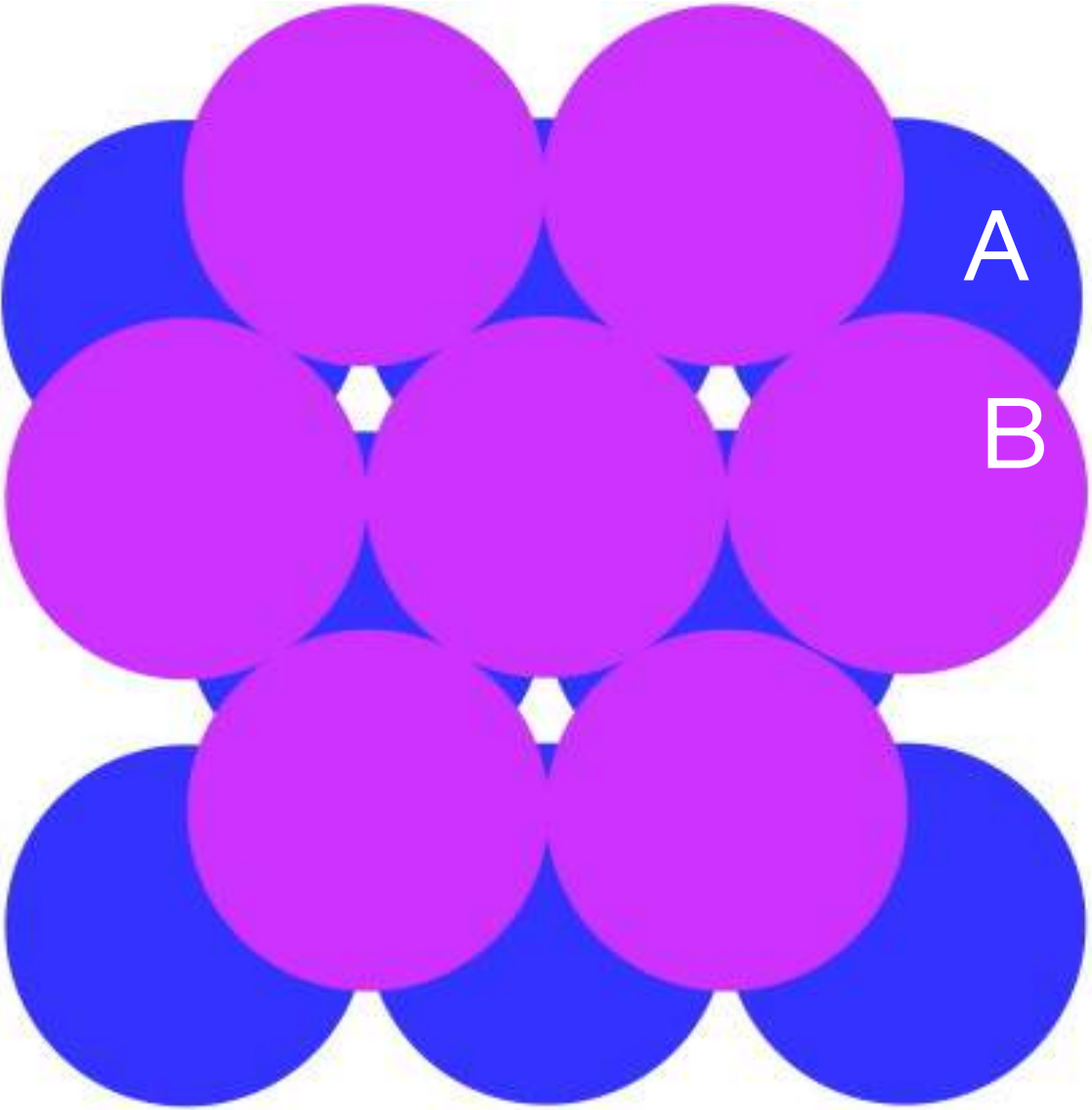
Hexagonal *P*

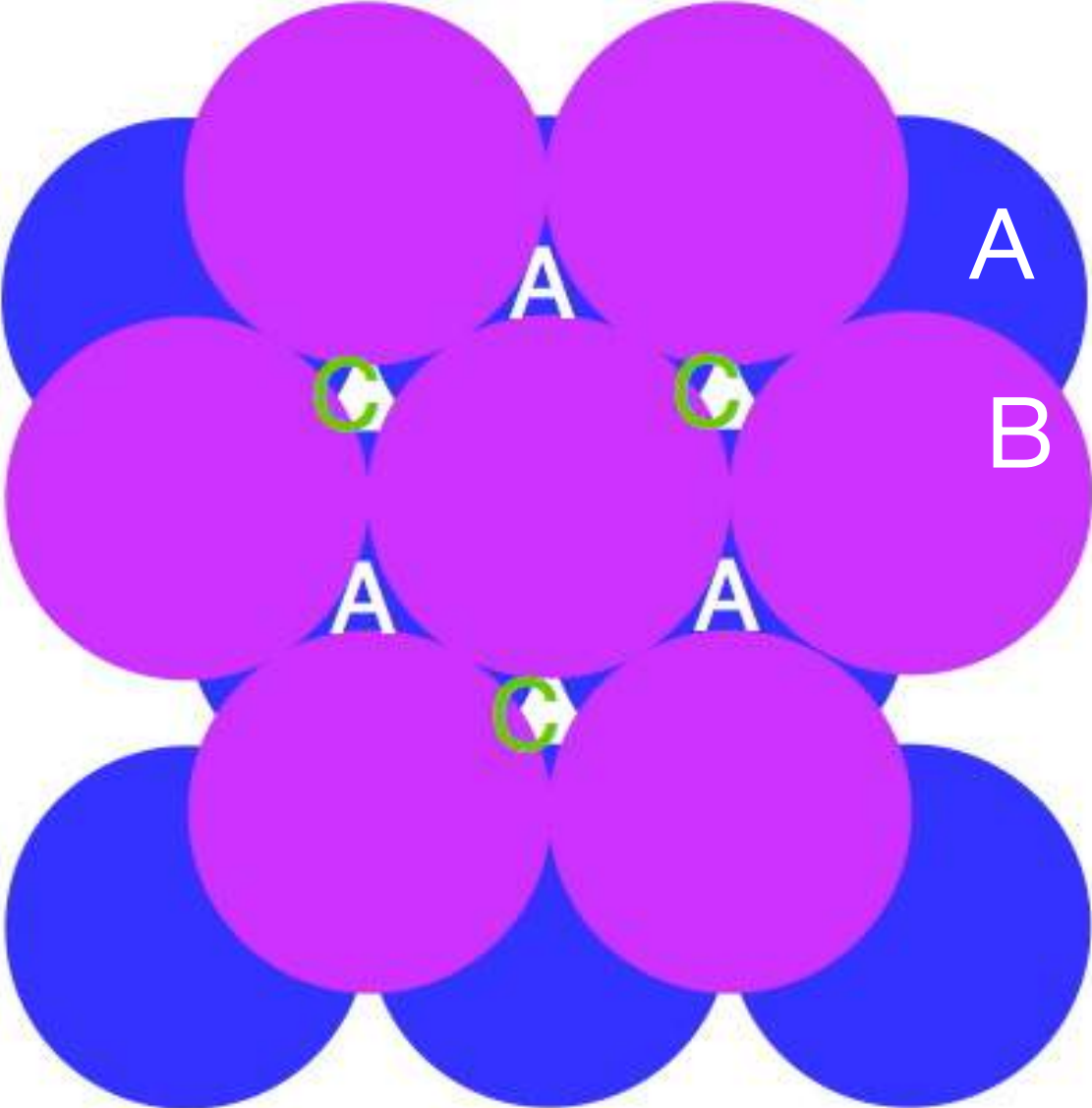


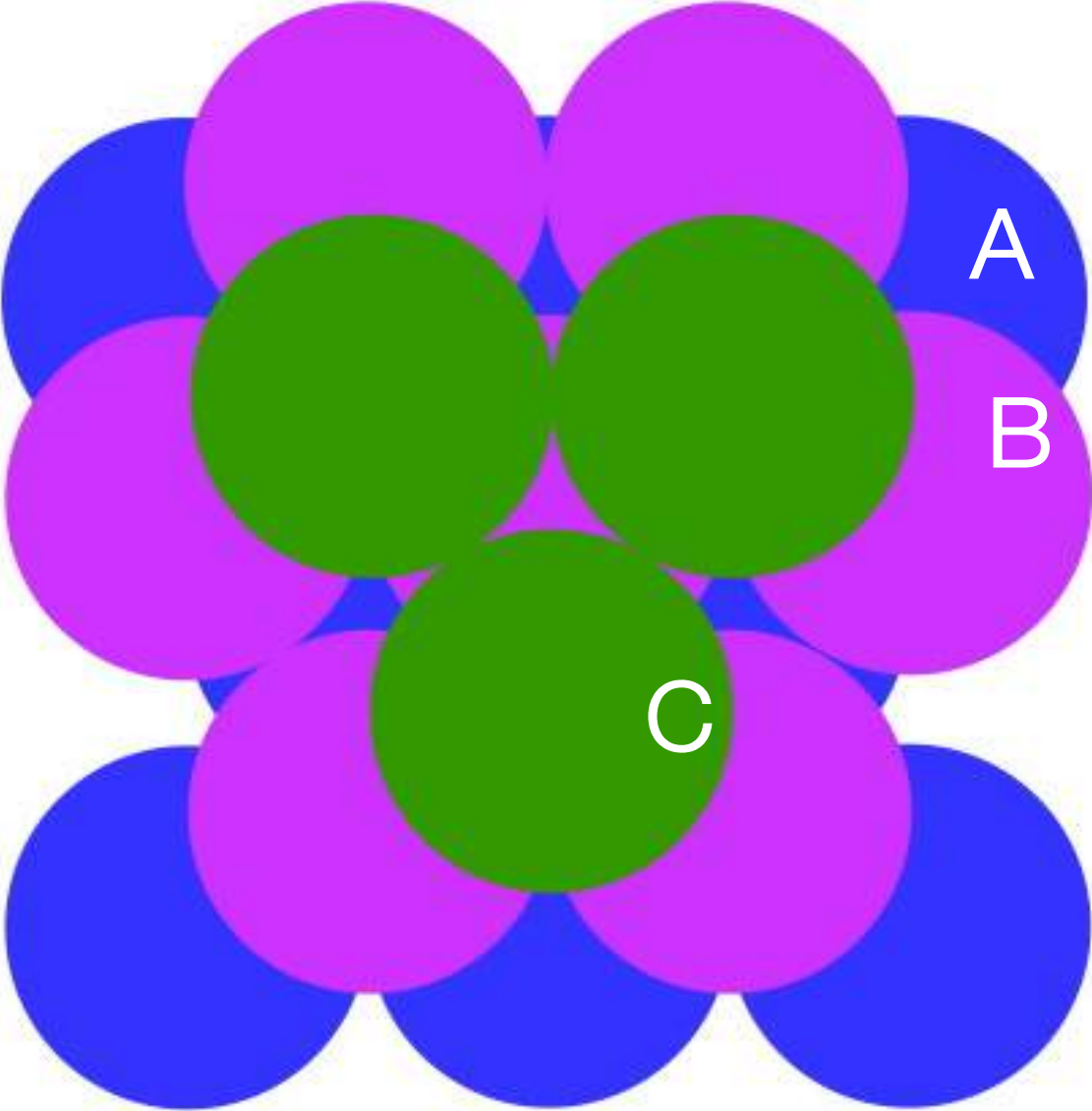
Eis - H₂O

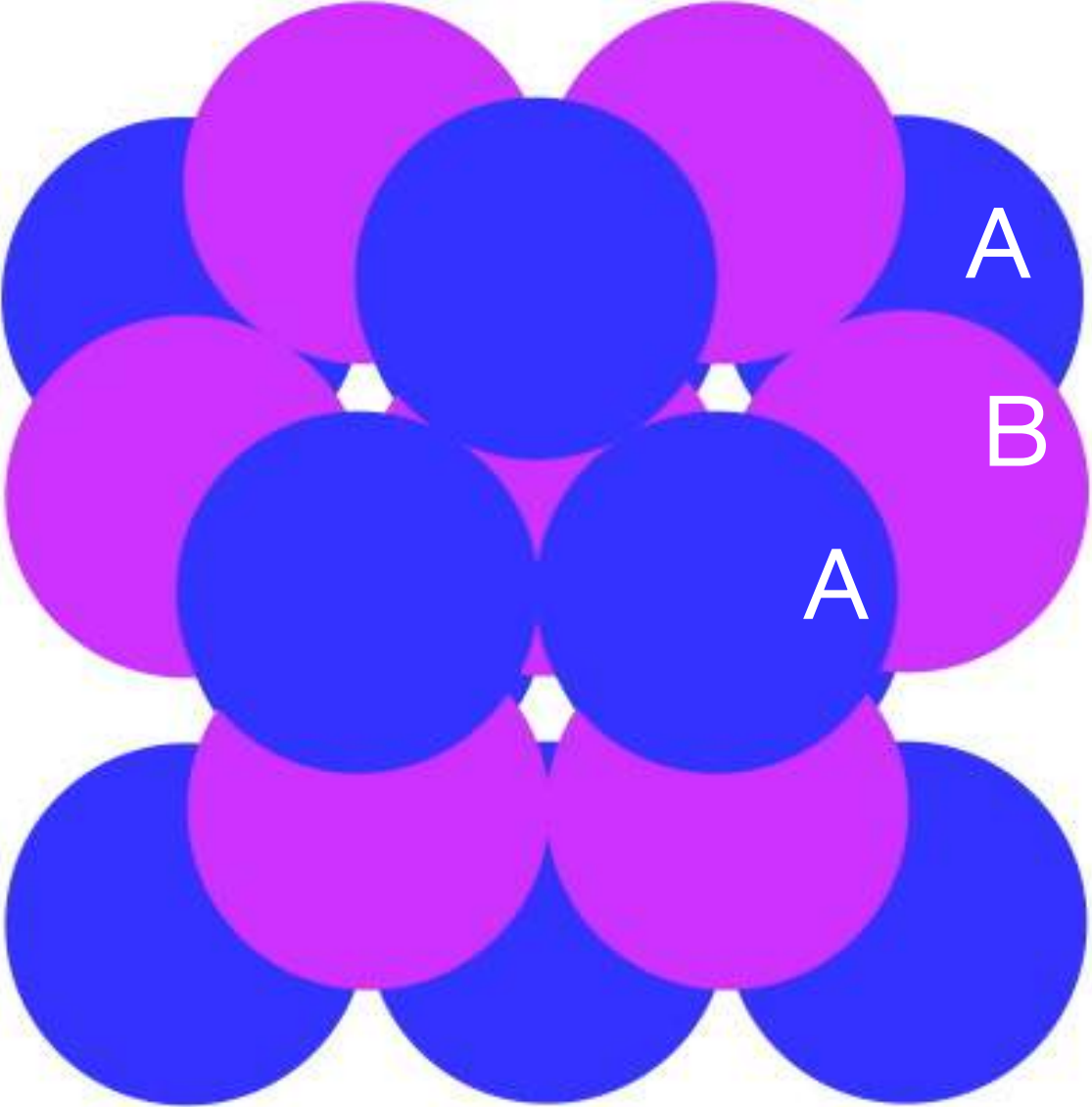
*(H-Atome ungeordnet über
zwei mögliche Plätze verteilt)*

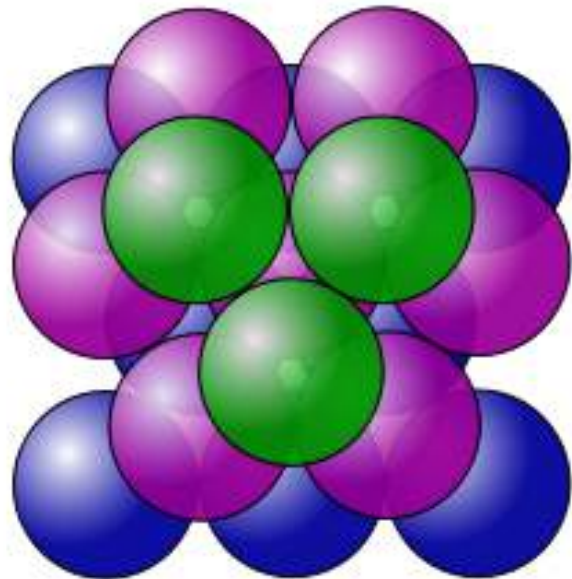
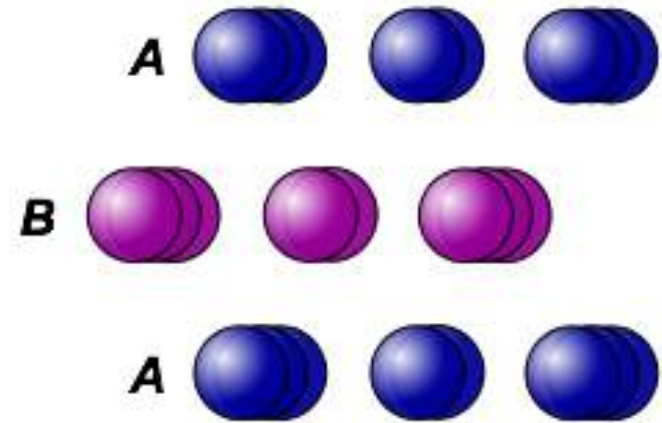
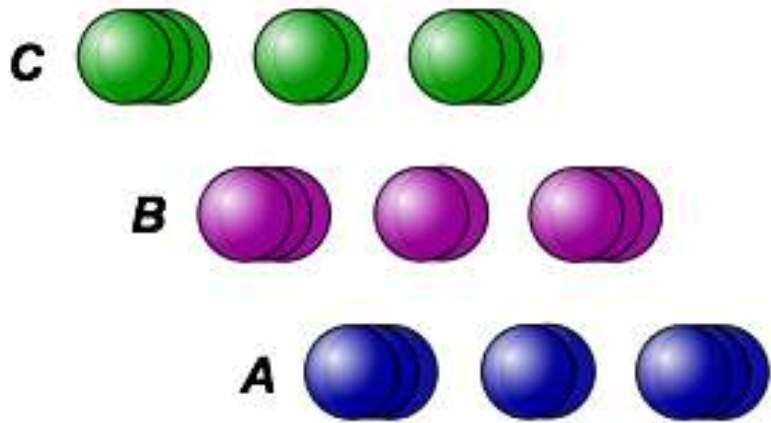




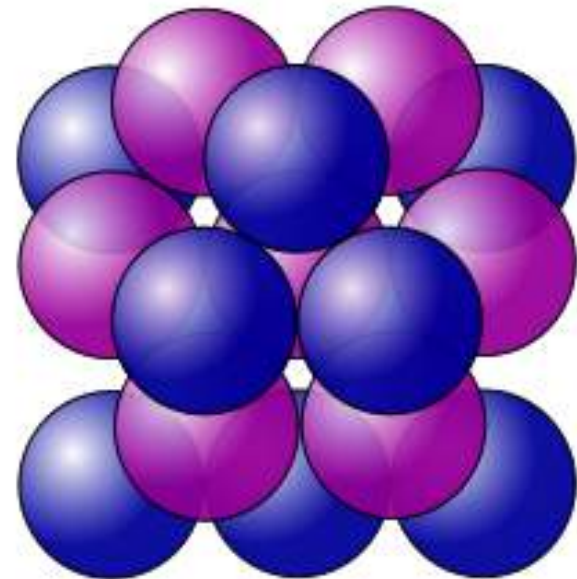






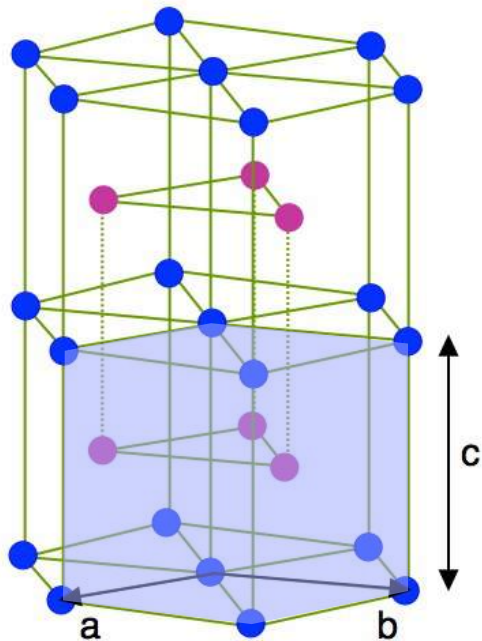


ABCABC



ABABAB

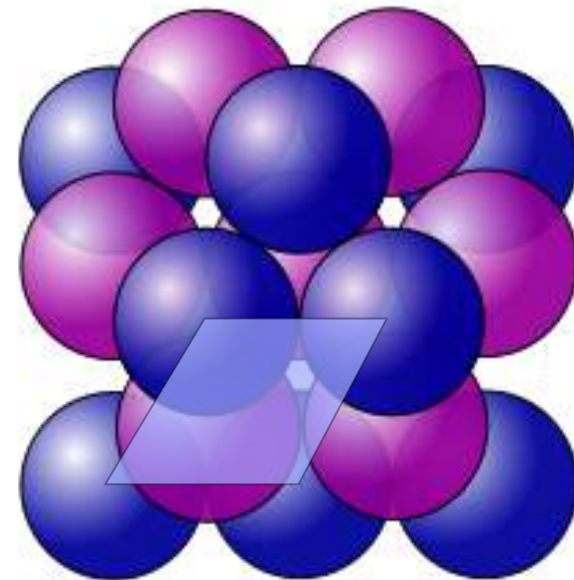
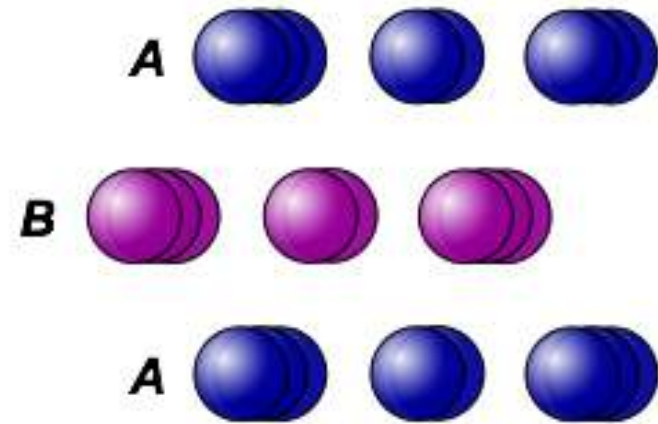
Hexagonal dichteste Kugelpackung (HCP)



0
1/3

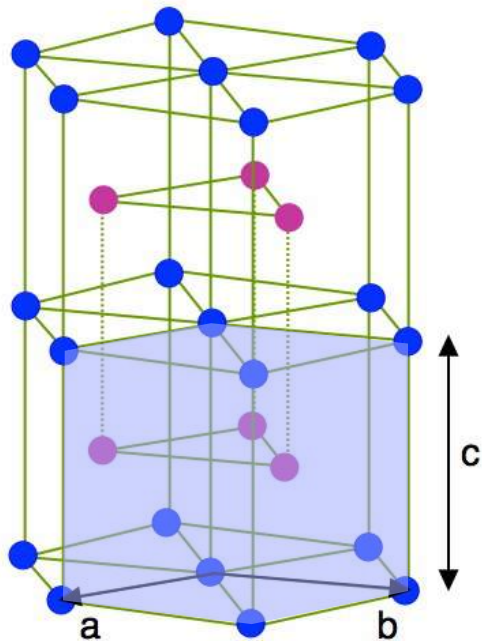
0
2/3

0
1/2



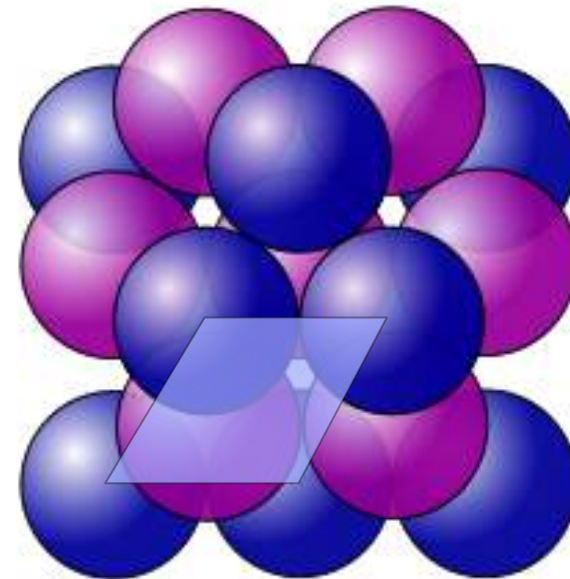
ABABAB

Hexagonal dichteste Kugelpackung (HCP)

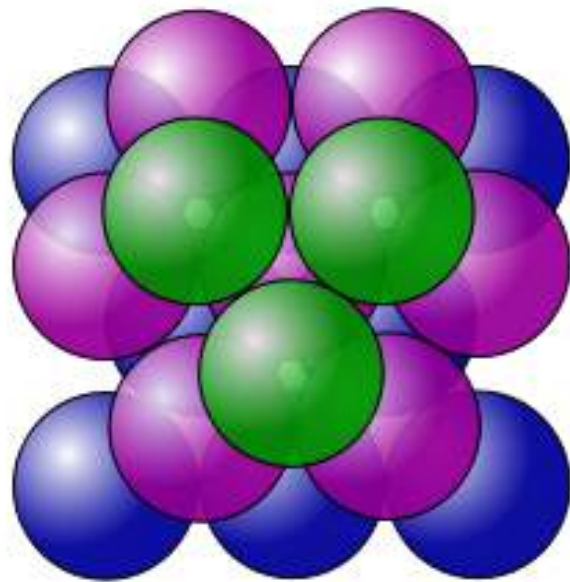
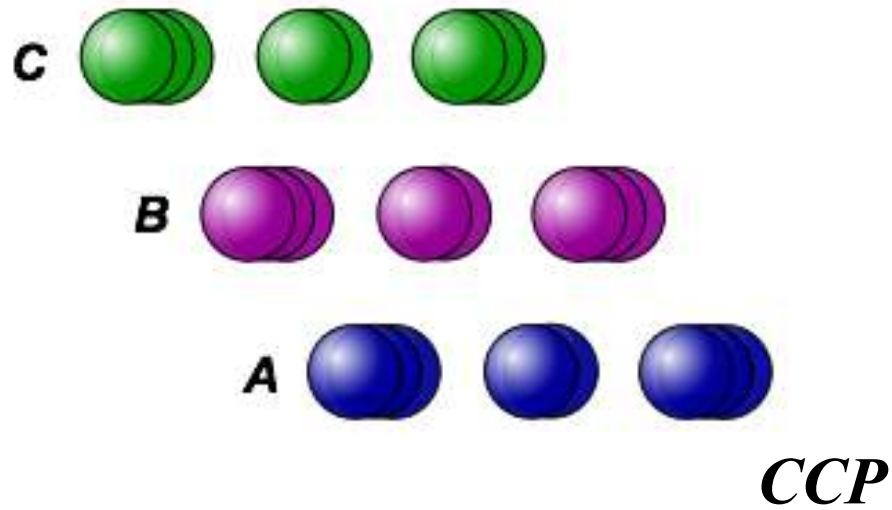


0 0 0
 $1/3$ $2/3$ $1/2$

Element	a (nm)	c (nm)	c/a
Be	0.229	0.358	1.56
Cd	0.298	0.562	1.89
Ce	0.365	0.596	1.63
α -CO	0.251	0.407	1.62
Gd	0.364	0.578	1.59
He (2K)	0.357	0.583	1.63
La	0.375	0.607	1.62
Mg	0.321	0.521	1.62
Pr	0.367	0.592	1.61
Zn	0.266	0.495	1.86
Zr	0.323	0.515	1.59

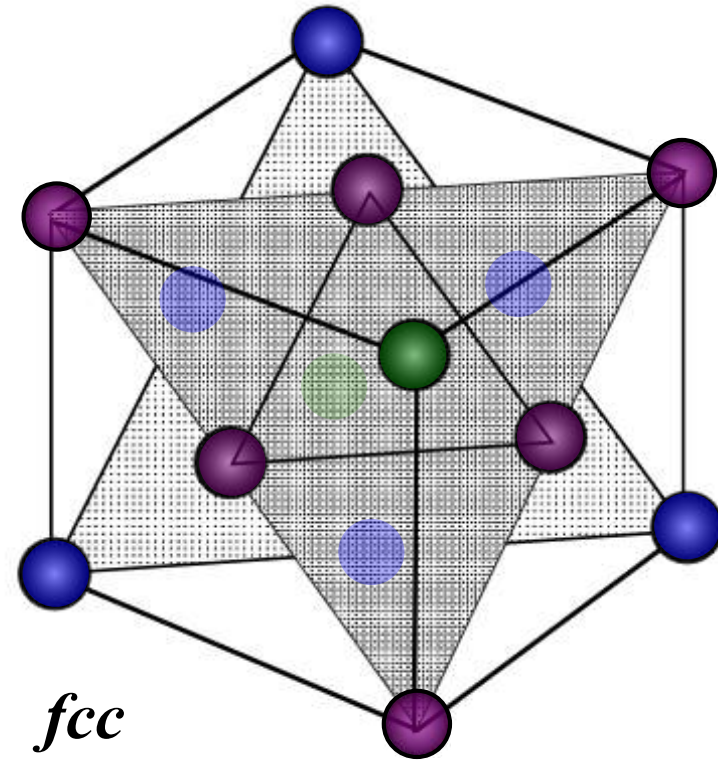


ABABAB



ABCABC

*Kubisch dichteste
Kugelpackung (CCP)*



0 0 0
1/2 0 1/2
& zyklisch