Condensed Matter Physics I

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Lectures and Working Class

Lectures & problem session on

Tuesday	10:00 : 11:30
Thursday	12:00 : 13:30

Problem sessions on Thursday alternating with lectures

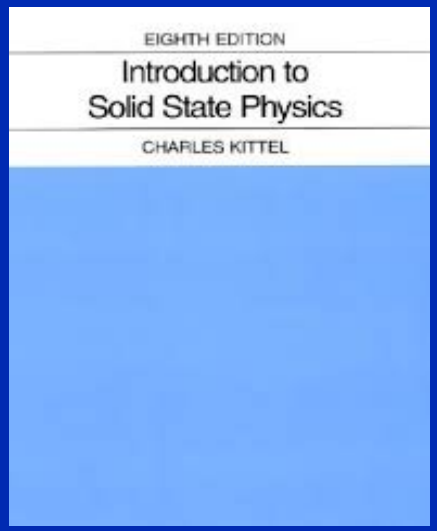
Problem session teacher:

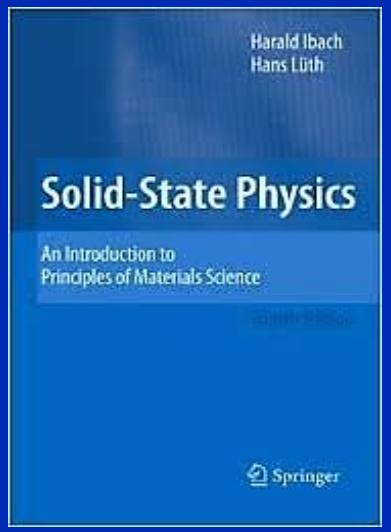
Dr. Matteo Montagnese, II P.I. room 318
m.montagnese@ph2.uni-koeln.de

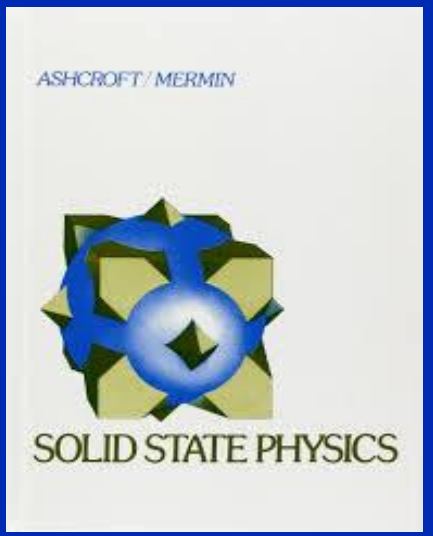
Hand in problem sets on Tuesday's (room 318).

Literature

Introduction to Solid State Physics, Charles Kittel
Solid State Physics, Ibach & Lüth
Solid State Physics, Ashcroft & Mermin







Quantum theory of solids, Kittel
Principles of condensed matter physics, Chaikin & Lubensky
Many, many more

States of matter

Plasma

Gas

Liquid

Liquid crystals

glasses

Amorphous solids

quasi crystals

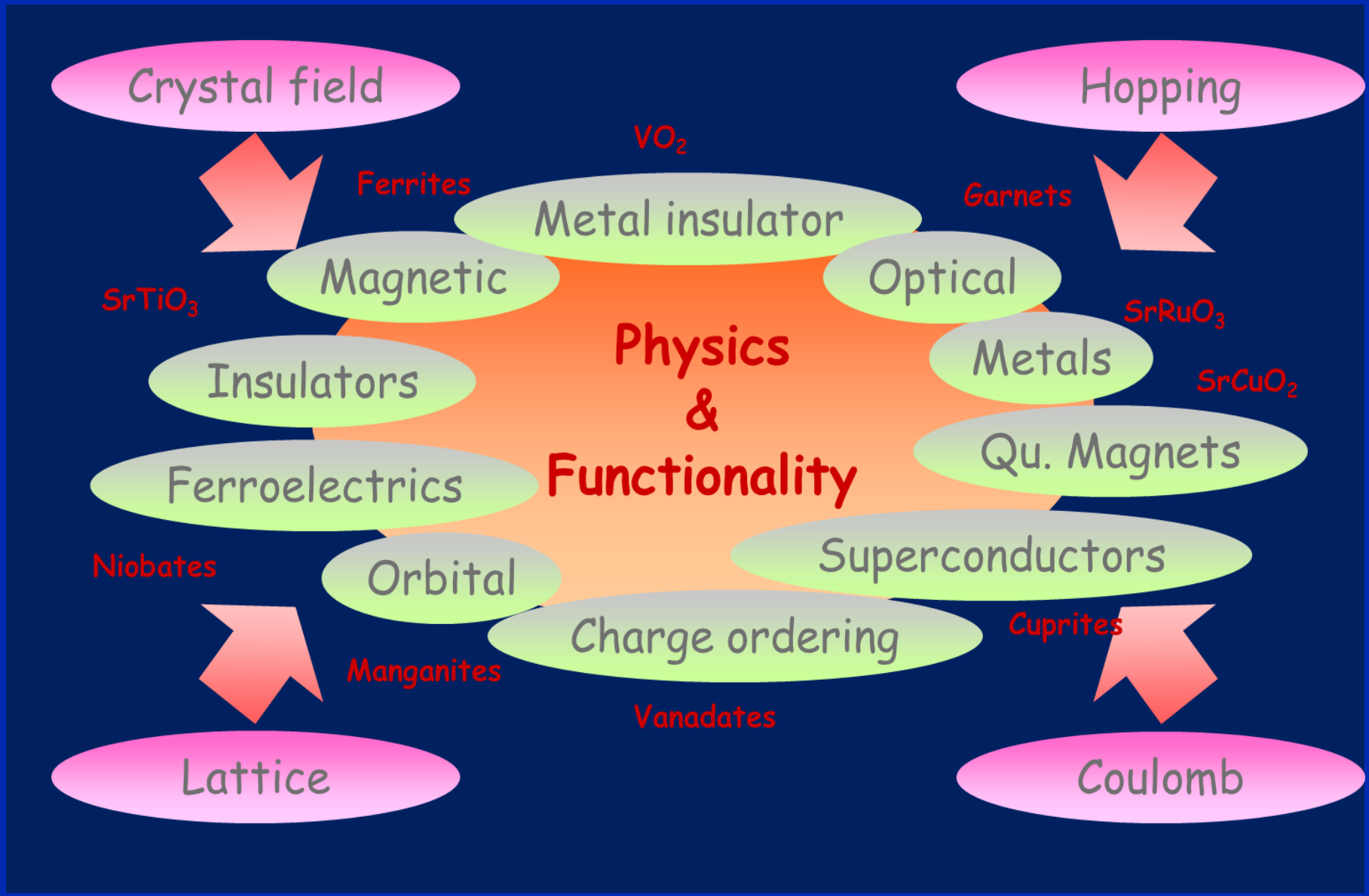
nearly periodic crystals

PERIODIC CRYSTALS

SOLIDS

- Structure and symmetry
- Binding
- Diffraction -> reciprocal space
- Vibrations & thermal properties, density of states
- Electrons, Fermi Gas, Energy bands, semiconductors
- Collective excitations (plasmons, excitons, etc.)
- Dielectrical properties
- Spins: magnetism & magnetic excitations

II. Physikalisches Institut

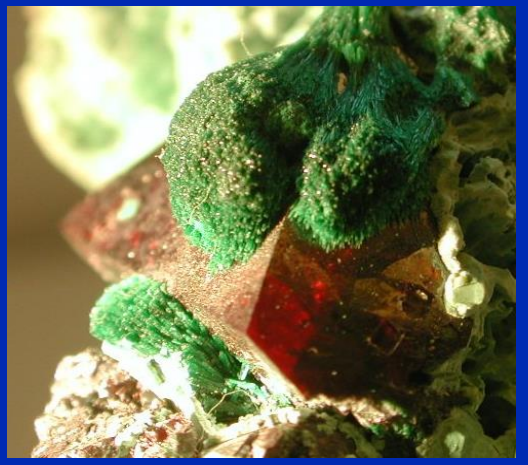


STRUCTURE

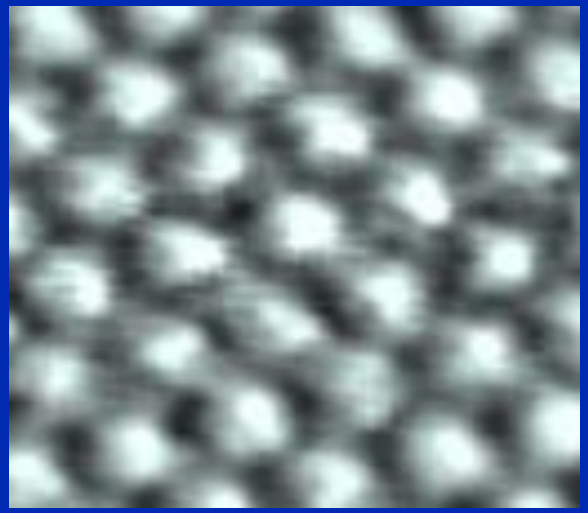
Kittel Ch.1

Quartz

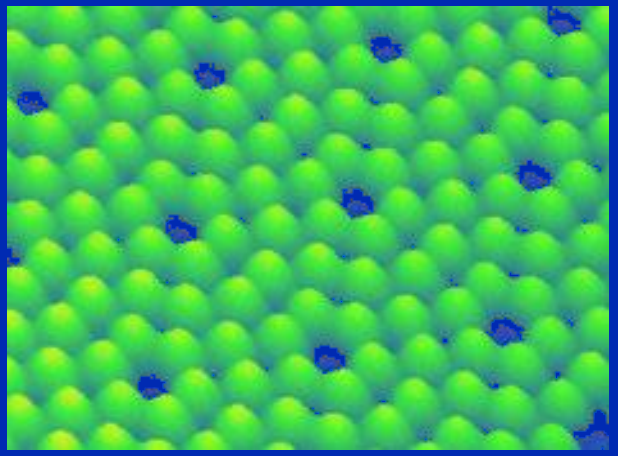
Protein



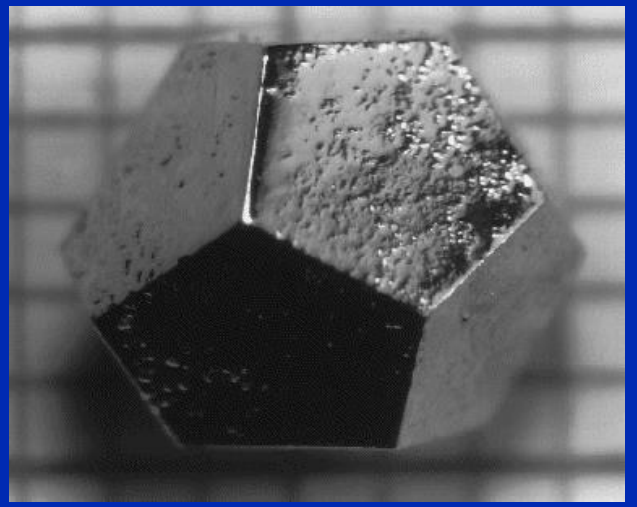
Cu_2O



Graphite



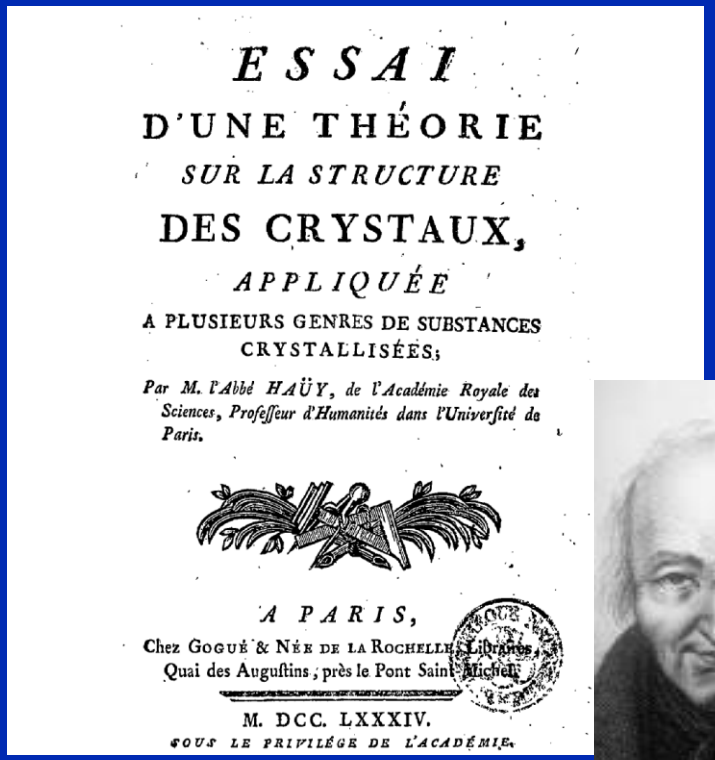
Silicon

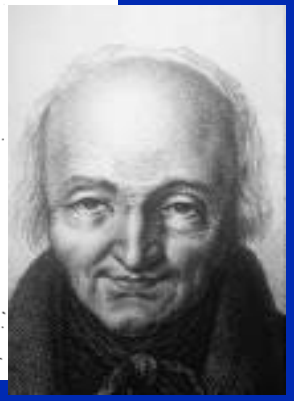


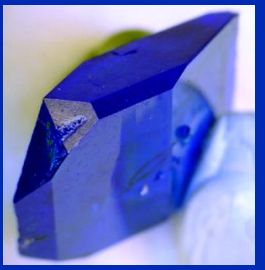
Quasi-crystal

Structure

460 BC Demokritus: idea that matter is made of ‘atoms’
1611 J. Keppler: Snow Xtals made of spherical water molecules
1784 R.J. Haüy: Law of integral indices
1802 J. Dalton: atomic theory


ESSAI
D'UNE THÉORIE
SUR LA STRUCTURE
DES CRYSTAUX,
APPLIQUÉE
A PLUSIEURS GENRES DE SUBSTANCES CRYSTALLISÉES;
Par M. l'Abbé HAÜY, de l'Académie Royale des Sciences, Professeur d'Humanités dans l'Université de Paris.
A PARIS,
Chez Gogué & Née de la Rochelle, Libraires, Quai des Augustins, près le Pont Saint-Michel.
M. DCC. LXXXIV.
AVEC APPROBATION ET PRIVILÉGE DE L'ACADÉMIE.





Structure

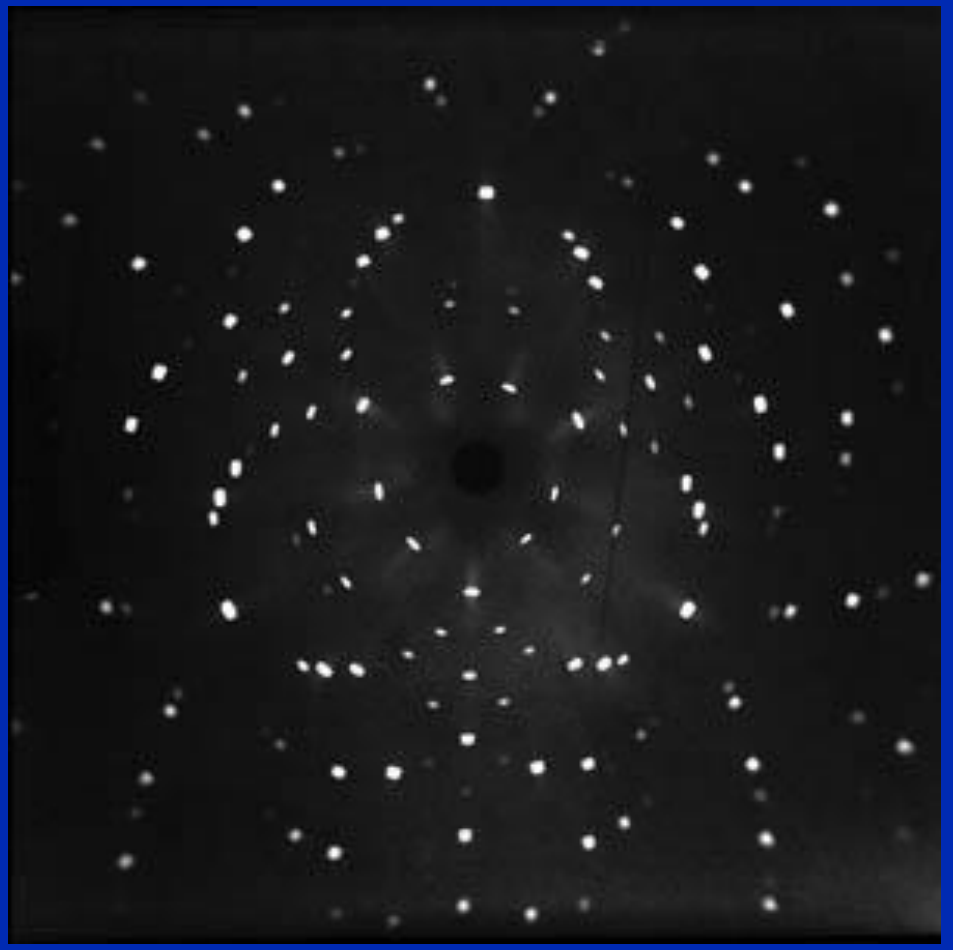
1784 R.J. Haüy: Law of integral indices

1850 A. Bravais: Space lattices

1895 W. Röntgen: X-rays (1st Nobel prize 1901,
Work on cathode rays: Lenard 1905)

1912 M. van Laue: Diffraction (Nobel prize 1914)

Beugungsexperimente

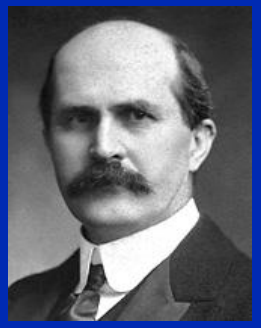


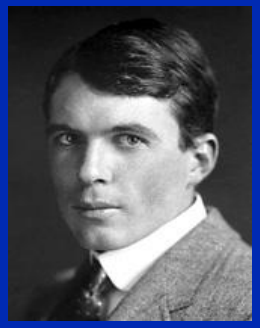
Si (FCC) 111 axis

Using hard X-rays (λ ~ a ~ 10 Å)

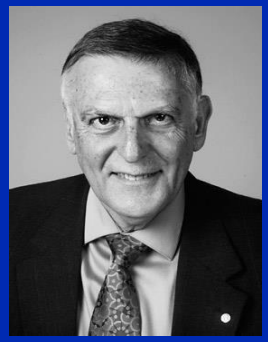
Structure

1913/14 W.&L. Bragg: Diffraction (Nobel prize 1915)





1984 D. Shechtman: Quasicrystals (Chem. Nobel prize 2011)



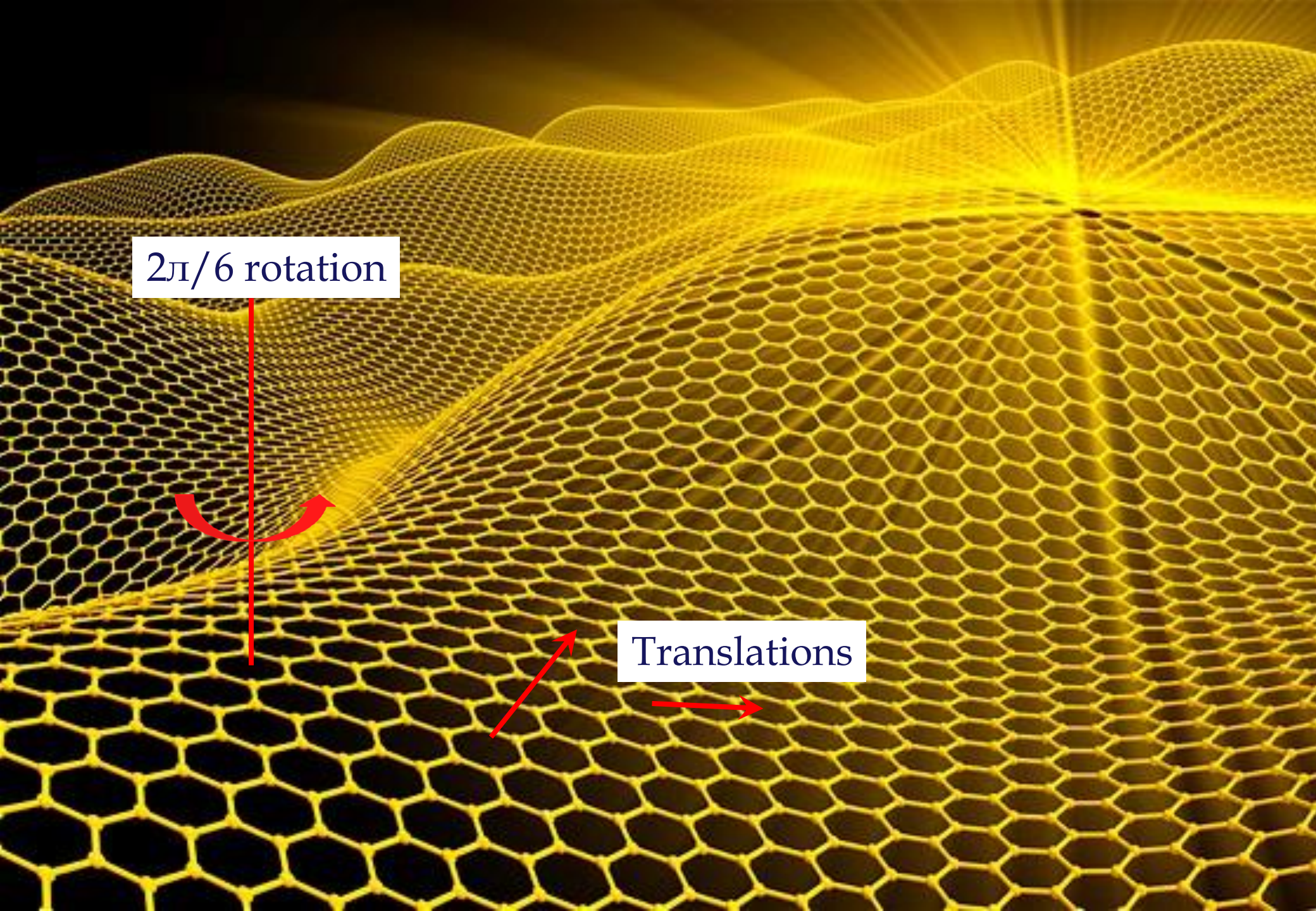
Symmetry

Translation symmetry:

vectors representing translations which transform a structure into itself

Rotation symmetry:

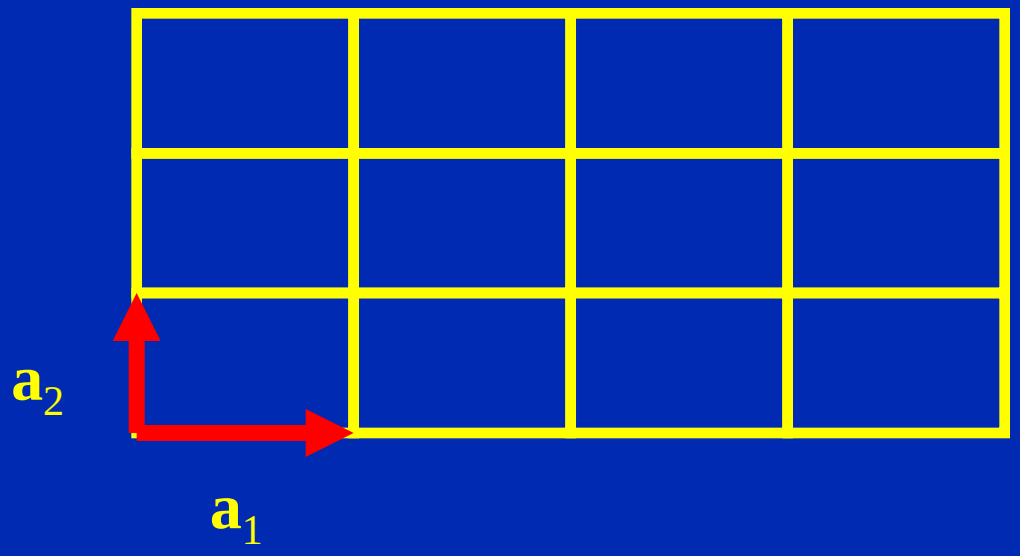
Operations (rotations, mirrors) which transform a structure into itself

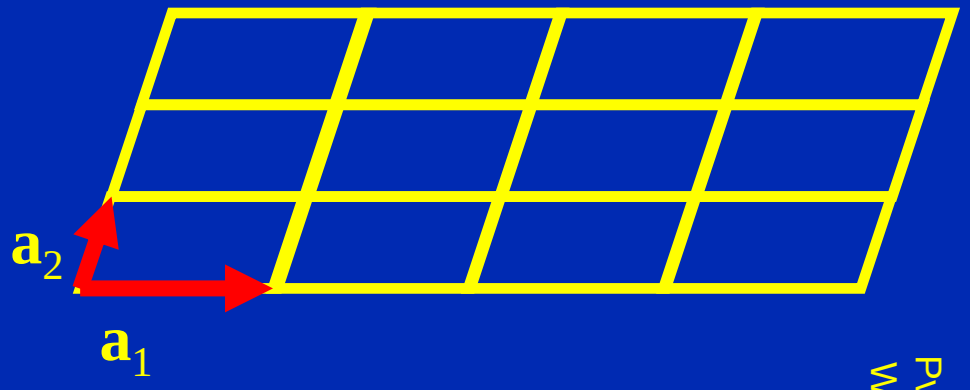

2л/6 rotation
Translations

Lattice

Periodic Arrays of points
or
Lattice = set of fundamental translation vectors:

$$\mathbf{T} = u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3$$

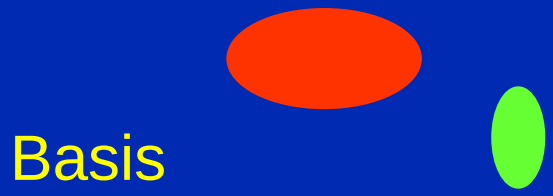




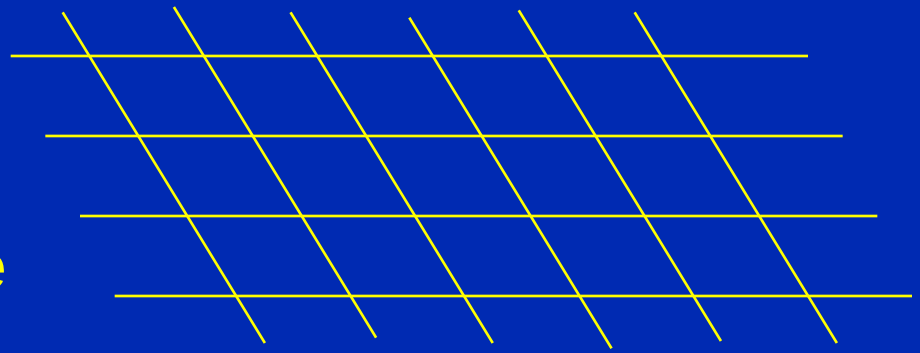
Crystal structure

Lattice + Basis = Crystal structure

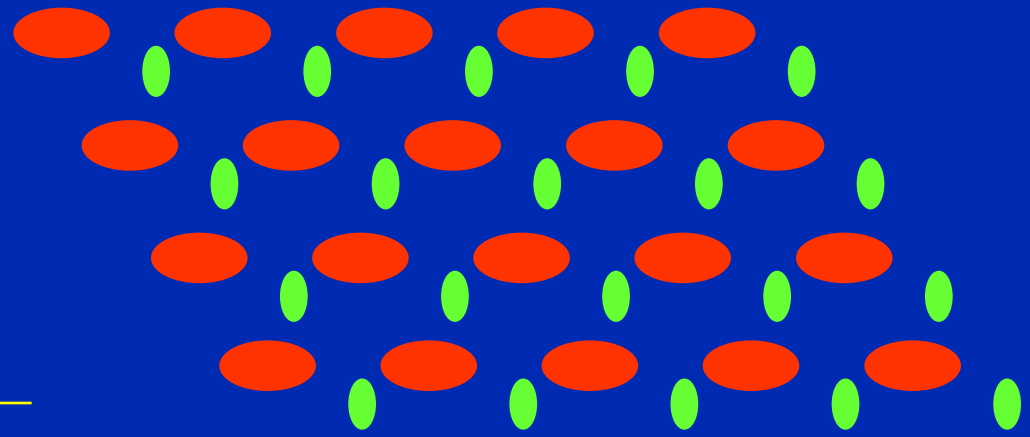
Basis = group of atoms forming the unit cell:



Basis



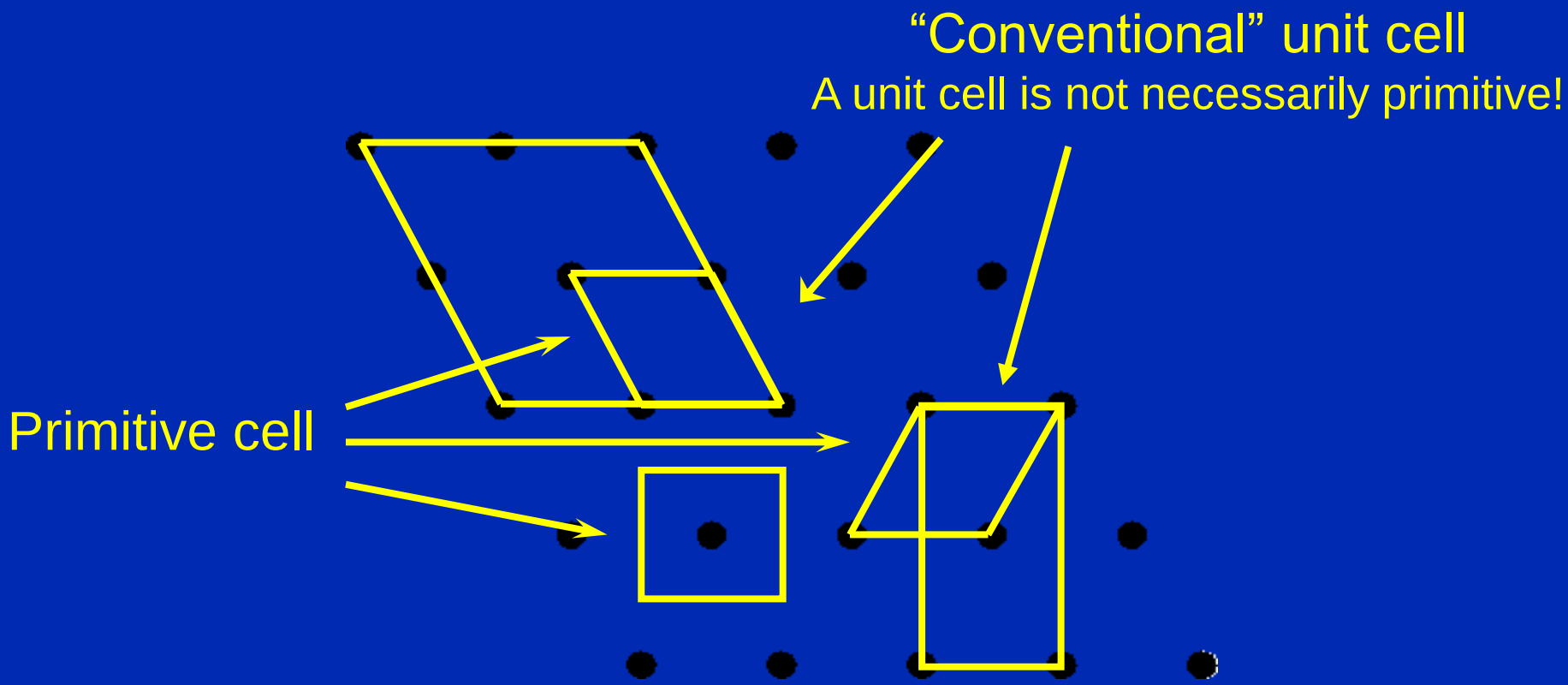
Lattice



Crystal Structure

Primitive cell

Minimal volume unit cell



Primitive cell

Minimal volume unit cell

Primitive Translation vectors: $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$

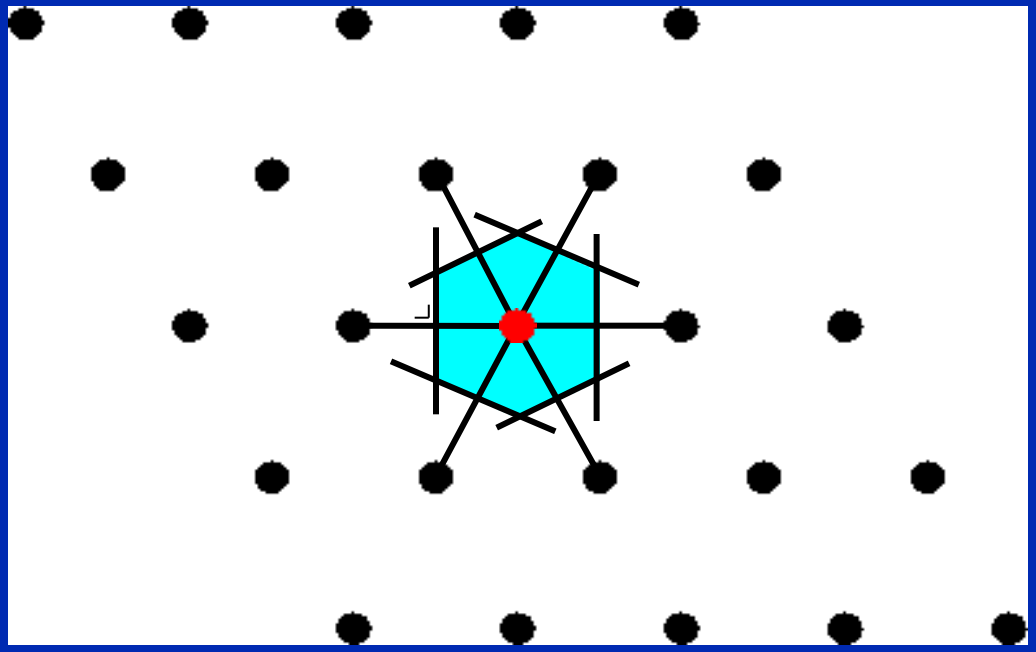
Primitive Lattice Cell = parallelepiped of $\mathbf{a}_1$, $\mathbf{a}_2$, $\mathbf{a}_3$

Many equivalent options to choose from,

Volume of Primitive Lattice cell: $V = \mathbf{a}_1 \cdot (\mathbf{a}_2 \times \mathbf{a}_3)$

Wigner-Seitz Cell: Most symmetric choice of Primitive Cell

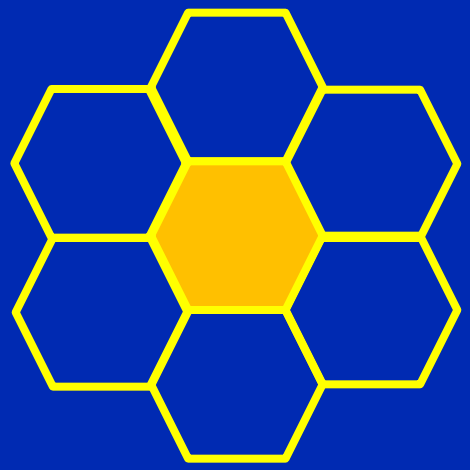
Wigner-Seitz cell



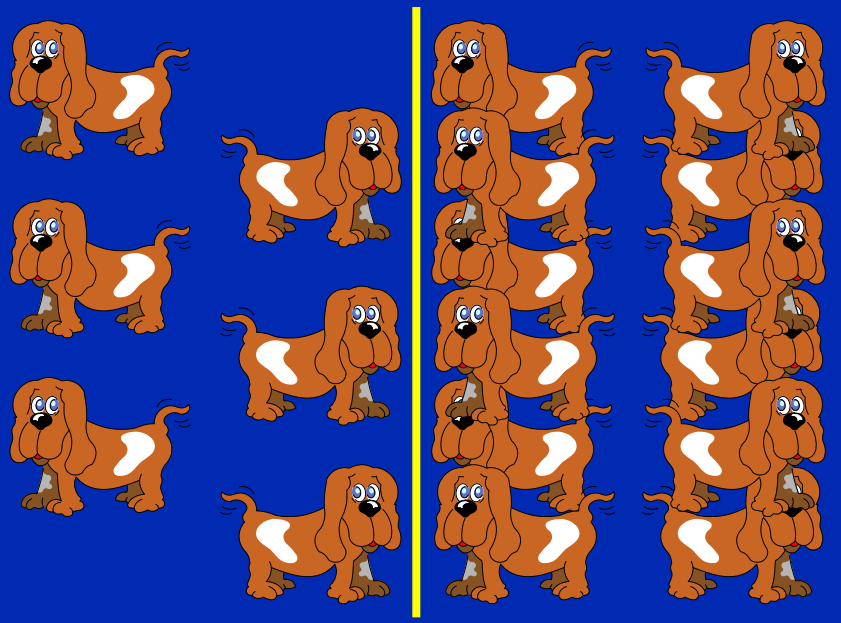
Symmetry elements

Translations: $\mathbf{T} = u_1\mathbf{a}_1 + u_2\mathbf{a}_2 + u_3\mathbf{a}_3$
Point group operations: Rotations and Mirrors
Combinations: Glide planes and Screw axes

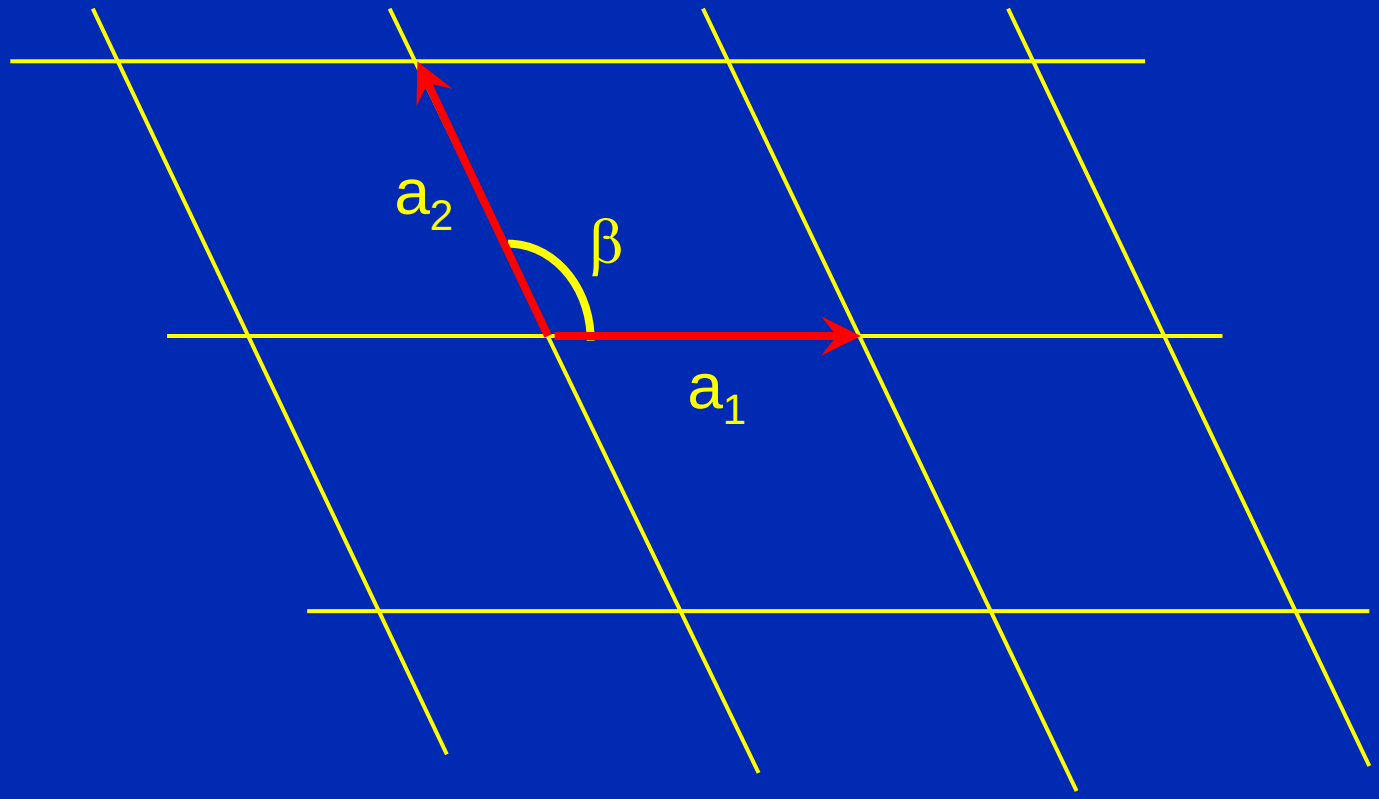
6 fold rotation



Glide plane

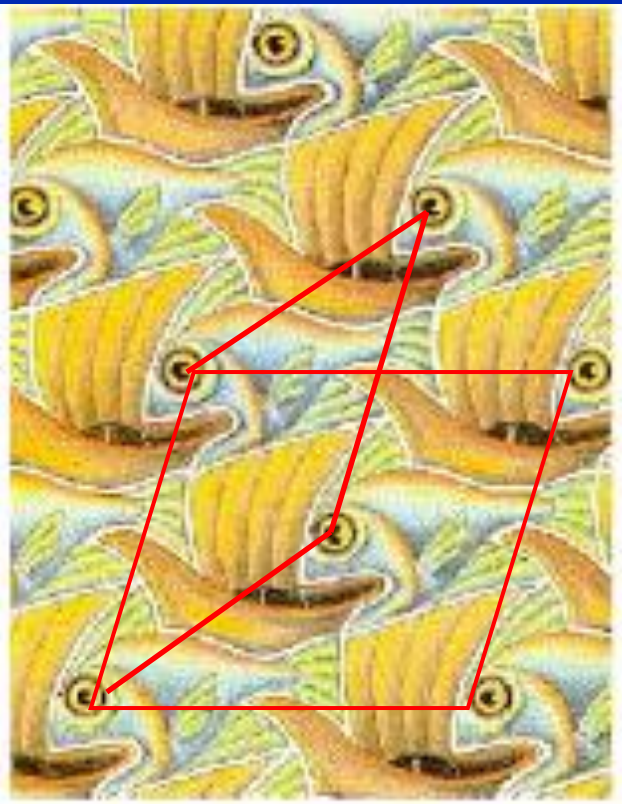


Two dimensional lattices (Net)



Ratio $|a_1/a_2|$
Angle β

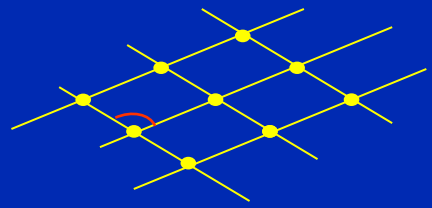
Two dimensional lattices (Net)



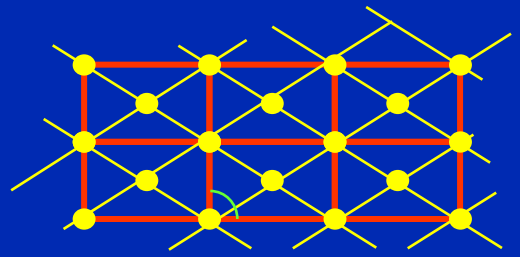
(M. C. Escher)

2D lattice types

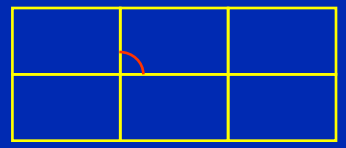
1-fold: Oblique $a_1 \neq a_2$; β



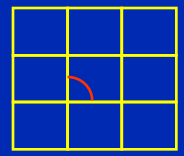
1-fold + mirror:
Centered rectangular $a_1 \neq a_2$; $\alpha = 90^o$



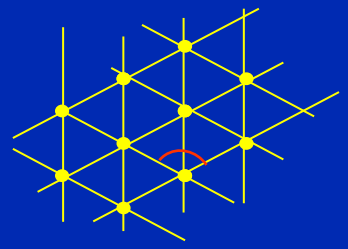
2-fold: Rectangular $a_1 \neq a_2$; $\beta = 90^o$



4-fold: Square $a_1 = a_2$; $\beta = 90^o$



6-fold: Hexagonal $a_1 = a_2$; $\beta = 120^o$



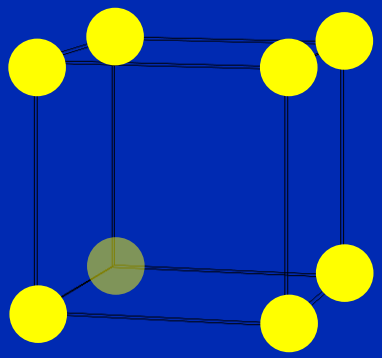
3D lattice types

The 3D lattice types (14)

Triclinic	1	No symmetries
Monoclinic	2	Two right angles
Orthorhombic	4	Three right angles
Tetragonal	2	Three right angles + 4 fold
Cubic (SC, FCC, BCC)	3	Three right angles + 4 fold + 3 fold
Trigonal	1	Three equal angles (not $90^{o)}$+ 3 fold
Hexagonal	1	Two right, one 120^{o} + 6 fold

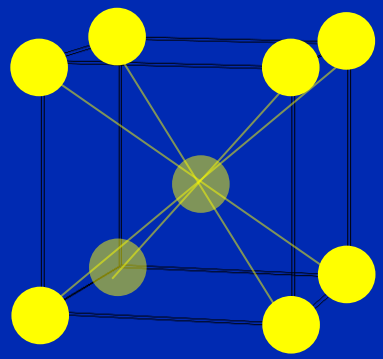
Cubic lattices

Simple cubic
SC



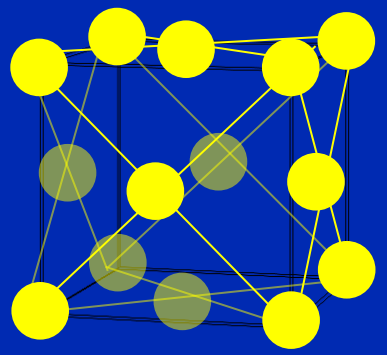
Po

Body centered
BCC



Na, K, Rb, Cs,
Fe, V, Cr, Mo, W

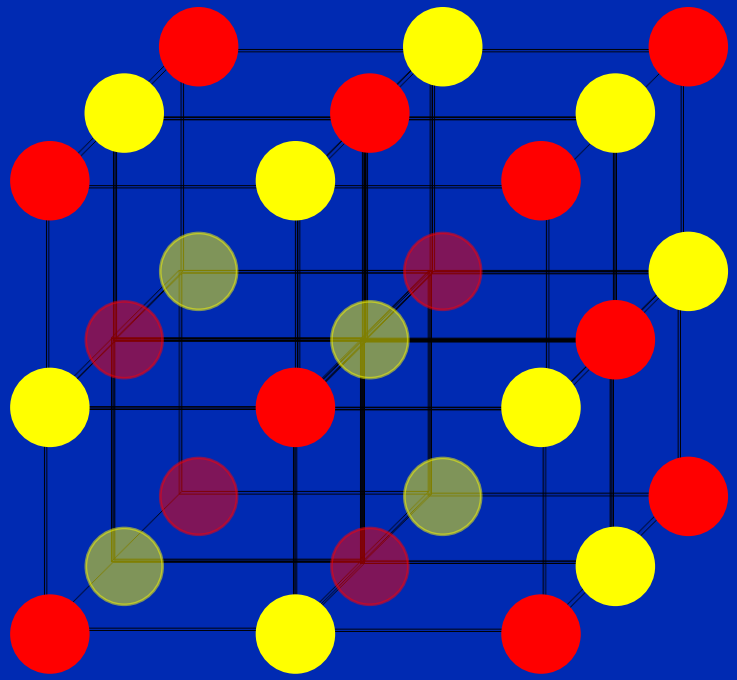
Face centered
FCC



Ni, Cu, Ag, Au, Pt,
Ne, Ar, Kr, Xe, Rn

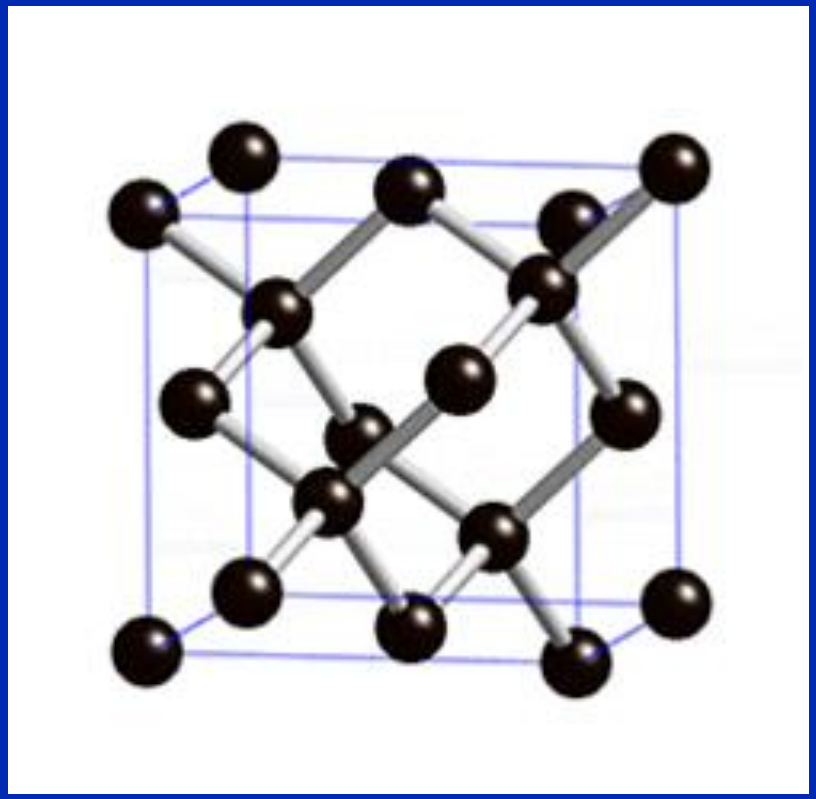
NaCl Structure

Rocksalt structure



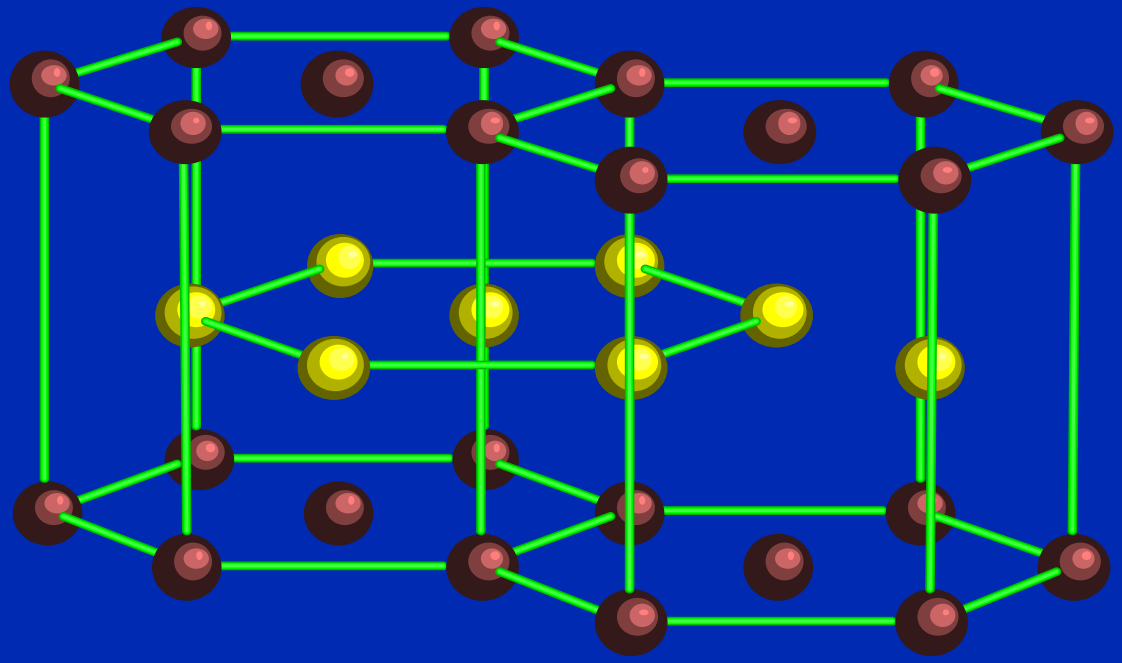
NaCl
SnTe
NaF
MgO

Diamond structure



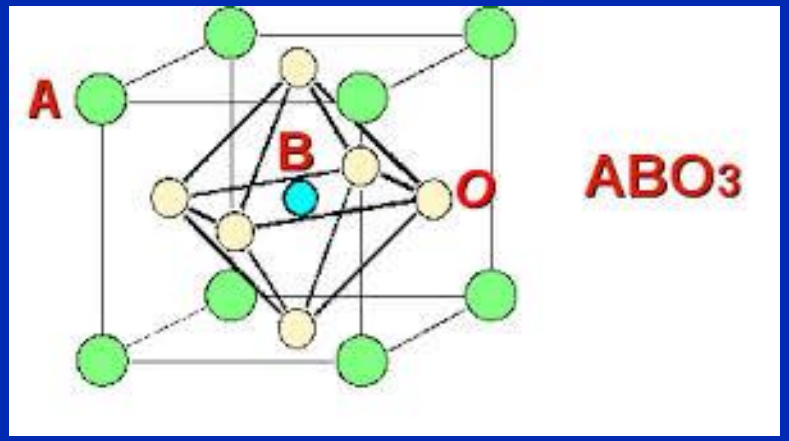
C,Si,Ge

Hexagonal closed packed

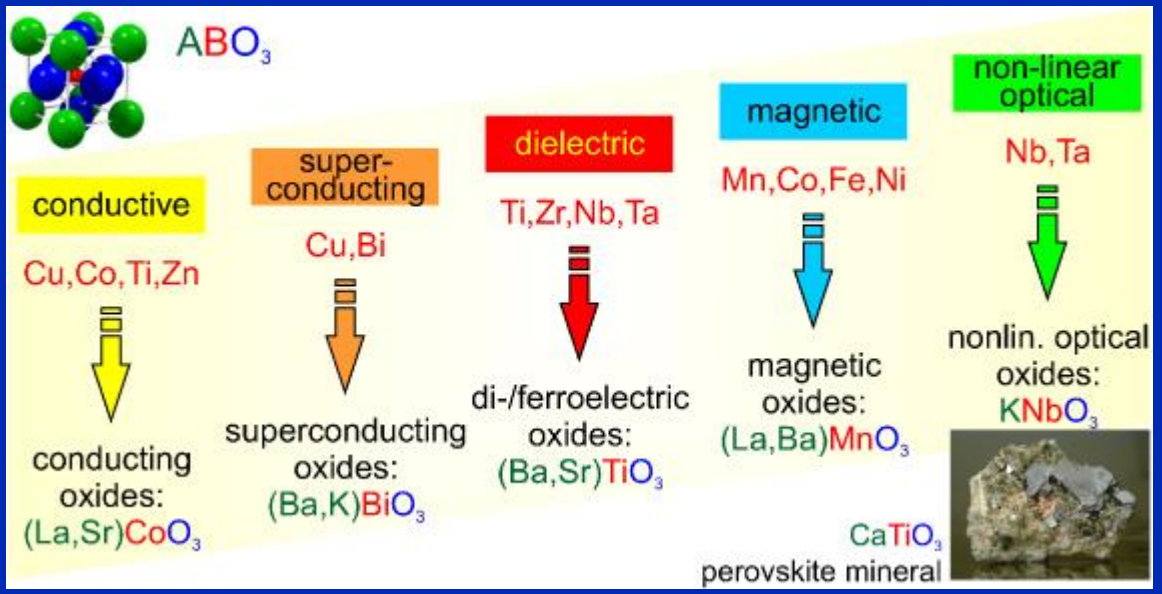


H, He, N
Be, Mg
Co, Zn, Sc, Ti
Y, Zr, Tc, Ru, Cd
Hf, Re, Os, Tl,
Pr, Gd, Tb, Dy, Ho, Er, Lu

Perovskite structure

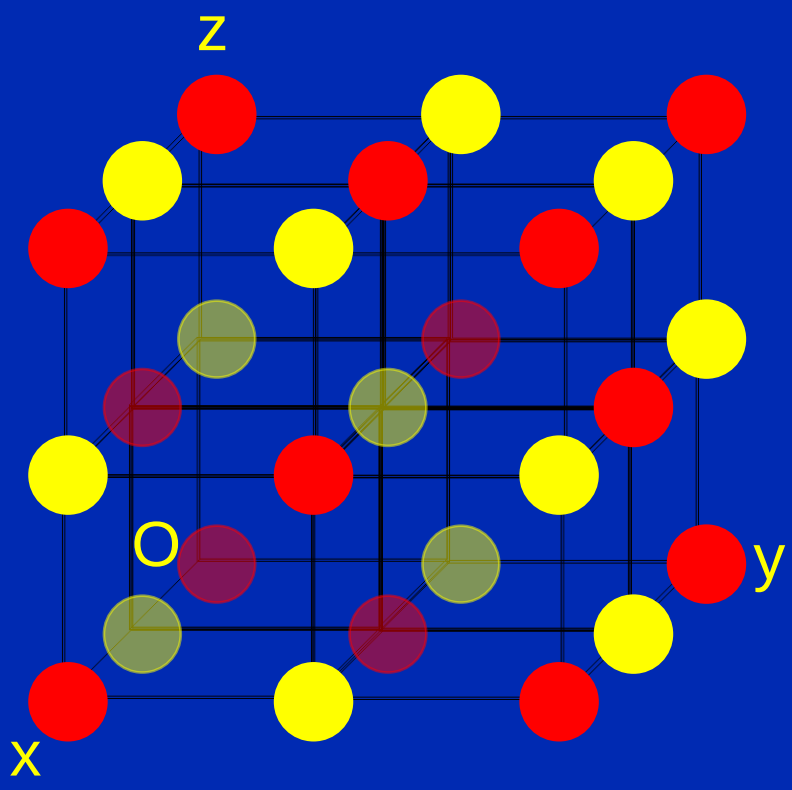


$CaTiO_3$



Matthias Opel 2012 *J. Phys. D: Appl. Phys.* **45** 033001

Planes and directions



Miller indices:

1. Find intercepts with axes of unit cell (in cell units).
2. Take reciprocals
3. Find (smallest) integers with the same ratio

() Planes

{} Equivalent planes

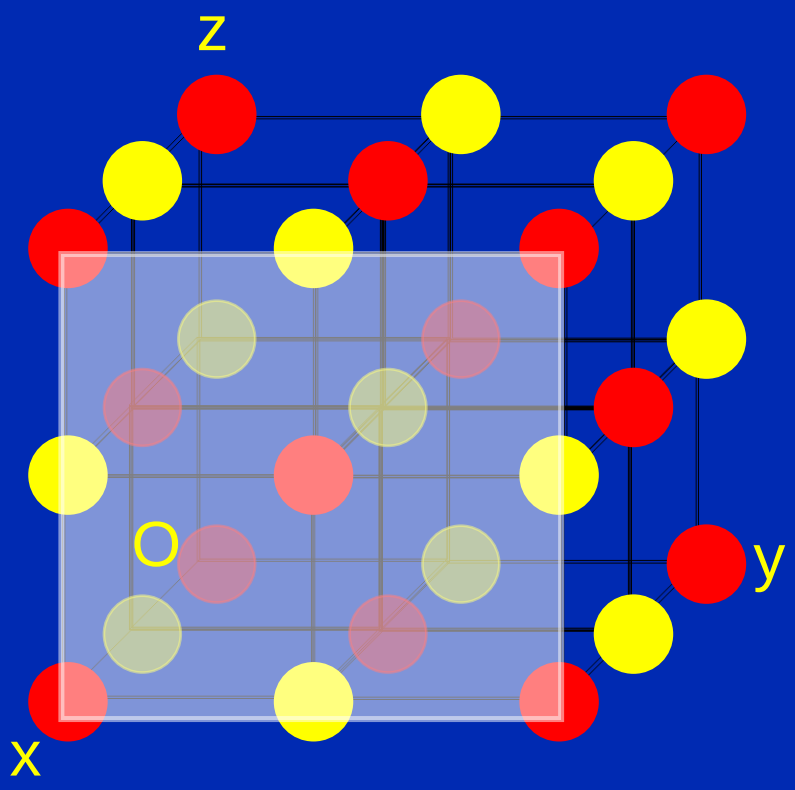
Cubic

{100}: (100),(200),(001)

[] directions:

x-direction [100]

Planes and directions



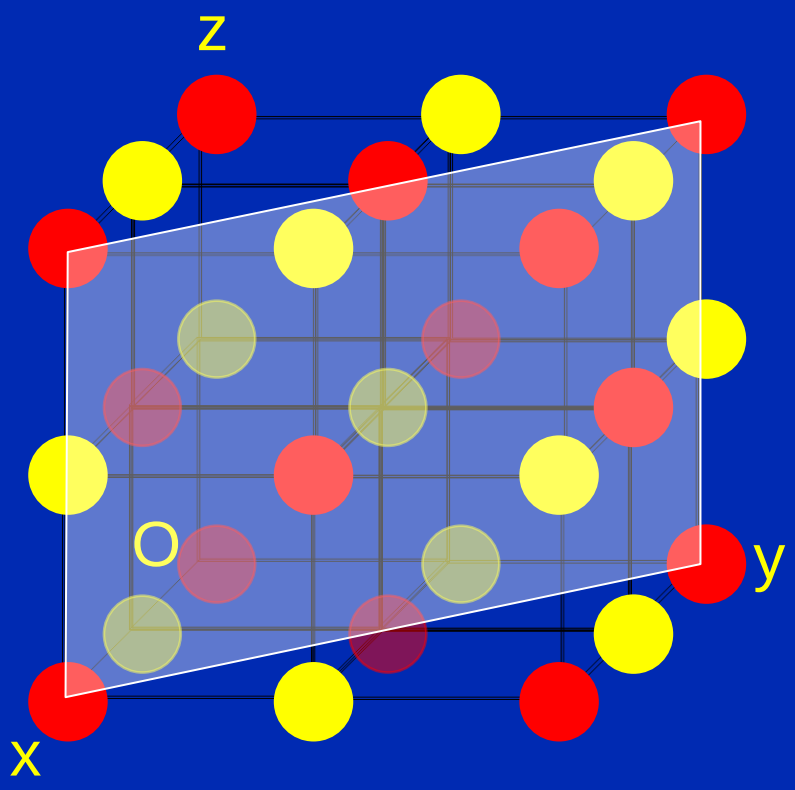
Miller indices:

1. Find intercepts with axes of unit cell (in cell units).
2. Take reciprocals
3. Find (smallest) integers with the same ratio

Intersections at $(1,\infty,\infty)$

Miller indices (100)

Planes and directions



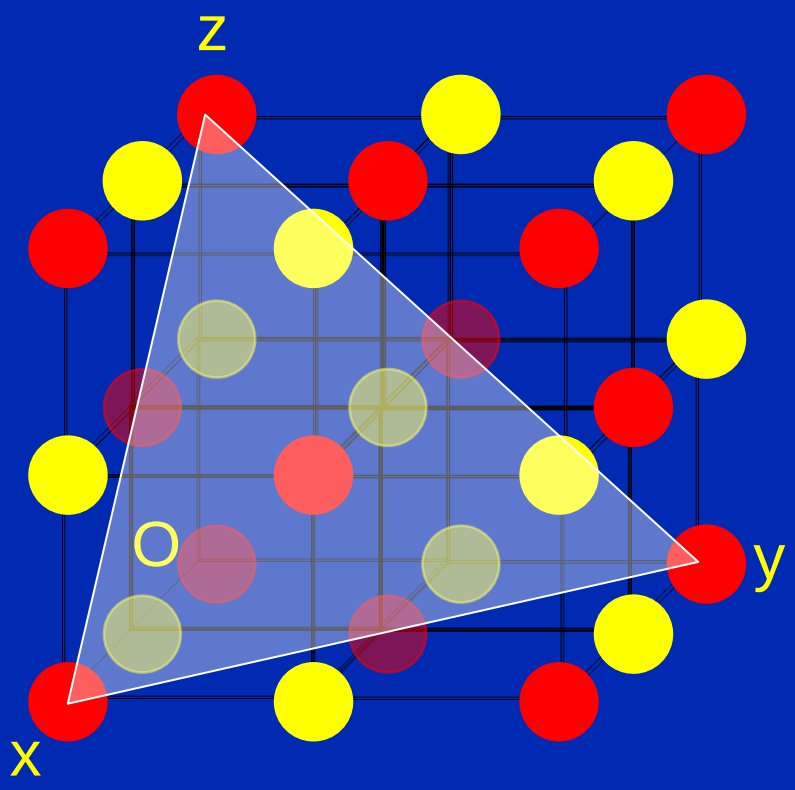
Miller indices:

1. Find intercepts with axes of unit cell (in cell units).
2. Take reciprocals
3. Find (smallest) integers with the same ratio

Intersections at $(1,1,\infty)$

Miller indices (110)

Planes and directions



Miller indices:

1. Find intercepts with axes of unit cell (in cell units).
2. Take reciprocals
3. Find (smallest) integers with the same ratio

Intersections at $(1,1,1)$

Miller indices (111)