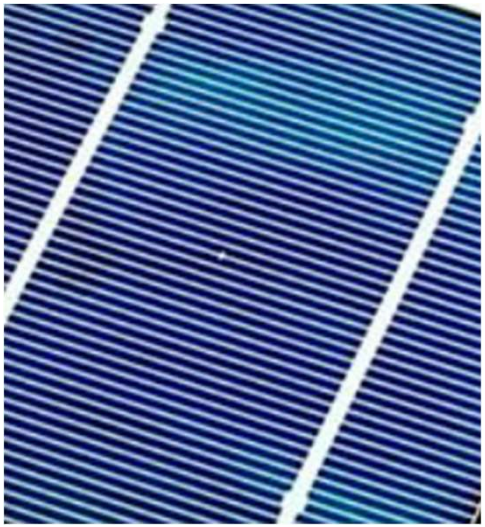
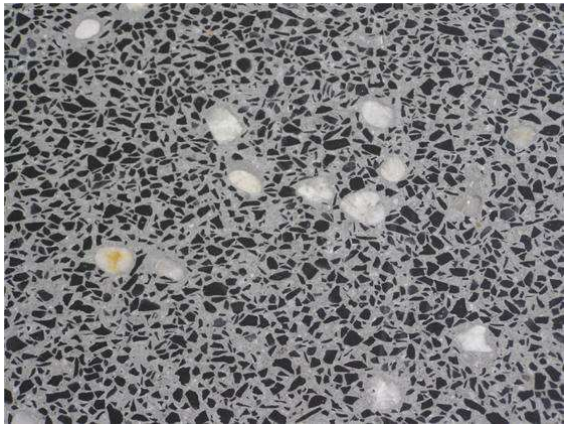
Introduction to Solid State Physics

Peter Hadley

Solid materials

Metals and alloys
Plastics
Ceramics
Biological materials
Composite materials

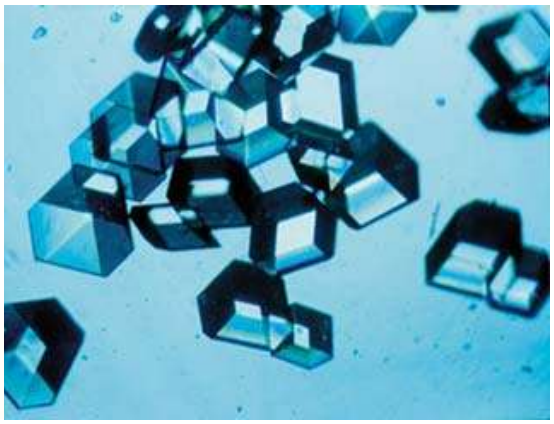




Crystal = periodic arrangement of atoms

Gallium crystals

quartz



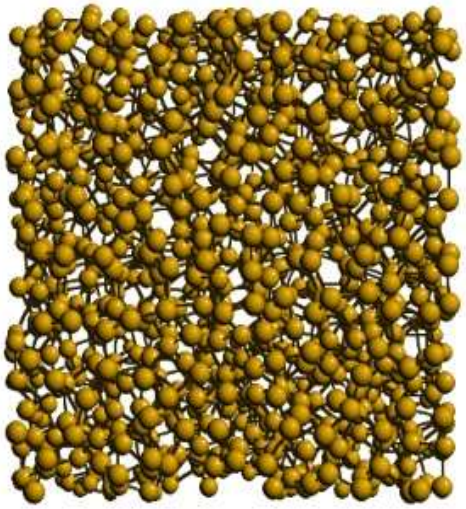
Insulin crystals

http://www.pmc.umontreal.ca/~mousseau/site_an/uploads/Main/si1000.jpg

http://www.wikipedia.org

amorphous metal

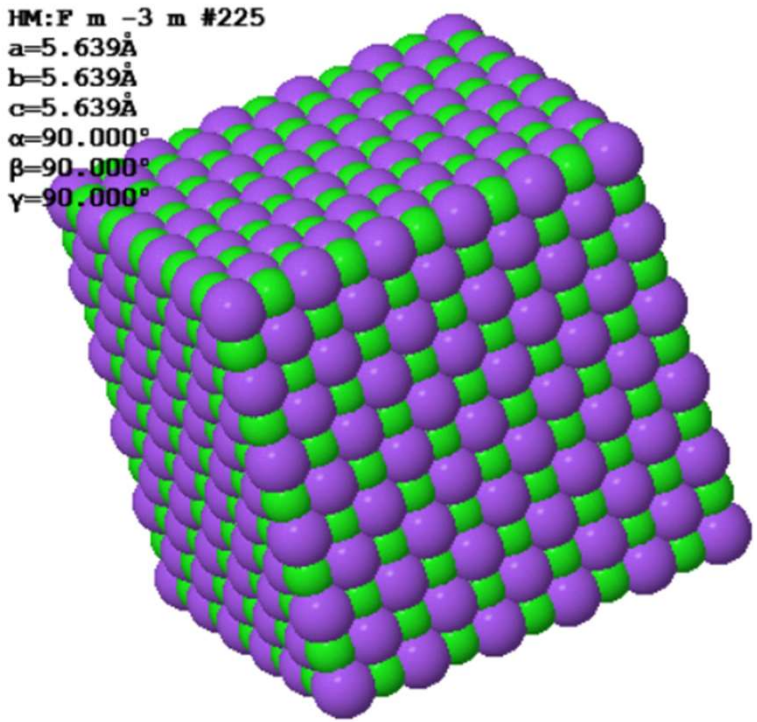
glass



amorphous silicon

Goal

From the microscopic structure



calculate any property of any solid.

http://lampx.tugraz.at/~hadley/mas

TU Graz

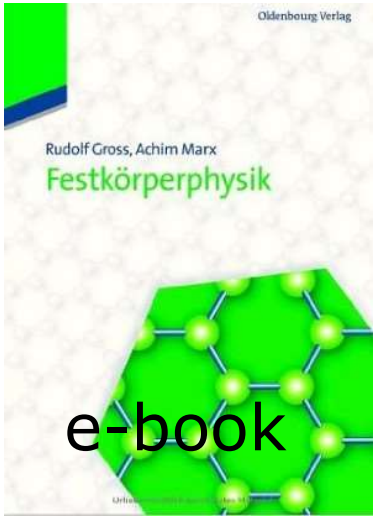
Print version

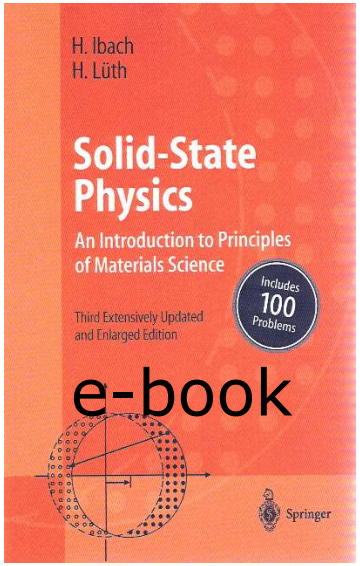
MAS.020UF Introduction to Solid State Physics

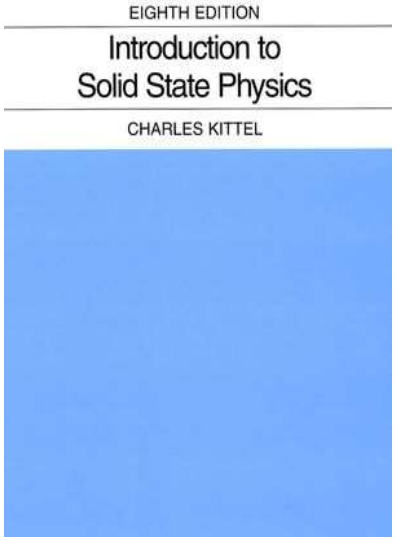
Course outline

- **Crystal structure**
  - Crystal structure W
  - Unit cell W
  - Bravais lattices W
  - Miller indices W
  - Wigner Seitz cell W
    - Drawing Wigner-Seitz cells
  - Asymmetric unit
  - Examples of crystal structures
    - simple cubic, fcc, bcc, hcp, diamond, silicon, zincblende, ZnO wurzite, NaCl, CsCl, perovskite, graphite, sugar
    - More crystal structures, CIF files, and programs to visualize crystal structures
  - Symmetries
    - Point groups W
      - Table of crystal classes and their associated point groups
      - Flowchart to determine the point group of a crystal
    - Space groups W
    - Space group → Bravais lattice
- **Crystal physics**
  - SGTE data for pure elements - The Gibbs energy as a function of temperature for many

Books







ICSD

Inorganic Crystal Structure Database

Materials Project

Carbon polytypes

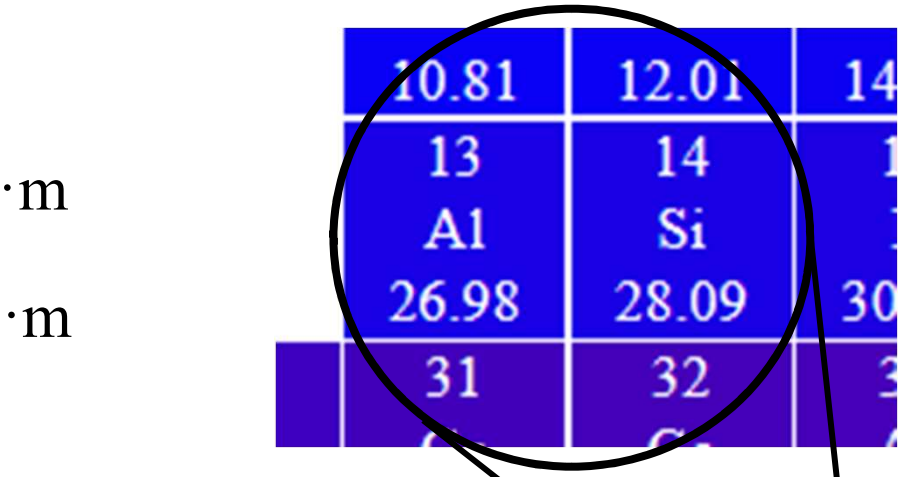
Different polytypes ⇨ Different properties

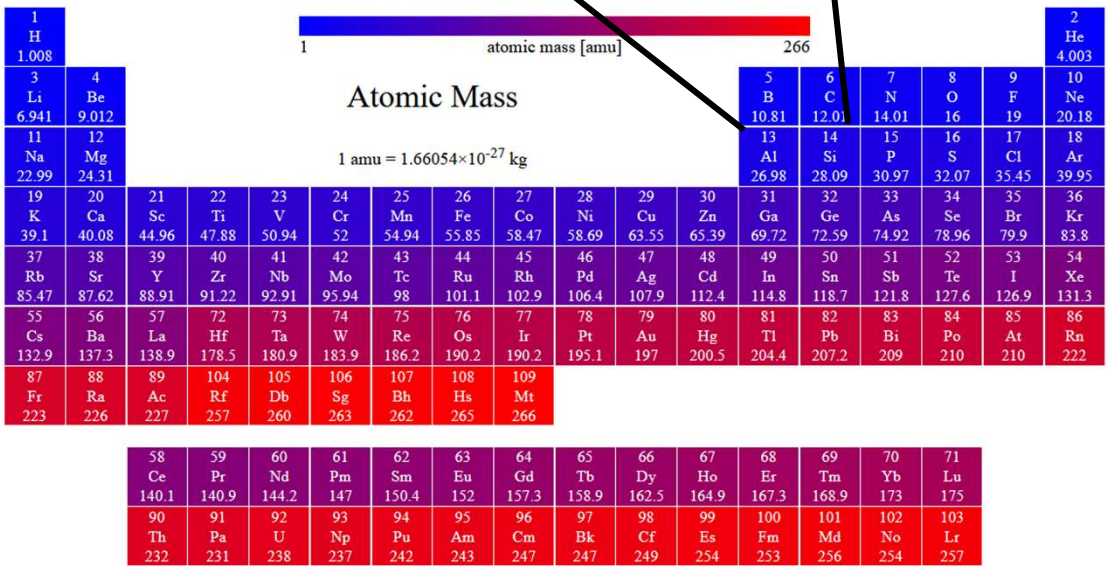
Aluminum and Silicon

Conductivity

Al: $\sigma = 3.5 \times 10^{7}\ 1/\Omega \cdot m$

Si: $\sigma = 4.3 \times 10^{-4}\ 1/\Omega \cdot m$



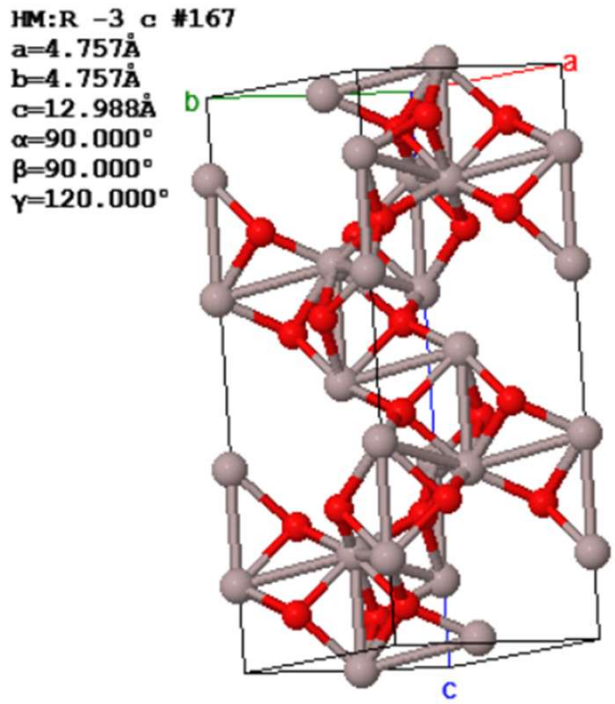


1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16	9 F 19	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.1	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.9	36 Kr 83.8
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc 98	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209	84 Po 210	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89 Ac 227	104 Rf 257	105 Db 260	106 Sg 263	107 Bh 262	108 Hs 265	109 Mt 266									

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm 147	62 Sm 150.4	63 Eu 152	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173	71 Lu 175
90 Th 232	91 Pa 231	92 U 238	93 Np 237	94 Pu 242	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 249	99 Es 254	100 Fm 253	101 Md 256	102 No 254	103 Lr 257

Sapphire and Ruby

Ti



Al_2O_3

Cr

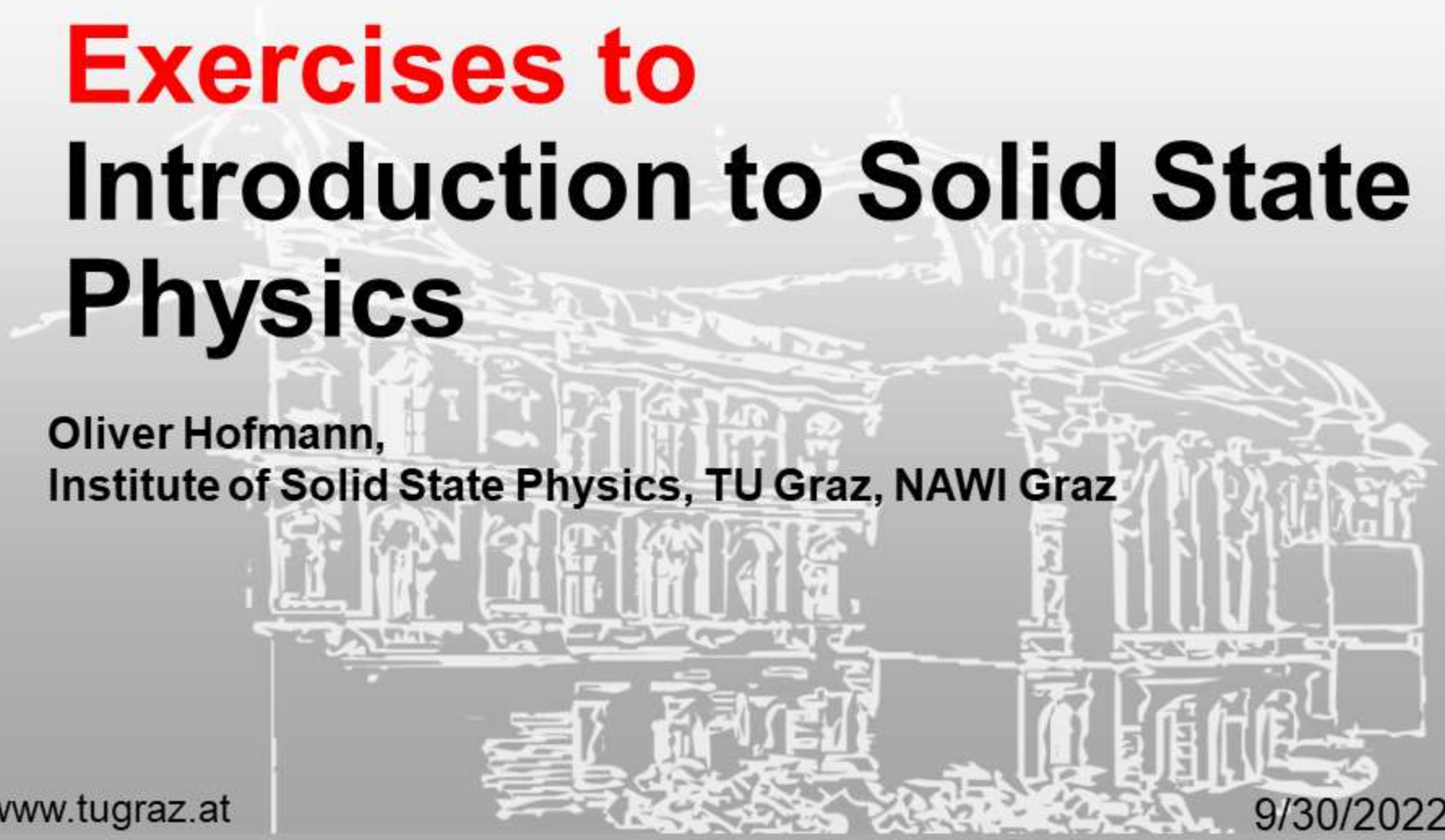
https://en.wikipedia.org/wiki/Ruby#/media/File:Ruby_gem.JPG
https://en.wikipedia.org/wiki/Sapphire#/media/File:Geschliffener_blauer_Saphir.jpg

SCIENCE • PASSION • TECHNOLOGY

TU Graz

Exercises to Introduction to Solid State Physics

Oliver Hofmann,
Institute of Solid State Physics, TU Graz, NAWI Graz



Purpose

- Repetition
- Examples and Training
- Identifying open questions
- Preparation for the Exam
- (Potential exam question will be given)

Procedure

Place: to be decided

Languange: as requested (German / English)

Implementation 7 x 90 min :

Data to be decided via doodle

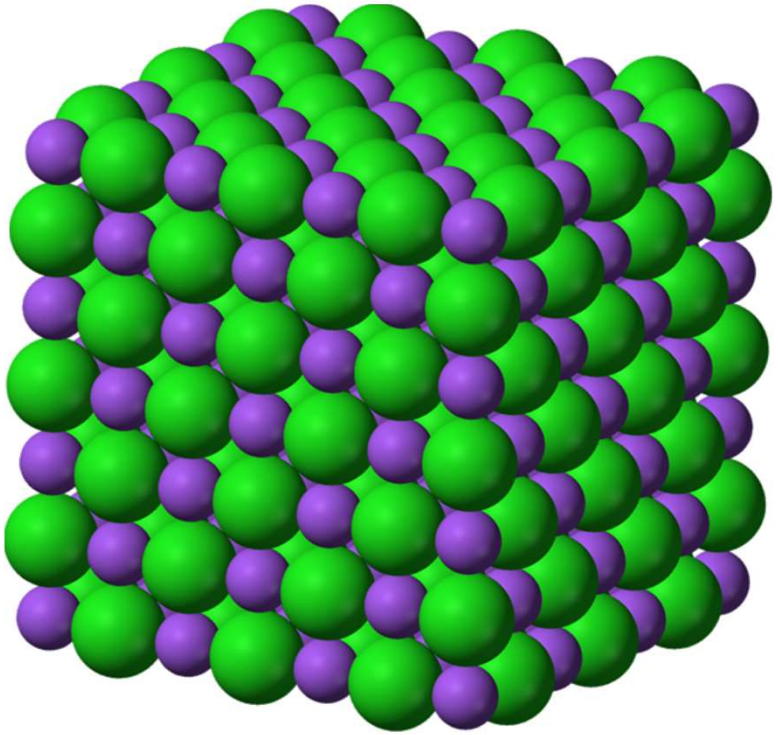
https://doodle.com/meeting/participate/id/el5lyA7a

Mandatory Presence!

Crystal structure

Crystal structure

A crystal is a three dimensional periodic arrangement of atoms.



7 Crystal Systems

triclinic: a ≠ b ≠ c and $\alpha \neq \beta \neq \gamma \neq 90°$

monoclinic: a ≠ b ≠ c and $\alpha \neq 90° \ \beta = \gamma = 90°$

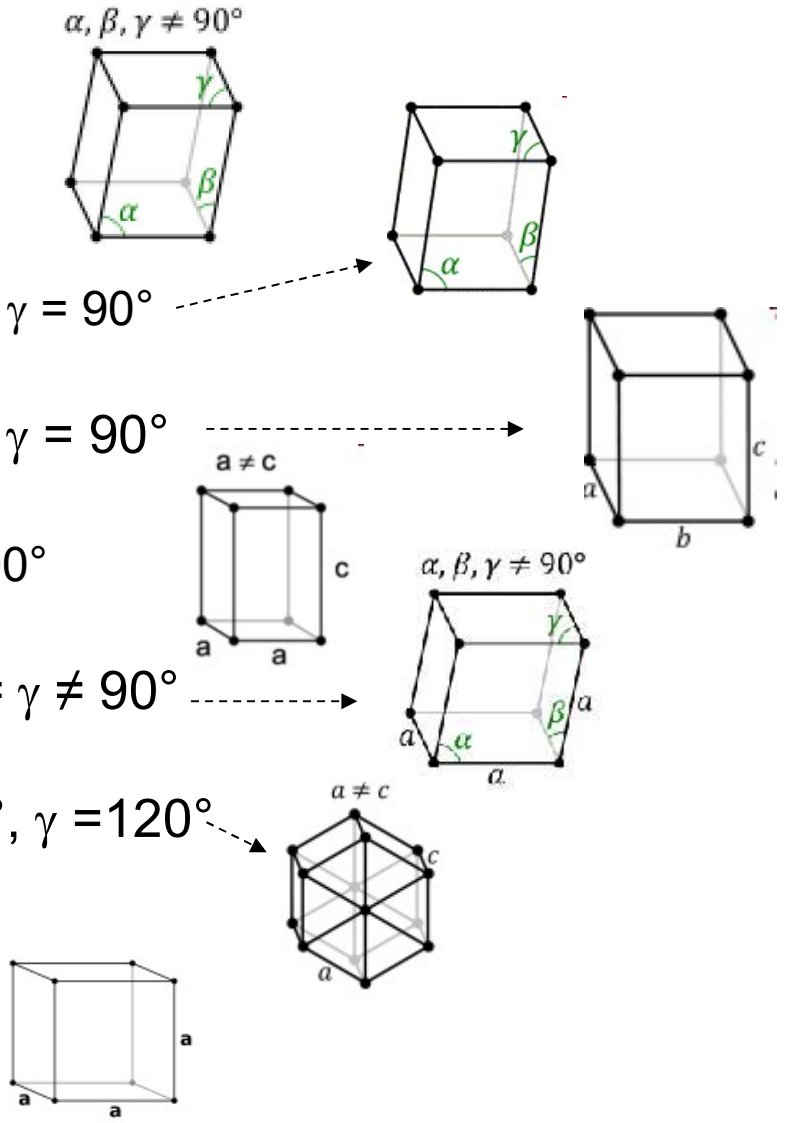
orthorhombic: a ≠ b ≠ c and $\alpha = \beta = \gamma = 90°$

tetragonal: a = b ≠ c and $\alpha = \beta = \gamma = 90°$

rhombohedral: a = b = c and $\alpha \neq \beta \neq \gamma \neq 90°$

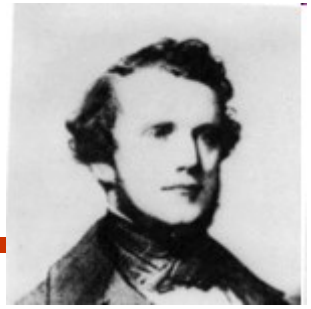
hexagonal: a = b ≠ c and $\alpha = \beta = 90°, \gamma = 120°$

cubic a = b = c and $\alpha = \beta = \gamma = 90°$

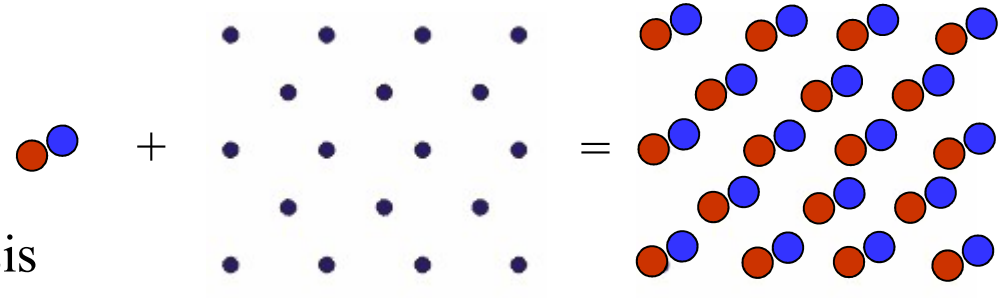


α is the angle between b and c

Bravais lattice



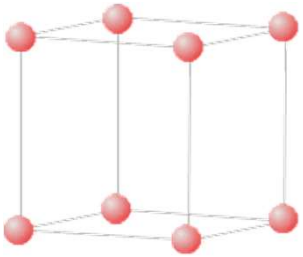
Auguste Bravais



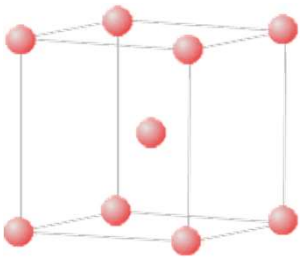
basis

Bravais lattice

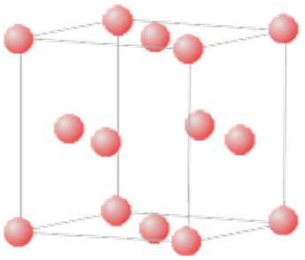
Crystal



simple cubic

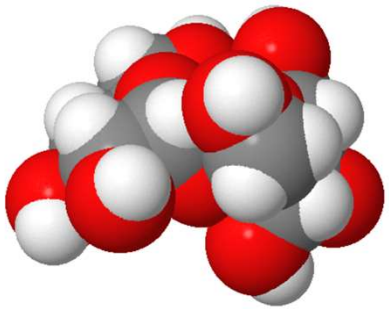


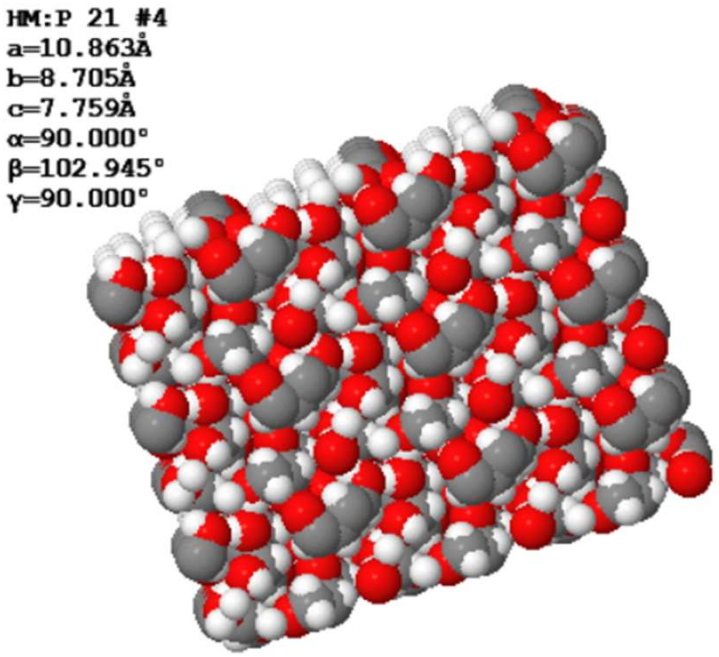
body centered cubic, bcc



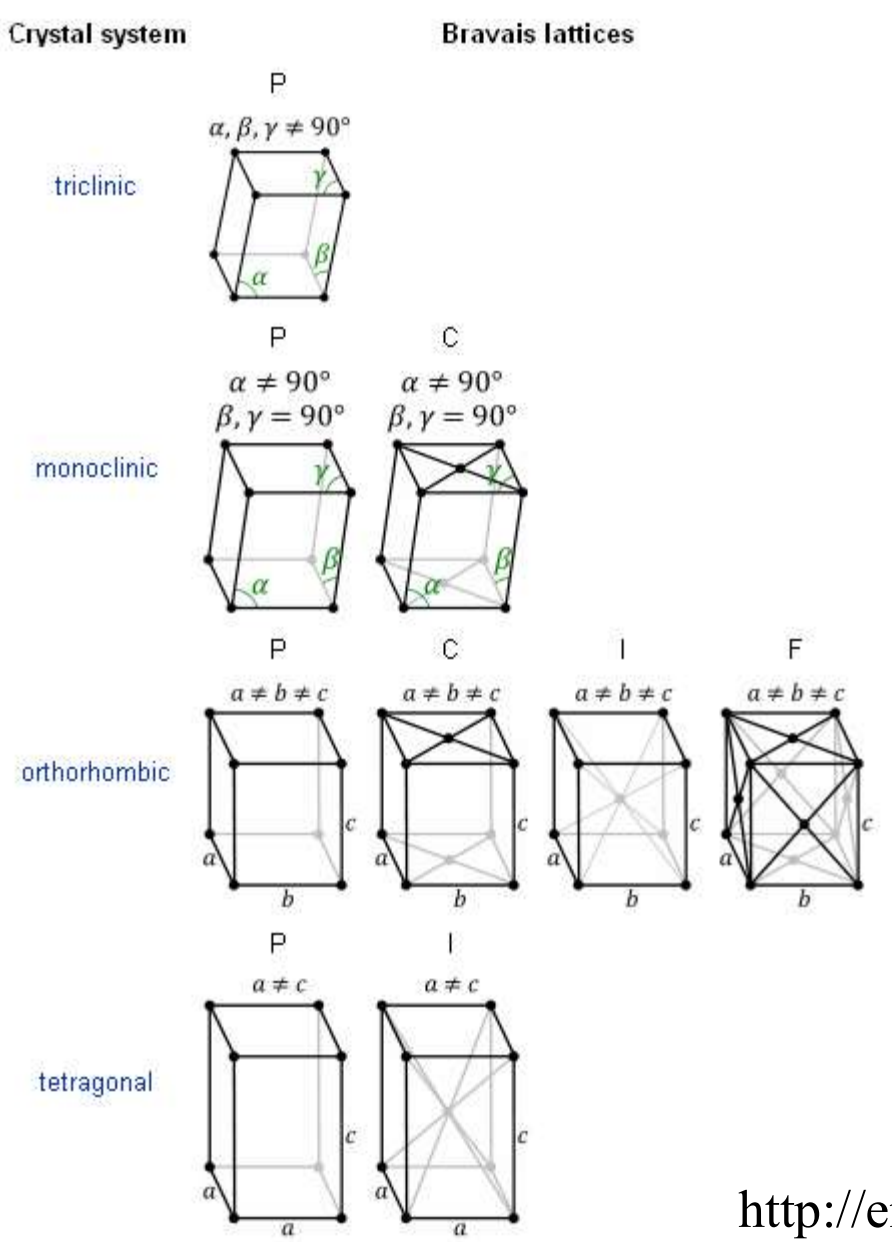
face centered cubic, fcc

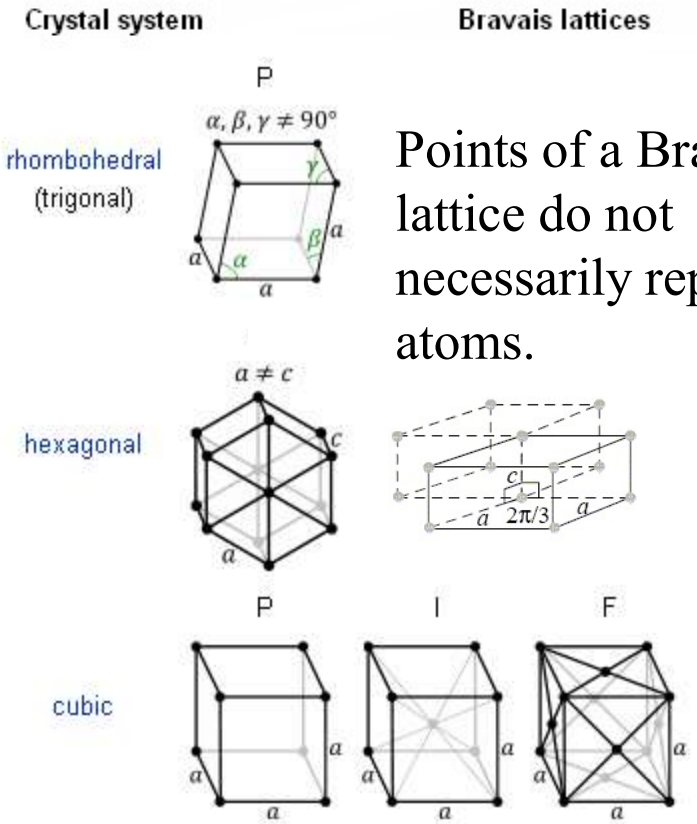
Sugar (Sucrose)





14 Bravais lattices





Points of a Bravais lattice do not necessarily represent atoms.

P … primitive
I … body centered
F … face centered
C … centered

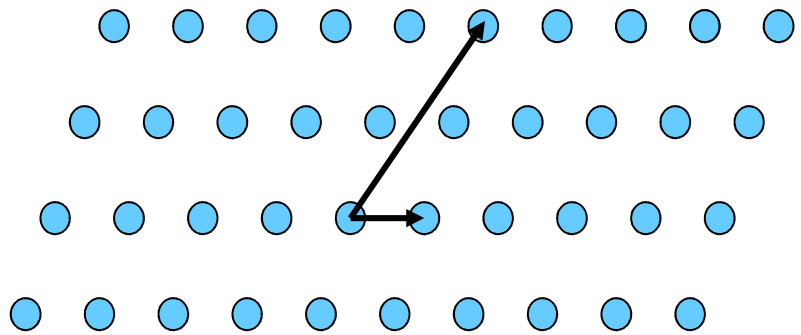
http://en.wikipedia.org/wiki/Bravais_lattice

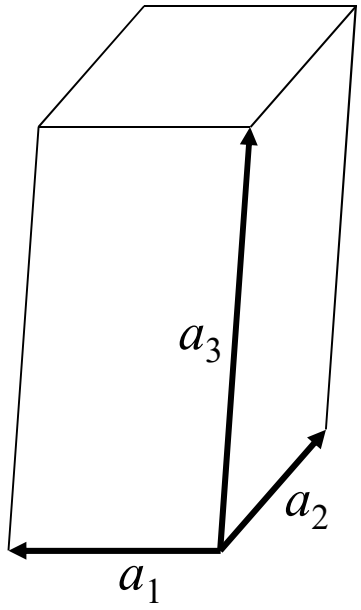
Primitive lattice vectors

Every point of a Bravais lattice can be reached from another point on the lattice by a translation vector

Translation vector

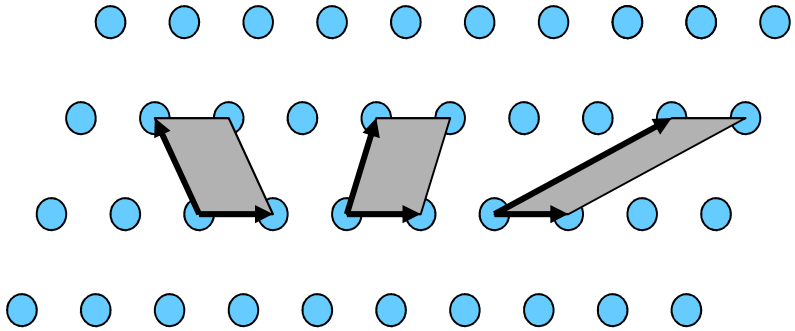
$$\vec{T} = n_1\vec{a}_1 + n_2\vec{a}_2 + n_3\vec{a}_3 \qquad n_1, n_2, n_3 = \cdots -2, -1, 0, 1, 2, \cdots$$



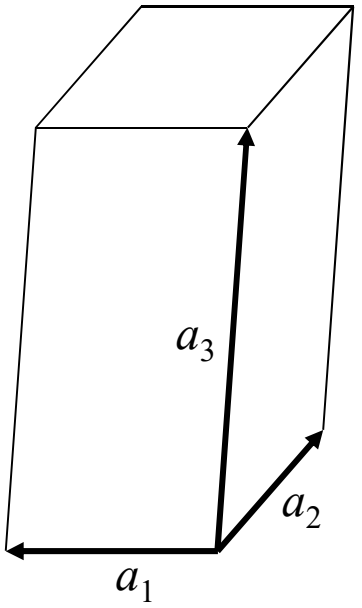


Primitive lattice vectors

Primitive Unit Cell



There is more than one choice for a primitive unit cell



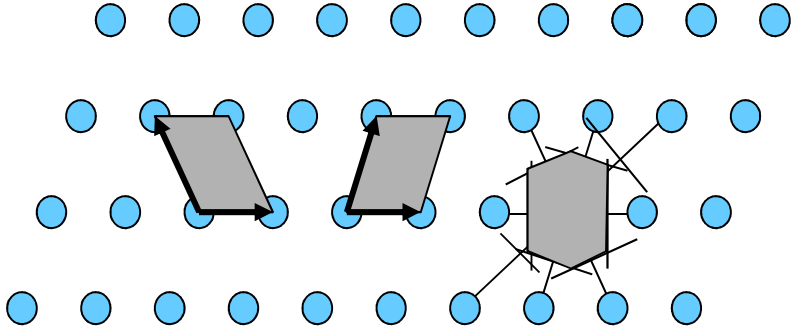
volume of a unit cell =

$$|\vec{a}_1 \cdot (\vec{a}_2 \times \vec{a}_3)|$$

$$\vec{T} = n_1\vec{a}_1 + n_2\vec{a}_2 + n_3\vec{a}_3 \qquad n_1, n_2, n_3 = \cdots -2, -1, 0, 1, 2, \cdots$$

Unit Cells

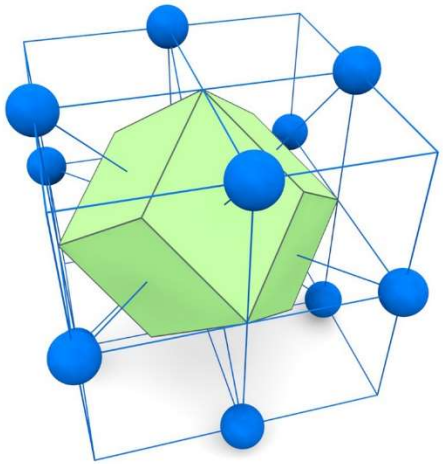
There is more than one choice for a primitive unit cell



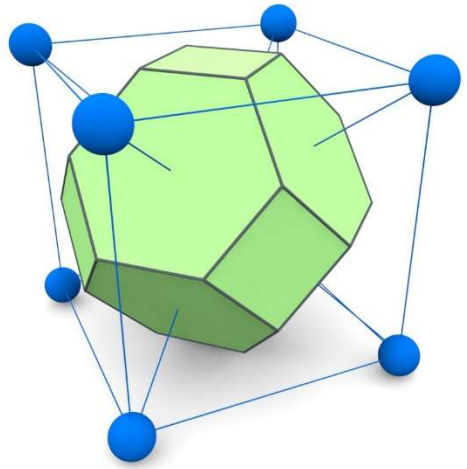
Eugene Wigner

Frederick Seitz

Wigner-Seitz primitive unit cell

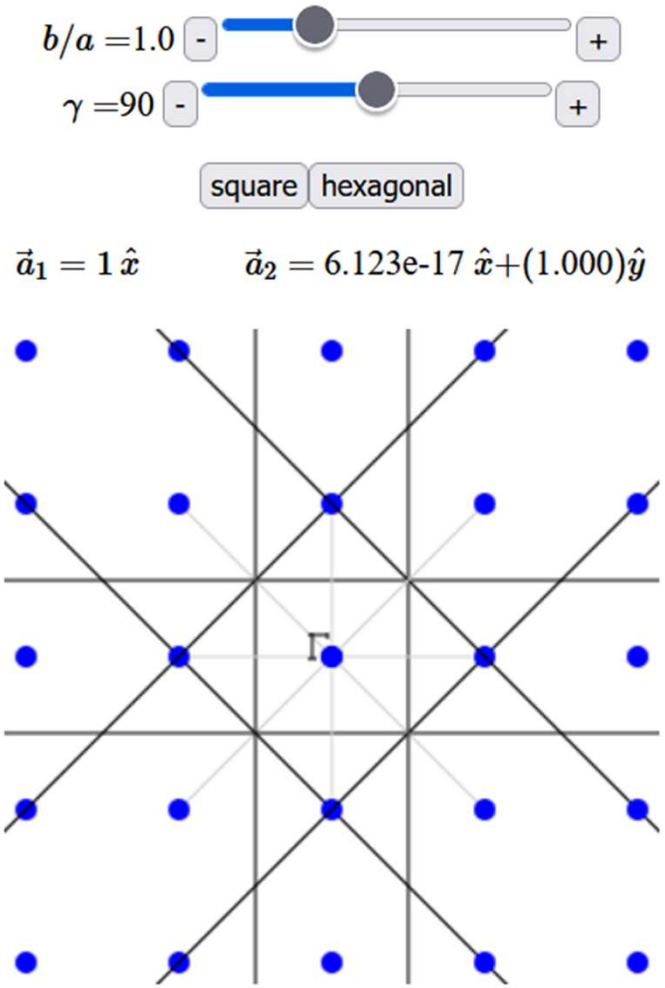


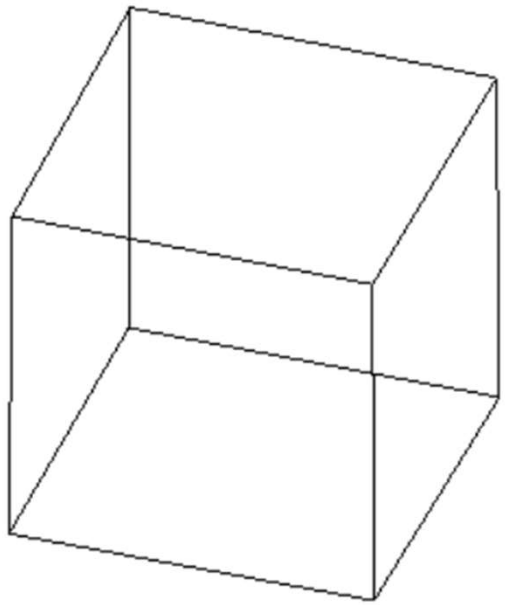
fcc



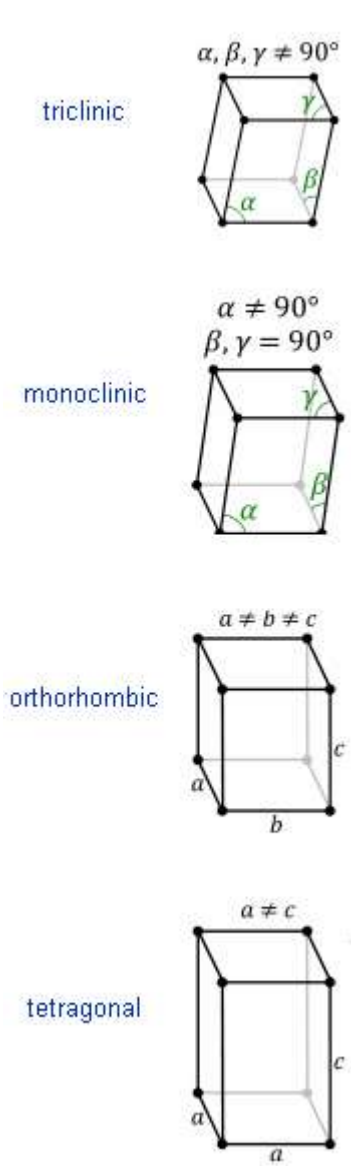
bcc

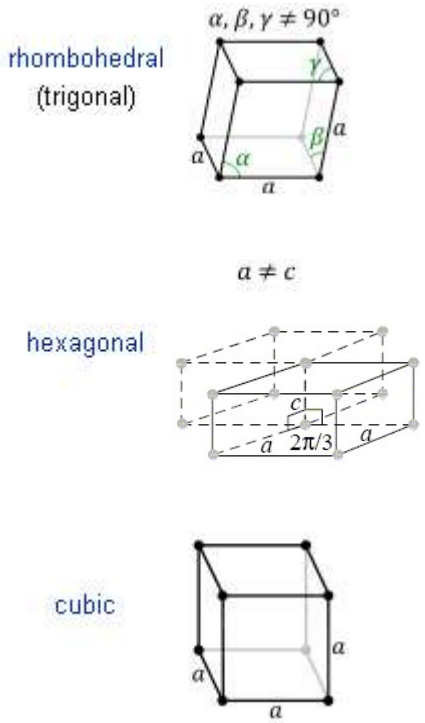
Wigner-Seitz cells





Conventional (crystallographic) unit cell





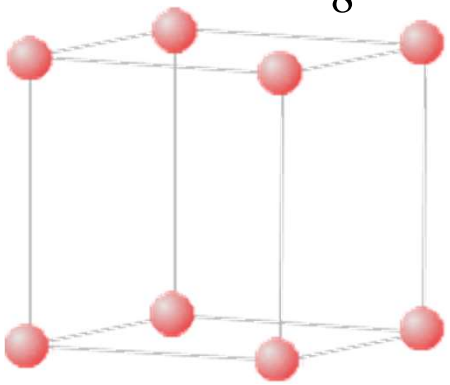
α is the angle between *b* and *c*
β is the angle between *a* and *c*
γ is the angle between *a* and *b*

6 faces, 8 corners

http://en.wikipedia.org/wiki/Bravais_lattice

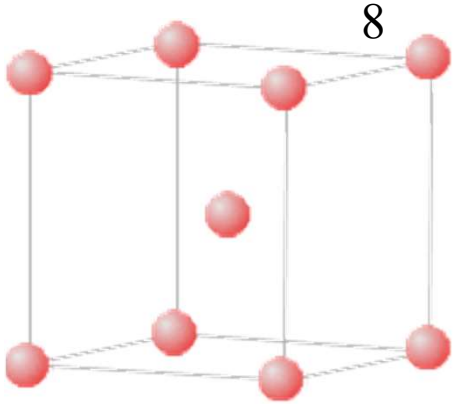
Conventional (crystalographic) unit cell

$$8 \times \frac{1}{8} = 1$$



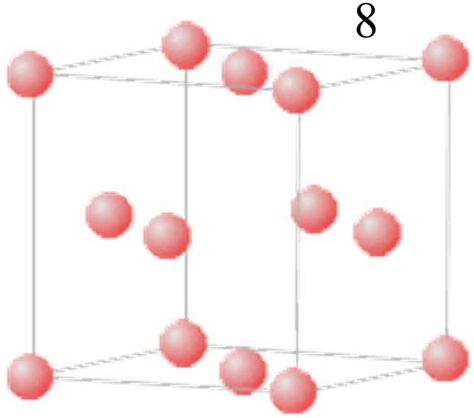
simple cubic

$$8 \times \frac{1}{8} + 1 = 2$$

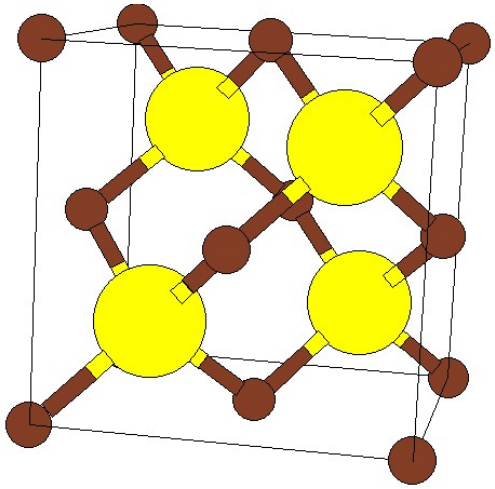


bcc

$$8 \times \frac{1}{8} + 6 \times \frac{1}{2} = 4$$

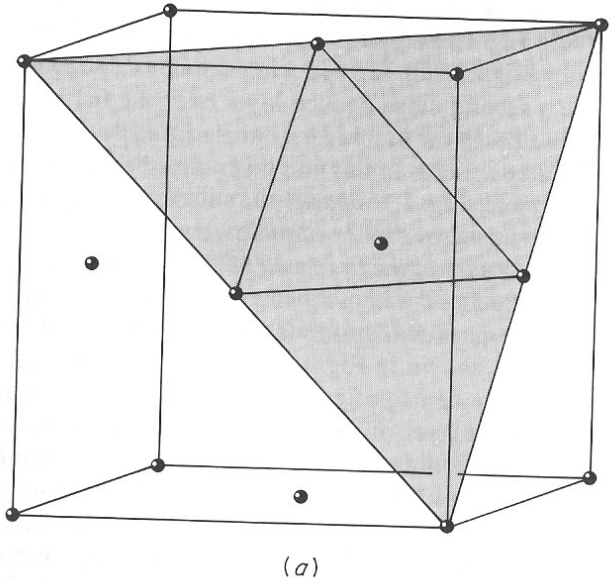


fcc

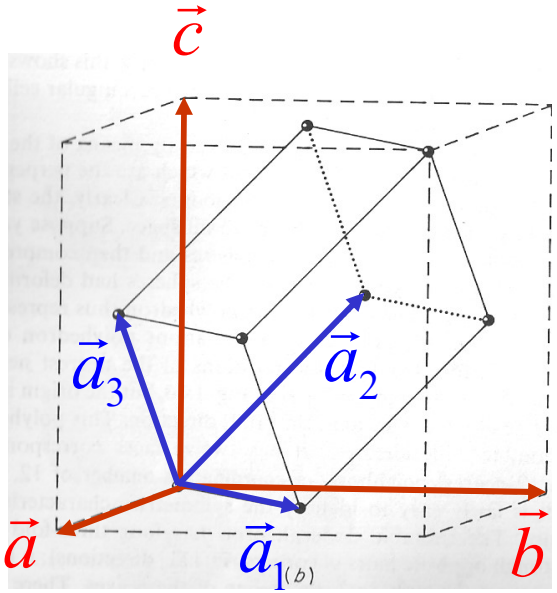


zincblende

Fcc

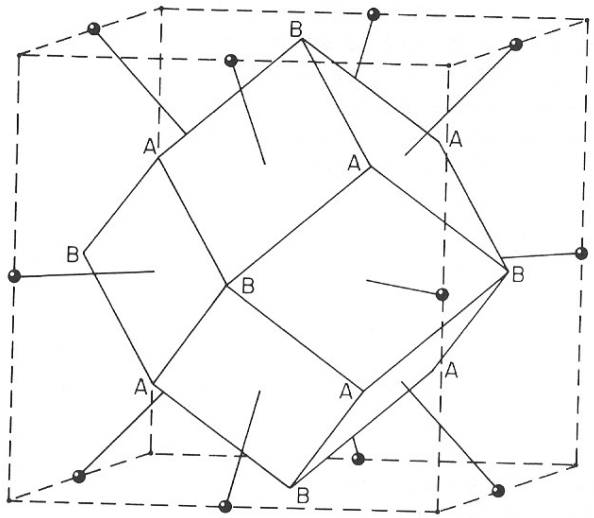


Crystalographic unit cell showing close packed plane



Crystalographic lattice vectors

Primitive lattice vectors



Wigner-Seitz cell

From: Hall, Solid State Physics