

Materials and Testing

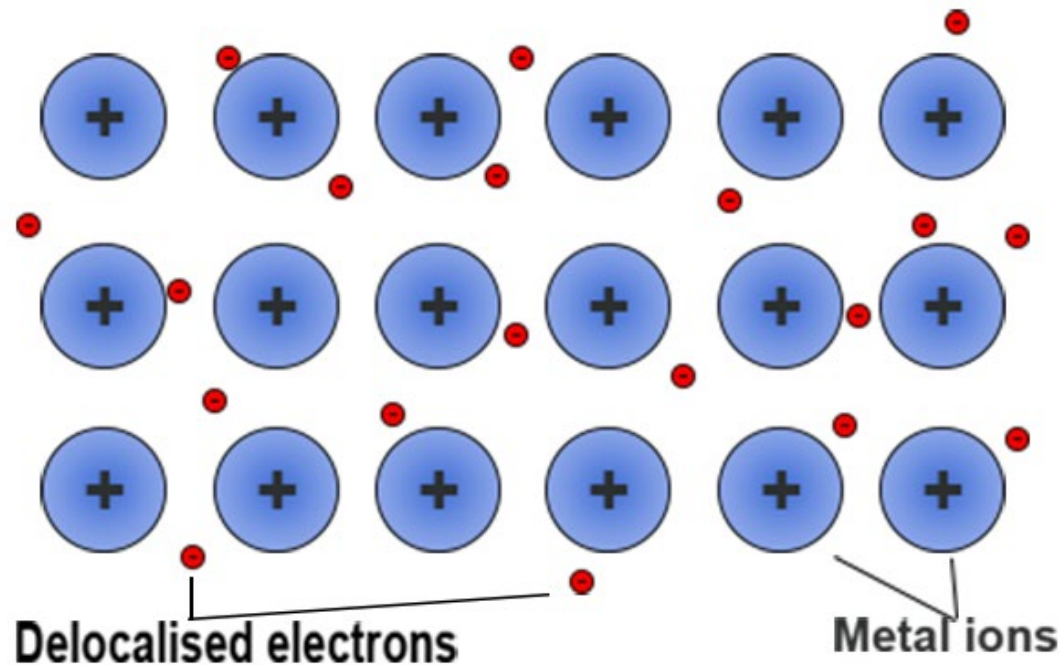
- Lecture Content -

- Introduction
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- **Metals 3**
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- **Polymers 2**
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- **Material Testing**

Metallic Bond

Repetition

Interaction between free (valence) electrons and metallic cations



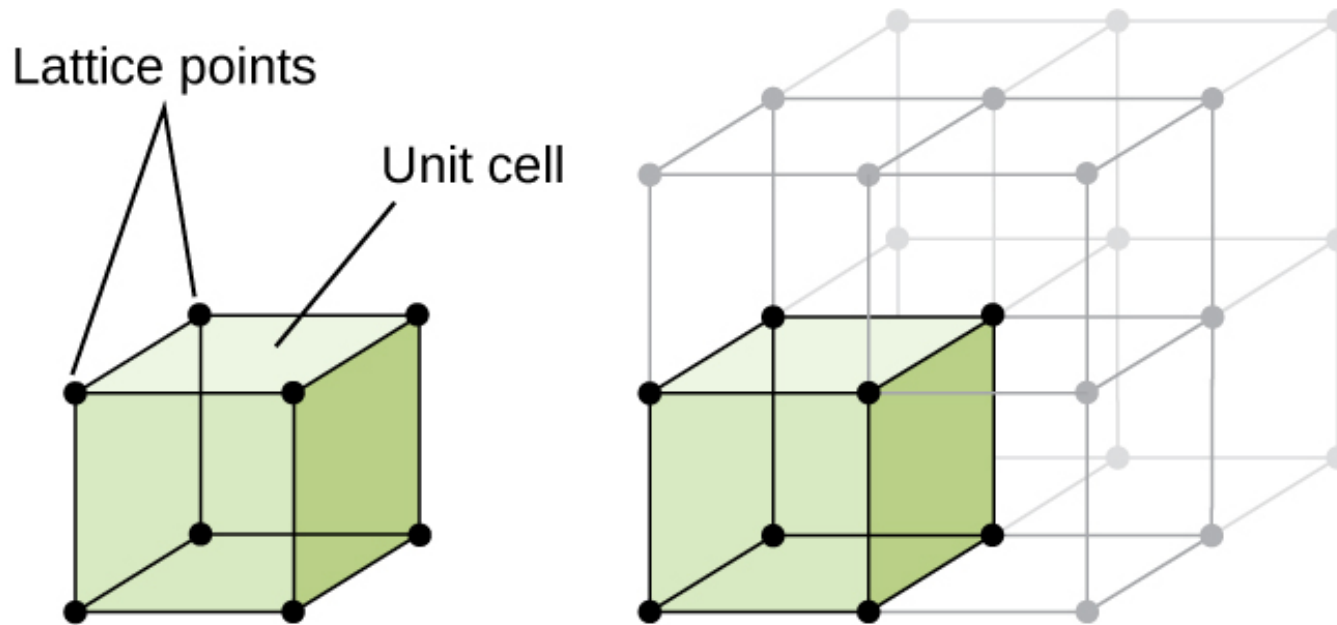
“The electrons do not know their mother”

picture:journalofrevision

Crystal Lattice and Unit Cell

Repetition

The smallest section of a crystal lattice that fully describes the entire structure is called **unit cell**.



The crystal system distinguishes between four types of unit cells and seven crystal classes, combining to 14 Bravais lattices.

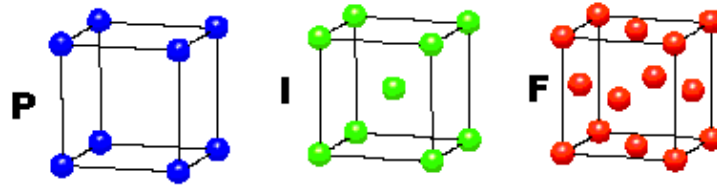
picture:opentextbc

Crystal System

CUBIC

$$a = b = c$$

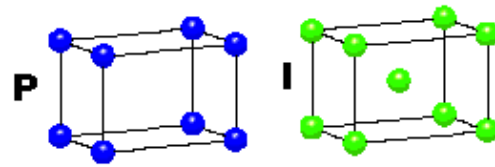
$$\alpha = \beta = \gamma = 90^\circ$$



TETRAGONAL

$$a = b \neq c$$

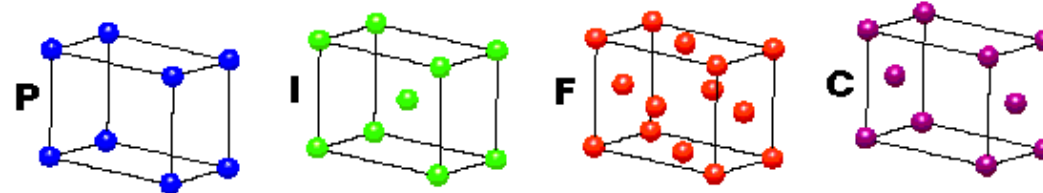
$$\alpha = \beta = \gamma = 90^\circ$$



ORTHORHOMBIC

$$a \neq b \neq c$$

$$\alpha = \beta = \gamma = 90^\circ$$

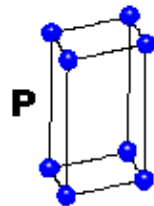


HEXAGONAL

$$a = b \neq c$$

$$\alpha = \beta = 90^\circ$$

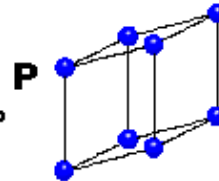
$$\gamma = 120^\circ$$



TRIGONAL

$$a = b = c$$

$$\alpha = \beta = \gamma \neq 90^\circ$$

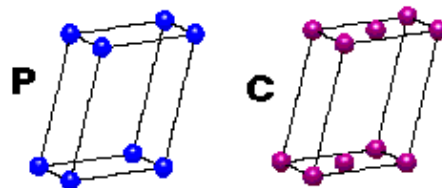


MONOCLINIC

$$a \neq b \neq c$$

$$\alpha = \gamma = 90^\circ$$

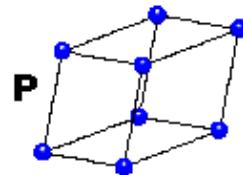
$$\beta \neq 120^\circ$$



TRICLINIC

$$a \neq b \neq c$$

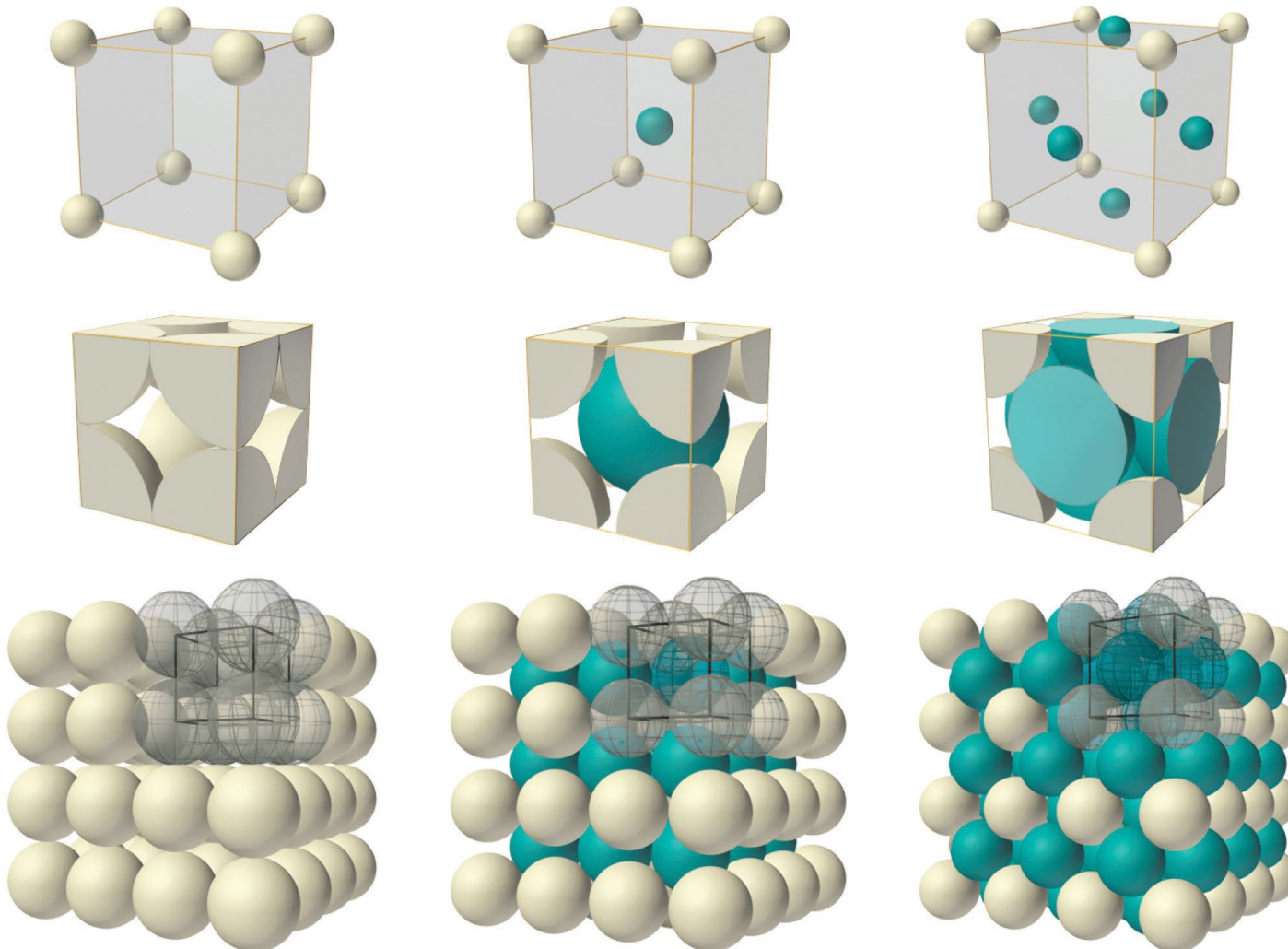
$$\alpha \neq \beta \neq \gamma \neq 90^\circ$$



4 Types of Unit Cell
P = Primitive
I = Body-Centred
F = Face-Centred
C = Side-Centred
 +
7 Crystal Classes
 → **14 Bravais Lattices**

Basic cubic Structures

Repetition



**(a) Simple cubic
(sc)**

**(b) Body-centered cubic
(bcc)**

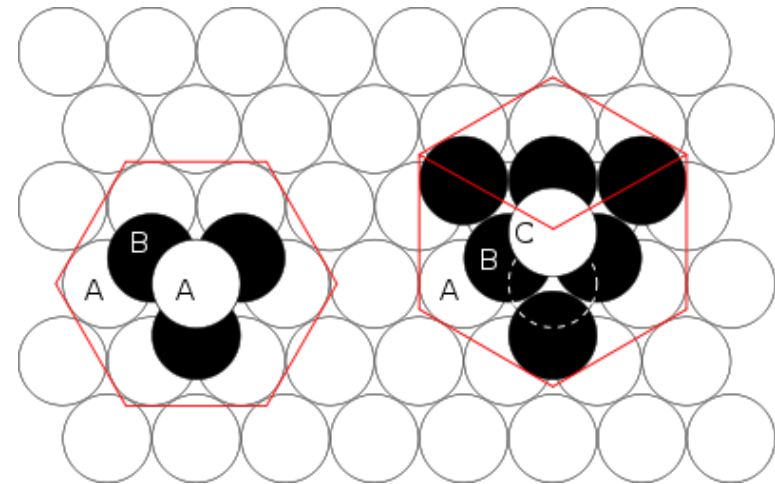
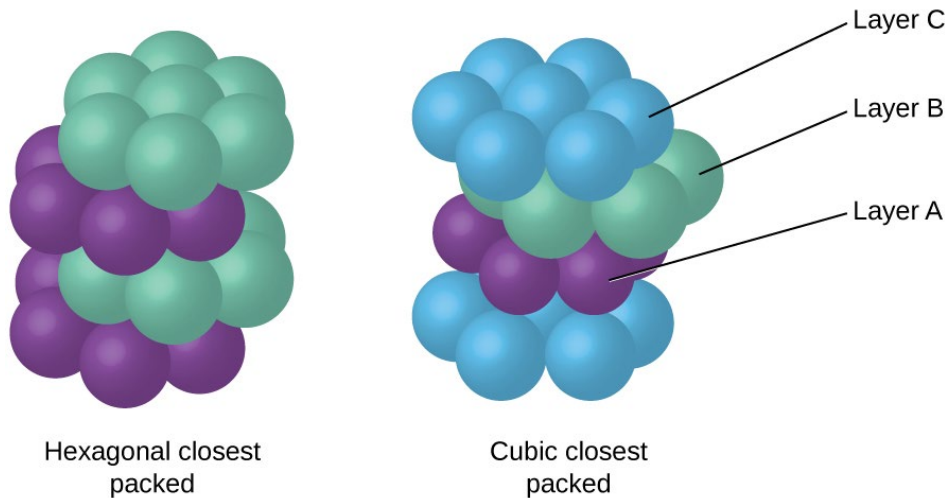
**(c) Face-centered cubic
(fcc)**

picture:saylordotorg

Comparison between hcp and fcc

Repetition

Hexagonal close packing (hcp) and face centered cubic packing (fcc) are very similar. The difference can be found in the way of stacking the layers: In hcp the third layer is exactly positioned above the first layer A (ABA-stacking), whereas in fcc the third layer is placed between layers A and B (ABC-stacking).



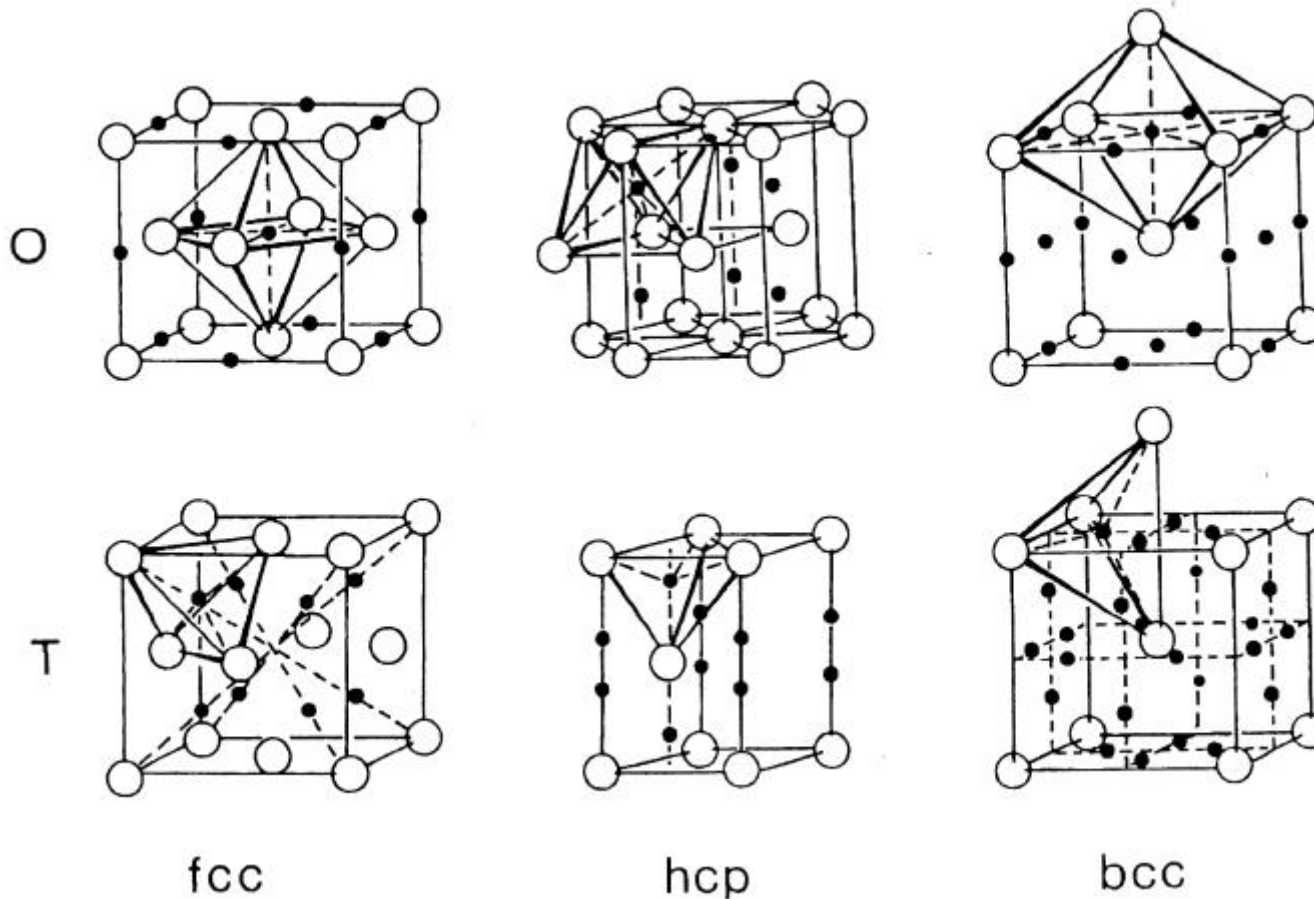
The fcc stacking may be converted to hcp by translation of the uppermost sphere, as shown by the dashed outline.

Stacking order in hcp (left) and fcc (right)

pictures: opentextbc
wikipedia

Tetrahedral and octahedral Sites

Repetition



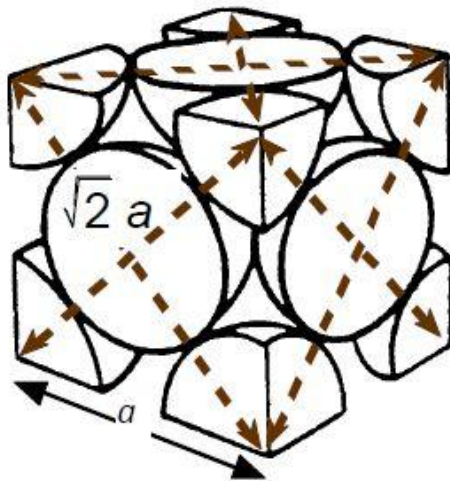
Octahedral (O) and tetrahedral (T) sites in crystal structures fcc, hcp and bcc: White spheres represent metal atoms. Interstitial sites O and T can be filled with small foreign atoms (black spheres).

picture: researchgate

Atomic Packing Factor (APF)

Repetition

Atomic Packing Factor of the face centered cubic structure (fcc)



Close-packed directions:

$$\text{length} = 4R = \sqrt{2} a$$

Unit cell contains:

$$6 \times 1/2 + 8 \times 1/8 \\ = 4 \text{ atoms/unit cell}$$

$$\text{APF} = \frac{\text{atoms/unit cell} \times \text{volume/atom}}{\text{volume/unit cell}} = \frac{4 \times \frac{4}{3} \pi \left(\frac{\sqrt{2} a}{4}\right)^3}{a^3}$$

APF = 0.740 (PD = 74.0 % of the unit cell volume are filled with atoms)

picture: studyblue

A brief Overview on selected crystal Structures

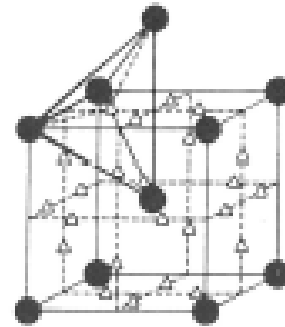
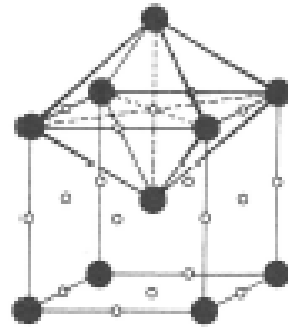
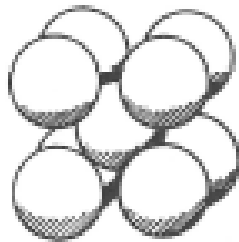
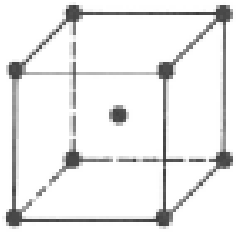
focus
model

real
model

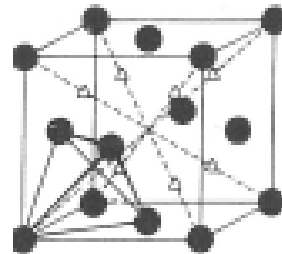
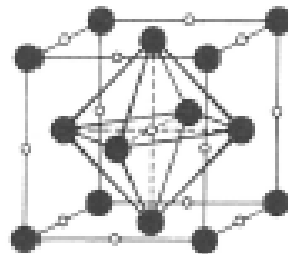
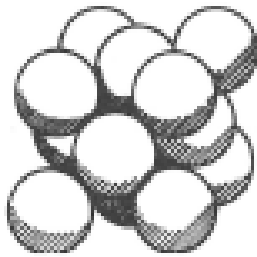
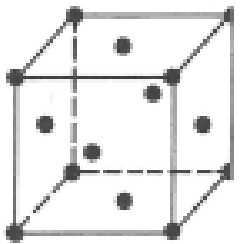
octahedral sites

tetrahedral sites

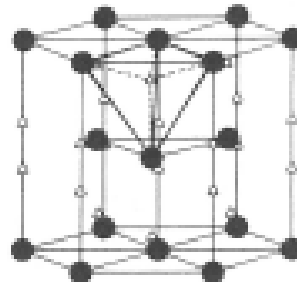
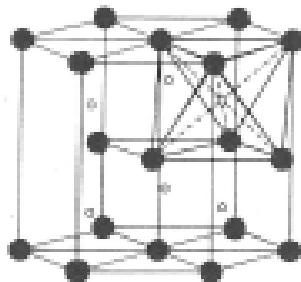
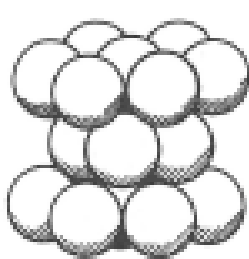
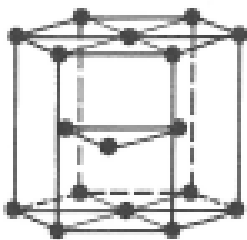
Repetition



bcc, $cn = 8$, $n = 2$, $PD = 68 \%$
 octahedral sites per unit cell: 6
 tetrahedral sites per unit cell: 12



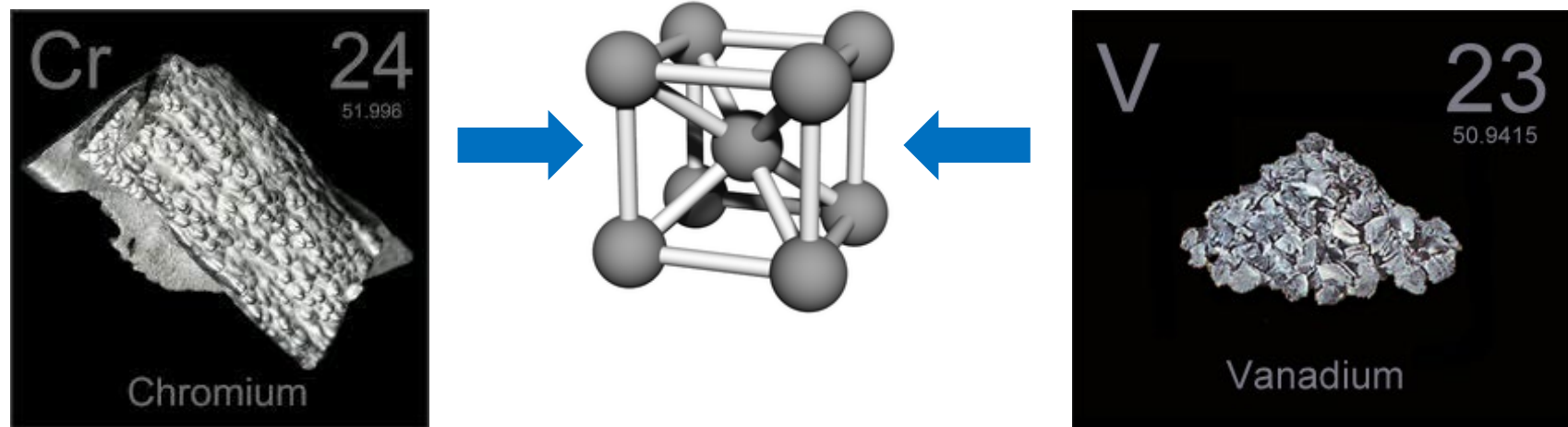
fcc, $cn = 12$, $n = 4$, $PD = 74 \%$
 octahedral sites per unit cell: 4
 tetrahedral sites per unit cell: 8



hex, $cn = 12$, $n = 6$, $PD = 74 \%$
 octahedral sites per unit cell: 2
 tetrahedral sites per unit cell: 4

Metals with body centered cubic Structure

The body centered cubic structure is characteristic for the entire group of alkali metals (first main group). Other examples for metals with bcc structure are Vanadium (V), Chromium (Cr), Manganese (Mn) and the ferritic phases of Iron (Fe).



Both Chromium and Vanadium have bcc structure

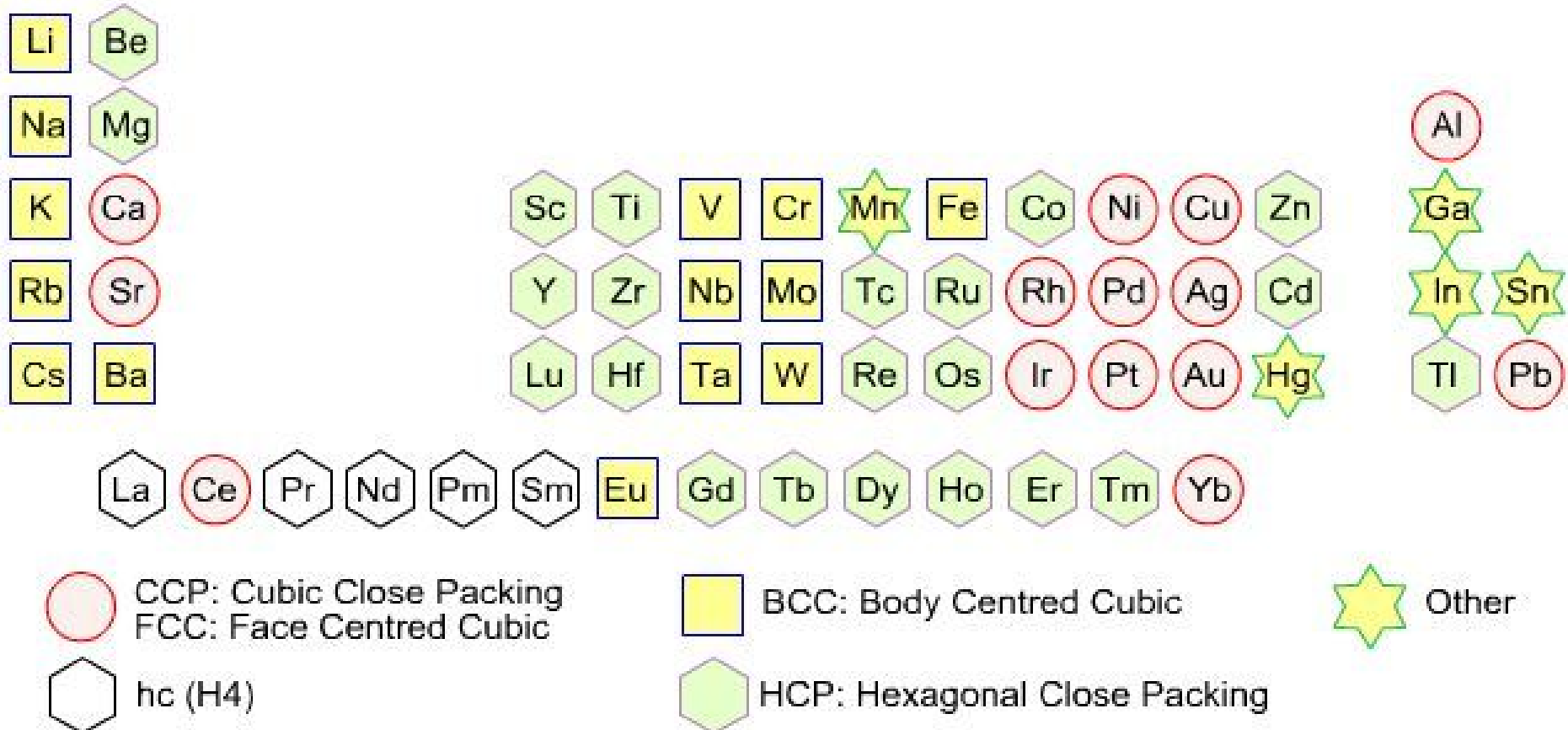
pictures:

prezi
gisaxs
ktep

A brief Overview on selected crystal Structures

Repetition

Metal crystal structure periodic table:



Metals 2

- **Lattice Structure Defects**
- **Impact of Lattice Structure Defects on mechanical Properties**

Goals for the lecture - learnings

- **Understand the four dimensions of lattice defects**
- **Be able to explain the four crucial lattice defects and its related strengthening mechanisms**
 - **alloying**
 - **strain hardening**
 - **grain fining**
 - **age hardening**
- **Know the proportionality of the strengthening effects**

Real Structure of Metals

In reality, the atomic structure of metals (and any other group of materials) is not perfect. There are defects, which do affect the macroscopic properties significantly.

The defects in the lattice structure are classified according to their dimension:

Dimension 0: Point Defects

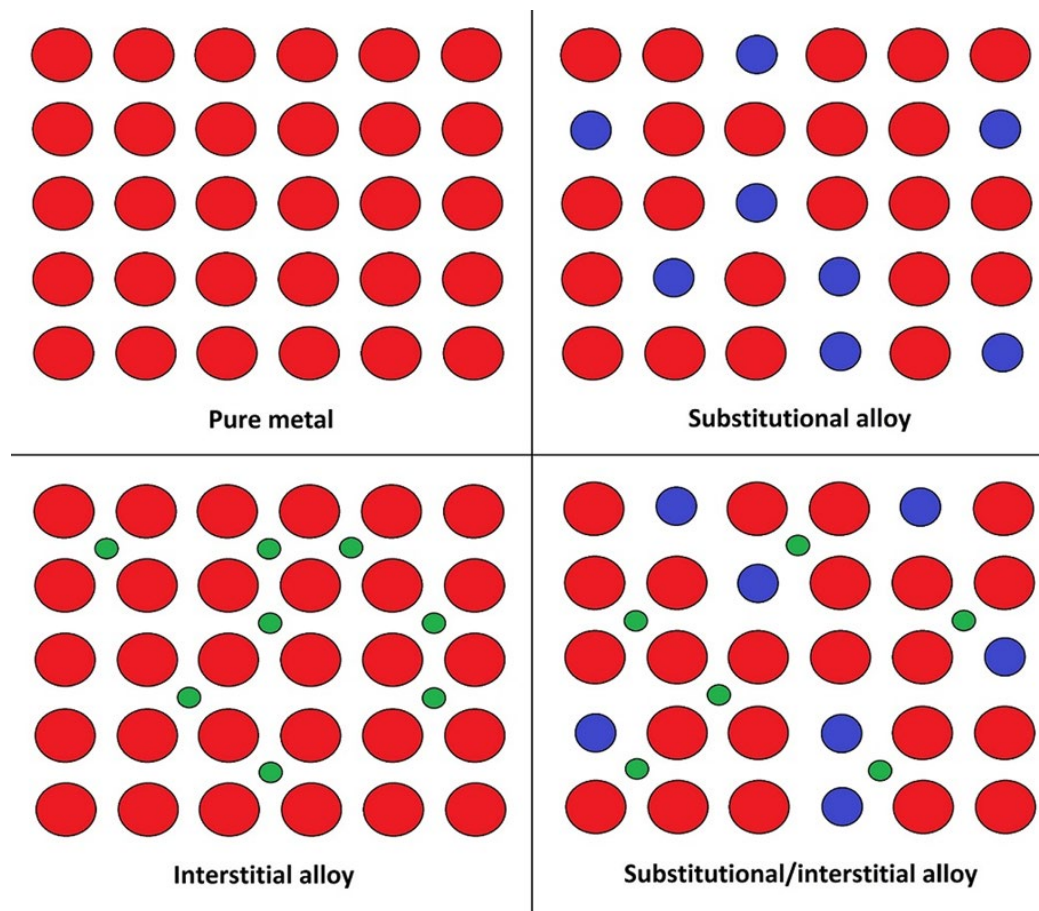
Dimension 1: Line Defects

Dimension 2: Planar Defects

Dimension 3: Bulk Defects

Impact of Point Defects

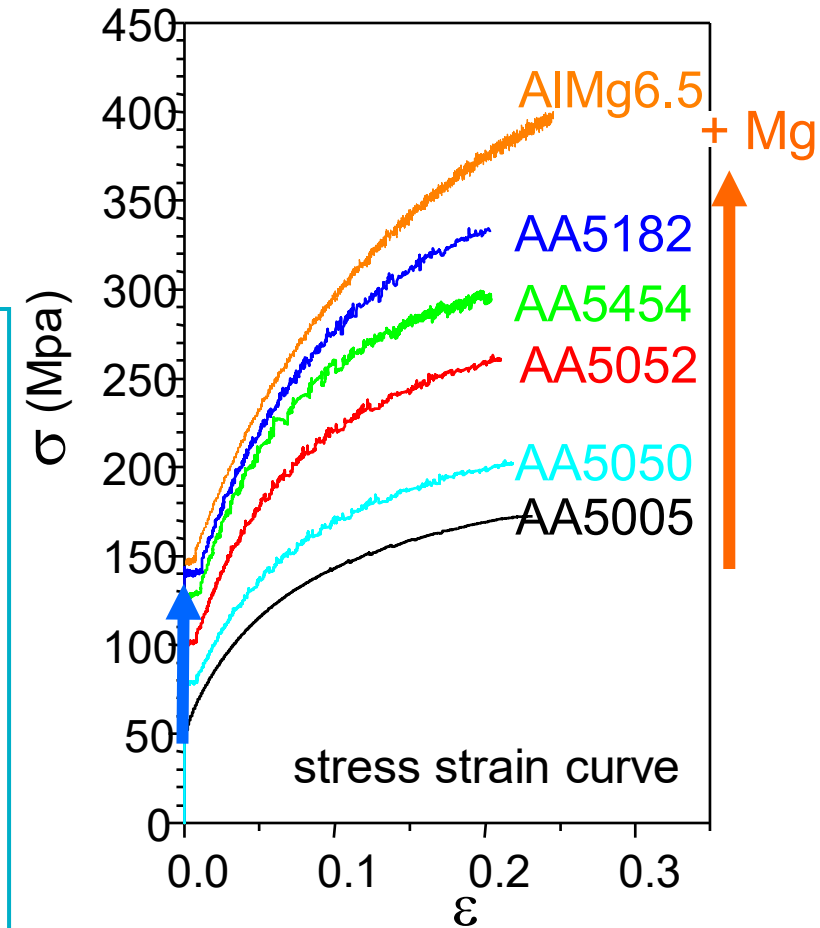
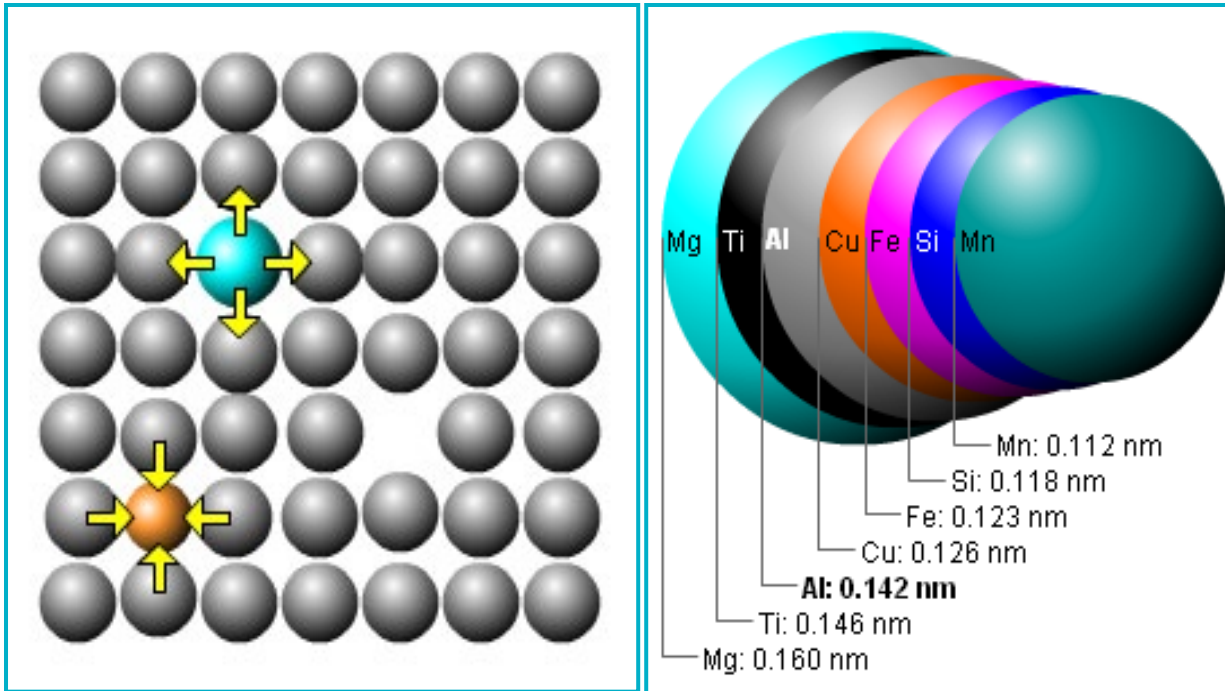
Point defects can be used to improve the strength of a metal. By adding foreign atoms (**alloying**), which, depending on their size, act as substitutes or interstitials, a so called **solid solution (alloy)** is generated:



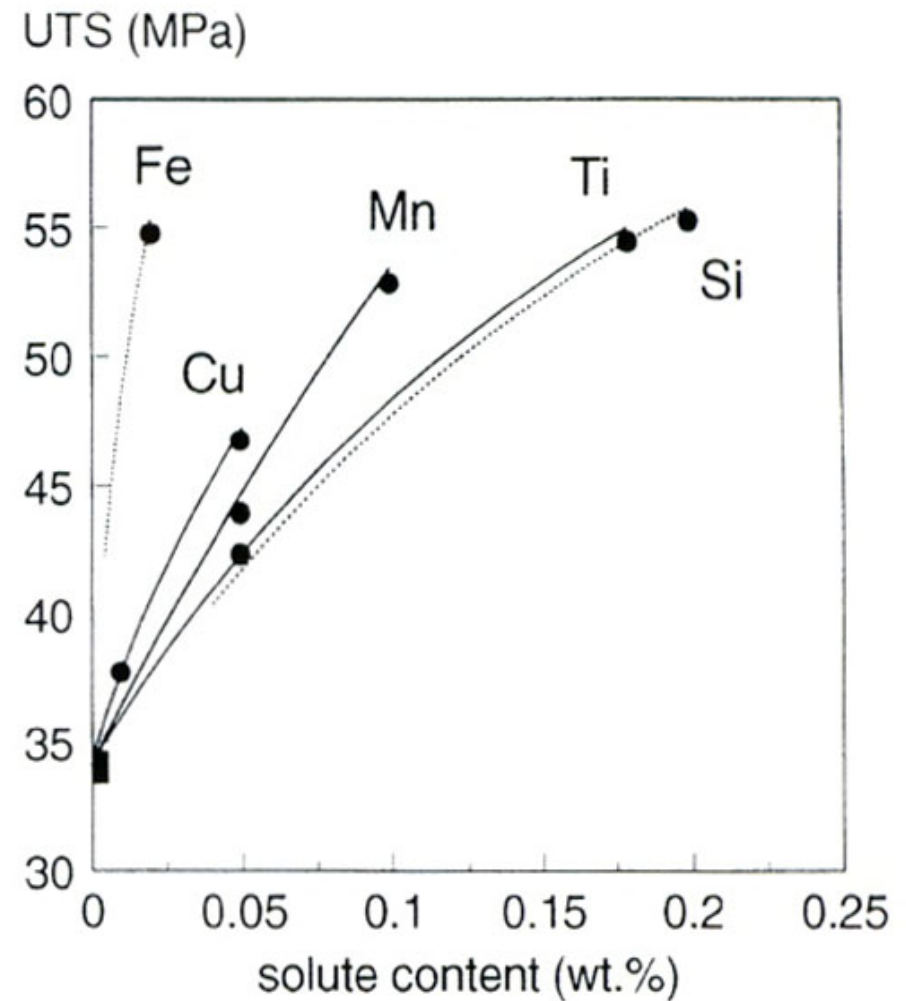
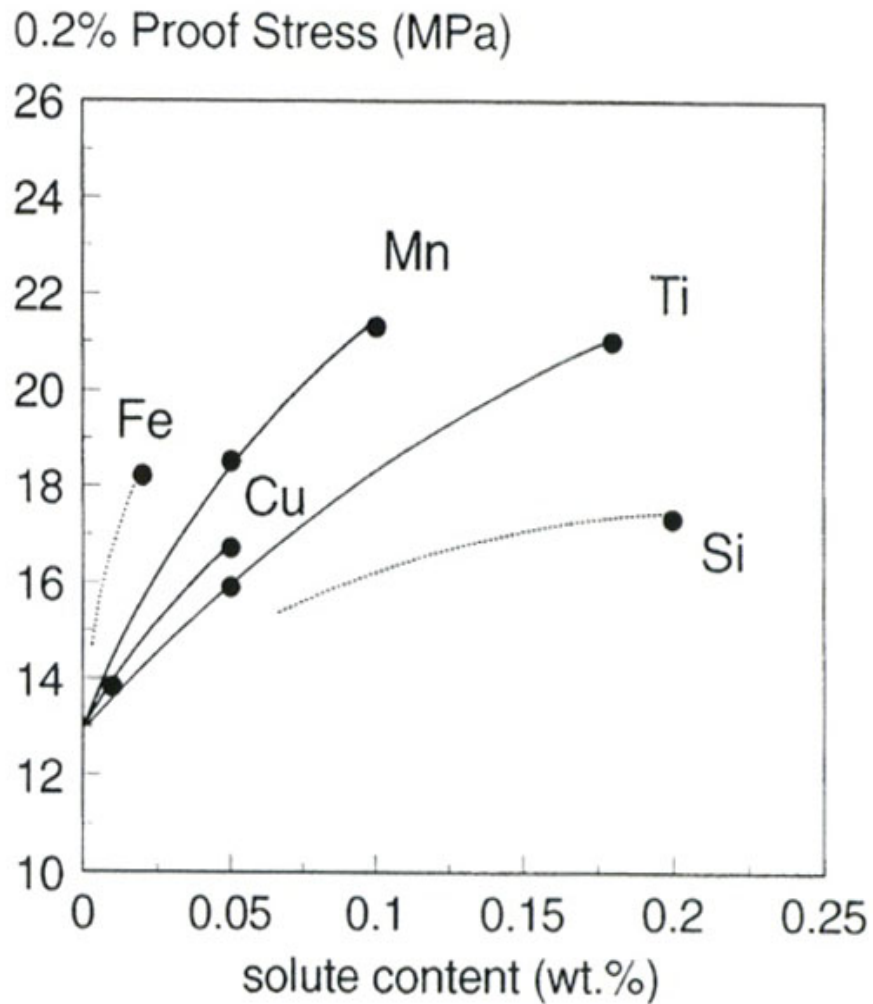
picture:wikipedia

Strengthening Mechanism in Metals and alloys

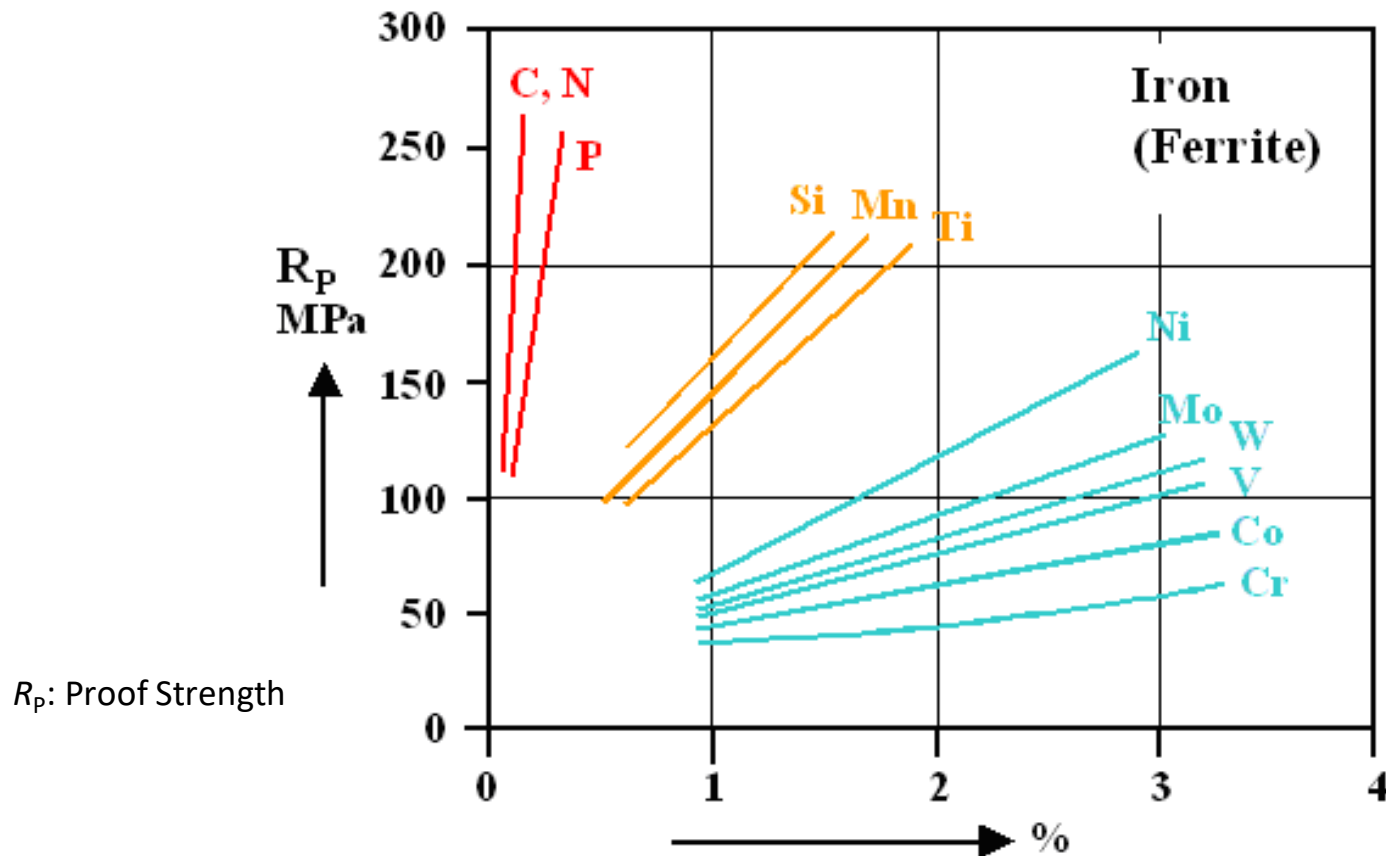
- 0-dim.: Solid solution strengthening
- Interaction Tension: $\tau \approx \sqrt{c}$
 Small atoms \rightarrow local tension force
 Larger atoms \rightarrow local pressure tension



Solid Solution Strengthening in Aluminium



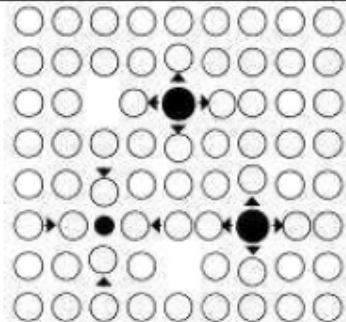
Impact of Point Defects in Iron (and Steel)



Solid solution strengthening of ferritic iron: The increase in strength depends on the type of alloying element as well as on its concentration (in above shown diagram given in percent by weight). Most effective elements for solid solution strengthening are the interstitials carbon (C) and nitrogen (N) plus substitutional phosphorus (P). At zero concentration all curves would converge at around 25 MPa, confirming that pure iron is very soft.

picture: tf.uni-kiel

Lattice Defects, their dimensions and effects

<u>dimension</u>		<u>lattice defect</u>	<u>effect \Rightarrow property</u>
0 = point defects		vacancies, foreign atoms (alloying)	diffusion solid solution hardening \Rightarrow strength