



# Point Defects

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OF ENGINEERING & TECHNOLOGY  
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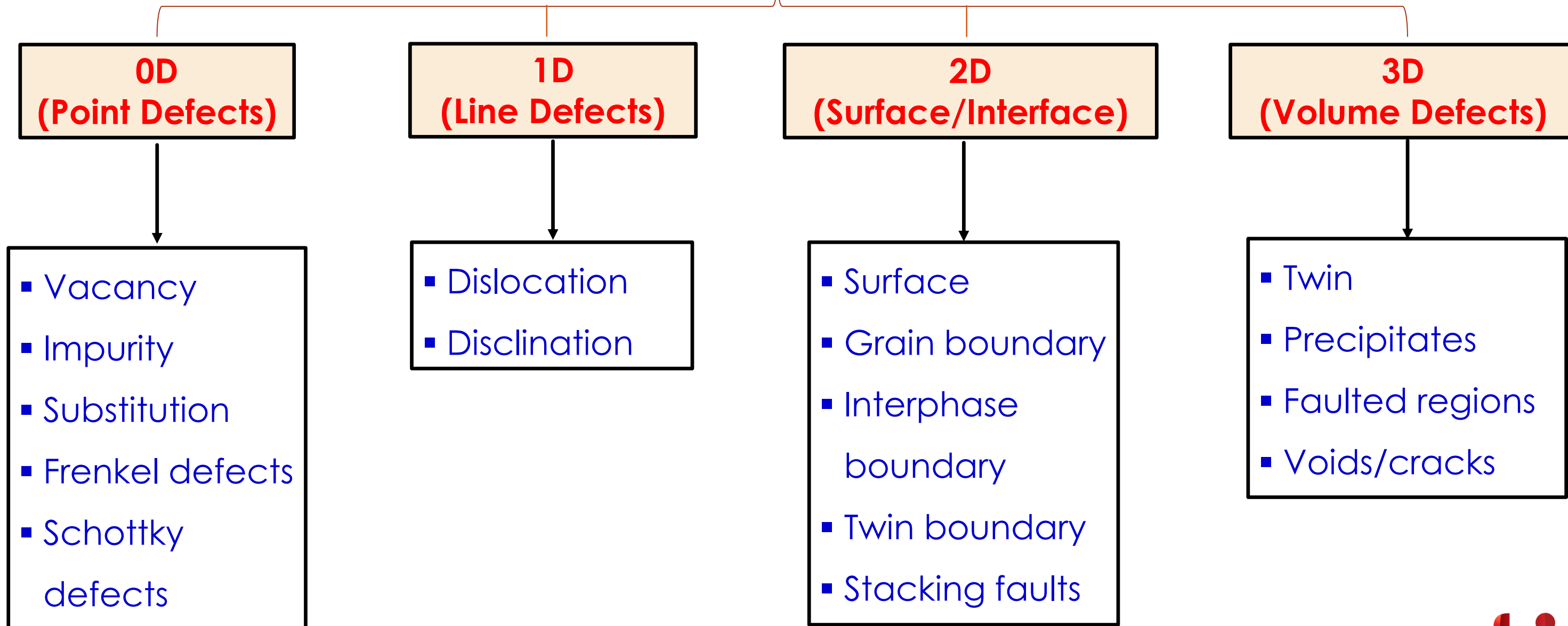
- Structural discontinuity and localized disorder regions are always present in real solids.
- With defects or imperfections, heterogeneity can exist on microscopic and macroscopic scales.

Many properties can be altered by the defects/impurities

For example

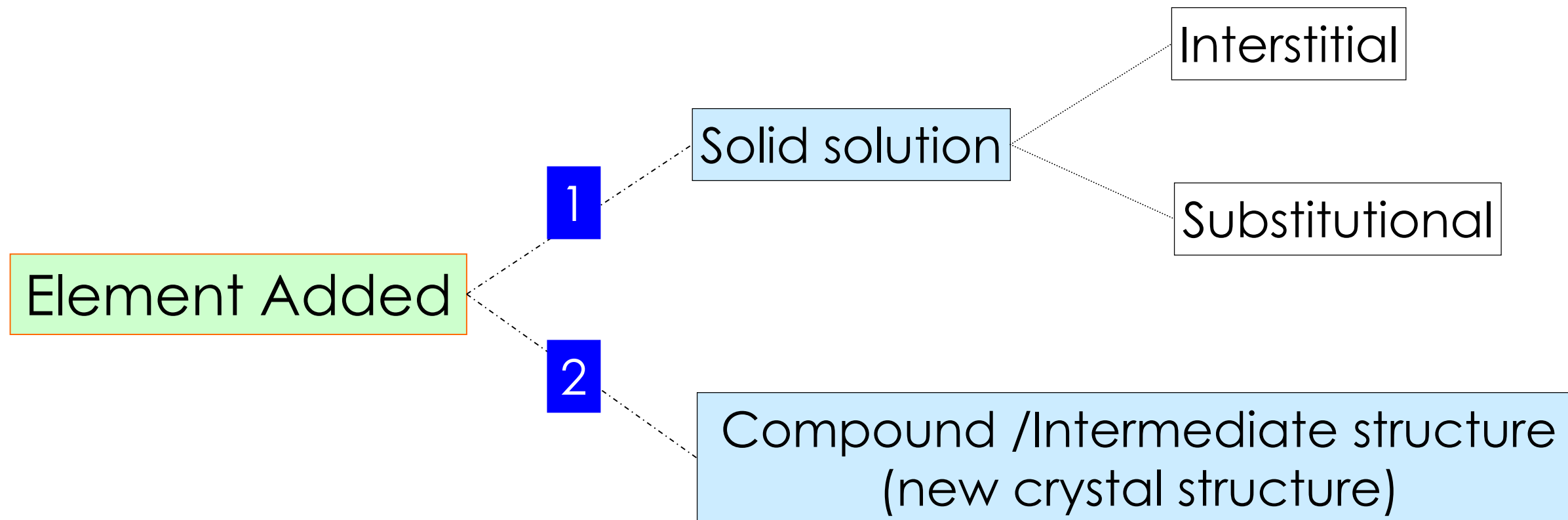
- Ni-, Co-, Ti- based superalloys have better mechanical properties compared to the pure metals.
- Doped semiconductors show much lower resistivity compared to pure semiconductors.
- Absorption or emission of different wavelengths of light by any material can be altered with defects.

## Based on Dimensionality

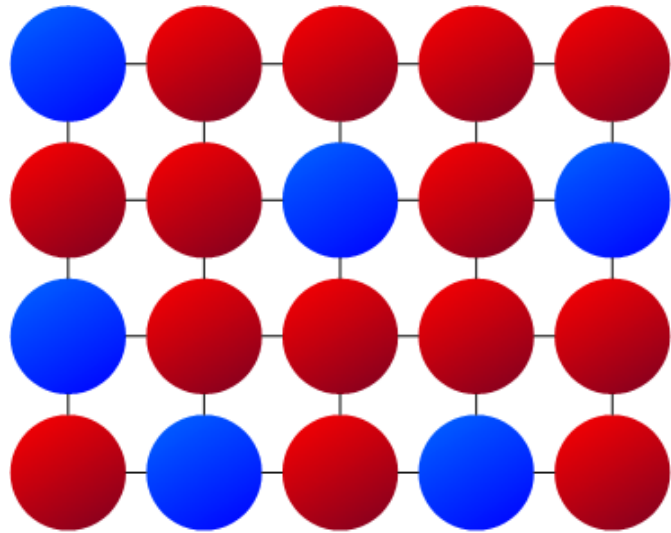


## Alloying

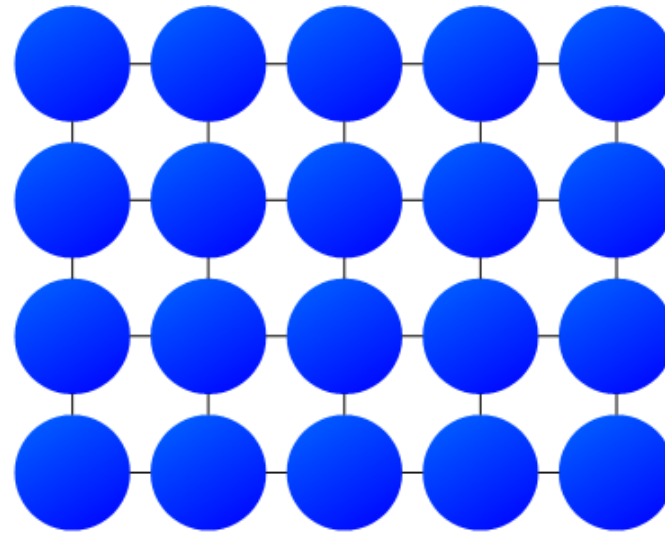
- In a pure material when other elements are added **intentionally** they are called alloying elements.
- When added small quantity it is often called doping
- There is no difference between an '*impurity*' and '*alloying*



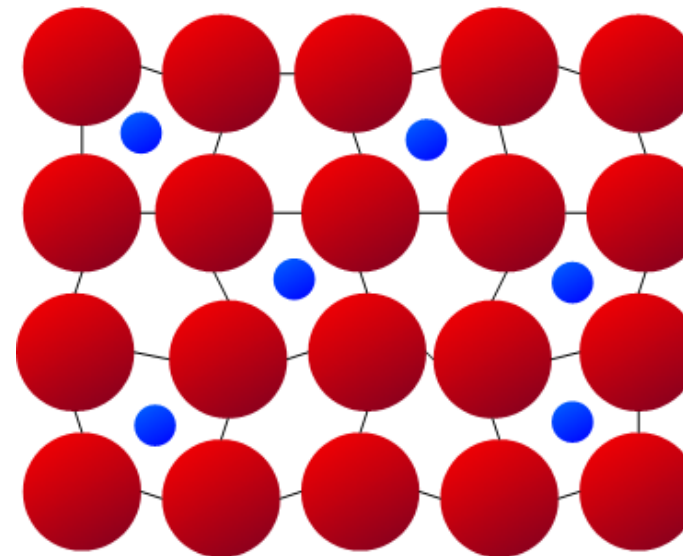
## Substitution and interstitial solid solutions



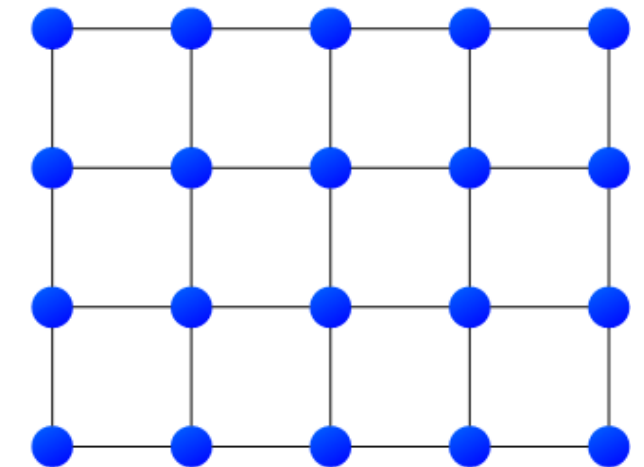
substitution of individual **host**  
**atoms A** by **alloying atoms B**



**alloying element B**



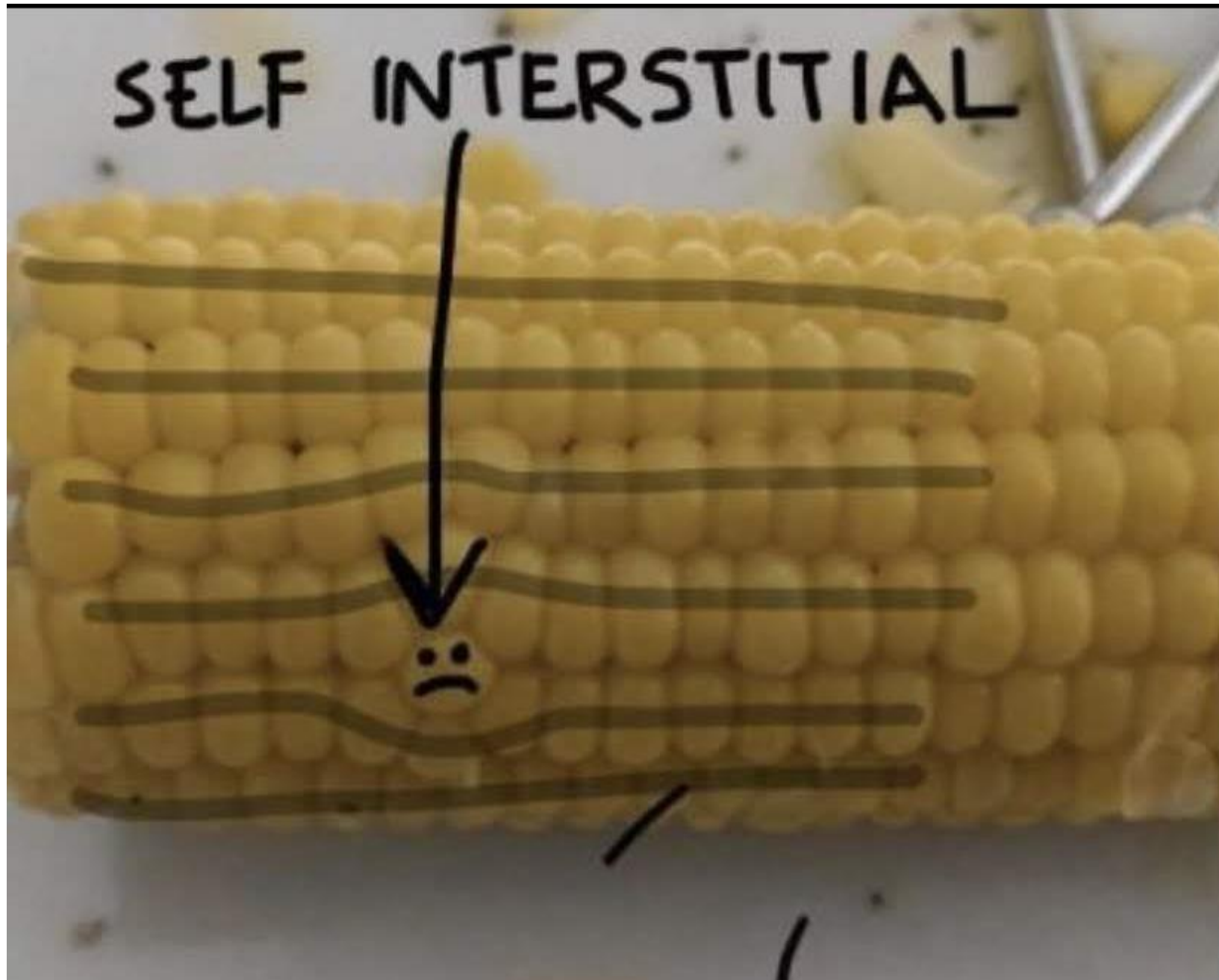
deposition of individual **alloying**  
**atoms B** in the lattice of the **host**  
**component A**



**alloying element B**

# Some basic terms

Substitution and interstitial solid solutions



## Solid solutions

The mixing is at the atomic scale and is analogous to a liquid solution.

### HUME ROTHERY RULES

*Empirical rules for the formation of substitutional solid solution*

1. The solute and solvent atoms do not differ by more than 15% in diameter.
2. The electronegativity difference between the elements is small.
3. The valency of the elements is same.
4. The crystal structure of the elements is same.

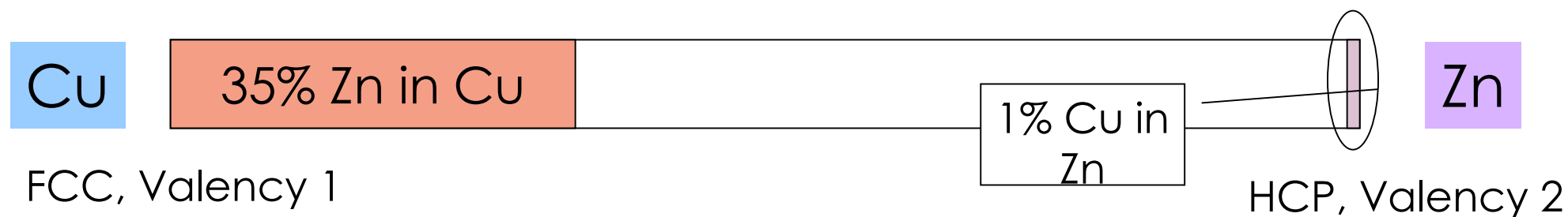
### *Additional rule*

- Element with higher valency is dissolved more in an element of lower valency rather than vice-versa.

## Example Hume-Rothery rule

System		Crystal structure	Radius of atoms (Å)	Valency	Electronegativity
Ag-Au	Ag	FCC	1.44	1	1.9
	Au	FCC	1.44	1	2.4
Cu-Ni	Cu	FCC	1.28	1	1.9
	Ni	FCC	1.25	2	1.8
Ge-Si	Ge	DC	1.22	4	1.8
	Si	DC	1.18	4	1.8

*Example of a pair of elements not forming solid solution in all proportions*

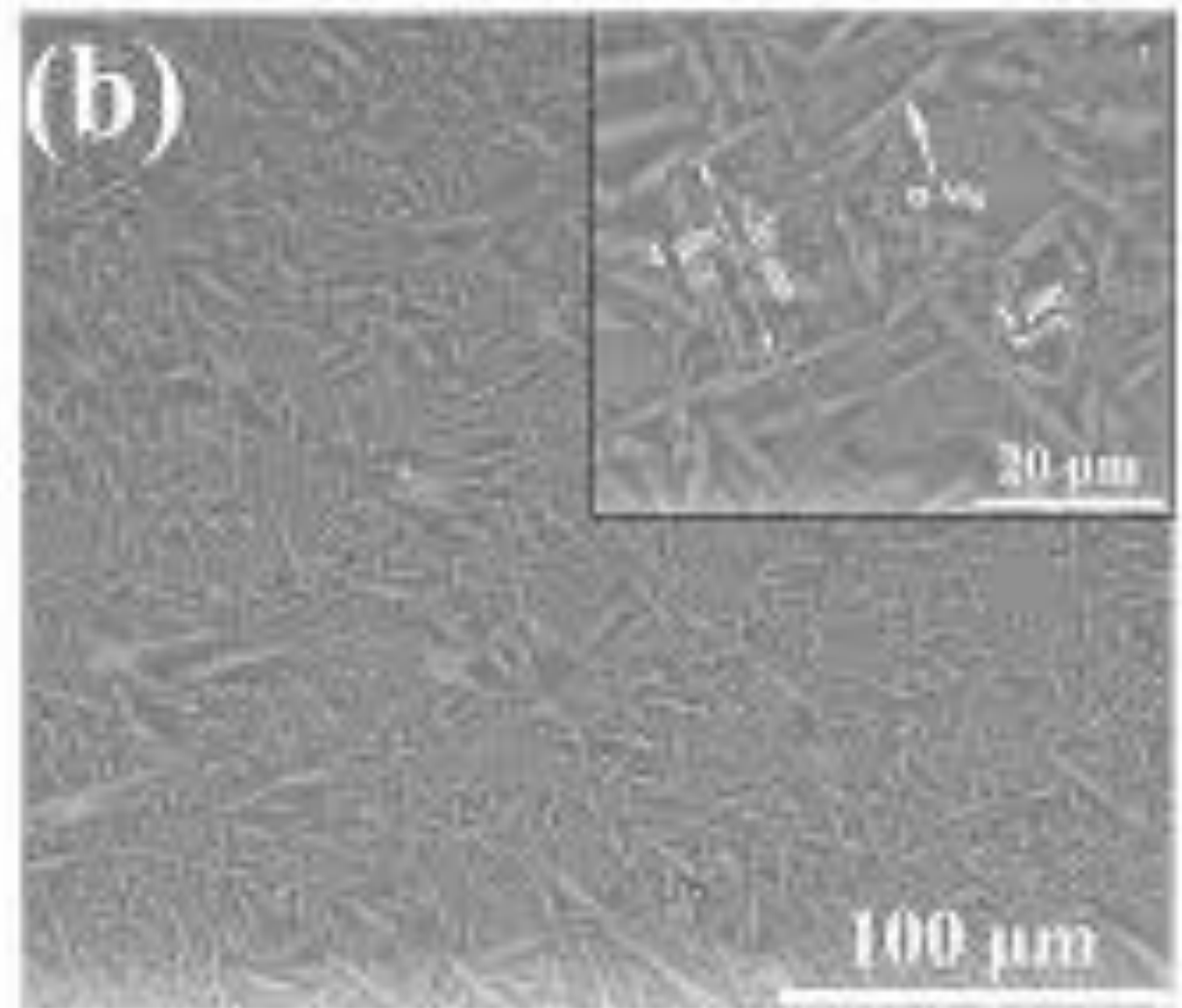
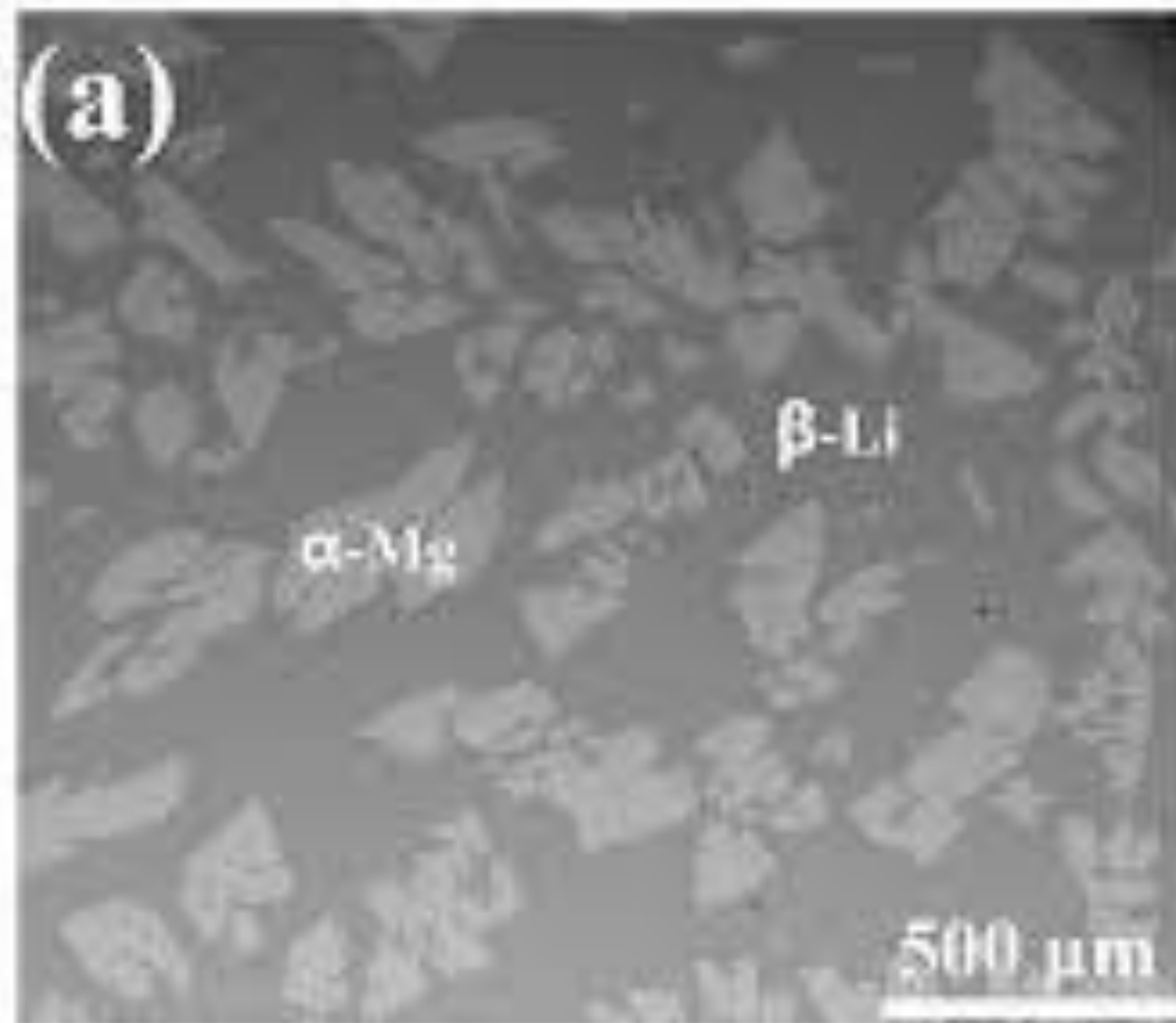




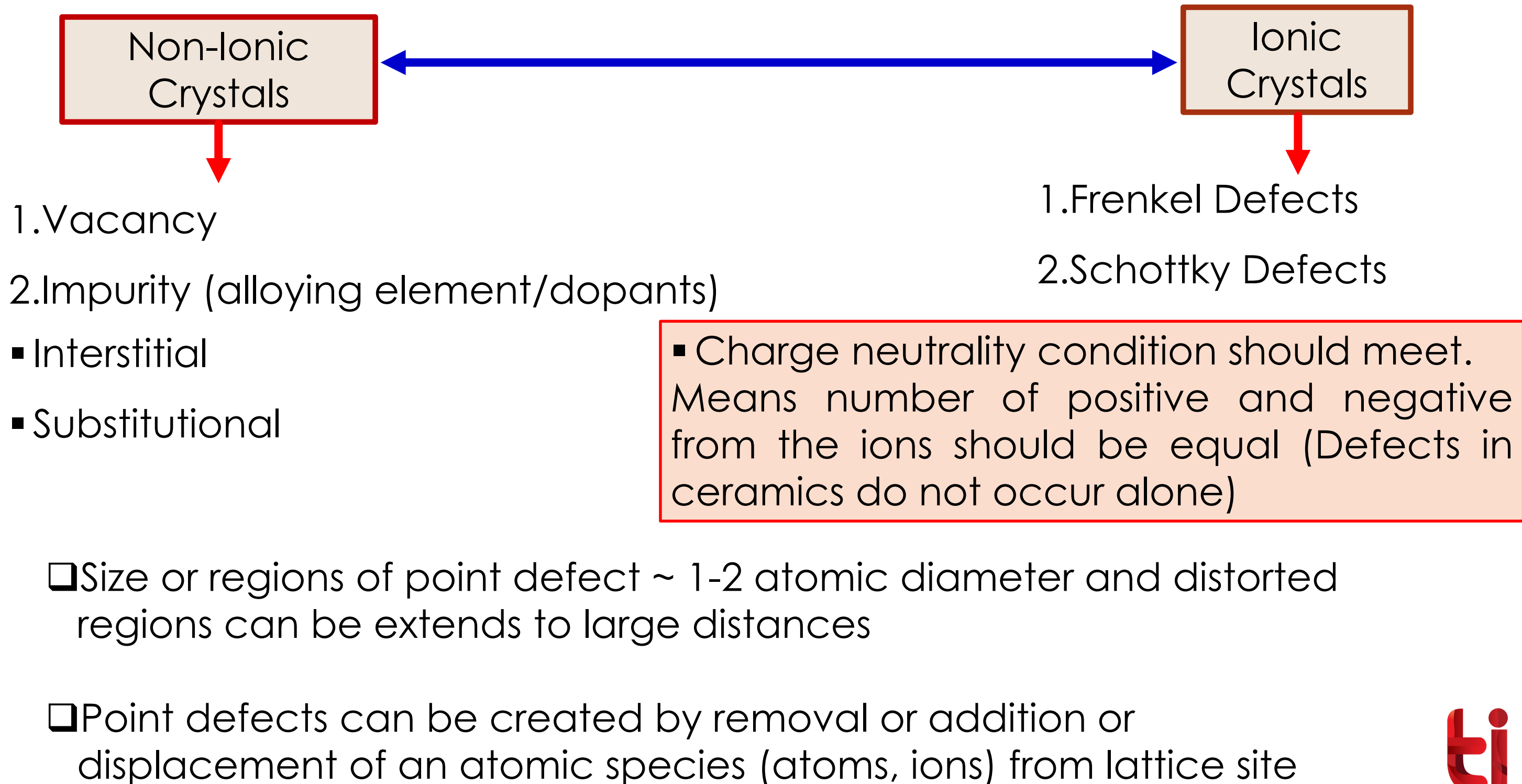
# Some basic terms

Examples of Alloy and

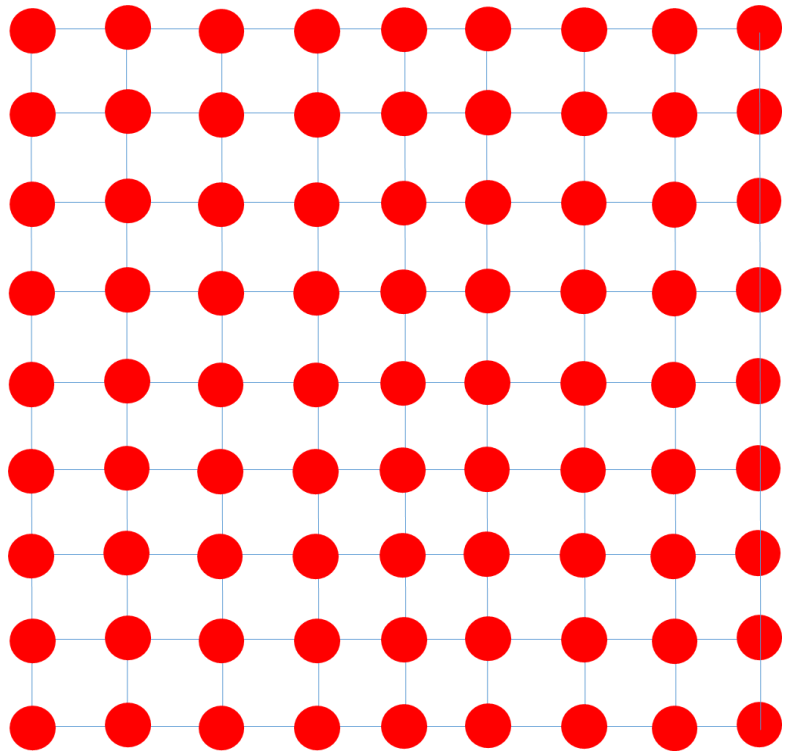
Solid solutions



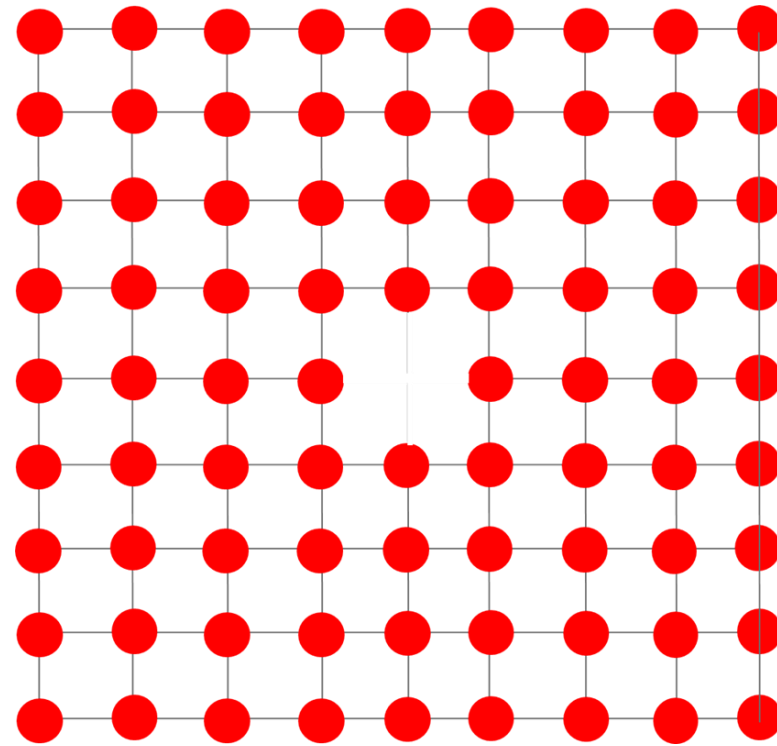
Solid solutions is atomic level mixing



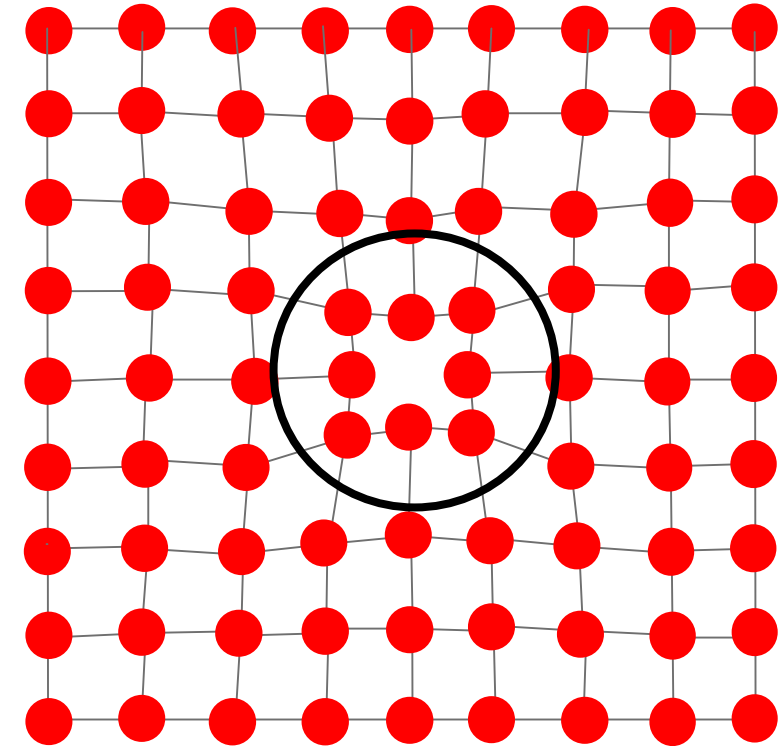
## Vacancy



Perfect crystal



Atom is missing from lattice site  
(creation of vacancy)

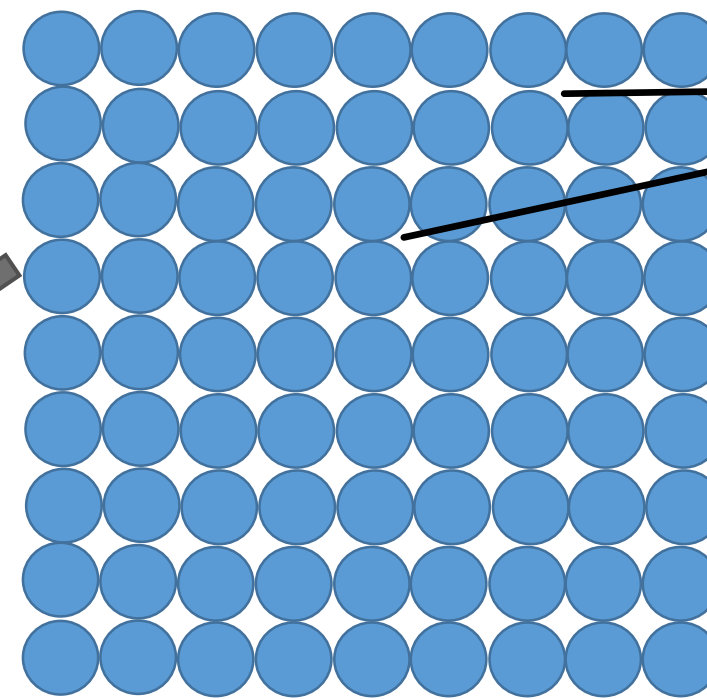


Lattice strain  
around the  
vacancy

# Point Defects (zero dimensional) : Non-Ionic Solids

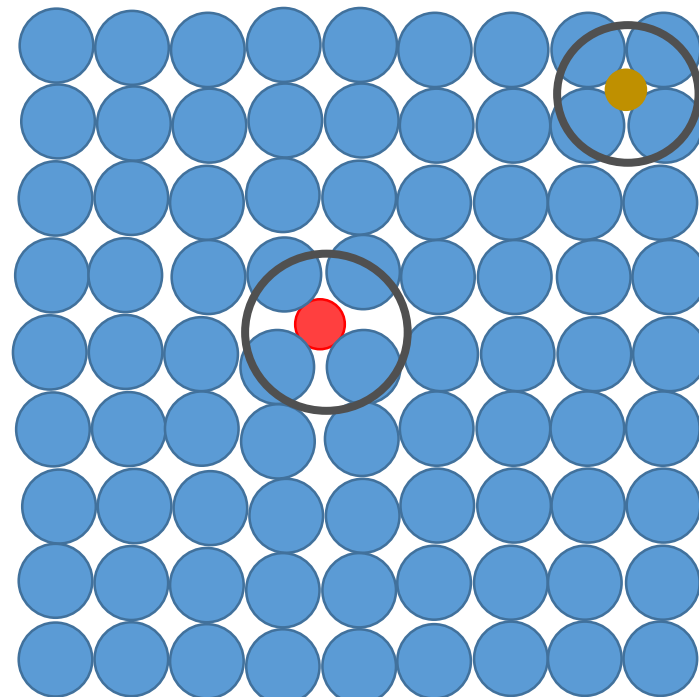
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Impurity (Alloying  
element/Dopant)



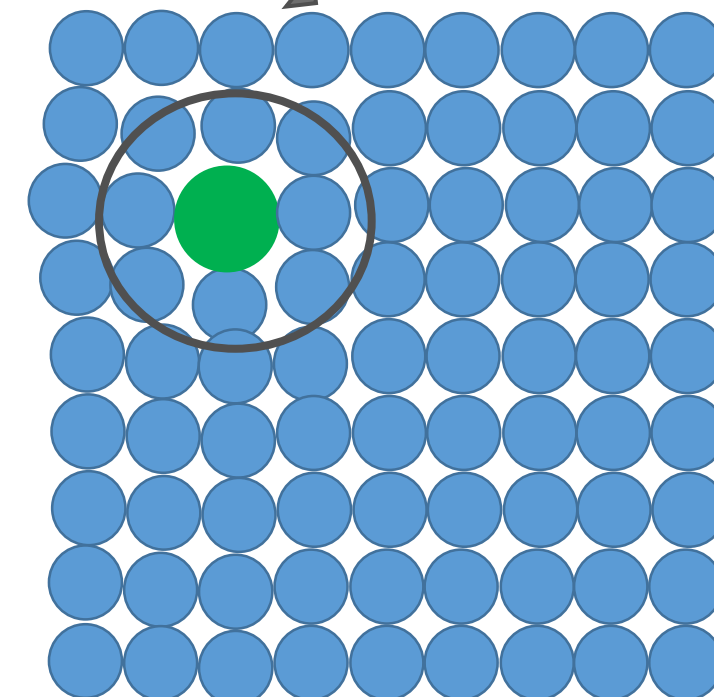
Void (interstitial sites)

Interstitial



Crystal with impurity  
atom sitting in the voids

Substitutional



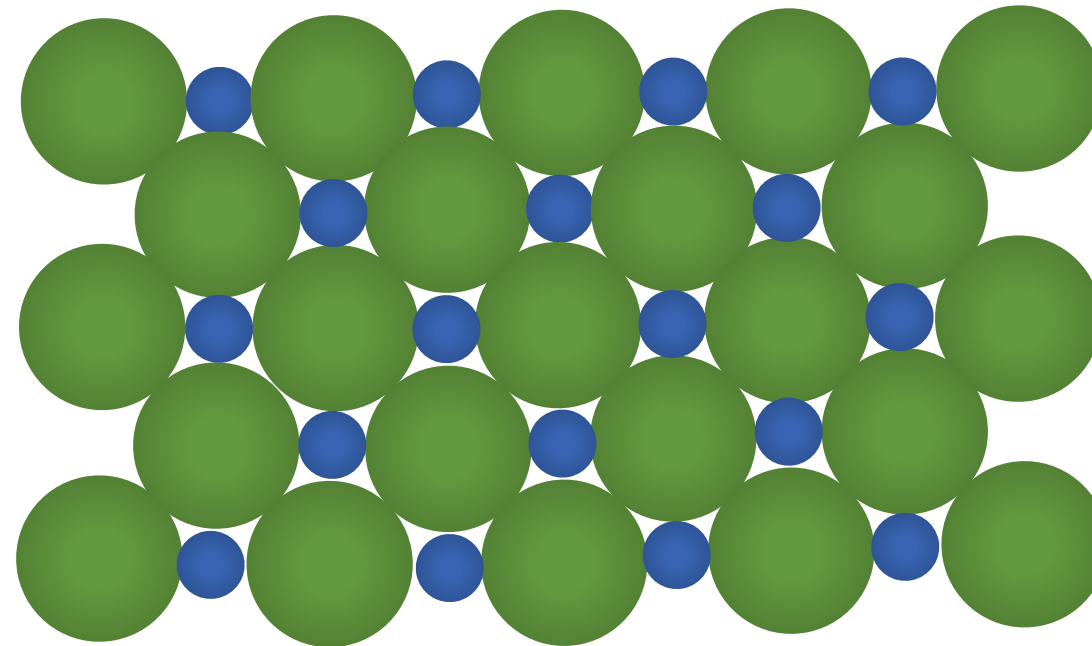
Impurity atom is replaced  
with parent atom of crystal



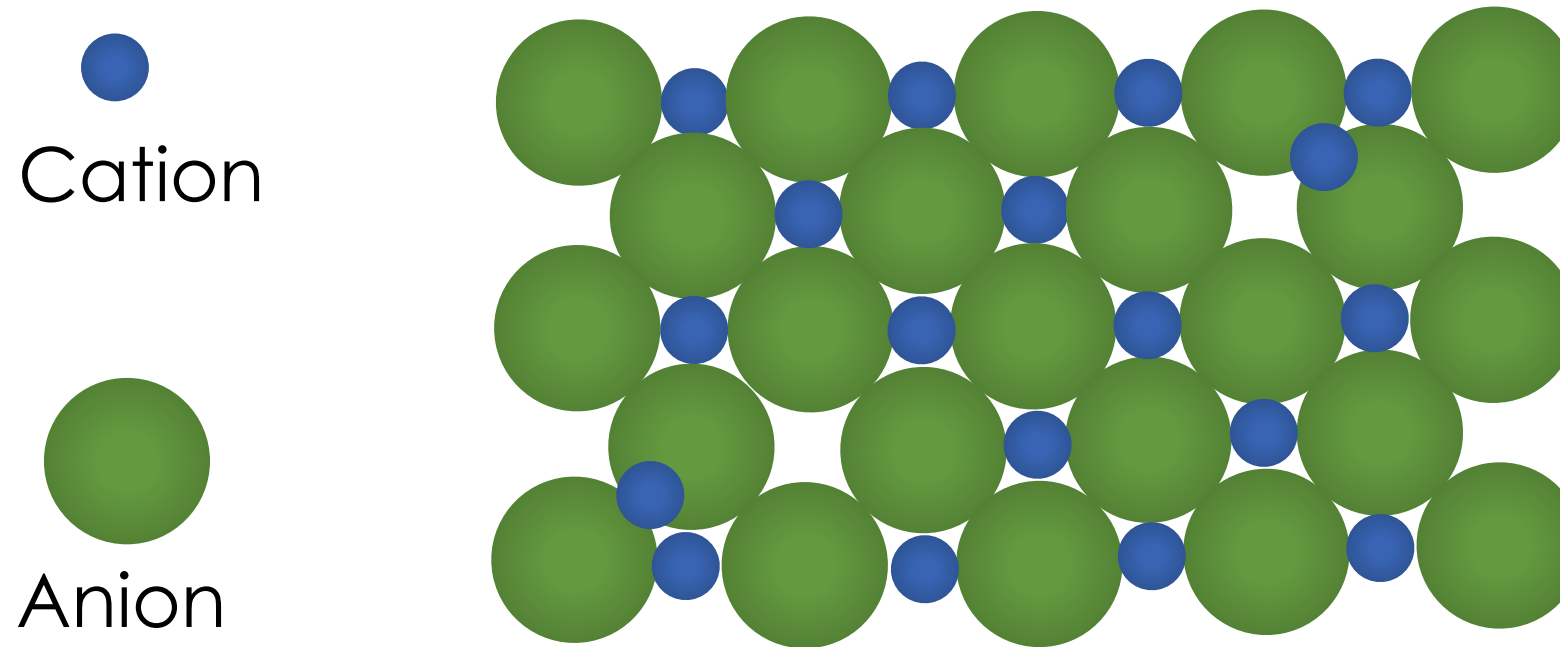
## Perfect Crystal

  
Cation

  
Anion



## Frenkel Defect

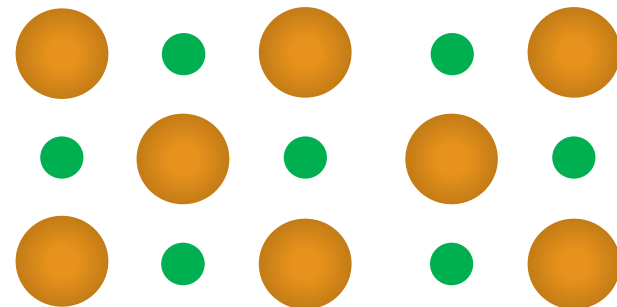


- ❑ Cation being smaller displaced to interstitial sites
- ❑ Charge neutrality maintained
- ❑ No change in density
- ❑ Examples: NaCl, AgBr, KCl,  $\text{CaF}_2$

## Impurities (Ionic Solids)

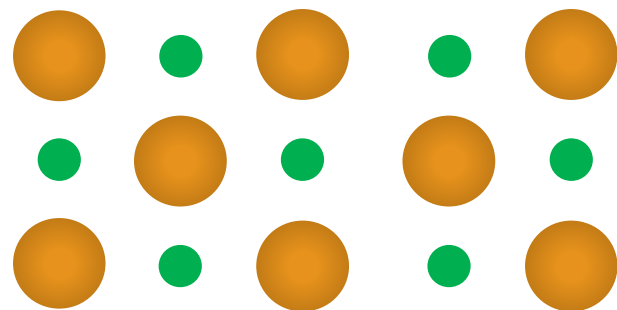
Example: KCl     ●  $\text{K}^+$      ●  $\text{Cl}^-$

### Substitutional cation impurity



Initial geometry

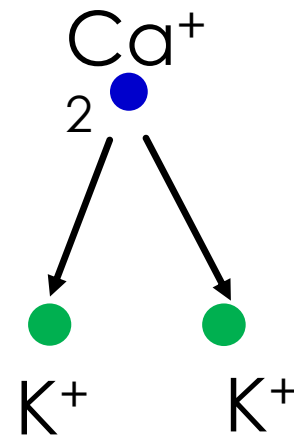
### Substitutional anion impurity



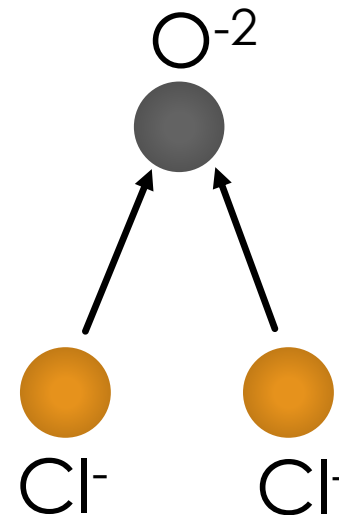
Initial geometry

Must satisfy charge neutrality condition

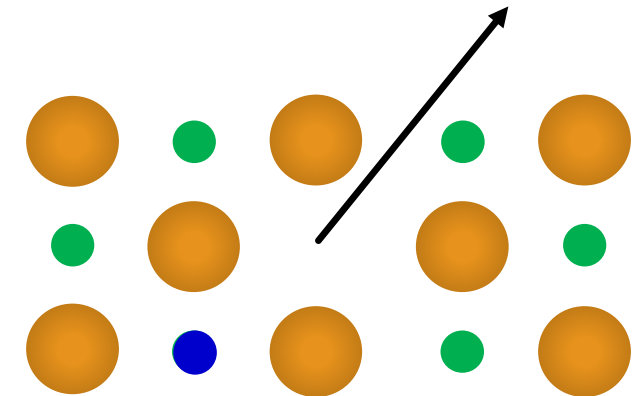
Replaced



Replaced

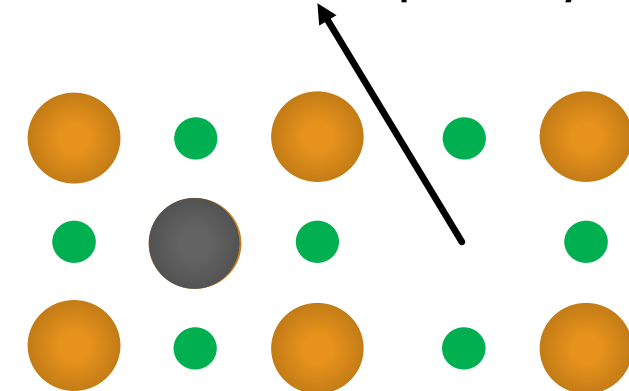


Cation impurity




Final geometry

Anion impurity

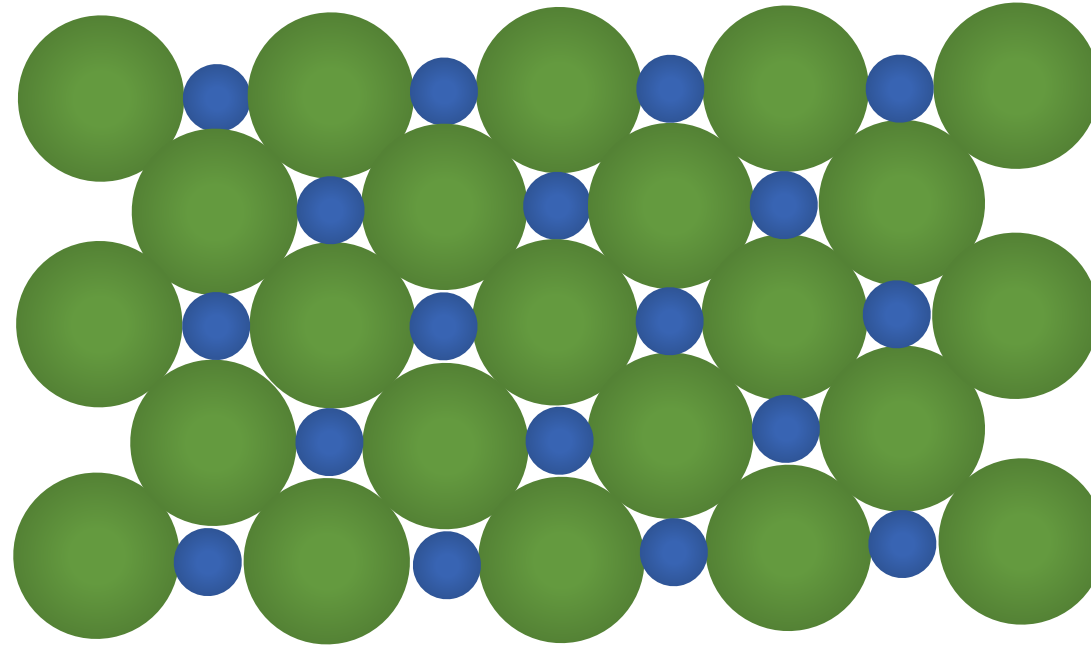


Final geometry

## Perfect Crystal

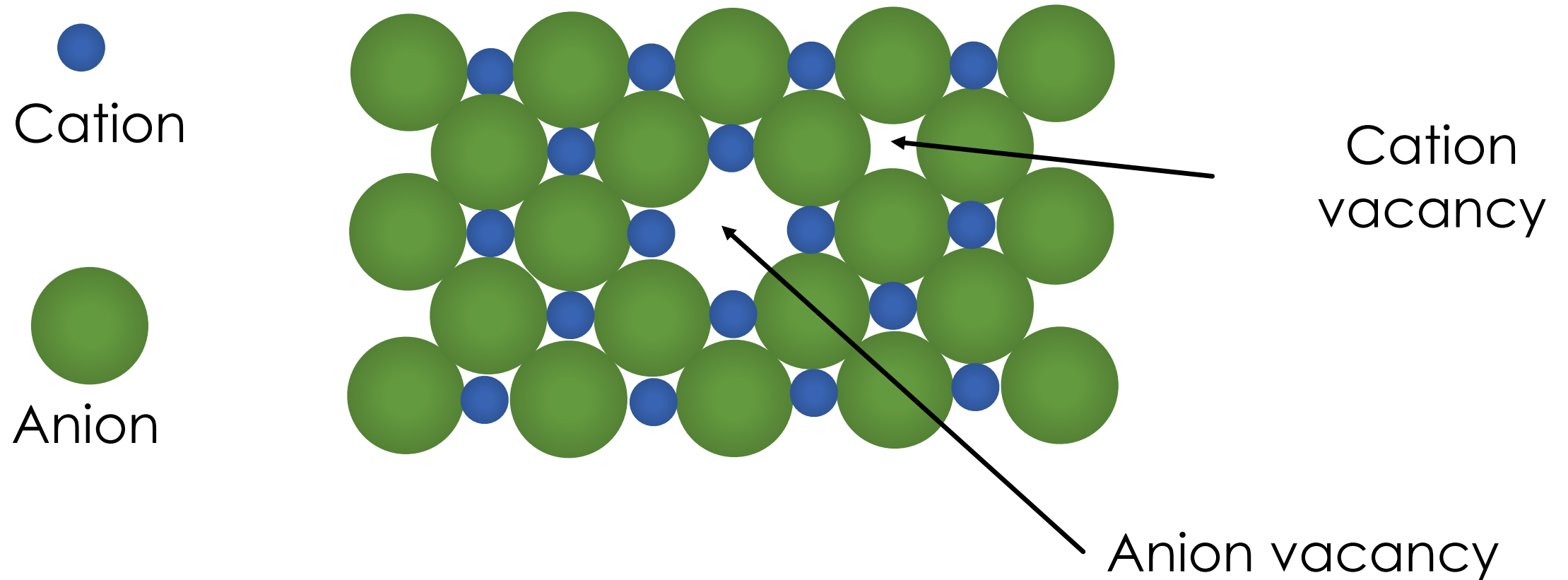
  
Cation

  
Anion





## Schottky Defect



- ❑ A Pair of anion and cation missing
- ❑ Charge neutrality maintained
- ❑ Change in density
- ❑ Examples: NaCl, AgBr, KCl,  $\text{CaF}_2$

# Concentration of point defects

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Change in free energy of crystal when we add  $n$  point defects in one mole of crystal

$$\Delta G = \Delta H - T\Delta S = n\Delta H_f - kT[N\ln N - (N - n)\ln(N - n) - n\ln n]$$

Where  $N$  is the Avogadro number

At equilibrium,

$$\frac{d\Delta G}{dn} = 0$$

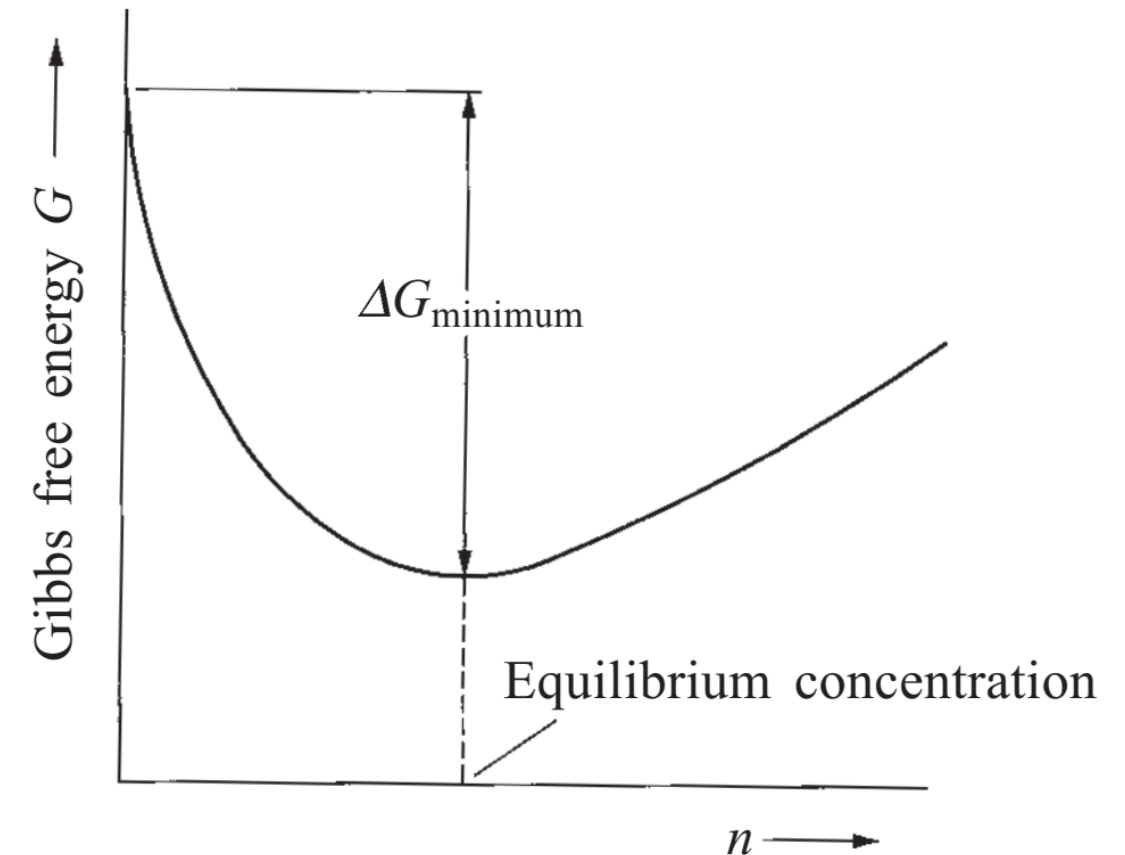
$$\frac{n}{N} = \exp.\left(-\frac{H_f}{RT}\right)$$

Where  $R$  is gas constant

OR

$$\frac{n}{N} = \exp.\left(-\frac{Q_d}{kT}\right)$$

Where  $N$ ,  $Q$  and  $k$  is the Avogadro number, activation energy and Boltzmann constant respectively.



$$\frac{n}{N} = \exp.\left(-\frac{H_f}{2RT}\right)$$

Where R is gas constant

OR

$$\frac{n}{N} = \exp.\left(-\frac{Q_d}{2kT}\right)$$

Where N, Q and k is the Avogadro number, activation energy and Boltzmann constant respectively

The factor 2 appears because the energy of formation  $H_f$  or  $Q_d$  refers to the formation of the defect pair.

1. Hume-Rothery condition is for the formation of solid solutions.
2. Defects can alter the properties of the materials.
3. Frenkel and Schottky defects takes place only in ionic solids.
4. Charge neutrality must be maintained in ionic solids.
5. Solid solutions is the atomic level mixing of atoms.



1. FCC lead has a lattice parameter of 0.4949 nm and contains one vacancy per 500 Pb atoms. Calculate (a) the density; and (b) the number of vacancies per gram of Pb.
2. Determination of the number of vacancies per cubic meter in gold at 900 °C. Given that the formation energy of the defect is 0.98 eV/atom, atomic weight is 197 g/mol and density of 19.32 g/cm<sup>3</sup>.
3. Calculate the activation energy for vacancy formation in aluminum, given that the equilibrium number of vacancies at 500 C is  $7.57 \times 10^{23} \text{ m}^{-3}$ . The atomic weight and density for aluminum are, respectively, 26.98 g/mol and 2.62 g/cm<sup>3</sup>.
4. Average energy required to create Frenkel defect in an ionic crystal is 1.4 eV. Calculate the ratio of Frenkel defects at 20°C and 300°C in 1 gram of crystal.