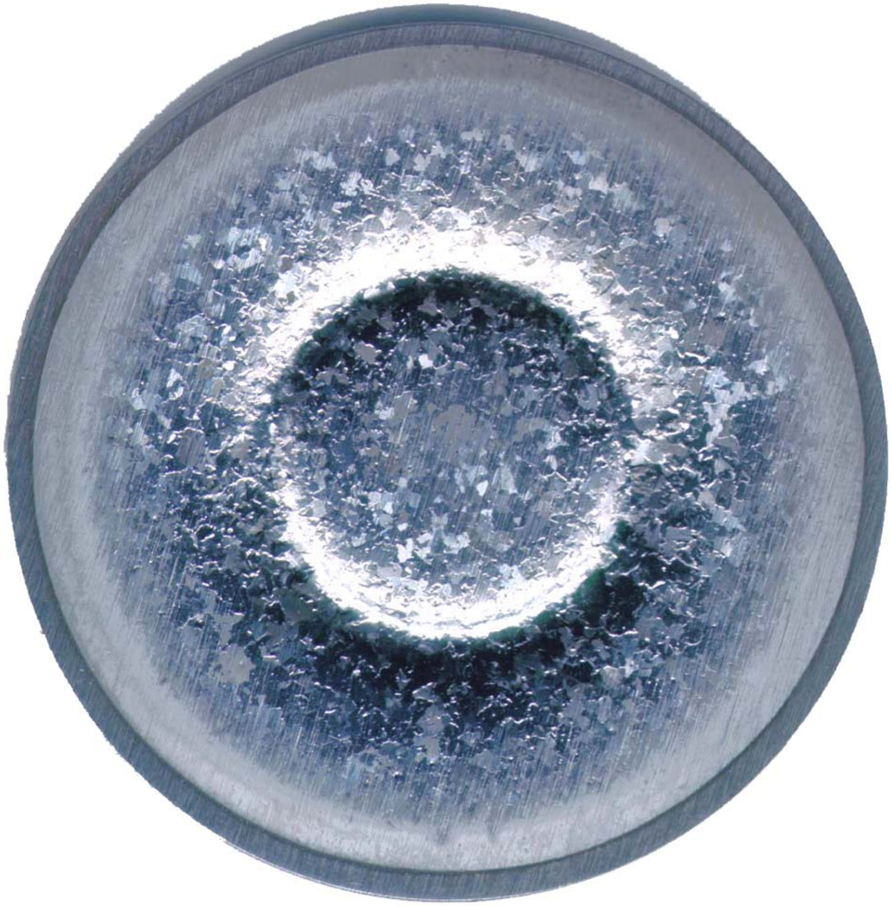
Announcements

- WebCT Quiz#1 – Average was about 92%
- Great job!
- In line with your survey responses
  - You have a good understanding of physics and chemistry (Class average 4.2 out of 5)
  - 98% of you have completed your university-level Chemistry and Physics
- Ch. 4 homework is posted on WebCT. Ch. 3 solutions after Monday's lecture 2nd half

To start today, we ask the question…

what is this?



$d = 2$ inches

what is it?

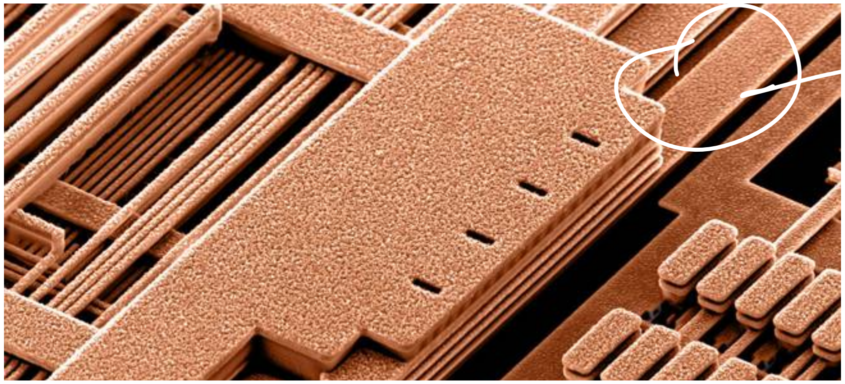
Metal "Poly" Crystalline

Shiny

Fe

What it actually is?

- Someone asked the very first day… what is "vapor deposition"?



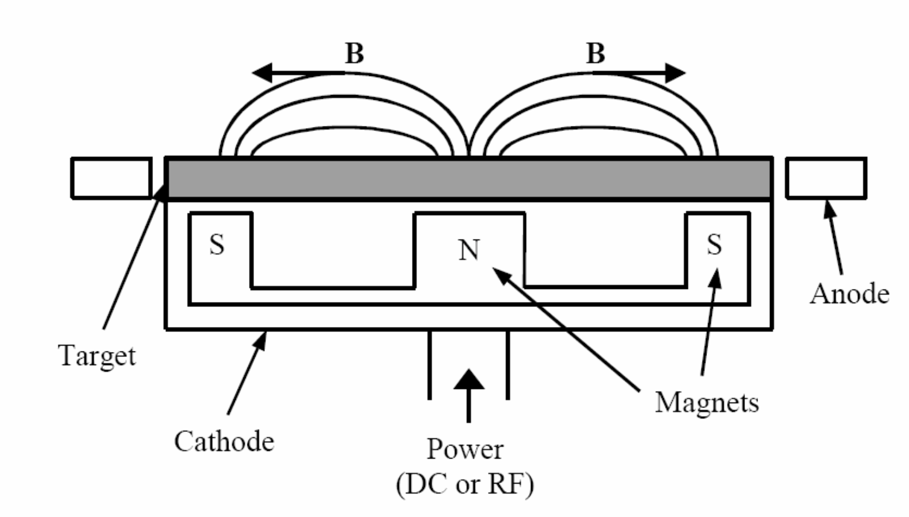
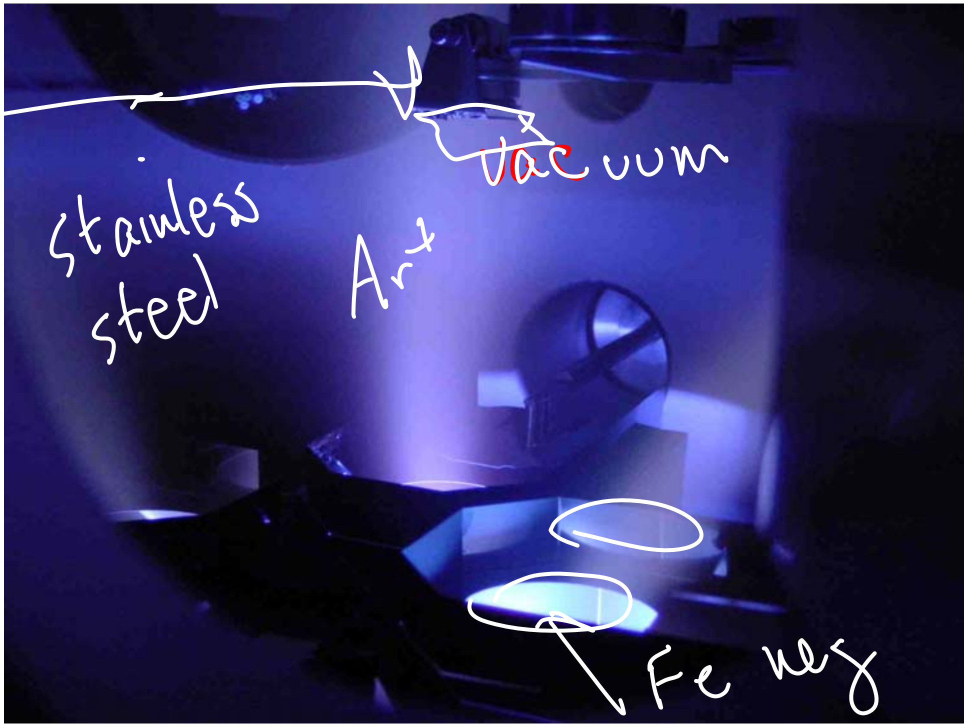


Figure 2.2- A sketch of some of the components of a magnetron sputtering gun.



Would you consider ‘vapor deposition’ to be an "ideal" materials preparation technique?

Defects

One reason the next topic is important

- Electrical resistivity of a metal?

scattering events → electron, ion

THERMAL

"phonons"

$$\rho_{total} = \rho_{thermal} + \rho_{impurities} + \rho_{defects}$$

SINGLE CRYSTALS AND POLYCRYSTALS

-A group of one or more unit cells = a single crystal

(a grain)

-A group of more than one grain = a polycrystal

(but not termed a polygrain!)

-Under normal (i.e. industrial) circumstances,

all crystalline solids are polycrystals

Liquids can be made to solidify as a single crystal

(Single crystals are very important in the electronics and aerospace industries.)

ISOTROPY/ANISOTROPY AND TEXTURE

Isotropy: material has same properties in all directions

Anisotropy

material has different properties in different directions

-A single crystal exhibits anisotropy because of different linear and planar atomic arrangements

-In a polycrystal,

-the single crystals are basically randomly oriented to each other

-therefore imparting isotropic properties to the polycrystal.

WHICH IS BETTER?

-Materials can be processed to orient polycrystals in one specific direction

-takes advantage of property in one particular crystal direction.

-resulting polycrystal has anisotropic properties = texture.

(aka: crystallographic texture)

preferred orientation

Very important for :

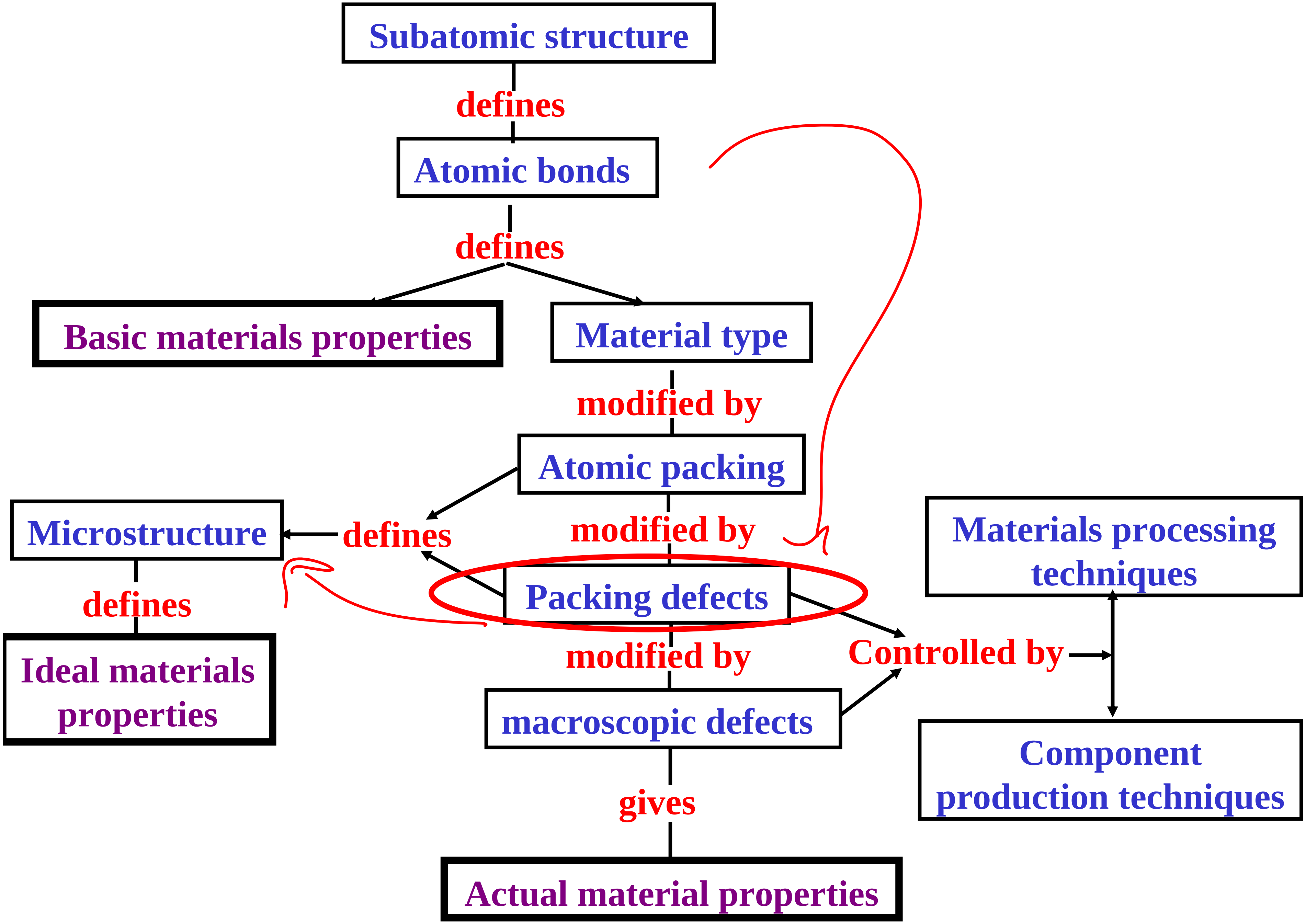
manufacturing products by cold forming (deformation) (e.g. cans)

magnetic properties,

fracture resistance and strength.

(note, 'surface texture' usually concerns topography, not crystallography)

careful



Subatomic structure

defines

Atomic bonds

defines

Basic materials properties

Material type

modified by

Atomic packing

modified by

Microstructure

defines

Packing defects

defines

Ideal materials properties

modified by

macroscopic defects

Controlled by

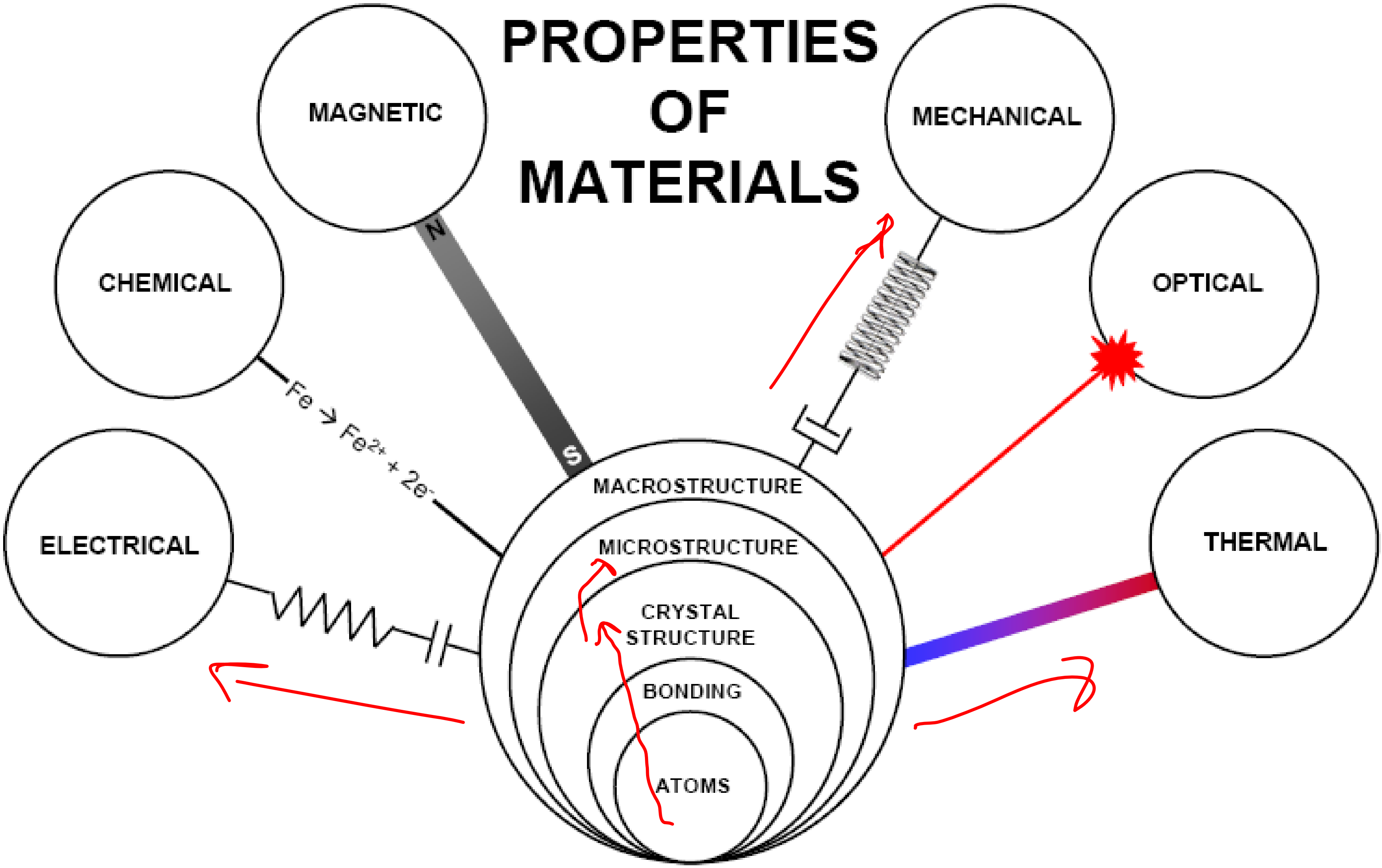
Materials processing techniques

Component production techniques

gives

Actual material properties

PROPERTIES OF MATERIALS



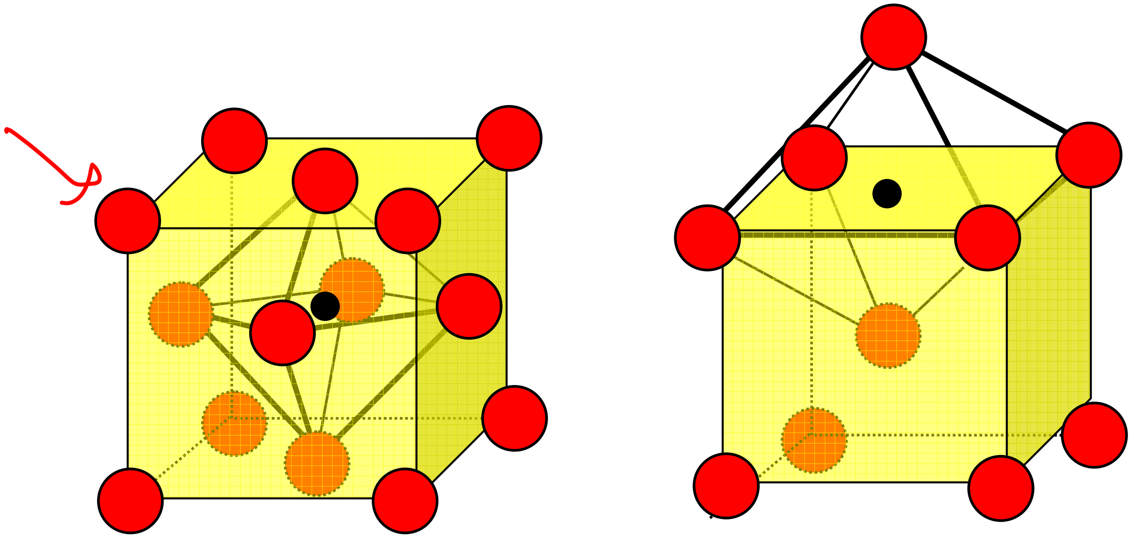
STRUCTURE OF MATERIALS

INTERSTICES

← interstitial sites

-3D spaces in crystals

OCTAHEDRAL SITES



INTERSTICES

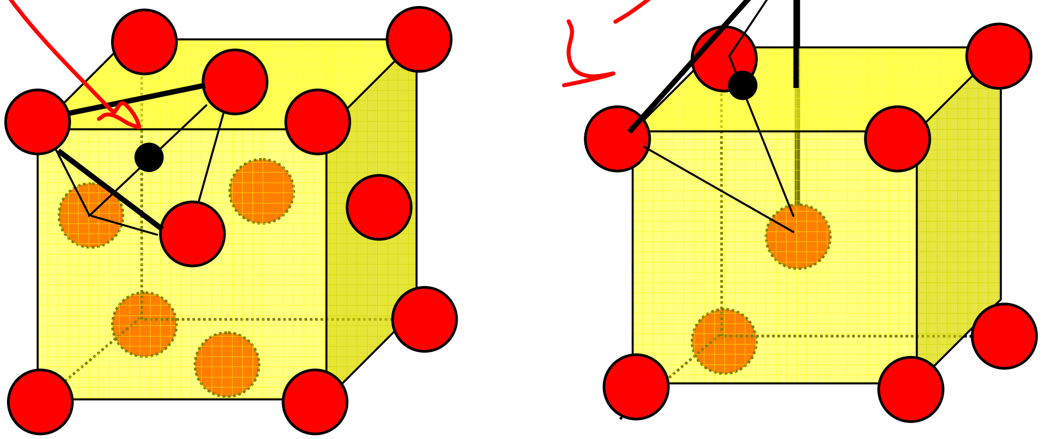
-3D spaces in crystals

C, H, N

TETRAHEDRAL SITES

Impurity

Close packed

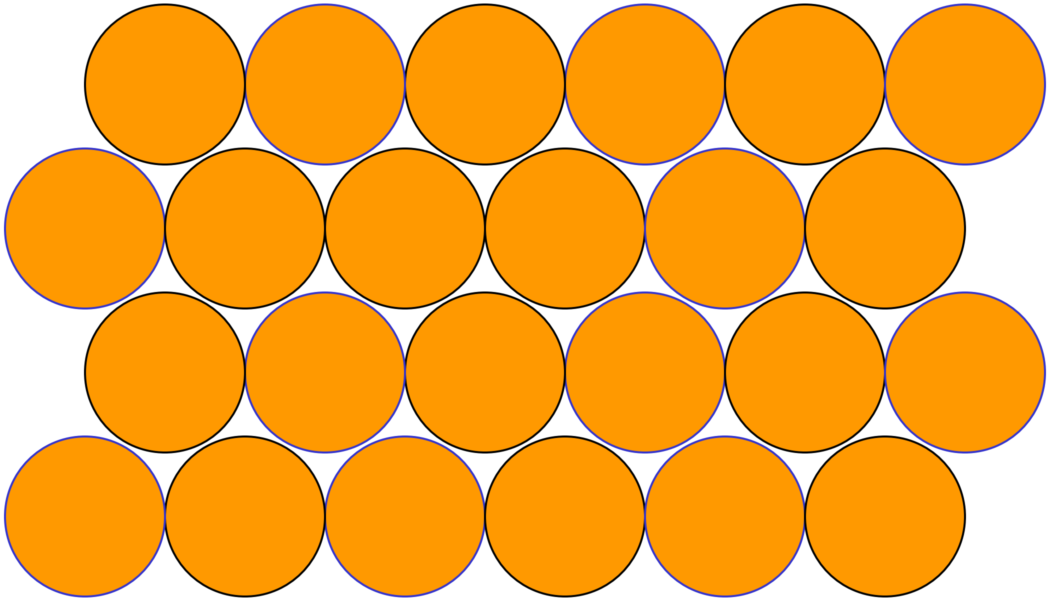


NOTE: Interstices themselves are not defects. They are simply locations in the crystal that appear naturally once you define the lattice.

structure → properties

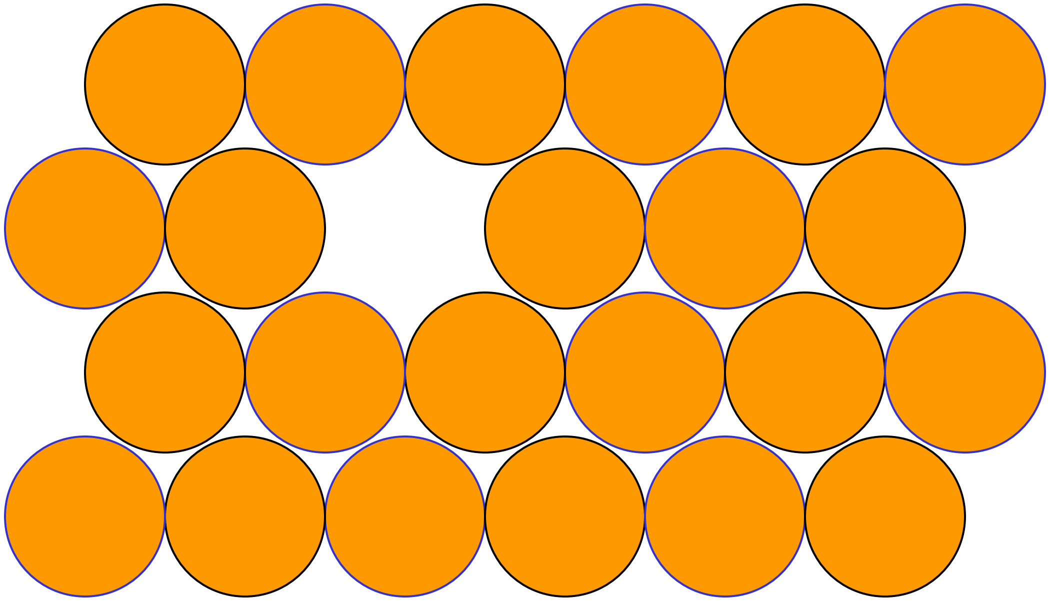
CRYSTAL DEFECTS

Responsible for many properties



CRYSTAL DEFECTS

Responsible for many properties



Vacancies

Point defects

POINT DEFECTS

Vacancy

-atom missing from a site

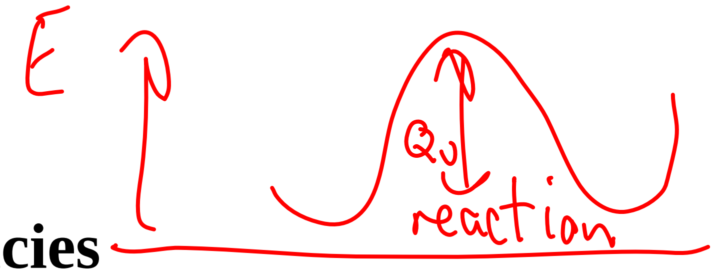
-simplest defect

they exist because of

entropy

tendency to disorder

POINT DEFECTS



- increase in **temperature** creates vacancies
  because atomic vibration amplitude increases with temp;
- atomic vibrations* can **displace** atoms

Equilibrium* **number of vacancies, N_v, increases with temp, T:**

$$N_v = N \exp\left(\frac{-Q_v}{kT}\right)$$

total number of atomic sites

Boltzmann's const

activation energy (energy required to displace atom)

Temperature

(just below M.Pt., 1 out of 10000 atom sites will be empty)

POINT DEFECTS

Impurities in solids

Impurities are always present (purest metals are 99.9999%pure) because of

99.5 99.9

entropy

is copper pure?

(major recycling problem*)

**Note:
impurities are NOT DELIBERATE additions**

Impurities can form solid solutions or second phases depending on concentration and temperature.

POINT DEFECTS

solid solution:

impurity has completely intermixed with the parent or host atoms

(the impurity is the 'solute', the parent element is the ‘solvent’)

compositionally homogenous

(i.e. impurity atoms completely and randomly distributed.)

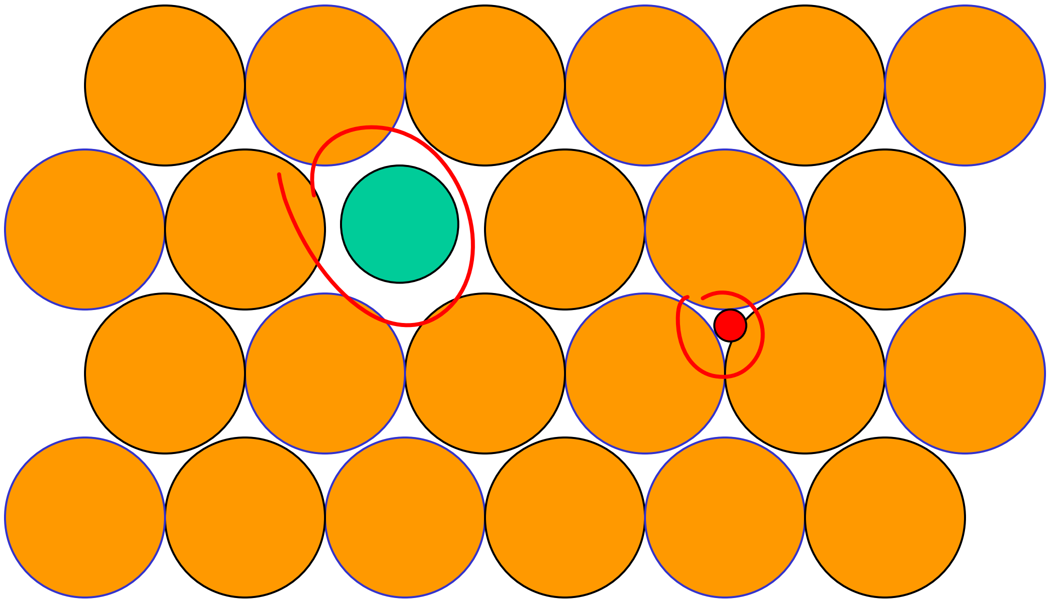
second phase

impurity has formed another phase……

(different crystal structure and/or compound),

…..either with the host atoms and/or with other impurities.

POINT DEFECTS



Vacancies

Substitutional atoms

interstitial atoms

POINT DEFECTS

Solid solutions

Interstitial solid solution

Small impurity atoms can fit in interstices

(= interstitial atom)

Atom size should be lower than host interstitial spacing.

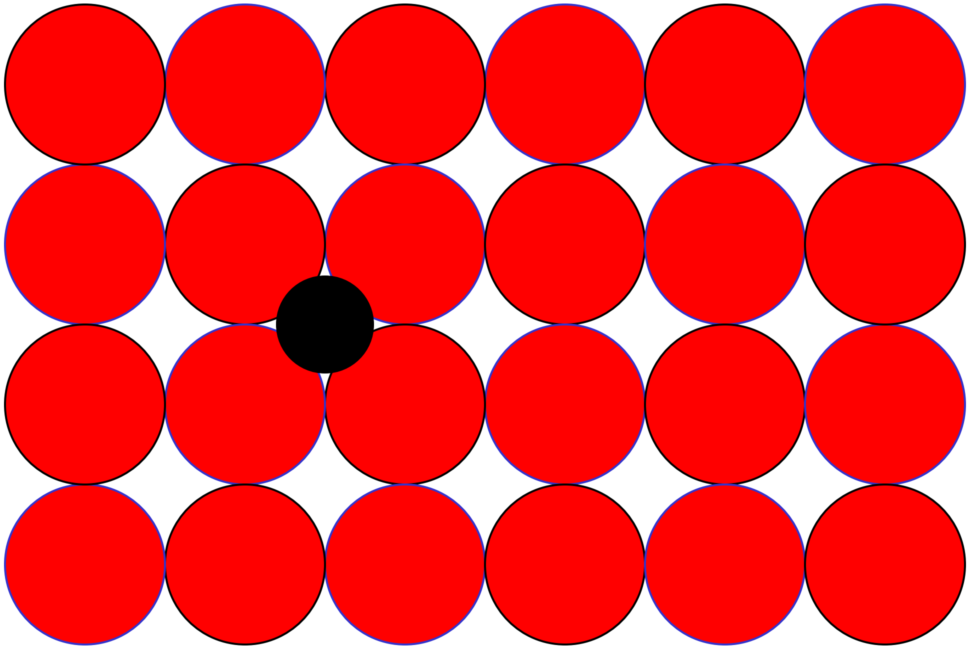
BUT metals have high APFs,

C H N

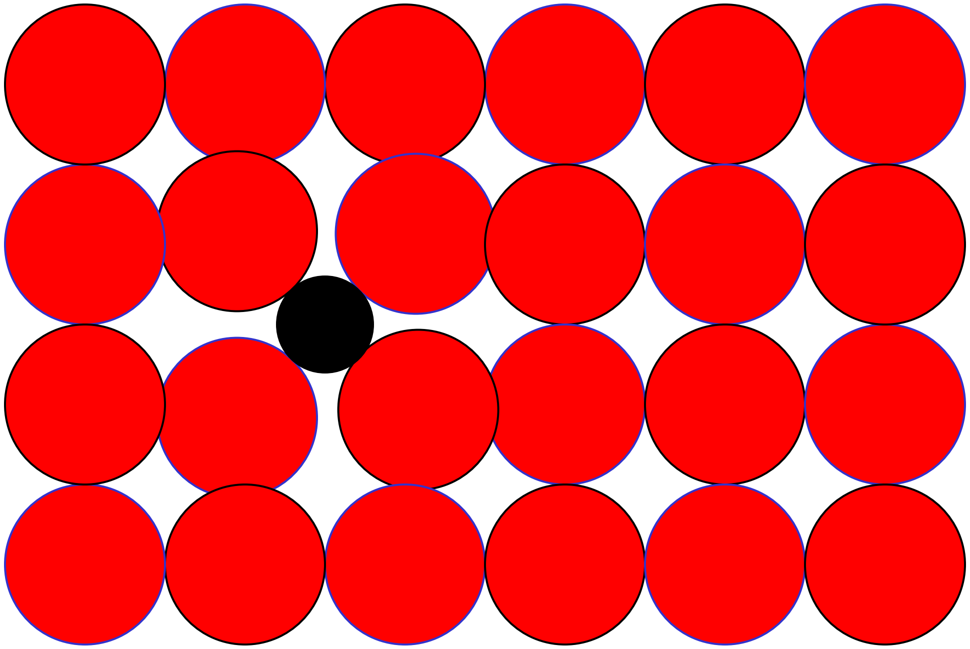
- **few elements are small enough to be ideal interstitials**

BUT 'many' elements can squeeze into interstitial sites.

POINT DEFECTS



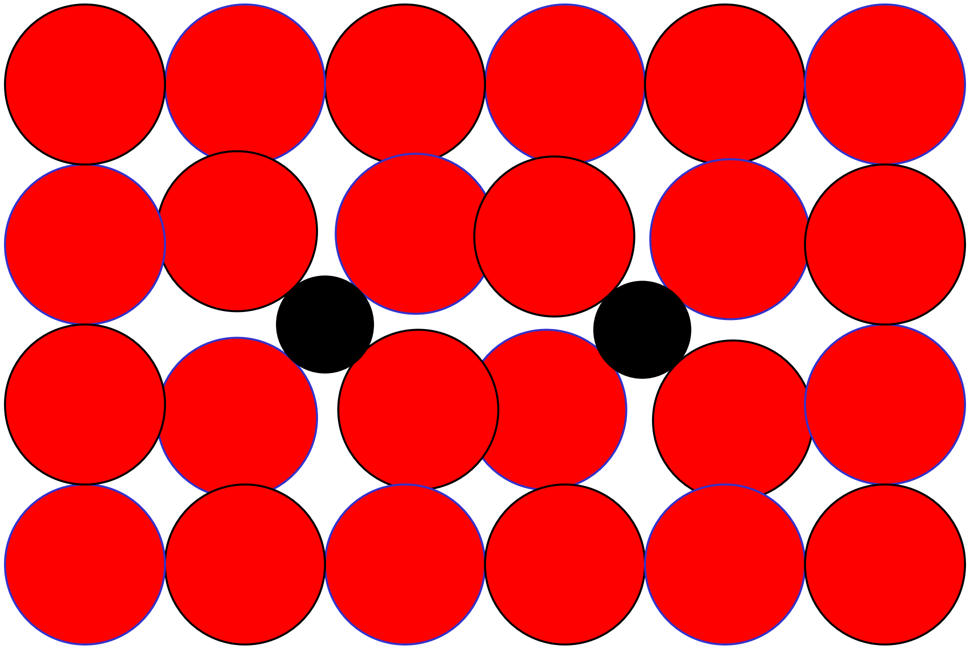
POINT DEFECTS



POINT DEFECTS

High lattice distortion results; (energy increases)

gives low max interstitial concn. R of T
(max. allowable interstitial concentration is less than 10%)



POINT DEFECTS

Substitutional solid solution

Large atoms

(i.e. somewhat larger than interstitial site)

can sit in a lattice site, substituting for a parent or matrix atom

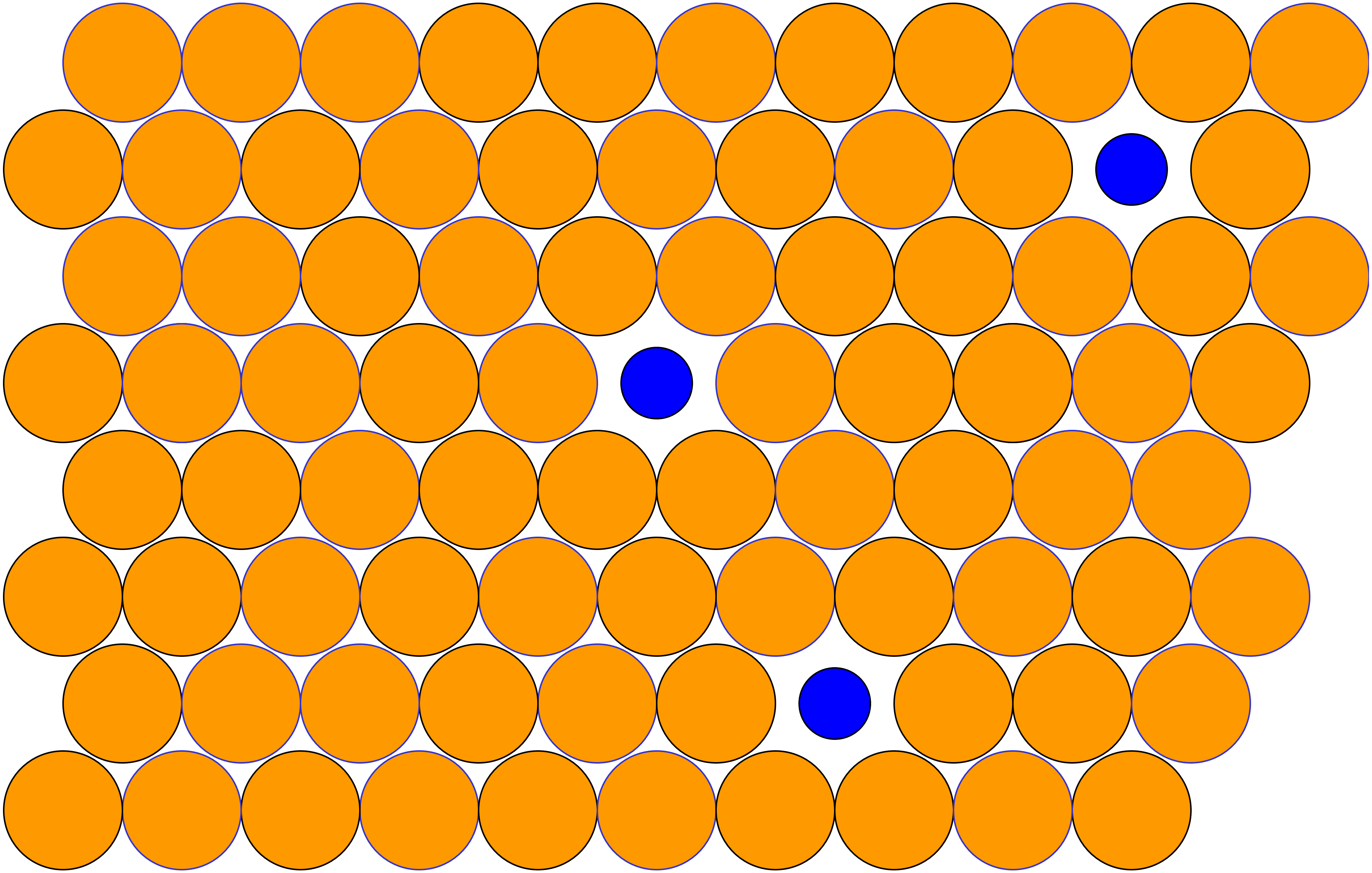
(= substitutional atom)

Ge Si

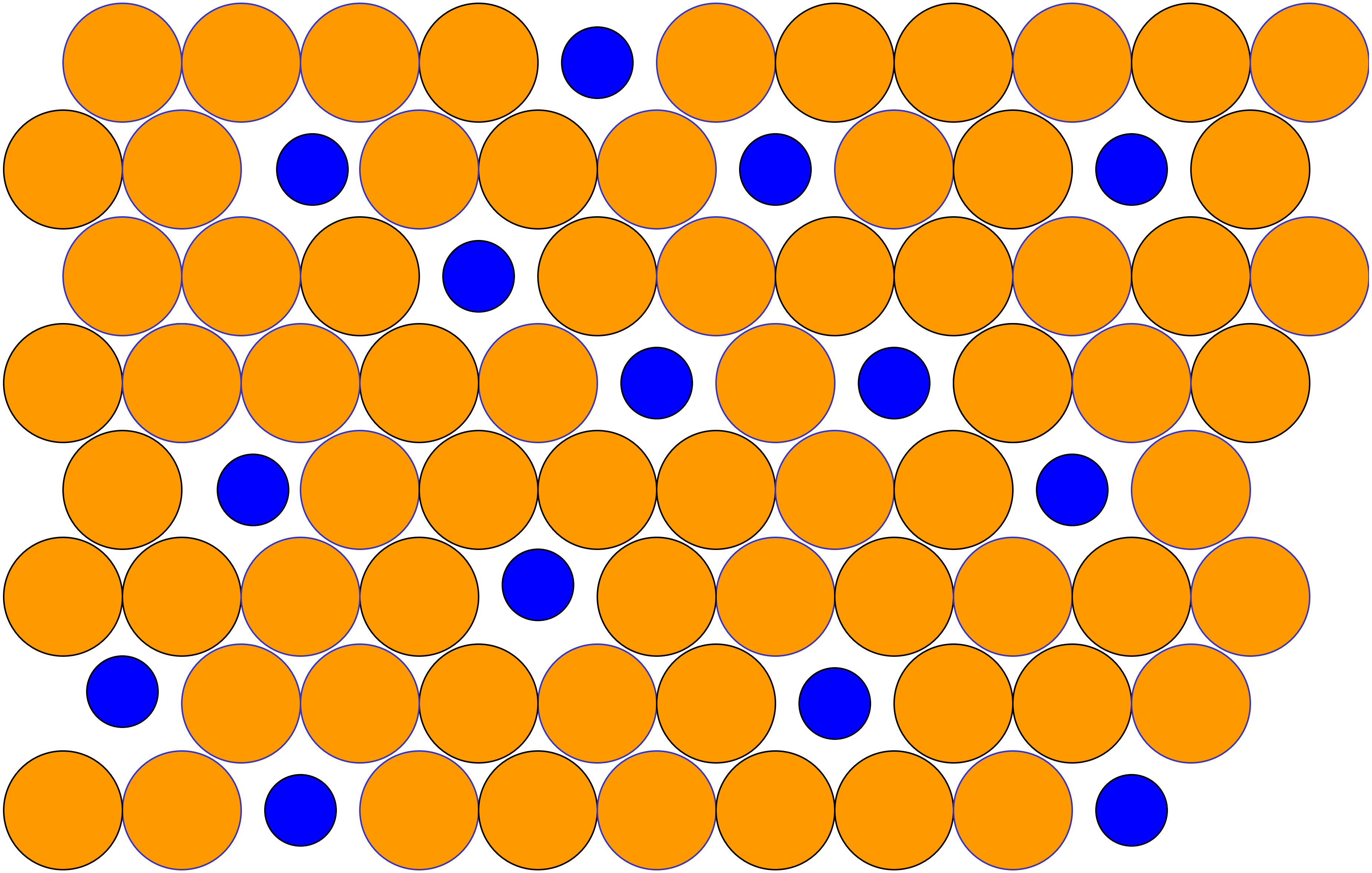
Cu Sn

e.g. solid solution of element A in element B

POINT DEFECTS PROPERTIES?



POINT DEFECTS **PROPERTIES?**



POINT DEFECTS can become…………..

Second Phases

Favoured if: Concentration exceeds ‘solid solubility’ (SS)

SS depends on:

~~**-concentration too 'high’, as determined by:**~~

- difference between atomic radii = 15% or more

-difference in electronegativity is high…………..

…………this leads to formation of a compound

‘solvent’

- host ^ has a lower valency than the solute

- crystal structures are different

e.g. Cu and Ni are completely (i.e. mutually) soluble……..

(same crystal structure-close in periodic table)

Inverse of this…

Conditions for substitutional solid solution (S.S.)

- W. Hume – Rothery rule
  - 1. Δr (atomic radius) < 15%
  - 2. Proximity in periodic table
    - i.e., similar electronegativities
  - 3. Same crystal structure for pure metals
  - 4. Valency
    - All else being equal, a metal will have a greater tendency to dissolve a metal of higher valency than one of lower valency

Imperfections in Solids

Application of Hume–Rothery rules – Solid Solutions

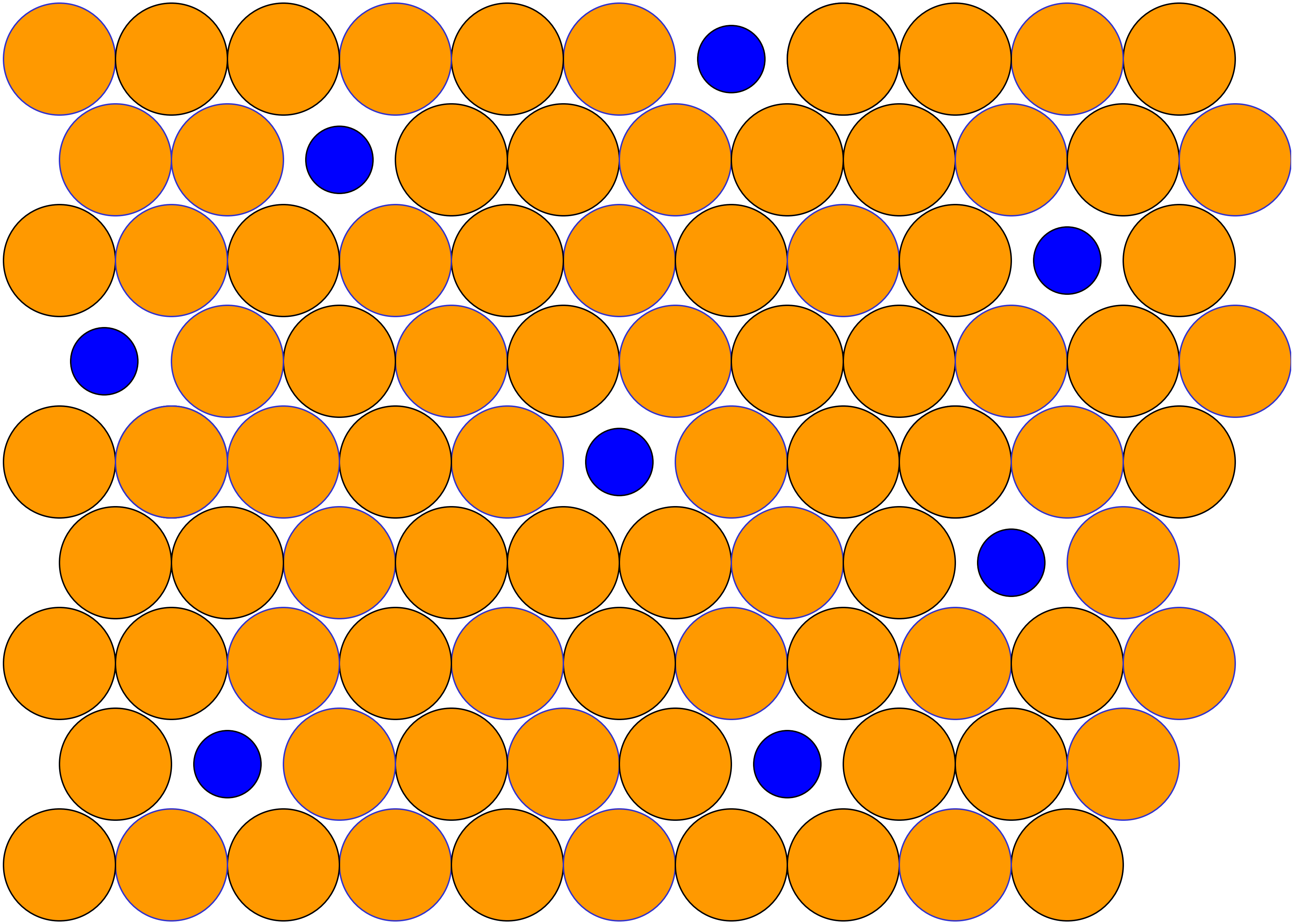
1. Would you predict more [✓ Al] or Ag to dissolve in Zn?

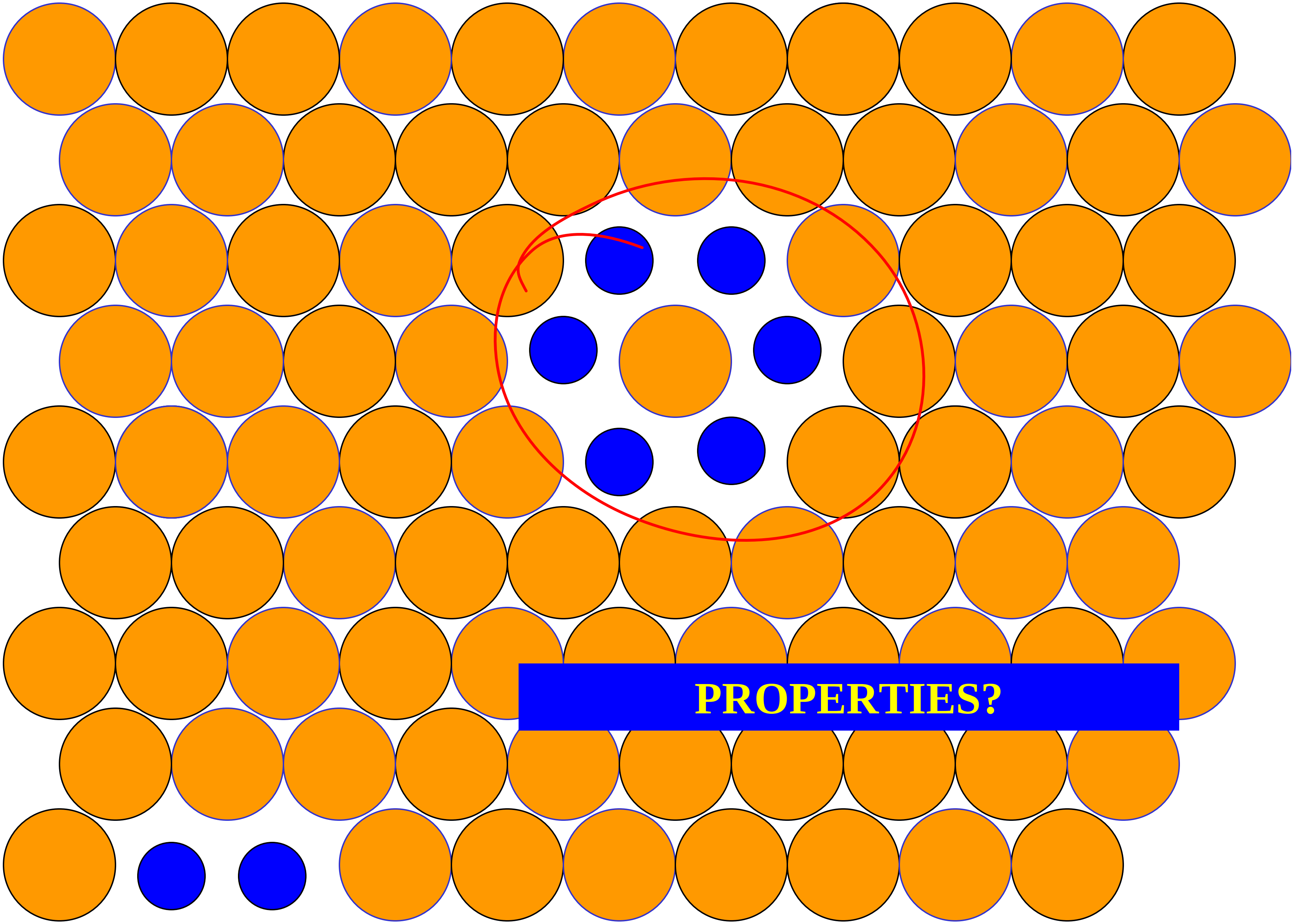
2. More Zn or Al in Cu?

do this one yourself

Element	*Atomic Radius (nm)*	*Crystal Structure*	*Electro-nega-tivity*	*Valence*
Cu	0.1278	FCC	1.9	+2
C	0.071			
H	0.046			
O	0.060			
Ag	0.1445	FCC	1.9	+1
Al	0.1431	FCC	1.5	+3
Co	0.1253	HCP	1.8	+2
Cr	0.1249	BCC	1.6	+3
Fe	0.1241	BCC	1.8	+2
Ni	0.1246	FCC	1.8	+2
Pd	0.1376	FCC	2.2	+2
Zn	0.1332	HCP	1.6	+2

Table on p. 106, *Callister 7e.*





PROPERTIES?

POINT DEFECTS

Alloys

Elements can be deliberately added to change the properties of the metal.

These additions are alloying elements.

(Interstitial and substitutional alloying elements are used)

POINT DEFECTS

A + B

5 wt %

Specification of Alloy Composition

(relative concentrations)

By weight (wt %)

Concentration of element A in wt %,

$$C_A = \frac{\text{Wt of A}}{\text{Total wt of alloy}} x100$$

A + B

By atom (at %)

Concentration of element A in atm %

$$C'_A = \frac{\text{Number of moles of A}}{\text{Total number of moles of all elements in the alloy}} x100$$

$$N_m(A) = \text{number of moles of element A} = \frac{\text{mass in grams of A}}{\text{Atomic weight of A}}$$

Callister, p. 86 & 87

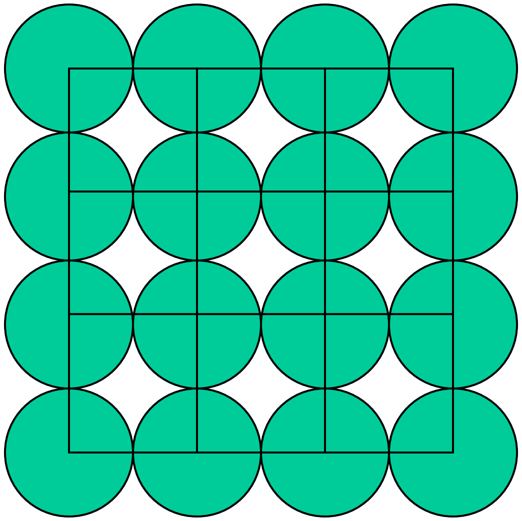
Line Defects

Dislocations:

1-D defect which displaces atoms in it's proximity

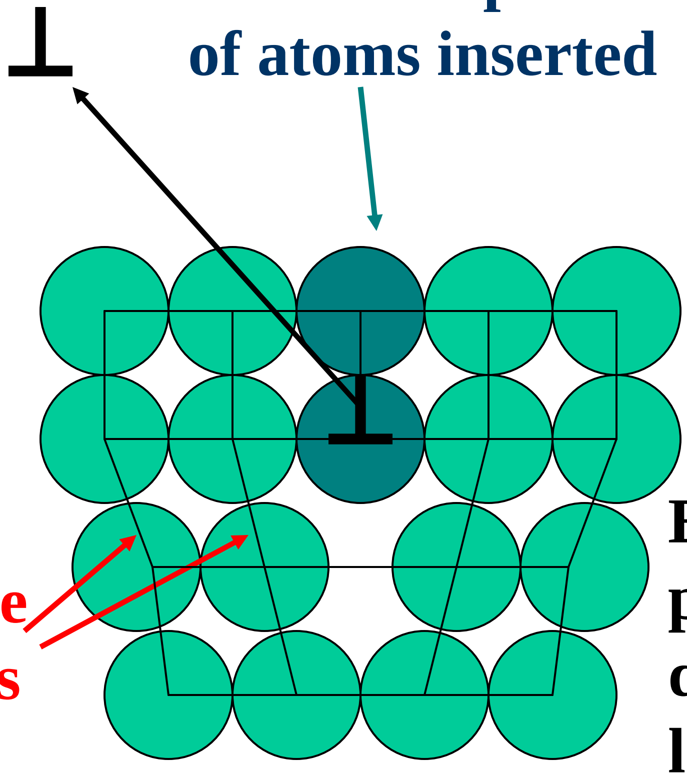
Edge dislocation is the easiest to visualize

Defect free lattice



Symbol for dislocation ⊥

Extra half plane of atoms inserted



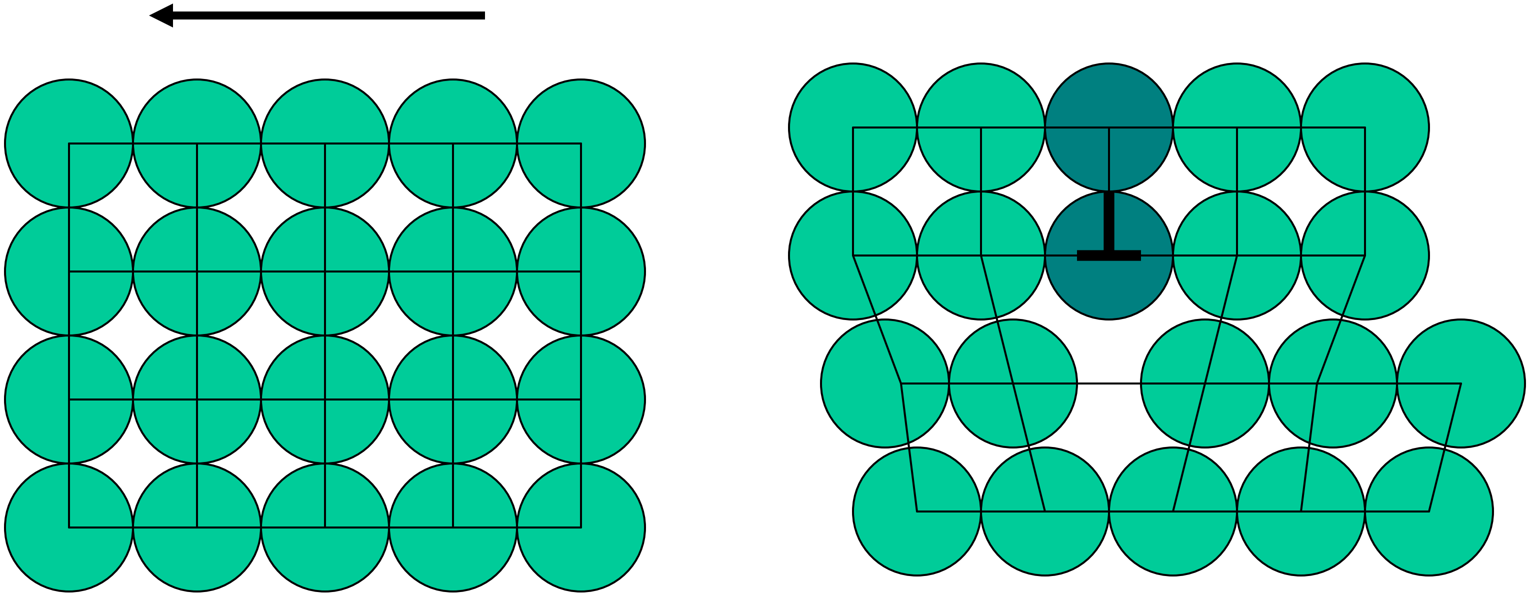
Lattice strains

Edge of half plane is dislocation line

Line defects

Alternative view of an edge dislocation

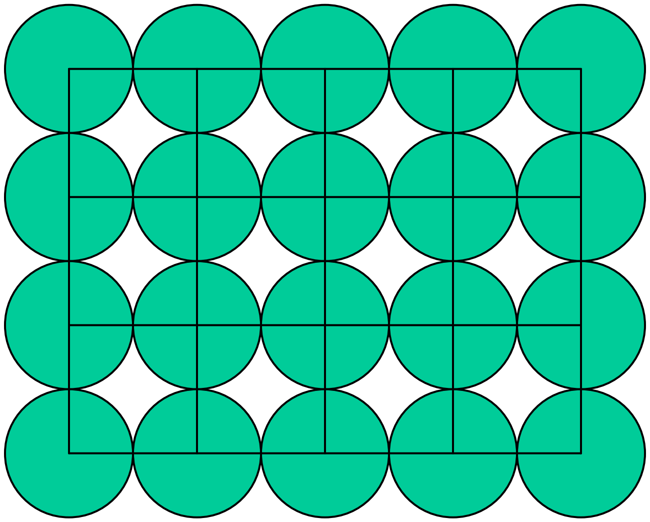
Defect free lattice

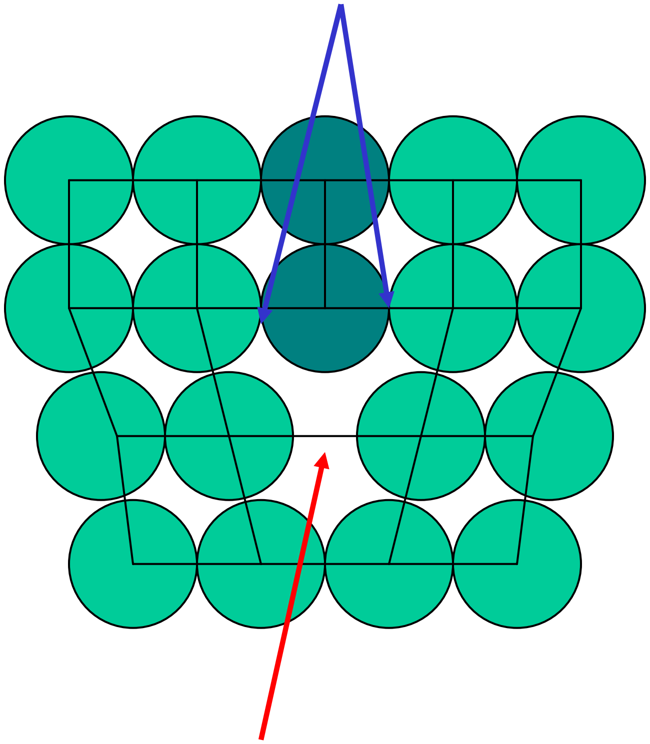


sheared

Lattice strains due to edge dislocation

Defect free lattice





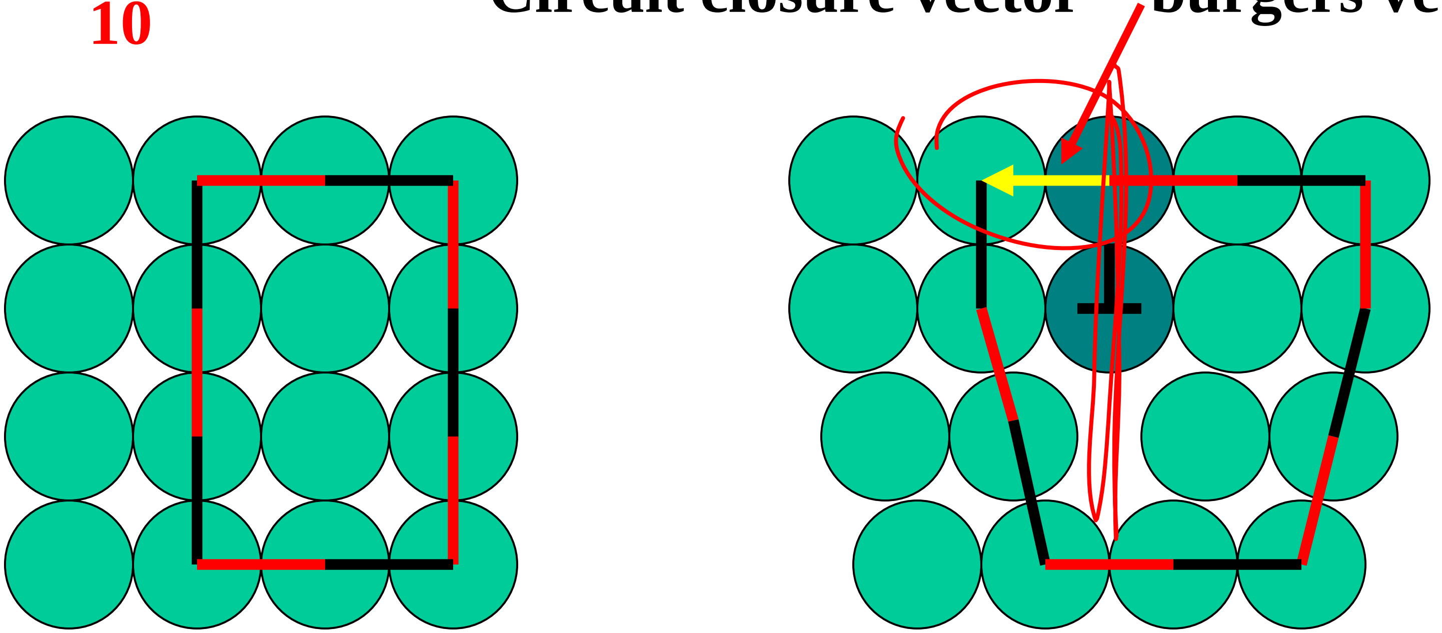
Bond in compression above the line

Bond in tension below the line

Quantification of dislocation

Burger's circuit

Circuit closure vector = burgers vector (bv)

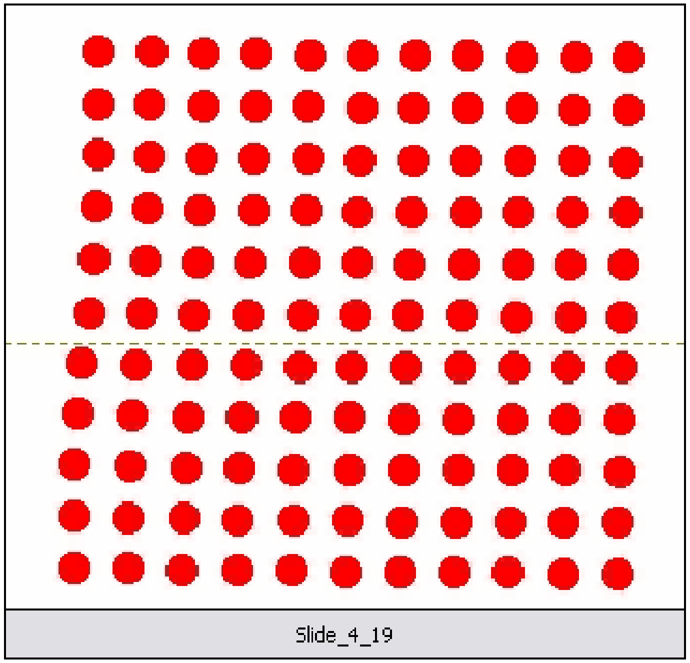


bv defines size and direction of dislocation

bv is perpendicular to edge dislocation line

Motion of Edge Dislocation

- Dislocation motion requires the successive bumping of a half plane of atoms (from left to right here).
- Bonds across the slipping planes are broken and remade in succession.



Atomic view of edge dislocation motion from left to right as a crystal is sheared.

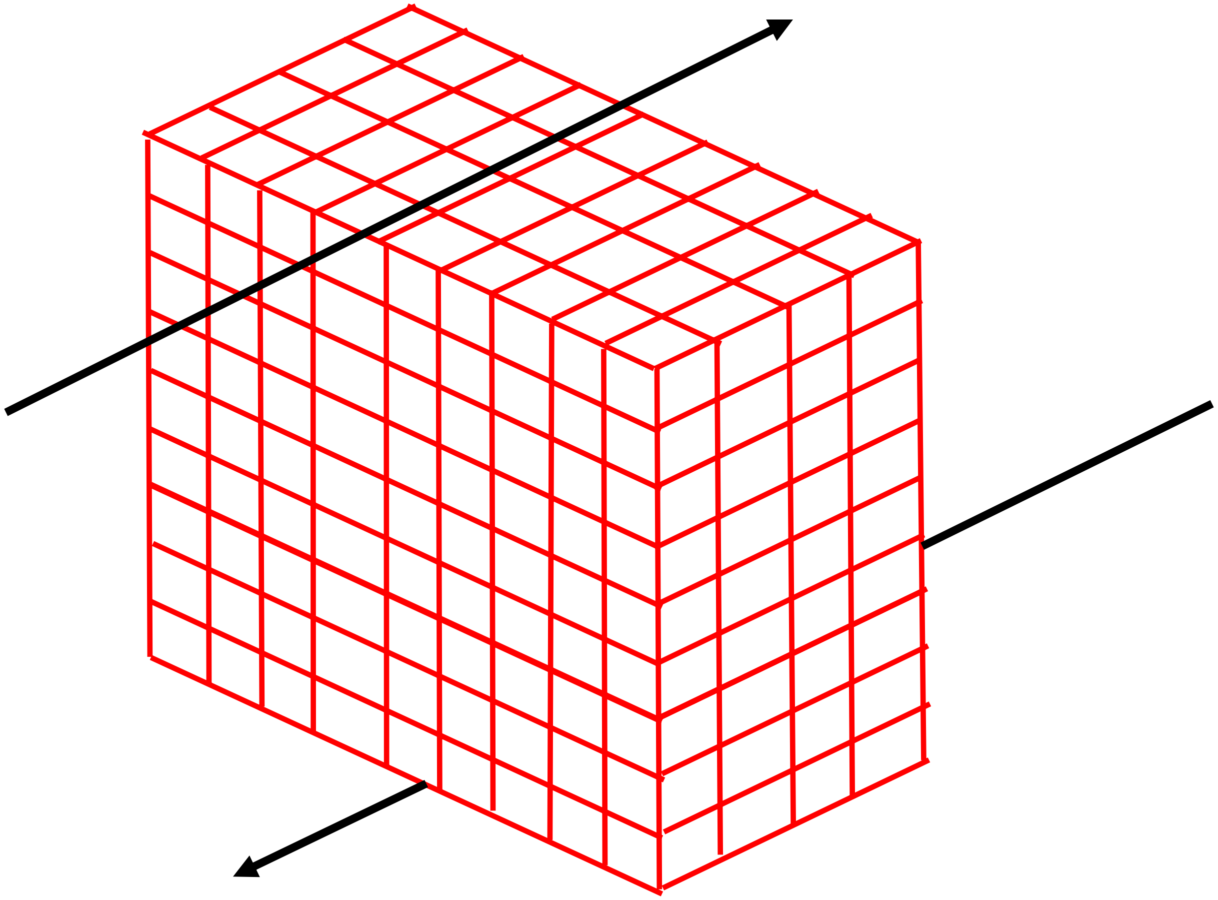
(Courtesy P.M. Anderson)

Line defects

Screw dislocation

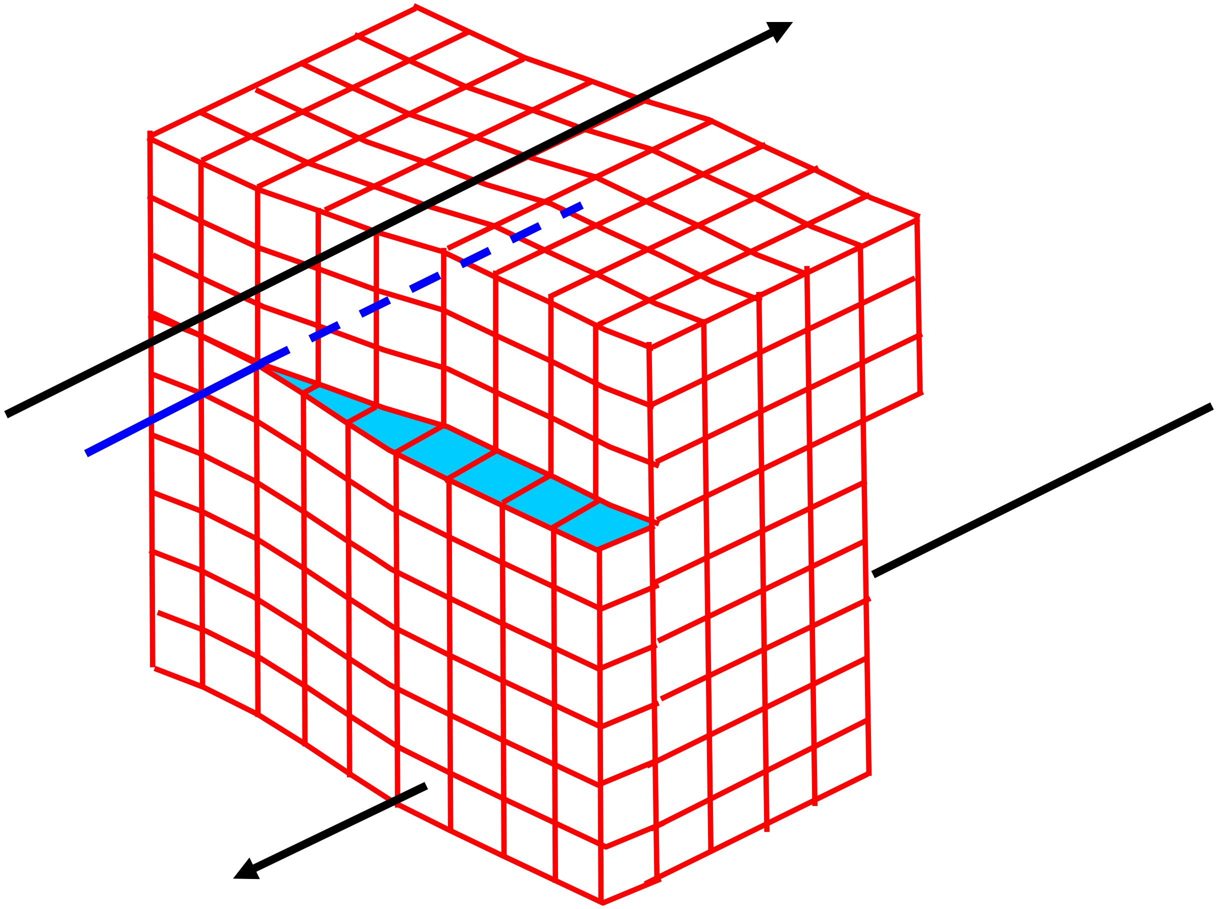
Line defects

Screw dislocation



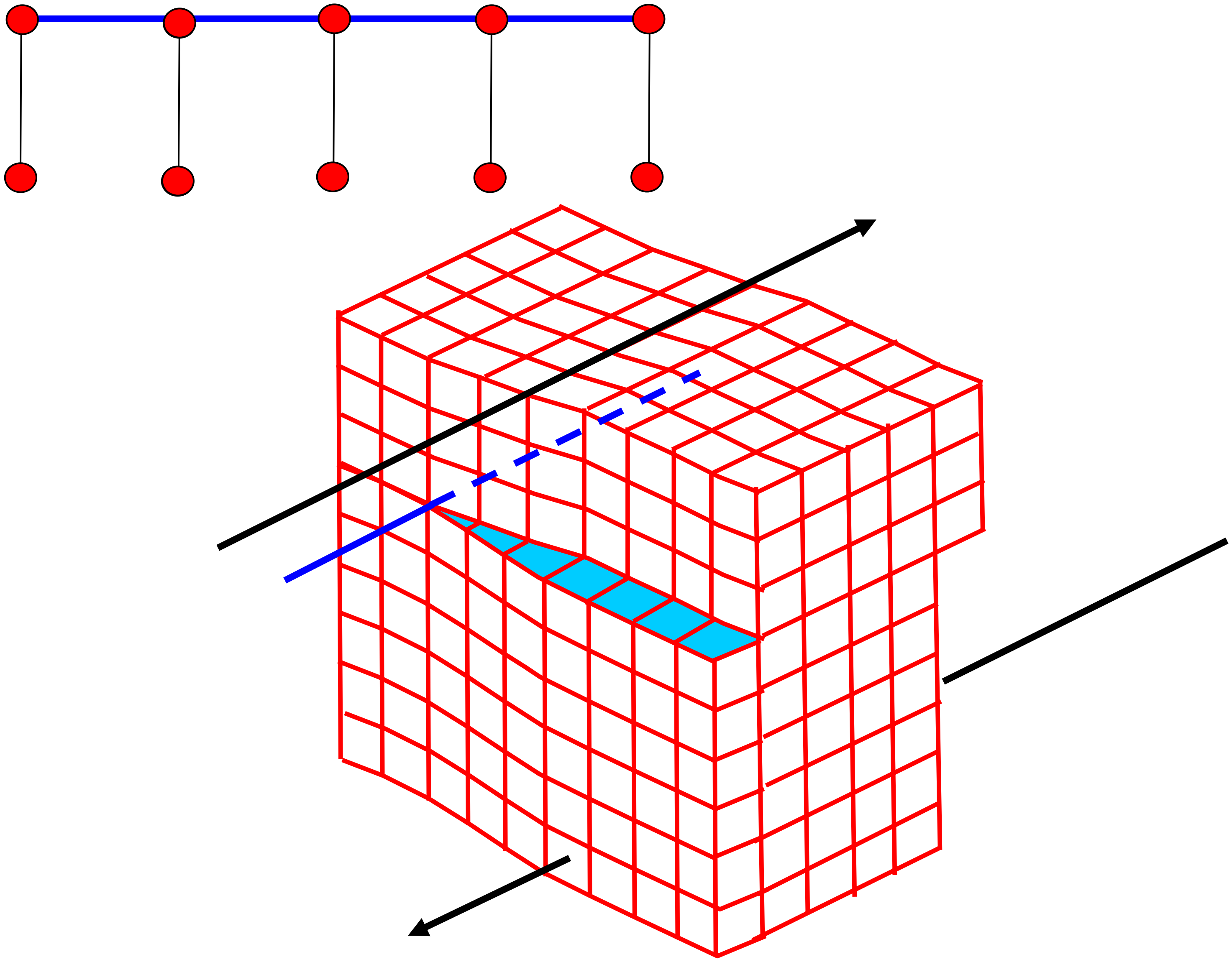
Line defects

Screw dislocation



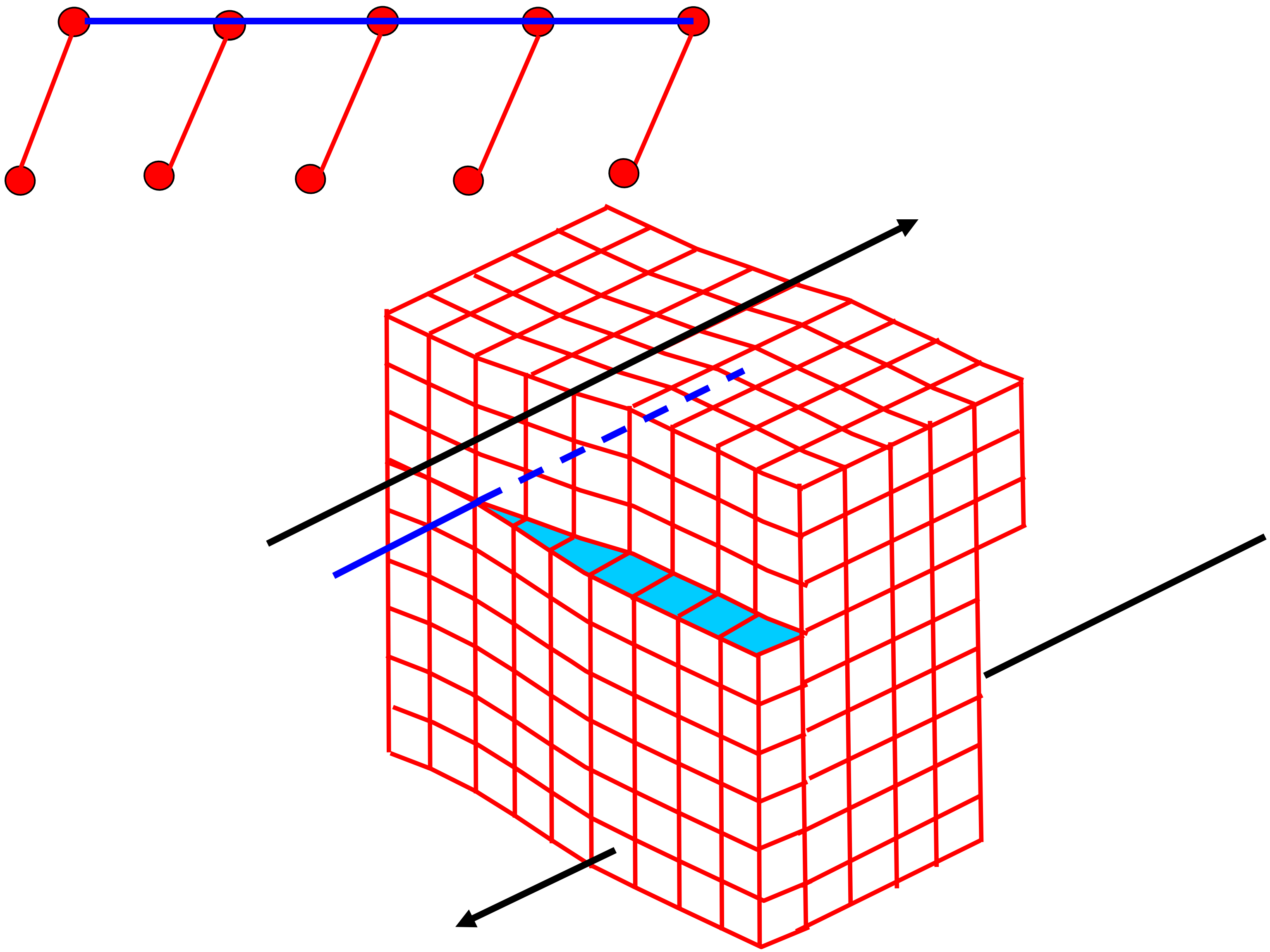
Line defects

Screw dislocation



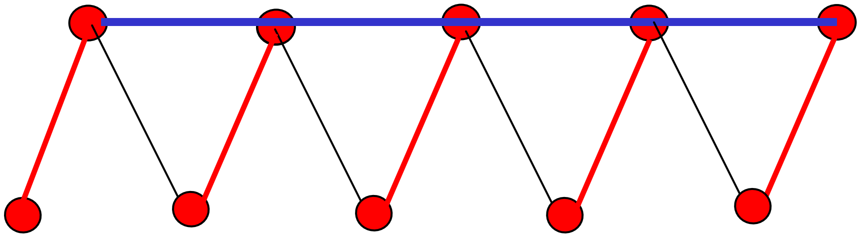
Line defects

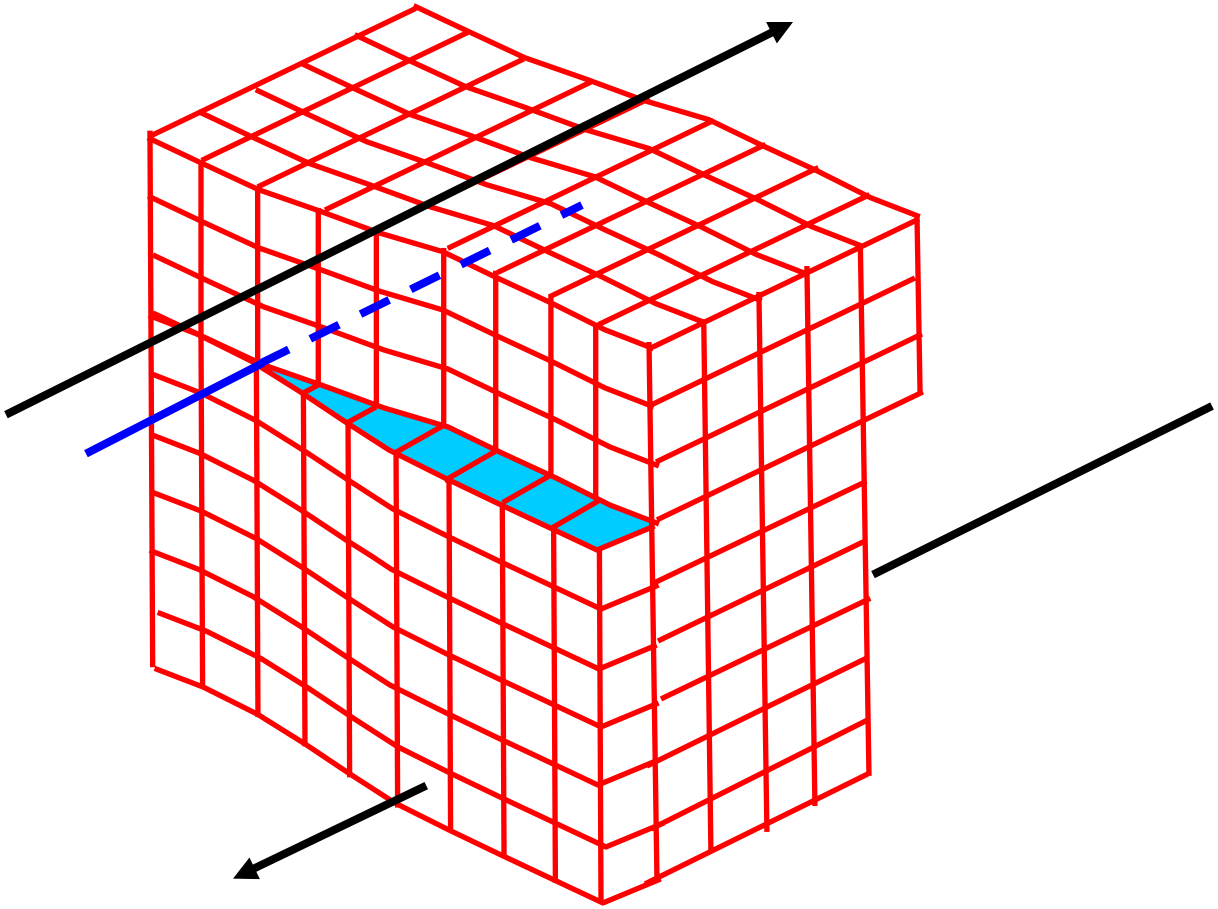
Screw dislocation



Line defects

Screw dislocation



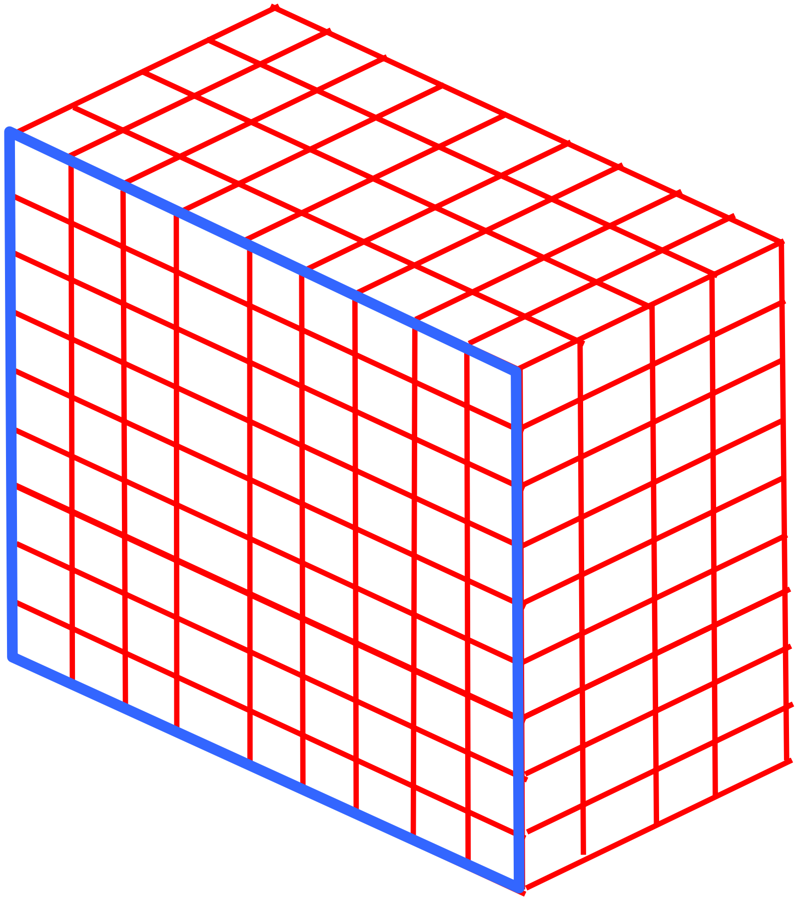


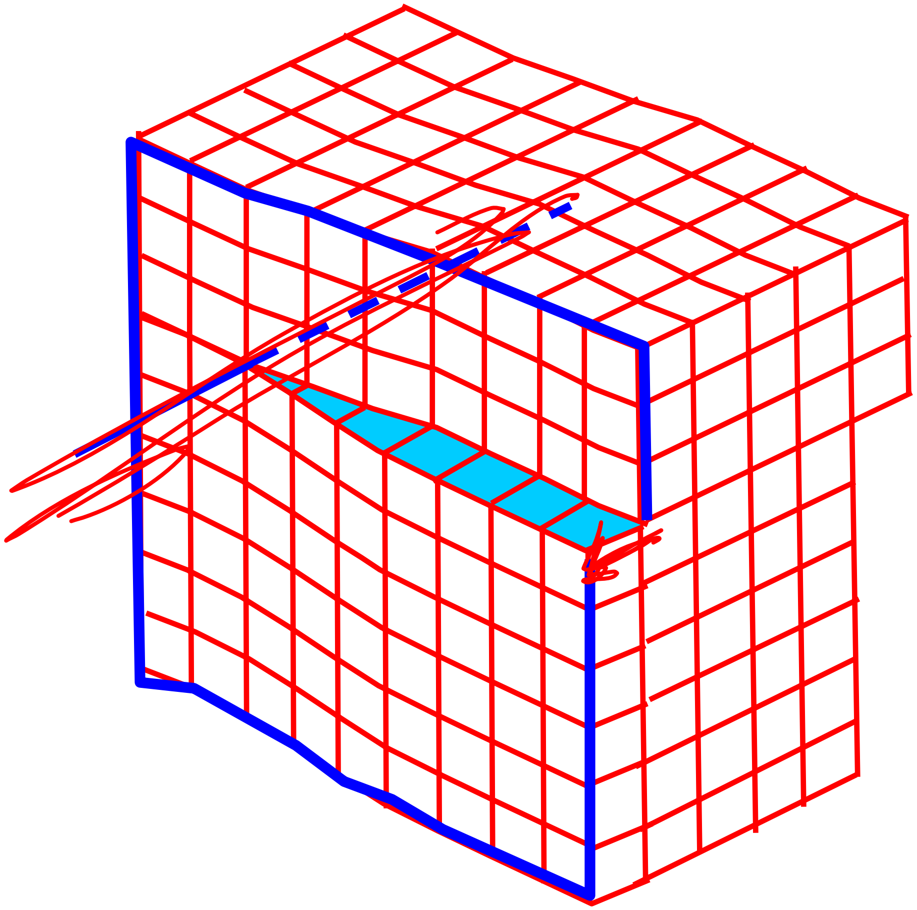
Line defects

Screw dislocation

‘screw’ refers to the helical arrangement of the atoms around the dislocation line

bv is parallel to disln line in a screw disln





Line defects

Screw dislocation

‘screw’ refers to the helical arrangement of the atoms around the dislocation line

bv is parallel to disln line in a screw disln

Dislocations are often mixed edge and screw

Dislocations control many aspects of strength and fracture