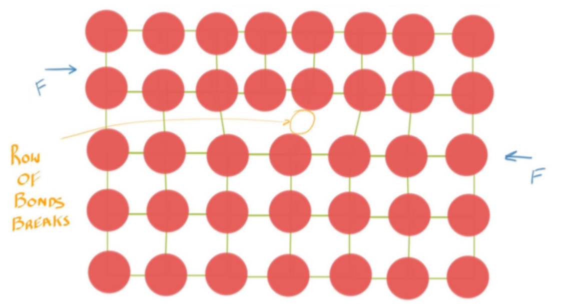
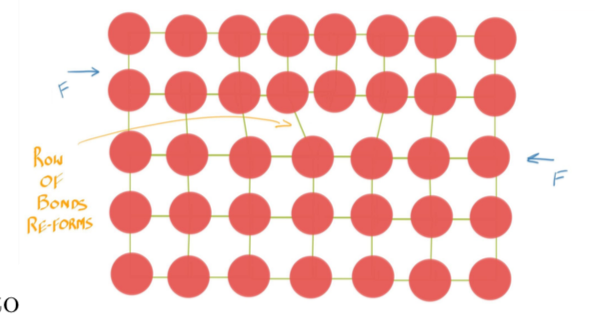
● Chapter 7: Meddling with matter

❖ MECHANISM FOR PLASTIC DEFORMATION:

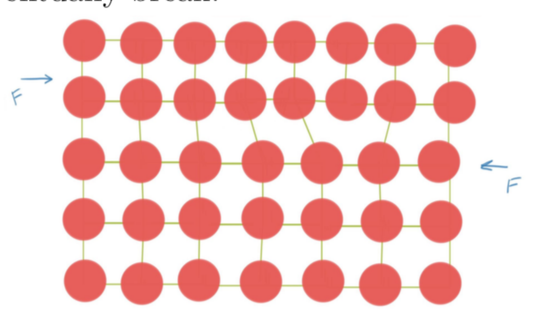
- ➢ Dislocation: crystalline imperfection that is responsible for the stepwise breaking and reforming of bonds during plastic deformation
- ➢ We can change the amount, or the dislocation density
  - ■ by heating a metal (annealing), which lowers the dislocation density
  - ■ by plastically deforming, which increases the dislocation density.
- ➢ **Plastic deformation** involves rows of bonds breaking and reforming in a step-by-step fashion (step-by-step movement of linear imperfections)



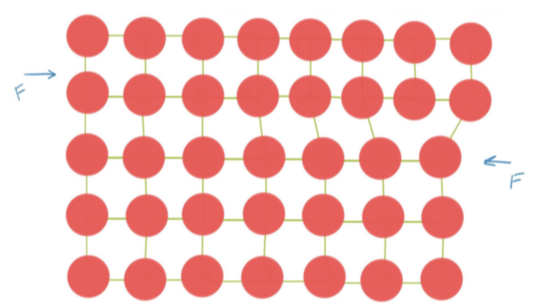
(a) As the force is applied the bonds to the right of the dislocation stretch and eventually break.



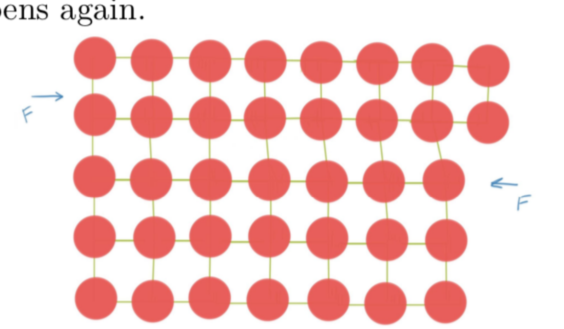
(b) A new set of bonds re-forms.



(c) This breaking and re-forming happens again.



(d) And again.



(e) And again.

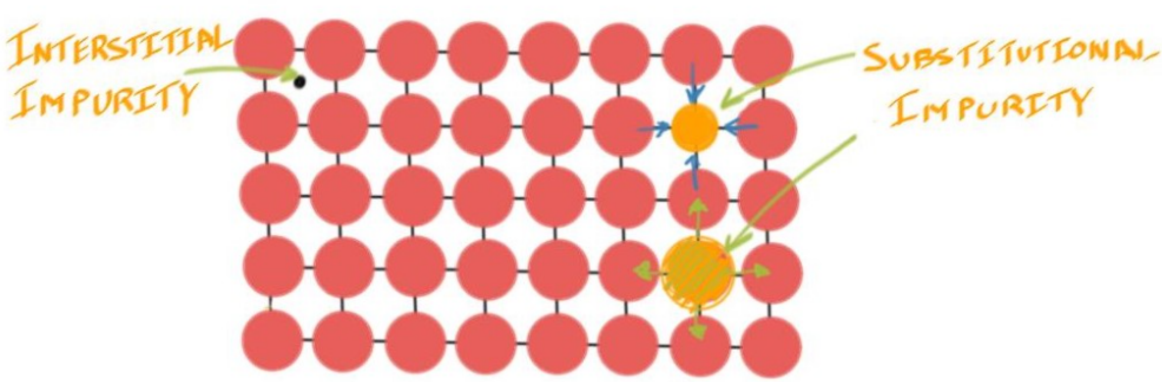
❖ INTERFERING WITH DISLOCATION MOVEMENT:

- This makes dislocation movement more difficult, and will increase the strength of a metal
- Known as crystalline imperfections
- There are four general ways that we can strengthen a metal (organized according to dimensionality):

   1. Zero-dimensional imperfections (Point Defects)
   2. One-dimensional imperfections (Linear Imperfections or Dislocations)
   3. Two-dimensional imperfections (Interfacial Imperfections)
   4. Three-dimensional imperfections (Volume Defects)

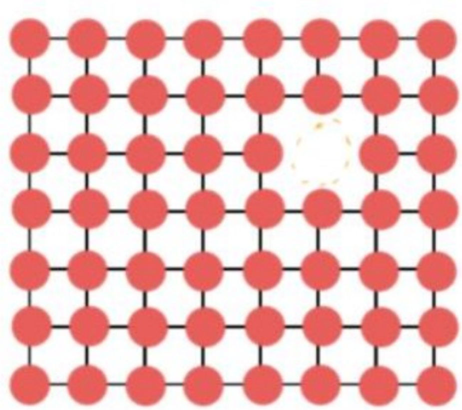
1. ZERO DIMENSIONAL IMPERFECTIONS // POINT DEFECTS:

- They occupy only one space in the lattice
- Types of point defects:
   - INTERSTITIAL IMPURITY: impurity atoms or molecules that occupy the spaces between the regularly arranged atoms or ions in this lattice.
   - SUBSTITUTIONAL IMPURITIES: are foreign atoms or ions that replace or substitute for the host atoms or ions in the crystal lattice of a material.
      - In contrast to interstitial impurities, which occupy spaces between the host atoms, substitutional impurities take the place of the original atoms in the lattice structure.



- The small arrows that are meant to show the strain imposed on the lattice as a result of the impurity atom.
- This strain field that results from the impurity atom interacts with the strain field surrounding a dislocation
- The net result is that it is more difficult for a dislocation to move through the lattice close to an impurity than it is to move through the undisturbed lattice.
- So, plastic deformation is more difficult.
- This is the reason that we add very small amounts of carbon to iron to make steel.
- Even very small concentrations, typically less than 1 weight percentage carbon, result in a significantly higher strength for steel versus iron.

- VACANCIES: an atom that has jumped out of its regular lattice position, leaving behind an empty site that would otherwise be occupied by an atom.
- They are the one crystalline imperfection that we don't use to increase the strength of a metal.



- A vacancy is formed when atoms are desperately vibrating in their lattice sites, trying to jump out of their sites.

- Most of the time they are unsuccessful because the binding energy is stronger than the thermal energy.
- But every so often an atom makes a successful jump from its lattice site and can move somewhere else in the lattice.
- This leaves behind a missing atom, or vacancy.

❓ If we raise the temperature so that the thermal energy wins out over the binding energy, then why doesn't the entire crystal just melt? How is it possible to have only a few atoms make successful jumps out of their lattice sites while the majority remain?

- Not all of the atoms have the same energy. There is a distribution of energies.
- So, it makes sense that a single atom may have enough energy to jump out of its lattice site, while the majority of the remaining atoms do not
- As we increase the temperature we find a larger number of atoms populate the higher energy states,
- As we approach lower temperatures we find fewer of the high energy states populated,
- At absolute zero, only the lowest energy state would be populated.

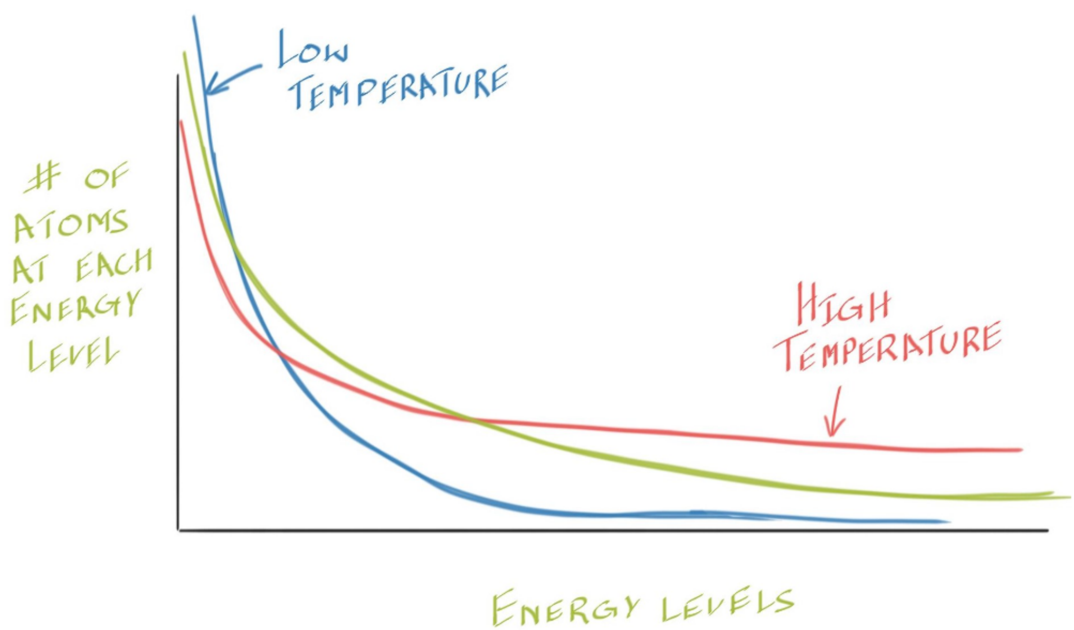


Figure 10: A cartoon depiction of the distribution of particles over permissable energy levels at high, medium and low

2. ONE DIMENSIONAL IMPERFECTIONS // DISLOCATIONS:

- When we plastically deform a metal we create new dislocations
- This increases the dislocation density and dislocations have difficulty moving past one another.
- The strain fields that surround dislocations interact with one another and can repel each other, or in certain cases, cancel one another out, leaving a small region of perfect crystal.

- Strengthening metal:
  - Cold work/ cold forging: referring to the fact that we obtain more strengthening when the metal is at a lower temperature.
  - Warm work/hot forging: the part warms up during deformation or we actually heat the part to make deformation easier and to prevent the part from becoming brittle and so we also call this strengthening
  - Strain hardening: Because the metal accumulates plastic strain during the strengthening process

3. TWO DIMENSIONAL IMPERFECTIONS // INTERFACIAL IMPERFECTION:

- FREE SURFACES:
  - Example: the surface of the sapphire lens cover on an iPhone.
  - Within the sapphire there are aluminum and oxygen atoms arranged in a regular crystalline lattice until you hit the surface and then suddenly there are missing nearest neighbor atoms - unsatisfied bonds with the atoms along the surface.
  - It is a crystalline imperfection, however, we don't really use this type of defect to increase the strength of a metal.

- INTERNAL INTERFACES OR GRAIN BOUNDARIES:
  - These occur anywhere one crystal contacts another.
  - the metal cooled from a liquid state, the crystals will often be randomly oriented and the atoms certainly don't line up with one another
  - if we consider a dislocation moving through one of these grains, to continue moving, it must cross the grain boundary
  - The dislocation must change direction, because the atomic plane that it is moving along in one crystal is at an angle relative to the corresponding plane in the next crystal.

  - The atomic spacing at the grain boundary is not the same as it is in the rest of the crystal and the dislocation requires more energy to navigate past this disruption in the regular spacing of atoms.
  - Finally, the plane that the dislocation is moving along in one crystal does not line up with the plane in the next crystal
  - All of these challenges with crossing a grain boundary mean that grain boundaries can be used to inhibit dislocation movement, thereby increasing the strength of a metal.
- How do we increase the number of grain boundaries in a metal?
  - use a powdered catalyst in aqueous chemistry to increase the surface area to volume ratio,
  - If we decrease the grain size of a metal we will create more grain boundaries and more obstacles to dislocation movement and can expect to increase the strength of a metal. [GRAIN SIZE REDUCTION]

4. THREE DIMENSIONAL IMPERFECTIONS // SECOND PHASE PARTICLES:

- if we have a region of a solid that has a different crystal structure we have a second phase, or three-dimensional imperfection.
- These second phase particles are often hard and brittle compounds that are already very hard to deform.
- This is a commonly used aluminum alloy that can be carefully heat treated to produce a fine distribution of second phase precipitates that greatly increases the strength of this alloy.
- A pore
- A region of FCC metal within an otherwise BCC metal
- A ceramic particle within a metallic sample

ZERO DIMENSIONAL IMPERFECTIONS	ONE DIMENSIONAL IMPERFECTIONS	TWO DIMENSIONAL IMPERFECTIONS	THREE DIMENSIONAL IMPERFECTIONS
INTERSTITIAL IMPURITY	DISLOCATION	FREE SURFACES	A PORE
SUBSTITUTIONAL IMPURITIES		GRAIN BOUNDARIES	A REGION OF FCC METAL WITHIN AN OTHERWISE BCC METAL
VACANCIES		INTERFACE BETWEEN TWO PHASES	A CERAMIC PARTICLE WITHIN A METALLIC SAMPLE