



7. Meddling with Matter



LEARNING GOALS

Learning Objectives

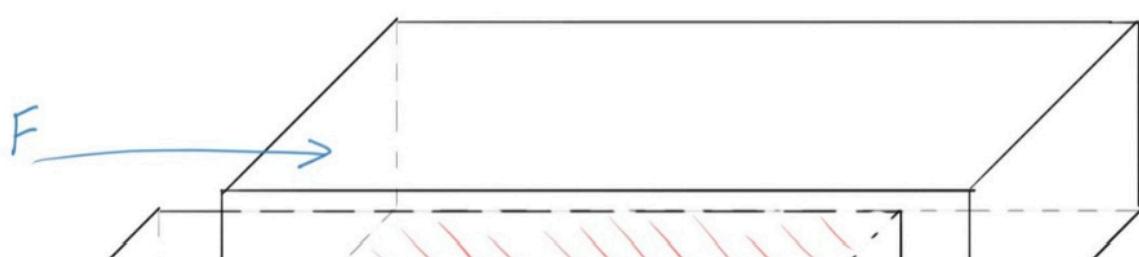
1. Show how knowledge of the mechanism of plastic deformation allows understanding of strengthening mechanisms
2. Organize crystalline defects according to their dimensionality, that is, zero-dimensional, one-dimensional, two-dimensional, and three-dimensional
3. Explain how 0-dimensional imperfections can increase strength of a metal
4. Provide several examples of 0-dimensional imperfections
5. Demonstrate how the distribution of particles over available energy states is characterized by the Boltzmann distribution
6. Show how changes in temperature are reflected in changes in the Boltzmann distribution
7. Explain how 1-dimensional imperfections can increase strength of a metal
8. Describe how the number of linear imperfections can be increased in a metal
9. Explain how 2-dimensional imperfections can increase the strength of a metal
10. Provide several examples of 2-dimensional imperfections in metals
11. Explain how 3-dimensional imperfections can increase the strength of a metal
12. Provide several examples of 3-dimensional imperfections in metals
13. Summarize the four major strengthening mechanisms in metals

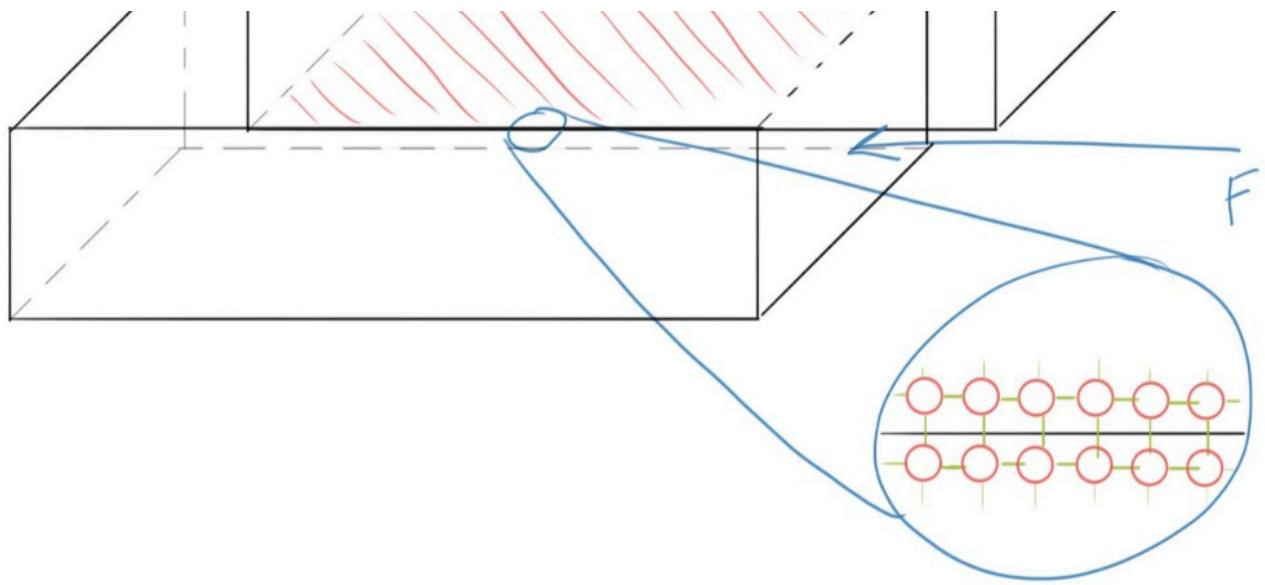


The Dislocation

That's Wrong! Quick, Give That Model a Dislocation!

You can imagine plastic deformation, at least initially as we did earlier as the sliding of planes of atoms past one another. If you took that model and imagined how plastic deformation would occur at the atomic scale you would imagine something like this:





Type caption for image (optional)

If you knew the bond density (how many bonds per unit area), the bond strength, and the area over which the crystal was being sheared (the area shaded red) you could calculate the theoretical strength of the crystal. This calculation was done decades ago and then a real crystal was tested. The theoretical value was compared to the experimental value and oh my! The theoretical value was about 5 times higher than the experimental value. This is bad! This tells us that the model depicted above, with all bonds breaking at the same time, is wrong. There is a different mechanism responsible for plastic deformation.



[Link to this video on U of T servers.](#)

So, the crystalline imperfection that is responsible for the step-wise breaking and reforming of bonds during plastic deformation is called the *dislocation*. A dislocation is shown in Figure 5.



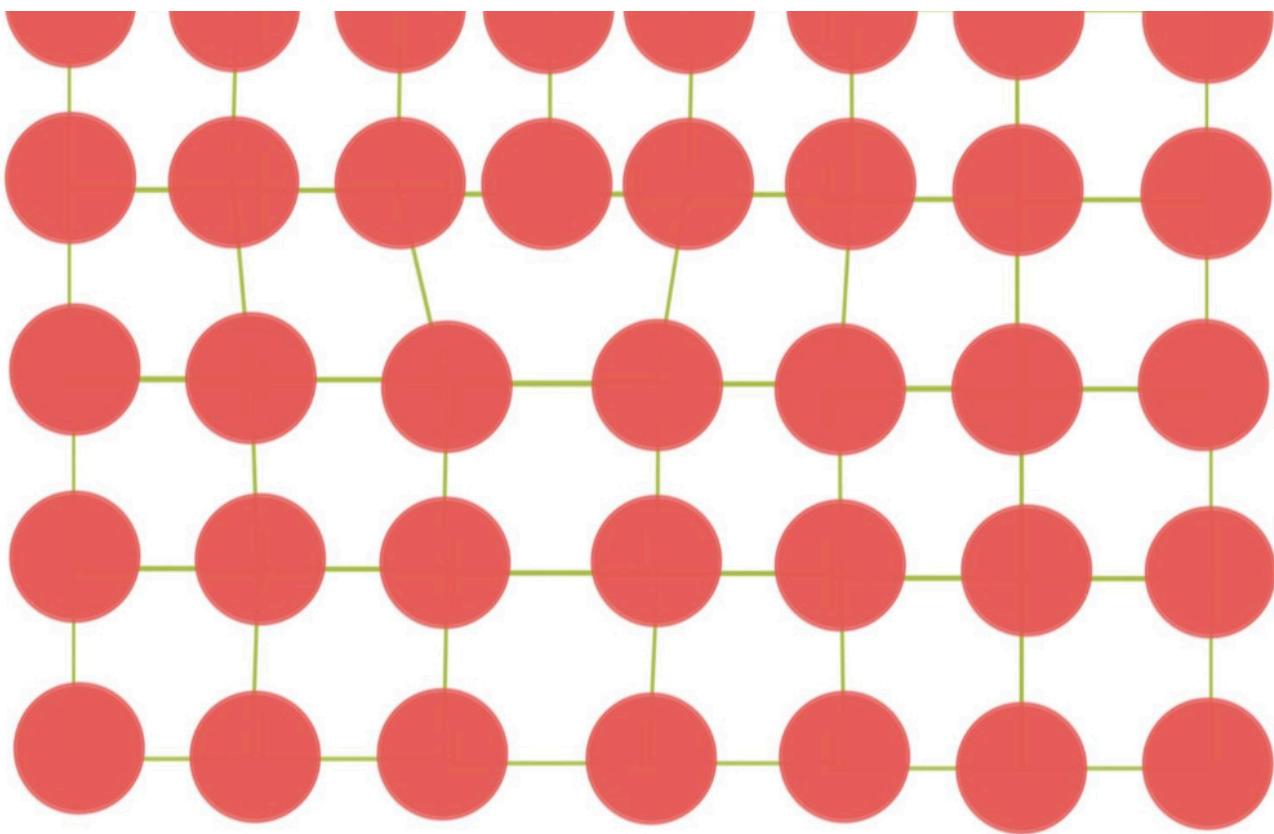
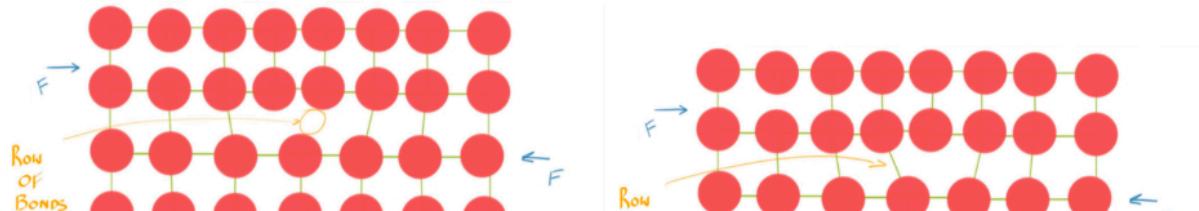


Figure 5: A dislocation (specifically, an edge dislocation) within a simple square lattice. Don't worry about whether the crystal is actually FCC, BCC, or HCP. It is too hard to draw in one of those crystal structures and the concept remains the same.

Dislocations are always present in metals. We can change the amount, or the *dislocation density* by heating a metal (*annealing*), which lowers the dislocation density or by plastically deforming, which increases the dislocation density.

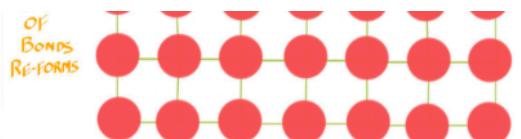
The dislocation is categorized as a so-called *linear imperfection*, although I can appreciate at first seeing one it can be difficult to understand what is one dimensional about it. To understand the one dimensional nature of a dislocation you need to imagine the same arrangement of atoms depicted in Figure 5, but out in front of the page. Are you picturing it? Now image several more of these stacked out in front of each other so that you now have a three-dimensional array of atoms. Now, focusing on the row of atoms coming out of the page with the missing bonds, that is, only three green lines, you will notice that there is almost a little tunnel running into the page with the missing bonds all along the top. This is known as the *dislocation line* and is the reason that a dislocation is a linear defect.

How do these move and cause plastic deformation? Great question. Figure 6 attempts to show the step-by-step breaking and reforming of bonds that is the mechanism for plastic deformation in metals.

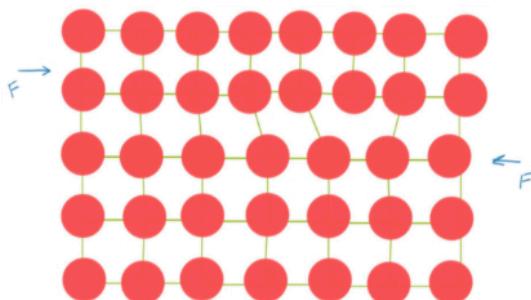




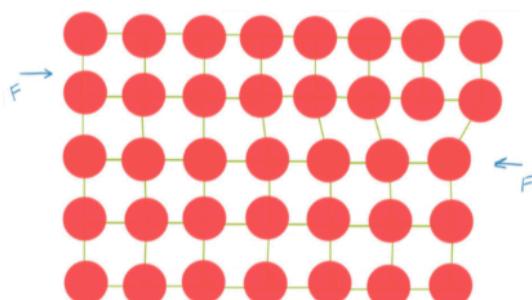
(a) As the force is applied the bonds to the right of the dislocation stretch and eventually break.



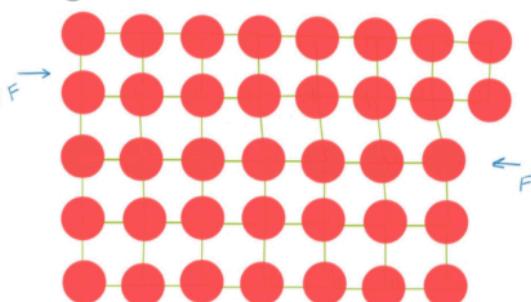
(b) A new set of bonds re-forms.



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



(d) And again.



(e) And again.

Figure 6: A dislocation moving through a simple square lattice of atoms due to an applied force. This process continues over and over again, and again, until it runs into something, like a grain boundary or a second phase, but don't worry, we haven't discussed those yet.



Q6.6.1
Review

Mark as: None ▾

Plastic deformation in metals occurs through which of the following mechanisms?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a The simultaneous breaking of all bonds along a crystallographic plane

b The step-by-step movement of point defects

c The simultaneous breaking of all bonds along a grain boundary

d The step-by-step movement of linear imperfections



Q6.7.1
Review

Mark as: None ▾

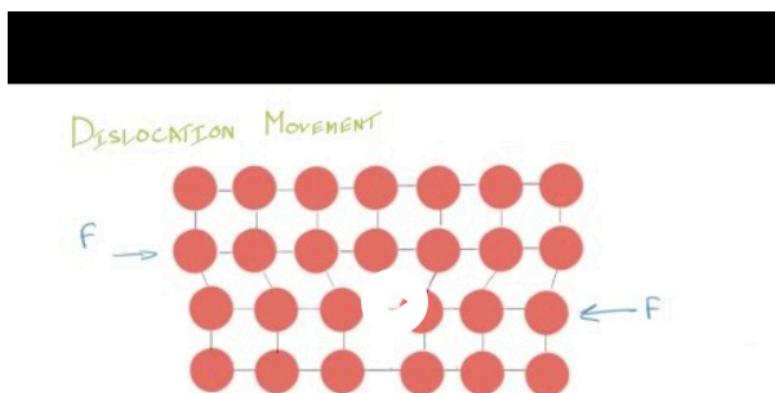
When a metal undergoes plastic deformation you would expect that atoms will move to new equilibrium positions.

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a True

b False

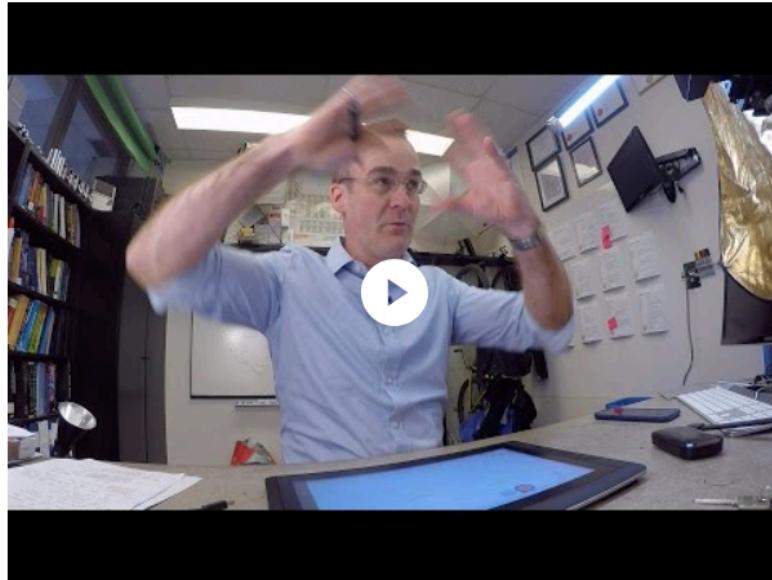
Because dislocations are always present they allow the step-wise breaking and reforming of bonds illustrated in Figure 6. Remember that the mechanism is *not* the breaking of all bonds at the same time on a plane of atoms.



[Link to this video on U of T servers.](#)

So what? (That's what I imagine you are saying.) Well now we can understand the various ways that we can interfere with this mechanism for plastic deformation. Why would we want to do that, you ask? Because interfering with dislocation movement, specifically, making dislocation movement more

difficult, will increase the strength of a metal. Now that's a noble cause. There are four general ways that we can strengthen a metal. They can be conveniently organized according to the *dimensionality* of the defect population that we introduce. What's more convenient is the fact that this is also convenient way to organize all of the possible crystalline imperfections that are possible.



[Link to this video on U of T servers.](#)



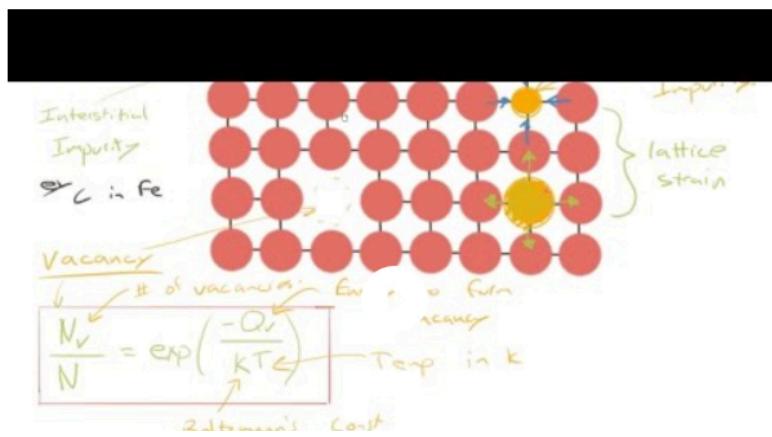
Specifically, we have the following imperfections in our toolbox as engineers:

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*)

What? You want to go through each of these in turn? And use an example of a strengthening mechanism for each? That's exactly what I was planning on doing!



Zero-Dimensional Imperfections or Point Defects



[Link to this video on U of T servers.](#)



Interstitial Impurities

These are neat. Think small. (Atomic scale small, that is. Subatomic small is too small for our purposes!) Point defects occur when a single atom surprises you. Imagine you were only 10–10 m tall and decided to walk through a sample of iron at room temperature. You pass atom after atom, all spaced at their equilibrium interatomic spacing, all organized in a BCC crystal structure. Each atom is the same iron atom that you expect. You start to get used to the regularity of it all. Maybe you turn on your favourite music. Maybe it's *All of You*. You're getting used to walking through a BCC crystal. You let your guard down just a little, tentatively at first, then you really relax into the beautiful regularity of it. But the music suddenly changes to *O Fortuna* by Carl Orff. Something's not right. You walk into something that shouldn't be there. Something hits you in the stomach! It's a carbon atom.



Q7.3.2
Review

Mark as: [None ▾](#)

Carbon dissolved in iron will be present as which of the following type(s) of crystalline imperfection

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a Second phase only

b Point defect only

c Point defect and second phase

d Neither point defect nor second phase



Q7.3.3
Review

Mark as: [None ▾](#)

An interstitial defect is a point defect produced when an atom is placed into the crystal at a site that is normally not a lattice point

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.



a True

b False

Substitutional Impurities

What I've described above (yes, in a highly unusual manner) is an example of an impurity atom forming a *solid solution*. Specifically this isolated carbon *solute* atom, since it is much smaller than the iron *solvent* atoms is an *interstitial* impurity. If you had been walking through an FCC lattice of copper atoms and encountered a nickel atom you would likely have walked into it. Nickel would have been occupying a *substitutional* impurity site.

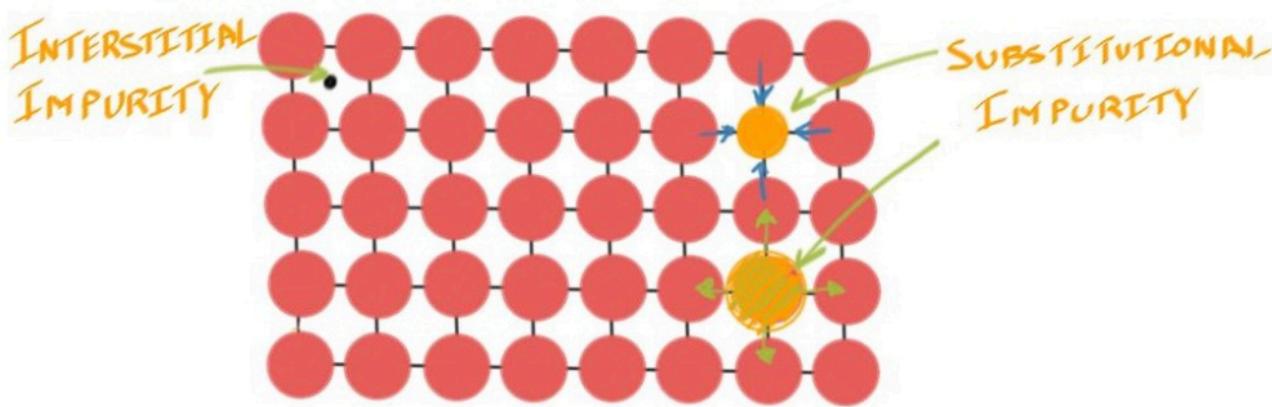


Figure 7: Several point defects illustrated within a simple square lattice. An interstitial impurity is typically a lot smaller than the solvent atoms. Substitutional impurities are typically within about 10% size difference relative to the solvent atoms. The little arrows are meant to indicate how the impurity atom will strain the lattice.

Copper and nickel are neighbours on the periodic table and so are very similar in size and electronegativity, and both form FCC crystals. In fact, copper and nickel are completely soluble in one another, but we'll get into that in more detail later. An interstitial impurity atom as well as a substitutional impurity, both larger and smaller than the solvent atoms is illustrated in Figure 7.

Now that we understand the basic concept of impurity atoms, we can consider how they can be used to make plastic deformation more difficult. Figure 7 shows substitutional atoms that are either larger or smaller than the solvent atoms. I've also drawn in small arrows that are meant to show the strain imposed on the lattice as a result of the impurity atoms. This strain field that results from the impurity

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 and 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. 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.



Q7.3.1
Review

Mark as: None ▾

An impurity atom occupying a substitutional site is considered a type of point defect.

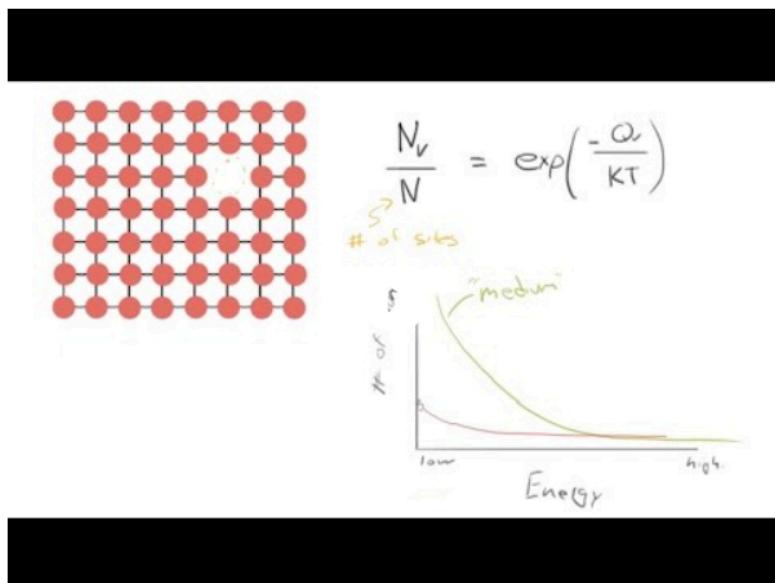
Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a False

b True



Vacancies



[Link to this video on U of T servers.](#)

Another point defect that is important to address at this point is the *vacancy*. A vacancy is simply an atom that has jumped out of its regular lattice position, leaving behind an empty site that would otherwise be occupied by an atom.

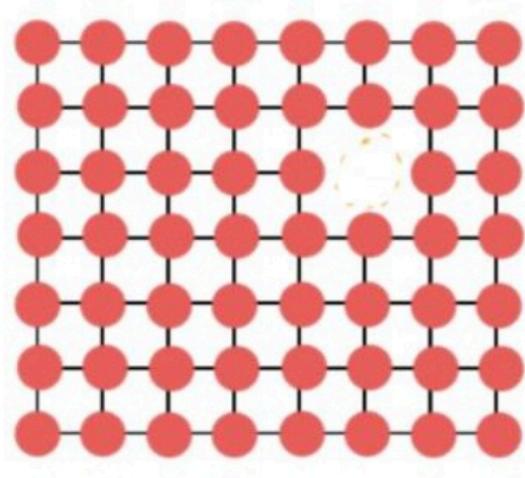


Figure 8: An atomic vacancy in a simple metallic square lattice.

A vacancy is illustrated in Figure 8. It is interesting to consider how a vacancy is formed. Essentially, atoms are desperately vibrating in their lattice sites, trying to jump out of their sites. They are really trying hard. I mean, somewhere on the order of 10¹³ times each second! In the solid state, most of the time they are unsuccessful (there is actually a significant energy saving incentive for atoms to form ordered solids, but we'll cover more on this later) 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. So, we can consider vacancy formation as an ongoing battle between the binding energy that is holding an atom in the lattice site and the thermal energy that is acting to knock the atom out of its lattice site. You'll see this type of battle many times in your academic career and often see the relationship modeled with a so-called *Arrhenius* type equation:

$$\frac{Nv}{N} = e^{\frac{-Qv}{kT}} \quad (1)$$

where $\frac{Nv}{N}$ is the ratio of the number of vacancies to the total number of possible atom sites, Qv is the energy required to form a vacancy, k is the Boltzmann constant, and T is the thermodynamic temperature (temperature in Kelvin, [an absolute scale](#)^①). The epic battle between binding energy and thermal energy plays out in the argument of the exponential in equation 1. The product of the Boltzmann constant and the absolute temperature describes the thermal energy, while the negative of the energy to form a vacancy represents the energy holding the atom in the lattice, or the binding energy.

At this point, you may well have a pesky question lurking somewhere in the periphery of your mind: indeed, one that haunted my dreams when I was first learning these concepts. The question goes something like this, "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?" The answer to this question gives

us a taste of entropy and a brief look into thermodynamics, which is incidentally a fascinating topic. The short answer is that not all of the atoms have the same energy. There is a distribution of energies.

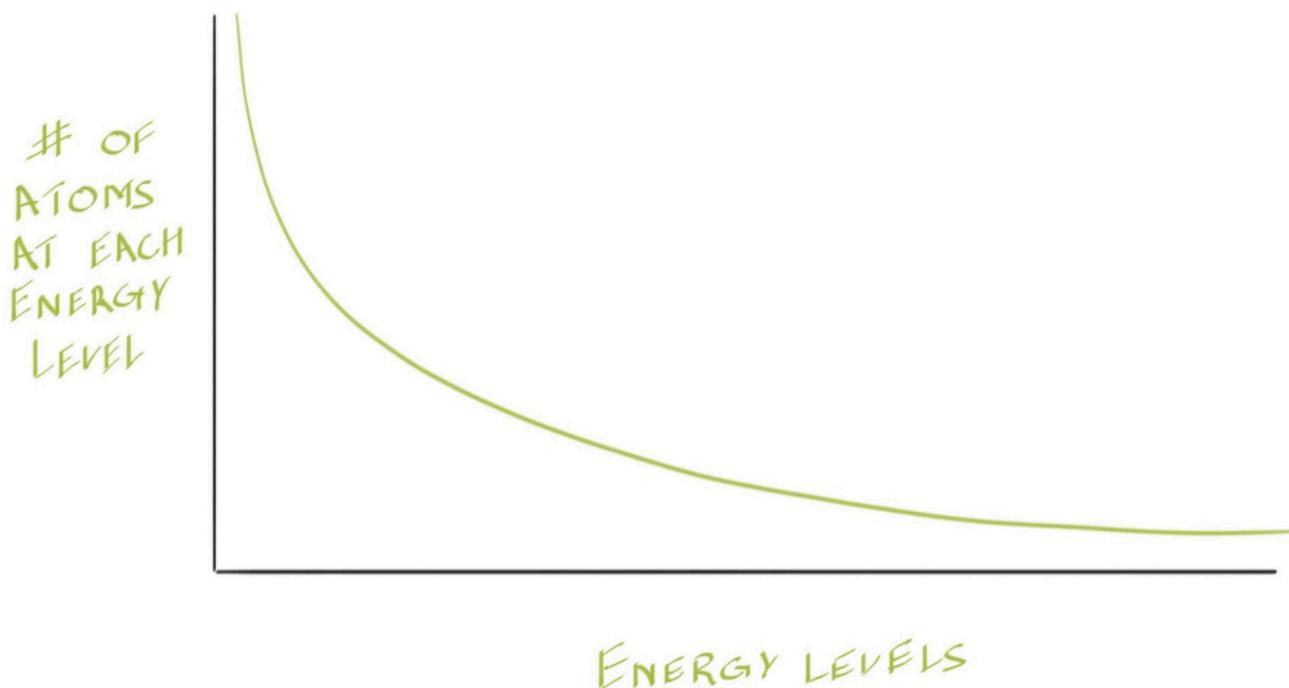
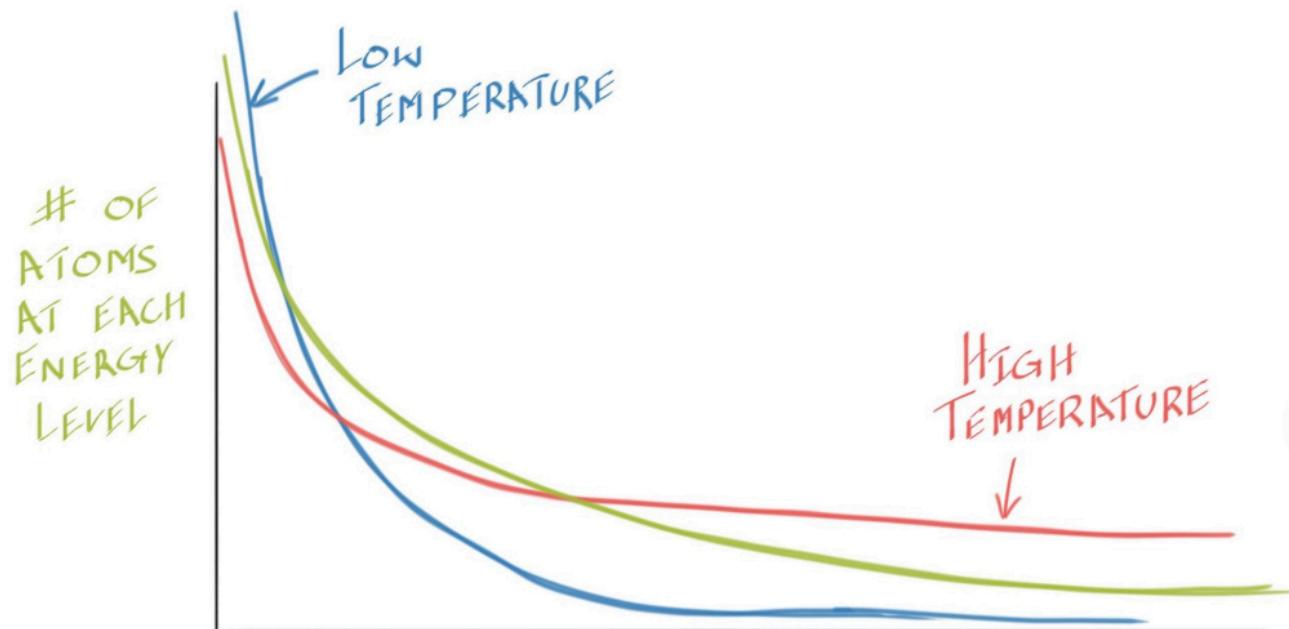


Figure 9: A cartoon depiction of the distribution of particles over permissible energy levels, as described by the Boltzmann distribution.

If we were to consider the distribution of all particles in a system over the possible energy levels we would see a distribution similar to that shown in Figure 9. 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 shown in Figure 10. Interestingly, as we approach lower temperatures we find fewer of the high energy states populated, and, hey, want in on a little secret?



ENERGY LEVELS

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

At absolute zero, only the lowest energy state would be populated. Wild, huh?

A Final Word on Vacancies - In case you are wondering, vacancies do have important implications in solid-state chemistry, however, they are the one crystalline imperfection that we don't use to increase the strength of a metal.



Q7.2.1

Review

Mark as: [None ▾](#)

Which of the following is true of the vacancy population in a metal?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a** The number of vacancies decreases with an increase in temperature
- b** The number of vacancies is a measure of the porosity of a material
- c** The number of vacancies is independent of temperature
- d** The number of vacancies increases with an increase in temperature



Q7.4.1

Review

Mark as: [None ▾](#)

The number of vacancy defects in a metal decreases with increasing temperature

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a** True
- b** False





Q7.5.1
Review

Mark as: [None ▾](#)

Regarding the Boltzmann distribution, which of the following is true of a system at infinite temperature

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a The particles will occupy a distribution of energy states shifted towards the higher energy states

b The particles will be evenly distributed across all of the possible energy states

c The particles will all occupy only the lowest energy state

d The particles will all occupy only the highest energy state



Q7.5.2
Review

Mark as: [None ▾](#)

Which of the following best describes the distribution of particles over possible energy states (Boltzmann distribution) for a population of particles at absolute zero?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a Only the lowest energy state is populated

b An intermediate energy state is most highly populated

c Only the highest energy states are populated

d All energy states equally populated



Q7.6.1
Review

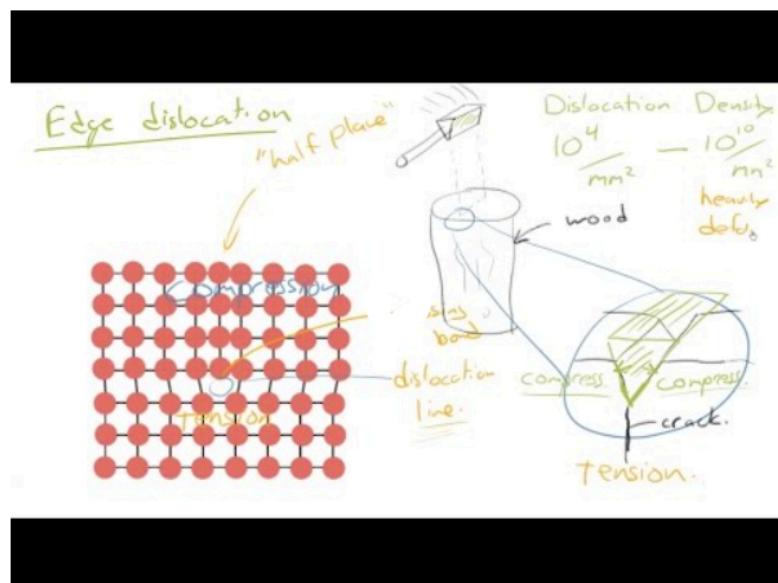
Mark as: None ▾

The Boltzmann distribution for a population of atoms theoretically at absolute zero and at infinite temperature would be described by which of the following?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a All atoms occupying lowest energy state, and all atoms occupying highest energy state
- b All energy states equally populated, and only the highest energy states populated
- c A distribution shifted towards the lowest energy state, and a distribution shifted towards the highest energy state
- d All atoms occupying lowest energy state, and all energy states equally populated

One-Dimensional Imperfections or Dislocations



[Link to this video on U of T servers.](#)

We covered the dislocation earlier, so why again now? Well, I wanted to quickly address how changing the number of dislocations can change the strength of a metal. When we plastically deform a metal we create new [dislocations^①](#). 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. We actually first observed strengthening a metal through plastic deformation when we looked at the stress-strain curve for a metal and saw that the stress continued to increase after the yield strength. In fact, if we unloaded a sample and re-loaded it, the sample would not begin to plastically deform until the stress level reached the stress that we left it at on the earlier cycle.

This is strengthening by plastic deformation, although industrially we would typically perform the plastic deformation by rolling or pulling a metal part through or pressing a metal part into a die, rather than by pulling a part in simple tension. This type of strengthening goes by many names. I know this can be frustrating when you are learning a topic, but I want to be honest with you. Most commonly we call this type of strengthening *cold work* referring to the fact that we obtain more strengthening when the metal is at a lower temperature. Many times, however, 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 *warm work*. A common industrial name for plastic deformation is *forging* and so we also use the terms *cold forging* and *warm forging*. Okay, I can't make this stuff up, but metal temperatures during extensive plastic deformation often get quite hot - hot enough to easily burn your skin, for example and you'll also likely come across the terms *hot work* and *hot forging*. Because the metal accumulates plastic strain during the strengthening process we also use the term *strain hardening*.



Q7.7.2
Review

Mark as: None ▾

Plastic deformation of a metal increases the yield strength for which of the following reasons?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a Plastic deformation reduces the number of dislocations, which increases the strength

b Plastic deformation increases the number of dislocations, which inhibits dislocation movement

c Plastic deformation increases the grain size, which increases the strength

d Plastic deformation increases the number of vacancies which inhibits dislocation movement



Q7.8.1
Review

Mark as: None ▾

Which of the following would you expect would increase the dislocation density in a metal?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a Increasing the temperature

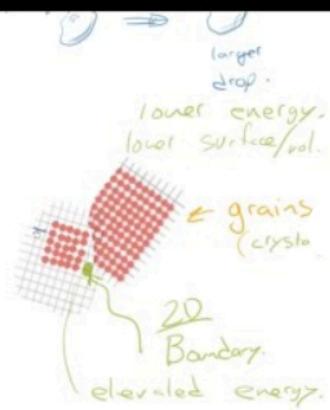
b Heating the metal for an extended time in a furnace

c Decreasing the temperature

d Plastic deformation



Two-Dimensional Imperfections



[Link to this video on U of T servers.](#)

What features are 2-dimensional? Surfaces and interfaces are 2-dimensional.

Free Surfaces

A surface could be a free-surface, such as 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 neighbour atoms - unsatisfied bonds with the atoms along the surface. That's definitely 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

A form of internal surface, if you will, is the grain boundary. These occur anywhere one crystal contacts another. Because the crystals in a metal typically formed individually as 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, as shown in Figure 11.

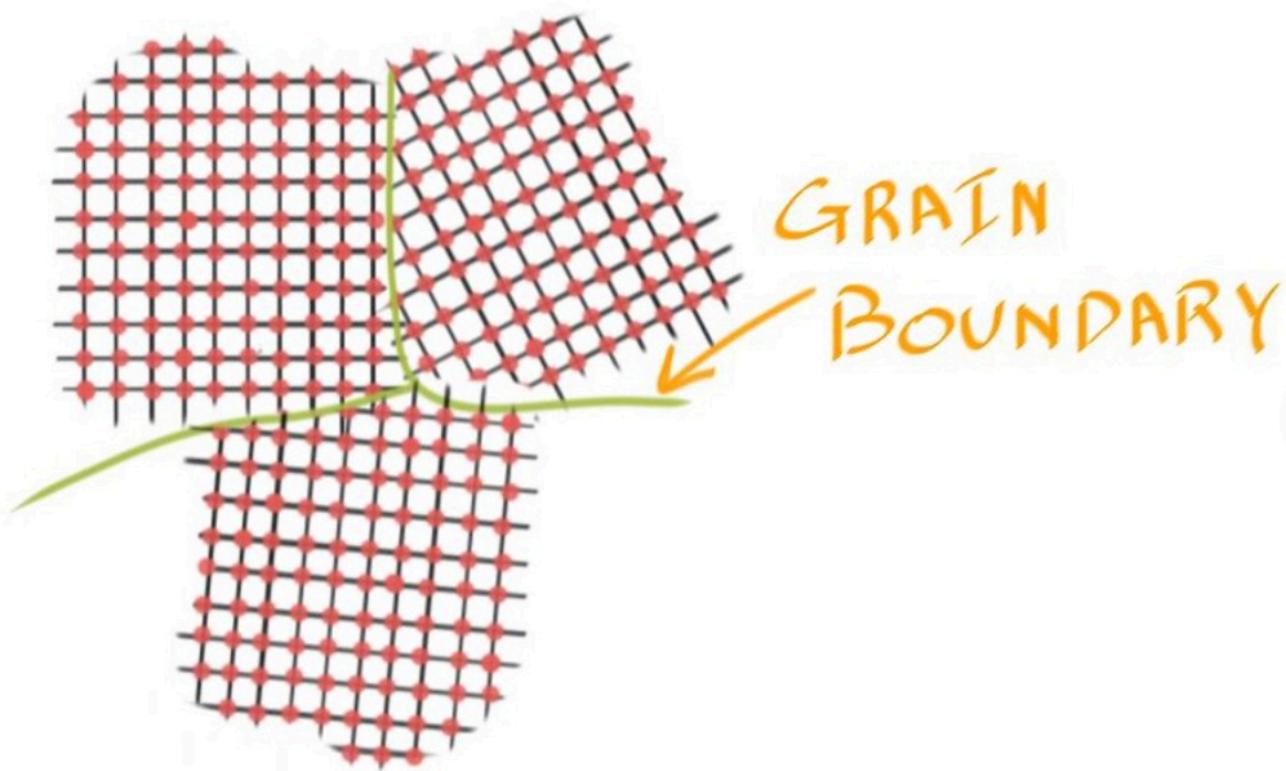


Figure 11: A cartoon depiction of grain boundaries. Each grain formed independently and grew until running into its neighbouring grain.

Now, if we consider a dislocation moving through one of these grains, to continue moving, it must cross the grain boundary, however this is somewhat of a challenge of the dislocation. You see, 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. What's more, 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 (this is in addition to the angle at the grain boundary). This essentially means that the dislocation must make a small step up or down to get into the next crystal. All of these challenges with crossing a grain boundary mean that grain boundaries can be used to inhibit dislocation movement, thereby in-

creasing the strength of a metal. So, how do we increase the number of grain boundaries in a metal? Well, just like we could 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. This strengthening mechanism has a pretty self-explanatory name: *grain size reduction*.



Q7.9.1

Review

Mark as: None ▾

Which of the following would you expect to increase the strength of a metal?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a Decreasing the dislocation density
- b Decreasing the grain size
- c Decreasing the temperature
- d Heating the metal for an extended time in a furnace



Q7.10.1

Review

Mark as: None ▾

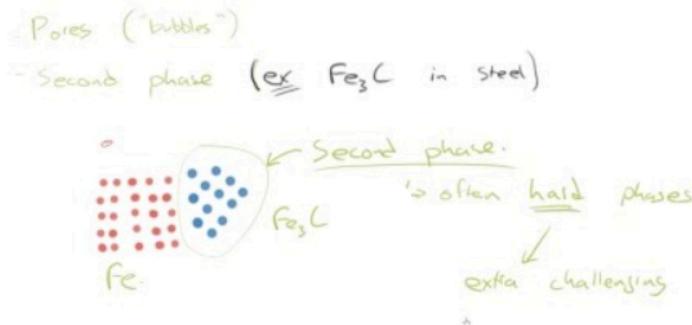
Which of the following is not an example of a two dimensional imperfection in a metal?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a A dislocation
- b A grain boundary
- c A free surface
- d The interface between two phases



Three-Dimensional Imperfections or Second Phase Particles



[Link to this video on U of T servers.](#)

Three-dimensional imperfections occur any time we have a second phase within a solid. We'll cover this concept in more detail when we get into phase diagrams, but for now, essentially, if we have a region of a solid that has a different crystal structure we have a second phase, or three-dimensional imperfection. A dislocation moving in a crystal that encounters a second-phase particle must deal with all of the obstacles discussed in the section above on grain boundaries, but additionally, these second phase particles are often hard and brittle compounds that are already very hard to deform. Second phase strengthening is quite an important strengthening mechanism as many of the alloys that we use as engineers contain multiple solid phases. A great example is AA6061 aluminum. 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. One specific heat treatment is known as the T6 heat treatment and if you look carefully at aluminum products you'll frequently see on a sticker or printed on an aluminum extrusion AA6061-T6 showing that the part has been heat treated to introduce a large number of tiny second phase particles to impede dislocation movement.



Q7.11.1
Review

Mark as: [None ▾](#)

Which of the following would you expect would increase the strength of a metal?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a Increasing the number of small second phase precipitate particles
- b Decreasing the average number of dislocations per unit volume
- c Increasing the purity level
- d Increasing the number of pores



Q7.12.1
Review

Mark as: [None ▾](#)

Which of the following would not be considered a 3-dimensional crystalline imperfection?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a A pore
- b A region of FCC metal within an otherwise BCC metal
- c A grain boundary
- d A ceramic particle within a metallic sample



Q6.8.1
Review

Mark as: [None ▾](#)

Ceramics do not plastically deform at room temperature for which of the following reasons?

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

- a Ceramics do not have dislocations
- b Ceramics have too high density



The bond strength in ceramic materials is too high to permit plastic deformation



Q7.1.1
Review

Mark as: [None ▾](#)

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more ▾](#)

Salt dissolved in hot water	<input type="text"/> 1-dimensional
	<input type="text"/> 3-dimensional
	<input type="text"/> 2-dimensional
	<input type="text"/> 0-dimensional



Q7.1.1b
Review

Mark as: [None ▾](#)

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more ▾](#)

Carbon dissolved in iron	<input type="text"/> 2-dimensional
	<input type="text"/> 0-dimensional





1-dimensional



3-dimensional

**Q7.1.1c**
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more](#) ▾

An air bubble within a piece of glass



0-dimensional



1-dimensional



3-dimensional



2-dimensional

**Q7.1.1d**
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more](#) ▾

The surface of a piece of aluminum

0-dimensional

1-dimensional

3-dimensional

2-dimensional



Q7.1.1e
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more ▾](#)

A grain boundary

1-dimensional

2-dimensional

0-dimensional

3-dimensional



Q7.1.1f
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more](#)

An atom missing from its lattice site

3-dimensional

1-dimensional

2-dimensional

0-dimensional



Q7.1.1g

Review

Mark as: [None](#)

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... [Show more](#)

A potassium atom occupying a lattice site normally occupied by sodium

1-dimensional

0-dimensional

2-dimensional

3-dimensional



Q7.1.1h
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... Show more ▾

A lump of graphite within a sample of iron

0-dimensional

3-dimensional

1-dimensional

2-dimensional



Q7.1.1i
Review

Mark as: None ▾

Match each of the following imperfections with its dimensionality by writing 0, 1, 2, or 3 in each box, for zero-dimensional, one-dimensional, two-dimensional, and three-dimensional, respectively.

Drag and drop options on the right-hand side and submit. For keyboard navigation... Show more ▾

A dislocation

2-dimensional

0-dimensional

3-dimensional

1-dimensional





Q7.2.2

Review

Mark as: [None ▾](#)



The yield strength of an alloy is generally lower than that of either of the constituent pure elements

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a False

b True



Q7.13.1

Review

Mark as: [None ▾](#)



Are the following statements true or false?

- (a) Reducing grain size increases yield strength
- (b) When a ductile material is plastically deformed, strain hardening occurs
- (c) Alloying decreases the strength of a material because of introducing impurities into the lattice
- (d) Dislocation motion causes plastic deformation
- (e) The actual strength of a material is always higher than the theoretical strength

Select an answer and submit. For keyboard navigation, use the up/down arrow keys to select an answer.

a False, False, True, False, False

b True, True, False, True, False

c False, False, True, True, False

d True, True, False, False, True