Bike Frames 4

Monday, January 5, 2026 11:49 AM

Bike Frames Day 4 Learning objectives

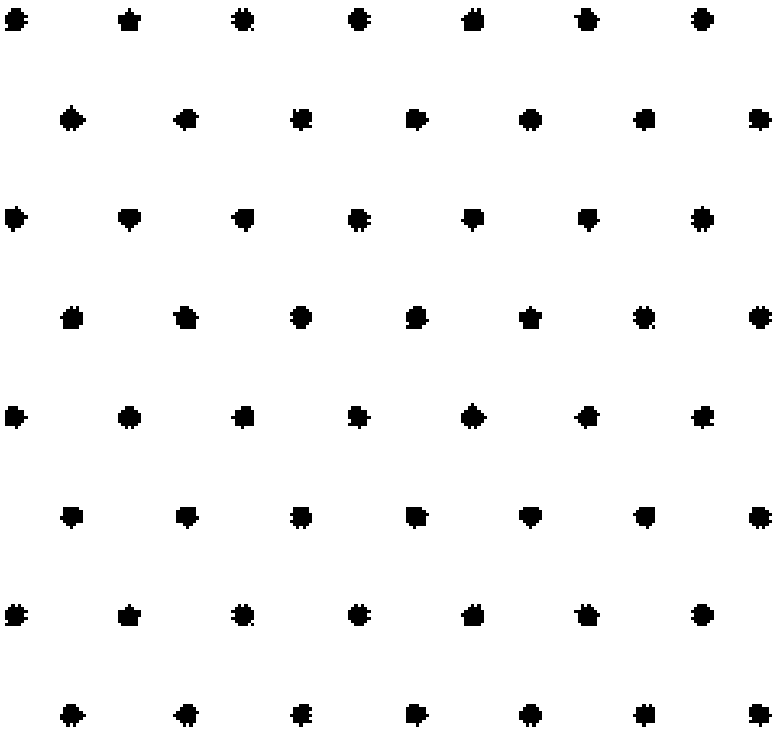
- Identify BCC, FCC, and HCP unit cells.
- Compare packing fractions & relate them to density and stiffness.
- Explain why different crystal structures give different mechanical behavior.
- Interpret binary phase diagrams (Al–Li and Ti α/β).
- Connect how structure & phase control modern bicycle frame performance.

Question: Why is Al lighter than steel even before we hollow tubes?

Unit cells

Most matter organizes into periodic arrangements of atoms. We call these **crystalline** materials or crystals even if they don't look like gemstones. There are a variety of different ways that we can arrange matter into repeating patterns. The smallest repeating pattern that can file space via translation only is called a **unit cell**.

Group activity: find the unit cell

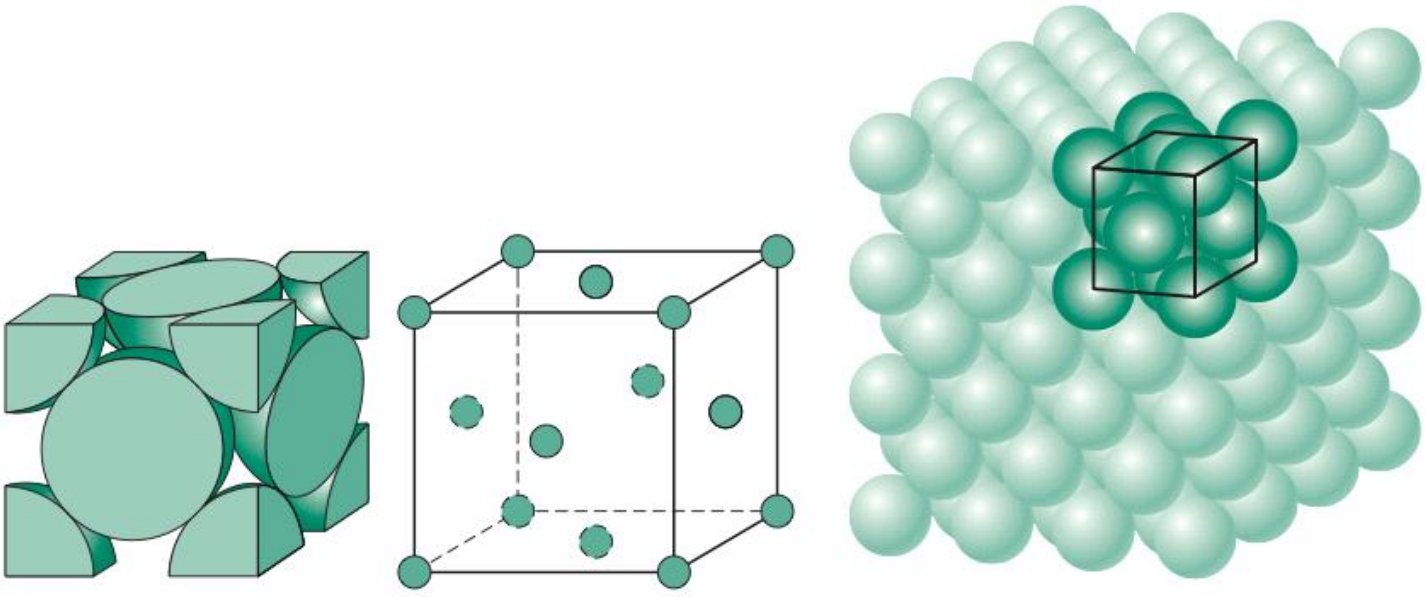


There are 14 different **Bravais Lattices** for arranging matter. The 14 Bravais lattices are found across seven different **crystal systems** by including 4 different **centering** types.

Bravais lattice	Parameters	Simple (P)	Volume centered (I)	Base centered (C)	Face centered (F)
Triclinic	$a_1 \neq a_2 \neq a_3$ $\alpha_{12} \neq \alpha_{23} \neq \alpha_{31}$				
Monoclinic	$a_1 \neq a_2 \neq a_3$ $\alpha_{23} = \alpha_{31} = 90°$ $\alpha_{12} \neq 90°$				
Orthorhombic	$a_1 \neq a_2 \neq a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Tetragonal	$a_1 = a_2 \neq a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Trigonal	$a_1 = a_2 = a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} < 120°$				
Cubic	$a_1 = a_2 = a_3$ $\alpha_{12} = \alpha_{23} = \alpha_{31} = 90°$				
Hexagonal	$a_1 = a_2 \neq a_3$ $\alpha_{12} = 120°$ $\alpha_{23} = \alpha_{31} = 90°$				

https://www.goseeko.com/blog/what-is-bravais-lattice/

Aluminum is a simple metal structure known as **Face-Centered Cubic or FCC**. It's one of the 14 Bravais Lattices.



Group activity: How many atoms are there per unit cell?

The unit cell side length is known as the **lattice parameter** and if we know the size of the metal atom and assume **close-packing** then we can estimate the lattice parameter.

Another super simple structure is Body-centered cubic

Another is Hexagonal Close-Packed

Each crystal structure is unique and some tend to have particular traits or qualities

- FCC tends to be…
- BCC tends to be…
- HCP tends to be…

A materials density is the mass divided by the volume

- Density usually has the units of g/cm^3 we sometimes write this as g/cc (cubic centimeters)
- The densest pure element is Osmium, $22.59\ g/cm^3$ while Lithium is $0.534\ g/cm^3$

- Steel is ~8 g/cc but liquid mercury is 13.54 g/cc…. So steel should float in mercury!? Yes!

[Floating an Anvil on Liquid Mercury]
Cody'sLab

Theoretical density calculation

If we know what atoms occupy the sites in a lattice, then we can calculate the theoretical density of the crystal

Avogadro's number: 6.023×10^{23} # of something per **mole** of substance

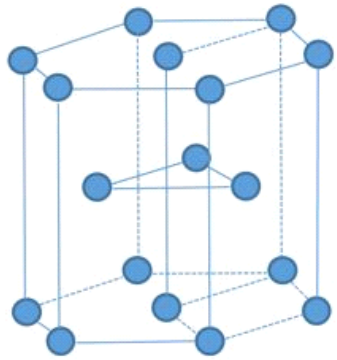
A mole is just a way to count very, very tiny things, like a "dozen" is used to count 12 items.

There are thousands of other different **crystal structures** and these can have way different properties!

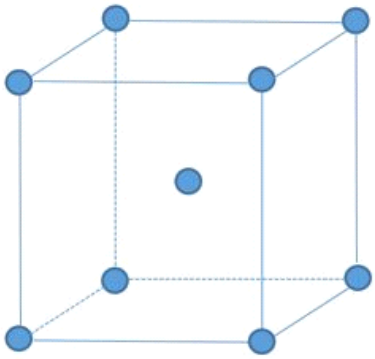
How do we know which phase (crystal structure) will exist and is it possible to have more than one present at a time!? Phase diagrams tell us!

Let's start with a super simple phase diagram for the Cu-Ni system

For example, titanium alloys come in two flavors the **brittle** and hard alloys or the soft and **ductile** ones

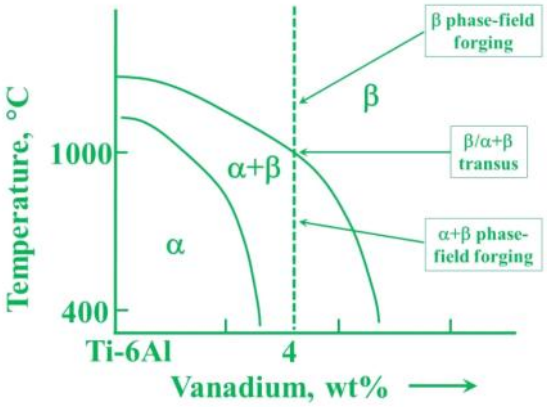


Hexagonal close-packed crystal structure (HCP)



Body-centered cubic crystal structure (BCC)

(HCP = alpha, BCC = beta)

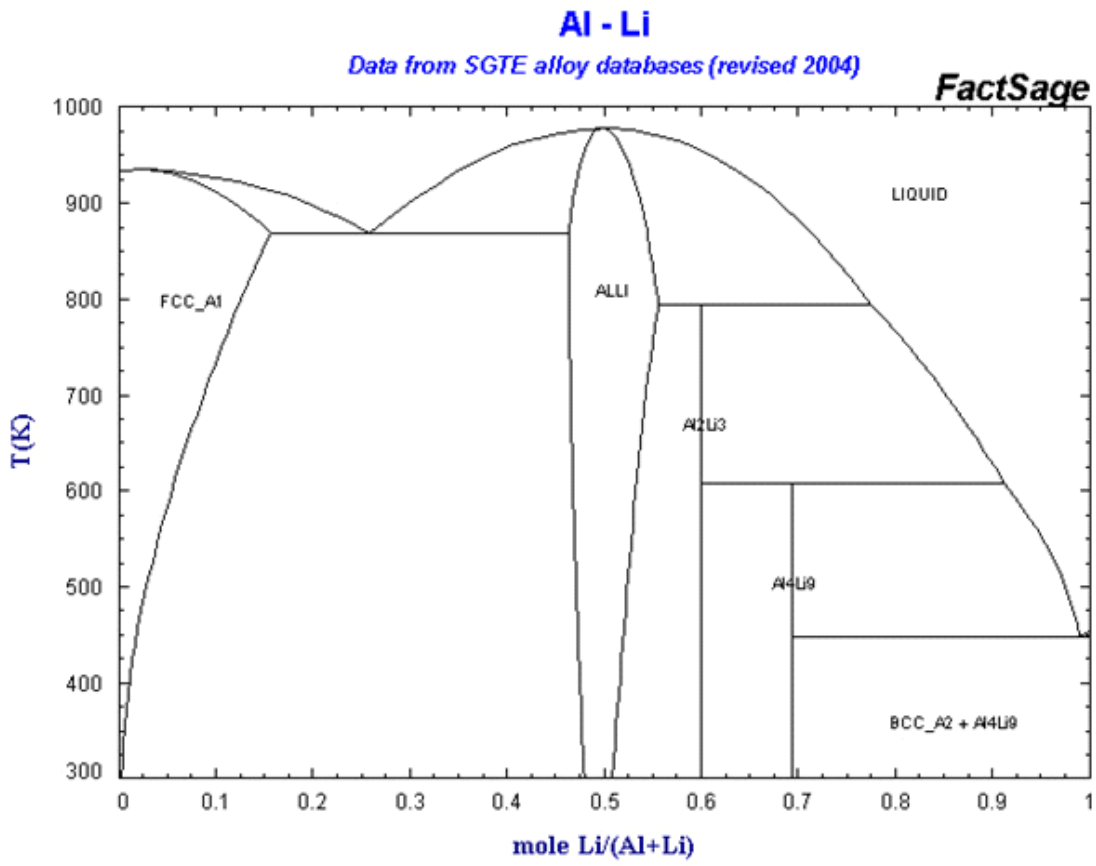


Lightweighting is big business in sports gear!

Some metals we use in their pure form, but others we intentionally mix with other components to form an **alloy**. We alloy metals for different reasons. For solders we form alloys to lower the melting point. For "sterling silver" we add copper to silver in order to increase the hardness of the jewelry (while also reducing the cost). When we alloy materials the lattice parameter usually changes size since the atoms are different sizes. The two metals can be **randomly distributed**, or they can form an **ordered intermetallic**.

Phase diagrams help us find the limits of **solubility** so we know to what extent we can form an alloy without forming additional **phases**.

Aluminum is already light, but what if we alloyed it with an even lighter element like lithium?



Lightweight alloys are extremely important for transportation applications. For example, in 2011 Polaris bought the Indian motorcycle brand and by 2015 had completely reinvented the original 1920 Indian Scout with a cast aluminum frame instead of steel. Despite having a smaller engine than a Harley Davidson Sportster (1133cc vs 1200cc) it delivers much more power (100hp vs 75hp) while weighing 100 lbs less. Ford's F-150 has an aluminum body shaving off 15% of its weight while increasing fuel efficiency by 20% and expanding hauling capacity by 11%. Consider the Al-Li phase diagram. Li-Al alloys are important to aerospace industry largely because they are very light. For every 1% by weight of lithium added to aluminum reduces the density of the resulting alloy by 3% and increases the stiffness by 5%. This effect works up to the solubility limit of lithium in aluminum. (taken from Wikipedia page on Al-Li)

AlLi has a density of 2.1 g/cc, pure Al is 2.7g/cc