Models of Crystals

Students do the "Models of Crystals" lab. They build 4 different unit cells using toothpicks and polystyrene balls. A recommendation is to use 1 ½” diameter spheres - the smaller ones tend to fall apart quickly after using just a few times. They build the most basic one (simple cubic) and the 3 most commonly found in metals (BCC, FCC, HCP). See the lab sheet the students fill out.

Permanent models made out of ping-pong balls and hot glue are very useful. These help the students compare the different models in terms of packing and slip planes since they dismantle their models before building the next one. It is also helpful to build planes of atoms and then stack them. This helps the students to see that the layers are all actually the same in a model; they are just "offset" when stacking them together to make the unit cell. This is also great to see the overall 3-D pattern of the crystal shape. This works especially well with FCC and HCP. If you make 3 planes for each, then the students can also try piecing them together into one layer instead of stacking them into 3 layers to make a unit cell. By building a bigger plane from smaller ones, the students can pick out the "section" that is used in each of the different layers in the unit cell. The repeating pattern is much more noticeable.

After the students have finished building the models and writing in their journals, ask the students the following question:

- "Why do we care what particular crystal structure a metal has?"
  - because crystal structure affects properties of the metal

Have the students rank the crystal models from "most closely packed" to "least closely packed".

1. HCP - "most closely packed"
2. FCC
3. BCC
4. simple cubic "least - closely packed"

Ask the students:

- "Which type of crystal structure allows a metal to be more workable, one with many slip planes or one with fewer slip planes?"
- "Which type of crystal structure allows a metal to be more workable, one that is closely packed or one that is loosely packed?" ("One that has a lot of 'gappiness' or one that has little 'gappiness'?"")

The students almost always get the answer to the first question right. It is logical that a crystal structure with many slip planes will be more workable. However, the answer to the second question isn't as obvious. At least half of the students always say that more loosely packed crystal structures (ones with more open space) make a metal more workable. By workable we mean malleable or ductile. I then use the "chalk demo" to illustrate the answer.
Chalk demo:

- Materials:
  - 5 pieces of chalk laid side by side with an ~ 1/8" gap between each piece (use hot glue to attach them to a piece of clear plastic)
  - 5 pieces of chalk laid side by side with no gaps between them (attach to plastic)
  - one piece of chalk to roll across the top of the other pieces

Give the students the following scenario:

You are riding your 4-wheeler in the country and you come to a deep ditch that someone has built a log bridge across. Which type of bridge would be easier to go across?

Then roll the single piece of chalk across the “chalk bridges” – first the one with gaps and then the one without gaps. Which one is harder to do and requires more energy? They will all agree that the one without gaps is easier.

Now tell the students you are going to ask them the original questions AGAIN:

- “Which type of crystal structure allows a metal to be more workable, one that is closely packed or one that is loosely packed?”
- “Which one is easier for the planes of atoms to slide past each other?”

The students get it. Common sense wants to tell us that having more “open space” in a crystal makes it easier for atoms to move around so the metal is more workable. But this isn't the case with planes of atoms. More ‘gappiness’ allows the atoms to fall into these spaces and makes it harder to keep them moving to work the metal.

- more tightly packed = more workable
- more slip planes = more workable

Workable – changing the shape of a solid (while remaining a solid) without it cracking or breaking (malleability and ductility)

Based on the above information, have the students reason out which crystal structure should be the most workable. Since FCC is both tightly packed and has many slip planes, it is the most workable.

Have the students fill in the following table:

<table>
<thead>
<tr>
<th>Type of crystal structure</th>
<th>Closely-packed?</th>
<th>Many slip planes?</th>
<th>Workability</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCC</td>
<td>Yes</td>
<td>Yes</td>
<td>Highest</td>
</tr>
<tr>
<td>BCC</td>
<td>No</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>HCP</td>
<td>Yes</td>
<td>No</td>
<td>Lowest</td>
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</table>
Ask the students if there is a way to figure out if the packing and the slip planes have an equal effect on the workability or if one of the two factors has more.

Since BCC and HCP both have a “yes” and a “no” and HCP is the least workable, reasoning would dictate that the number of slip planes has more effect on the workability than how closely packed the atoms are.

Now ask the students to predict which familiar metals should have an FCC crystal structure. They can usually correctly name several such as gold, copper, aluminum, lead, etc…

Then compile a list of some common metals and their crystal shapes.

<table>
<thead>
<tr>
<th>BCC</th>
<th>FCC</th>
<th>HCP</th>
<th>Other</th>
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<tbody>
<tr>
<td>chromium</td>
<td>aluminum</td>
<td>cobalt</td>
<td>tin</td>
</tr>
<tr>
<td>iron (&lt;910 °C)</td>
<td>copper</td>
<td>magnesium</td>
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</tr>
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Iron appears in two different columns because it is allotropic. This concept will be further developed in the Iron Wire Demo. But the students should be able to grasp the idea that blacksmiths pound on a piece of iron when it is glowing red hot and stop when it loses its color since FCC is a more workable crystal structure than BCC.

I provide my students a copy of the Sargent-Welch periodic table. It has a tremendous amount of info for each element including crystal structure. It is a very useful tool for students of materials science.

This is a great place to demo the tin cry. Students love it. They may not be able to see the individual crystals move but they sure can hear their collective noise. IASCO is a great source of tin - a one pound bar is about $10.

A sheet of copper and a sheet of titanium are also useful for demonstrating the difference in the workability of an FCC metal and an HCP metal. Simply hold down one end of the metal against the edge of a table, push down on the other end and release. The copper is very workable and easy to bend and will not completely return to its original shape. The titanium takes more force to bend and will spring back to its original shape.
Models of Crystals Lab

Terms:
crystal:
unit cell:
slip plane:

Name and abbreviation of unit cells that will be constructed:

Brief Method:

Construct the crystal models one at a time as pictured “a” through “d” in the figure on the next page.

Journal the following for each model you build:

- sketch of unit cell
- label with name and abbreviation
- describe the packing and slip planes
  - examples: close, tight, loose, “gappiness”, many or few slip planes
Before dismantling a model and building the next one, as a class, try to assemble the individual unit cells into a bigger crystal. The teacher will assist with this.

- Pay close attention to spacing and alignment.
- For example, the spheres in layer 1 of model C do not touch each other. The center sphere in model C should touch all the spheres of the 1st and 3rd layers but none of the other spheres should touch each other.
- When stacking the layers to build each model, be sure the orientation is the same as in the diagram.
- Use the fewest number of toothpicks possible.
Models of Crystals Lab

Terms:

Crystal: -an object with a regularly repeating arrangement of its atoms  
-it often has external plane faces

Unit cell: -the simplest and smallest arrangement of atoms that can be repeated to form a particular crystal

Slip plane: -a surface along which layers of atoms can slide

Name and abbreviation of unit cells that will be constructed:

- Simple cubic
- Body-centered cubic - BCC
- Face-centered cubic - FCC
- Hexagonal close packed - HCP

Brief Method:

We are going to make models of 4 different crystals using toothpicks and Styrofoam balls.

Construct the crystal models one at a time as pictured “a” through “d” in the figure on the next page.

Journal the following for each model you build:

- sketch of unit cell
- label with name and abbreviation
- describe the packing and slip planes
  - examples: close, tight, loose, “gappiness”, many or few slip planes
  - (Hint: cubic structures have many slip planes)
Before dismantling a model and building the next one, as a class, try to assemble the individual unit cells into a bigger crystal. The teacher will assist with this.

a. simple cubic
   - loosely packed, lots of “gappiness”
   - lots of slip planes

![Simple Cubic](image1)

b. face-centered cubic
   - tightly packed, much less “gappiness”
   - lots of slip planes

![Face-Centered Cubic](image2)

c. body-centered cubic
   - loosely packed, more “gappiness”
   - lots of slip planes

![Body-Centered Cubic](image3)

d. hexagonal close-packed
   - tightly packed, not much “gappiness”
   - few slip planes

![Hexagonal Close-Packed](image4)
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