

GUMDROP CRYSTAL MODELS

John J. Thomas

Purpose

This exercise is to demonstrate the internal ionic structure of minerals and how the internal arrangement of ions is reflected in the crystal shape of the mineral. This exercise works especially well if you do it after you have grown the halite crystals in the Easy (and Cheap) Crystal growing exercise.

Definitions

Bonding - the forces, or links, that tie an ionic structure together.

Crystal - the shape of a mineral when it grows free of interference.

Electron - a negative particle that orbits around the nucleus of an atom.

Ion - an atom that has lost or gained electrons and, therefore has a positive or negative charge.

Nucleus - the center of an atom that consist of positive and neutral particles.

Unit Cell - The smallest three dimensional structure of a mineral that can form.

Teacher information

A mineral is defined as a naturally occurring, inorganic substance with a chemical composition fixed within a range and an ordered internal structure. Naturally occurring means that it cannot be man-made. Inorganic means that it cannot come from living material. A fixed chemical range indicates that we know which elements can occur in a mineral and which can substitute into the structure. An ordered internal structure is one in which the ions in the minerals are arranged in a regular pattern that is repeated throughout the structure. It is this structure that this exercise addresses.

There are only three rules for building a mineral structure:

- 1) Geometric stability. All the parts must fit together. When the ions are stacked in their ordered internal structure they must not stretch the structure breaking it or be so small that they fall out.
- 2) Electrostatic stability. All the charges must balance. In a mineral the charges take care of themselves. The right ions of the right charges will go into the structure in the right amounts.
- 3) Polarizability. If we cannot explain how things fit together, we say that the ions polarized, changed shape or squished, in order to fit in. Ions can change size up to 25% larger or smaller. They are squishy like nerf balls.

Atoms are neutral and cannot make a crystalline structure. Ions are atoms that have gained or lost electrons and, therefore, have a charge and can build a structure. If an atom loses electrons, it becomes an ion, gets a positive charge, and is much smaller in size. If it gains electrons, it becomes an ion, gets a negative charge, and becomes larger in size.

Geometric stability is the first rule of building a mineral. That means that the size of the ions is the most important factor. The large ions determine the structure. Negative ions are the large ones, so they rule. The large (negative) ions are stacked together and then the small (positive) ones fit in the holes between the larger ions. The concept is like a fieldstone wall. The stones (negative ions) stack next-to and on each other and the chipmunks (positive ions) live in the holes.

Take the mineral halite (salt) as an example. As you will see its structure is simple. Halite is made up of Na^+ (sodium) and Cl^- (chlorine) ions. The structure is determined by the Cl^- ions.

When you fit all the same size spheres together they form a seven member six sided structure, figure 1.

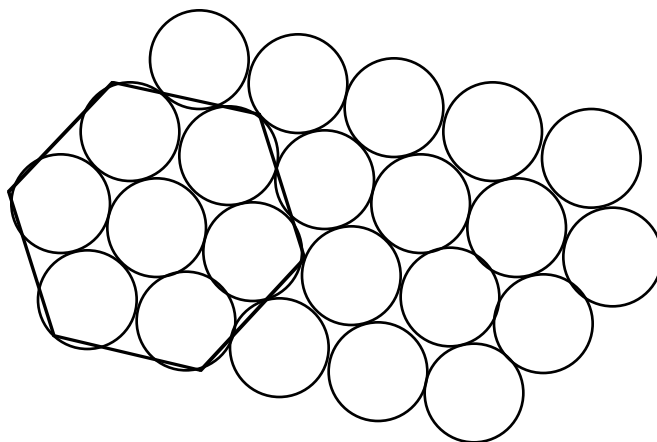


Figure 1. An array of chlorine ions all the same size. Viewed from above.

You can try this with any spheres all the same size, tennis balls, golf balls, pingpong balls, styrofoam balls, etc. This is only a two dimensional array. When you put a layer of ions on top of this the first ball rolls into the low point in the middle of three spheres. Then there is only one way that all of the other spheres can be put in the second layer and all be touching. The bottom layer is referred to as the "A" layer, the second as the "B", see figure 2.

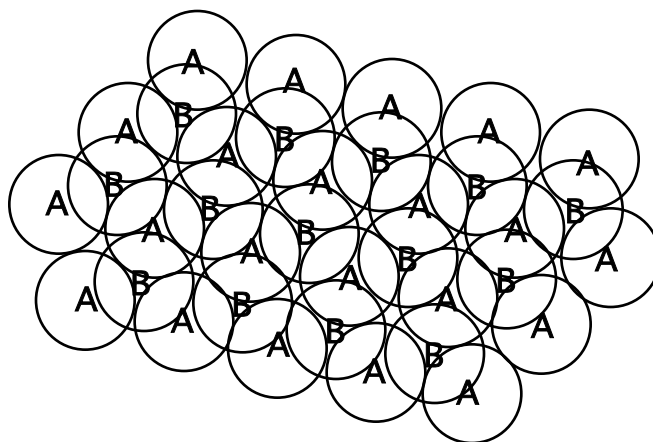


Figure 2. Two layers of Chlorine ions. Viewed from above

The third layer would be above the A, then a B, an A, etc. Thus the layers are stacked in an A-B-A-B-A-B-A-B-A etc. sequence. Noticed there are big gaps in the structure that could be filled by smaller ions. Since the A and B layers are all Cl^- ions, then the holes must be filled with positive ions. In this case, Na^+ is the exactly correct size to fit. The Na^+ ions will go into the voids in the Cl^- array. See figure 3 on the next page for an illustration.

If you have the spheres of the right size, you can build a model of a halite crystal and will end up with a structure that looks like figure 4. Remember that the Na^+ ions must be just the right size so that they just fit in the voids in the Cl^- structure.

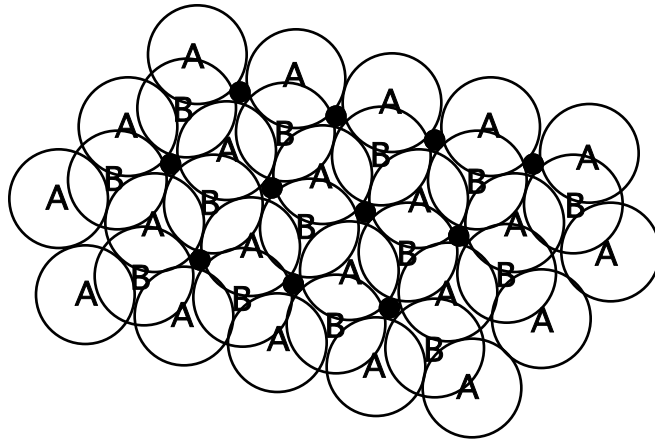


Figure 3. Chlorine ions (A and B) with sodium ions in the voids (●). Viewed from above.

Figure 4 is an illustration of the halite structure in Three dimensions. Notice that in this structure the chlorines are at the corners of a cubic structure and the sodiums fit in the voids. The bottom layer of chlorine would be the A layer, the middle the B, and the top another A.

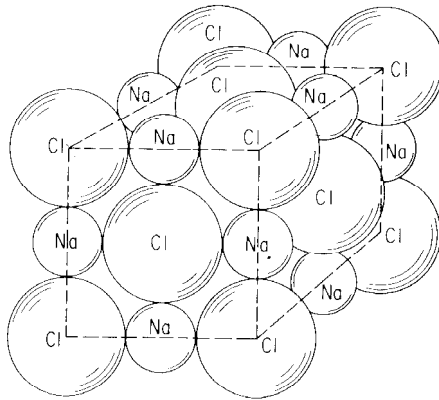


Figure 4. A three dimensional model of a unit cell of halite (from Keith Frye, 1974, Modern Mineralogy, Prentice-Hall, Inc.).

Notice that on an ionic scale the unit cell is a cube. Crystals of halite are also cubes. That means that the cubic shape of the crystal is determined by the cubic arrangement of the ions in the crystallographic structure. If you look at the halite crystals that you grew in the crystal growing exercise, you can easily see this cubic structure.

This exercise will build a stick model like figure 5 on the next page. The ions will be gumdrops. The stick bonds will be toothpicks.

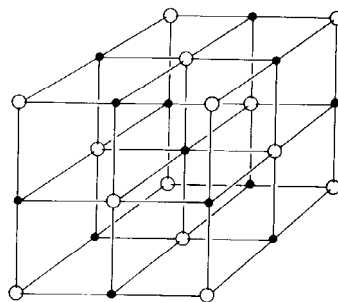


Figure 5. A stick model of a unit cell of halite. The open spheres are chlorine. The closed are spheres are sodium. (from Keith Frye, 1974, Modern Mineralogy, Prentice-Hall, Inc.).

Equipment

Gumdrops
Toothpicks
Paper towels

Student Exercise

A word of caution. The students will eat all of the gumdrops before you can distribute them. Start the exercise by telling them they may not eat the gumdrops until the exercise is over.

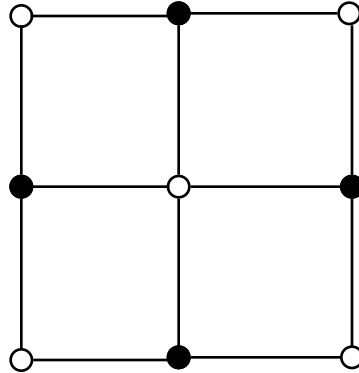
A second word of caution. Students will pig out on gumdrops! They will eat enough to make themselves sick. We have taught this exercise to students from fourth grade to college. They all eat too many gumdrops. Warn them at the beginning that they can get sick from eating too many!

Give each student 30 gumdrops, 15 of one color and 15 of another, and a bunch of toothpicks. Tell them to choose one color to be chlorine ions and one sodium. Have them break the toothpicks in half; this makes a much stronger model. By sticking toothpicks in the gumdrops they can build the model. Have them build it up three layers like the picture. It is a good idea if you build a model as a demonstration while they are building theirs.

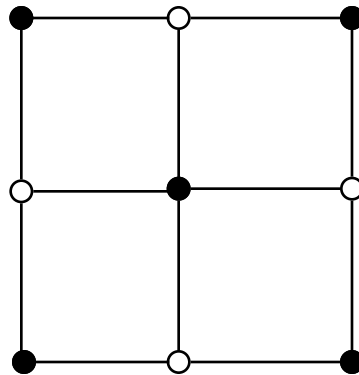
WORKSHEET

Get from your teacher 30 gumdrops, 15 of each color, and a bunch of toothpicks.
Break the toothpicks in half.

Build a layer of a crystal like the following picture. Put one color gumdrop in the position of the open circles. These are chlorine ions. The other color will go where the solid circles are. These are sodium ions. Link the gumdrops together with toothpicks.



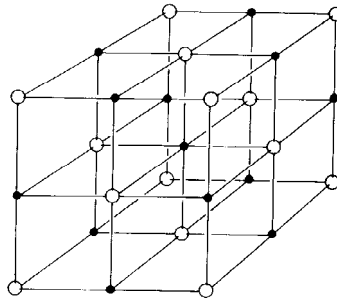
Make a second layer like the next picture.



Link this layer directly above the first layer with toothpicks.

Make a third layer like the first and link it above the second.

Your final structure should look like:



You have built a unit cell of halite. If you have a sample of halite, notice that the crystal of halite and its ionic structure are both cubes.

Advanced Activities

There are only three rules for building a mineral structure:

- 1) Geometric stability. All the parts must fit together. When the ions are stacked in their ordered internal structure they must not stretch the structure to break it or be so small that they fall out.
- 2) Electrostatic stability. All the charges must balance. In a mineral the charges take care of themselves. The right ions of the right charges will go into the structure in the right amounts.
- 3) Polarizability. If we cannot explain how things fit together, we say that the ions polarized, changed shape or squished, in order to fit in.

You can prove the structure of halite by proving that the three rules are fulfilled.

Information for the exercise:

Ion sizes for halite:

Ion	Charge	Ionic radius
Na ⁺	+1	1.24
Cl ⁻	-1	1.67

Radius Ratio Formula:

$$\text{Radius Ratio} = \frac{\text{Radius of the positive ion } r^+}{\text{Radius of the negative ion } r^-} = \frac{r^+}{r^-}$$

Range of radius ratios for 4- and 6-fold voids

Void	Radius Ratio
4-fold	0.225-0.414
6-fold	0.414-0.732

- 1) Geometric stability depends on stacking of the ions. The larger ions build the basic framework of the mineral by forming a closepack array. Then the other ions have to fit in the voids left in the array of the larger ions. The voids are 4-fold and 6-fold (they have 4 or 6 ions of the opposite charge around the voids. You need to know the size of the positive and negative ions, the size ions the voids will hold, and the radius ration of the positive to negative ion. The mineral structure is stable if the positive ion will fit into one of the voids in the close pack array of the negative ions.

Which ion will build the basic framework? _____

Radius ratio of Na⁺ to Cl⁻. _____

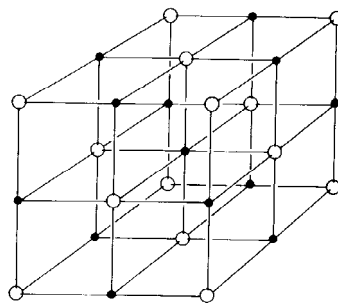
The void Na⁺ will fit into. _____

Is halite geometrically stable? _____

- 2) Electrostatic stability can be proven if all the charges in the unit cell are balanced. You have built a unit cell of halite. Now you have to add up the charges. To do this you need 1) the charges on the ions and 2) the amount of the charge that belongs to the unit cell.

Unit Cell Position	Charge belonging to the Unit Cell
Corner	1/8
Edge	1/4
Face	1/2
Inside the cell	1

The ion in the corner of the unit cell is shared by eight unit cells in the mineral, so the charge belonging to the unit cell is 1/8. Each edge ion is shared by four unit cells, 1/4. Face unit cells are shared by two unit cells, 1/2. The ions inside the unit cell belong entirely to the unit cell.



So what you have to do is count the corner, edge, face and inside ions of each charge in the picture above. The Na^+ are solid circles, Cl^- are open circles.

Ion	Position	Number	Multiply by	Charge
Na^+	Corner		1/8	
	Edge		1/4	
	Face		1/2	
	Inside		1	
Total positive charge on the Unit Cell				
Cl^-	Corner		1/8	
	Edge		1/4	
	Face		1/2	
	Inside		1	
Total negative charge on the Unit Cell				

Does the number of positive charges equal the negative? _____

- 3) Polarizability is satisfied if the positive ions can fit in the voids.

ANSWER SHEET FOR ADVANCED EXERCISE FOR CRYSTAL MODELLING

1) Radius ratio of Na⁺ to Cl⁻. 0.743

Radius of the positive ion 0.102
 Radius Ratio = $\frac{0.102}{0.136} = 0.743$
 Radius of the negative ion 0.136

The void Na⁺ will fit into. 6 fold if it polarizes

Is halite geometrically stable? if Na⁺ polarizes slightly

2)

Ion	Position	Number	Multiply by	Charge
Na ⁺	Corner	8	1/8	0
	Edge	12	1/4	3+
	Face	6	1/2	0
	Inside	1	1	1+
Total positive charge on the Unit Cell				4+
Cl ⁻	Corner	8	1/8	1-
	Edge	0	1/4	0
	Face	6	1/2	3-
	Inside	0	1	0
Total negative charge on the Unit Cell				4-

Does the number of positive charges equal the negative? Yes

3) Is Na⁺ polarized? Yes

Why? The difference in size between the 0.731 of the 6-fold void and the radius ratio for Na⁺ is less than 25% difference in size.