Growing Crystals: A Lesson on the Structure of Matter and Self-Assembly

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These crystals of quartz are large and well formed because they grew out of mineral-rich solutions in large open rock cavities. When solutions are completely saturated with mineral components, in this case silicon oxide (SiO_2), crystals can begin to form on rock walls, on other crystals, or even on particles of dust. They can grow quickly or slowly, or even stop — depending on changes in temperature and the concentration of the solution.

Grade Level: Middle School/High School

Content Integration: Chemistry, Mineralogy, Meteorology

Overview:

Crystal growing is related to the notion of 'bottom up' nanotech. This is a 'self assembly' process where we rely on the components at the nanoscale (the atoms/molecules) to have the information 'built into' them that is necessary for assembling a structure (in this case a crystal).

Background:

For a crystal, the structure of matter is in an ordered manner due to an arrangement of atoms, molecules or ions. Atoms are a little less than 1 nm in diameter. Every crystal has a repeating pattern based on its unique chemistry and molecular alignment causing a distinct shape. Crystals may differ in size, but each has its own structure. Rock salt (halite), sugar (sucrose), borax (sodium borate) and alum all show a crystal structure when precipitated from a super-saturated solution. For example, halite indicates a cubic structure.

Crystals "grow" when distilled water is heated thus allowing molecules to move more rapidly and farther apart from one another. This causes the condition whereby, the introduced substance (rock salt, sugar, borax or alum) can dissolve due to the increased space in the heated solution. When no more of the introduced matter can dissolve into solution, that mixture has become saturated. As the mixture cools, the water molecules move closer together and as a result, there is less space in the solution for the dissolved substance thus allowing the formation of crystals. As the water continues to cool and evaporate, crystals build on one another and the crystal construction becomes larger.

This process takes place in nature when snowflakes form. As atmospheric moisture cools on a particle (nuclei), the water molecules form a 6 sided crystal. The repeated pattern results from the chemical structure and composition of water. For additional reading on this topic, refer to the Resources section.

Objectives:

1. Construct a model of crystal growth noting the structure that results when certain rules or conditions are applied.
2. Generate an understanding of self-assembly during the process of growing crystals.
3. Apply the process skills of scientific inquiry during experimentation.

BIG IDEAS of Nanotechnology* Addressed:

BIG IDEA #2 – Structure of Matter

* The BIG IDEAS of Nanoscale Science and Engineering;
A Guidebook for Secondary Teachers (ISBN:978-1-935155-07-2).

The atomic theory describes a model on which matter is composed of discrete units called atoms. Slightly more than 100 types of atoms make up all substances. The type of atoms and their arrangements determine their identity and affect the properties of a material.

BIG IDEA #6 – Self-Assembly

Under specific conditions, some materials can spontaneously assemble into organized structures. This process provides a useful means for manipulating matter at the nanoscale.

BIG IDEA #8 – Models and Simulations

Scientists use models and simulations to help visualize, explain, predict, and hypothesize about structures, properties and behaviors of phenomena (e.g., objects, materials, processes, systems). The extremely small size and complexity of nanoscale targets make models and simulations useful for the study and design of nanoscale phenomena.

National Science Education Standards Addressed – Science

Physical Science Standards: Level 5-8:

Properties and changes of properties in matter:

Physical Science Standards: Level 9-12:

Structure of atoms

Structure and properties of matter

- NSES: All students should understand that scientists formulate and test their explanations of nature using observations, experiments and theoretical and mathematical models.
- Benchmarks for Science Literacy: Models are listed as a "common theme" of science.

Science Inquiry Continuum Level: Guided Inquiry. Note: To increase the level of inquiry, encourage students to find the laboratory procedures to grow crystals as a research assignment.

Basic Science Process Skills Applied: Observation, Prediction, Measurement, Recording and Analyzing Data (Communicating), Experimental Design

Integrated Science Process Skills Applied: Experimenting, Acquiring Data, Analyzing Data, Analyzing Investigations, Understanding Cause and Effect Relationships, Formulating Models

5 E Inquiry:

ENGAGE – 'No two snowflakes are alike' – why? How does a snowflake form? Ask students why certain commonalities in snowflakes exist. Although the answer of "self assembly" may not surface, use student ideas to direct thinking and discussion to the idea that snowflakes, on a minute scale, do conform to a certain natural order, the natural phenomenon of self-assembly.

EXPLORE - Explain to students that they will have an opportunity to model and also observe the process of self-assembly and the resulting structure of matter. The students will model self-assembly by following a set of rules and then move themselves into positions that comply with

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those rules. The resulting pattern relates back to the structure of matter that is macroscopically observed due to the conditions applied.

In small groups, students will choose one of four substances (borax, sugar, rock salt or alum), prepare a supersaturated solution and construct a system whereby crystals of that substance will form. Following the directions on the laboratory procedures provided, students will complete the chemical preparation and process to create the situation for crystal growth of that substance. Within the class, students will have a common base of experiences that result in a variety of crystal growth patterns due to the differing solutions used. Upon completing the lab, students will share their procedures for the creation of borax crystals, alum crystals, rock salt crystals or sugar crystals. Upon sharing this procedure, students should recognize the similar patterns and conditions necessary for the growth of these crystals. Laboratory teams will also explain their observations of the crystal structures that develop.

Additionally, students will discuss the collectively derived summaries of their experiment. The summary should include an explanation of the natural phenomena of crystal growth. This explanation should relate to student understanding of the snowflake crystal in the Engage component of the lesson. At this point in the discussion, self-assembly should be a focus.

Teams of students will share their observations, procedures, ideas and explanations with every other experimental teams in the class. Their common experiences should promote pattern-finding related to procedure, resulting phenomena and developed structure of crystals. The patterns determined can then be used to explain the BIG IDEA of self-assembly. Additionally, the BIG IDEAs of the structure of matter, and models and simulations can be discussed as each relates to the lab experience completed. As a whole class, student's ideas of procedural modifications can be exchanged and notes made to detail student generated experimental design modifications. This adds to student scientific literacy in experimentation.

EXPLAIN – Crystal growth is accomplished through the process of self-assembly. Crystals like salt (halite) are made of ions. The resulting crystal formations are ionic crystals. Crystals made of atoms, such as silicon, are atomic crystals and crystals composed of molecules such as sucrose (sugar, $C_{12}H_{22}O_{11}$) are molecular crystals.

Crystals can be grown from saturated solutions (examples of naturally occurring situations include rock salt and quartz crystals), Crystals that develop from saturated solutions mimic the internal structure of the matter added to the solution. Crystals grown as a result of self-assembly at the "tiniest" level develop in a pattern representative of that matter. Therefore, salt crystals have a cubic structure while quartz crystals develop in a physical form of a six-sided prism with a 6-sided pyramid-shaped off-set point. Crystals have a repeating pattern based on unique chemistry and internal molecular structure. Snowflakes, the crystalline structure of water at a temperature below 0 ° Centigrade, form a six-sided structure while salt crystals are cubic in shape. The observed structure of matter can be verified or further explored by conducting a web-search for the given crystal structure and images.

During the EXPLAIN stage, students should be able to:

Relate the process of self-assembly to crystal growth and to other natural phenomena

Explain the procedure for growing crystals

Explain observations of crystal growth

Describe the similarities and differences of a variety of crystals, detailing the unique patterns present due to the specific structure of that matter.

Relate observations made during the experimental process to an explanation of the phenomena

Provide reasonable responses to questions related to the experiment

Note: The detail of explanation for crystal growth will depends upon a student's ability to conceptualize the tiny structure of matter at the nanoscale and their ability to conceptualize self-assembly.

ELABORATE – The relationship of "building blocks" or self-assembly is applied in other disciplines of science including biology (proteins in DNA and RNA) and geology (stalactites and stalagmites in cave formations). To extend and apply student learning of content to a new context, students can research the science behind hand warmers. Steve Spangler Science provides a great starting point (www.stevespanglerscience.com).

EVALUATE - A Teacher Evaluation Page is included.

EVALUATE – Skills of Scientific Literacy

Assess student ability to complete the laboratory activity successfully –

* Collaboratively working within a team of students toward a goal
* Effectively implementing science process skills during lab
* Completing the Student Pages associated with the lab activity
* Individually representing student learning (through writing or orally)

EVALUATE – Connecting BIG IDEAS to Content Understanding

Assess student ability to relate BIG IDEAs of nanoscience to experiences

EVALUATE – Student Understanding of Science Content

Assess student understanding of content – crystal structure development

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Evaluate Skills of Scientific Literacy and Connection to BIG IDEAS – Growing Crystals

Date: _________ Students are able to: (+ = Advanced, ✓ = Novice, ○ = Not Yet Present)

Names	Work in Teams	Implement Science Process Skills	Complete Student Pages	Communicate Results (written /oral	Convey BIG IDEAS	Relate BIG IDEAS to Applications	BIG IDEAS : #2 Structure of Matter, #6 Self-Assembly, #8 Models/Simulations Comments:
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Lesson Sequence and Timeframe:

#1. Modeling self-assembly – 15 minutes

#2. Initial experience with Sodium Acetate crystal growth (entire class) – 50 minutes

NOTE: this is not required, but can be used to have the entire class experience the same crystal growth prior to growing individual crystal types.

NOTE: Integration of English Language Arts can be facilitated with requiring students to complete journal entries detailing the experiment.

#3. Specific crystal growth from list included in materials section (small groups) – Two 50 minute sessions allowing an overnight growth

NOTE: Integration of English Language Arts can be facilitated with requiring students to complete journal entries detailing the experiment.

#4. Group comparison of the various crystals grown – 25 minutes

#5. Repeat #1 above with an additional structure, reinforcing self-assembly – 10 minutes

Materials:

Rock salt, Epsom salt, sodium acetate, salt, borax, alum, or sugar
Glass beakers (clean and dry)
Scale
Distilled water (if available)
Scissors
Stirring rod
Heat source (hot plate)
Thermometer
Pencils (used to hang string from beaker top)
String
Tongs (to move heated distilled water from hot plate)
Microscope (viewing grown crystals)
Ice or access to a fridge
Pens and pencils (used for self-assembly)

Procedures:

Lesson #1 and #5 – Modeling Self-Assemby (games taken from Dragonfly – see Resources)

1. Disperse your students throughout the classroom
2. Give your students the following set of rules and instruct them to self-assemble into a pattern.

Pattern A (even number of students):

Rule 1) You must hold hands. No hand can be left untouched.

Rule 2) Your right hand must touch another person's right hand and your left hand must touch another person's left hand.

Rule 3) You cannot cross your arms.

Result: Complete circle with each child alternating the direction they are facing.

Pattern B (fifteen students with Group 1 = 3 kids; Group 2 = 6 kids; Group 3 = 6 kids):

Group 1 – pen in each hand

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Rule 1) You must touch hands. No hand can be left untouched.
Rule 2) You can only touch hands with someone who also has a pen.
Rule 3) You may NOT touch hands with any other members of Group 1.
Rule 4) You touch both your right and left shoulders to the shoulder of someone else in Group 1.

Group 2 – pen in one hand, pencil in other hand

Rule 1) You must touch hands. No hand can be left untouched.
Rule 2) You can only touch hands with someone who has the SAME writing utensil as you.
Rule 3) You may NOT hold hands with any other members of Group 2.

Group 3 – pencil in only one hand (other hand is empty)

Rule 1) You can only touch hands with someone who has the SAME writing utensil as you.
Rule 2) You may NOT touch hands with any other members of Group 3.

Result: Star or snowflake pattern.

Pattern C: Have the students make their own design and required rules

Lesson #2 – Growing Sodium Acetate (complete included Student Page)

1. Label beakers
2. Saturate solution
   a. Prepare a solution by first dissolving sodium acetate in warm water, stirring frequently.
      NOTE: For reference, 160+ grams of sodium acetate for 30 mL of water.
   b. Continue to add material until added material drops out of solution.
   c. Once solution is super saturated, allow solution to cool without disturbing the solution.
3. Monitor crystal growth
4. Examine crystal structure

Lesson #3 – Growing Crystals (complete included Student Page)

1. Label beakers
   NOTE: Larger volumes of water will require more material to reach saturation. Final volumes (step 4 below) only requires a depth of two centimeters.
2. Saturate solution
   a. Prepare a solution by first dissolving the material in warm water, stirring frequently.
   b. Continue to add material until added material drops out of solution.
   c. Once solution is super saturated, allow solution to cool.
3. Collect seed crystal (for larger crystal growth, but this step is not required)
   a. Dip a length of thread into the saturated solution
   b. Allow the thread to dry
   c. Remove any excess crystals
4. Pour saturated solution into two separate beakers to at least a depth of two centimeters.
5. Suspend thread
   a. If Step 3 was completed above, use this thread.

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   b. Suspend the thread from a pencil laid across the top of the jar.
   c. Place beaker in desired conditions (i.e., ice bath, fridge, countertop) undisturbed.
6. Monitor crystal growth
7. Research the type of material used in the experiment, finding crystal structure and images
8. Examine grown crystal structure and compare to results found in Step 7 above

Lesson #4 – Group Comparison of Grown Crystals

1. Examine the crystals grown by each team and share results.
2. Discuss with each team the commonalities and differences that exist between the structures formed. These include:
   a. every crystal is grown from a supersaturated solution
   b. a thread or string is placed in the solution as a medium for the growth of the crystal
   c. the crystal structure that develops is unique to the material (chemical composition).

Resources:

Web-based

Snowflake development - http://www.its.caltech.edu/~atomic/snowcrystals/faqs/faqs.htm
The Physics of Snow Crystals - http://www.its.caltech.edu/~atomic/publist/rpp5_4_R03.pdf
Crystal Cave of the Giants - http://www.canyonsworldwide.com/crystals/index.html
Sodium Acetate crystal growth – http://www.stevespanglerscience.com/experiment/00000078
Self-assembly games - http://pbskids.org/dragonflytv/pdf/DragonflyTV_SelfAssemblyGames.pdf

Tradebooks/Papers

Snowflakes by Kenneth George Libbrecht (ISBN: 0760334980)
The Art of the Snowflake by Kenneth George Libbrecht (ISBN: 0760329974)
The Snowflake: Winter's Secret Beauty by Kenneth George Libbrecht (ISBN: 0895686308)
The Secret Life of a Snowflake by Kenneth George Libbrecht (ISBN: 0760336768)

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Student Page – Growing Crystals

Name: ______________________________________

Group Members: ______________________________

____

____

Crystal Material: _____________________________

Procedure	Observations, Data, Exceptions
1. Label beakers	*Date, material, team members*
2. Saturate solution	
a. Prepare a solution by first dissolving the material in warm water, stirring frequently.	*Record water volume* *Record temperature*
b. Continue to add material until added material drops out of solution.	*Record starting material weight* *Record final material weight*
c. Once solution is super saturated, allow solution to cool.	
3. Collect seed crystal (if required)	
a. Dip a length of thread into the saturated solution	*Observation/comment*
b. Allow the thread to dry	
c. Remove any excess crystals	
4. Pour saturated solution into two separate beakers to at least a depth of two centimeters.	*Observation/comment*
5. Suspend thread	
a. If Step 3 was completed above, use this thread.	
b. Suspend the thread from a pencil laid across the top of the jar.	
c. Place beaker in desired conditions (i.e., ice bath, fridge, countertop) undisturbed.	*Record conditions*
6. Monitor crystal growth	*Observations, time stamp*
7. Research the type of material used in the experiment, finding crystal structure and images	*Record crystal structure* *Document images*
8. Examine grown crystal structure and compare to results found in Step 7 above	*Acquire images of grown crystals*

Conclusions:

Recommended changes to above procedure:

BIG IDEAS and the connection to applications:

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