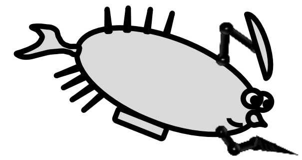
Unit 1: Setting the Stage



NOTES

Introduction

The last 8,000 years of human history was shaped by many events, but none more influential than the development of science and technology. Advances in technology often hinged on the creation of new materials or discovery of previously unknown material properties.

Most of the materials properties we will study in this curriculum are determined by:

- the type of atoms in a substance.
- the crystalline structure formed by those atoms.

Every element on the periodic table is composed of a unique type of atom. Gold and silver have different properties because their atoms are different. Some materials, such as diamonds, graphite, and charcoal, have different properties due to the manner in which their atoms are assembled together. All three of these materials are made from identical carbon atoms. In each, the carbon atoms are arranged in a different pattern. Such patterns are known as a material's crystalline structure.

The atoms in a liquid are constantly interacting with each other but are still free to move. The average speed of those moving atoms is a function of the liquid's temperature. If the temperature falls below a critical "freezing point", the motion of the atoms will drop dramatically. Although they are still free to vibrate, they no longer move past each other. The liquid has become a solid.

If the change of phase happens slowly, atoms will naturally arrange themselves into a pattern which contains the least possible amount of stored energy. This pattern, repeated many times through a certain volume, is called a crystal. Crystals have specific geometries which give the solid material some of its properties.

The formation of crystals usually begins in many places at once, leading to the simultaneous formation of multiple crystals. The faster the liquid cools, the smaller these crystals will be as it takes time for larger crystals to organize. If the liquid cools very rapidly, it may freeze into a solid before any detectible crystalline patterns have a chance to form. Such a material is called an amorphous solid. Window glass is a familiar example of an amorphous solid.

Unit 1: Setting the Stage

NOTES

Inquiry Overview

In the first activity, students work with a set of fictional materials which have very real properties. They will examine these materials and make decisions about which material is best for a number of applications related to an underwater robot. Then they will begin to explore why different materials have different properties.

In the second activity, the class will construct a timeline to mount on the wall. Throughout the curriculum, this will serve as a reference for putting into historical context various developments in materials science.

The third activity delves into crystalline structures by having the students move about the room in a kinesthetic simulation.

Activities

Activity 1: Diving into Material Properties

Estimated Time: 90 minutes
Student Grouping: groups of 3

Objectives:

The students will:

- Select materials to serve a specific purpose based on their material properties.
- Examine why materials have differing properties.

Standards:

NGSS	MS-PS1-1, MS-ETS1-1, MS-ETS1-2, SEP (1,2)
CCSS Math	MP (7,8)

Materials for this Activity

Per group of three students:

- Student Pages
- 1 Diagram of a submarine robot
- 26 Plastic chips (labelled A through Z)
- 3 copies of Anodami Materials List
- *1 computer with internet access*

Advanced Preparation: none

Suggested Inquiry Approach:

Point to some object in the room and challenge students to **name the materials from which it is made**.

Now ask **why these materials, and not some others?**

Encourage them to **debate the suitability of other materials which might have been used**.

Help students form groups of three and obtain their materials.

Give them their student pages and, as a class, read the story about the Anodami. Allow them to continue through the first part of the activity to select suitable material for their robot. As they work, you can get the computers/laptops ready for the second part.

Students will have questions about vocabulary. Allow them to use an online dictionary for help.

As soon as you see that all groups have placed their material markers on their robots, start a class discussion. Go through each part of the robot and ask students what material they selected and why. There are many good answers and students will have different opinions. Encourage them to debate the merits of each choice. There is no single "correct" answer. Every choice has trade-offs. This is an important aspect of engineering design.

Following this discussion you may allow them to complete the remaining questions in Part 1 either independently or as a class, as you prefer.

Part 2 requires students to access an online computer simulation. They will build atoms of the first six elements. Finally they will read about different structures of carbon atoms.

Debrief:

- **What two things determine the properties of a material?**

NOTES

Activity 2: Timeline of Materials Science

Estimated Time: 85 minutes
Student Grouping: groups of 2 or 3

Objectives:

Students will establish a reference timeline which will be used throughout the curriculum for placing developments in Materials Science into a historical perspective.

Standards:

CCSS Math	6.NS.B, MP (1,2,4)
CCSS ELA	6-8.RI.9, 6-8.RST.3

Materials for this Activity

Per group of 2 or 3 students:

- Student Pages
- ≈ 10 Post-it notes
- *1 computer with internet access*

For the class:

- 1 roll of blue tape
- Timeline (12 sections)

Advanced Preparation: Select a wall on which to maintain a 15 foot-long timeline.

Suggested Inquiry Approach:

Explain that the class will be assembling a timeline on the wall. The timeline is divided into pieces like a puzzle. Each group will get one piece. **Without talking**, students will need to assemble the timeline, in correct order, and attach each piece to the designated wall.

1. Have students form groups of two or three.
2. Give each group a section of the timeline (there are 12 sections).
3. Give the roll of blue tape to a student who will assist with attaching pieces to the wall.
4. Each group sends one member, with their piece of the timeline, to work in silence with others at the wall.

   Remaining group members can get the computers up and running. Each group will need one.

NOTES

5. Once the timeline is correctly assembled, each group makes a list of significant events to plot on the timeline. If a group needs help, you might suggest any of the following to add to their list:
   - First writing, or alphabet
   - First block printing or printing press
   - Construction of the pyramids of Egypt, Stonehenge, Great Wall, etc
   - Domestication of wheat, corn, horses, etc
   - Invention of gunpowder, steam engine, telephone, etc
   - First paved road, suspension bridge, skyscraper, railroad, etc
   - First human flight

6. Facilitate a class discussion in which students share what their group thinks should go on the timeline. As a class, come to a consensus on 10 to 20 appropriate historic events for the timeline. These events do not need to be Materials Science related. That will come later.
7. Working in their groups, students use the internet to find when these events occurred. Rather than use calendar dates, the timeline will measure everything in "years ago". Students will have to translate 3,500 BCE into 5,515 ya and mid-fifteenth century into 565 ya. If you feel calendar dates are important you may have students add those labels above the timeline.
8. Students can put their results on sticky notes to attach to the timeline. Expect there to be some discrepancies between groups. Different sources may give different dates for some events. Highlight discrepancies and moderate a discussion toward consensus. Once everyone is in agreement on the timing of their important events, the sticky notes could be replaced with more permanent (and attractive) markers or labels could be written on the timeline itself using a marker.

Debrief:

- Were you surprised by the sequence of these events? Did anything happen sooner or later than you would have guessed?

- Pick some famous inventions or construction projects on your timeline and ask the questions:
  - Could this event have happened 100 years sooner?
  - 500 years sooner?
  - If not, what was missing that had to be accomplished first before the event on your timeline would be possible?

- Stone Age hunters began exploiting the material properties of rocks to make sharp-edged tools about 1.7 million years ago. How far to the left would you have to extend your timeline to document that important event? (The scale of this timeline is 50 years per centimeter.)

NOTES

Activity 3: Crystallography
Estimated Time: 45 minutes
Student Grouping: pairs

Objectives:

- Simulate the motion of atoms in a liquid as it transitions to a solid.
- Explain what causes the formation of three crystalline structures:
  1. Amorphous
  2. Crystalline
  3. Polycrystalline

Standards:

NGSS	MS-PS1-1, MS-PS1-4
CCSS ELA	6-8.W.1

Materials for this Activity

Per group of two:

- Student Pages
- 1 Fruit candy
- 1 White mint candy

Advanced Preparation: none

Suggested Inquiry Approach:

The following script is offered. There is no need to use it verbatim. Rather it is an example of how to coach students toward an understanding of the three crystalline structures.

Part 1 – forming an Amorphous Solid

- "Imagine that you are an atom of a liquid."
- "You are free to move slowly about the room."
- "Walk slowly, but never come to a stop."
- "Slowly bounce away from any obstacle you encounter."
- *Let students get used to this motion. To help manage their behavior, tell them as often as necessary:*
  - "Atoms that move too fast will have to sit down and watch!"
  - "Atoms are silent. They listen but don't make noise!"
- "You feel electrical forces from the other atoms nearby."

NOTES

- "These forces pull you closer until you are within arm's reach, but push you apart if you get any closer."
- "You feel most comfortable when you are one arm's length from other atoms."
- "If you find yourself too close or too far away, slowly adjust the direction of your motion."
- "You will seldom be exactly one arm's reach away from the nearest atoms but try to maintain that as your average."
- "Your walking speed will vary but your average speed is a reflection of your temperature."
- "How do you think the movement of atoms changes when the temperature drops?" *Give students a moment to answer: the atoms move more slowly*
- "If I reduced the temperature in this room far enough, the liquid which you are simulating would freeze into a solid."
- "What will happen to your movement if the temperature drops to freezing?" *Give students a moment to answer: we stop completely*
- "When I say "now" I want you all to freeze in-place."
- "Now!"
- "You used to be part of a liquid. Now what have you become?" *Give students a moment to answer: a solid.*
- "Without moving your feet, look around the room at the other atoms."
- "Are you all facing the same direction?" *Give students a moment to answer: no*
- "Were you all moving in the same direction?" *Give students a moment to answer: no*
- "Are you all equally spaced around the room?" *Give students a moment to answer: no*
- "Are you exactly one arm's length from your neighbors?" *Give students a moment to answer: no*

- "Can anyone give examples from the real world in which a liquid freezes very quickly into a solid?" *Give students a moment to answer. Lava flowing into water would be one example.*
- "The solid substance of which you are now a part is referred to as an **amorphous solid**. It has no repeating pattern or geometry. You are a somewhat random arrangement of atoms."
- "Everybody say the word "**amorphous**"!"

Part 2 – forming a Crystalline Solid

- "Now I am turning up the heat in this room so that you melt back into a liquid. Begin walking around slowly as you did before."
- "I am about to drop the temperature again but this time I will do so very slowly."
- "As the temperature drops there will be one atom in the room which will be the first to stop moving."
- "I am about to call out the name of that one atom."
- "If you hear your name called, freeze in-place. The rest of you keep moving but do so very slowly."
- *Call the name of one student who is close to the center of the room.*
- "_________ is now motionless and facing in a particular direction."
- "_________, please raise your hand so everyone can see you."
- "The rest of you will continue to move ever more slowly as the temperature drops."
- "The atoms which are closest to _________ finally have a chance to park themselves exactly one arm's length from a neighbor."

NOTES

- “_________ is no longer a moving target so I want the four people currently surrounding _________ to come to rest one arm-length away from him/her and facing in the same direction in which _________ faces.”
- “A **crystal** has begun to form.”
- “The rest of the atoms are still moving about very slowly.”
- “If you find yourself within reach of any of the stationary atoms, park yourself exactly one arm’s length away and face the same direction as everyone else in the crystal.”
- “The crystal begins with _________ and grows outward until all the atoms have joined it.”
- *All students should come to rest one arm-length from their neighbors, and all facing the same direction.*
- “Once again you have become a solid. You are not an amorphous solid now, but a **crystalline solid**.”
- “Everybody say “**crystalline**”!”
- “How is a crystalline solid different from an amorphous solid?” *Give students a moment to answer: spaced equally, facing same direction, more organized*

Part 3 – forming a Polycrystalline Solid

- “Some crystalline solids are formed from a single, large crystal, such as snowflakes. More commonly, multiple crystals begin forming at the same instant and they grow until they reach the edges of the other crystals forming around them. Such a substance is called a **polycrystalline solid**.”
- “I am turning up the temperature again, so melt back into a liquid and resume moving.”
- “This time I am going to call three names. If you hear your name, raise your hand and stop moving.”

- "Everyone else join a crystal as soon as your motion brings you within arm's reach of an atom which has already stopped. Be sure you are one arm-length away and facing in the same direction as the atom you are joining."
- *Call the names of any three students. The others should come to rest, aligned with the nearest of the three names you called.*
- "Once again you are a solid, made up of crystals, but this time you are polycrystalline solid."
- "Everybody say "**polycrystalline**"!"
- "How many crystals have you formed?" *Give students a moment to answer: 3*
- "Are all three crystals facing in the same direction?" *Give students a moment to answer: the 3 crystals are probably not facing the same direction but all the atoms within each crystal are all facing the same.*

Now have students work in pairs to answer questions on their Student Pages. Each pair will need one fruit candy and one white candy.

Debrief:

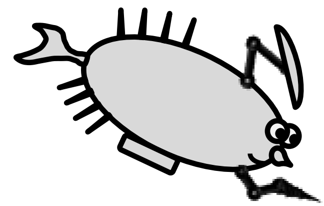
Crystalline structures are important for a broad range of solids including everything from sugar to steel. As a class, share answers to the questions on the Student Pages.

Extensions:

- During this activity, students were told that atoms like to stay "an arm's length" apart. The attractive and repulsive forces which contribute to this behavior may be examined using a web-based computer simulation here: http://phet.colorado.edu/en/simulation/atomic-interactions
- If your school has the necessary equipment (glassware and hot plate), there is an interesting experiment in crystallography outlined by Northwestern University at this site: http://www.earth.northwestern.edu/public/seth/demos/XTAL/xtal.html

Student Pages

Unit 1, Activity 1, Diving into Material Properties



Problems:

- Select materials to serve a specific purpose based on their material properties.
- Why do materials have different properties?

Materials for this Activity:

Per group of 3:

- 1 Diagram of a submarine robot
- 26 Plastic chips (labelled A through Z)
- 3 copies of Anodami Materials List
- A computer with access to the internet

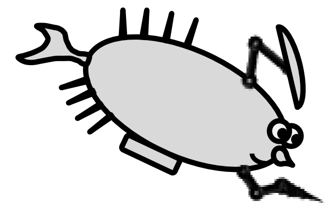
Our Story:

Far from Earth, the inhabitants of a planet called Anodam have a problem. The Anodami obtain all their food from the sea. Lately, it has become difficult to catch fish. Seaweed harvests have fallen dramatically. These difficulties are thought to be related to recently detected changes in the seawater.

Anodami scientists have hypothesized that volcanic activity on the sea floor might be responsible for these unfortunate changes. This possibility must be investigated immediately! The Anodami must design a submarine robot which will dive to an undersea volcano to obtain a sample of newly formed rock. An examination of that rock will help determine if the volcanoes are responsible for the damaging changes to the sea.

In this activity you will play the role of an Anodami engineer. Your task is to select appropriate materials from which to construct a submarine robot.

Unit 1, Activity 1, Diving into Material Properties



Procedure:

Form groups of three for this activity.

1. The Submarine Robot

Examine the diagram of the submarine robot. Read the description of each labelled part. How many labelled parts are there?

Examine the plastic chips. Verify that you have 26 chips, labelled A through Z.

Each chip represents one type of material which is available for use on your robot. Supplies are limited, however, so each material can only be used for one part of the robot. Some materials will not be used at all.

Read the information on your Materials List which explains the properties of each material.

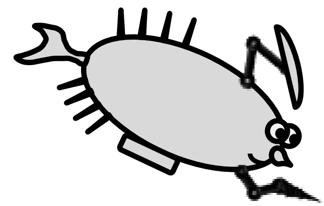
Select a material for each labelled part of your robot and place the appropriate chip on that part.

As a class, compare your designs. Discuss why you chose these particular materials for each part of your robot.

The chips come in four different colors. In the boxes below, record any similarities you notice in the materials of each color.

Red:	Green:
Blue:	Yellow:

Unit 1, Activity 1, Diving into Material Properties



Characterize each group of materials with a label or name that contains as few words as possible:

Red:	Green:
Blue:	Yellow:

Think of some materials that might be available to engineers here on Earth. List a few materials that might fit into each category:

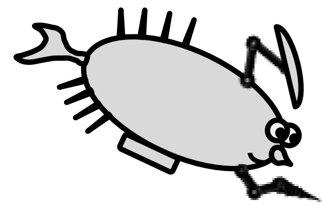
Red:	Green:
Blue:	Yellow:

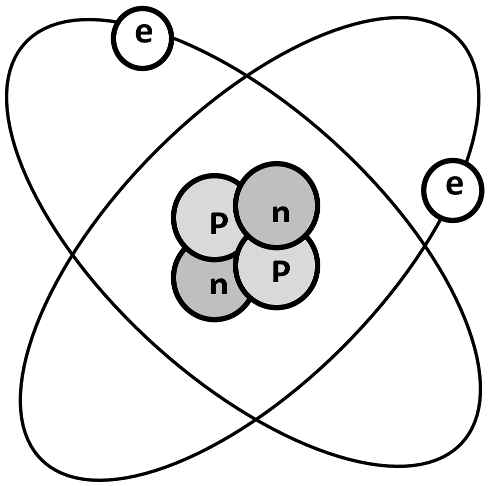
2. Material Properties

What gives a material its particular properties? There are two factors:

1) The chemical elements from which it is made.
2) The structural arrangement of its atoms.

Unit 1, Activity 1, Diving into Material Properties





Atoms are made of three different types of subatomic particles. Can you name them?

1)

2)

3)

Atoms of different elements behave differently due to having a different number of these subatomic particles. At your computer, open your browser to the following website: http://phet.colorado.edu/en/simulation/build-an-atom

Click the green "Run Now!" button to start the simulation.

Drag a single proton into the nucleus (marked with an "x").

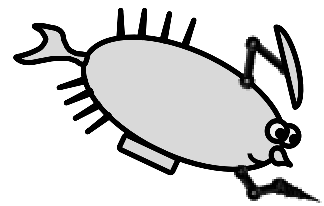
Is your nucleus stable or unstable?

Now add an electron.

With one proton and one electron, you have created an atom of hydrogen, the most basic element in the Universe. Congratulations!

Add another proton to your atom.

Is your nucleus stable? If not, add a neutron and keep adding neutrons until your nucleus is stable.



Add another electron to keep the charge of your atom neutral.

What element have you created with this atom?

Can you think of any similarities between the two elements you have created so far?

Add a third proton, a third electron, and as many neutrons as you need to stabilize the nucleus.

This is an atom of lithium. Unlike hydrogen and helium, lithium is a solid. It is a light metal often used in batteries. When matter first formed in the early universe, it was mostly hydrogen, with some helium and a tiny bit of lithium. These three elements formed the first stars. All of the other elements formed later, inside stars, where small atoms are sometimes crushed together, forming larger atoms.

Continue adding protons, electrons, and neutrons to form larger atoms. In the space below, record the element composed of each atom:

An atom with 4 protons is: ___________

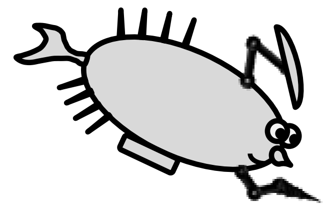
An atom with five protons is: ___________

An atom with six protons is: ___________

All atoms are composed of the same three "building blocks". What distinguishes one atom from another is how many of those blocks it has. Many of the properties of a material are due to those differences. But some properties require another explanation.

Student Pages

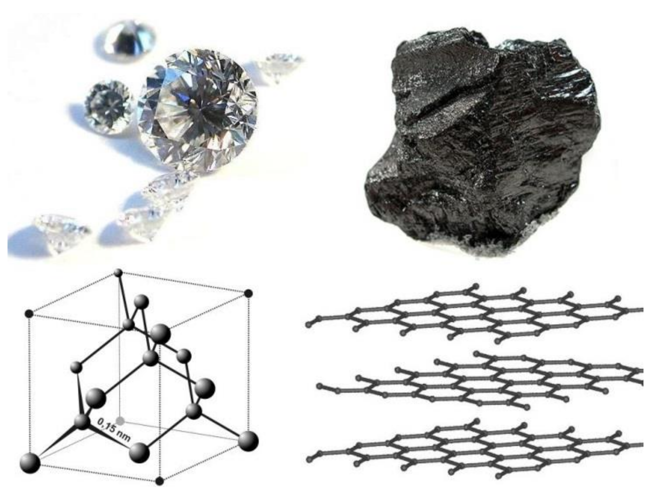
Unit 1, Activity 1, Diving into Material Properties

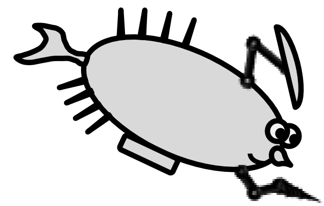


Your pencil point, which we often call "lead", is not really made of lead. It is made of graphite. In the space below, record some observable properties of graphite:

As you know from writing with a pencil, graphite is not that hard. The hardest material in nature is diamond. In the space below, record some properties of diamond:

Obviously these two materials are very different. Surprisingly, each is composed entirely of carbon atoms. How those atoms are attached to each other makes a big difference. Graphite and diamond atoms are arranged in very different structures.

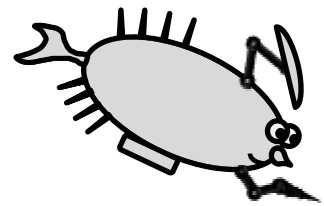




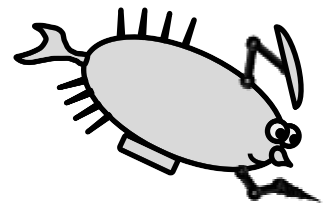
Unit 1, Activity 1, Diving into Material Properties

The carbon atoms in diamond are locked into a rigid crystalline structure. The carbon atoms in graphite are stacked in thin sheets of hexagons. Carbon atoms can be arranged in many other structures as well, each with unique properties.

Materials throughout the universe are made from the same types of atoms and structures. Whether you are on Earth or sailing the seas of Anodam, the same rules apply.



Unit 1, Activity 2, Timeline of Materials Science



Problem: Create a timeline for your class on which you can track the developments in materials science which influenced the course of human history.

Materials: You and your partner(s) will need:

- 1 Computer with internet access
- Post-It notes
- 1 section of the class timeline

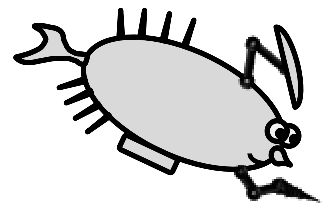
Procedure:

The entire timeline will span 8,400 years, but your group will be given just a small section of the total. Your teacher will indicate the wall on which you are to assemble the timeline.

1. Send one person from your group up to the wall with your small section of the timeline. The challenge is to assemble the entire timeline in the correct order, and fix it to the wall, without speaking!

   While one member of your group is up at the wall, the others should get a computer up and running. Later in the activity you will need to do some research using the internet.

2. You and your partners will now make a list of events that could be placed on the timeline. Think of the most important events from human history. These might be important inventions or accomplishments, the rise and fall of civilizations, the birth of important people, or other important “firsts”.

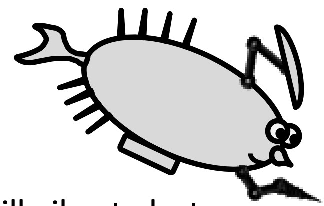


3. Share your list with the class and, together, decide on 10 to 20 events to plot on the timeline.

4. Search the internet to see when those events happened. When you find the information, use a small post-it note to record the event, the year, and your name. Place the note on the appropriate year of the timeline.

5. After all the events are placed on the timeline, check the results which other groups found. Once the class agrees on the dates you may wish to label the timeline with something nicer than post-it notes.

Student Pages



Unit 1, Activity 3, Crystallography

Atoms in a liquid are in constant motion. In a solid, atoms can still vibrate but their locations are generally fixed. Depending on how quickly they transitioned from a liquid to a solid, the atoms may be arranged randomly or in regular, geometric patterns.

Problem: What different types of crystalline structures may be formed by a liquid material as it cools and becomes a solid?

Procedure:

In this activity, you will simulate an atom of a liquid material as it cools and freezes into a solid. Your teacher will guide you on the procedure. Your liquid will freeze into a solid three times, forming different types of patterns. After completing the activity, answer the following:

1. What type of cooling produced an amorphous solid?

2. What type of cooling produced a crystalline solid?

3. How is the size of individual crystals related to the rate of cooling?

Look at the diagram of four solid materials on the next page.

4. Which object(s) are amorphous solids?

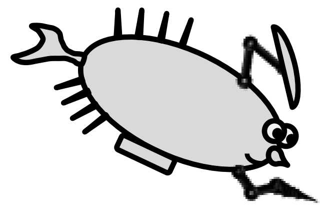
5. Which object(s) are crystalline solids?

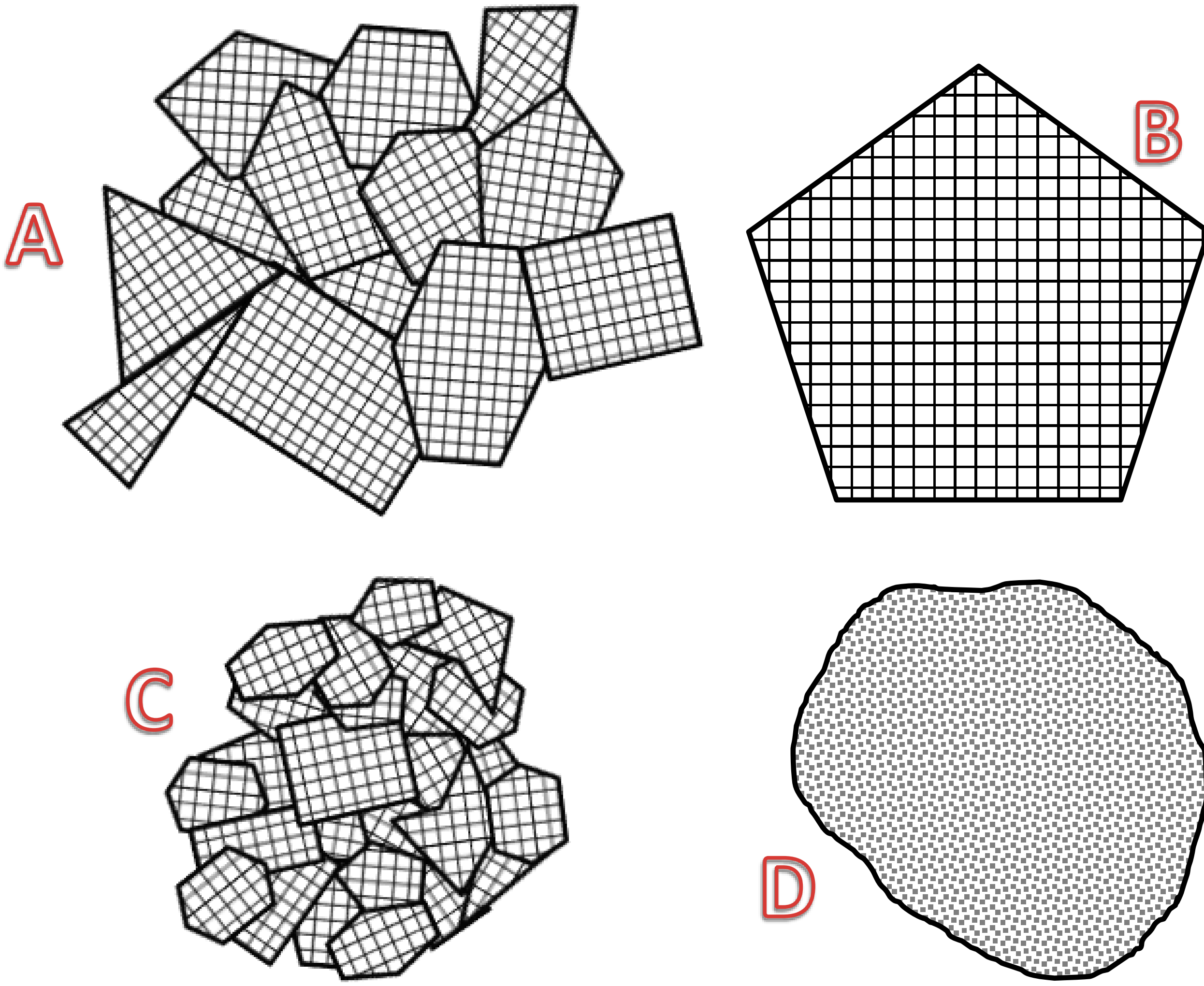
6. Which object(s) are polycrystalline solids?

7. List the objects in the order of which cooled the fastest to which cooled the slowest:

   ___________ ___________ ___________ ___________

Unit 1, Activity 3, Crystallography



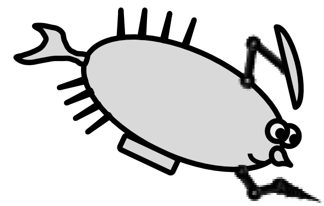


8. Imagine you held these objects in your hand. Some would feel smoother than others. List the objects in order from smoothest to roughest:

   ____________ ____________ ____________ ____________

9. Take one fruit flavored candy and one white candy. Break each candy in half. Examine the interior surfaces where the candy broke. Use a hand lens as well as your finger tips.
10. Which candy is an example of a polycrystalline solid?

11. Which candy is an example of an amorphous solid?



12. Both candies are made from the same type of sugar. Which candy cooled more slowly during production?

13. This form of candy, using crystallized sugar from the sugar cane plant, was invented in India around 500 CE. Ask your teacher for the marker representing the first hard candy. Place it on your timeline.