States of Matter mini-module

Goals

Research goals

This module is designed as a research tool. The goal of the research is two-fold: 1) to learn about the conceptual framework students use to explain atomic scale phenomenon; and 2) to assess the effectiveness of Molecular Workbench by evaluating students reasoning with these models about phenomenon they have not been taught.

Learning Goals:

The module is focused on matter in its various states and the molecular properties of these states. Students will be asked to reason using the kinetic molecular theory. The power of the kinetic molecular theory in understanding the states of matter lies in helping students understand the molecules themselves do not change during physical changes in substances such as melting; instead, the changes reflect different arrangements and motions of the molecules.

The following are the goals for the mini-module:

1. The central goal of this module is to research whether these tools help students identify and describe matter in its various states (solid, liquid, and gas) and to understand the molecular aspects of these states.
2. The second goal is determine whether the tools in this module help students explain observable phenomena and observable properties of matter in terms of the arrangement and motion of molecules.
3. The third goal is to research whether students are able to reason about models.

Prior Knowledge and Naïve Conceptions

Many students in the middle school are familiar with the terms "atom" and "molecule"**.** Some are even familiar with the concept that matter is made of particles. However, research on the topic of kinetic molecular theory has shown that students entering middle school have many alternative ideas about what the world is made of. Researchers from the institute for Research on Teaching at Michigan State University have outlined and summarized the following ideas regarding middle school students conceptions of matter and the kinetic molecular theory:

1. With regard to the concept “Matter is anything that has weight and takes up space,” students believe that air and other gases that are invisible are weightless, and that heat and light take up space.
2. Many students know that atoms and molecules exist and that matter is made of tiny particles. They have, however, many questions about this topic such as: How tiny are molecules? Is there air between molecules? Are all molecules moving? Even in solids? Is there just one type of molecule or are there many molecules?
3. Many students assume that there is a fairly simple relationship between the properties of a substance and the properties of its molecules. For example, they may believe that

ice is made of cold, hard molecules, and that ice melts because the molecules become warmer and turn into liquid.

Various studies show that most middle school students will use particulate ideas in describing states of matter, especially when they are prompted to do so. A number of ways these ideas are used can be identified including: lack of appreciation of particle motion or of cohesive forces between particles in a solid; a tendency to associate increased separation of particles with increases in temperature; and, perhaps most significant of all, a tendency to attribute bulk properties to the particles themselves. The interplay between the action of cohesive forces on the one hand and particle motion and energy on the other hand is evident in very few students thinking.

Our goal is to help students address their alternate ways of thinking and begin a complex learning process that will allow them to incorporate unfamiliar ideas that are more scientifically accurate.

About Models

This module makes extensive use of multiple representations of atomic level models, including macro-micro models. The activities in the unit are organized around the development of specific science concepts but simultaneously students will be asked to analyze the models they are learning from. Students need to learn that models are tools and that they must be wrong in some respects or else it would be the thing itself. The trick is to see—with the help of a teacher—where it is right.

Unlike most models students think of (small versions of visible things), chemistry's tangible models are large metaphors for small, invisible things. Take, for example, a ball-and-stick model. To a chemist a molecule doesn't look like this model. Rather the model expresses our insight into the nature of the molecule. Joining the sticks and balls helps us visualize and learn about that molecule.

In this module students do not have to construct their own models. Students will:

- run a model and analyze its reasonability and fidelity by comparing model outputs to a target phenomena;
- understand the behavior of a model by varying parameters, testing limits, and examining the interrelationships between variables;
- apply model-based reasoning by grappling with a variety of explanations and phenomena.

In understanding the models students will need to reason using the key scientific concepts from this unit. It is our belief that students will gain a greater understanding of the concepts they will be studying and a facility with creating and understanding their own models as a result of these activities.

Investigative Questions

Located in the Activity Design and Execution section of each activity in an investigative question. It is this question that frames the learning goals and experiments for each activity. You may want to write the question on the board at the beginning of each session, point it out to the class, then return to the question at the end of each session and discuss how their experiences may have helped answer the question. Or you might have students write their thoughts as homework.

Pre/Post Test

- Suppose you were the size of a water molecule, and could stand on a water molecule in a glass of water. Someone takes that glass of water and puts it in the freezer. After a while the water turns to ice. How does what you see and feel change?

- Imagine you could use special glasses that allowed you to see very small particles. Draw a picture that shows how you think molecules are arranged and how they might be moving in an iron bar.

- Draw a picture that shows how molecules are arranged and how they move in Oxygen gas. Draw what it would look like if you cooled the oxygen gas down to form liquid oxygen. Use arrows to show how molecules are moving. Include an explanation of your picture.

• A model in science can be used to help you imagine or understand something you can not see. These models simplify the original situation and make it visible. Describe how the picture you drew of how molecules are arranged and how molecules move in liquid oxygen can be considered a model in science.

• Could there be a compressible liquid? Explain your answer using molecules/atoms in your answer.

• My friend says that there is water between the molecules of liquid water. Do you agree? Explain your answer. (from Berkheiner, et al.)

Activity One: What Happened?

Activity Overview

Everything is made of particles.

Students begin this module learning about a volcano eruption in Iceland and identifying real-world examples of different states of matter. In order for students to understand about the molecular properties that are related to the states of matter students must first learn that matter is made of particles. This first activity is intended to engage students in defining matter as particulate and not continuous. The activity has students mix alcohol and water to find that the volume of the mixture is less than the sum of the two individual volumes.

Learning Objectives

Students will:

- Observe a phenomenon that helps students define that matter is particulate.
- Determine that a model is a tool that can help explain a phenomenon.
- Categorize materials as matter or non-matter.

Conceptual Prologue

Macro-Micro Connection

In this unit students will be exploring the basic characteristics of how atoms behave and how the behavior of these invisibly small atoms (micro-scale) can explain observable phenomenon (macro-scale). To draw students into a study of the behavior of atoms and the properties of matter, they begin with a real world example of matter in different states. Students read about the eruption of the volcano Heimay in Iceland and the attempts by people living in Iceland to control the flow of the lava. Students will learn that lava is just rock in a liquid state and that water, when put in contact with very hot lava will change to steam (the gaseous state). Throughout this unit, students will return to this story and apply their increased understanding of the properties of matter to describe the differences among the states of matter.

Science Concepts

There are only two possibilities for the underlying structure of matter: either there is a smallest piece of something (the particle theory of matter), or you can divide a thing in half forever, never reaching a smallest piece that can’t be divided (the continuous theory of matter).

After many years and experiments there is good evidence that all matter consists of atoms and molecules [tightly bonded groups of atoms]. The smallest part of an element is a single atom and the smallest part of a compound [more than one kind of element bonded together] is a molecule. The molecule can be broken down into single atoms, but those separate atoms are no longer a piece of the compound because the definition of a compound requires bonded atoms. For simplicity, the term particle used in this activity could refer to either atoms or small molecules.

Students will also begin an analysis of the role of models in the service of scientific inquiry. They will look into the nature of the models used in this module, the different types of models that are included in this module, how they are made, what the models actually represent, and what the limitations of the model might be.

Naïve Conceptions

Students of all ages have trouble understanding that matter is made of discrete particles that are in constant motion and have empty spaces between them. (Novick and Nussbaum, 1978)

Students are deeply connected to a theory of continuous matter. (Nussbaum, 1985)

Activity Design and Execution

Major Science Concepts: Matter is particulate
Assumed Prior knowledge*:* None
Time*:* 50-minute class session
Materials: (For each pair)

- 5 ml of water
- 5 ml of alcohol
- small test tube
- eyedropper

Advance Preparation: Administer the pre-test. Make copies of the student worksheets for this session.

Investigative question: What is matter?

Procedure

1. Prior to starting this unit administer the pre-test. As this is a very full session, you may want to consider giving the pre-test prior to this session. The pre-test should take approximately 15 minutes.

2. Introduce this unit to the students by explaining that they will be investigating the different phases of matter.

3. Ask students if they know what is meant by "matter," "phases," "states."

4. Distribute the worksheet "**Control of Nature: Cooling the Lava**" and have them read and answer the questions.

HTML file
http://www.concord.org/workbench_web/states_of_matter/control_nature.html

PDF file
http://www.concord.org/workbench_web/states_of_matter/pdf/control_nature.pdf

5. After students have completed reading, ask a few volunteers to describe their answers. Accept all ideas at the moment. Tell students that they will get more insight into the answers while completing this module.

6. Distribute the worksheet "**What's The Matter?**" and have students complete the activity.
   HTML file
   http://www.concord.org/workbench_web/states_of_matter/what_the_matter.html

   PDF file
   http://www.concord.org/workbench_web/states_of_matter/pdf/what_the_matter.pdf

7. After students have completed the activity, have students present their ideas for why the volume is less than the sum of the two individual volumes. Discuss with students how each model explains their observations or part of their observations.
   - How closely does this model compare to the real experiment?
   - How does the model illustrate/help explain what you observed?

8. If no one comes up with a model that describes the intermixing of different size particles, then illustrate on the blackboard loosely packed particles of different sizes where some of the smaller particles (water) fit in between the larger particles (alcohol). Explain that this is another model that might explain their observations. (It is important to not make this "the right way" and invalidate students' ideas.)

9. Discuss with the students the ways each model explains their observations.
   - Ask them how each model of matter might relate to other types of matter and other states of matter.
   - When making this model, what did the model maker have to keep in mind?
   - Explain that scientists think this model describes matter. This model assumes that these liquids are made of "particles." Are all liquids made of particles? What about solids? What about gases?

10. Introduce to students the idea that some things are not matter. These things include forms of energy such as heat and light, love, shadows, echoes. Have students come up with their own ideas of things that are not matter.

Reminder: Though this is not a comprehensive introduction to the nature of matter, the goal of this first activity is to give students both the vocabulary and the notion that matter is particulate. This concept will be reinforced throughout this unit as students explore how microscopic properties of matter relate to macroscopic properties.

Worksheet
Control of Nature: Cooling the Lava

The eruption came out of nowhere. Earthquakes had not even alerted the people who lived on the island of Heimay (part of Iceland). Even Icelandic seismologists thought nothing of them. Then it happened, on January 23rd, 1973 -- a new volcano erupting awakened the country.

The sounds that accompanied the eruption were equivalent to low-pitched roars. Then the volcano exploded violently, sending molten rock hurling into the air. Nearly all of the island's residents were evacuated to the mainland. For months the volcano would spill constant streams of lava (liquid or molten rock) over its edge engulfing the countryside adjacent to the volcano. Its slow and steady progress began to approach the village on Heimay. What worried the people of the island the most was that the volcano's lava migrated toward the harbor. It threatened to fill the harbor, which, was the center of the economic life of this fishing community.

On the third day of the eruption, there was a sudden onrushing of the lava and twenty-three houses and a large fish plant were engulfed in a single night. It was astonishing to see what an essentially liquid body of rock would destroy in its path.

Cooling the lava was Thorbjorn's idea. That such a feat had not been tried, let alone accomplished, in the known history of the world did not burden Thorbjorn, a physicist, who had reason to believe it could be done. During a previous eruption, Thorbjorn watched lava approach the sea. He had noticed the lava flow to the beach and then follow the coastline for a long distance. "The sea cooled it," he explained. "Then lava ran along the cooled wall. I wondered could anything similar be done by man?" (McPhee, p. 104)

The people on Heimey reasoned that buildings could be rebuilt**,** but if they lost the harbor it would be gone forever, and with it their livelihood. The Icelanders therefore sprayed seawater on the lava to try to slow or stop its movement. It was the largest effort ever exerted to control volcanic activity. More than 19 miles (30 km) of pipe and 43 pumps were used to deliver sea water at a rate of up to 1.3 cubic yards per second. By the end of the eruption, the people in Iceland had pumped 8 million cubic yards (6 million cubic meters) of water onto the flow.

The molten lava was about two thousand degrees Fahrenheit. Where the lava came in contact with the water it changed states from liquid to a solid, creating a wall of chilled lava to dam the flow. The water hitting the lava produced billows of steam. By early May, about 300 buildings had been engulfed in the lava despite the effort to try and restrict the lava flow.

Not only did the tremendous efforts save the port they actually improved it. The residents returned to rebuild their town and even use the heat from the cooling lava to construct a heating system. One scientist from Iceland said, "If we hadn't done something, I very much doubt that we would be here now. (McPhee p.178)

Analysis

1. In this story what substances are changing and how are they changing?

2. What do you think is happening to the molecules of each the substances?

Worksheet
What's the Matter?
All matter that we see or touch, and even ones that we can't see or touch are in one of three states: They are solids, liquids, or gases. In this module you will be studying the different states of matter. When scientists think or talk about matter they mean every substance in the universe from the largest planet to the tiniest speck of dust. But what is matter? In the following experiment you will observe a form of liquid matter to try to determine what matter is made of.

Materials
- small test tube
- eyedropper
- water
- alcohol

Procedure
1. With the eyedropper fill your test tube half way with water.
2. With the eyedropper carefully, trying not to mix the two liquids together, add alcohol on top of the water until the test tube is completely full to the top.
3. Place your finger over the test tube to seal it. There should be no air inside the tube. It should be completely filled with liquid and sealed with your finger.
4. Mix the two liquids by vigorously shaking the test tube and turning the test tube upside down.
5. Observe what happened in the test tube and answer the questions below.

Questions:
1. What happens when you mix the two liquids together?

2. After the liquids were mixed together, do they take up the same space as they did before? How do you know?

3. Do your observations seem to support the theory that atoms exist or that matter can be divided into infinitely small pieces? Why?

4. Draw a series of pictures showing what you think is happening when the alcohol and water mix.

Activity 2: A Closer Look at Matter

Activity Overview

Solid, liquid, and gas differ in terms of their macroscopic properties as well as the arrangement and movement of its molecules.

In this activity students begin by observing phase changes, in which ice changes to water and dry ice changes to gas at room temperature. Students will be asked to explain what happens macroscopically and microscopically during the phase change. Then they will be introduced to the Molecular Workbench software, observe models of macroscopic and microscopic solids, liquids, and gases.[1] The result of this first experiment with the molecular workbench is to demonstrate that there is space between the molecules of a gas and very little or no space between the molecules of a liquid and a solid.

Learning Objectives

Students will:

- Observe and model matter that has changed state.
- Describe what a gas, liquid, and solid looks like at the atomic level.
- Describe the behavior of particles in each phase of matter.
- Compare the macroscopic characteristics with microscopic characteristics for the three phases.
- Analyze the molecular model.

Conceptual Prologue

Macro-Micro Connection

Students will observe some macroscopic properties for the three phases of matter and then compare these properties to the microscopic properties depicted in the molecular model. By directly correlating observable macro-scale properties to the micro-scale behavior of atoms in matter students will begin to develop their own kinetic conception of the particulate model of matter.

Science Concepts

The atoms or molecules of a solid tend not to move very far very quickly and are generally spaced as closely together as possible. The atoms or molecules of a liquid are also generally spaced as closely together as possible. However, the atoms or molecules of a liquid tend not to stay in one place. They slide by each other, allowing the liquid to conform to its container. Gasses have, comparatively, a great deal of space between their atoms or molecules.

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[1] Matter can exist in four phases: solid, liquid, gas, and plasma. Scientists use the phases of matter to classify various types of matter in the world. This unit will focus on the properties and characteristics of the most common phases found on Earth. As a result Plasma will not be addressed in this unit.

Naïve Conceptions

- Students hold a static rather than kinetic conception of the particulate model of matter. (Driver, 1985)
- Students think that molecules of the same substance can change shapes in different phases.(Anderson, 1990)
- Students lack an appreciation of the very small sizes of particles. Students often think that molecules are similar in size to other tiny objects such as dust specks, or cells. (Berkheimer, Anderson, Lee, and Blakeslee, 1988)

Investigative question: What are the properties of each phase of matter?

Activity Design and Execution

Major Science Concepts:
Matter is particulate
Models are tools used to understand certain phenomena
Microscopic behavior of molecules relates to macroscopic behavior in each phase of matter.
Assumed Prior knowledge: None
Time: 50-minute class session
Materials:
For the class:

- Model car or airplane,
- Stick and ball model of water.

For each pair:

- Computer with Molecular Workbench software
- 1 ice cube
- 1 very small block of dry ice
- 2 Ziploc plastic bags
- clock with a second hand

Advance Preparation: Make copies of the student worksheets for this session.

Procedure

1. Have students complete the activity "**Ice, Water, and Gas**."
   HTML file of "Ice Water, and Gas" Worksheet
   http://www.concord.org/workbench_web/states_of_matter/worksheet_icewatergas.html

   PDF file of "Ice Water, and Gas" Worksheet.
   http://www.concord.org/workbench_web/states_of_matter/pdf/worksheet_icewatergas.pdf

2. When students have completed the activity, ask students how they sped up the melting of ice to water. Ask them why they chose the methods they chose. What method do they think worked best? The point of this discussion is to encourage students to think about the idea that they were trying to add heat in some way to speed up the melting process.
3. Introduce the Molecular Workbench software to the students. Explain that this software is designed to help them observe the behavior of matter both macroscopically and microscopically.
   Have students bring up the Molecular Workbench software to run “Mini States of Matter.” Have students open the "Mini States of Matter" activity by double clicking on the Molecular folder and then on the “Mini States of Matter” activity. (These folders are on the hard drive.)
4. During this activity students will be looking at particles of different substances. It is important to help students understand that even the few hundred particles that are represented in the atomic level window really represents an incredible small amount of matter, one they can't see even with a microscope.
5. After students have completed the activity, hold a class discussion on scale. Hold up the model car or airplane. Explain that this is a model. Give them the length of the model car and the approximate length of the actual car it is a model of and have them calculate the scale representation for this model. (Depending on the sophistication of your students you may want to help them complete this first calculation.) Then repeat the process by giving them the approximate size correlation for the water model and a water molecule. Finally, have students compare the size of the molecules on the computer with the actual water molecule. The goal of this exercise is to help students understand the relative size ratios and that the molecules that they are studying are really, extremely small!
6. When students have completed all the steps and recorded their responses on the computer, distribute the worksheet “**Modeling Matter**.” Have them complete the worksheet for homework.

   HTML file of “Modeling Matter” Worksheet.

   http://www.concord.org/workbench_web/states_of_matter/modeling_matter.html

   PDF file of “Modeling Matter” Worksheet.

   http://www.concord.org/workbench_web/states_of_matter/pdf/modeling_matter.pdf

Worksheet
Ice, Water, and Gas

Materials List
- 1 ice cube
- 1 very small block of dry ice
- 2 Ziploc plastic bag
- Clock with a second hand.

Procedure
1. Get an ice cube and place it in a plastic bag. Seal the plastic bag so nothing can get out.
2. Get a small block of dry ice and place it in a plastic bag. Seal the plastic bag so nothing can get out.
3. Place the dry ice and bag on the table and observe what happens.
4. At the same time, see how quickly you can get the ice cube to change into liquid water.
5. Record the initial time.___
6. Record the final time (after ice is melted.)___
7. How did you try to speed up the melting?

8. Draw two pictures' showing what you think is happening when the ice changes to liquid water. The first picture is what you can see. The second picture should include molecules in your drawing.

9. Draw two pictures showing what you think is happening as the dry ice changes. The first picture is what you can see the second picture should include molecules in your drawing.

10. Describe your drawings.

Questions

1. Are ice and liquid water the same thing? Explain your answer.

2. How could you change the liquid water back into ice?

3. Suppose you kept both bags with the different kinds of ice in a freezer. Would anything happen? Explain your answer.

Worksheet

Modeling Matter

1. What is the computer model in this unit used for?

2. How does this model help you compare the differences between gases, liquids, and solids?

3. What is this model helping you to visualize?

4. Draw a picture of what you think salt might look at the atomic level.

5. Describe the important features of your drawing.

Activity Three: Just Add Heat
Activity Overview

Inter-atomic forces and temperature are related to a substance's ability to change from gas, to liquid, to solid.

In this activity students will experiment with the relationship of the change in temperature to changes in phases. Students describe the motion of molecules, their relative proximity to each other, and compare different substances as heat is added. Students investigate the role of inter-atomic forces as substances make the transition from gas, to liquid, to solid.

Learning Objectives
Students will:
- Observe changes in matter when they manipulate temperature.
- Predict what macroscopic phase they will be in as they manipulate the temperature at the microscopic phase.
- Investigate the role of inter-atomic forces in making the transition between gases, liquids, and solids.

Conceptual Prologue

Macro-Micro Connection
One goal of this module is to help students identify and describe matter in its various states both macroscopically and microscopically and to understand the molecular composition and properties that are related to these states. Students will be able to apply this understanding to real world phenomena. In this activity students will be looking at both inter-atomic forces and temperature as they relate to the different phases of matter and then apply this knowledge to the lava and water in the story of the Heimay volcano they read earlier in this module.

Science Concepts
Consider the process by which a substance changes states. As a solid the atoms/molecules will be well ordered, vibrating around relatively fixed positions. When they are heated, they begin to vibrate even more, until, when the temperature gets high enough, the atoms/molecules start to slide by each other becoming fluid, easily changing shape, with atoms/molecules still being held close together. If more heat is added, the atoms/molecules start to move even faster, eventually bouncing off each other with enough force to break free and becoming a gas.

This model has assumed there is only an interaction between atoms/molecules when they collide. If this were true, then there would be no way for anything to exist in a liquid or solid state. Everything would be a gas! To model liquids and solids another set of rules needs be added to make the model more accurate:

• There is an attractive force between all atoms/molecules.
• This force is only significant when the atoms/molecules are very close together.
• The attractive force also varies depending on the type of atoms/molecules.

When atoms/molecules are moving around fast enough, they bounce off of each other with enough force to overcome the attraction felt between them. If you cool them down enough, they slow down, having less kinetic energy [energy of motion], and start sticking together. They are unable to bounce off of each other because the attractive force holds them close. A substance in this state is called a liquid. The change from gas to liquid is called condensation, the opposite change, boiling.

In the liquid state, atoms/molecules are not bouncing around freely, but they don't form rigid structures either. The atoms/molecules have enough energy to flow by each other, continuously changing which atoms/molecules are next to each other. If the substance is cooled even more, the atoms/molecules will form a more ordered structure with little more than vibrational movement. Substances that form a more rigid, ordered structure are considered to be solids. The change from liquid to solid is called freezing, the opposite change, melting. The process of changing directly from solid to gas is called sublimation.

Naïve Conceptions
• Students have trouble appreciating the intrinsic motion of particles in solids, liquids and gases. (Children's Learning in Science, 1987)
• Students have trouble conceptualizing forces between particles. (Children's Learning in Science, 1987)
• Students think molecules of the same substance change shape in different phases (for example you heat up a molecule and the molecule gets bigger.)
• Students often think the attraction between atoms gets weaker when a substance melts or boils. (Berkheimer, Anderson, Lee, and Blakeslee, 1988)

Activity Design and Execution

Major Science Concepts: Phase change, inter-atomic forces, matter is made of atoms/molecules.
Assumed Prior knowledge*:* How to recognize when a bunch of atoms/molecules represents a solid, a liquid, or gas.
Molecules are in continuous motion.
Time*:* 50-minute class session.
Materials:
For each pair:

· Computers with Molecular Workbench software.

Advance Preparation: Make copies of the student worksheets for this session.

Investigation Question: Can you make a solid from a gas using the molecular model? What variables affect your ability to do this? How does this relate to changes in states of matter?

Procedure

1. Begin class by discussing students' homework. Pay particular attention to questions students have with regard to analyzing the model.
2. Have students bring up the Molecular Workbench simulation "Changing Phases" using the Molecular Workbench software. (In this portion of the simulation students will be able to view the macroscopic and microscopic world and complete the activity at the same time.) The software will prompt them to add heat and observe the changes both microscopically and macroscopically.
3. Explain to the class that they are now going to do something called "kinesthetic modeling" which will involve them acting like molecules. Ask them to describe how a person would move if they were pretending to be a molecule in a gas. List the rules the class comes up with. (Rules should include that the person should move in a straight line until they hit a wall, or another molecule; the person should bounce off the walls, they should be moving rather quickly. Etc.) Then have them describe rules for how a person should move if they were pretending to be a molecule in a liquid, and a solid. List these rules on the board.
4. Set up the class in an open space. Have some of the students form a square (they represent a container (or you may want to tape a square on a floor) and the rest of the students should be molecules.
5. Have the students who are the molecules start together as a solid moving, jostling but staying in place. As a class decide at what temperature the substance would change from solid to liquid and then from liquid to gas so that students can move appropriately during the modeling activity. Then you will need to "raise the temperature" by calling out 10 degree increments and have students move as if they were molecules in a liquid and then a gas.
6. You may want to repeat the simulation more than once. Have a discussion about modeling using the following questions to frame the discussion:
   • What was this exercise a model of?
   • What were all the parts of the model necessary for it to work?
   • What did you learn from the model?
   • How does this idea of a model differ form your previous ideas of a model? .
7. After students have completed this portion of the activity discuss "weak attraction" among atoms. This attraction is referred to as "Van der Waals bonding." This type of bonding is what makes many phase changes possible. Explain that there are other types of bonds that exist which are much stronger. For example the covalent bond. This bond joins atoms together in small groups. The forces holding the atoms together in this case are typically a thousand times stronger than a Van der Waals bond.

8. Discuss with students their conclusions regarding the ways heat and attractions among models are related to the different states of matter.
9. Distribute the worksheet "**Modeling Phase Changes**."

HTML file
http://www.concord.org/workbench_web/states_of_matter/modeling_phase_changes.html

PDF file
http://www.concord.org/workbench_web/states_of_matter/pdf/modeling_phase_changes.pdf

Worksheet
Modeling Phase Changes

1. How does this model help someone understand what happens when ice changes to liquid water? When liquid water changes to steam?

2. Heat from within Earth is great enough to melt rocks. Suppose you could be very tiny and could stand on a molecule in a rock inside Earth. Describe how the temperature changes and what happens to the molecules as you move from inside Earth, through the erupting volcano, to the surface of the island of Heimay.

3. Every model has limitations. What was "wrong" with the kinesthetic model? How does it behave like an actual substance? How is it not an exact representative of a substance?

4. How does the computer model and your understanding of Van der Waals bonds help explain why ice changes to liquid water whereas dry ice changes to gas?

Activity Four: A Tight Squeeze

Activity Overview

The compressibility of a substance indicates the space, or lack of it, between the atoms or molecules of various states of matter.

In this activity students relate macroscopic space filling properties of substances to microscopic properties. Students determine that gas will expand to fill a container, whereas liquids and solids will not. Students will learn that a liquid will fill any space but only to a fixed volume, and that a solid has a fixed volume and shape. Finally, students predict what will happen when different "models" of gases, liquids, and solids are compressed.

Learning Objectives

Students will:

- Relate macroscopic space filling properties to microscopic properties.
- Predict what happens when different gases, liquids and solids are compressed.

Conceptual Prologue

Macro-Micro Connection

Very often students prior studies of solid, liquids, and gases has led them to be able to categorize these states of matter by their space filling properties. Students are often able to describe that solids have a fixed volume and shape, that liquids will fill a space to a certain volume, and that gas will expand to fill the container. Students have learned this through observation and experience. In this activity students will further refine their understanding by looking at these space-filling properties macroscopically and microscopically as well as analyzing compressibility doing a hands –on activity and a molecular modeling activity. In this way students will complete a study which correlates macroscopic properties of matter with microscopic properties.

Science Concepts

The atoms or molecules of a solid often form a crystal pattern [geometrically symmetrical packing of particles]. The atoms or molecules are generally spaced as closely as possible and vibrate in place. Because of this close packing, solids can’t be significantly compressed either.

The atoms or molecules of a liquid are also generally spaced as closely as possible. However, the atoms or molecules tend not to stay in one place. They slide by each other allowing the liquid to conform to its container. Because of this close packing, liquids can’t be significantly compressed.

Gasses have, comparatively, a great deal of space between their atoms or molecules. Because there is so much empty space between gas molecules, the volume of gasses can be significantly compressed, moving the molecules closer together. If you compress a gas enough you can form a liquid. This is, in fact, how many "gasses" are stored, because a very large amount of gas can be compressed into a small volume. Gasses generally take up 1000 times the volume of that same substance in the liquid state.

Naïve Conceptions

- Students often think that liquids have atoms or molecules that are much further apart than solids. (Damelin, 2001)
- Some students think the affects of compression could change the shape of the molecule. (Berkheimer, Anderson, Lee, and Blakeslee, 1988)

Activity Design and Execution

Major Science Concepts: Phase change, inter-atomic forces, matter is made of atoms/molecules, compressibility of matter
Assumed Prior knowledge: How to recognize when a bunch of molecules represents a solid, a liquid, or gas.
Molecules are in continuous motion.
Time*:* 50-minute class session.
Materials:
For each pair:

- Computers with Molecular Workbench software
- 20 ml plastic syringe with no needle
- 1 100 ml beaker
- Water
- Wood chip or pebble

Advance Preparation: Make copies of the student worksheets for this session.

Investigative Question: What happens when gasses, liquids, and solids are compressed?

Procedure

1. Discuss student responses to the **Modeling Phase Changes** worksheet. Focus on the benefits and limitations of each type of model.
2. Distribute the worksheet "**A Tight Squeeze**" and have students complete the activity. In this activity they will put air, water, and sugar in a sealed syringe and try to compress the substance. They will be asked to predict how the molecular model will explain the experience.

   HTML file
   http://www.concord.org/workbench_web/states_of_matter/
   wkst_tight_sqeeze.html

PDF file
http://www.concord.org/workbench_web/states_of_matter/pdf/wkst_tight_sqeeze.pdf

3. Have students bring up the Molecular Workbench software to run the “Space Filling” simulation.
4. The software will show them a solid, liquid and a gas, and prompt them to experiment with changing the shape of the container while running the model, and to describe what they observe.
5. The students will then work with the Molecular Workbench software to create a model of the syringe activity. Students will be encouraged to create a model that shows why gas is compressible and the liquid was not and then describe the model and the choices they made.
6. Distribute the “**Models Limitations**” worksheet and have students respond to the questions.

HTML file of “Models Limitations” worksheet
http://www.concord.org/workbench_web/states_of_matter/model_limitations.html

PDF file of “Models Limitations” worksheet
http://www.concord.org/workbench_web/states_of_matter/pdf/model_limitations.pdf

Worksheet
Models Limitations

1. How are atoms/molecules depicted in the computer models?

2. Can you describe other ways in which atoms/molecules have been depicted in this module, in your textbooks, or in three dimensions? Describe why there are different models for the same thing?

3. In this activity you designed a model to show why gas is compressible and liquid is not. Describe the way your model reflects the experiment you did with the syringe.

4. Can you think of ways your model was not able to illustrate what you observed? What are they?

Worksheet
A Tight Squeeze

Materials
1 20 ml plastic syringe
1 100 ml beaker
Water
Sugar

Procedure
1. Fill the syringe with air by pulling the plunger of the syringe out with out having the plunger separate from the case.
2. Place your index finger over the end of the syringe
3. Can you compress the gas by pushing the plunger down? _____. If so, how far were you able to press the plunger?
4. Place about 50 ml of water in the beaker.
5. Place the tip of the plunger in the water and then fill the syringe with water by pulling the plunger out.____________
6. Depress the plunger so that only water is in the syringe. Remove air bubbles by pointing the syringe upward, tapping it and squeezing the water out.
7. Place your finger over the edge of the syringe.
8. Can you compress the liquid? ____ If so, how far were you able to press the plunger?_____________
9. Pull the plunger out of the syringe and place a wood chip or pebble in the syringe.
10. Replace the plunger and depress it until the plunger comes in contact with the solid.
11. Place your finger over the end of the syringe.
12. Can you compress the solid?______ If so, how far were you able to press the plunger?______________
13. Predict how the molecular model will explain what happened in this activity. Describe or draw a series of pictures to show how the molecular model will explain or show the phenomena you observed in this activity.

Activity Five: An Explanation

Activity Overview

Modeling atoms and molecules can help explain the macroscopic of a substance.

In this activity students return to the experiment from Activity Two where they observed ice changing to water and dry ice changing to gas. They revisit their models and explanations of the changes of state, evaluate their ideas, and revise them based on new understanding they gained from this module.

Learning Objectives

Students will:

- Revise explanation and models using particulate theory as it relates to macroscopic properties and observations.

Conceptual Prologue

Macro-Micro Connection

Throughout this module students have observed and described several examples of substances and their different phases of matter. However, these are just a few of the many examples students encounter. One enjoyable example includes making ice cream. As a conclusion to this module you may want to have students come up with an explanation for what happens when you make ice cream. Then perhaps have the kids make it.

Science Concepts

For scientists, a model is not a true description of a system. Instead they think of it as a set of rules and assumptions that when put together will help them think about and perhaps explain some aspect of reality. As a result of this idea, scientists understand that models are limited in scope. The models that are created cannot represent everything; the real world is too complex. Scientists therefore use models as a tool and analyze them for their strengths in representing phenomenon as well as their weaknesses.

Naïve Conceptions

- Students typically think of models as little replicas or pictures of reality. (Bent, 1984)
- Models are truth and therefore don't need to be evaluated. (Grosslight, Unger, Jay, 1991)

Activity Design and Execution

Major Science Concepts: Phase change, inter-atomic forces, matter is made of atoms/molecules

Assumed Prior knowledge:

Ability to recognize when a bunch of atoms/molecules represents a solid, a liquid, or gas. Understand that molecules are in continuous motion.

Time*:* 50 minute class session.

Materials: None

Advance Preparation: Make copies of the student worksheet and the posttest for this session.

Investigation Question: What is the difference between a solid, a liquid, and a gas? How does the nature of the model help you understand these differences?

Procedure

1. Begin this activity by explaining to the class that they will be going back to some of their original work from this module and evaluating their ideas based on what they have learned. Have students look at the illustrations they created of the macro and microscopic changes that occurred when they melted the ice into liquid water and observed dry ice changing into gas. Distribute the "**Judging Your Model**" worksheet and have them complete it.

    HTML file

    http://www.concord.org/workbench_web/states_of_matter/judging_model.html

    PDF file

    http://www.concord.org/workbench_web/states_of_matter/pdf/judging_model.pdf

2. After students have revised their drawings and their descriptions, have some of the students' present their models to the class. Discuss the models.
3. Remind students of the Volcano story they read. Ask them the following question: "In this story what substances are changing and how are they changing? What do you think is happening to the molecules of each the substances?" Discuss what is happening to the lava and the water in the story.
4. Distribute and administer the posttest.

Worksheet
Judging Your Model

The diagrams you constructed at the beginning of this unit can be considered models of how ice changes to water. One way to judge how useful a model is would be to determine how well it helps you imagine or understand something you can not see or did not understand. **The following is a set of questions that you will use to judge your models of how ice changes to liquid water and how dry ice changes to a gas.**

1. Are the most important features relating the behavior of the molecules to the changes in state of each substance shown in your models? Use the rating system below to judge whether or not the model provides a good explanation of what is happening.

1	2	3	4	5
Poor description		Moderate description		Accurate description

2. Would this model be useful to teach someone who had never studied this topic before?

1	2	3	4	5
Definitely yes	Probably	I think so	I don't think so	Definitely not!

3. What important features are NOT included in your models?

4. What do you think should be added to this model in order to make it better for someone who had never studied this topic before?

(Over)

5. Revise your models based on your critique as well as what you have learned about the different states of matter. Draw a series of new pictures based on your critique of the model and anything you learned in this unit.

6. Finish the following sentences:

   I changed my original model because it did not explain or include….

   My model now includes …

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