Computer models to support scientific understanding in 7-12 students

Introduction and Chemistry Examples

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System Requirements

Phet Simulations

- <u>Windows Systems</u>

  Intel Pentium processor
  Microsoft Windows XP/Vista/7
  256 MB RAM minimum
  Approximately 428 MB available disk space (for full installation)
  1024 x 768 screen resolution or better
  Sun Java 1.5.0_15 or later
  Adobe Flash Player 9 or later
  Microsoft Internet Explorer 6 or later, Firefox 2 or later

- <u>Macintosh Systems</u>

  G3, G4, G5 or Intel processor
  OS 10.5 or later
  256 MB RAM minimum
  Approximately 416 MB available disk space (for full installation)
  1024 X 768 screen resolution or better
  Apple Java 1.5.0_19 or later
  Adobe Flash Player 9 or later
  Safari 2 or later, Firefox 2 or later

- <u>Linux Systems</u>

  Intel Pentium processor
  256 MB RAM minimum
  Approximately 414 MB available disk space (for full installation)
  1024 x 768 screen resolution or better
  Sun Java 1.5.0_15 or later
  Adobe Flash Player 9 or later
  Firefox 2 or later

- <u>Tablet/iPad/Android devices</u>

  At this time tablet/iPad/Android device platforms do not fully support Java or Flash, which is to require to run PhET simulations.

iPads cannot run any of PhET's simulations because these devices lack full support for Java and Flash.

Android devices cannot run any of PhET's Java simulations. These devices can run a limited number of the Flash simulations, but these simulations will have poor performance and user input response on these devices.

Overview

These lessons are intended for an audience of preservice teachers, inservice teachers, and others interested in teaching science. This is not intended as a science text book, as the author assumes that the reader has some science knowledge of the topics presented. Models of scientific phenomena are readily available on the Internet and can be used to help students better grasp complex concepts. Yet the efficacy of the simulations may be confounded by common or naïve conceptions that many learners bring to science topics. The lessons introduce the reader to ways in which the models can be used to address these naïve views held by many learners. Armed with the knowledge of common naïve conceptions, and powerful modeling tools, teachers can help guide students to stronger scientific understanding of the basic tenets of modern science.

Online resources are available either for free or for purchase and come with a variety of support materials. Some include complete lessons, student worksheets, and assessments ready made for classroom use. Others provide sophisticated models with few supporting materials. These sites assume that the teacher will be able to figure out how to use the animations to create classroom lessons. The units and lessons in this material provide suggestions for teachers to explore online simulations to evaluate how the simulations support scientific understanding of difficult concepts and how they might help students understand the artistic limitations and artistic representations used in the models. Each of the units describes a scientific concept, a set of learning objectives, and examples of simulations that can be used to simulate the phenomenon. It then goes on to describe some possible naïve concepts that the instructor needs to keep in mind when using these models. Each unit also describes how the concepts and simulation fit with the *Next Generation Science Standards*.

Unit 1: States of Matter

Introduction

Most students are familiar with solid and liquid states of matter at the macroscopic scale. Gases are more problematic for some, and are often perceived as invisible and 'not really a form of matter.' One of the primary theories of chemistry provides explanations for the easily observable macroscopic behavior of gases, liquids, and solids by positing the presence of atoms and molecules at the submicroscopic scale. The particulate theory of matter suggests specific arrangements of atoms or molecules and specific behaviors of these non-static particles. Teachers often struggle to explain the particulate nature of matter to their students. The use of simulations can provide representations of the particles and their behavior that can help teachers overcome the challenges of teaching this concept. However, the limitations of artistic representations may also bring their own student interpretations that may not conform to current scientific understanding. This unit describes the use of a variety of simulations to introduce the spacing and motion in different phases, the nature of temperature during phase changes, intermolecular forces and phase changes, the comparison between boiling and evaporation, and the effect of pressure on phase changes.

Unit Objectives

At the end of this unit, the teachers should:

- Know the naive concepts that students have regarding the particulate nature of matter and states of matter.
- Describe simulations that model these concepts.
- Identify the strengths and weakness of those simulations, especially with regard to how the simulation helps students develop scientific understanding.
- Identify appropriate learning objectives for each simulation.

Unit Description

This unit introduces three different computer simulation sites, ExploreLearning[1], Molecular Workbench and PhET. The unit consists of 5 lessons. Each lesson begins with a review of some naïve concepts identified in the science education literature that students have regarding states of matter. Next, simulations are explored that address the science topics. Finally, rubrics for each simulation focus attention on how the images help students develop scientific understanding

[1] Note that ExploreLearning is a site that provides only limited free time to examine their simulations. A license is required for unlimited access.

related to these concepts. In each lesson, you will identify appropriate learning objectives for classroom lessons for each simulation.

Learning Objective

Learning objectives are statements that define the expected goal of a lesson or activity in terms of demonstrable skills or knowledge that will be acquired by a student as a result of instruction. They consist of three parts, performance, condition and criteria. Performance defines what students will be able to do after instruction. Condition determines the means necessary to achieve the objective. Criteria sets up the level of success expected after instruction and are often assumed to be perfect mastery. For example,

- Performance: Students will write chemical formulas for binary ionic compounds,
- Condition: given a periodic table,
- Criteria: with 100% success.

Naïve Concepts

Naïve concepts are commonly held views or opinions that are considered scientifically inaccurate by modern science because they are based on incomplete understanding. Vanessa Barker explains that students aged 11-18 are likely to have misconceptions in several areas of chemistry. Students, she continues, struggle to come to terms with the abstract ideas that comprise chemistry (Barker, 2004). We have to be aware that students perceive and interpret the world with their intuition and personal experiences and those ideas may be very different from scientific views.

Next Generation Science Standards

Developing and using models is one of the Scientific and Engineering Practices identified in the Frameworks for K-12 Science Education (2013). Computer simulations along with diagrams, physical models, mathematical models, and analogies are all included in the definition of models articulated in the Next Generation Science Standards [NGSS] (2013). The approximations and limitations that limit the predictive power of models are characteristics of scientific modeling and important elements for students to recognize. The NGSS highlight the role of models as presentations of systems under study, as key to scientific explanations, and as data generators to support predictions. Models play an important role in the development of academic language and scientific communications. The Common Core English Language Arts Standard RST.6-8.7 articulates the importance of integrating quantitative or technical information with a visual representation such as a flowchart, diagram, model, graph or table.

	K-2	3-5	6-8	9-12
PS1.A Structure of matter (includes PS1.C Nuclear processes)	Matter exists as different substances that have observable different properties. Different properties are suited to different purposes. Objects can be built up from smaller parts.	Because matter exists as particles that are too small to see, matter is always conserved even if it seems to disappear. Measurement of a variety of observable properties can be used to identify particular materials.	The fact that matter is composed of atoms and molecules can be used to explain the properties of substances, diversity of materials, states of matter, phase changes, and conservation of matter.	The sub-atomic structural model and interactions between electric charges at the atomic scale can be used to explain the structure and interactions of matter, including chemical reasons and nuclear processes. Repeating patterns of the periodic table reflect patterns of outer electrons, A stable molecule has less energy than the same st of atoms separated; one must provide at least this energy to take the molecule apart.

Figure 1. Next Generation Science Standards.

Lesson Description

Each lesson is composed of an introduction, naïve concepts that students often hold related to the topic covered in the unit, activities and explanation of the simulations used.

The five lessons that this unit includes are:

- Spacing and motion in the solid, liquid and gas state
- Phase change - constant temperature during phase change
- Phase change - intermolecular forces
- Phase change - boiling vs. evaporation
- Phase change - effect of pressure

Lesson 1: Spacing and motion in the solid, liquid and gas state

Introduction

This lesson addresses the behavior of particles on a submicroscopic level. The spacing and motion between atoms or molecules in each state of matter will be examined. A brief discussion of naïve concepts related to spacing and motion opens the lesson. Next, you will explore three simulations in order to determine how each communicates a scientific view of the particulate nature of matter, paying particular attention to how the simulation depicts the spacing between particles and the motion of particles. Finally, after using the simulations, you will analyze how the simulations deal with the learning objectives identified at the beginning of the lesson.

Naïve Concepts

Three aspects of the particulate nature of matter that chemistry students struggle to understand include:

- The space between particles is empty.
- Particles are in constant random motion.
- The spacing between particles is about 1000 times greater in the gas phase than in the liquid and solid phases. The differences in spacing between liquid and solid are small compared to the differences in spacing between liquid and gas phases.

<u>The space between particles is empty</u>

"The notion that empty space exists between particles causes students considerable difficulties" (Kind, 2004, p. 11). Students think that the space between particles is either filled with dust or other particles or there is no space between them. The use of filler color in models of particles can contribute to this misconception. The blue color often used as in depictions of water molecules implies to some students that the blue 'water' exists between the particles of H_2O.

<u>Particles are in constant motion</u>

Students have difficulty understanding the random particle motion in liquids and gases. Even older students can accept that gas particles are uniformly distributed in a container, but fail to understand why the particles do not eventually fall to the bottom (Driver, et al., 2007; Kind, 2004).

<u>Spacing between particles in solid, liquid and gas states</u>

Students often think about the spacing between particles in the liquid state as being halfway between the spacing in solid and gas states (Driver, Squires, & Wood-Robinson, 2007).

Learning Objectives

Students will draw pictures of the solid, liquid and gas states of matter at the particle level showing empty space between the particles.

Students will describe the continuous random motion of particles in the solid, liquid and gas states of matter.

Students will draw picture of solid, liquid and gas states of matter at the particle level showing the difference in proximity between particles in each state.

ExploreLearning Simulation – Phases of Water

http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=661

The ExploreLearning Phases of Water Simulation presents the students with an image of a container with water at 25º C. Next to the container, the student finds a magnifying glass that s/he can drag to the container to have a submicroscopic view of the water, and a temperature control to increase or lower the temperature of the water (Figure 1).

Drag the magnifying glass to the water in the container and observe the submicroscopic view. Look at the colors used for oxygen and hydrogen. It will be a good idea to discuss the colors used in the simulations with your students and explain that is only a model and not the actual color of the particles. Use the temperature control to increase the temperature until all the water evaporates and observe the submicroscopic view. Finally lower the temperature until the water freezes.

How does the simulation represent the spacing and motion of the particles in all three states? Compare the volumes of water in the three different states; is that an accurate representation? How does the simulation help students achieve the learning objectives? How does this simulation help students overcome their naïve concepts?

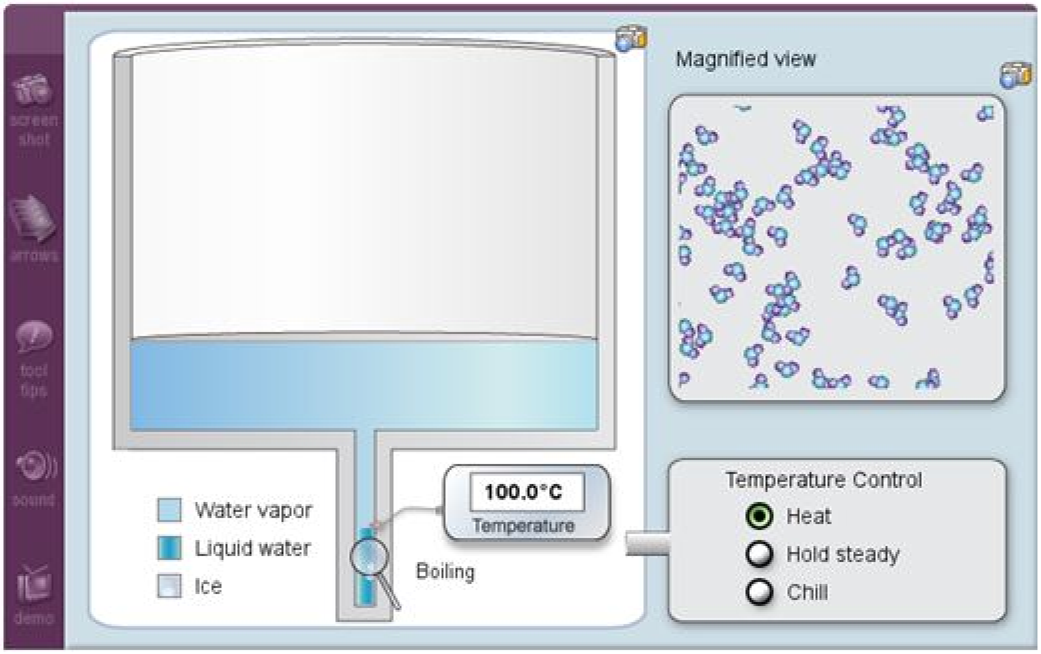


Figure 2. Explore Learning Phases of Matter.

Molecular Workbench Simulation – States of Matter

http://mw.concord.org/modeler/

From the Home Page for Molecular Workbench, select ShowCase from the top menu bar. Select chemistry and then the simulation titled: *Gas, Liquid, and Solid in a Container*. The simulation is started by clicking on the run button (Figure 3). Java 7 (or the most recent version) should be installed to facilitate the simulation. Compare and contrast how these simulations depict the spacing and motion in the gas, liquid and solid states.

How does the simulation deal with the spacing and motion of the particles in all three states?
How does the simulation help students to achieve the learning objectives?
How does this simulation help students overcome their naïve concepts?

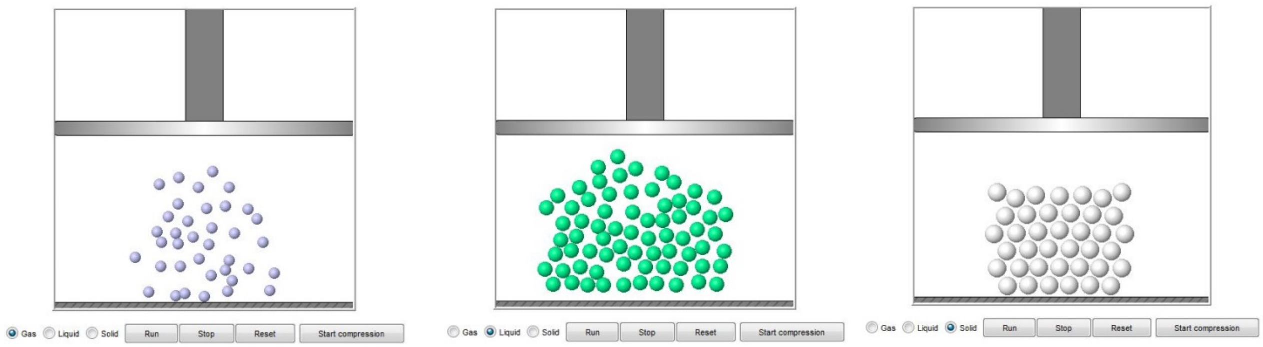


Figure 3. Molecular Workbench states of matter simulations.

PhET Simulation – States of Matter: Basics

http://phet.colorado.edu/en/simulation/states-of-matter-basics

This program contains two simulations. In this lesson only the first simulation, entitled “Solid, Liquid, Gas” will be used. The simulation shows a container with particles in the solid state at 13 K. A choice of substances includes neon, argon, oxygen and water. Temperature controls are located under the container and on the right hand menu are shortcuts to go directly to the solid, liquid and solid state (Figure 4).

Using neon first, change between the solid, liquid and gas state and record your observations. Repeat the process using oxygen and water, and compare their representations. Water in the solid state will have a different arrangement than neon or oxygen due to the presence of hydrogen bonding.

How does the simulation deal with the spacing and motion of the particles in all three states? What happens to the volume of the substances when you change the state?

Does this simulation help students overcome their naïve concepts?

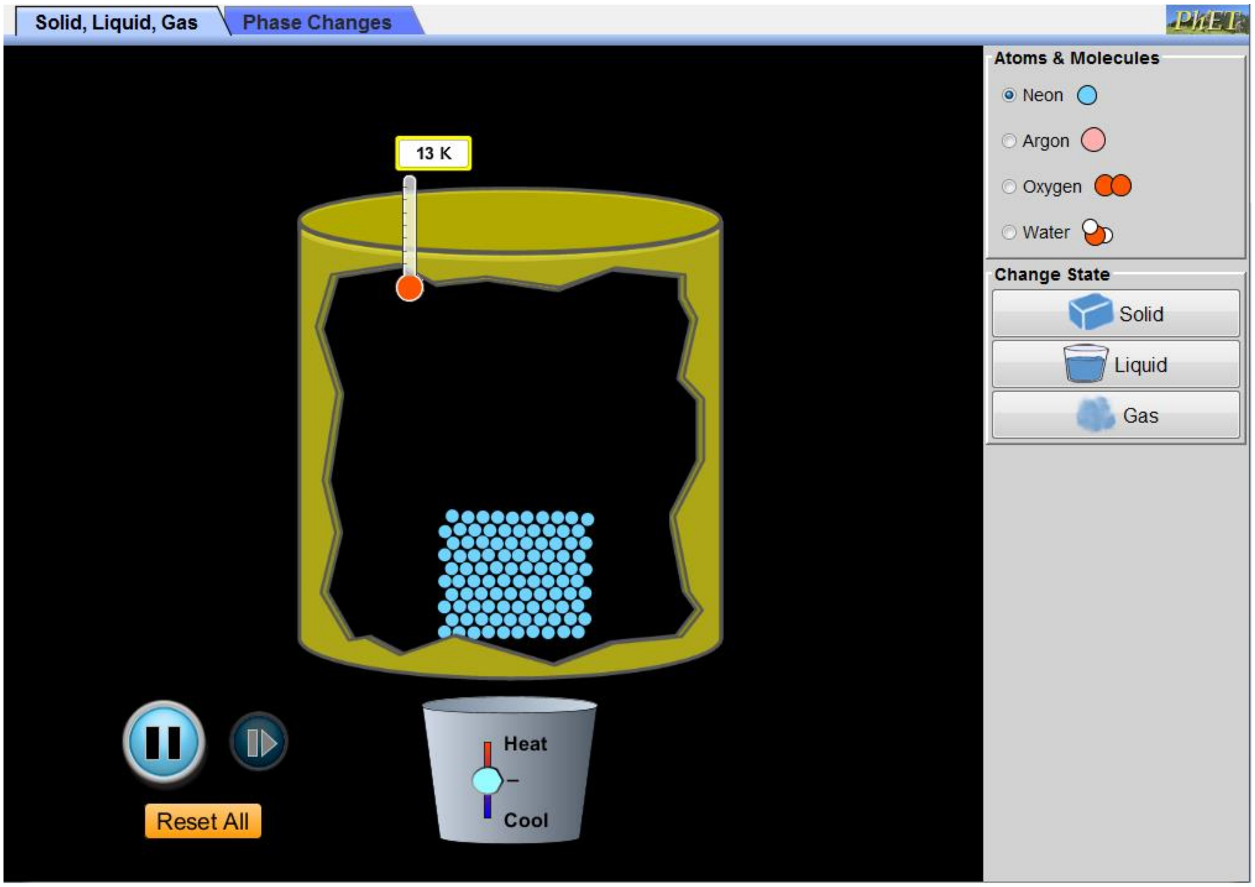


Figure 4. PHeT States of Matter.

Summary

Students have naïve concepts about the particulate nature of matter, and those should be addressed in class for them to fully understand what is occurring on a submicroscopic scale.

The rubric in below may be used to summarize how well each simulation addresses the learning objectives focused on spacing between particles in different phases of matter and the motion of particles (Figure 5).

Learning Objectives	How does the simulation address the learning objective?		
	ExploreLearning	Molecular Workbench	PhET
Students will draw pictures of the solid, liquid and gas states of matter at the particle level showing empty space between the particles			
Students will draw picture of solid, liquid and gas states of matter at the particle level showing the difference in proximity between particles in each state			
Students will describe the continuous random motion of particles in the solid, liquid and gas states of matter			

Figure 5. Rubric for states of matter.

Lesson 2: Phase Change – Constant temperature during phase change

Introduction

This lesson focuses on the notion that temperature remains constant when a phase change occurs. A brief discussion of naïve concepts related to phase changes and temperature will take place at the beginning of the lesson. The discussion will be followed by the learning objectives for the lesson. Next, you will explore the ExploreLearning simulation. Finally, after using the simulation, you will analyze how the simulation deals with the learning objectives identified at the beginning of the lesson.

Naïve Concepts

Chemistry students struggle with the idea that during a phase change the temperature of the substance remains the same. Driver *et al.* (2007) identified the following misconception: after boiling water for 5 minutes, the temperature will be higher than 100ºC.

This lesson helps you examine one simulation that models temperature and phase change relationships. How does this simulation help students develop scientifically accepted views of the relationship between temperature and phase change?

Learning Objectives

Students will understand that during a phase change the temperature remains constant.

Students will be able to explain why temperature remains constant during a phase change.

ExploreLearning Simulation – Phases of Water

http://www.explorelearning.com/index.cfm?method=cResource.dspDetail&ResourceID=661

The simulation shows a container with water at 25º C. Next a magnifying glass can be moved to the container to produce a submicroscopic view of the water. A temperature control allows the viewer to increase or decrease the temperature of the water.

Drag the magnifying glass to the water in the container and observe the submicroscopic view. Increase the temperature until the temperature reaches 100º C. What happens at that temperature? Does the temperature remain constant or does it vary? What happens after all the water evaporates?

Lower the temperature until it reaches 0º C. What happens at that temperature? Does the temperature remains constant or does it vary? What happens after all the water freezes?

How does the simulation teach the notion of constant temperature during a phase change? Compare the volumes of water in the three different states; is the volume represented accurately? How does the simulation help students to achieve the learning objectives? How does this simulation help students overcome their naïve concepts?

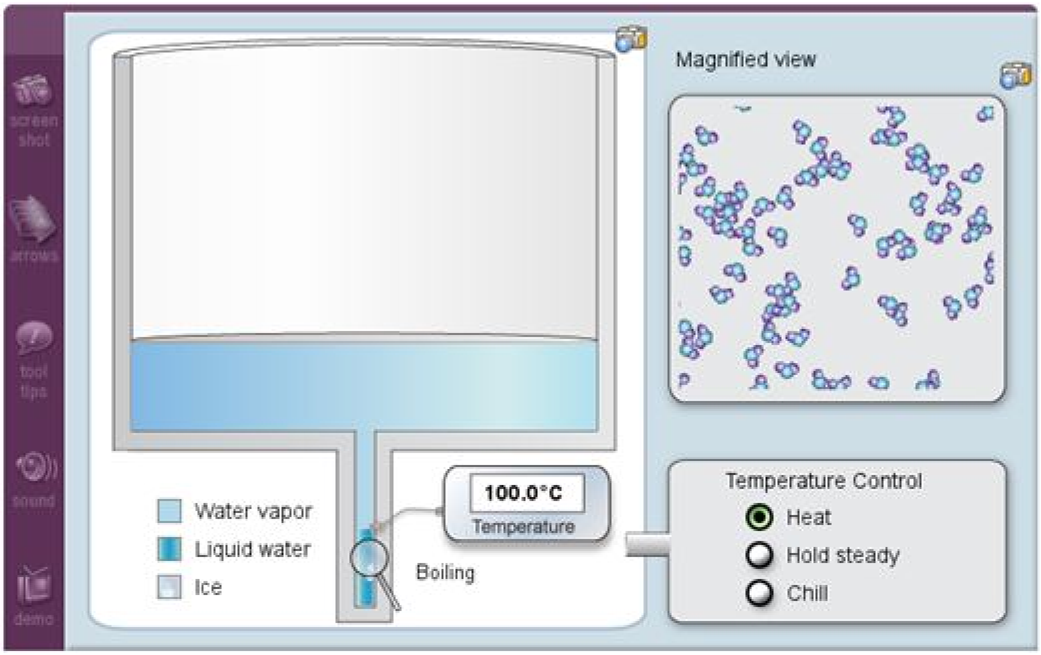


Figure 6. Explore Learning State of Matter.

Summary

Students have naïve concepts about the notion that continuing to heat a substance during a phase change will cause a steady increase in temperature. After exploring the simulation, do you think the simulation address the naïve concept students have?

Use the rubric below to summarize how the simulation addresses the common naïve conceptions students hold regarding phase changes and temperature (Figure 7).

Learning Objectives before using the simulation	How does the simulation address the learning objective?
Students will understand that during a phase change the temperature remains constant	
Students will be able to explain why temperature remains constant during a phase change	

Figure 7. Rubric for phase changes and temperature.

Lesson 3: Phase Change – Intermolecular Forces

Introduction

This lesson examines how simulations model the role of intermolecular forces on the states of matter.

Naïve Concepts

"Students may reason that attractive forces are present between gas particles and that these explain why gas particles may clump together. A student may modify this later to explain the uniform distribution of gas particles in terms of repulsive forces. In contradiction, forces may be present when the substance is gaseous, but not when solid. These ideas may contribute to difficulties for students in understanding chemical bonding" (Kind, p. 13).

Learning Objectives

Students will be able to understand the relationship between intermolecular forces and the states of matter.

Molecular Workbench Simulation – Phase Change: Interatomic interactions and States

http://mw.concord.org/modeler/

Select from the Chemistry Showcase, the simulation titled Phase Change: Interatomic Interactions and States (direct link is http://mw2.concord.org/tmp.jnlp?address=http://mw2.concord.org/public/part2/phasechange/ind ex.cml. Run the simulation and set the attraction forces to weak and record your observations. Now change the attraction forces to moderate. How does the model depict this change? Finally set the attraction forces to strong. Compare and discuss these three settings.

How does the simulation present intermolecular forces and states of matter? How does the simulation help students to achieve the learning objectives? How does this simulation help students overcome their naïve concepts?

Underneath the simulation are questions for the students to answer. Do you think these questions are useful for your students?

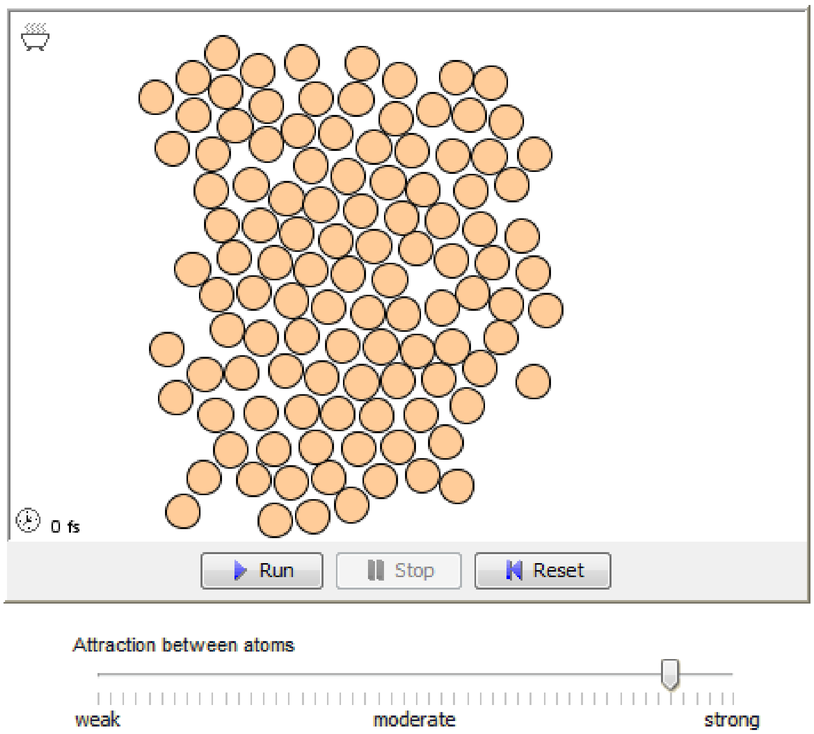


Figure 8. Molecular Workbench: Intermolecular forces and states of matter.

Summary

Students have naïve concepts about the notion of intermolecular forces and their effects on states of matter. After exploring the simulation, how do you think the simulation addresses the naïve concepts students have?

Use the following rubric to summarize how this simulation helps students develop scientific understanding of the role of intermolecular forces on states of matter (Figure 9).

Learning Objectives before using the simulation	How does the simulation address the learning objective?
Students will be able to understand the relationship between intermolecular forces and the states of matter	

Figure 9. Rubric Intermolecular forces and phase changes.

Lesson 4: Phase Change –Evaporation

Introduction

This lesson explores the phase change from liquid to gas below the boiling temperature, a process called evaporation. A brief discussion of naïve concepts related to evaporation will take place at the beginning of the lesson. Next, you will explore the Molecular Workbench simulation to view see how the model presents the evaporation process.

Naïve Concepts

According to Kind (2004), young children have a vague idea about evaporation. When presented with a container from which water is evaporating, children focus on the remaining water, noting that some of the original water in a container has disappeared. Students may think that water soaks into a pan when it is boiled, or goes into the plate instead of evaporating.

High school students have problems linking evaporation with conservation of mass. The phrase "gas weighs less than a liquid" implies for students that less gas must be present.

Learning Objectives

Students will be able to explain the process of evaporation from the submicroscopic perspective.

Molecular Workbench – Phase Change

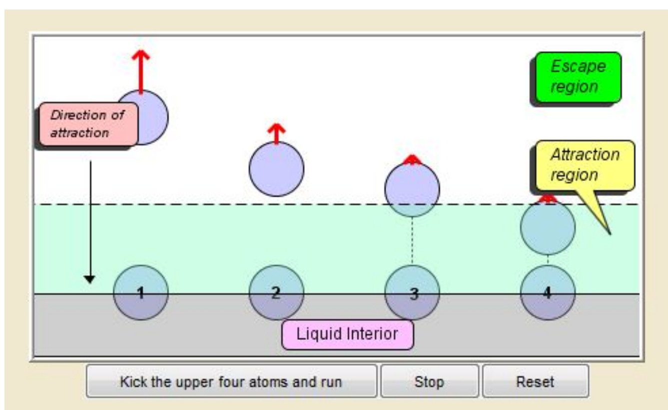
http://mw.concord.org/modeler/

This simulation contains nine activities, for this lesson activity number eight, "Phase Change: Evaporative Cooling" will be used (in the same collection as the previous phase change exercise). This activity contains two simulations. The first one, entitled "A simple experiment", presents 4 atoms with different given speeds and lets the viewer explore what happens when the atoms are "kicked out." The atoms represent different speeds and illustrates that the molecules with the higher speeds are more easily removed from the container. The second simulation, "A more realistic model", shows 120 atoms in a container that is heated to 270º C. The teacher will need to clarify to students that this liquid is not water as this temperature is well above the boiling point of water. The simulation lets the viewer remove the cover and observe what happens to the atoms and the temperature (Figure 10). The loss of molecules due to evaporation and the subsequent evaporative cooling are noticed with the help of a thermometer and a molecule counter.

How does the first simulation help students understand the concept of evaporation? After this proceed to the second simulation. First run the simulation without removing the lid, wait for a couple of seconds and record the temperature. Then remove the cover and record your observations. What happened with the temperature and with the number of molecules in the container?

How does the simulation help students develop sound understanding of evaporation? Does this simulation help students overcome their naïve concepts?

Underneath the simulation is a question for the students to answer. Do you think this question is useful for your students?



A simple experiement

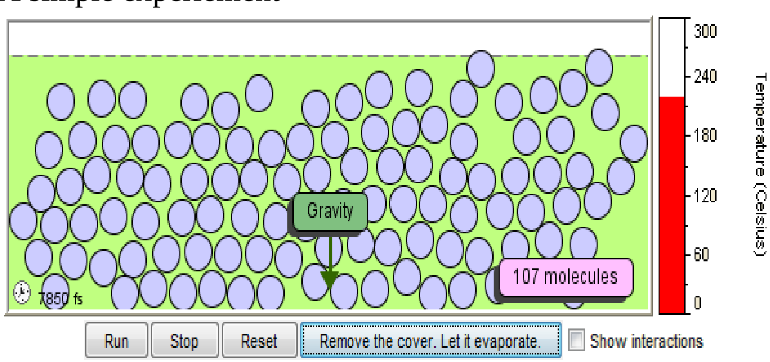


Figure 10. Evaporative cooling.

Summary

Students have naïve concepts about the notion of intermolecular forces and their effects on states of matter and that should be addressed in class for them to fully understand what is occurring in a submicroscopic scale. After exploring the simulation, do you think the simulation addresses the naïve concepts students have?

Now that you have explored the simulation that deal with intermolecular forces and state of matter, complete the following table to report your findings.

Learning Objectives before using the simulation	How does the simulation address the learning objective?
Students will be able to explain the process of evaporation and evaporative cooling.	

Figure 11. Rubric, Evaporative Cooling.

Lesson 4: Phase Change – Effect of Pressure

Introduction

This lesson deals with the effect of pressure on the states of matter. The PhET simulation provides a model to explore how pressure interacts with phase changes.

Learning Objectives

Student will describe the effects of pressure on solids.

Students will describe the effects of pressure on liquids.

Students will describe the effects of pressure on gases.

Naïve Concepts

The concept of pressure challenges many students. Confusion between the ideas of force and pressure contribute to this difficulty (Kind, 2004).

PhET Simulation – States of Matter: Basics

http://phet.colorado.edu/en/simulation/states-of-matter-basics

For this lesson only the second simulation, entitled "Phase Changes" will be used. When you run the simulation, you will see a container with neon in the solid state at 13 K, but argon, oxygen and water can also be used. Temperature controls are located under the container and a pump to add more substance is located on the right of the container. The lid of the container can be lowered or raised and by doing so the pressure will change; to measure the pressure inside the container a pressure valve is located in the top left corner. The right menu has an option to view a phase diagram of the system you are working with.

Use water as the substance in the container and lower the lid until the pressure is between 10 and 15 atm. What happened with the temperature of the water? Did a phase change take place? Now lower the temperature until the water becomes solid again, what happened with the pressure? Finally lower the lid all the way to the bottom. At this point the lid will blow away and most of the molecules will escape the container. Can you explain the correlation between pressure and phases?

How does the simulation deal with the effect of pressure on states of matter? What happens to the temperature when the pressure is changed? Does the simulation help students to achieve you learning objectives?

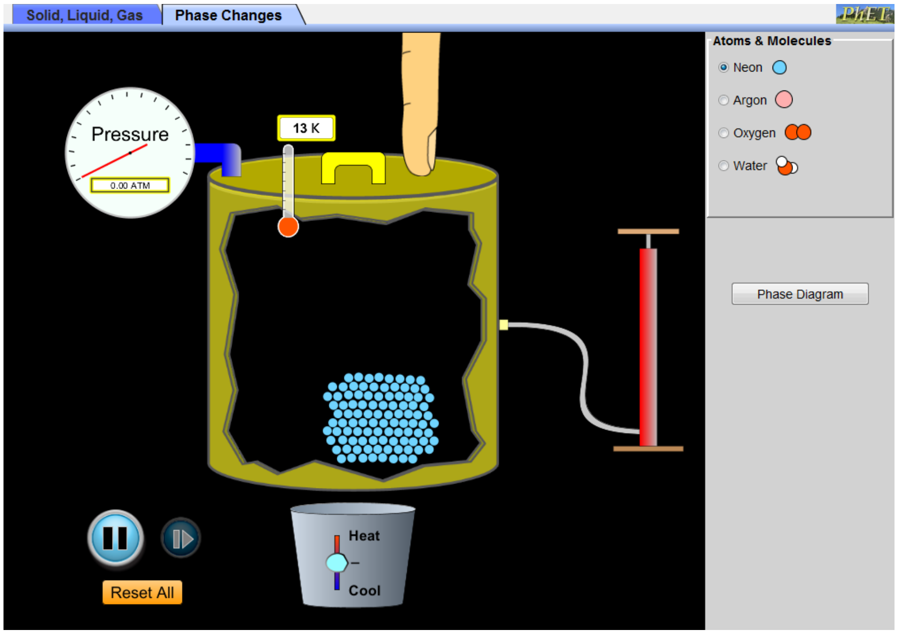


Figure 12. PhET Model. Pressure and phase changes.

Summary

Students have naïve concepts about the notion of intermolecular forces and their effects on states of matter and that should be addressed in class for them to fully understand what is occurring in a submicroscopic scale. After exploring the simulation, do you think the simulation address the naïve concepts students have?

Now that you have explored the simulation that deal with intermolecular forces and state of matter, complete the following table to report your findings (Figure 13).

Learning Objectives before using the simulation	How does the simulation address the learning objective?
Student will describe the effects of pressure on solids.	
Students will describe the effects of pressure on liquids.	
Students will describe the effects of pressure	

on gases.	

Figure 13. Rubric. Pressure and phase changes.