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| Phases and the Particle Model of Matter Demonstration |
| C2.1b & C4.1a |
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Phases & the Particle Model of Matter

**A Short Demonstration**

**Background:**

At room temperature different compounds exist in different phases. For example, at room temperature table salt, sodium chloride, is a solid, water is a liquid and carbon dioxide is a gas. This is because the amount of attraction between the particles that make these compounds up is not the same.

**Figure 1**: Sodium chloride ionic crystal lattice. Sodium is gray & chloride is lime.

The solid sodium chloride is made up of Na+ ions and Cl– ions attracted to each other in a three dimensional lattice so that each ion is surrounded by six ions of opposing charge (see Figure 1). Under these conditions the ions are held in place so rigidly that they are unable to move past each other. The Explanation of a solid’s behavior is that the particles are in contact with each other, and are unable to move past each other.

Water is a polar covalent compound, so there is a dipole-dipole attraction between water molecules at room temperature known as a hydrogen bond. Hydrogen bonds from be­tween molecules that contain a hydrogen atom bond­ed to a oxygen, nitrogen or fluorine atom. The difference in electronegativi­ty in this type of atom pairing results in a strong bond dipole, and in water’s case, this combined with the two lone electron pairs results in a definite positive region around water’s hydrogens, and a negative region around the lone pair electrons. Therefore water molecules form weak bonds with each other (see Figure 2). This bonding is strong enough at room temperature to keep water molecules held next to each other, but not strong enough to keep the molecules from moving past each other. The explanation of a liquid is that the particles are in contact with each other and able to move past each other.

**Figure 2**: Hydrogen bonding between water molecules.

A quick Lewis structure analysis of carbon dioxide reveals it to have a linear geometry and to be non-polar(see Figure 3). The only type of attraction between non polar molecules is as a result or dispersion forces. When one molecule moves along side another their electron clouds begin to repel each other. With the electron clouds dispersed unevenly around the nuclei of the molecules, a temporary dipole is created, with a negative region on the side of the molecules where the electrons are denser, and a positive region where the electrons are thin. The positive side of one molecule then attracts the electrons of the other molecule so the electrons of the second molecule begin to move toward the first. Eventually a sort of rhythm is established in which the electrons clouds of the two molecules sway back and forth in synchrony. The result is a very weak attraction between the molecules, known as a dispersion force, London force or van der Waals force. At room temperature the dispersion forces between carbon dioxide molecules are so weak that the molecules collide, but do not stay in contact with each other, and therefore naturally are able to move past each other. The explanation of a gas’ behavior is that the particles are not in contact with each other and can move past each other.

**Figure 3**: The linear geometry of carbon dioxide. Black is carbon & red is oxygen.

In the case of dispersion forces, the larger the molecule, the more pronounced the electron cloud distortion and therefore the attraction created. For example, consider the halogens. Fluorine and chlorine are gasses art room temperature, bromine is liquid, and iodine is solid. Find a table of bond radii in your book and see if you can explain this trend.

In all the above cases there is a dynamic balance between the forces that hold the particles of the compound together and the kinetic energy in the sample of the compound that determines what phase the compound will be in.

**Purpose:**

In this demonstration the student will be able to:

* Observe the behavior of water in all three phases discussed above.
* Explain each of the phases based on the dynamic between kinetic energy of the water molecules and the attraction between these molecules.
* Use these principles to explain the phases of different substances at room temperature.

**Hypothesis:** (a testable prediction)

During this demonstration solid water will be heated until it boils. Water melts at zero degrees Celsius, and boils at on hundred. Predict whether the water will all melt as soon as the solid reaches zero degrees, and whether it will all boil as soon as the liquid reaches one hundred degrees.

**Materials:**

Safety goggles, beaker tongs, ice, 250 mL beaker, watch glass to cover beaker, hot plate, thermometer, ring stand, ring & string.

**Procedure:**

Caution should be exercise at all times during this demonstration. The hot plate and beaker become hot during the process, and neither gives any outside indication of this. Do not touch them. When water boils it contains a lot of heat energy, and can cause severe burns. Wear safety goggles at all times and practice safe laboratory behavior at all times.

For this procedure your teacher will have set up an apparatus so that ice can be heated unto boiling in the beaker by the hot plate, and the temperature of the system recorded by a thermometer that is suspended from the ring on the ring stand. The thermometer should be hung from the string so that it is immersed in the water, and does not touch the bottom of the beaker.

During this procedure, several observations will have to be made. Student discussions during this time are disruptive to the learning process. The students should refrain from discussion unless recognized by the teacher.

1. Solid water will be place in the beaker. Observe and record whether it fills the beaker and whether it takes the shape of the beaker.
   1. As the solid water is heated several observations of the temperature will be made. Record the temperature, and the phase/s of the water in the beaker.
2. Eventually all of the solid water will have turned to liquid. Observe and record whether the liquid takes the shape of the beaker and whether it fills the beaker.
   1. As the liquid water is heated several observations of the temperature will be made. Record the temperature, and the phase/s of the water in the beaker.
3. Eventually the water will begin to turn to gas. Based on your experience, if the beaker were sealed to contain all of the water, record whether the water would take the shape of the beaker and whether it would fill the beaker. When the teacher allows, discuss this with the class if necessary.

**Data & Observations:**

**Solid phase observations:**

**Liquid phase observations:**

**Gas phase observations/predictions:**

**Analysis & Conclusions:**

1. Use the explanation of solid’s behavior described in the background of this demonstration to explain your observations of whether the solid water took the shape of the beaker and whether it filled the container.

* 1. Did the temperature of the water change during the solid phase?

* 1. When the water reached its melting point it took time for it all to melt, what was the hot plate doing to the water during this time?

* + 1. In terms of kinetic energy(particle motion), what was happening during this time of constant temperature?

* + - 1. As the water turned from solid to liquid, it was because the kinetic energy in the water exceeded the strength of the hydrogen bonds that hold the water molecules so they couldn’t move past each other. What can be said of the strength of the bonds that hold a solid together at room temperature compared to the bond strength between the particles of a different material that is liquid at the same room temperature?

1. Use the explanation of a liquid’s behavior described in the background of this demonstration to explain your observations of whether the liquid water took the shape of the beaker and whether it filled the container.

* 1. Did the temperature of the water change during the liquid phase?

* 1. When the water reached its boiling point it took time for it all to turn to gas, what was the hot plate doing to the water during this time?

* + 1. In terms of kinetic energy(particle motion), what was happening during this time of constant temperature?

* + - 1. As the water turned from liquid to gas, it was because the kinetic energy in the water exceeded the strength of the hydrogen bonds that hold the water molecules next to each other. What can be said of the strength of the bonds that hold a liquid together at room temperature compared to the bond strength between the particles of another material that is a gas at the same room temperature?

1. Although we were unable to observe the temperature of the gas after all the liquid boiled off, what would the temperature do as more heat energy was added?

Teacher Companion Notes for Phases & the Particle Model of Matter

**Safety Notice:**

It is assumed that the instructors presenting this material are trained in appropriate safety procedures in the chemistry laboratory, and that the students under their tutelage have been completely informed of the specific precautions to be undertaken for this laboratory and the general behaviors appropriate to the chemistry laboratory. It is further assumed that instructors have familiarized themselves with the Material Safety Data Sheets (MSDS) for all the chemicals used in this laboratory, observe all the precautions that the MSDS indicates and have a copy of the MSDS on hand during the investigation. Additionally, it is assumed that all appropriate safety gear necessary to an adequately equipped chemistry laboratory is present in the room in which the laboratory is taking place, the instructor and students are familiar with its proper use, and that this equipment is in excellent functioning order.

It is the instructor’s sole responsibility to insure the safety of the students and staff in the chemistry laboratory, and the individuals in the surrounding areas. It further is the instructor’s sole responsibility to be fully informed of the regulations pertinent to their locale and to follow those regulations completely. This applies to the proper use and disposal of chemicals in the laboratory, equipment in the laboratory, and training of the instructor and students as to procedures in the laboratory.

An excellent resource for MSDSs is Flinn Scientific: <http://www.flinnsci.com/search_MSDS.asp> .

The class room teacher takes sole responsibility for the safe conduction of this laboratory.

**High School Content Expectations:**

**C2.1b** Describe energy changes associated with chemical reactions in terms of bonds broken and formed (including intermolecular forces).

**C4.4a:** Explain why at room temperature different compounds can exist in different phases.

Almost any good Chemistry book will contain a Heating Curve for Water graph. It would be wise to review this with the students before having them complete the Analysis & Conclusions portion of the demonstration. Focus on the energy relationship especially at the plateaus for heat of melting and heat of evaporation.

A common misconception of the students is that the strength of the hydrogen bonds is changing as the water’s temperature changes. Hydrogen bond strength is constant, it is the kinetic energy that changes and overcomes the ability of these bonds to keep the water molecules from moving past each other, and then exceeds the ability of these bonds to keep the molecules in contact with each other, as the sample is heated. Make this clear during the demonstration, and contrast this with the different bond strength that results in **different** substances being in different phases at the **same** temperature.

The watch glass is helpful in aiding student visualization of a sealed container with gas in it.

This demonstration does not include the behavior of metallic bonding, and the electron sea model. This would make a discussion for the class after the demonstration has been graded as part of clearing up misunderstandings.

**Contact Information:**

Please contact the author if it is found that the safety precautions are incomplete or inaccurate, factual information is inaccurate, or there are any modifications/augmentations that could improve this laboratory. [KingChemistry@comcast.net](mailto:KingChemistry@comcast.net) .

**Please Provide Feedback:**

If this material was useful in improving student understanding of the content, please let me know. If this material could use revision to improve student learning, again, please let me know. [KingChemistry@comcast.net](mailto:KingChemistry@comcast.net) .

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