Solubility

Big Ideas

- The relationship between the gas solubility in a liquid and temperature and pressure.
- Dynamic physical and chemical equilibrium systems
- Concentration and saturation.
- The equilibrium system of a weak acid
- The pH of a weak acid

Learning Objectives

- Students will make predictions and explore the effects of temperature and pressure on the solubility of a gas in a liquid.
- Students will understand what it means for one substance to be "dissolved" into another at a molecular level.
- Students will understand the dispersion of a solute in a solvent and the factors affecting this dispersion.
- Students will understand dynamic equilibrium at a molecular level.
- Students will create and manipulate representations in order to show understanding
- Students will use their own understanding to develop their own version of Henry's law.
- Students will use simulations to help them understand the concept of physical and chemical equilibrium systems.
- Students will design and conduct their own lab to study an equilibrium system.
- Students will take a field trip to a bottling industry [optional].

Part 1 (approximately 45 minutes)

Introductory Activity. Students represent the contents of a can of soda at the macroscopic level and at the molecular level. These representations will be kept so that students can map their understanding over time.

Purpose
To have students start thinking and representing their ideas at two different levels – the macroscopic and the microscopic levels.

Background Discussion
Depending on the students' previous background and understanding of chemistry, a quick review of the differences between the states of matter (solid, liquid, gas) at the macro and particulate levels, and intermolecular bonding may be helpful to bring students up to speed. After the review, the concept of ***Aggregation*** as it applies to gases dissolving in a liquid should be emphasized. The class discussion may also include a review of polar and non-polar molecules and their intermolecular bonding. This discussion could be centered on the following questions:

> What keeps water together as a liquid?
> Why and under what conditions does water become a gas?

What keeps CO_2 together as a solid?
Why and under what conditions does it become a gas?

The students should be encouraged to question why different types of substances stay together as a solution. Likewise, the concept of ***Concentration*** in terms of physical change (i.e., mixing) should also be discussed. The bigger idea of how and why solutions occur (in terms of entropy) can also be discussed (at whatever level is appropriate for the given students.)

Lab 1 – Making Oxygenated Water

Purpose
To understand the chemical processes that occur as a gas (oxygen) goes into solution (de-ionized water). This lab is designed as an introductory activity in which student start to become familiar with the setting up the lab equipment and using the electronic probes and computer interface.

Background Discussion
In this experiment students make their own solution by mixing a gas into a liquid. The gas (air) will be passed through de-ionized water using a small fish tank pump. Students will measure the amount of dissolved oxygen in the solution by using a dissolved oxygen sensor.

While working on this lab, students should be encouraged to think about and to represent what they think is happening at the molecular level. Also, encourage students to start thinking about *equilibrium* in the solution – solute particles moving into and out of solution continuously, with the overall aggregate affect of creating a stable balance.

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and refer to during the laboratory.

Materials

Large Beaker	Supply of de-ionized water	Stirring rod
Air pump with tubing	Support stand and clamps	
Dissolved oxygen sensor, Interface and computer		

Procedure
- Pour 500 mL of de-ionized water into the beaker.
- Submerge the probe 3/4 of the way into the water.
- Let the probe get adjusted to the water by stirring the water for about one minute.
- Place the end of the air pump tubing into the water.
- Decide what data needs to be collected and for how long
- Press the “start” button on the computer at the same time air starts bubbling through the water.
- After the data is collected, reflect on the data. Write a summary paragraph explaining how the data fit the predictions made. If it did not support the predictions explain why they were different and write a revised explanation. Revise drawings as well.
- Repeat the experiment in order to have a complementary set of data.
- Write down at two interesting questions or ideas related to the experiment.

Part 1 1/2 (approximately 45 minutes)

Introductory Discussion Now that the students have completed an activity into making a solution, it is important to discuss some of the terms that will be used when discussing solubility. We use the term *soluable* to refer to the capability of a substance to be dissolved – “Sugar is *soluable* in water.” The resulting mixture is called a *solution*. The definition of a solution is *a homogeneous mixture of two or more substances in a single phase*. It is important for the students to understand that even though a gas may be dissolved into a liquid, once the gas is in solution it is now in the liquid phase. Using the sugar dissolved in water example, the sugar is now in the liquid phase. We call the sugar (the substance being dissolved) the *solute,* and we call the water (the medium the solute is being dissolved into) the *solvent*.

These four terms – soluable, solution, solute, and solvent – are helpful terms used to describe various parts of the solubility process. This section can be referred back to for reference.

Another important part of the solution process is having a general idea if a particular solute will dissolve in a particular solvent. Looking back at the first experiment, the oxygen molecules easily dissolved into the water when they were pumped through it. Without performing the investigation, would we have known if oxygen can dissolve in water? Is there a way to predict what will dissolve in what?

Now that we have a general idea why some substances will dissolve in others, it is important to visualize what happens at the molecular level when a solute is added to a solvent. What do the pieces of the solute do immediately upon entering the solvent? What happens over time if we could watch the solute and solvent interact? In the following mini investigation, we will try to conceptualize this process.

Mini-Lab - Determining what happens when a solute is added to a solvent. In this mini investigation you will be using food coloring and various amounts of water to help you get a sense of what might be happening on the molecular level when a solute is added to a solvent. You may have had experience using food coloring before while cooking and know about some of its properties. If you don’t, that’s O.K. This mini investigation is for you to explore.

<u>Materials</u>

Assorted beakers
Deionized water
Colored pencils
4 Color box of food coloring
Stirring rod

Procedure

Use the beakers, water, and food coloring to explore the effects of adding food coloring to water. You may use any amounts of water and any colors to experiment with. The main question that you are trying to answer is: “What is happening on a molecular level when I add the solute to the solvent?” Use your notebook to draw two types of pictures: a) what you observe happening in the beaker when food coloring is added, and b) what you think is happening at the molecular level when you add the food coloring to the water. It is important to draw pictures that show what is happening over time. A good way to do this is to draw several ‘frames’ in a row that you can fill in with pictures.

You may repeat the investigation as many times as you want and with any combination of materials. The important thing is that you take the time to make as detailed pictures as possible. Along with your drawings, please answer the following questions:

- what do you think makes the food coloring molecules spread throughout the liquid?
- at what point do the food coloring molecules stop spreading? What do you think makes them stop spreading? Do you think they really stop? Why or why not?
- what are some things that you can do to increase or decrease how fast the food coloring molecules move through the water?
- what do you think is happening in the solvent (water) before you add the food coloring? Would heating the water change what you think is going on before the food coloring is added?

Feel free to add any drawings of unusual or interesting experiments you came up with.

Homework

Homework for this evening is a short handout (approximately 1-2 pages) on the molecular theory for why and how solutes disperse through solvents. Included here are the ideas of solutes that are soluable, partially soluable, and insoluable, as well as discussion of factors related to the rate of dispersion.

Part 2 (approximately 45 minutes)

Lab 2 - Temperature and Solubility

Purpose

To show the effect of temperature on the solubility of a gas in liquid at constant pressure.

Background Discussion

Students should now be considering the effect of a single variable on the solubility of a gas in a liquid – temperature. Here the students saturate the water with oxygen while they heat the solution. The idea here is for the water to be saturated at all times. The students measure the change in the saturation amount as the temperature increases. After completing the experiment they should find that the saturation level decreases as temperature increases.

While working on this lab, students should be encouraged to think about and to represent what they think is happening at the molecular level. In addition, they should keep in mind the idea of equilibrium taking place within the solution and in the space immediately above the solution. For many students the idea that air (or oxygen) particles go into the solution from the space above and not just come out of solution may be a new idea to them. Since this phenomenon is hard to observe, probing questions from the teacher as the students conduct the investigation is encouraged.

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and refer to during the laboratory.

Materials

Large Beaker	Hot plate	Supply of de-ionized water
Support stand and clamps	Stirring rod	Air pump with tubing

Dissolved oxygen sensor and temperature sensor, interface, and computer

Procedure

1. Pour 500 mL of de-ionized water into the beaker.
2. Set the beaker on the hot plate. Do not turn the hot plate on yet.
3. Submerge the oxygen and temperature sensors into the water.
4. Place the end of the air pump tubing into the water and turn the pump on..
5. Think about what data needs to be collected and how long it needs to be collected.
6. Press the "start" button on the computer at the same time the hot plate is turned on.
7. After the data is collected, reflect on the data collected. Write a summary paragraph explaining how the data fit the predictions made. If it did not support the predictions explain why they were different and write a revised explanation. Revise drawings as well.
8. Repeat the experiment in order to have a complementary set of data.
9. Now that you have results from running the first two experiments, write down at least two questions that you are wondering about.

Part 3 (approximately 45 minutes)

Lab 3 - Making Carbonated Water

Purpose

Students create another type of liquid/gas solution – carbonated water. This lab is designed to provide another opportunity for students to create a solution of dissolved gas in a liquid. The solution they create this time has a "real-world" extension that should be familiar to most students – carbonated sodas. In effect, students created carbonated water, similar to Calistoga sans gas. Students are challenged to think about what this "new" solution might look like at the molecular level and how it might be different from the previous solution they created (dissolved oxygen in water). In addition, students have the opportunity to work with frozen carbon dioxide (dry ice). If interested, additional discussion can center around properties of dry ice, how it is made, why/how it sublimes, etc.

Following the lab, students are asked to relate the three labs conducted thus far. Specifically, their discussion should involve why they think one substance will dissolve into another substance (since they have been limited to dissolving a gas into a liquid, it is O.K. if their discussion is limited to this type of solution.) As much as possible, students should be encouraged to represent their ideas through drawings, diagrams, 3-D models, or other types of representations. Since equilibrium has also been an underlying theme throughout the labs, encourage students to include the idea of equilibrium in their representations. Their discussion should also involve the effect of temperature on the ability of a gas to dissolve into a liquid. Again, their ideas should be shared in multiple representations.

Background Discussion

Students will bubble the CO_2 into the water using a carbon dioxide "pump". This is just a sealed flask with a piece of dry ice in it and a tube coming out of the side of it. As the dry ice goes from the solid to the gas phase, pressure builds up in the flask and pushes the CO_2 out. Students will use a pH sensor to detect how much CO_2 has gone into solution and when the solution is finally saturated. In this investigation, the pH sensor is used as an indirect way to measure dissolved

CO_2. In the process of making carbonated water, CO_2 gas combines with H_2O to form carbonic acid, H_2CO_3:

$$H_2O\ (l) + CO_2\ (g) \text{ -----> } H_2CO_3\ (aq)$$

The amount of H_2CO_3 is detected by measuring the pH of the solution since H_2CO_3 in water is considered an acid. Thus, the pH sensor indirectly measures the amount of CO_2 in solution.

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and refer to during the laboratory.

Materials

Large Beaker	Supply of de-ionized water	Support stand and clamps
Air pump with tubing	pH sensor, interface, computer	Stirring rod

Procedure

- Pour 500 mL of de-ionized water into the beaker..
- Submerge the pH sensor into the water and let it adjust for about one minute.
- Think about what data needs to be collected and how long it needs to be collected.
- Press the “start” button on the computer at the same time that you put the tube from the CO_2 pump into the water.
- After the data is collected, reflect on the data collected. Write a summary paragraph explaining how the data fit the predictions made. If it did not support the predictions explain why they were different and write a revised explanation. Revise drawings as well.
- Once the data has been collected, the experiment may be run again (recommended).
- Now that you have the results of the first three experiments write down at least two questions that you are wondering about.
- Go back and examine all of the results from the three experiments and write a summary paragraph or explanation about how the three experiments relate to each other.

Part 4 (approximately 45 minutes)

Lab 4 - Pressure and Solubility

Purpose

To show the effects of pressure and its relation to the solubility of a gas in a liquid. This section of the module is divided into 3 short investigations. In the first part, students will conduct an investigation into Boyle’s Law (pressure vs. volume) using a pressure sensor and a syringe. In the second part of the experiment they will hold temperature constant as they vary the pressure on a solution in a sealed flask. In the third part, they will vary the temperature on a liquid in a sealed flask and observe how pressure changes with temperature.

In part 1, students develop a tactile sense of pressure and measure its change. In the second and third parts, the students consider the relationship between the a gas (solute) and a liquid (solvent) as pressure is changed. The underlying big idea here is *dynamic equilibrium* between the solution and the gas in the space above the solution.

Background Discussion

The students will first conduct an intro experiment to develop a sense of pressure by physically changing the volume of a syringe with air inside of it. The head of the syringe is directly attached to the Pasco pressure sensor so students can simultaneously see how pressure changes as the volume is manipulated. In this part of the investigation it is important to have the students think about the nature of the gas inside the syringe and what gives rise to "pressure". What do the molecules of the air look like inside the container? How do they "make" pressure? How do the molecules look after the volume is decreased and why does the pressure change? These are all good probing questions that can be asked as students conduct this part of the investigation. In the student handout of the lab (see Appendix A) the students are prompted with these types of questions and are asked to create representations of what they think is happening on the molecular level.

In the second part of the investigation, the students will measure pressure within sealed flask containing carbonated soda. The emphasis on this part of the lab is getting students to think about what is happening within the soda in the space above the soda when the flask is shaken. Students are asked to think about this and to create representations based on what they think is happening. They should begin to think about a pressure equilibrium between the liquid and the gas above the liquid and also that this equilibrium is *dynamic* in nature – CO_2 molecules are continually moving in and out of solution but maintaining an aggregate balance in pressure. Students should notice that when they shake the flask the soda starts to fizz and the pressure in the container increases. Once they let it sit for a minute, the bubbles die down but the pressure remains constant – it appears that the environment inside the flask is static. This is the point where students may need help (a probing question or two) to think that even though they can't see anything happening, could there be something happening and, if so, what that might be. Again, students are pushed to represent their thinking here in the form of drawings, diagrams, graphs, etc.

For the third part of the lab, students put room temperature oxygenated water into the flask, seal the flask, and then place it in an ice bath. Here they have the opportunity to see that the pressure inside the flask will decrease due to the cooler water being able to capture more oxygen molecules from the space above the liquid. Again they are encouraged to think about what is happening above the liquid and within the liquid, and to represent their ideas. As in the first part of the experiment, the emphasis is on the dynamic equilibrium that is taking place within the flask.

Prior to doing this lab, it would be helpful to discuss both the idea of pressure and the idea of equilibrium in nature (this discussion can certainly take place prior to this lab or any of the earlier labs.) This can take the form of a short class discussion the day before or the day of the lab (depending on your class lengths) or can be made into a handout the students review as homework prior to the lab. Most students will have knowledge of pressure since it is typically introduced early on in the chemistry sequence. Some students will most likely be familiar with the idea of equilibrium, but may think of it in a limited way or only in a limited set of situations, such as equilibrium as applied to chemical reactions.

After students complete the pressure and solubility lab, the next activity (as homework) is "Henry's Law"

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and to refer to during the laboratory.

Materials

Flask with tube and stopper	Carbonated water or soda
400mL Beaker	Tray for ice bath
De-ionized water	Ice
Pressure sensor, interface, and computer	

Procedure

Part A – Measuring Pressure

Before you start setting your investigation up and collecting data, there are a few preliminary questions to answer that will help in thinking about the investigation.

- If you connect the pressure sensor to the computer and start collecting data without the sensor's pressure port attached to anything, what reading would you expect to get? In other words, what pressure will the graph show if the pressure sensor is simply exposed to the outside air? Why do you think so?

For this question, create a drawing with annotations.

- What is pressure and what does it "look like" at the molecular level? In other words, explain pressure at the molecular level by creating a drawing and including notes on the drawing to help explain your ideas.

Begin the investigation:

1. Locate the syringe and the pressure sensor.
2. Set the syringe to a position such as 15cc.
3. Connect the syringe to the pressure port connector on the sensor
4. Open the pressure investigation template on the computer.
5. Click on the 'start' button to begin collecting data
6. Take data as you change the volume, beginning with a volume that is greater than your beginning volume. For example, move the syringe to 20cc.
7. Continue to take data as you decrease the volume to 15cc and below.
8. Experiment with how quickly you can make the pressure change, what the maximum pressure you can create, etc.

Part B – Changing Pressure While Holding Temperature and Volume Constant

1. Attach pressure sensor to tubing coming off of flask.
2. Fill flask with 150mL of carbonated soda.
3. Run tubing from flask over stand, so as to create a high point in the tubing.
4. Click on the "start" button on the computer screen.
5. Place the stopper on flask and press on it firmly to create a good seal. Take notice if the pressure starts to change as soon as the stopper is on the flask.
6. Lift the flask and shake it. Make note of what happens in the flask and on the computer readout. Be careful not to let any of the liquid go into the tubing.
7. Once you have shaken the flask for about 10 seconds, set the flask down. Record your observations. Also make note of what the computer reading shows.
8. Very important - pay particular attention to the space above the liquid inside the flask. Create molecular-level drawings to answer these questions: What do you see? What do you think is there?
9. Does the pressure sensor provide any information about if there is or is not something there?

10. Make a detailed drawing of what you think is going on at the microscopic level. Make sure you include in your drawing both the solution and the space above the solution.
11. What does shaking the flask do? What does this have to do with pressure?

Part C – Measuring the Effects of Temperature on Pressure

1. Take stopper out of flask. Empty and rinse the flask.
2. In a beaker, pour 100mL of de-ionized water.
3. Prepare an ice bath large enough for the flask to be placed in. Make sure the bath is deep enough so the flask can sit at least 10mm into it.
4. Pour water into flask. Seal immediately.
5. Press "start" on the computer interface to start the pressure sensor running. Make note of the pressure and anything you observe within the flask.
6. Now place the flask into the ice bath.
7. Observe the flask and monitor the pressure. Record all observations.
8. Very important - pay particular attention to the space above the liquid inside the flask. Create molecular-level drawings to answer these questions: What do you see? What do you think is there?
9. Does the pressure sensor provide any information about if there is or is not something there?
10. Make a detailed drawing of what you think is going on at the microscopic level. Make sure you include in your drawing both the solution and the space above the solution.

Homework - Henry's Law Activity

Purpose

Students attempt to develop their own version of Henry's Law[1] to provide an additional learning situation for understanding solubility and equilibrium.

Background Discussion

In order for students to develop Henry's Law on their own, these questions might be helpful:

1. How are the gas molecules moving in comparison to those of the liquid?
2. Will some of these gas molecules escape from the liquid?
3. Will some of the gas molecules be returning to the liquid if the container is closed?
4. If there is no change in temperature but there is more gas above the liquid, will more gas dissolve? And if there is less gas will less dissolve?

Students should attempt to write out a sentence that states their ideas. As a student writes the law, she or he gets to put her or his name on it; the student/class should then use it that way. Later, the students can be told that in the chemistry books the credit for the law will be given to "Henry."

Students then need to think of other examples of their law. For instance, when fish breathe in oxygen gas, more gas will dissolve to replace the used-up O_2.

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[1] Henry's law – When the partial pressure of the gas over the solution increase, the concentration of the dissolved gas also increases according to the relationship $c = kP$, where c is concentration, P is partial pressure, and k is a constant characteristic of temperature and the gas-liquid system. (From *Chemistry*, 2nd Ed., Raymond Chang, l984.)

Part 5 (approximately 45 minutes)

Particle Nature of Solubility Activity

Purpose

Students represent the particle nature of a silution using the ideas of chemical equilibrium to provide a deeper understanding of the particle nature of solubility.

Background Discussion

To further student understanding of equilibrium, it should be noted that the examples to this point have been describing physical equilibrium systems. In order to expand this topic, a chemical system can be demonstrated using the equilibrium system of

$$2NO_2(g) \leftrightarrow N_2O_2(g)$$

[These demonstration tubes are available from Flinn Scientific Co. (AP 8476) for $48.15]
The advantage of these tubes is that they show a color change as the temperature changes. Students can be asked to explain the process as it changes from one color to the other.

After the students have had experience with this chemical equilibrium system, the teacher can bring the discussion back to the soda can and help students understand that what is actually occurring inside the unopened soda can is a chemical equilibrium system (also can be called a "weak acid".) Using their previously developed (possibly named) "Amy's Law," students can be asked to predict all the effects when this system is subjected to the stress of less pressure as when a can of soda is opened at the atomospheric pressure at sea level. This would also be an appropriate place to review the concepts of ***Aggregation*** and ***Concentration*** and as well as the concept of ***Connectivity***.

Procedure

Using **ChemSense,** students should once again represent the particle nature of the solution inside a soda can using the ideas of chemical equilibrium. There also needs to be a brief discussion (perhaps a homework reading) that gives a simple explanation that the pH of a solution is an indication of the concentration of H^+ in that solution.

Part 6 (approximately 45 minutes)

Lab 5 - Student Led Investigation of Solubility, Concentration, and Saturation

Purpose

To explore different aspects of solubility through use of everyday substances and compare the behavior of dissolved gases to dissolved solids. Here students will be able to compare the behavior of solids as they are dissolved in a liquid to the behavior of gases dissolved in a liquid as previously studied.

Background Discussion

In this lab, students are asked to predict how much KoolAid they think can be dissolved in a beaker of water. Since they are in charge of designing their experiment, this initial question is intentionally kept vague – no quantities are specified. In designing their experiment, they need to determine what relevant questions/constraints need to be determined. For example, students need to determine how much water they are going to work with and how much the "increments" of KoolAid need to be.

In addition to the "driving" question of how much KoolAid can be dissolved in water, students need to think about and answer additional, related questions:

1. Will there be a point at which the powder stops dissolving? If so, how will you be able to tell?
2. Thinking back on your experiments with gases, was there a limit to how much gas you could put into the water? How could you tell?
3. What will happen to the color of the KoolAid as more and more is put into solution?
4. What factors might affect the solubility of KoolAid in water, including the saturation point?

During this investigation, the students should keep the behavior of gas in mind while they now turn their attention to solid materials dissolving in water. With their predictions they need to draw pictures of what it might look like at the molecular level as more and more KoolAid powder is added to water.

Since the students are in charge of coming up with a lab experiment to test their predictions, they should be encouraged to try variations on their experiments to confirm their findings. For example, students should be encouraged to consider the effects of different variables, such as temperature and pressure, on the solubility of the KoolAid. They could also run a controlled experiment on the effect of stirring on solubility as an additional extension.

Students will write the purpose, hypothesis, and procedure for this lab. They should also prepare data charts that they think might be necessary to organized their data. Their analyis should include a discussion about their design as it related to the hypothesis. The students also need address what they would do differently if they were able to do it again.

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and refer to during the laboratory.

Procedure

Students use the ChemSense Portfolio tool to design their lab. Their lab might be outlined in several sections: "place to state goals and purpose," "equipment list" (icon for specific type of piece of equipment), "chemicals needed," "procedure," "hypothesis of the outcome," "place to record observatons and data." An "outcome section" should also be included so that they have a place to explain which results in the experiment were expected and which were not. This section can also include their discussion on ways to improve the experiment.

Part 7 (approximately 45 minutes)

Lab 6 – Determining Concentration and Saturation with a Colorimeter

Purpose
To study the relationship of concentration and absorption using a colorimeter.

Background Discussion
In this investigation, students use a "colorimeter", a device that passes four different wavelengths of light through a sample and determines the absorbance (or transmittance) percentage of each. Students use this device as another way to think about and measure the solubility and concentration of a solution.

To begin this lab, students make up several solutions of colored KoolAid and make predictions about how much light of the different colors (red, orange, green, and blue) might pass through each. They then sse the colorimeter to test the levels of different colored lights that actually do pass through each solution, starting with a pure vial of de-ionized water. They are asked to draw some initial pictures of what they "see" happening for at least two of the solutions they made.

Once they have been able to test some of their solutions, they will be handed a vial with an unknown KoolAid concentration in it. They then design and conduct an experiment to determine the unknown concentration.

The following is a brief outline of the student lab. Please see appendix A for the complete student lab. The labs in Appendix A are intended to be handouts for students to read before and refer to during the laboratory.

Materials
Colorimeter BeakersKoolAid Deionized water Empty vials

Procedure
1. Make a "saturated" KoolAid solution in a beaker using 200mL of deionized water.
2. Pour 100mL of this solution into a second beaker. Dilute this second solution with deionized water until you have 200mL of solution.
3. Pour 100mL of this solution into a third beaker. Dilute this third solution with deionized water until you have 200mL of solution.
4. Compare these three solutions noting similarities and differences.
5. Draw pictures of the solutions at a molecular level. What can you infer about the proportion of KoolAid molecules in each with relation to the amount of water? How would you compare the total number of KoolAid molecules in each beaker?
6. Predict the results of the colorimeter readings.
7. Take the colorimeter readings of the solutions (calibrating with de-ionized water).
8. Does the data support your predictions?
9. Students are now given an unknown concentration of KoolAid solution. Students are to figure out the concentration of the solution.

Part 8 (approximately 45 minutes)

Additional supporting activities to be conducted if time permits:

"Real World" Activity. Students view "real world" examples of solubility phenomena.

<u>Purpose</u>
To provide students with multiple, real-life instances to help them develop a deeper understanding of "solubility."

<u>Background Discussion.</u>
Students are encouraged extend their understanding of solubility through additional instances such as scuba diving and Lake Nyos, Cameroon. While viewing, the students can be asked to consider the following questions:

- Why doesn't "the Bends" occur at sea level conditions? In other words, what factor(s) are "making" more gas dissolve in the liquid?
- Why doesn't CO_2 collect in all types of bodies of water? In other words, what factor(s) allow for all the gas to stay dissolved in this particular lake?
- In general, what is else is happening in an unopened can of soda?

The students should now be able to represent the particle nature of each of these situations. To check for understanding, these representations can be compared to the ones they had previously made.

Marshmallow Activity. Students create a human simulation of equilibrium through the tossing of marshmallows

<u>Purpose</u>
To develop further understanding of the concept of equilibrium.

<u>Background Discussion</u>
We will study the chemical reaction A $\leftrightarrow$ B to determine when the reaction is complete. At this point the term "equilibrium" can now be applied to these systems.

<u>Materials and Procedure</u>
Four bags of marshmallows are needed for this activity. Divide the class into two groups, team "A" and team "B," and assign each one side of the room. Team A will open the marshmallow bags and count the number of "particles."

The game works as follows: The reaction is defined as the physical location of the marshmallow. If it is on Team A's side of the room, the marshmallow is A. If the marshmallow resides on team B's side of the room, it is said to be a B. The reaction proceeds by students throwing the marshmallows to the other side of the room. The teacher allows the reaction to proceed for about 1 minute and calls stop. Each side picks up the marshmallows and counts them. This is the data.

<u>Rules</u>
- Students may only throw one marshmallow at a time.
- There are no viscous throws – throws that are hard and/or aimed at someone.

- All throwing must stop when the teacher calls “stop.”
- Breaking any of the rules means removal from the game.
- Play proceeds for several rounds (7 - 10).

Analysis

After graphing the data, the teacher should discuss with the class the shape of the curve and what that means. The teacher should also ask the following (or related) questions to help facilitate understanding:

- What would happen if 5 new students were assigned to Team B?
- What if 4 students from Team A were called to the office?
- What if all of Team A was given caffeine?
- What if I changed the rules about throwing so all the throws were backward (you couldn’t face the direction of your throw)?

These questions can be answered in ChemSense or as homework. They should also be able to define equilibrium, recognize a stress on the system and predict the equilibrium shift of some stresses.

Appendix A – Student Handouts

Investigation 1: Making “Oxygenated” Water

Purpose

To understand the chemical processes that occur as a gas (oxygen) is dissolved into a liquid (de-ionized water.)

Background Discussion and Ideas to Think About

Many gases mix easily with water to make a liquid solution. When a gas such as oxygen is mixed with a liquid such as water, a *solution* is created. The combining of the gas and the liquid make a solution where the gas molecules are dispersed throughout the liquid. An example of this process is “oxygenated” water in a fish tank. The water in a fish tank has a continual supply of air. The air is pumped into the tank using a small air pump that sits outside of the tank. As the fish swim though the water, the water passes though their gills and various gas molecules from the air that were mixed into the water are pulled out and used by the fish. Thus, the different molecules that make up air are continually dissolved into the water and continually pulled out.

In this investigation you will make a solution by mixing a gas into a liquid. The gas you will be pumping into the water is air. Air is a mixture of several gases, among which is oxygen. The water you will be using is de-ionized water, which is basically water that has had ions removed from it (it is purer than regular tap water). You will use a “dissolved oxygen” sensor to detect the amount of oxygen that you have mixed into the water.

The focus of this investigation is on understanding what is happening at a *nanoscopic* level in the water as you mix oxygen into it. By *nanoscopic* level we are referring to what things would look like if you could see the individual water and oxygen molecules. Do the water molecules and the oxygen molecules stick together or bounce off of each other? Are there more water molecules than oxygen molecules in the solution? Is there space between the different molecules and, if so, what is in that space? These are some of the questions we can answer if we begin to think about things at a *nanoscopic* level. The word nanoscopic means being able to “see” objects that are around 10^{-9} meters across – much smaller than can be seen with a standard microscope. We will be asking you throughout the various investigations to make observations and to think and draw what might be happening at the nanonscopic level.

Before you begin this investigation, each person in your group needs to do two things:

- using pictures and words, predict what you think you will see when you bubble air through water
- using pictures and words, predict what you think may be happening at the nanoscopic level as you bubble air through water

Each person should record their predictions in their lab books. Make sure you label the page with your name, date, and Lab 1. Once each person has done their predictions, the group needs to agree on which ones best predict what will happen. Once you’ve come to an agreement, your group should now take the best predictions and recreate them using the ChemSense drawing tool on the computer. Using this tool you can draw, annotate, and even animate your explanations. Feel free to check out what the tools can do. Once you are finished, save your work and start the investigation.

Materials

Large Beaker	Supply of de-ionized water	Stirring rod
Air pump with tubing	Support stand and clamps	
Dissolved oxygen sensor	Computer and Pasco interface box	

Procedure

1. Pour 500 mL of de-ionized water into the beaker
2. Using the support stand to hold the dissolved oxygen sensor, submerge the probe 3/4 of the way into the water. Make sure it is not touching the bottom or side of the beaker.
3. Let the probe get adjusted to the water by stirring the water for about thirty seconds.

4. Place the end of the air pump tubing into the water.
5. On the computer, open up the template that says “Lab 1”
6. Locate the “start” button on the computer screen, but do not click on it yet
7. Before you start running your experiment, think about what data you will be collecting. What does the probe you are using measure? What will you see happening on the computer once you plug the air pump in and start collecting data? When should you stop collecting data? How will you know? Make sure your group has discussed and answered all of these questions before you move to step 8.
8. You are now ready to start collecting data. First, press the “start” button on the computer. Next, plug in the air pump. This will make it so the computer starts the dissolved oxygen sensor at the same time air starts passing through the water.
9. Continue collecting data until you have reached your group’s approved ending time.
10. Now that you have run the experiment once, how can the data you collected help confirm or disconfirm your predictions? In other words, how does the data you collected provide insight into what might be happening at the nanoscopic level? Discuss this issue in your group and, using pictures and words, explain the connection between the data and your group’s predictions. Record this using the ChemSense drawing tool.
11. Now, run the investigation a second time. You do not need to predict again what you think is happening, but you can alter your procedure if you think of a different way to collect the data so it fits your earlier predictions better. In other words, if you think you can explain your predictions better by changing part of the procedure, feel free to do so. If you have questions, you can check with one of the researchers.
12. For the second run of the investigation, make sure you note in your lab book any alterations you made to procedure and record the data you collect. Also, make note of the following in you lab book as well:
    1. Does your second run of the investigation better confirm you predictions? Why or why not?
    2. Was your data similar to the data you got the first time? Why do you think so?
    3. As a group, write down two questions you have regarding gases dissolved in liquids.

Investigation 1 1/2 – Solutes and Solvents

Purpose
To explore how materials mix to make solutions.

Background Discussion and Ideas to think About
Now that you have completed an investigation into making a solution, it is important to discuss some of the terms that will be used when discussing solubility. We use the term *soluable* to refer to the capability of a substance to be dissolved – "Sugar is *soluble* in water" or "Koolaid is *soluble* in water." If a substance is not *soluble*, we say it is *insoluble*. For example, water is *insoluble* in oil.

When one substance is soluble in another, the resulting mixture is called a *solution*. Using sugar dissolved in water, the sugar molecules are dispersed throughout the liquid water. Even though the water now has sugar molecules mixed in it, the properties of the sugar-water solution are still liquid-like. For example, the sugar-water solution takes the shape of the container it is in and you can still pour the solution. However, the properties of the sugar-water solution are not identical to the properties of the original water. If, for example, you heated the solution you would find that it now has a different boiling temperature. You would also find that it freezes at a different temperature as well. If you shine light through it, the solution may look slightly different from just the water. Even though a gas may be dissolved into a liquid, once the gas is in solution we do not really consider it to be a gas any more. Rather, we would say the gas molecules are now mixed throughout the liquid. Using oxygen mixed with water as an example, we would say that we now have O_2 molecules dispersed throughout the H_2O molecules in the container.

Two more definitions **-** we call the substance being dissolved the *solute*, and we call the medium the solute is being dissolved into the *solvent.* For example, if we are talking about sugar mixed into water, the sugar is the *solute* and the water is the *solvent*.

These five terms – soluble, insoluble, solution, solute, and solvent – are helpful terms used when discussing solubility. This section can be referred back to for reference.

It is important to visualize what happens at the nanoscopic level when a solute is added to a solvent. What do the molecules of the solute do immediately upon entering the solvent? What happens over time if we watch the solute and solvent interact? What happens if we stir the solution? In the following investigation you will look closely at the interaction between solutes and solvents and try to predict what you think is happening at the nanoscopic level when the solute is added to the solvent.

Investigation **–** Determining what happens when a solute is added to a solvent. In this investigation you will be using food coloring, Koolaid, and water to help you get a sense of what might be happening on the molecular level when a solute is added to a solvent. You may have had experience using food coloring before while cooking and know about some of its properties or you may be familiar with making Koolaid. If not, that's O.K. This investigation is for you to explore.

Materials
Assorted beakers	4 Color box of food coloring	Deionized water
Unsweetened Koolaid	Stirring rod	Colored pencils

Procedure
Use the beakers, water, food coloring, and Koolaid to explore the effects of adding a solute to water (solvent). You may use any amounts of water and any colors to experiment with. The main question that you are trying to answer is: "What is happening on a molecular level when I add the solute to the solvent?" Use your notebook to draw two types of pictures: a) what you observe happening in the beaker when the solute is added, and b) what you think is happening at the molecular level when the solute is added to the water. Make sure you add notes to your picture (annotations) to help explain what is going on. It is also

important to have pictures that show what is happening over time. A good way to do this is to draw several boxes in a row that you can fill in with pictures to show how things change over time.

Repeat the investigation at least four times, using any combination of materials you want. In some cases try adding the solute without stirring and observe what happens. Each time you do the investigation, make sure you draw a) what you observe, and b) what you think is happening at the nanoscopic level between the solute molecules (food coloring, Koolaid) and the solvent molecules (water.) The important thing is that you take the time to make as detailed pictures as possible. Along with your drawings, please answer the following questions in your notebook:

- what do you think makes the solute molecules spread throughout the liquid? Are there molecules that are spreading that you cannot see?
- At what point do the solute molecules appear to stop spreading?
- What are some things that you can do to increase or decrease how fast the solute molecules move through the water?
- what do you think is happening in the solvent (water) before you add the solute? Would heating the water change what you think is going on before the solute is added?

Now that you have made your individual drawings and explanations, choose one from all of the group members that best explains what is happening at a nanoscopic level when a solute is added to a solvent. Using the ChemSense drawing tools on the computer, create either a detailed picture or an animation of your group's choice. Make sure you save your work.

Homework

Homework for this evening is a short handout (2 pages) on the *molecular theory* explaining why and how solutes disperse throughout solvents. Make sure you answer the questions on the handout and be prepared to turn the handout in during the next class.

Investigation 2: Saturation vs. Temperature

Purpose

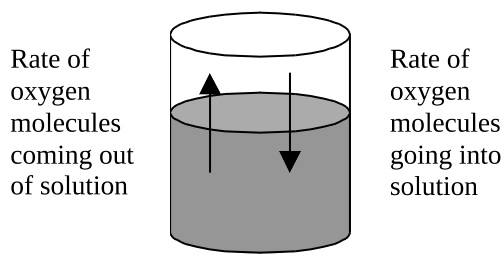
To determine the relationship between water temperature and the amount of oxygen it can hold.

Background Discussion

When you add a teaspoon of sugar to a cup of hot coffee and stir it, you can easily dissolve all of the sugar. If you add another teaspoon, you can usually get that to dissolve too. What would happen if you tried to add 10 teaspoons of sugar to your coffee? When you dissolve one substance into another, you will eventually reach a point when you can not add any more. This point is called *saturation*. A solution that is not able to hold any more of a substance is called a *saturated solution*.

There are many factors that influence how much of one substance can be dissolved into another. In this investigation you are going to investigate how temperature affects saturation. Instead of adding sugar to coffee, you are going to continually add oxygen to water while you raise the temperature of the water. Using the dissolved oxygen sensor you used before, you will monitor the amount of dissolved oxygen as the water is heated. You will use a temperature sensor keep track of temperature changes. The oxygen will be supplied by pumping air through a sample of de-ionized water.

Another focus of this investigation is on the idea of *equilibrium*. In this investigation, the term equilibrium refers to the rate in which oxygen is dissolved into the water compared to the rate in which the oxygen comes out of the water. If these two rates are the same, we say the system is in equilibrium. The following picture helps to explain this idea.



The rate of oxygen molecules going into solution (the down arrow on the right) is due to how fast oxygen is pumped into the water using the air pump. The rate of oxygen molecules coming out of solution is due to how fast oxygen molecules in the solution randomly pass through the surface of the water and into the air above the water. When these two rates are the same, we say the system (the beaker and water) is in equilibrium. When these rates are not the same, say when we are adding oxygen to the water faster than it can leave the water, we say the system is not in equilibrium. When the solution has hit the maximum amount of oxygen it can hold, the oxygen that is leaving the water leaves room in the water for more oxygen to be added. This room is immediately filled up by the oxygen we are pumping into the water. What do you think happens to the equilibrium when we turn the pump off and let the oxygen-water solution sit for awhile?

Before you begin the investigation, write down your predictions about what will happen to the solubility of the oxygen as you heat the saturated solution. Do you think more, less, or the same amount of oxygen can be dissolved in the water when it is heated? Why? Also, draw what you think is occuring at the nanoscopic level as the solution is heated. Include on your drawing if and when equilibrium might be occuring (you can use arrows and annotations to highlight this.)

Materials

Large Beaker	Hot plate	Supply of de-ionized water
Support stand and clamps	Stirring rod	Air pump with tubing
Dissolved oxygen sensor	Temperature sensor	Pasco interface and computer

Procedure

1. Pour 500 mL of de-ionized water into the beaker.
2. Set the beaker on the hot plate. Do not turn the hot plate on yet.
3. Using the support stand to hold the dissolved oxygen sensor, submerge the sensor 3/4 of the way into the water. Make sure it is not touching the bottom or side of the beaker. Do the same with the temperature sensor.
4. Place the end of the air pump tubing into the water and turn the pump on. Let the pump run for about a minute and let the sensors get adjusted to the water by stirring the water for about one minute.
5. **Important:** Check to make sure none of the wires or the air pump tubing are touching the hot plate anywhere.
6. On the computer, open up the template for your group.
7. Locate the "start" button on the computer screen.
8. Before you start running your experiment, think about what data you will be collecting. What do the probes you are using measure? What will you see happening on the computer once you start collecting data? When should you stop collecting data? How will you know? Make sure your group has discussed and answered all of these questions before you move to the next step.
9. **Important**: Since the dissolved oxygen sensor is very sensitive to temperature, do not allow the temperature of your solution to go above $50^{O}C$ while the dissolved oxygen sensor is in the solution. The temperature sensor is rated to about $105^{O}C$.
10. You are now ready to start collecting data. To do this accurately, press the "start" button on the computer at the same time that you turn the hot plate to "high" (or "10" on some hotplates). This will make it so the computer starts the temperature and dissolved oxygen sensors at the same time the hot plate starts heating the water.
11. Now that you have run the experiment once, how can the data you collected help confirm or disconfirm your predictions? In other words, how does the data you collected provide insight into what might be happening at the nanoscopic level? Discuss this issue in your group and, using pictures and words, explain the connection between the data and your group's predictions. Record this using the ChemSense drawing tool.
12. Now that you have run the experiment once, how can the data you collected help confirm or disconfirm your predictions? In other words, how does the data you collected provide insight into what might be happening at the nanoscopic level? Discuss this issue in your group and, using pictures and words, explain the connection between the data and your group's predictions. Record this using the ChemSense drawing tool.
13. Now, run the investigation a second time. You do not need to predict again what you think is happening, but you can alter your procedure if you think of a different way to collect the data so it fits your earlier predictions better. In other words, if you think you can explain your predictions better by changing part of the procedure, feel free to do so. If you have questions, you can check with one of the researchers.
14. For the second run of the investigation, make sure you note in your lab book any alterations you made to procedure and record the data you collect. Also, make note of the following in you lab book as well:
15. Does your second run of the investigation better confirm you predictions? Why or why not?
16. Was your data similar to the data you got the first time? Why do you think so?
17. As a group, write down two questions you have regarding the effects of temperature on solubility. For instance, one question might be about something that you still do not understand and would like to test by running an additional experiment.

Lab 3: Making Carbonated Water

Purpose

To create a solution of carbon dioxide and water.

Background Discussion

Carbonated sodas such as Calistoga and Sprite have the interesting property of "fizzyness". If you have ever opened a can or bottle of soda and poured it into a glass, you may have noticed bubbles coming from different parts of the liquid that seem to form out of nowhere. In this investigation you will have the opportunity to create your own carbonated water

Carbonated water is a solution of carbon dioxide (CO_2) and water. Similar to creating a saturated solution of oxygen and water that you made earlier, carbonated water is also a gaseous solute (oxygen) dissolved in a liquid solvent (water.) To actually make carbonated water you need a source of carbon dioxide that can be bubbled into the water. The source that will be used is frozen carbon dioxide or "dry ice". Dry ice is the solid form of gaseous carbon dioxide and is very cold. It has the unique feature of going from the solid phase to the gaseous phase when it is heated. In other words, it skips going the liquid phase. Since frozen carbon dioxide is extremely cold, it doesn't take much to heat it – letting it sit out on the table or in a beaker full of room temperature water is enough to rapidly change the solid to a gas.

You will bubble the CO_2 into the water using a carbon dioxide "pump". Instead of having a fish tank pump, you will use a sealed flask with a piece of dry ice in it and a tube coming out of the side of it. As the dry ice goes from the solid to the gas phase, pressure builds up in the flask and pushes the CO_2 out. You will place the end of the tube into a beaker filled with de-ionized water and let the CO_2 bubble through the water.

You will use a pH sensor to detect how much CO_2 has gone into solution and when the solution is finally saturated. In this investigation, the pH sensor is used as an indirect way to measure dissolved CO_2. In the process of making carbonated water, CO_2 gas combines with H_2O to form carbonic acid, H_2CO_3:

$$H_2O\ (l) + CO_2\ (g) \text{ -----> } H_2CO_3\ (aq)$$

The amount of H_2CO_3 is detected by measuring the pH of the solution since H_2CO_3 in water is considered an acid. The pH sensor measures how acidic a solution is. By using the pH sensor in this investigation, you are able to detect how much carbon dioxide is in the solution. Remember, the lower the pH, the more acidic the solution is. Therefore, as the pH goes down you know there is more carbon dioxide in the solution.

Before you begin this investigation, your group needs to do two things:

- using pictures and words, predict what you think you will see when you bubble carbon dioxide through water. While one person works on creating the drawings in the lab book, the other lab partner(s) should use the ChemSense tools to construct similar drawings on the computer.
- using pictures and words, predict what you think may be happening at the nanoscopic level as you bubble carbon dioxide through water. Do you think the carbon dioxide molecules will interact with the water molecules? Why or why not?

Since your drawings and animations at the nanoscopic level are an important part of this lab (and the other ChemSense labs) make sure you do a good job on these.

Materials

Large Beaker	Stirring rod	Supply of de-ionized water
Support stand and clamps	Gloves	Dry ice
pH sensor, Pasco interface and computer	Goggles	Flask, stopper, and tubing

It is important that you wear you goggles at all times during this lab. Make sure you wear gloves while handling the dry ice – contact with even a small piece of can cause burns.

Procedure

1. Pour 500 mL of de-ionized water into the beaker.
2. Using the support stand to hold the pH sensor, submerge the sensor 3/4 of the way into the water. Remember to take the storage bottle off the end of the sensor before you put it in the water. Also, make sure the pH sensor is not touching the bottom or side of the beaker. Let the sensor get adjusted to the water by stirring the water for about one minute.
3. Locate the flask and make sure the tubing is connected to it.
4. Pour about 50 mL of water into the flask.
5. Raise your hand for a piece of dry ice – we will break a piece off that will fit through the mouth of the flask.
6. Put the dry ice into the flask and put the stopper on it. Make sure the stopper is tight.
7. You now have a carbon dioxide "pump" – carbon dioxide should be flowing out of the end of the tube. If it is not, check to see if the tubing is connected tightly.
8. On the computer, open up the Pasco template for your group.
9. Before you start running your experiment, think about what data you will be collecting. What does the probe you are using measure? What will you see happening on the computer once you start pumping carbon dioxide through the water and start collecting data? When should you stop collecting data? How will you know? Make sure your group has discussed and answered all of these questions before you move to step 10.
10. You are now ready to start collecting data. Press the "start" button on the computer. Next, place the tube from the CO_2 pump into the water. This will make it so the computer starts the pH sensor in the water without the carbon dioxide, and then starts the measure the water with carbon dioxide in it.
11. Now that you have run the experiment once, how can the data you collected help confirm or disconfirm your predictions? In other words, how does the data you collected provide insight into what might be happening at the nanoscopic level? Discuss this issue in your group and, using pictures and words, explain the connection between the data and your group's predictions. Record this using the ChemSense drawing tool.
12. Now, run the investigation a second time. You do not need to predict again what you think is happening, but you can alter your procedure if you think of a different way to collect the data so it fits your earlier predictions better. In other words, if you think you can explain your predictions better by changing part of the procedure, feel free to do so. If you have questions, you can check with one of the researchers.
13. For the second run of the investigation, make sure you note in your lab book any alterations you made to procedure and record the data you collect. Also, make note of the following in you lab book as well:
    - Does your second run of the investigation better confirm you predictions? Why or why not?
    - Was your data similar to the data you got the first time? Why do you think so?

Now that you have the first three ChemSense experiments, write a summary paragraph about how the three experiments relate to each other. Make sure your paragraph is long enough to capture the essential ideas in each lab and how they relate, but short enough to straight to the point. Use the ChemSense text tool to type your paragraph.

If you have time left over at the end of this investigation use it to work on your presentation. This is good time to make a list of all the images you have worked with, what the main themes of each lab have been, what ideas you think are important to be included in a presentation on "solubility," etc.

Investigation 4: The Effect of Pressure on Solubility

Purpose

To understand “pressure” and demonstrate the effect of pressure on the solubility of a gas dissolved in a liquid.

Background Discussion

In the previous experiments you have created solutions and, in some cases, ran experiments on the effect of temperature on solutions. In this experiment you will be investigating the **effect of pressure on a solution**. You will use a new sensor – a pressure sensor – to measure pressure in a sealed container. If the pressure sensor is not attached to a container, it will read the air pressure in Mr. Abram's classroom. Once you attach it to a container, it will measure the pressure of the *gas* in the container.

This investigation has three parts to it, each of which is a slightly different experiment. The main emphasis in Part 1 is to think about what pressure is at the nanoscopic level – what is it and why does it change. In Parts 2 and 3, the main emphasis is on what is happening at the nanoscopic level between the solution and the space right above the solution. What are the dissolved particles in the solution doing while sitting inside the container? What is in the space above the solution? How does equilibrium apply to what's going on in the container?

Before you start setting up your investigations, there are a few preliminary questions to answer that will help in thinking about the investigation. *Make sure you label in your notebook "Lab 4, Section A". Write each of these questions in your lab book and answer them:*

1. If you connect the pressure sensor to the computer and start collecting data without the sensor attached to anything, what reading would you expect to get? In other words, what pressure will the computer show if the pressure sensor is simply exposed to the outside air? What is this pressure due to?

2. For this question, create a drawing showing the molecules in a container of carbon dioxide gas. Using annotations, explain what pressure is and what it “looks like” at the nanoscopic level? In other words, explain what you think pressure is by creating a nanoscopic level drawing (a drawing showing molecules) and annotating your drawing to explain your ideas.

3. Using pictures and words, explain the concept of "equilibrium".

Materials for all three parts of the lab

Flask with tube and stopper	Carbonated water or soda	Ice
Large Beaker	Tray for ice bath	Pasco syringe
De-ionized water	Pressure sensor, interface, and computer	

Part A – Measuring Pressure

In this section you will set up and practice using the pressure sensor.

Procedure:

1. Locate the syringe and the pressure sensor. The pressure sensor is the small black box with writing on the side of it.
2. Set the syringe to about the15cc level.

3. Connect the syringe to the pressure port connector on the sensor
4. Open the pressure investigation template on the computer - it should say "Lab 4" and your period.
5. Start collecting data.
6. While the data collection software is running, change the volume of the syringe and watch the reading on the computer change. Begin with a volume that is greater than your beginning volume. For example, move the syringe to 20cc.
7. Continue to take data as you decrease the volume to 15cc and below.
8. Experiment with how quickly you can make the pressure change, what the maximum pressure you can create is, etc.

Do the following in your notebook:

- Record a) the highest pressure you could achieve and b) the lowest pressure.
- Draw two large syringes. Make the first syringe have the stopper pulled almost all of the way out. In the second drawing, make the stopper pushed almost all of the way in (leave at least a little space). On each drawing show what the gas molecules are doing in the syringe. Assume you have the same number of molecules in each syringe. Make sure you note on each drawing why pressure exists inside the syringe. In other words, what is pressure a measure of?

Part B – Changing Pressure While Holding Temperature and Volume Constant

In this section you will measure the pressure of carbonated water in a sealed container. Since you will not be changing the temperature of the container nor will you change the volume of the container, we say it is at constant temperature and volume.

Procedure:

1. Attach pressure sensor to tubing coming off of flask.
2. Fill flask with 150mL of carbonated soda. Do not put the stopper on the flask yet.
3. Run tubing from flask over stand, so as to create a high point in the tubing. Since the pressure sensor can be damaged by liquid getting into it, you need to keep the soda from going from the flask into the tube, and down the tube into the pressure sensor.
4. Start collecting data. You should notice that the time has started running and that there should be some pressure reading (around 101 kPa, which is roughly atmospheric pressure).
5. Place the stopper on flask and press on it firmly to create a good seal. Note in your lab book the pressure. Look to see if the pressure starts to change as soon as the stopper is on the flask.
6. Lift the flask and shake it. Make note of what happens in the flask and on the computer readout. Be careful not to let any of the liquid go into the tubing.
7. Once you have shaken the flask for about 10 seconds, set the flask down. Make note in your lab book of the pressure right when you stop shaking the flask and after you let it sit for 30 seconds.
8. **Very important - pay particular attention to the space above the liquid inside the flask**. In your lab book create a nonoscopic-level drawing of the molecules in the flask, both in the liquid and above the liquid.

Answer the following questions in your lab book:

- Does the pressure sensor provide any information about if there is or is not something in the space above the liquid?
- Using pictures and words, explain what shaking the flask does to the molecules inside the flask? What does this have to do with pressure?
- Using pictures and words, explain how "equilibrium" applies to what is happening inside the flask.

Part C – Measuring the Effects of Temperature on Pressure

In this part of the investigation you will hold volume constant and measure the effect of temperature on pressure. In your lab book make the following prediction. Make sure you take your time to answer this question - it is important.

- What do you think will happen to pressure if you cool a solution in sealed flask? Why do you think so?

Procedure:

1. Take stopper out of flask. Empty and rinse the flask.
2. In a beaker, pour 100mL of de-ionized water.
3. Fill the tub at your station with ice and water to create an ice bath large enough for the flask to be placed in. Make sure the bath is deep enough so the flask can sit at least 10mm into it.
4. Pour water into flask. Seal immediately.
5. Start the pressure sensor running. Make note in your lab book of a) the pressure and b) anything happening within the flask.
6. Now place the flask into the ice bath.
7. Observe the flask and monitor the pressure. Record all observations in your notebook.

Do the following in your lab book:

- Pay particular attention to the space above the liquid inside the flask. In your lab book, create a nanoscopic-level drawing showing what you think is happening inside the flask. Make sure your drawing shows the molecules in the liquid and in the space above the liquid.
- Using pictures and words, explain how "equilibrium" applies to the liquid and the space above the liquid in the flask.
- Using pictures and words, explain how the pressure sensor provides information about if there is or is not something in the space above the liquid. In other words, does the pressure sensor confirm or disconfirm there is something in the space above the liquid? Make sure you explain your answer.

Lab 5: Student Led Investigation of Solubility

<u>Purpose</u>

To explore different aspects of solubility through student-designed experiments.

<u>Background Discussion</u>

Over the past week, you have had the chance to investigate many aspects of solubility: the behavior of a gas as it is bubbled through water; the effect of heat on dissolving a gas in a liquid; how a liquid solute dissolves into a liquid solvent (lab 1.5); the effect of pressure on a solution (lab 4). Now you will extend these ideas by creating your own investigations. There are three parts to this lab, all of which focus on dissolving solids into liquids. In each part your group will design an experiment to test an idea. The reason we made this the last lab you do was to make sure you had an opportunity to use ChemSense and the various probes to investigate different aspects of solubility. In most of the previous labs you investigated how gases (oxygen and carbon dioxide) dissolve in a liquid (water.) Now you will focus on dissolving solids into a liquid. You'll be able to compare the behavior of solids dissolved in water to the behavior of gases dissolved in water,

<u>Part A – The Effect of Temperature on Dissolving</u>

In the first part of the lab you will investigate how temperature effects the rate at which a solute dissolves in a solvent. In other words, can you dissolve more salt (or sugar) in warm water compared to cold water? In figure A, a solid solute has been placed in water – let's say a sugar cube dropped in a beaker of water. As the sugar cube sits in the water, individual water molecules, because they are moving, run into the cube and break sugar molecules off. These sugar molecules are now moving in the water, detached from the cube. We say that solvation is occurring – the dissolving of a substance into a solvent. Once sugar molecules are moving in the water, some of them will run back into the cube (or other sugar molecules) and become attached again.

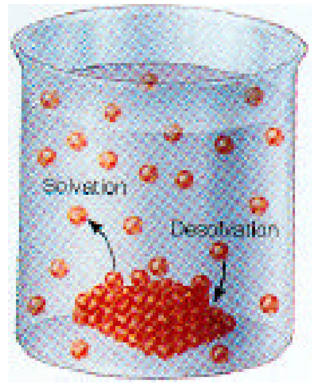


Figure A. A solid placed in a liquid solvent. Assuming that the solid will dissolve in the solvent, the process of solvation (dissolving into the solvent) and desolvation (reforming of the solute) takes place.

This process is called desolvation (the opposite of solvation.) Even though you can not necessarily see this happening, it is happening at the nanoscopic level.

In this part of the investigation your group is to design an experiment to answer the question: "Can you dissolve more salt (or sugar) in hot water compared to cold water? " You can use either salt or sugar (or both) to conduct this investigation. There is no one "right" investigation to do. Rather, there are many ways you can find an answer to the question. What we are looking for is a) how well the investigation you design helps answer the question, b) how well you document your procedure, and c) how well you interpret your data. In your lab book, you need to do the following:

1. Make a prediction that your group agrees upon – Does increased temperature of the solvent (water) slow down, speed up, or have no effect on how fast sugar or salt dissolves? If your group cannot come to an agreement, that's O.K – just write both predictions down.
2. State the reason for your prediction. This does not have to be long – state in a sentence or two why your group made the prediction it did.
3. Create a drawing or animation of what you think is happening at the nanoscopic level that helps explain why or why not temperature effects the ability of salt or sugar to dissolve in water.
4. Record the steps you did (your procedure) as you conducted your investigation. Make sure you list the probe(s) you used (if any) and why you used it. The procedure doesn't have to be a long, detailed list of every single step (i.e. "I opened up ChemSense, then I clicked the start button, then I turned the hot plate on, etc.") Instead, list the important steps of the procedure so someone who reads it will have an understanding of what you did and could repeat your experiment if they wanted.
5. Report your findings. What does the data look like that you collected? Make sure you record this in your lab book.
6. Interpret your findings. After looking at the data, what does it tell you? Does the data confirm or disprove your prediction(s) at the beginning of the lab?

Make sure you complete the above 6 steps before moving on to the next section of the lab.

Part B – The Effect of a Solute on Boiling Temperature

In the second part of the lab you are going to investigate the effect of a solute (either salt or sugar) on the temperature at which water boils. Does adding a solute to the water increase, decrease, or not effect the temperature at which water boils? Similar to what you did in Part 1, you will create an investigation that shows the effect of a solute on boiling point. Just like you did in Part 1 you need to complete the following steps:

1. Make a prediction that your group agrees upon – Does a solute (salt or sugar) effect the temperature at which a solvent (water) boils? Again, if your group cannot come to an agreement, that's O.K – just write both predictions down.

2. State the reason for your prediction. This does not have to be long – state in a sentence or two why your group made the prediction it did.
3. Create a drawing or animation of what you think is happening at the nanoscopic level that helps explain why or why not a solute effects boiling point temperature.
4. Record the steps you took (your procedure) as you conducted your investigation. Make sure you list the probe(s) you used (if any) and why you used it. As before, the procedure doesn't have to be a long, detailed list of every single step, just list the important steps of the procedure so someone who reads it will have an understanding of what you did and could repeat your experiment if they wanted.
5. Report your findings. What does the data look like that you collected? Make sure you record this in your lab book.
6. Interpret your findings. After looking at the data, what does it tell you? Does the data confirm or disprove your prediction(s) at the beginning of the lab?

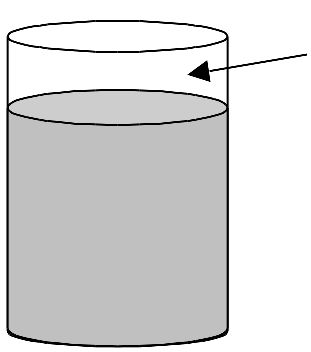
Make sure you complete the above 6 steps before moving on to the next section of the lab.

<u>Part C – The Effect of a Solute on Vapor Pressure</u>

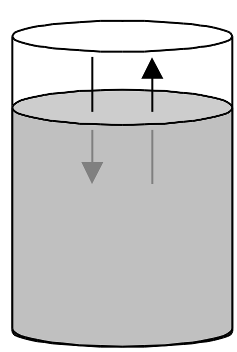
In this part of the lab you will investigate another aspect of solutions – vapor pressure.

Let's say you have a beaker with water in it. If you let the beaker sit for a few days, you would start to notice that the level of the water starts to go down. If you let it sit long enough, you would see that the water totally evaporated. Where did the water go? If you could see the water in the beaker at the nanoscopic level, you would see water molecules moving around, bouncing off each other and the walls of the beaker. Some of these water molecules would move through the surface of the water and make it into the air above. These water molecules would be considered water vapor. The water molecules do not change form – we just call them water vapor now because they are individual water molecules moving around like a gas in the air. Given enough time, all of the water molecules would eventually make their way into the air, and the beaker would be empty.

Now what would happen if you put a lid on the beaker? As the water molecules make it through the surface of the water, they move around in the air above the liquid, bouncing off the different particles that make up air (nitrogen, oxygen, etc.) and off the walls and lid on the beaker. These molecules create pressure in the space above the water. Since the beaker is sealed, some of the water molecules would bounce back *into* the liquid water. Therefore, once the beaker is sealed, water molecules move out of the water and back into the water continuously. We say the liquid water and the water vapor are in dynamic equilibrium. *Vapor pressure* is the pressure exerted by a vapor (water molecules) that is in dynamic equilibrium with its liquid (water.) We say "dynamic" because the water molecules are always moving; we say "equilibrium" because the rate of water molecules coming out of the water is the same as the rate they are going back into the water. The idea of dynamic equilibrium can be thought of as similar to a person walking up the "down" escalator. The person would be in equilibrium if she is walking up at the same rate the escalator is moving down. It is important to understand that equilibrium doesn't mean



Vapor pressure due to water molecules moving in space above the water



At equilibrium, the rate of water molecules going into the water is the same as the water molecules coming out of the water

everything has stopped because it is somehow balanced. Instead, it means that things are moving at the same rate – the rate of water molecules moving out of the water is the same as the rate at which they go back into the water; the rate at which the person is walking up is the same as the rate at which the escalator is moving down.

Now, something happens when you add a solute (like salt) to the water – the vapor pressure goes down (see figure D). By adding a solute to the water, the pressure of the water vapor above the water

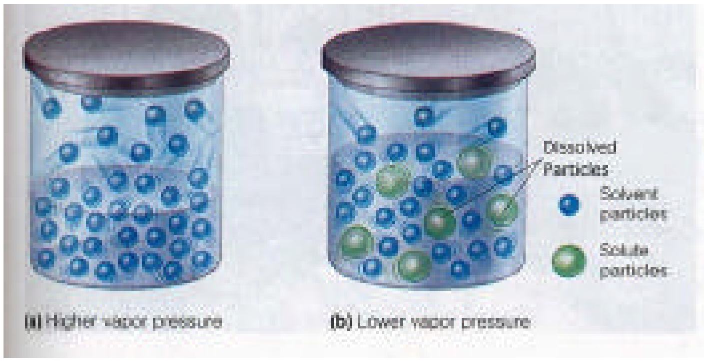


Figure D. The lowering of vapor pressure due to solute particles

decreases. What the solute does is make it harder for the water molecules to make it through the surface of the water. Why do you think this is? Your group's job In this part of the investigation is to design an experiment that shows that this actually happens. You may use any of the equipment on the lab bench. Since you have experience using the probes, you may use any that you find in front of you.

Make sure your group does the following:

1. Record the steps you took (your procedure) as you conducted your investigation. Make sure you list the probe(s) you used (if any) and why you used it. As before, the procedure doesn't have to be a long, detailed list of every single step, just list the important steps of the procedure so someone who reads it will have an understanding of what you did and could repeat your experiment if they wanted.
2. Report your findings. What does the data look like that you collected? Make sure you record this in your lab book.
3. Do a second run. Run your investigation again so you have a second set of data to complement the first.
4. Interpret your findings. After looking at the data, what does it tell you? Does the data show a lower vapor pressure by adding a solute to the water? If your data does not show this, list two possible reasons why