Colligative Properties & Osmotic Pressure

Peter Jeschofnig, Ph.D.
Version 42-0149-00-01

Review the safety materials and wear goggles when working with chemicals. Read the entire exercise before you begin. Take time to organize the materials you will need and set aside a safe work space in which to complete the exercise.

Experiment Summary:

Students will have the opportunity to explore the colligative properties of freezing point depression and osmotic pressure in solutions. They will define colligative properties as well as discuss membrane permeability and osmotic pressure.

Objectives

- Colligative Properties: Freezing Point Depression
  To compare the freezing point of a pure solvent to that of the solvent in solution with a nonvolatile solute
- Colligative Properties: Osmotic Pressure
  To observe the phenomenon of osmosis and gain a fundamental understanding of the principle on which dialysis is based.

Materials

PART I: COLLIGATIVE PROPERTIES		
MATERIALS FROM:	QTY	ITEM DESCRIPTION:
Student Provides	1	Small rubber bands
	1	Salt
	1	Tap water
	1	Distilled water
	1	1/8-teaspoon Measuring spoon
	1	Crushed ice
From LabPaq	1	Beaker, 100 mL, plastic
	1	Stopwatch-digital
	1	Test Tube(5), 13 x 100 mm in Bubble Bag
	1	Thermometer-in-cardboard-tube
	1	Well-Plate-24

PART II: OSMOTIC PRESSURE		
MATERIALS FROM:	QTY	ITEM DESCRIPTION:
Student Provides	1	Distilled water
	1	Rubber bands
	1	Household white vinegar
	1	Raw egg with intact shell
	1	Karo® light syrup – NOT the dark kind!
	1	Pint jar with lid
	1	Glass bowl
From LabPaq	1	Funnel
	6	Dialysis Tubing - inches - Note Qty = length in inches, not the # of pieces

This section takes 2 - 3 days to complete. Allocate your time appropriately.

Note: Chemicals in a bag labeled for a specific experiment (e.g., Experiment 1) will be used **only** in that experiment and chemicals remaining can be disposed of when you are completely finished with that experiment. Chemicals in the Auxiliary Chemicals Bag will be used in multiple experiments in the LabPaq and should be kept until the end of the course.

Note: The packaging and/or materials in this LabPaq may differ slightly from that which is listed above. For an exact listing of materials, refer to the Contents List form included in the LabPaq.

Discussion and Review

Part I: Colligative Properties

Recall that a solution is made up of a solvent and one or more solutes. Most of the properties of a solution are extremely dependent on the identity and properties of the solute. Four properties, however, are not.

These properties are called the Colligative properties. They are those properties of a solution that depend solely on the number of solute particles present, not on the identity of those solute particles. The four colligative properties of solutions are:

1. Vapor pressure lowering,
2. Boiling point elevation,
3. Freezing point depression, and
4. Osmotic pressure.

Recall that any volatile substance – that is, any substance that will evaporate – will have a vapor pressure. Nonvolatile substances do not have vapor pressures. Suppose you have a volatile solvent, such as water. In the absence of any solute the mole fraction of the water is 1.00. If you make a solution of a nonvolatile solute such as table sugar (sucrose) in the water the mole fraction of the water will be less than 1.00. Consequently, the vapor pressure of the water in the solution is less than that of the pure solvent because the mole fraction is less in the solution than in the pure solvent.

Freezing point and boiling point are affected in similar ways by the presence of a nonvolatile solute. In this experiment you will observe how freezing point changes once a nonvolatile solute is introduced. Sometimes it is possible to observe supercooling as a substance freezes. Supercooling is the rapid decrease in temperature of a substance to a temperature below the expected freezing point. It occurs because the first crystals of the frozen substance are slow to form, allowing the temperature of the liquid to decline precipitously.

Procedure - Part 1

Completely read all instructions and assemble all equipment and supplies before beginning work on this experiment.

Before beginning, set up a data table similar to the Data Table 1: Pure Water and Salt Solution in the Lab Report Assistant section.

1. Make a water bath assembly by doing the following:
   a. Half-fill the 100-mL beaker with cool tap water.
   b. Place crushed ice in the beaker so the water level is just below the top of the beaker. The water level should not be higher than the length of the test tube.
   c. Sprinkle a little salt into the ice water. Mix well.
2. Half-fill the test tube with distilled water. Set the tube into the 24-well plate. (The well plate will function as a test tube holder.)
3. Insert the thermometer into the test tube and take readings every 30 seconds until the readings remain constant, then record the temperature of the distilled water.
4. Place the test tube in the beaker's ice water bath and set your stopwatch at zero.
5. Carefully stir the water in the test tube with the thermometer and record the temperature of the water at 30-second intervals. You should see the temperature of the water rapidly decrease to from -1°C to -3°C then rise to 0°C. At that time the readings should remain constant before again decreasing. This is supercooling. ***Caution:*** *Do NOT let the water in the test tube freeze completely or the thermometer may break.*
6. Once five consecutive readings have been made at a constant temperature, remove the test tube from the bath and empty it into a sink.
7. Refill half of the test tube with room temperature distilled water (at least 10°C) and add 1/8 teaspoon of salt to the distilled water in the test tube. Mix well until dissolved.
8. Either prepare a fresh water bath or add more ice and a little salt to the existing water bath.
9. Repeat Steps 2 - 5 above using the saltwater solution prepared in Step 7 above. You may not observe supercooling this time.
10. Pour the water from the test tube and from the water bath down the drain. Clean up your equipment and replace it in the LabPaq.
11. Make two graphs of your data. On one graph plot the data from the pure water. On the other graph plot the data from the salt solution. On both plot temperature on the y-axis and time on the x-axis.

12. Once the points are plotted you should observe two fairly linear regions on each graph. (Using the pure water as an example, one linear region should be from the initial temperature to the coldest temperature observed. The other linear region should be the readings made at constant temperature – after the temperature had risen).
13. Draw the best straight lines for these regions. Thus you should have two straight lines on each graph.
14. On each graph extend these lines until they intersect. The points of intersection are the points you will record as your freezing points.

Part II: Osmotic Pressure

This section takes 2 - 3 days to complete. Allocate your time appropriately.

A *membrane* is a thin, flexible layer of material. In living organisms membranes are frequently found lining cells. The largest membrane in a human is the skin. All membranes have pores in them. Substances can pass through a membrane through its pores.

A *semi-permeable membrane* is a membrane through which only solvent molecules can pass. The pores are too small to allow passage of solute particles.

If two solutions of different concentrations are separated by a semi-permeable membrane, solvent from the less concentrated solution will pass through the membrane into the more concentrated solution. This process will continue until the solute concentration is the same on each side of the membrane. This phenomenon is called *osmosis*. It is the basis for hemodialysis where the blood of patients with kidney malfunction is filtered to remove waste products normally removed by the kidneys.

The pressure that must be applied to stop the movement of solvent through the membrane is the *osmotic pressure* of the solution. It is a colligative property of the solution.

It is important to note that in the laboratory the semi-permeable membrane material can be selected to also allow passage of some small particles. Likewise, biological membranes allow passage of certain small molecules and not others. This is one reason why dialysis is effective.

Procedure - Part 2

Completely read all instructions and assemble all equipment and supplies before beginning work on this experiment.

Sugar Solution

1. Half-fill a glass bowl with distilled water. Place the dialysis tubing in it. Make sure the tubing is completely submerged and let it soak for 20 - 30 minutes
2. Gather your funnel, two rubber bands, and your Karo® syrup and proceed to "Raw Egg" while the tubing is soaking.
3. After the tubing has soaked 20 - 30 minutes remove it from the water and put it on a paper towel.
4. Pour the water down the drain and rinse the bowl with distilled water. Then refill the bowl halfway with distilled water.
5. Carefully close off one end of the dialysis tubing using a rubber band. You may want to cut the rubber band and tie off the tubing or you may want to just wrap the rubber band around the tubing several times. Regardless, make certain the closure is as tight as possible to avoid leaks.
6. Use the funnel to carefully fill the dialysis tubing 1/3-full with Karo® syrup. Do not get any Karo® on the outside of the tubing. Close off the other end of the tubing as in Step 5.
7. Put the Karo®-filled tubing into the distilled water in the glass bowl. Make sure the tubing is completely submerged.
8. Observe the tubing several times over the next several hours. Record your results.
9. Clean up by pouring the liquids down your drain, washing and rising the bowl, and throwing the used dialysis tubing into the garbage.

Raw Egg

1. Carefully check your raw egg to make sure the shell is NOT cracked. Use ONLY an egg with an intact shell for this experiment or it will not work!
2. Gently place the egg into the pint jar. Record your observations of the egg.
3. Pour vinegar over the egg to cover it completely, put the top on the jar, and set it aside for 12 to 24 hours to allow the vinegar to completely dissolve the shell of the egg. During this period observe the egg several times and record your observations.
4. After the shell has dissolved, record your observations of the egg.
5. Very carefully remove the egg from the vinegar over the sink and gently rinse it under cool tap water. Be careful to not break the membrane.
6. Rinse the jar well with tap water and then half-fill it with Karo® syrup.
7. Carefully place the egg into the Karo® syrup. Put the lid on the jar and set it aside for 12 to 24 hours. During this period observe the egg several times and record your observations.
8. Carefully remove the egg from the Karo® syrup and gently rinse it under tap water as before. Record your observations.
9. Dispose of the egg by throwing it in the trash or down a garbage disposal. Dispose of the Karo® syrup by rinsing down the sink. Clean all the equipment you used.

Colligative Properties & Osmotic Pressure

Peter Jeschofnig, Ph.D.
Version 42-0149-00-01

Lab Report Assistant

This document is not meant to be a substitute for a formal laboratory report. The Lab Report Assistant is simply a summary of the experiment's questions, diagrams if needed, and data tables that should be addressed in a formal lab report. The intent is to facilitate student's writing of lab reports by providing this information in an editable file which can be sent to an instructor

Observations & Questions for Part 1

Record your observations and your time and temperature data in tables. Use one table for the pure water and one table for the salt solution.

Data Table 1: Pure Water and Salt Solution

Seconds	Distilled H_20 Room temp	Distilled H_20 Ice bath	Saltwater Room temp	Saltwater Ice bath
0				
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				
330				
360				
390				
420				
450				
480				
510				
540				
570				
600				
630				
660				

Make two graphs of your data. On one graph plot the data from the pure water. On the other graph plot the data from the salt solution. On both plot temperature on the y-axis and time on the x-axis.

A. Record the freezing point of the pure water and the freezing point of the salt solution.

B. How do these two freezing points compare?

C. What are some practical applications of freezing point depression, boiling point elevation, and vapor pressure lowering?

Questions - Part 2

A. To what biological structure is the dialysis bag comparable? How is it similar? How is it different?

B. In biological systems if a cell is placed into a salt solution in which the salt concentration in the solution is lower than in the cell, the solution is said to be hypotonic. Water will move from the solution into the cell, causing lysis of the cell. In other words, the cell will expand to the point where it bursts. On the other hand, if a cell is placed into a salt solution in which the salt concentration in the solution is higher than in the cell, the solution is said to be hypertonic. In this case, water will move from the cell into the solution, causing cellular death through crenation or cellular shrinkage. In your experiment is the Karo® hypertonic or hypotonic to the egg?

C. Historically certain colligative properties – freezing point depression, boiling point elevation, and osmotic pressure – have been used to determine molecular mass. (Now there are instrumental methods to determine this.) Of these three, osmotic pressure is the most sensitive and gives the best results. Molecular mass can be found according the following equation:

$$\Pi = MRT$$

Where: Π = osmotic pressure,

M = molarity of solution,

R = the ideal gas constant (0.0821 L×atm/mol×K), and

T = Kelvin temperature.

Sample Problem

0.125 grams of a starch is dissolved in 100 mL of water at 25°C and has an osmotic pressure of 5.15 mmHg. What is its molecular mass?

Since the gas constant, R, requires atmospheres as pressure units, we have to convert 5.15 mmHg to atmospheres:

5.15 mm Hg * 1 atm/760 mm Hg = 0.00678 atm.

0.00678 atm = *M* (0.0821) (273 + 25 = 298 K);

We solve for *M* = 0.00678/(0.0821*298);

M (molarity) = 2.77×10^{-4}

Molarity = moles/L: 2.77×10^{-4} = moles/.1 = 2.77×10^{-5} moles of starch;

If 2.77×10^{-5} moles = 0.125 grams,

Then 1 mole = 0.125 g/2.77×10^{-5} = 4512 g/mole = molar mass of starch.

Problem for Lab Report:

At 23.6°C, 0.500 L of a solution containing 0.302 grams of an antibiotic has an osmotic pressure of 8.34 mmHg. What is its molecular mass?