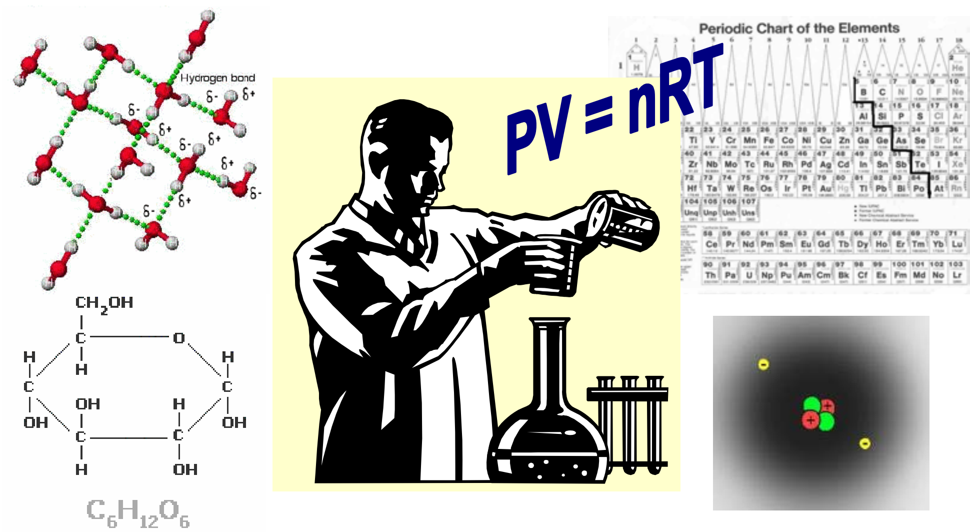
Project EASE

(Effective Alternative Secondary Education)

CHEMISTRY



MODULE 6

Colligative Properties of Solution

BUREAU OF SECONDARY EDUCATION
Department of Education
DepEd Complex, Meralco Avenue
Pasig City

Module 6
Colligative Properties of Solution

What this module is about

When a non-volatile (substances that do not readily form vapors), non-electrolytic (substances that do not form ions and do not conduct electricity when placed in water) solute such as sugar is dissolved in a given volume of solvent to form a sugar solution, it changes the set of properties of the pure solvent entirely. In this regard, the set of properties such as freezing point, boiling point, vapor pressure, and osmotic pressure of a solvent are affected by the presence of the solute particles in the solution. This set of properties will depend only on the number of dissolved particles in the solution and not on their identity. These properties are collectively known as *colligative properties of solution.*

This module will focus on four colligative properties of electrolyte and non-electrolyte solutions namely, *vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure*.

To make the discussion easy for you, the module is divided into four lessons:

- **Lesson 1 – What is the Difference Between Osmotic Pressure and Vapor Pressure?**
- **Lesson 2 – What is Boiling Point Elevation?**
- **Lesson 3 – What is Freezing Point Lowering?**
- **Lesson 4 – What is the Importance of Colligative Properties in Our Daily Lives?**

What you are expected to learn

After going through this module, you should be able to:

1. differentiate between colligative and non-colligative properties of a solution;
2. differentiate vapor pressure from osmotic pressure;
3. identify boiling point elevation;
4. state and explain freezing point lowering; and
5. apply knowledge of the importance of colligative properties of solutions to daily living.

How to learn from this module

Here are some pointers to remember as you go over this module.

1. Read and follow the instructions carefully.
2. Answer the pretest first before reading the content of the module.
3. Take down notes and record points for clarification.
4. Always aim to get at least 70% of the total number of items given.
5. Be sure to answer the posttest at the end of the module.

What to do before (Pretest)

Take the pretest before proceeding to the lessons. Check your answers against the answer key at the end of the module.

I. Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. A substance whose water solution conducts an electric current is called a(n)
   a. electrolyte
   b. nonelectrolyte
   c. polar substance
   d. nonpolar substance

2. A substance that vaporizes easily is known as
   a. volatile
   b. nonvolatile
   c. electrolyte
   d. nonelectrolyte

3. Adding a solute such as NaCl to water increases its
   a. boiling point
   b. melting point
   c. osmotic pressure
   d. vapor pressure

4. Which of the following is **NOT** a colligative property of solution?
   a. solubility
   b. boiling point
   c. melting point
   d. osmotic pressure

5. Which of the following statements is **TRUE** about vapor pressure?
   a. The vapor pressure of the solvent is less than the solution.
   b. The vapor pressure of the solution is higher than the pure solvent.
   c. The vapor pressure of the pure solvent is higher than the solution.
   d. The vapor pressure of the pure solvent and the solution are the same.

6. The **i factor** gives the number of particles per formula unit of the solute. What is the i factor for NaCl?
   a. 0
   b. 1
   c. 2
   d. 3

7. What happens during osmosis?
   a. Pure solvent diffuses through a membrane but solutes do not.
   b. Pure solutes diffuse through a membrane but solvent does not.
   c. Gases diffuse through a membrane into a solution and build up pressure.
   d. Pure solvent and a solution both diffuse at the same time through a membrane.

8. What is the temperature at which the vapor pressure equals the atmospheric pressure?
   a. 100 ^{o}C
   b. freezing point
   c. boiling point
   d. melting point

9. The freezing point of a solution is always ___________ the pure solvent.
   a. less than
   b. same as
   c. greater than
   d. greater than or equal to

10. If a potato is placed in brine (concentrated NaCl solution), the potato cell is expected to:
    a. shrink
    b. swell
    c. become rigid
    d. no considerable change

II. TRUE or FALSE. Write **TRUE** if the statement is correct. Otherwise, write **FALSE**.

___________ 1. Colligative properties will only depend on the number of dissolved particles in the solution and not on their identity.
___________ 2. The addition of a solute will increase the boiling point of the solution.
___________ 3. The van’t Hoff factor is only applicable for non-electrolyte solutions.
___________ 4. The boiling point of the solution is always greater than that of the pure solvent.
___________ 5. All biological membranes are regulated via osmosis.

Key to answers on page 21.

Lesson 1. What is the Difference Between Osmotic Pressure and Vapor Pressure?

Before differentiating these two terminologies, let us first understand the difference between the two classifications of solutions according to their properties – colligative and non-colligative properties. Earlier, we have defined that ***colligative properties*** will just depend on the number of dissolved particles in the solution and not on their identity. Non-colligative properties state otherwise. To clearly understand the difference between these two properties, let us do Activity 1.1.

What you will do

Activity 1.1 Classifying Colligative and Non-Colligative Properties of Solution

Materials: 1% (w/v) brown sugar solution
0.5 % (w/v) salt solution (NaCl)
thermometer

Procedure:

Prepare the brown sugar and salt solutions of concentration 1% and 0.5%, respectively. Observe the following properties in the two solutions and identify whether the property observed is a colligative or non-colligative property based on the definition.

Properties of Solution	0.5 % (w/v) salt solution	1% (w/v) brown sugar solution
Solubility (ability of the solute to be dissolved in a solvent)		
Viscosity of solution ("viscosity" is a property of solution to resist flow)		
Color of the solution		
Taste of solution		
Temperature upon boiling		
Temperature upon freezing		

Analysis:

1. Which of the following properties of solution can be considered colligative? Why?
2. Which of the following properties of solution can be considered non-colligative? Justify your answer.

After finishing the activity, we can clearly distinguish what properties of solution are colligative and what properties are not. Again, for as long as the number of dissolved particles in solution is taken into consideration, then that property of solution (e.g. boiling point, freezing point, etc.) is a *colligative property*. On the other hand, if the identity of the dissolved species and solvent is being analyzed (e.g. color, taste, viscosity, solubility), then it is a *non-colligative property*. Having learned their difference, we can now describe vapor pressure and osmotic pressure of solutions.

Vapor-Pressure Lowering

When a ***nonvolatile*** (does not turn to vapor easily) solute is added to a liquid to form a solution, the vapor pressure above that solution decreases. To understand why that might occur, let us do a simple experiment in Activity 1.2.

What you will do

Activity 1.2 Vapor-Pressure Lowering

Materials: Water
Aqueous sugar solution
Two glasses
One sealed enclosed container

Procedure:

1. Get two glasses placed side by side in a sealed enclosed container. One glass contains pure water, the other an equal volume of an aqueous solution of sugar. Take note of the volume of water and sugar solution. (See figure 1.1a)
2. Leave the set-up until the next day. Gradually measure the volume of the sugar solution and that of the pure water. Is there any change in their original volume? (See figure 1.1b)

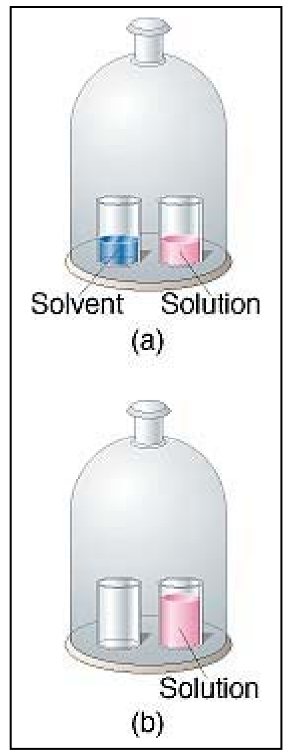


Figure 1.1 Experiment set-up for vapor-pressure lowering

Analysis:

1. What can you infer about the change in volume of the sugar solution and that of pure water?
2. What has caused this change in volume of the sugar solution and that of pure water?

After finishing the activity, you should now see why the vapor pressure of the solvent decreases upon addition of a non-volatile, non-electrolyte solute (sugar).

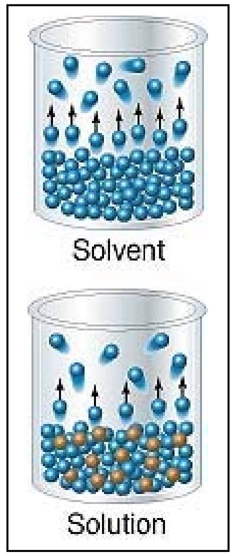


Figure 1.2 A nonvolatile solute reduces the rate of vaporization of the solvent.

The extent to which a nonvolatile solute lowers the vapor pressure is proportional to its concentration. This was discovered by French chemist Francois Raoult (1830-1907). ***Raoult's law*** states that for nonelectrolyte solutions, the partial vapor pressure of a solvent over a solution (P_1) is equal to the vapor pressure of the pure solvent ($P^o{}_1$) multiplied by the mole fraction of the solvent (X_1). This law is mathematically expressed as:

$$P_1 = X_1 P^o{}_1$$

For solutions of electrolytes, the vapor pressure lowering equation can be expressed as:

$$P_1 = \boldsymbol{i} P^o{}_1 X_1$$

where *i* is the van't Hoff factor, named after Jacobus Henricus van' Hoff (1852-1911), who won the very first Nobel Prize in chemistry in 1901 for his work on colligative properties of solution. The ***i factor*** gives the number of particles per formula unit of the solute. For example, NaCl solution dissociates to give one $Na^+{}_{(aq)}$ and one $Cl^-{}_{(aq)}$, the $i_{NaCl} = 2$, because there is one Na^+ and one Cl^- ion in solution per formula unit of solute.

On the other hand, if both components of a solution are ***volatile*** (readily evaporates), the vapor pressure of the solution is the sum of the individual partial pressures. The total pressure is given by ***Dalton's law of partial pressure:***

$$P_T = P_A + P_B$$

or

$$P_T = X_A P^o{}_A + X_B P^o{}_B$$

Sample Problem:

What is the vapor pressure of the solution containing 20 g of sugar ($C_{12}H_{22}O_{11}$) in 1.5 kg water at 25°C. Note: P^o_{water} at 25°C is 24 torr

Explanation:

1 mole of sugar ($C_{12}H_{22}O_{11}$) is 342 g and 1 mole of water (H_2O) is 18 g. The number of moles of each component is computed as:

For sugar:

$$20\text{ g } C_{12}H_{22}O_{11} \times \frac{1\text{mol } C_{12}H_{22}O_{11}}{342\text{ g } C_{12}H_{22}O_{11}} = 0.06\text{ mol } C_{12}H_{22}O_{11}$$

For water:

$$1500\text{ g} H_2O \times \frac{1\text{mol } C_{12}H_{22}O_{11}}{18\text{ g } C_{12}H_{22}O_{11}} = 83.33\text{ mol } H_2O$$

And mole fraction of water (solvent) is computed as:

$$X_{H_2O} = \frac{83.33\ C_{12}H_{22}O_{11}}{83.33 + 0.06\ C_{12}H_{22}O_{11}} = 1.00$$

Therefore, the vapor pressure is:

$$\begin{aligned} P_{H_2O} &= X_{H_2O} \times P^o{}_{H_2O} \\ &= 1.00 \times 24\text{ torr} \\ P_{H_2O} &= 24.0\text{ torr} \end{aligned}$$

Practice Exercise:

Calculate the vapor pressure of salt solution containing 20 g salt (NaCl) in 1.5 kg of water at 25°C? Note: P^o_{water} at 25°C is 24 torr and molecular weight of NaCl is 58 g/mol.

Note: Remember that NaCl is a strong electrolyte and dissociates to Na^+ and Cl^- ion respectively.

Answer: 48 torr

Osmotic Pressure

Osmosis is of prime importance to living organisms because it influences the distribution of nutrients and the release of metabolic waste products. Living cells of both plants and animals are enclosed by a ***semipermeable membrane*** called the cell membrane, which regulates the flow of liquids and of dissolved solids and gases into and out of the cell.

> **Did you know?**
>
> Oceans cover over 72% of the earth and a reservoir for 97.2% of the earth's water. However, out of the 97.2% of earth's water, only 2.5% is available as freshwater and less than 1% is available as groundwater or surface water for human use. Scientists have found a new, cheaper and more economical way of making seawater possible for drinking. The process is known as ***reverse osmosis***. Through this process, seawater is made to pass through a semi-permeable membrane and by applying a pressure greater than 30 atm (Note: 30 atm is the pressure that must be applied to saline solution of seawater in order to facilitate osmosis), the osmotic flow would be reversed, and fresh water made to run through the membrane. Now, that's chemistry in action!

The ***osmotic pressure (Π)*** of a solution is the pressure required to stop osmosis. The osmotic pressure of the solution is given by:

$$\Pi = MRT$$

where M is the molarity of solution, R the gas constant ($0.0821\ L \cdot atm / K \cdot mol$), and T the absolute temperature (in Kelvins).

The osmotic pressure is expressed in *atm*. And since osmotic pressure measurements are carried out under constant temperature, molarity is preferred over molality as concentration. Again, for solutions of electrolytes, the osmotic pressure equation can be expressed as:

$$\Pi = \boldsymbol{i}MRT$$

where i is the van't Hoff factor, the number of particles per formula unit of the solute.

Sample Problem:

What is the osmotic pressure of the solution containing 0.2 M sugar ($C_{12}H_{22}O_{11}$) solution at 25°C?

Explanation:

$$\Pi = MRT$$

$$\Pi = \frac{0.2\,\text{mol}\ C_{12}H_{22}O_{11}}{1\text{L solution}} \times 0.0821\frac{\text{L}\cdot\text{atm}}{\text{K}\cdot\text{mol}} \times 298\,\text{K} = 4.89$$

$$\Pi = 4.89\,\text{atm}$$

> **Practice Exercise:**
>
> Calculate the osmotic pressure of 0.2 M salt solution (NaCl) at 25 °C?
>
> *Answer: 9.78 atm*

What you will do

Self-Test 1.1

Now that you are through with the first lesson, try to answer the following questions and see for yourself how much you learned.

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. What happens during osmosis?
   a. Pure solvent diffuses through a membrane but solutes do not.
   b. Pure solutes diffuse through a membrane but solvent does not.
   c. Gases diffuse through a membrane into a solution and build up pressure.
   d. Pure solvent and a solution both diffuse at the same time through a membrane.

2. What is the van't hoff factor for $CaCl_2$?
   a. 0 c. 2
   b. 1 d. 3

3. The osmotic pressure found for a 2.50 g sugar solution at 25°C is 1.79 atm in a 1.0 L of water. What is its molar mass (g/mol)?
   a. 342 g/mol c. 3.42 g/mol
   b. 34.2 g/mol d. 7.32×10^{-2} g/mol

4. Cold-blooded animals and fish thrive in sea water. Which of the following situations is true about their condition?
   a. Their blood has greater osmotic pressure than that of sea water.
   b. Their blood has less osmotic pressure than that of sea water.
   c. Their blood has the same osmotic pressure as that of sea water.
   d. The osmotic pressure of sea water is greater than that of their blood.

5. According to Raoult's law, which statement is **FALSE**?
   a. The vapor pressure of a solvent over a solution decreases as its mole fraction increases.
   b. The solubility of a gas increases as the temperature decreases.
   c. The vapor pressure of a solvent over a solution is less than that of pure solvent.
   d. The greater the pressure of a gas over a solution the greater its solubility.

Key to answers on page 21.

Lesson 2. What is Boiling Point Elevation?

Remember that boiling point is the temperature at which the vapor of a liquid is equal to the atmospheric pressure. In the presence of a non-volatile, non-electrolytic solute such as sugar, the pressure that will be exerted by the vapor of the solvent is lesser in comparison with that of the pure solvent at equal volumes. And as a consequence, the solution will boil at a higher temperature than that of the pure solvent.

To clearly understand what boiling point elevation is all about let us do Activity 2.1.

What you will do

Activity 2.1 Boiling Point Elevation

Materials: three eggs
1 tbsp of salt
1 tbsp of sugar
boiling water

Procedure:

1. Put the first egg in two cups of water and take note of the time until the water boils.

2. Again, using two cups of water, put the second egg in the water and add 1 tbsp of salt. Record the time it will take the water to boil.
3. Repeat step 2, but add 1 tbsp of sugar instead of salt. Again, take note of the time it will take the water to boil.
4. Compare the time it will take for water to boil and cook the hard-boiled egg in step 1 to step 3. Record your observations.

Analysis:

1. Which set-up took less time to cook hard-boiled eggs? Why?
   ____
2. Did the water take more time to boil when electrolyte (NaCl) solute was added? Why? ____
3. Did the water take more time to boil upon addition of non-electrolyte (sugar) solute? Justify your answer.
   ____

Since we have already established that the boiling point of the solution is greater than that of the pure solvent, the boiling point elevation (ΔT_b) is mathematically expressed as follows:

$$\boxed{\Delta T_b = K_b m}$$

where (K_b) is boiling point elevation constant, equivalent to 0.52 $^oC/m$ for aqueous solutions. This means that, for example, 1 mole of sugar (nonelectrolyte) in 1 kilogram of water will increase the boiling point from 100^{o}C to 100.52^{o}C. And (m) is the molal concentration of solute. It is also important to note that ΔT_b is a positive quantity and should be added to the boiling point of pure solvent (water), which is 100^{o}C.

Remember that molality is used here over molarity because we are dealing with a solution whose temperature is *not* constant and concentration cannot be expressed in molarity because it changes with temperature.

Again, for solutions of electrolytes, the boiling point elevation equation can be expressed as:

$$\boxed{\Delta T_b = \boldsymbol{i} K_b m}$$

where *i* is the van't Hoff factor, the number of particles per formula unit of the solute.

Sample Problem:

At what temperature will the sugar solution boil if 20 g sucrose ($C_{12}H_{22}O_{11}$) is added to 1.5 kg of water?

Explanation:

Remember that sugar is a nonelectrolyte so there will be no need for the van't Hoff factor. A mole of sugar ($C_{12}H_{22}O_{11}$) is 342 g. Thus, molality of sugar can be computed as:

$$\frac{20\text{ g } C_{12}H_{22}O_{11}}{1.5\text{ kg } H_2O} \times \frac{1\text{mol } C_{12}H_{22}O_{11}}{342\text{ g } C_{12}H_{22}O_{11}} = \frac{0.04\text{ mol } C_{12}H_{22}O_{11}}{\text{kg } H_2O} = 0.04\text{ m}$$

The boiling point elevation is calculated as:

$$\Delta T_b = K_b m$$

$$= 0.52\,\frac{^oC}{m} \times 0.04\text{ m}$$

$$\Delta T_b = 0.02^oC$$

Thus, the boiling point of the solution is:

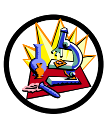
$$100^oC + 0.02^oC = 100.02^oC$$

Practice Exercise:

At what temperature will salt solution boil if 20 g salt (NaCl) is added to 1.5 kg of water? (Molecular weight of NaCl is 58 g/mol)

Note: Remember that NaCl is a strong electrolyte and dissociates to Na^+ and Cl^- ion, respectively.

Answer: 100.24 °C



What you will do

Self-Test 2.1

Again, try to check how much you have learned from the lesson by answering the following questions.

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. If Solution A contains 5 g NaCl in 100 mL water and Solution B contains 10 g NaCl in 100 mL water, which of the following conditions is true about solution A and B?
   a. Solution A has greater boiling point than Solution B.
   b. Solution B has greater boiling point than Solution A.
   c. Solution A and B have the same boiling point.
   d. Solution A has less boiling point than Solution B.

2. What is the boiling point of a 0.20 m NaCl solution in water? For water, K_b is 0.512^{o}C. kg/mol.
   a. 100.0^{o}C
   b. 100.2^{o}C
   c. 100.3^{o}C
   d. 100.4^{o}C

3. What happens to the boiling point of water when 0.5 m sugar (nonelectolyte) is added to it?
   a. 100.0^{o}C
   b. less than 100.0^{o}C
   c. greater than 100.0^{o}C
   d. none of the above

4. Which of the following statement is **TRUE** about the boiling point of the solution?
   a. The boiling point of the solvent is greater than that of the solution.
   b. The boiling point of the solution is less than that of the pure solvent.
   c. The boiling point of the solution is the same as that of the pure solvent.
   d. The boiling point of the solution is greater than that of the pure solvent.

5. The boiling point of an impure compound is generally __________ that of pure solid.
   a. same as
   b. less than
   c. greater than
   d. greater than or equal to

Key to answers on page 21.

Lesson 3. What is Freezing Point Depression?

Have you ever tried sprinkling salt over ice? What have you noticed? Salts such as NaCl and $CaCl_2$ cause ice to melt. This method of thawing depresses the freezing point of water. To learn more about freezing point depression, it will help to do Activity 3.1.

What you will do?

Activity 3.1 Freezing Point Depression

Materials:	one tsp. salt	stirrers
	one glass of water	spoon
	one glass of crushed Ice	thermometer

Procedure:

1. Using one glass of water and one glass of crushed ice, stir the mixture; then using a thermometer, observe and record this temperature.
2. Add one tsp. of salt to the water/ice mixture, then observe and record the temperature. You should repeat this procedure until the temperature reaches 10^oC. More ice should be added if necessary.

Analysis:

1. What happens to water and ice when salt is added to this mixture?
2. What happens to the temperature when salt is added to the mixture?
3. What variables would cause these differences?

Water freezes at 0^oC and boils at 100^oC. Salt water will not freeze until the temperature is below 0^oC. The more salt, the lower the freezing point of the solution. In the above experiment, energy is lost from the water in the form of heat. This heat is used to melt the ice. Since heat is lost from the water the temperature of the water goes down. Since there is now salt dissolved in the water it cannot freeze again, hence we observe a lower temperature.

The freezing point depression (ΔT_f) is mathematically expressed as:

$$\boxed{\Delta T_f = K_f m}$$

where K_f is the freezing point depression constant. equivalent to -1.86 $^oC/m$ for aqueous solutions. Again, for example, 1 mole of sugar (nonelectrolyte) in 1 kilogram of water will decrease the freezing point from 0^oC to -1.86^oC. (m) is the molal concentration of solute. And since we have already established that the freezing point of the solution is less than that of the pure solvent, then ΔT_f is a negative quantity and should be subtracted from the freezing point of pure solvent (water), which is 0^oC.

Again, for solutions of electrolytes, the freezing point lowering equation can be expressed as:

$$\Delta T_f = iK_f m$$

where *i* is the van't Hoff factor, the number of particles per formula unit of the solute.

Sample Problem:

At what temperature will the sugar solution freeze if 20 g sucrose ($C_{12}H_{22}O_{11}$) is added to 1.5 kg of water?

Explanation:

Since sugar is a nonelectrolyte, there will be no need for the van't Hoff factor. A mole of sugar ($C_{12}H_{22}O_{11}$) is 342 g. Molality (m) of sugar can be computed as:

$$\frac{20\text{ g } C_{12}H_{22}O_{11}}{1.5\text{ kg } H_2O} \times \frac{1\text{mol } C_{12}H_{22}O_{11}}{342\text{ g } C_{12}H_{22}O_{11}} = \frac{0.04\text{ mol } C_{12}H_{22}O_{11}}{\text{kg } H_2O} = 0.04\text{ m}$$

The freezing point depression is calculated as:

$$\Delta T_f = K_f\,m$$

$$= -1.86\ \frac{^{o}C}{m} \times 0.04\text{ m}$$

$$\Delta T_f = -0.07^{o}C$$

Thus, the freezing point of the solution is:

$$0^{o}C - 0.07^{o}C = -0.07^{o}C$$

Practice Exercise:

At what temperature will salt solution freeze if 20 g salt (NaCl) is added to 1.5 kg of water? (Molecular weight of NaCl is 58 g/mol)

Note: Remember that NaCl is a strong electrolyte and dissociates to Na^+ and Cl^- ion, respectively.

Answer: -0.86 ^{o}C

Did you know?

NaCl (salt) is added to ice to make a freezing mixture that results in a tasty, homemade ice cream. Lowering the freezing temperature of the ice-water-salt mixture causes the ice cream ingredients to freeze more quickly.

What you will do

Self-Test 3.1

Let us try to check how much you have learned from this lesson by answering the following questions.

1. The melting point of an impure compound is generally __________ that of the pure solid.
   a. less than
   b. the same as
   c. greater than
   d. greater than or equal to

2. Adding sodium chloride to water will cause the:
   a. boiling point to rise and the freezing point to lower.
   b. boiling point to lower and the freezing point to rise.
   c. both boiling point and freezing point to rise.
   d. both boiling point and freezing point to lower.

3. What is the freezing point of a 0.20 m sucrose (nonelectrolyte)?
   $K_f = 1.86\ ^oC /m$.
   a. 0.00^oC
   b. 0.37^oC
   c. 3.7^oC
   d. 37^oC

4. What is the freezing point of a 0.50 m NaCl (strong electrolyte)?
   $K_f = 1.86\ ^oC /m$.
   a. 0.0^oC
   b. 0.93^oC
   c. 9.3^oC
   d. 1.86^oC

5. Which of the following solutions has the **HIGHEST** freezing point?
   a. 0.1 m sugar
   b. 0.1 m NaCl
   c. 0.08 m $CaCl_2$
   d. 0.04 m Na_2SO_4

Did you encounter any problem? Well, compare your answers with the answer key and see for yourself the items you missed. Good luck!

Key to answers on page 21.

Lesson 4. What is the Importance of Colligative Properties in Our Daily Llife?

We have already established that addition of salt, such as NaCl, lowers the freezing point of ice. Even some organisms have evolved to survive freezing water temperatures with natural "antifreeze." Some fishes living in the Arctic ocean have blood containing a high concentration of a specific protein. This protein behaves like a solute in a solution and lowers the freezing point in their blood enabling them to survive in very cold temperatures.

Biologists and biochemists often take advantage of osmotic pressure when they isolate the components of a cell. They further classify solutions depending on the concentration of the solutes inside the cell as hypertonic, isotonic or hypotonic solutions. Suppose you cut a potato into cubes and immerse it in brine (concentrated NaCl). What will happen? The potato will tend to shrink. This method is used for curing meats like country ham. It is done to eliminate the bacteria since the bacteria cannot survive in high salt concentration.

Alternatively, ***hypotonic*** means the solution has a lower concentration of particles than the cell. Suppose you cut a potato into cubes, but this time immerse it in water. What will you notice? There would be more water moving into the potato cell causing it to swell. When a cell is placed in a solution that has a much smaller ionic strength, water pours into the cell, and the cell expands until the cell membrane bursts. In the case of red blood cells, the process is known as ***hemolysis***.

On the other hand, an ***isotonic*** solution has the same osmotic strength on both sides of the semipermeable membrane. Physiological saline (0.9% NaCl) is isotonic with blood. In this condition, the cell retains its normal shape and function.

Did you know?

Dialysis uses the same principle as osmosis to remove salt or other ions in the blood. In the dialysis machine, the blood is circulated through a long tube of cellophane in an isotonic solution and then returned to the patient's vein. The ions can pass out and the large proteins remain. When protein is found in the urine, that means there is some type of damage to the kidney. The isotonic solution has 0.6% NaCl, 0.04% KCl, 0.2% $NaHCO_3$, and 0.72% glucose (w/v). Thus no sodium ions or glucose is lost from the blood. The isotonic solution is changed every 2 hours and the patient stays on the dialysis machine for 4 to 7 hours.

What you will do

Self-Test 4.1

Let us try to check how much you have learned from the lesson by answering the following questions.

Modified True or False. Write **TRUE** if the statement is correct otherwise CHANGE the underlined word to correct the statement.

__________ 1. A hypertonic solution is a solution that has a higher concentration of article than the cell.

__________ 2. The normal physiological saline concentratrion of the blood is 0.6% NaCl.

__________ 3. Cells shrink if the concentration of solute inside the cell is greater than that outside the cell.

__________ 4. Hemolysis is the phenomenon that causes the membrane of red blood cells to burst due to a hypotonic environment inside the cell.

__________ 5. Some fishes living in the Arctic ocean were able to survive in very cold temperature because their blood contained the same concentration of solutes as the seawater.

Did you encounter any problem? Well, compare your answers with the answer key and see for yourself the items you missed. Good luck!

Key to answers on page 21.

Let's Summarize

A. Summary of Key Equations

For nonelectrolytes:

Raoult's Law:	$P_1 = P^o_1 X_1$
Dalton's Law of Partial Presssure:	$P_T = P_A + P_B$
Osmotic Pressure:	$\Pi = MRT$
Boiling Point Elevation:	$\Delta T_b = K_b m$
Freezing Point Depression:	$\Delta T_f = K_f m$

For electrolytes:

Raoult's Law:	$P_1 = iP^o_1 X_1$
Dalton's Law of Partial Presssure:	$P_T = iP_A + iP_B$

Osmotic Pressure: $\Pi = iMRT$
Boiling Point Elevation: $\Delta T_b = iK_b m$
Freezing Point Depression: $\Delta T_f = iK_f m$

B. Summary of Facts and Concepts

1. Colligative properties (or collective properties) are properties that depend only on the number of solute particles in solution and not on the nature of the solute particles.
2. The four colligative properties of a solution are vapor pressure, osmotic pressure, boiling point and freezing point.
3. The change in vapor pressure where the solute is less volatile than the solvent is regulated by Raoult's law, which states that the vapor pressure of a solvent over a solution is equal to the mole fraction of the solvent times the vapor pressure of pure solvent.
4. The osmotic pressure of a solution is the pressure required to stop osmosis.
5. The freezing point of the solution is always less than the freezing point of the pure solvent.
6. The boiling point of the solution is always greater than the boiling point of the pure solvent.
7. In electrolyte solutions, the interaction between ions leads to the formation of ion pairs. The van't Hoff factor (i) provides a measure of the extent of dissociation of electrolytes in solution.
8. Solutions can be classified as hypertonic, hypotonic or isotonic depending on the concentration of solute inside and outside the cell.
9. A hypertonic solution has a higher concentration of particle than the cell causing the cell to shrink.
10. A hypotonic solution has a lower concentration of particles than the cell causing the cell to swell.
11. An isotonic solution has the same osmotic strength on both sides of the semipermeable membrane.

Posttest

I. Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. According to Raoult's law, which statement is **FALSE**?
   a. The solubility of a gas increases as the temperature decreases.
   b. The greater the pressure of a gas over a solution the greater its solubility.
   c. The vapor pressure of a solvent over a solution is less than that of pure solvent.
   d. The vapor pressure of a solvent over a solution decreases as its mole fraction increases.

2. Consider a solution made from a nonvolatile solute and a volatile solvent. Which statement is **TRUE**?
   a. The osmotic pressure is the same as vapor pressure of the solution.
   b. The vapor pressure of the solution is always greater than the vapor pressure of the pure solvent.
   c. The boiling point of the solution is always greater than the boiling point of the pure solvent.
   d. The freezing point of the solution is always greater than the freezing point of the pure solvent.

3. Dissolving a solute such as NaCl in a solvent such as water results in:
   a. an increase in the melting point of the liquid
   b. a decrease in the boiling point of the liquid
   c. a decrease in the vapor pressure of the liquid
   d. no change in the boiling point of the liquid

4. What is the freezing point of a solution that contains 10.0 g of glucose ($C_6H_{12}O_6$) in 100 g of H_2O? K_f = 1.86 $^oC/m$?
   a. -0.186 ^oC
   b. 0.186 ^oC
   c. -0.10 ^oC
   d. -1.03 ^oC

5. Which of the following solutions has the highest osmotic pressure at 25^oC?
   a. 0.2 M KBr
   b. 0.2 M C_2H_5OH
   c. 0.2 M Na_2SO_4
   d. 0.2 M KCl

6. A solution that contains 55.0 g of ascorbic acid (Vitamin C) in 250 g of water freezes at -2.34 C. Calculate the molar mass (g/mol) of the solute. K_f = 1.86 $^oC/m$.
   a. 1.26
   b. 10.9
   c. 43.6
   d. 175

7. What mass of ethanol, C_2H_5OH, a nonelectrolyte, must be added to 10.0 L of water to give a solution that freezes at -10.0^oC? Assume the density of water is 1.0 g/mL?
   a. 85.7 kg
   b. 24.8 kg
   c. 5.38 kg
   d. 2.48 kg

8. If solution A contains 5 grams of NaCl in 100 grams of water and solution B contains 10 grams of NaCl in 100 grams of water, which of the following comparisons is true?
   a. A has a higher boiling point and a higher freezing point than B.
   b. A has a lower boiling point and a lower freezing point than B.
   c. A has a lower boiling point and a higher freezing point than B.
   d. A has a higher boiling point and a lower freezing point than B.

9. Which solution has lower concentration of particles than the cell causing the cell to swell?
   a. hypertonic
   b. hypotonic
   c. isotonic
   d. unsaturated

10. In what temperature does the vapor pressure of the liquid equal the atmospheric pressure?
    a. 100^{o}C
    b. boiling point
    c. melting point
    d. freezing point

II. Matching Type. Match the correct equation in Column B with the principles in Column A.

Column A	**Column B**
______ 1. Raoult's law	a. $\Delta T_b = K_b m$
______ 2. Dalton's law of partial pressures	b. $\Pi = MRT$
______ 3. Boiling point elevation	c. $P_1 = P^o_1 X_1$
______ 4. Freezing point depression	d. $P_T = P_A + P_B$
______ 5. Osmotic pressure	e. $\Delta T_f = K_f m$
	f. $\Delta P = P_2 - P_1$

Key to answers on page 22.

Key to Answers

Pretest

I. Multiple Choice		II. True or False
1. a	6. c	1. True
2. a	7. a	2. False
3. a	8. c	3. False
4. a	9. a	4. True
5. c	10. a	5. True

Lesson 1	**Lesson 2**	**Lesson 3**	**Lesson 4**
Self-Test 1.1	**Self-Test 2.1**	**Self-Test 3.1**	**Self-Test 4.1**
1. a	1. b	1. a	1. True
2. d	2. b	2. a	2. 0.9 % NaCl
3. b	3. b	3. b	3. True
4. c	4. d	4. d	4. Hypertonic
5. a	5. c	5. c	5. greater

Posttest

I. Multiple Choice		II. Matching Type
1. d	6. d	1. c
2. c	7. d	2. d
3. c	8. c	3. a
4. d	9. b	4. e
5. c	10. b	5. b

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