

Analysis of Concepts and Propositions through Multi-Representation Based Inquiry Learning on Colligative Properties

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Abstract. In chemistry, there are three levels of representation namely macroscopic, submicroscopic, and symbolic. Chemistry is a branch of science that requires students to have an understanding of concepts and mathematical skills, one of which is colligative properties. The aim of this research is to analyze the concept of colligative properties so that students don't have misconceptions and can enhance their understanding through a multi-representation approach. The method used is the scientific approach, based on a series of five main learning experiences: Observing, Questioning, Reasoning, Associating, and Communicating. Information collection techniques include concept maps, concept analysis, and propositions. Colligative properties consist of vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure. The van't Hoff factor is present in most colligative properties where the solute is an electrolyte substance.

Keywords: colligative properties, concept analysis, proposition, scientific approach, multi-representation

INTRODUCTION

Chemistry is a scientific discipline that explores the structure, properties, and changes in matter and the energy changes associated with these transformations [1]. In the realm of chemistry, there are three levels of representation, namely (1) the macroscopic level, which involves observations that can be made with our senses; (2) the submicroscopic level, where we examine entities such as atoms, ions, and molecules; and (3) the symbolic level, where we use formulas or models to express these entities [2]. In studying chemistry, students need a strong understanding of concepts and mathematical skills [3]. Both of these are very important when learning chemical materials such as colligative properties.

Colligative properties are chemical phenomena that are often encountered in everyday life and include the exploration of abstract concepts [4]. In Attachment 9 of Minister of Education and Culture Regulation of Indonesia No. 24 of 2016, various fundamental competencies related to colligative properties are outlined, including (1) Analyzing the phenomenon of colligative

properties; (2) Distinguishing between colligative properties in electrolyte and non-electrolyte solutions; (3) Explain the application of colligative properties in everyday life; and (4) Analyzing experimental data to determine the degree of ionization [5]. Through concept analysis, colligative properties cover four dimensions of knowledge: factual, conceptual, procedural, and metacognitive knowledge, as defined in the revised Bloom's taxonomy [6]. Widarti *et al.* [7] stated that colligative properties material includes all three levels of representation, namely macroscopic, submicroscopic, and symbolic levels. Employing multi-representation, which involve using various chemical models, is one approach to enhancing concept understanding.

The multi-representation approach enhances concept comprehension through diverse representations [8]. This approach is widely recognized as effective in enhancing concept understanding. Inquiry-based learning is a suitable educational model for fostering a deeper grasp of concepts through multi-representation in the classroom. Inquiry-based learning readily attains educational objectives within the classroom [9]. Students derive

advantages from revisiting their understanding of the concept and being given the chance to construct their comprehension, drawing upon their existing knowledge [10].

An inquiry-based approach is one of the necessary learning methods to enhance these skills [11]. Inquiry, or scientific explanation, lies at the core of science and science education [12]. Science teaching should engage students in discussions and enable them to share their scientific knowledge alongside scientific insights from various sources. Inquiry-based learning empowers students to elaborate on their studied concepts rather than simply memorizing and recording the material [13].

The inquiry learning model allows active students to acquire information through investigation. Scientific inquiry combines traditional scientific processes, knowledge, scientific reasoning, and the development of scientific knowledge with critical thinking. Scientific inquiries involve scientists' systematic approach to address questions [14]. As conceptualized through inquiry-based learning, the analysis of concepts and propositions related to colligative properties material is expected to provide an understanding of the knowledge and skills required in high school and in the current digital era. This article aims to analyze the concept of colligative properties to prevent students from developing misconceptions and enhance their understanding through multi-representation.

METHOD

Research or the scientific method is the result or series of actions to gain scientific understanding. This article applies a scientific

approach, and the learning model is based on the scientific method as the main point in the teaching and learning process. The scientific inquiry model in the scientific approach is the steps used to investigate problems, overcome challenges, and find valid solutions. This model emphasizes critical thinking processes, using valid data, and analyzing the obtained information to draw logical conclusions. This process guides researchers to explore problems and produce valid answers systematically. In its application, students will explore the learning materials through a series of activities: observing, questioning, collecting data, and communicating the results [15].

- a. Observation prioritizes the meaningfulness of the learning process.
- b. Questioning allows students to ask about what they have seen, heard, or read.
- c. Reasoning involves processing the collected information, whether limited to data collection, experiments, or collecting information, to find connections between pieces of information and discover patterns.
- d. Associating/experimentation results in tangible or authentic learning outcomes when students try or conduct experiments.
- e. Communication allows students to communicate what they have learned in the scientific method.

Information gathering in this article involves reading chemistry books from reliable sources, such as [16], [17], [18], [19], [20], [21], using references from Scopus indexed journals, and then using it to create a concept map for the it's a colligative property's material and conducts concept and proposition analysis. The concept map of colligative properties is shown in Figure 1.

RESULT AND DISCUSSION

Solution

A homogenous mixture made of a solute and a solvent is called a solution [18]. Meanwhile, the components of the solution appears in Figure 2.

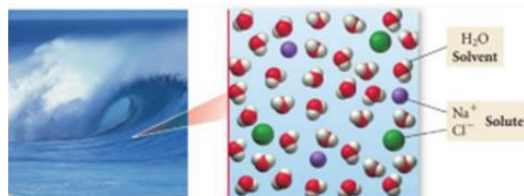


Figure 2. Solution Components [16]

A solvent is an agent capable of dissolving other agents. It generally has a greater amount than the dissolved substance (the principal component). Meanwhile, a solute refers to a substance that can dissolve in a solvent. It generally has a small amount (minor) compared to the solvent. Table 1 shows the types of solutions and their examples.

Table 1. Types of Solutions [18]

Components 1	Components 2	State of the Solution	Example
Gas	Gas	Gas	Air
Gas	Liquid	Liquid	Soda water (CO ₂ in the water)
Gas	Solid	Solid	H ₂ in the palladium
Liquid	Liquid	Liquid	Ethanol in the water
Solid	Liquid	Liquid	NaCl in the water
Solid	Solid	Solid	Brass (Cu/Zn)

Phase Change

The process of forming a new phase with a different composition and structure is known as phase change. Changes in molecular organization are the hallmark of phase changes, which are physical transformations. Molecules exhibit the highest degree of order in the solid phase and highest degree of randomness in the gas phase. Understanding the changes in energy and the level of molecular order is essential in characterizing the physical changes of a substance.

Liquid-Gas Equilibrium

Although molecules in the liquid state aren't confined to a rigid lattice, they nevertheless don't move as freely as molecules in gases. State differently, molecules in a liquid state continue to move constantly. Because liquids have a larger density than gases, compared to the gas phase, the rate of molecular collisions in the liquid phase is substantially higher. The process of converting a liquid into a gas is called vaporization.

The liquid's molecular kinetic energy distribution at temperature T_1 (a) and T_2 (b), respectively, at higher temperatures, are plotted on graphs. It is observed that the kinetic energy

distribution becomes more uniform at increasing temperature. On the graph, the shaded area indicates the quantity of molecules whose kinetic energy is at least as high as the E_1 value. Temperature increases the quantity of molecules with high kinetic energy, it is shown in Figure 3.

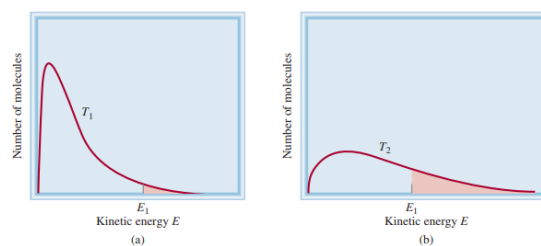


Figure 3. Solution Components [18]

Figure 4 depicts the device used to measure the vapor pressure of liquids.

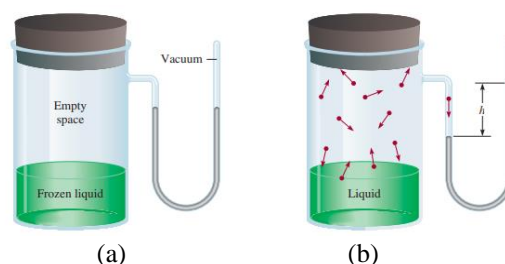


Figure 4. A Manometer is an Instrument Used to Measure the Vapor Pressure of Liquids [18]

(a) The liquid first freezes, preventing any molecules from entering the vapor state, and (b) The evaporation process starts when a hot liquid phase occurs. At the equilibrium, there are the same number of molecules exiting and entering the liquid.

Liquid-Solid Equilibrium

Melting is the opposite process of solidification, which is the change from a liquid to solid. The temperature at which a substance coexists in both liquid and solid phases in an equilibrium state is known as the melting or freezing point of that substance. The "standard melting (or freezing) point" is the temperature at which a substance melts (or freezes) at a pressure of one atmosphere. Water and ice have the most well-known liquid-solid equilibria. We see the heating curve in Figure 5.

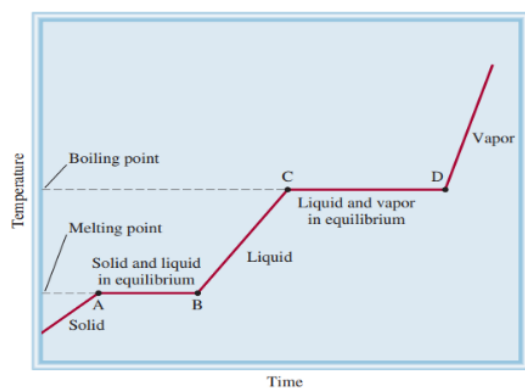


Figure 5. Heating Curve [18]

The standard heating curve, which depicts a substance's phase shift from solid to liquid and subsequently to gas, is shown in Figure 5. The material melts more quickly than it boils because the fusion heat (H_{fus}) is less than the vaporization heat (H_{vap}). The shorter length of (A→B) compared to (C→D) explains this phenomenon. This is because substances have unique heats in each of their states, which determines the steepness of the heating lines of solids, liquids, and vapors. The temperature change that occurs when a substance absorbs heat from its surroundings is seen in Figure 5. It has been shown that heating a solid material will cause the temperature to rise until it melts. The average molecular kinetic energy at this temperature is high enough to start overcoming the intermolecular interactions that keep in the solid form. It is important to remember that during this transition, the molecules' average kinetic energy doesn't change (A→B), meaning

that the temperature also stays constant. Heat absorption greatly increases as the material melts completely. When the amount of liquid increases during the condensation period (D→C), the system releases heat. This happens as a result of the system's potential energy declining. The liquid's temperature starts to drop when all of the steam has condensed. The liquid finally freezes as a result of constant cooling (B→A). The occurrence of a liquid being momentarily cooled below its normal freezing point is known as supercooling.

Solid-Gas Equilibrium

The solid also undergoes the process of evaporation and, therefore, has vapor pressure. Sublimation occurs when molecules transition straight from the solid to the gas phase. In other words, deposition is opposite process when molecules go straight from gas to solid state. The component of champor, naphthalene, possesses a solid with a rather high vapor (equilibrium) pressure (1 mmHg at 53°C); as a result, its unpleasant gas enters retracted places with great speed.

The amount of energy needed to sublimate one mole of a material is known as the molar heat of sublimation (H_{sub}), and it is expressed in kJ. The quantity is determined by the molar heat of vaporization and fusion:

$$H_{\text{sub}} = H_{\text{fus}} + H_{\text{vap}}$$

The equation above illustrates Hess's law. Whether the substance goes through a direct transition from a solid to a gaseous state or a transition from a solid to a liquid and then back to a gas, the overall process' enthalpy, or heat change, stays the same. This equation only applies if all phase changes occur at identical temperatures. Otherwise, the equation can only be used as an approximation.

Phase Diagram

Matter can spontaneously change from one phase to another depending on temperature and pressure. Therefore, phase diagrams are a convenient way to show the relationship between temperature and pressure in pure substances in closed systems without air. Phase diagrams also show the states in which substances can become solid, liquid, or gas.

Figure 6 illustrates a typical phase diagram, which shows a phase that is stable under various combinations of pressure and temperature, similar to what happens in water.

Phase transitions occur when the boundary lines between phases cross as a result of changes in temperature or pressure.

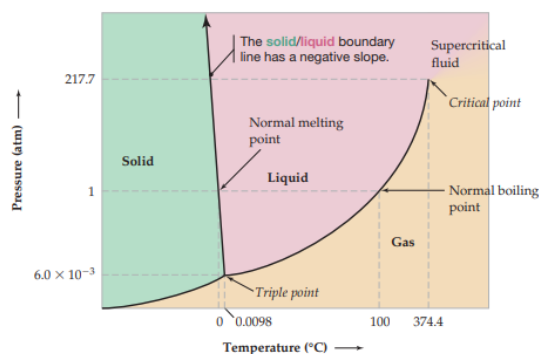


Figure 6. Phase Diagram for H₂O [19]

These lines indicate pressure and temperature points, where in a closed system, solid ice and gaseous water vapor directly undergo a phase change. At different points along the solid/gas boundary line, there are triple points, where two lines come together to form the liquid boundary.

As the boundary between solid and liquid bends upward and to the right, the border between solid and liquid H₂O rises slightly to the left. This triple point, as it is sometimes called, is a unique location when pressure and temperature combine to create a condition of equilibrium where all three phases coexist. The triple-point pressure and temperature of water are 6×10^{-3} atm and 0.0098°C respectively.

The melting point or specially 0°C , the melting point is accurately known as the typical melting point at 1 atm pressure. The boundary line between liquid and gas is the pressure or temperature combination where both phases, specifically, when liquid and gas coincide, water moves from the triple point to the right and evaporates (or condenses). The normal boiling level of water at 1 atm pressure is 100°C . By following the liquid/gas boundary line, one might arrive at the critical point, which is where it abruptly ends. Critical pressure and temperature are the points at which a liquid cannot evaporate at a given pressure and temperature, respectively, and at which a gas cannot be liquefied. $T_c = 374.4^\circ\text{C}$, $P_c = 217.7$ atm.

The boundary between two areas indicates conditions in which these two phases cannot function together. We are able to predict which way phase transitions caused by temperature changes will go, as well as changes in a

substance's melting and boiling temperatures, by using the phase diagram; phase transitions brought on by variations in pressure and temperature can also be predicted in terms of their direction.

The substance reaches the critical point at a temperature so high that its molecules are too close together to be separated from a gas. Consequently, what starts as a liquid and ends up as a supercritical fluid is the outcome of the two phases coming together. When going above the critical point, there doesn't seem to be any physical phase change.

Colligative Properties

Colligative properties are those whose features solely rely on the solute's concentration [18]. The main factor that causes changes in the environment is the number of dissolved substance particles, which can be atoms, ions, or molecules. Colligative properties consist of vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure.

Vapor Pressure Lowering

Equilibrium between the solvent and its vapor will be achieved in a closed system, where this system only involves energy exchange [19], as seen in Figure 7. The resulting pressure is called the solvent's saturated vapor pressure.



Figure 7. Solvent's Saturated Vapor Pressure in a Closed System [20]

The solution will reach equilibrium with the vapor when it is in a closed system, as seen in Figure 8. The resulting pressure is called the solution's saturated vapor pressure.



Figure 8. Solution's Saturated Vapor Pressure in a Closed System in a Closed System [20]

In a solution, the solute prevents the solvent molecules from evaporating [19]. The difference in irregularity between the pure solvent and its vapor is greater than that between the solution and its vapor, as seen in Figure 9, where the regularity of the pure solvent is smaller than that of the solution. Consequently, the likelihood of solvent molecules leaving the solution is reduced compared to the case of pure solvent turning into vapor.

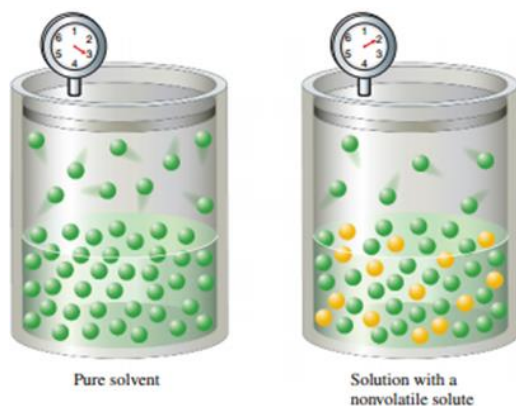


Figure 9. Saturated Vapor Pressure of Solvents and Solutions [20]

The presence of volatile solutes also causes a decrease in vapor pressure [18], as seen in Figure 10. The presence of these solutes causes the equilibrium to be rearranged with a smaller quantity of molecules.

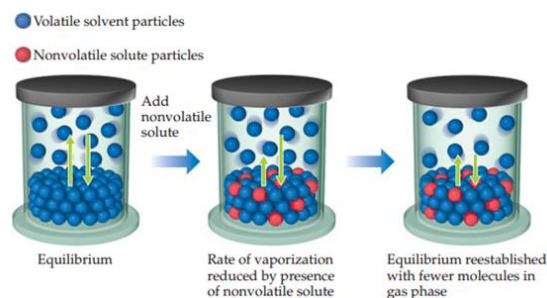


Figure 10. The Presence of Nonvolatile Dissolved Substances can Cause a Decrease in Vapor Pressure [17]

Raoult's law states that the solute concentration in the solution determines the relationship between the vapor pressures of the solvent and the solution. In other words, P_{soln} versus solvent mole fraction yields a straight line with the same slope as the solvent. P^0 , as shown in the following Figure 11.

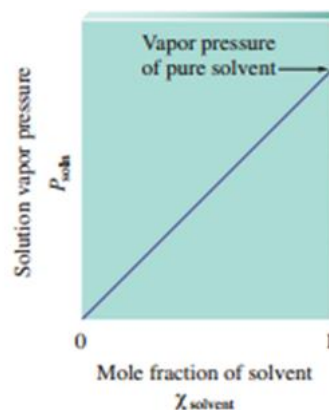


Figure 11. A Plot of P_{soln} vs Solvent Fraction [20]

So, the following formula is obtained:

$$P_{\text{Solution}} = X_{\text{Solvent}} P^0$$

Note: P^0 is the solvent's pure vapor pressure.

$X_{\text{Solvent}} = 1 - X_2$ in a solution with a single solute, where X_2 represents the solute's mole fraction. Thus, the equation is as follows:

$$P_{\text{Solution}} = (1 - X_2) P^0$$

$$P^0 - P_{\text{Solution}} = \Delta P = X_2 P^0$$

According to the equation, there is a direct correlation between mole fraction and the decrease in vapor pressure (P). An illustration of the practical application of decreasing vapor pressure is evident in the pressure cooker mechanism depicted in Figure 12.



Figure 12. Pressure Cooker

Before adding fish (only water) to the pressure cooker, the pure solvent (water) will have a high vapor pressure. When the pressure cooker has fish in it, the steam pressure will be lower than the water vapor pressure. It is because the presence of a solute will prevent solvent molecules from leaving the solution.

Assume that a mixture of two liquids has both of its components volatile, meaning that their vapor pressure is measurable. In that scenario, the total of the partial pressures of each component is the solution's vapor pressure [19]. It can be seen in Figure 13.



When a solution contains two volatile components, both contribute to the total vapor pressure. Note that in this case the solution contains equal numbers of the components \circ and \bullet but the vapor contains more \circ than \bullet . This means that component \circ is more volatile (has a higher vapor pressure as a pure liquid) than component \bullet .

Figure 13. A Solution Containing Two Volatile Components [20]

In this instance, Raoult's law is equally applicable:

$$P_A = X_A P_A^\circ$$

$$P_B = X_B P_B^\circ$$

Dalton's law states that the sum of the pressures of two volatile liquids can be added. Therefore, the formula is as follows:

$$P_{\text{total}} = P_A + P_B$$

A liquid-liquid solution that meets Raoult's Law is considered optimal. An ideal solution has interactions that are indistinguishable from

one another. The vapor pressure in a two-component solution can be seen in Figure 14.

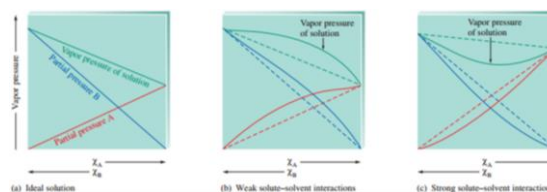


Figure 14. Vapor Pressure in a Two-volatile Liquid Solution. (a) Raoult's Law Predicts the Behavior for a Perfect Liquid-liquid Mix. (b) There is a Positive Deviation from Raoult's Law (The P_{total} Solution is Larger than The Value Derived from Raoult's Law). (c) There is a Negative Deviation from Raoult's Law in The P_{total} Solution Compared to the Value Derived from Raoult's Law [20]

Real solution variations are influenced by the type and potential of intermolecular forces in a solution. Positive deviation occurs if the interaction between solvent molecules alone is greater than the force between solute particles and solvent molecules, such as a mixture of ethanol and hexane as shown in Figure 14(b). Meanwhile, negative deviation occurs if the interaction between solute particles and solvent molecules is stronger than the solvent force alone, for example in a mixture of acetone and water, as shown in Figure 14(c).

Boiling Point Elevation

The solvent's vapor pressure decreases with the addition of nonvolatile solutes. Therefore, the solution's vapor pressure curve in Figure 15 shifts downward in comparison to the pure solvent's vapor pressure curve.

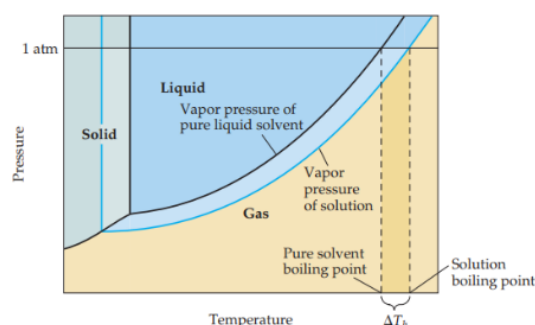


Figure 15. Boiling Point Elevation Phase Diagram [17]

When a liquid comes into contact with a solid surface that is warmer than the liquid's saturation temperature, boiling takes place. For

example, water that has a pressure of 1 atm will experience boiling if it comes into contact with the surface of a solid substance that has a temperature of 110°C because the saturation temperature of water at 1 atm is 100°C. This boiling process requires heat or energy from the surroundings. Evaporation is the transition of a liquid state into a gas, as opposed to boiling. In this event, the substance does not require heat energy. A liquid's boiling level is usually defined as the temperature at which vapor pressure is equal to one atmosphere. When the pure solvent's vapor pressure is at a lower temperature, the solution needs to be heated to a higher temperature in order to obtain a vapor pressure of one atm. As a result, the boiling point of the solution is higher than the boiling point of the pure solvent. When compared to the pure solvent, higher boiling point because the horizontal line at 1 atm crosses the vapor pressure curve, which is also referred to as the blue line. Figure 16 illustrates the process of raising the boiling point of a solution.

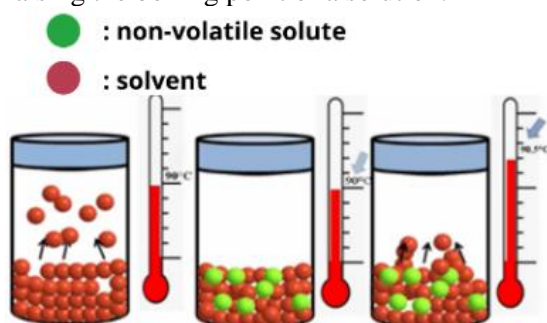


Figure 16. Representation of The Process of Increasing the Boiling Point of a Solution

Solute particles make the boiling point of water lower than other solutions, such as solutions containing sugar and salt. Then, the solution's boiling point rises with the amount of solute added to the water solvent. In the event of heating pure water with a salt solution or sugar solution, there is a difference in temperature obtained when a sugar or salt solution boils and pure water when it boils. For the boiling point to rise, the solute needs to be nonvolatile. The boiling point elevation is (T_b) a positive number that can be calculated by subtracting the pure solvent's boiling point from the solution's boiling point.

$$T_b = T_b - T_b^0$$

The molality of the solution has a direct relationship with T_b 's value.

$$\Delta T_b = k_b \cdot m$$

Fixed molal boiling point elevation k_b and solution molality m are measured in °C/m. The boiling point elevation constant, or k_b , is the only value that depends solely on the solvent. Table 2 below provides some typical values for a few popular solvents.

Table 2. Solvent k_b [17]

Solvent	Normal Boiling Point (°C)	k_b (°C/m)
Water	100.0	0.51
Benzene	80.1	2.53
Ethanol	78.4	1.22
Carbon Tetrachloride	76.8	5.02
Chloroform	61.2	3.63

The constants given in the table only function well for solutions that are not very concentrated since solutions typically do not behave perfectly. When electrolyte substances are dissolved in water, polar covalent compounds suffer ionization, while ionic compounds experience dissociation. This results in an elevated boiling point for electrolyte solutions compared to non-electrolyte solutions, which, even with the same amount of particles, produces more electrolyte solute particles than non-electrolyte. The degree of ionization determines how many ions are released from the electrolyte.

Refining, often known as distillation, is a chemical separation technique based on variations in the materials volatility, or ease or speed of evaporation. In the distillation process, a combination of chemicals is boiled until it evaporates, and then the vapor is cooled back into liquid form. Lower boiling point substances will evaporate first [21]. The principle of distillation is the evaporation of a liquid and the condensation of the vapor again at the boiling point temperature.

Freezing Point Depression

The freezing point of a solution is the temperature at which, at equilibrium between the liquid and solution phases, the first pure solvent crystals form. Figure 17 shows freezing point depression phase diagram.

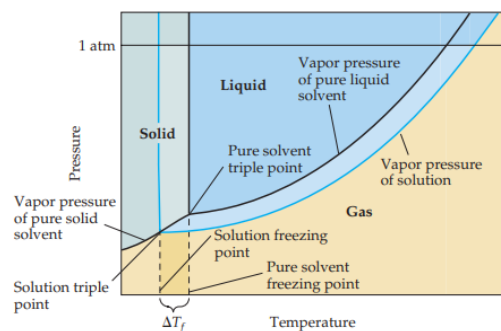


Figure 17. Freezing Point Depression Phase Diagram [17]

From the triple point, it is evident that the solid-liquid equilibrium line rises nearly vertically. Because the triple point temperature of a solution is lower than that of a pure liquid, the freezing point temperature of a solution is likewise lower. The process of freezing entails going from an unorganized to an organized condition. Because solutions are more disordered than pure solvents, more energy needs to be extracted from the system to achieve this. The impact of solute addition on the freezing point of a pure solvent is depicted in Figure 18.

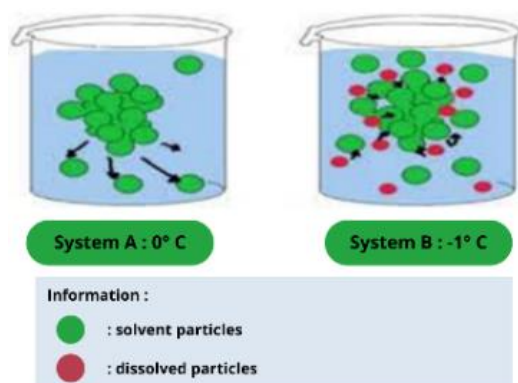


Figure 18. Submicroscopic Representation of The Freezing Point Depression Process

Figure 18 shows how a solvent causes the freezing point to drop from 0 to -1, creating the freezing point depression, which is a temperature differential between the pure solvent and the solution. When the freezing point of solution is subtracted from the freezing point of a pure solvent, The freezing point depression is formed when ΔT_f a positive value, is reached.

$$\Delta T_f = T_f^\circ - T_f$$

The value of T_f is directly correlated with the molality of the solution, just like the boiling point elevation:

$$\Delta T_f = k_f \cdot m$$

Where m is the molality of the solution, and k_f is the molal freezing point depression constant. The quantity (k_f), also known as the freezing point depression constant, depends only on the solvent. The unit of k_f is $^\circ\text{C}/m$. Table 3 below shows typical values for some common solvents.

Table 3. Solvent k_f [17]

Solvent	Normal Freezing Point ($^\circ\text{C}$)	k_b ($^\circ\text{C}/m$)
Water	0.0	1.86
Benzene	5.5	5.12
Ethanol	-114.6	1.99
Carbon	-22.3	29.8
Tetrachloride		
Chloroform	-63.5	4.68

The freezing level of the solution is lower than that of the pure solvent affected by the concentration of solute particles and the height of the boiling point. An electrolyte substance has a higher freezing point than a non-electrolyte substance, much like boiling point elevation. It is because non-electrolyte substances can't undergo dissociation or ionization, whereas electrolyte substances undergo both.

Making ice cream is a real-world example of how the freezing point depression principle is used. Ice cream, which consists of various solute particles, is frozen using ice cubes and salt. If only ice cubes are added, the ice cream won't freeze; but adding salt will cause the ice cubes' freezing point to drop because it is lower than that of water. This results in a decrease in the temperature around the ice cream, causing it to freeze.

Osmotic Pressure

The movement of particles from a pure solvent or more diluted solution to a more concentrated solution over a semipermeable membrane is known as osmosis. Only specific molecules can cross a semipermeable membrane, preventing others from doing so [20]. This occurs because semipermeable membranes possess pores or structures that exclusively permit molecules of a certain size and polarity to pass through. Typically, semipermeable membranes have pores with sizes ranging from approximately 1 nanometer to 10 nanometers [20], [22]. Solutions containing solutes with larger and more

complex molecules encounter difficulty passing through the pores of semipermeable membranes, particularly when the size or polarity of the solute molecules doesn't align with the membrane's structure [19], [20]. Therefore, semipermeable membranes only permit the passage of pure solvents and not solutions containing solutes. The structure of a semipermeable membrane can be observed in the following Figure 19.

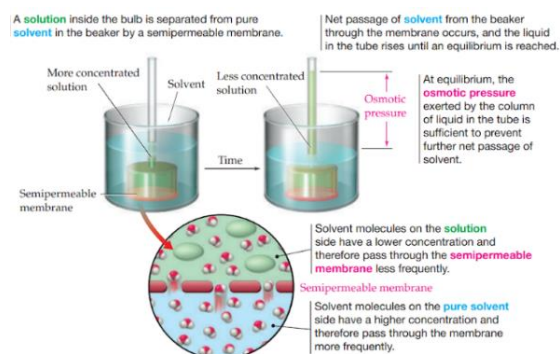


Figure 19. Tube with Semipermeable Membrane [19]

Figure 19 illustrates the phenomenon of osmotic pressure. The left tube contains only pure solvent or more dilute solution, while the bulb tube contains a more concentrated solution. A semipermeable membrane that separates the two tubes permits solvent molecules to flow through while obstructing solute molecules. This creates a condition where only the solvent can move past the membrane, while the solute is trapped on one side of the membrane. More concentrated solutions generate greater hydrostatic pressure than pure solvents or more dilute solutions. Hydrostatic pressure is due to the specific gravity of the solution and is related to its concentration. A more concentrated solution in the bulb tube causes higher hydrostatic pressure. Over time, solvent molecules move from the tube with the pure solvent or more dilute solution to the bulb tube until equilibrium is reached. This process stops when the hydrostatic pressure on both sides of the membrane becomes balanced. Once equilibrium is reached, the water level in the tube remains constant, indicating that no further changes can be observed. The process of solvent molecule movement continues, but in equal amounts in both directions, so there is no net change in the water level. By adding external pressure to the solution, it is possible

to stop the solvent's natural osmosis migration into the solution. The lowest pressure needed to halt osmosis in a solution is known as its osmotic pressure (π) [18].

An isotonic solution is one that has two solutions with the same solute concentration, a hypotonic solution is one that has a lower solute concentration than the other, and a hypertonic solution is one that has a higher solute concentration than the other. These three types of solutions are found in an osmosis system. During the osmosis process, solvent molecules move from a hypotonic solution to a hypertonic solution [18]. Figure 20 shows the red blood cells are in isotonic, hypotonic, and hypertonic solutions.

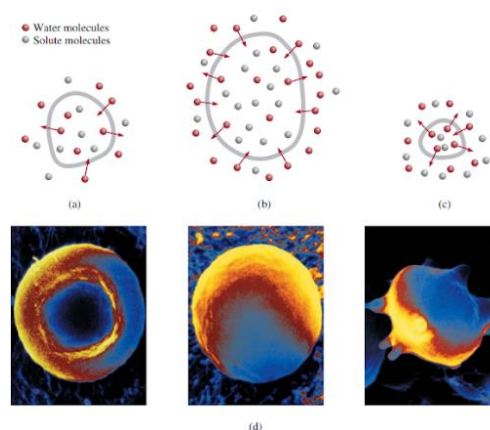


Figure 20. Cells are in (a) Isotonic, (b) Hypotonic, and (c) Hypertonic Solutions. The Cell Remains Unchanged in (a), Swells in (b), and Shrinks in (c). (d) From Left to Right by Macroscopic Level: Red Blood Cells in Isotonic, Hypotonic and Hypertonic Solutions [18].

Hemolysis is the breakdown of the red blood cell membrane that causes the release of hemoglobin into the plasma. This process involves the formation of holes in the red blood cell membrane, which ultimately leads to the release of its contents. Although the term "hemolysis" is often associated with the destruction of red blood cells, in the context of biochemical research, it is a method deliberately used to access and study the inner components of red blood cells. The osmotic pressure (π) of a solution is calculated using the following formula equation.

$$\pi = MRT$$

Osmotic pressure (π) is expressed in atm, where M is the molarity of the solution, R is the gas constant (0.0821 L.atm/K.mol), and T is the absolute temperature. The relationship between

osmotic pressure and solution concentration is linear.

Van't Hoff Factor

The colligative properties of electrolyte solutions require slightly different calculations than non-electrolyte solutions because electrolyte solutions dissociate into ions in solution, and electrolyte compounds separate into two or more particles when dissolved. The van't Hoff factor is the ratio between moles of particles in solution to the moles of solute dissolved [20]. The van't Hoff factor is formulated as follows:

$$i = \frac{\text{moles of particles in solution}}{\text{moles of solute dissolved}}$$

As a result, the equation for colligative properties of electrolyte solutions must be modified as follows:

$$\begin{aligned} T_b &= k_b \cdot m \cdot i \\ T_f &= k_f \cdot m \cdot i \\ \pi &= M \cdot R \cdot T \cdot i \end{aligned}$$

CONCLUSIONS

A homogenous mixture made of a solute and a solvent is called a solution. This solvent can undergo phase changes, including solid, liquid, or gas phases, as depicted in the phase diagram. During a phase change, it is referred to as phase equilibrium, which is a condition where the change process between two phases is balanced. Phase equilibrium include liquid-gas, liquid-solid, and solid-gas. Colligative properties include vapor pressure lowering, boiling point elevation, freezing point depression, and osmotic pressure. In each colligative property for the solute, particularly for electrolytes, there exists a van't Hoff factor. The multi-representational approach can enhance the process and assessment of chemistry learning, including the topic of colligative properties.

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