Examiner's commentary

This is clearly a chemistry-focused piece of work, with stress on concepts like Raoult's law that are not usually read in an Extended Essay, which shows the student has embraced a challenging topic. The candidate offers a hypothesis based on previous knowledge exposed, which always helps keeping focus when reading the work. The application of sources is relevant throughout, with good use of terminology, and a key point is the interpretation of results which shows very good knowledge and understanding of the chemistry principles underlying the investigation. The conclusion accounts for results and is reflective of the evidence presented, which is another good point to stand out together with a well-done argument. There is a good evaluation that shows awareness of limitations in the approach of the task. While there are some flaws in the graphs, this is a good example of an Extended Essay that is not "perfect", but that complies with most of what is expected in the different criteria. The one criterion which brings some issues is communication, as students tend to keep the format of an internal assessment and include safety and environmental facts which are not relevant in this context.

Title

Deviation of Colligative Properties for Non-ideal Solutions: Total Ionic Radii of Salt particles and its Relevance to Boiling and Melting Points of Saline Solutions

Research Question

How Does the Total Ionic Radii of the Salt Particle Affect the Disparity Between the Melting and Boiling Point of Saline Solution?

Subject

Chemistry

Word count: 3946

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Introduction

As a nonvolatile solute dissociates in a solvent, the solution formed will possess a higher boiling point and lower melting point compared to the pure solvent, enlarging the disparity between the temperatures at which the two phase changes occur. Such properties are known as the colligative properties of solution and can be applied to cooking, road safety, medicine, and other industrial processes. Observable examples extracted from daily life include spreading salts on roads in response to winter weather or putting salts into a pot of boiling water when making pasta. While theories relevant to colligative properties are established based on the assumption of an ideal solution, this paper focuses on the non-ideal behavior of real solutions in terms of boiling point elevation and melting point depression by analyzing the interaction between salts and water on a molecular level during the two phase changing processes. Understandings on real solutions shell be developed in order to gain insight or maximize its possible practical applications.

Background Information

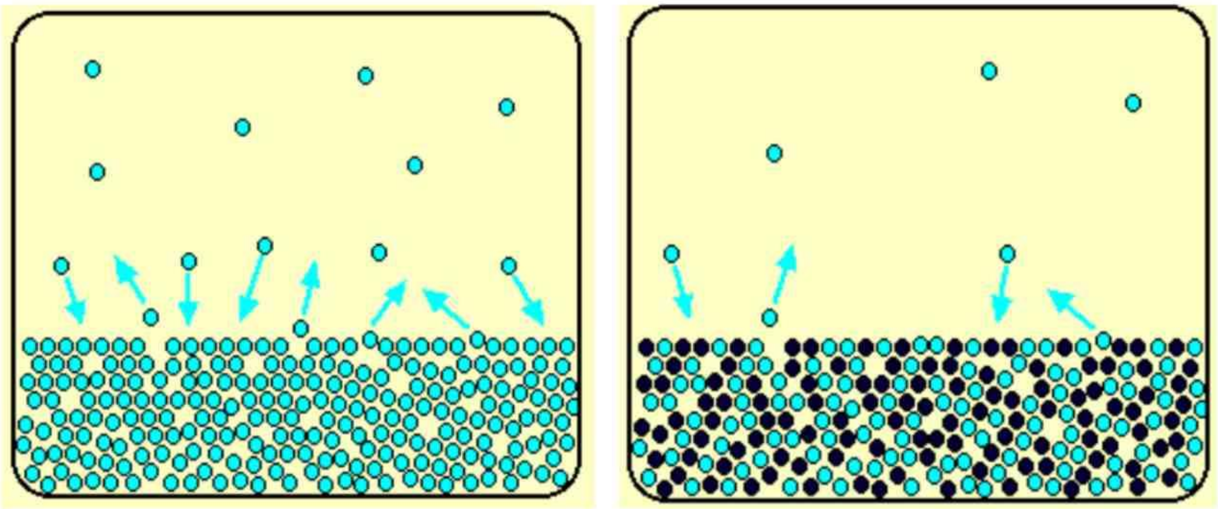
Colligative properties of solution states that degree of boiling point elevation and melting point depression is dependent on the molal concentration of the solution but not the identity of the solute, based on the assumption of an ideal solution. This assumes that the interactions between all particles in a solution are identical, where $\Delta H_{solution}$, enthalpy of solution, equals to zero. In other words, the electrostatic forces between solvent-solvent particles, solvent-solute particles, and solute-solute particles requires equal amount of energy to be disrupted. Species that makes up the ideal solution are required to be similar in size, structure, and chemical nature (Trebal). To explain the two phenomena, two approaches that are still in debate are used: the thermodynamic approach and the kinetic approach.

From the thermodynamics perspective, the entropy of a solution is greater than the pure solvent, while the entropy of the vapor, regardless the solution or pure solvent, is constant since the non-volatile solute does not vaporize. As $S_{solution} > S_{solvent}$ and S_{vapor} remains the same, it can be established that $\Delta S_{vap\ solution} < \Delta S_{vap\ solvent}$. Assuming that the interactions between solvent-solvent, solute-solvent particles are identical, the $\Delta H_{vap\ solution} \approx \Delta H_{vap\ solvent}$ (Atkins and Loretta). Applying the equation $\Delta G_{vap} = \Delta H_{vap} - T\Delta S_{vap}$, where both enthalpy and entropy changes are positive, $T\Delta S_{vap}$, has to be equivalent to ΔH_{vap} in order for boiling to occur spontaneously (Chemistry Stack Exchange). The inverse relationship between temperature and entropy change illustrates the idea which the solution with a smaller ΔS requires higher temperature to boil. The same concept is applied to the melting/freezing process. The thermodynamic approach suggests the that the phenomena is entirely influenced by entropy of solution, which is determined by the number of solute particles, and implies no relevance to solute identity, which is only considered in real solutions.

The kinetics approach, on the other hand, refers to the particle-obstruction theory and the vapor pressure of the solvent and solution. Boiling occurs when the vapor pressure of the substance is equivalent to the atmospheric pressure, hence the boiling point varies for substances with different vapor pressure at the same temperature (Willman). Nonvolatile solute has a low tendency to enter the vapor phase. When introduced to a solvent, the dissociated particles do not affect the rate at which gaseous solvent particles enter liquid phase but do affect the rate at which liquid solvent particles enter the vapor phase (Rogers). With the solution consisting both solvent and solute particles, equally dispersed, there are fewer solvent particles on the surface compared to a volume of pure solvent, which reduces the effective number of volatile solvent particles to vaporize.

This eventually shifts the equilibrium towards the liquid side and lowers the vapor pressure at that temperature as well as all temperatures. A higher temperature is resultantly required in order for the vapor pressure to reach the atmospheric pressure.

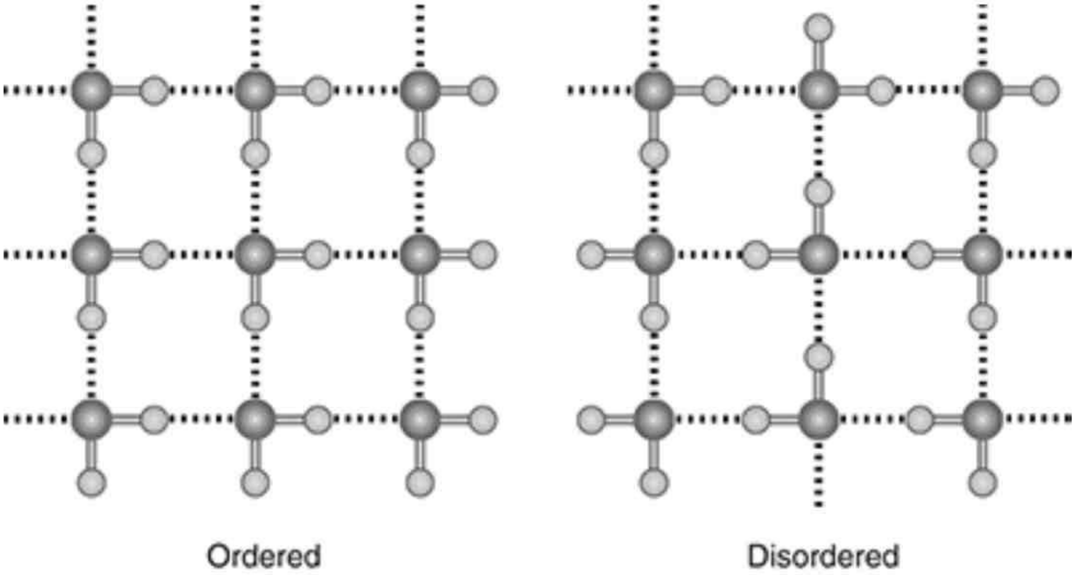
Figure 1. vapor pressure of pure solvent and solution consisting nonvolatile solution



According to Raoult's law, $P_{solvent} = X_{solvent} P^{\circ}_{solvent}$, where $P_{solvent}$ represents the new vapor pressure of the solvent after forming solution with solute, and $P^{\circ}_{solvent}$ represents the vapor pressure of the pure solvent (Florida state university department of chemistry). $X_{solvent}$ is the mole fraction of the solvent, which is derived from dividing the moles of solvent particles by the total number of moles of particles present in the solution (Clark). The more concentrated the solution, the lower the new vapor pressure, resulting in stronger effect on boiling point elevation.

Freezing point depression is explained in a similar fashion. A very ordered state must be achieved in order to freeze (Colligative properties). In the case of water, a tetrahedral crystalline structure is formed stabilized by hydrogen bonds, where there is exactly one hydrogen between every two oxygen (Finney). With impurities, in this case the solute, the hydrogen bonds are distorted, which hinders the formation of a crystalline lattice. A lower temperature is thus needed to reduce the kinetic energy of particles and the space in between water molecules, so the ice structure can be restored.

Figure 2. Ordered and disordered structure of water molecules



Although both properties are dependent on the concentration based on the assumption of the solution being ideal, the reduction of the effective number of solvent particls to vaporize due to obstruction on the surface implies that larger particle will cause more significant lowering of the vapor pressure when present in same numbers. Similar question was raised in 1955 by Mysels (Donati). The obstruction logic can also be applied to the freezing process, where larger particle will cause the water molecules to be less connected, which makes formation of hydrogen bonds more difficult. This explanation offered from the kinetic approach suggested the effects of solute identity on the non-ideal behavior of colligative properties, which ultimately became the premise of this investigation.

Raoult's law deviation, a model that demonstrates the vapor pressure of non-ideal solutions, offered a different view, stating that non-ideal behaviors are dependent on the intermolecular force. In the context of salt particles dissociating into ions, this means the larger the ion, the weaker the intermolecular force, thus the vapor pressure of the solution will be relatively higher compared to other solutions with smaller ions and the boiling point will be elevated less.

Based on the fact that the size of solute particles influences the degree to which the boiling point is elevated and the melting point is depressed, this investigation explores the relationship between the total ionic radii of salt particles with the two physical properties. Six salts composed of different ions with different ionic radii were chosen as the set of independent variable. Since every salt is consisted of different ions, the total ionic radii of the salt particle is therefore taken. An important factor that is involved during the selection of salts is the number of particles that one salt particle can dissociate into. The molal concentration of the solution in terms of moles of solute particles per kg differs for a solute that can dissociate into 2 separate particles and a solute that dissociates into 3, which directly affects the extent of temperature elevated to boil and depressed to melt, regardless of the solution being ideal or not. Therefore, all salts selected are binary compounds, where they will dissociate into two ions in water. By specifically looking at group 1 alkali metals and group 7 halogens, 6 combinations are chosen from sodium, potassium, chloride, bromide, and iodide ions, each with different total ionic radii.

Table 1. List of salts used and their relative total ionic radii in the order from small to large

Type of Salt	Total Ionic Radii (pm)
NaCl	283
NaBr	298
KCl	319
NaI	322
KBr	334
KI	358

The premise of investigating the disparity between the boiling and melting point of saline solution is that the temperature of the two phase changing process is elevated and depressed simultaneously due to the addition of the nonvolatile salt. The experimental environment is maintained throughout the process to keep the atmospheric pressure constant. Other variables suspected to alter the results, for example the concentration of all solutions is controlled at 1.00 mol kg^{-1}, having taken consideration of the solubility of all solutes at room temperature. The volume of solution for measuring boiling and freezing point, the strength of flame and distance between the tube of solution and the Bunsen burner are also controlled.

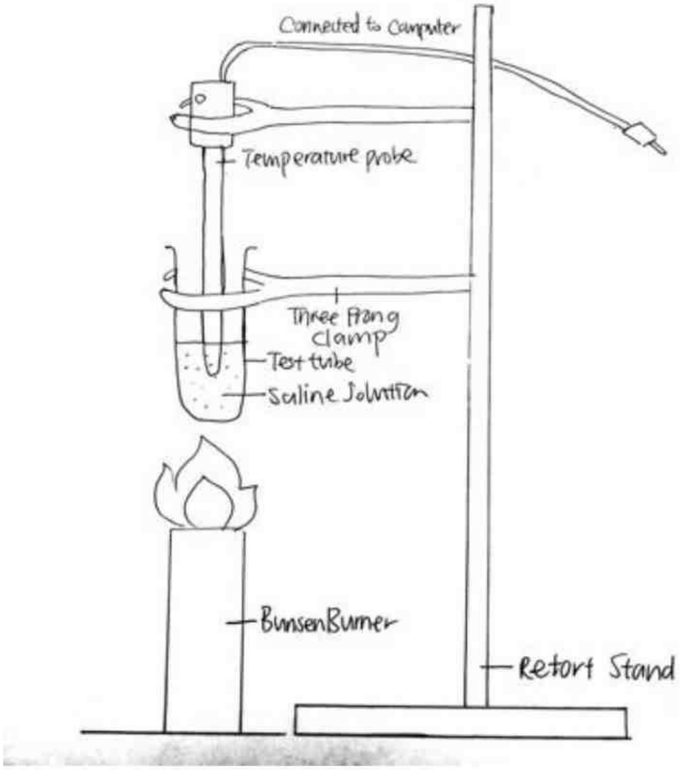
Hypothesis

Based on the interpretation of the particle obstruction explanation, it was hypothesized that as the total ionic radii increases, there will be a greater change in boiling point elevation and freezing point depression, hence the disparity between the two temperatures enlarges.

Methodology

Saline solutions are diluted and kept constant at molality=1.00 mol kg^{-1}. Sample calculation and procedural instruction can be seen in the appendix. Initially, a heating curve was established to measure the average boiling temperature of the vaporizing solution. However, the methodology was adjusted based on the premise that the solution becomes increasingly concentrated as it boils, due to the presence of a nonvolatile solute. As the concentration is directly proportional to the boiling point, this means that the boiling temperature would continue to rise until all solvent particles are vaporized. In addition, the concentration would increase during the heating process prior to boiling, since at every temperature, there will be certain particles vaporizing, contributing to the vapor pressure and leaving the open system. In order to minimize the effect of changes in concentration and keep it as close to 1.00 molal as possible, the temperature at which the solution initially boils is recorded. This method also turns the random error resulted from temperature fluctuations during vaporization into a systematic error due to the partial vaporization of particles prior to boiling.

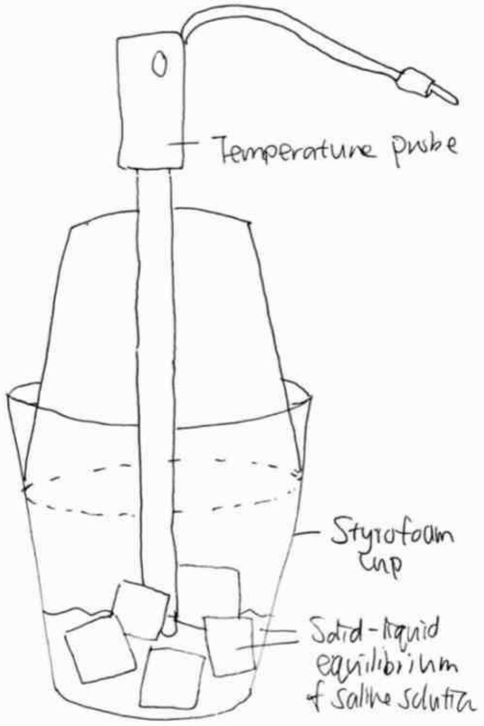
Figure 3. Diagram of apparatus for measuring boiling point



15mL of the solution is transferred to a test tube, which is stabilized by a three-prong clamp attached to a retort stand. The temperature probe, connected to the computer through logger pro, is held by another clamp on top of the tube. The position is adjusted to ensure the tip of the probe is in contact with the solution but not the wall of the tube. Three test trials were conducted using 5mL and 10mL of solution and was found that the boiling temperature was either rising too rapidly or fluctuating, creating difficulties to identify the initial boiling temperature. 15mL sample size was eventually the volume tested.

Freezing or melting point depression involves the measurement of the temperature when the solution is at solid aqueous equilibrium, which can be observed when a mixture of aqueous and solid solution is present and the temperature remains relatively constant. Similar to vaporization, the melting process involves a melting range, where the area disrupted by the solute melts at a lower temperature than the area containing pure solvent, resulting in an unequal temperature distribution among the body of the solution (Forsey). By making measurements when the temperature remains at a relatively consistent level, which occurs at equilibrium where liquid and solid coexist, the random error of temperature fluctuation could be minimized. For each trial, 25mL of frozen solution, which is equivalent to 5 ice cubes, was crushed into smaller pieces by a sharp ended spatula to ensure the melting process is happening simultaneously in all parts of the solution. The ice cubes were then transferred into a Styrofoam cup, which is capped by another Styrofoam cup with a smaller opening positioned oppositely, to minimize temperature fluctuations. The temperature probe is inserted into the system of interest and stirred the crushed ice cubes continuously as a solid-liquid mixture equilibrium is formed. A repetition of 5 trials for both boiling and melting point measurements were conducted.

Figure 4. Diagram of apparatus for measuring melting point



Safety Awareness:

For all salts, irritation may result from contact with eye, skin, and the respiratory tract. One may experience skin reddening, itching, and scaling, eye reddening, itching, and watering as an inflammatory response (MSDS). In particular, inhalation and ingestion of sodium bromide and potassium bromide at may cause central nervous system depression, characterized by excitement, headache, and nausea etc. (Valdosta state university). Sodium iodide and potassium iodide may cause irritation in the digestive tract, and are correlated with negative reproductive and fetal effects, as well as developments of goiter. Ingestion has resulted in fetal death and cretinism of the new born. While handing the materials, wear safety goggles, rubber gloves, and lab coat.

Data Collection

Table 2. Boiling points of 1.00 molal saline solutions

Total Ionic Radii/ pm	Trial 1/ ±0.3˚C	Trial 2/ ±0.3˚C	Trial 3/ ±0.3˚C	Trial 4/ ±0.3˚C	Trial 5/ ±0.3˚C
283 (NaCl)	101.7	102.0	101.8	101.6	101.7
298 (NaBr)	101.8	101.7	101.7	101.9	101.9
319 (KCl)	101.6	101.3	101.7	101.7	101.6
322 (NaI)	101.4	101.5	101.5	101.2	101.5
334 (KBr)	101.4	101.2	101.4	101.3	101.3
358 (KI)	101.1	101.2	100.9	101.2	101.1

Table 3. Melting points of 1.00 molal saline solutions

Total Ionic Radii/ pm	Trial 1/ ±0.3˚C	Trial 2/ ±0.3˚C	Trial 3/ ±0.3˚C	Trial 4/ ±0.3˚C	Trial 5/ ±0.3˚C
283 (NaCl)	-3.7	-3.7	-3.5	-3.6	-3.6
298 (NaBr)	-3.8	-3.4	-3.7	-3.6	-3.7
319 (KCl)	-3.3	-3.2	-3.3	-3.4	-3.4
322 (NaI)	-3.1	-3.5	-3.3	-3.2	-3.0
334 (KBr)	-3.2	-3.1	-3.2	-3.4	-3.3
358 (KI)	-3.2	-3.2	-3.0	-3.1	-3.1

The average boiling and freezing point for each saline solution along with the corresponding uncertainties are calculated. The difference between the two values is presented as the disparity.

$$Average \pm Uncertainty = \frac{Sum\ of\ values}{\#\ of\ values} \pm \frac{max - min}{2}$$

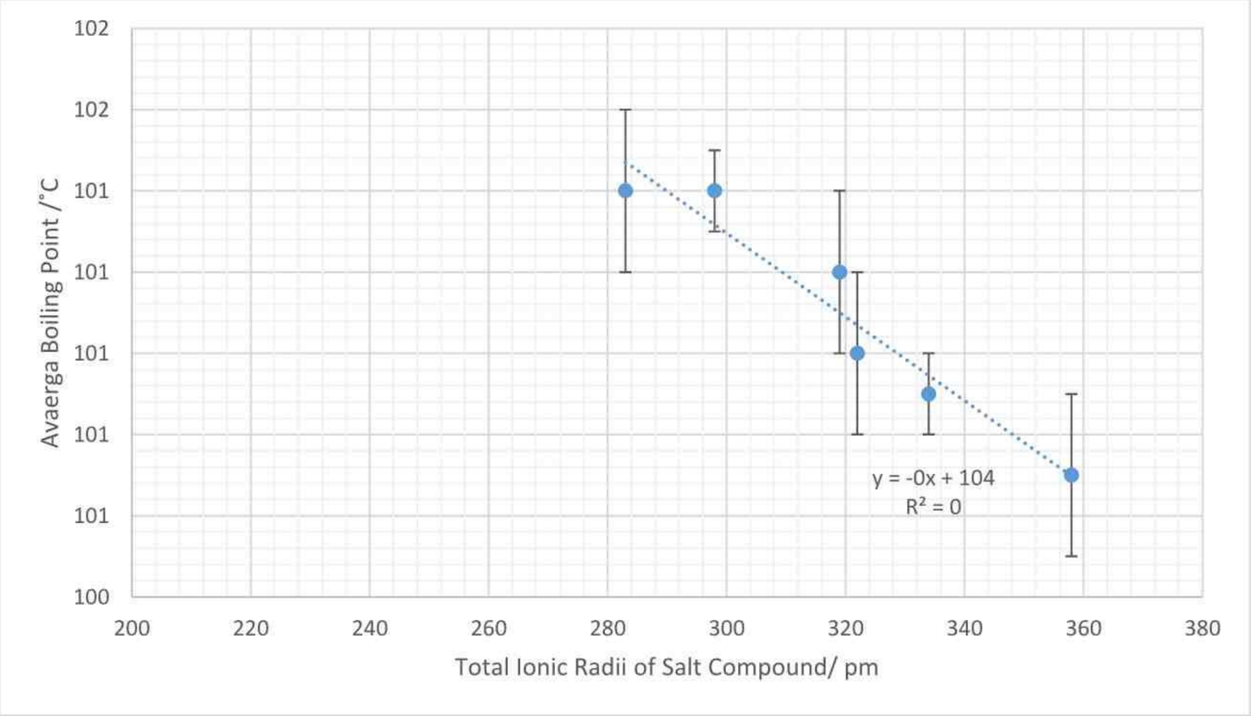
$$= \frac{101.7 + 102.0 + 101.8 + 101.6 + 101.7}{5} \pm \frac{102.0 - 101.6}{2}$$

$$= 101.8 \pm 0.2^{\circ}C$$

Table 4. Average boiling and melting points of 1.00 molal saline solutions

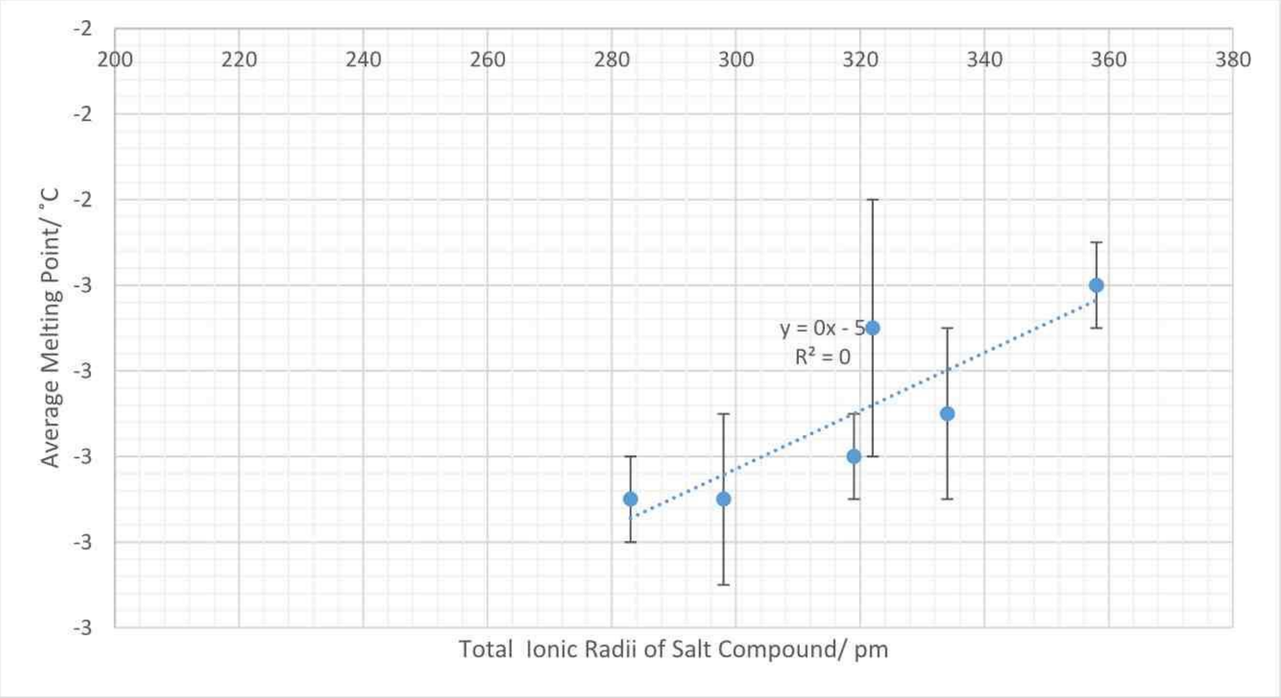
Total Ionic Radii/ pm	Average Boiling Point /°C	Average Melting Point /°C
283 (NaCl)	101.8±0.2	-3.6±0.1
298 (NaBr)	101.8±0.1	-3.6±0.2
319 (KCl)	101.6±0.2	-3.5±0.1
322 (NaI)	101.4±0.2	-3.2±0.3
334 (KBr)	101.3±0.1	-3.4±0.2
358 (KI)	101.1±0.2	-3.1±0.1

Fig 5. Graph of average boiling points of 1.00 molal saline solutions in relevance to total ionic radii of salt particles



According to the line of best fit, a general trend of which the boiling point is inversely related to the total ionic radii was suggested; however, the overlapping error bars showed that the steepness of negative slope may either be significantly reduced to form a relatively straight, horizontal line, which would otherwise indicate a lack of correlation, or be increased, which would indicate that changes in ionic radii significantly affects the boiling point. Despite having a moderate correlation of R^2= 0.9278, The impreciseness of data caused significant amount of uncertainties. As such, a supported conclusion could not yet be derived through the data obtained up till this stage, but there is an indication of inverse linear relationship.

Fig 6. Graph of average melting points of 1.00 molal frozen saline solutions in relevance to total ionic radii of salt particles



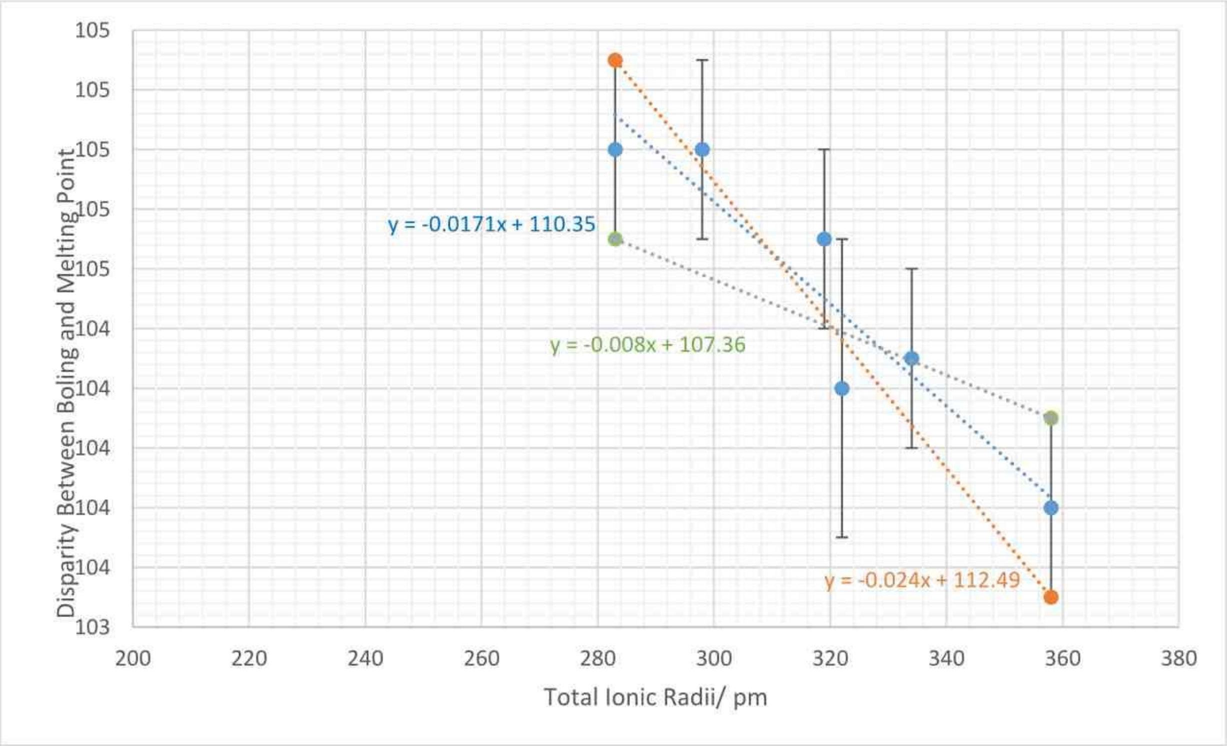
The line of best fit suggested a positive linear relationship; however, a valid conclusion could not be made due to the lack of precision of the data and a weak correlation of R^2= 0.7311. The melting points presents a trend of gradual increase except for the sodium iodide solution, where its melting point had a relatively significant increase from the previous data point while the increase in total ionic radii is extremely small. A similar behavior of sodium iodide solution was observed in the graph of boiling points, where its boiling point is higher than the rest in relation to the corresponding ionic radii. This suggests that there were potential systematic errors involved exclusively in the trials conducted for sodium iodide.

$$
\begin{aligned}
Disparity &= Average\ boiling\ point - Average\ melting\ point \\
&= (101.8 \pm 0.2) - (-3.6 \pm 0.1) \\
&= 105.4 \pm 0.3^{\circ}C
\end{aligned}
$$

Table 5. Disparity Between Boiling and Melting Point for Different Saline Solutions

Total Ionic Radii	Disparity Between Boiling and Melting Point/˚C
283 (NaCl)	105.4±0.3
298 (NaBr)	105.4±0.3
319 (KCl)	105.1±0.3
322 (NaI)	104.6±0.5
334 (KBr)	104.7±0.3
358 (KI)	104.2±0.3

Fig 7. Graph of disparity between boiling and melting points of 1.00 molal saline solutions plotted against the total ionic radii of of salt particles

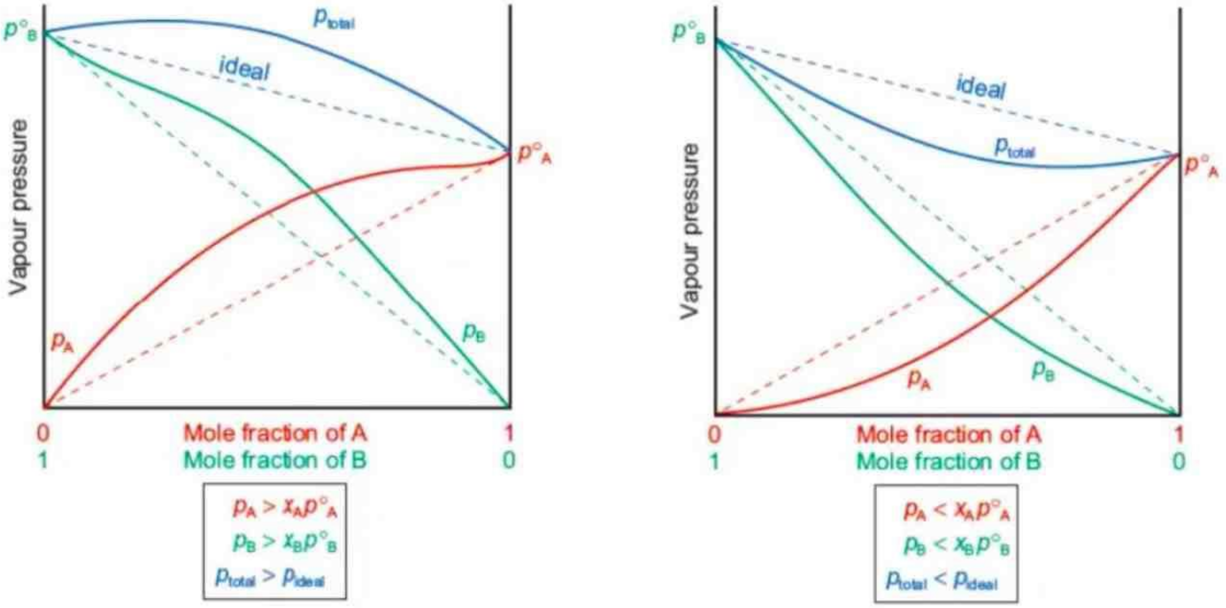


The graphical representation indicated a weak inverse linear relationship between the independent and dependent variable, with a parameter of $283 \leq x \leq 358$, where $x = total\ ionic\ radii$. The maximum and minimum slope were -0.024 and -0.008 respectively, which makes the slope of the line of best fit -0.0171±0.008≈ -0.017±0.008˚C pm^{-1}. This means that the disparity between boiling and melting point decreases by 0.017˚C for every picometer of increase in total ionic radii, with approximately 47% of it being uncertain.

Interpretation of Results

The results could be explained in terms of Raoult's law deviation, which describes the vapor pressure of the components in a non-ideal solution and its deviation from the predicted value according to Raoult's law. The two types of deviation, positive and negative, occurs when the vapor pressure of the solution is higher or lower than that predicted by Raoult's law respectively (Oxford academic). Non-ideal saline solutions are examples of negative deviations.

Figure 8. Positive and negative deviation of Raoult's law



To be negatively deviated from the ideal model, the solute-solvent interaction should be stronger than the solvent-solvent, solute-solute interaction (Solutions and colligative properties). For saline solution, the solute-solute interaction is not taken into consideration because the total vapor pressure is entirely contributed by the solvent. According to the enthalpy of hydration for ions and the enthalpy of condensation for water which is -40.7kJ mol^{-1}, the ion-water electrostatic force is shown to be stronger than the hydrogen bonds between water molecules (Smith). With its polar ends attracted to the oppositely charged electrolyte particles, water molecules experience more difficulties to vaporize, resultantly there will be even less vapor pressure compared to the amount calculated from Raoult's law.

Table 6. Different Ions with Corresponding Hydration Enthalpy

Ions	Hydration Enthalpy/ -kJ mol^{-1}
Na^+	409
K^+	322
Cl^-	381
Br^-	347
I^-	305

Since all saline solutions are negative deviations of Raoult's law, the investigation was essentially testing the extent of which negative deviations occur due to the total ionic radii of salts. Ions with smaller ionic radii exerts stronger electrostatic forces of its own charge as they possess greater charge density. When equal amounts of salt particles dissolve, the strongest interaction will be formed among the smallest ions and water molecules, which distorts the local structure of water, lowers the total vapor pressure, and elevate the boiling point by the most. By comparing the hydration enthalpies of the ions involved in this investigation, it could be seen that the smallest cation and anion, Na^+ and Cl^-, have the most exothermic enthalpy change. This suggests that the hydrated ions with small ionic radius are at a more stable energy state, where water molecules are less likely to vaporize.

The concept of interparticle force can also be applied to explaining the experimental trend of melting points. Since the small, hydrated ions and water molecules are stabilized due to the strong dipole-ion attraction, water molecules are less willing to form hydrogen bonds with other water molecules. As the crystalline structure is stabilized by hydrogen bonds, the prevention of formation of this intermolecular force causes the solvent molecule to lose its four-fold motif, where water molecules are no longer surrounded by 4 similar molecules (Finney). This hinders the formation of an ordered structure, specifically when the solute particles are almost equally dispersed throughout the volume of solution so that the four-fold motif is being continuously disrupted.

Conclusion

Through conducting this research, the colligative properties of non-ideal solutions were investigated. The results were inconclusive but suggestive that in non-ideal solution, increasing the total ionic radii of salt particles reduces the degree to which boiling point is elevated and freezing point is depressed, narrowing the disparity between the two phase changing temperatures. Although the observed trend did not support the hypothesized situation, the 47% uncertainty of the slope as well as an average of ±0.3˚C uncertainty of the temperature probe showed that the results were not valid enough to entirely reject the hypothesized situation.

Literature values of the boiling and melting points of the 1.00 molal saline solutions were not found in the sources accessed aside from the value calculated from the equation $\Delta T=K_b mi$, which is only applicable to ideal solutions and does not take ionic radii into account. Experiments were commonly conducted to test for the effect of solution concentration but not of the solute identity. Further studies into the non-ideal conditions of solutions and their effect on certain properties are needed in order to maximize the practical applications of boiling point elevation and melting point depression. For example, the parameter of the total ionic radii in this investigation was limited to of $283 \leq x \leq 358$. The relationship between the temperature disparity and the size of ion particles can be further explored by expanding the parameters and take smaller or larger ions such as lithium fluoride and cesium bromide into consideration. The effect of other nonvolatile solutes such dissociated salt particles with ions having greater charges than ±1, sugars including glucose, fructose, and sucrose, and glycerin, a nonvolatile liquid, could also be researched. Comparison could be made across the salts, carbohydrates, and organic substances, as well as solid and liquid solutes. In fact, colligative properties extend beyond the scope of phase changing temperatures of solutions but also the osmotic pressure across a semipermeable membrane, which is essential to cell functions. With a difference in pressure, water desalination can take place in plant cells, which supplies living systems—for example trees—with water. Research of this kind may also enhance understandings of colligative properties.

Evaluation

Despite measuring temperature was a relatively simple procedure, both precision and accuracy remain concerned. The random error was extremely throughout the procedure, mainly due to the imprecision of temperature probe, which only measures up to 1 decimal place with uncertainty ±0.3˚C. As the consecutive boiling and melting points were very close in value, the disparity between them differ by small amounts as well. An uncertainty ranging from 0.3 to 0.5˚C therefore significantly weakens the relationship. This ultimately contributed to the 47% uncertainty for the slope of line of best fit in figure 7. A set of more professional apparatus such as the Thiele tube, Fisher Johns apparatus, and Gallenkamp apparatus could be used if available in the laboratory. The uncertainty of the apparatus used when diluting the salts cause the concentration saline solutions made to vary in a minor extent. Although not involved in data processing but this directly influences the initial boiling temperatures if the solutions start with different concentrations.

A number of factors were suspected to contribute to the systematic errors. When boiling, the relatively small sample size goes through vigorous activity and the increase in temperature is fast due to high rate of vaporization of water. Also, solvent molecules may vaporize prior to boiling since there will always be particles with enough energy to overcome the interparticle force. This means the boiling point recorded for 1.00 molal saline solutions actually belongs to a more concentrated solution. A sample with greater volume or boiling chips could be used so that the liquid boils less vigorously, allowing less rapid temperature increase to occur at the initial stages.

As for melting point, it was observed that the ice melted at a relatively fast rate and the equilibrium did not last long. An alternative method of which the temperature is measured when the solution is freezing could be conducted instead. Applying the knowledge gained from studying the colligative properties, adding salts to a solution decreases the temperature of the system without using a freezer. A system in which a tube of solution is placed within a beaker with ice water can be set up. High solubility salts are continuously added to the beaker of ice water to decrease the temperature below the freezing point of the solution and the temperature of the solution can be recorded once it becomes relatively constant and begins to crystalize. This process is generally slower and allows the equilibrium to last longer. Another source of error comes from refreezing the solutions, which may result in impurities caused by substances other than the tested solute.

Practical Applications

The applications of colligative properties cover a wide range of uses. Aside from melting snows on the road and reduce the time to boil spaghetti, such phenomena is used to help making antifreeze in radiators of automobiles to prevent boiling or freezing during extreme hot and cold temperatures respectively (Colligative properties). Although not completely miscible with water, Ethylene is commonly chosen as the solute to make the radiator liquid due to its non-volatile nature. Understanding such properties are also relevant to the sugar refining industry, where the cane juice extracted from sugarcane crop is needed to be boiled in order to produce crystalline sugar. The boiling point elevation of the juice offers insights into the saturation of the sugar content, a major consideration for producers to determine the type of sugarcane to cultivate, hence maximizing their output and reducing input cost. In medicinal chemistry, Raoult's law is highly relevant to drug isolation and purification through fractional distillation (Brown). There were also methods developed to predict the hydrate stability zone through analyzing data of boiling point elevation (Mohammadi). Under emergency situations, salts, along with ice, can be used to treat inflammation to allow efficient cooling of the site of injury. The high practicality of colligative properties makes the topic worthwhile to pay the attention with.

Appendix

List of apparatus:

Analytical Balance (±0.001g), weighing boat, temperature probe (±0.3˚C), 150±5mL beaker, spatula, retort stand, three-prong clamp, 20mL test tube, Bunsen burner, Styrofoam cup, 20.0±0.5 mL graduated cylinder, Erlenmeyer flask, ice mold, forceps.

Sample calculations; determining mass of NaCl used for dilution of 1 molal saline solution

$$Molal\ concentration = \frac{mol\ of\ solute}{mass\ of\ solvent\ (kg)}$$

$$1.00 = \frac{mol\ of\ solute}{0.200kg}$$

$$mol\ of\ solute = 1.00 \times 0.200 = 0.200$$

$$0.200mol\ \times \frac{58.443g}{mol} \approx 11.688g\ NaCl$$

Procedure of dilution:

1. Place a 150±5mL beaker on the analytical balance and tare. Transfer 100 grams of distilled water into the beaker.
2. On weighing boat, measure 11.688±0.001g solid sodium chloride using analytical balance.
3. Transfer the measured sodium chlorides into the beaker of distilled water to make saline solution. Use stirring rod for complete solvation.
4. Store the solution in an Erlenmeyer flask, with the opening stemmed by a cork to prevent evaporation.

Procedure of measuring boiling point:

1. Measure 15mL of saline solutions in a 20.0±0.5mL graduated cylinder.

2. Transfer the solution into a 20mL test tube.
3. Position the test tube above a Bunsen burner using a three-prong clamp connected to a retort stand.
4. Position the temperature probe above the test tube, with the tip of the probe in contact with the saline solution. Stabilize the probe with another three-prong clamp.
5. Heat the solution with constant flame. Meanwhile, start data recording using the logger pro software on computer to track for temperature change.
6. Stop temperature recording when the solution has been boiling for approximately 10 seconds.
7. Repeat step 1 to 6 for five trials for every type of solution.

Procedure of measuring melting point:

1. Pour 125 mL of saline solution into a 150mL beaker, then transfer the solution into an ice mold. 25 five mL ice cubes should be made for every saline solution.
2. Place the ice trays into the freezer. The school freezer is set at -27˚C.
3. Obtain 5 frozen ice cubes with forceps and place them into the Styrofoam cup.
4. Crush the ice cubes using a spatula to ensure simultaneous melting for all ice cubes.
5. Cap the Styrofoam cup holding the melting ice cubes with another Styrofoam cup positioned oppositely to minimize temperature fluctuation. The bottom of the Styrofoam that is placed on the top is poked with a hole, so temperature probe could be inserted inside to measure the temperature of the melting ice cubes.
6. Start recording on logger pro until the temperature becomes relatively constant. Use the probe to stir the ice liquid mixture throughout the process.

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EE/RPPF

For use from May/November 2018

Extended essay - Reflections on planning and progress form

Candidate: *This form is to be completed by the candidate during the course and completion of their EE. This document records reflections on your planning and progress, and the nature of your discussions with your supervisor. You must undertake three formal reflection sessions with your supervisor: The first formal reflection session should focus on your initial ideas and how you plan to undertake your research; the interim reflection session is once a significant amount of your research has been completed, and the final session will be in the form of a viva voce once you have completed and handed in your EE. This document acts as a record in supporting the authenticity of your work. The three reflections combined must amount to no more than 500 words.*

The completion of this form is a mandatory requirement of the EE for first assessment May 2018. It must be submitted together with the completed EE for assessment under Criterion E.

Supervisor: *You must have three reflection sessions with each candidate, one early on in the process, an interim meeting and then the final viva voce. Other check-in sessions are permitted but do not need to be recorded on this sheet. After each reflection session candidates must record their reflections and as the supervisor you must sign and date this form.*

First reflection session

Candidate comments:

My investigation topic is inspired by the fact that salt is used to melt snow while raising a solution's heat of vaporization. Initially, I planned to research titration in antacids produced by different manufacturers, but I realized that this is more of a pure comparison, while personally, a scientific research is meaningful if it is applicable and relatable to our lives. This motivated me to change to my current topic, as it allows me to explore a phenomenon observed in my daily life on a scientific level and have wider implications such as salt water coolant and other industrial processing.

For further research, I will look into the process of fusion, dissolution, and vaporization on a molecular level, seeing how the nature of ions within salts including atomic radius, molar mass, electronegativity can potentially affect those processes of physical change.

Date: February 7, 2018

Interim reflection

Candidate comments:

By this stage, the most difficult decision was deciding the independent variable. While all sources suggest that boiling point elevation and freezing point depression is dependent on colligative property, the role that ion nature plays in the process is unexplored.

However, as I learned that the solute particles take up area in the surface of solution and block the water molecules from vaporizing or freezing, I interpreted that if the ionic radius alters, the blockages towards the water molecules will change as well, resulting in different changes in boiling and melting point. Furthermore, the solubility is considered when selecting the combination of salts, since infinite dilution of the solution is needed with a controlled concentration.

Despite the possibility that manipulating the ionic radius may yield no trend, I urge to seek for evidence that rebuts my reasoning, as there is no previous studies justifying my topic is dependent on colligative property.

Date: March 28, 2018

Final reflection - Viva voce

Candidate comments:

By the end, I not only gained insights of my topic, but also of how to conduct research. I learned and employed multiple strategies, such as to look for reoccurring key words and concepts, organize them, and continue research from there. For example, when I first began my research, I spotted the key word “colligative property”. This directed me to “Raoult’s Law”, which then lead to the “assumptions for ideal solution”. Uncovering these concepts step by step eventually allowed me to find “Raoult’s Law deviation”, which ultimately drove me to my answer. I recognized that science consists a complex system, so it is important to choose the essential information desired.

I also learned to stay open and seek for contradicting arguments. I initially formulated my hypothesis based on the kinetic approach; however, I later discovered the thermodynamic approach, which would lead to a different interpretation. Acknowledging this discrepancy helped me to understand why my hypothesis wasn’t supported. It also fascinated me that scientific progress is stimulated by contrasting ideas.

While being aware that the experiment was relatively simple and involved large uncertainties, I attempted to make it more well controlled, from carefully deciding what temperature to take during the phase changing processes to designing the setup of apparatus.

Date: November 9, 2018