Experiment 1: Freezing Point Depression

Purpose:

The purpose of this lab is to experimentally determine the freezing point of two solutions and compare the effect of solute type and concentration for each solution.

Introduction:

Solutions are homogeneous mixtures that contain two or more substances. The major component is called the *solvent*, and the minor component(s) are called the *solute(s)*. Since the solution is primarily composed of solvent, the physical properties of the solution resemble those of the pure solvent. However, some of these physical properties, called *colligative properties*, are independent of the nature of the solute and depend only upon the concentration of solute particles. Examples of colligative properties include boiling point elevation, freezing point depression, and osmotic pressure.

Pure water freezes at 0.0 °C (273 K), boils at 100.0 °C (373 K). These values are altered by the presence of a solute. You are probably familiar with some common examples of these effects: Antifreeze is used to lower the freezing point and raise the boiling point of your engine coolant (water); and salt is used to melt ice on road.

These effects are expressed quantitatively by the *colligative-property law*, which states that the freezing point and boiling point of a solution differ from those of the pure solvent by amounts that are directly proportional to the *molal* concentration of the solute. In its general form this equation is written:

$$\Delta T = K \bullet m$$

where ΔT is the boiling point elevation or freezing point depression, K is a constant that is specific for each solvent, and m is the molality of the solution and is expressed as the number of moles of solute per kilogram of solvent. Some representative constants, boiling points, and freezing points are given in the table below.

Solvent	Freezing Point (°C)	K_f (°C/m)	Boiling Point (°C)	K_b (°C/m)
CH_3CO_2H (acetic acid)	16.6	3.90	118.1	2.93
C_6H_6 (benzene)	5.4	5.12	80.2	2.53
$CHCl_3$ (chloroform)	-63.5	4.68	61.3	3.63
C_2H_5OH (ethyl alcohol)	-141	----	78.4	1.22
H_2O (water)	0.0	1.86	100.0	0.512
$C_{10}H_8$ (naphthalene)	80.6	6.9	218	5.65
C_6H_{12} (cyclohexane)	6.5	20.0	81	2.79
$C_{10}H_{16}O$ (camphor)	179	39.7	208	5.95
$C_4H_{10}O$ (t-butanol)	25.5	9.1	----	---

The equations relating the boiling point elevation and freezing point depression to molality are:

$$\Delta T_b = K_b \cdot m \cdot i$$

$$\Delta T_f = K_f \cdot m \cdot i$$

where ΔT_b and ΔT_f are the change in boiling point and freezing point respectively, K_b and K_f are the boiling and freezing constants for a particular solvent, and *i* is the factor which is used to account for the number of particles a given solute generates in solution. Substances are usually classified as ionic or covalent, or more precisely, *electrolytes* and *non electrolytes*. Electrolytes dissolve in a solvent to give *ions* (charged particles) in solution while non electrolytes dissolve to give *molecules*. A mole of non electrolyte such as ethanol would dissolve to produce a mole of ethanol molecules. However, a mole of sodium chloride (NaCl) would dissolve to form two moles of ions (Na^+ and Cl^-). Because colligative properties are related to the number of solute particles, we would expect a mole of NaCl to have twice the effect as a mole of ethanol. Therefore, (i =1) for ethanol and other non electrolytes, (i =2) for NaCl, and (i = 5) for $Al_2(CO_3)_3$.

Prelab Exercise:

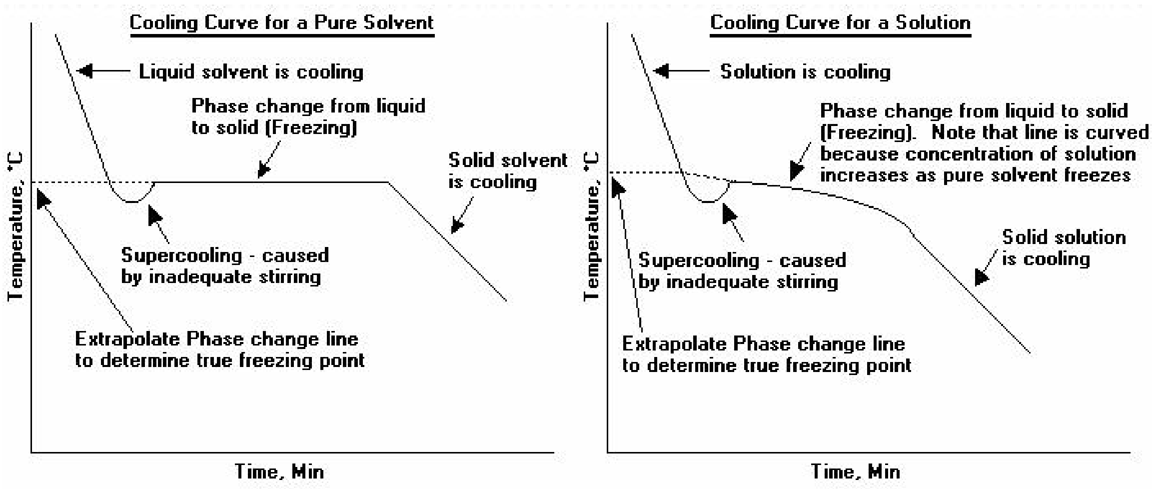
If 10g of ethanol, C_2H_5OH, is dissolved in 100 g of pure water, what would the boiling point and freezing point be for this solution?

First determine the molality of the solution:

For water the K_b = 0.512°C/m, and K_f = 1.86°C/m. Calculate ΔT_b and ΔT_f for this solution:

Method:

In this experiment you will need to determine the freezing point depression for several solutions. However, the temperature at which a solution freezes is difficult to determine by direct visual observation because of a phenomenon called super cooling and also because solidification of solutions usually occurs over a broad temperature range. To overcome these problems, temperature-time graphs, called *cooling curves*, are used which readily reveal the true freezing temperature. The major features of a general cooling curve are shown below:



You will construct cooling curves for both the pure solvent (water) and various solutions. From the cooling curve you will extrapolate the true freezing temperature. Extrapolation is necessary because as the solution freezes the solid that is formed is essentially pure solvent. The remaining solution becomes more and more concentrated and its freezing point becomes lower and lower. Also, super cooling introduces an ambiguity in the freezing point and should be minimized using through stirring.

Materials:

- Beaker of ice water
- Beaker of warm water
- Thermometer
- 25 mL Test Tube
- Parafilm
- t-butyl alcohol
- Benzoic acid
- Ethylene glycol

Procedure:

Freezing Point Depression for t-Butanol:

1. Fill a large test tube approximately ¼ -way with t-butanol.
2. Place the test tube, and a thermometer into the water bath so that the level of the t-butanol in the test tube is below the level of the water in the beaker. Make sure you can still read the thermometer. Cover the top of the tube with a small piece of parafilm
3. Continue heating the test tube until all its content melts.
4. Remove the water bath and allow the test tube to cool in air.
5. **Record** the temperature of the test tube every **30 seconds** while gently agitating the contents with the thermometer.
6. Continue to record the temperature for 15 minutes, even after the t-butanol solidifies. You will have to continually cool the water bath with ice in order to freeze the sample.
7. Repeat steps 2-6 to obtain data for a second trial.
8. Consult the instructor to determine if the trials are successful, or if you should perform a third trial.
9. Once the trials are completed, melt the contents of the test tube and discard into waste container in the hood

Freezing Point Depression of Other Solutions:

1. Similar to the directions above, determine the freezing point of the other solutions (0.5 m ethylene glycol, 1 m ethylene glycol and 0.5 m benzoic acid).
2. Place all used solution samples in the waste container.

DATA:

Pure t-Butanol			
#	**Time**	1ST Trial Temp (°C)	2nd Trial Temp (°C)
1	0:00		
2	0:30		
3	1:00		
4	1:30		
5	2:00		
6	2:30		
7	3:00		
8	3:30		
9	4:00		
10	4:30		
11	5:00		
12	5:30		
13	6:00		
14	6:30		
15	7:00		
16	7:30		
17	8:00		
18	8:30		
19	9:00		
20	9:30		
21	10:00		
22	10:30		
23	11:00		
24	11:30		
25	12:00		
26	12:30		
27	13:00		
28	13:30		
29	14:00		
30	14:30		
31	15:00		

t-Butanol with Ethylene Glycol (0.5 m)			
#	**Time**	1ST Trial Temp (°C)	2nd Trial Temp (°C)
1	0:00		
2	0:30		
3	1:00		
4	1:30		
5	2:00		
6	2:30		
7	3:00		
8	3:30		
9	4:00		
10	4:30		
11	5:00		
12	5:30		
13	6:00		
14	6:30		
15	7:00		
16	7:30		
17	8:00		
18	8:30		
19	9:00		
20	9:30		
21	10:00		
22	10:30		
23	11:00		
24	11:30		
25	12:00		
26	12:30		
27	13:00		
28	13:30		
29	14:00		
30	14:30		
31	15:00		

t-Butanol with Ethylene Glycol (1 m)			
#	**Time**	1ST Trial Temp (°C)	2nd Trial Temp (°C)
1	0:00		
2	0:30		
3	1:00		
4	1:30		
5	2:00		
6	2:30		
7	3:00		
8	3:30		
9	4:00		
10	4:30		
11	5:00		
12	5:30		
13	6:00		
14	6:30		
15	7:00		
16	7:30		
17	8:00		
18	8:30		
19	9:00		
20	9:30		
21	10:00		
22	10:30		
23	11:00		
24	11:30		
25	12:00		
26	12:30		
27	13:00		
28	13:30		
29	14:00		
30	14:30		
31	15:00		

t-Butanol with Benzoic Acid (0.5 m)			
#	**Time**	1ST Trial Temp (°C)	2nd Trial Temp (°C)
1	0:00		
2	0:30		
3	1:00		
4	1:30		
5	2:00		
6	2:30		
7	3:00		
8	3:30		
9	4:00		
10	4:30		
11	5:00		
12	5:30		
13	6:00		
14	6:30		
15	7:00		
16	7:30		
17	8:00		
18	8:30		
19	9:00		
20	9:30		
21	10:00		
22	10:30		
23	11:00		
24	11:30		
25	12:00		
26	12:30		
27	13:00		
28	13:30		
29	14:00		
30	14:30		
31	15:00		

Calculations:

Graph each trial data and obtain the freezing points for each solution:

- The freezing point of pure t-butanol:
  - Trial 1………………………………….____________
  - Trial 2………………………………….____________
  - Average…………………………………………………______________
- The freezing point of the 0.5 m t-butanol and ethylene glycol solution:
  - Trial 1………………………………….____________
  - Trial 2………………………………….____________
  - Average…………………………………………………______________
  - ΔT_f (1)…………………………………………………______________
  - K_f (exp.)…………………………………………………______________
    (show calculations below)
- The freezing point of the 1 m t-butanol and ethylene glycol solution:
  - Trial 1………………………………….____________
  - Trial 2………………………………….____________
  - Average…………………………………………………______________
  - ΔT_f (2)…………………………………………………______________
  - K_f (exp.)…………………………………………………______________
    (show calculations below)

Calculations (cont'd):

- The freezing point of the 0.5 m t-butanol and benzoic acid solution:
  - Trial 1……………………………….._____________
  - Trial 2……………………………….._____________
  - Average…………………………………………………_______________
  - ΔT_f (3)…………………………………………………_______________
  - K_f (exp.)…………………………………………………_______________
    (show calculations below)

- Average experimental value for K_f……………………………_________________

- Theoretical value for K_f………………………………………_________________

- Percent Error…………………………………………………_________________
  (Show calculations below)

Questions:

1. How did the freezing point of pure t-butanol compare with the freezing points of the solutions? Support your observations with theoretical concepts.

2. How did the freezing points of 0.5 m and 1 m solutions of ethylene glycol compare with one another? Support your answers with theoretical concepts.

3. How did the freezing points of solutions with different solutes (ethylene glycol and benzoic acid) compare to one another? Support your observations with theoretical concepts.