Chemistry 201

Freezing point depression
Boiling point elevation

NC State University

Freezing point depression

The freezing point depression can be calculated as a function of the molality of the solute:

$$\Delta T = K_f m_{solute}$$

In this expression the identity of the solute does not matter. We use molality since the solvent properties do matter and therefore, we would like to calculate the result in relation to a fixed amount of solvent (1 kg). The constant K_f depends on the solvent and is a function of the enthalpy of freezing and the molar mass.

Application: Dept. of Transportation

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What is the melting point of ice if 40 grams of NaCl are added for every kg of ice on the road?

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Solution: If you are not given the density of ice you may assume it is the same as water. We will work the problem this way first.

Step 1. To determine the molality, we calculate the number of moles of NaCl.

$$n_{NaCl} = \frac{m_{NaCl}}{M_{m,NaCl}} = \frac{40\ g}{58.5\ g/mol} = 0.683\ mol$$

Note that NaCl forms ions in solution so the molality is twice This value or 1.37 mol/kg.

Application: Dept. of Transportation

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Step 2. Substitute into the freezing point depression formula.

$$\Delta T = K_f m_f = \left(\frac{1.86\ ^oC}{molal}\right)(1.37\ molal)$$

The temperature is 2.5 ^{o}C below the normal melting point or 270.5 K.

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Solution: The answer is the same. Molality is defined per kg. This is another reason for this definition. It would be a nightmare to keep track of the density changes otherwise.

Application: Anti-freeze

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Solution: first calculate the molality of the solution required.

$$m_f = \frac{\Delta T}{K_f} = \frac{30\ ^{o}C}{1.86\ ^{o}C/molal} = 16.1\ molal$$

Application: Anti-freeze

What volume of ethylene glycol must be added to 5 L of water in a radiator to prevent freezing at -30 ºC? (ρ_{EG} = 1.11 g/mL)

Solution: first calculate the molality of the solution required.

$$m_f = \frac{\Delta T}{K_f} = \frac{30\ ^oC}{1.86\ ^oC/molal} = 16.1\ molal$$

Second, multiply by 5 since there is a total volume of 5 L and mass of 5000 g.

$$n_f = m_f mass_{H2O}$$
$$= 16.1\ molal(5\ kg)$$
$$= 80.5\ moles$$

Application: Anti-freeze

What volume of ethylene glycol must be added to 5 L of water in a radiator to prevent freezing at -30 ºC? (ρ_{EG} = 1.11 g/mL)

Third, use the molar mass to obtain the mass of EG.

$$mass_{EG} = n_{EG} M_{m,EG}$$

$$mass_{EG} = (80.5 mol)(62 \frac{g}{mol})$$

Fourth, convert the calculated mass of 4990 g EG to a volume.

$$V = \frac{mass_{EG}}{\rho} = \frac{(4990\ g)}{(1.11 \frac{g}{mL})}$$

The answer is 4495 or approx. 4500 mL or 4.5 L.

Application: Ice cream

The dissolved sugar lowers the freezing point of cream from 0˚C to approximately –3˚C. This is why the cream solution will not freeze at a temperature of 0˚C, which is the normal freezing point. As the solution freezes there is a residual that is more concentrated with sugar so its freezing point is even lowered further. It is clear from this trend that the liquid phase of ice cream will never freeze completely though the lower the temperature, the less liquid remains… thus the harder the ice cream. Ice cream at -6˚C (22˚F) is the typical temperature of soft ice cream (because it contains more water).

Application: Making ice cream

When freezing ice cream, salt must be added to the water in a surrounding container in order for the ice cream to freeze. Salt reduces the freezing point of water. Thus when salt is added to ice the ice melts.

$$H_2O(s) + \text{heat} \longrightarrow H_2O(l).$$

When this heat is absorbed by the melting ice, the ice cream gets colder because heat is removed from it. Thus, freezing point depression is used to create a refrigerator around the ice cream.

Application: Ice cream

How many grams of NaCl must you add to 2 kg of ice to make ice cream? The ice must reach a temperature of -6˚C.

$$\boldsymbol{m} = \frac{\Delta T}{K_f}$$

$$\boldsymbol{m} = \frac{6\ {}^{o}C}{\left(1.86\ \frac{{}^{o}C}{molal}\right)} = 3.22\ molal$$

Since there are 2 kg and the dissociation number is also 2 we must add 3.22 moles of NaCl (M_m = 58.5 gm/mol). Therefore, we must add 188.4 grams.

Boiling point elevation

The boiling point elevation can be calculated as a function of the molality of the solute:

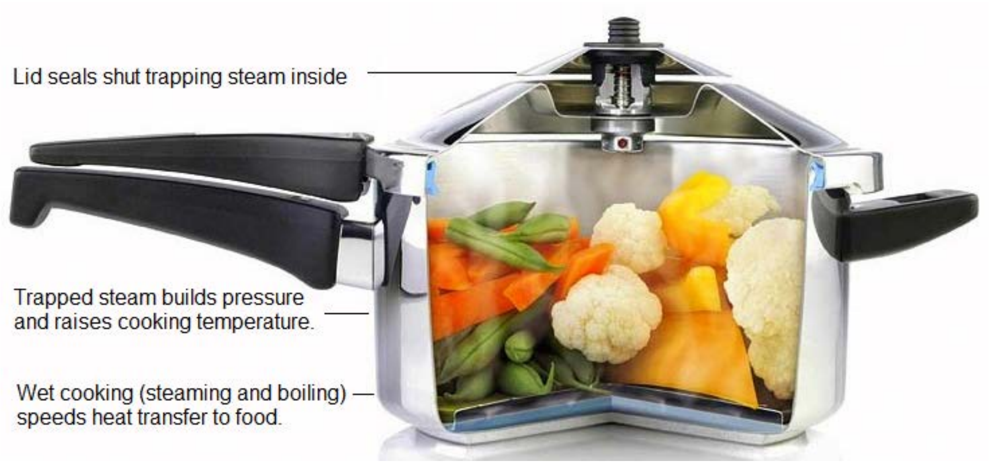
$$\Delta T = K_b m_{solute}$$

The similarity between freezing point depression and boiling point elevation is not accidental. They both depend on the shift in the equilibrium caused when a solution is formed and changes the equilibrium of the liquid with respect to the solid or vapor.

Cooking kinetics

The temperature of water determines how long it takes for food to cook. This pressure effect is not related to the colligative properties. However, addition of solutes will increase the temperature at which water boils and increase the rate of cooking.

Low P and T
Slow cooking



High pressure and temperature
Rapid cooking