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CHEMFILE MINI-GUIDE TO PROBLEM SOLVING

Colligative Properties

Colligative properties of solutions are properties that depend solely on the number of particles of solute in solution. In other words, these properties depend only on the concentration of solute particles, not on the identity of those particles. Colligative properties result from the interference of solute particles with the motion of solvent molecules.

Solute molecules can be either electrolytes or nonelectrolytes. When a nonelectrolyte dissolves, the molecule remains whole in the solution. Glucose and glycerol are examples of nonelectrolyte solutes.

Ionic solutes are electrolytes. When they dissolve, they dissociate into multiple particles, or ions. When magnesium chloride dissolves in water, it dissociates as follows.

$$MgCl_2(s) \xrightarrow{H_2O} Mg^{2+}(aq) + 2Cl^-(aq)$$

As you can see, when a mole of $MgCl_2$ completely dissociates in solution, it produces 1 mol of Mg^{2+} ions and 2 mol of Cl^- ions for a total of 3 mol of solute particles. Because colligative properties depend on the number of particles in solution, 1 mol of $MgCl_2$ in solution should have three times the effect of 1 mol of a nonelectrolyte solute, such as glucose.

Two important colligative properties are freezing-point depression and boiling-point elevation. A dissolved solute lowers the freezing point of the solution. The freezing point of a solution differs from that of the pure solvent according to the following equation, in which Δt_f is the change in freezing point.

$$\Delta t_f = K_f m$$

K_f is a constant that differs for each solvent. Because the freezing point of the solution is lower than that of the solvent alone, K_f is a negative number. The symbol m represents the molality (moles of solute per kilogram of solvent) of the solution.

Boiling-point elevation works in the same way. The equation to determine the change in boiling point is as follows.

$$\Delta t_b = K_b m$$

Like K_f, K_b is a constant that differs for each solvent. But unlike K_f, K_b is a positive number because the boiling point of the solution is higher than that of the solvent alone.

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General Plan for Solving Problems Involving Freezing-Point Depression and Boiling-Point Elevation

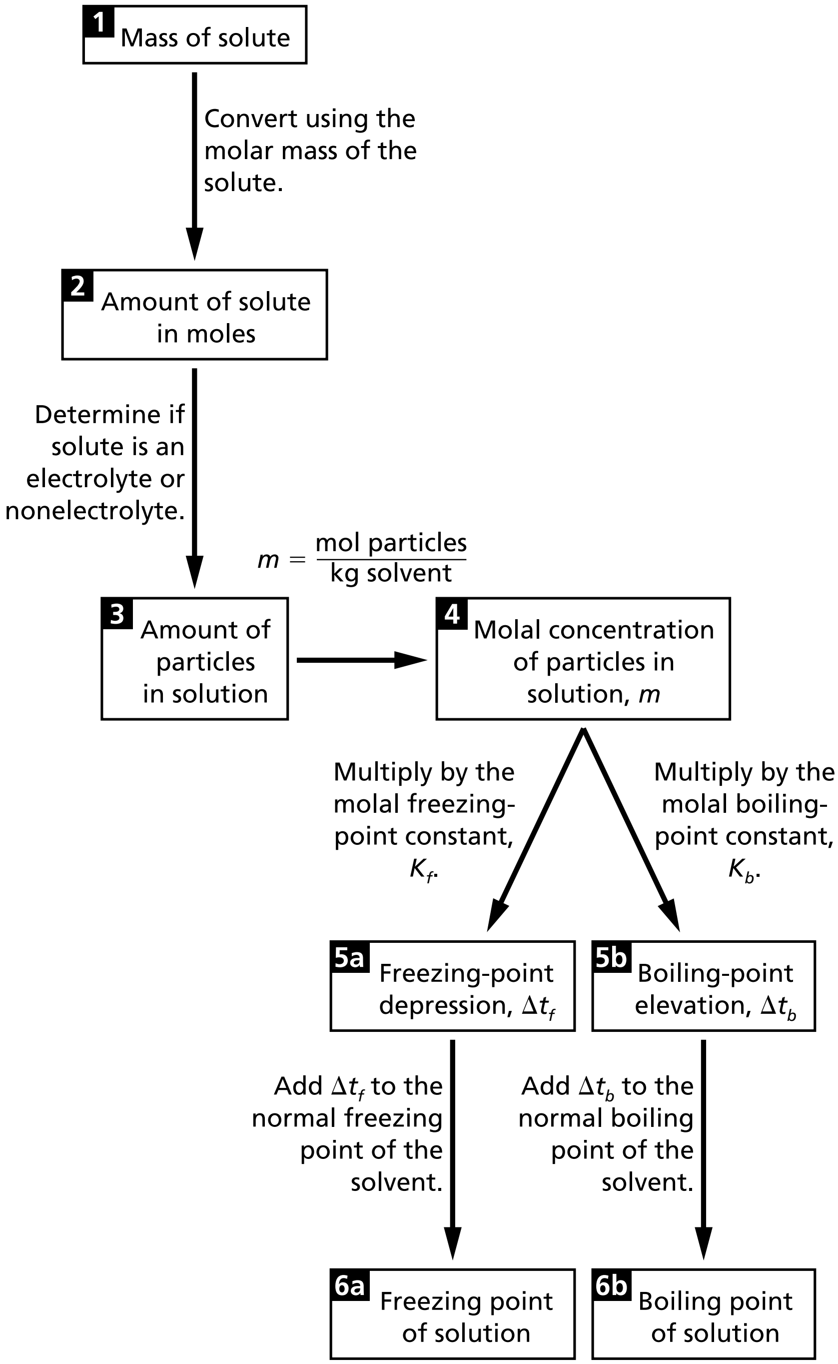

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Table 16-1 lists freezing-point depression and boiling-point elevation constants for common solvents.

TABLE 16-1

Solvent	Normal f.p.	K_f	Normal b.p.	K_b
Acetic acid	16.6°C	−3.90°C/*m*	117.9°C	3.07°C/*m*
Camphor	178.8°C	−39.7°C/*m*	207.4°C	5.61°C/*m*
Ether	−116.3°C	−1.79°C/*m*	34.6°C	2.02°C/*m*
Naphthalene	80.2°C	−6.94°C/*m*	217.7°C	5.80°C/*m*
Phenol	40.9°C	−7.40°C/*m*	181.8°C	3.60°C/*m*
Water	0.00°C	−1.86°C/*m*	100.0°C	0.51°C/*m*

SAMPLE PROBLEM 1

What is the freezing point of a solution of 210.0 g of glycerol, $HOCH_2CHOHCH_2OH$, dissolved in 350. g of water?

SOLUTION

1. *ANALYZE*

- *What is given in the problem?* — the formula and mass of solute, and the mass of water used
- *What are you asked to find?* — the freezing point of the solution

Items	Data
Identity of solute	glycerol, $HOCH_2CHOHCH_2OH$
Particles per mole of solute	1 mol
Identity of solvent	water
Freezing point of solvent	0.00°C
Mass of solvent	350. g
Mass of solute	210.0 g
Molar mass of solute*	92.11 g/mol
Molal concentration of solute particles	? *m*
Molal freezing-point constant for water	−1.86°C/*m*
Freezing-point depression	?°C
Freezing point of solution	?°C

* determined from the periodic table

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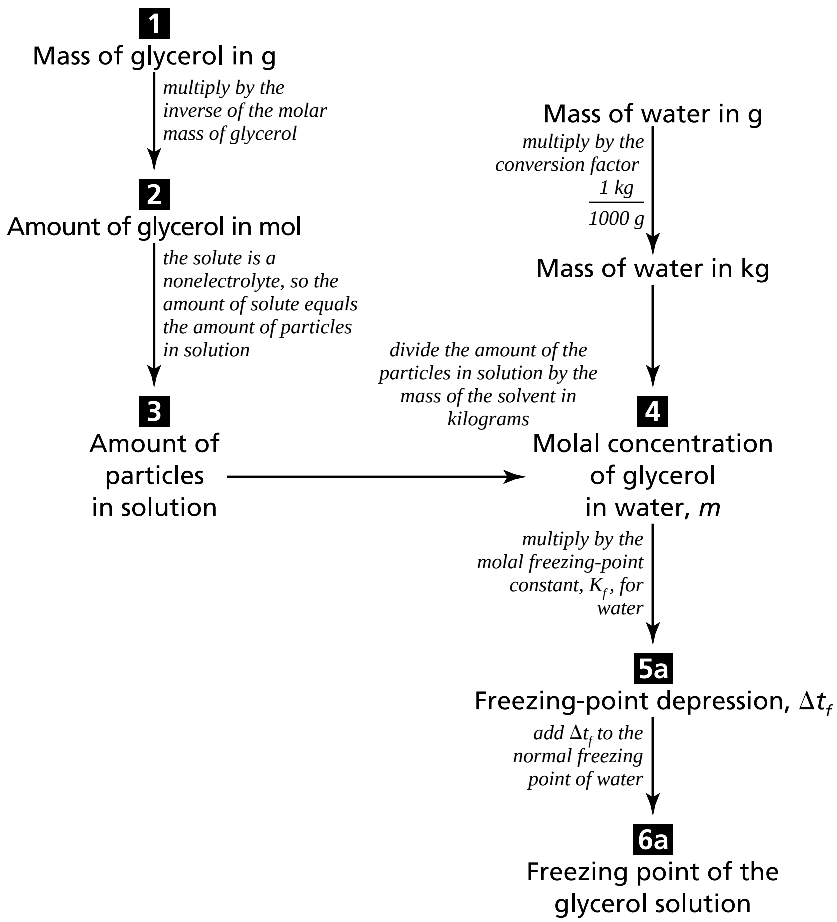
2. *PLAN*

- *What steps are needed to calculate the freezing point of the solution?*

Use the molar mass of the solute to determine the amount of solute. Then apply the mass of solvent to calculate the molality of the solution. From the molality, use the molal freezing-point constant for water to calculate the number of degrees the freezing point is lowered. Add this negative value to the normal freezing point.



$$\overset{given}{g\ H_2O} \times \frac{1\ kg}{1000\ g} = kg\ H_2O$$

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$$\underset{\textit{given}}{\text{g glycerol}} \times \underset{\frac{1}{\textit{molar mass of glycerol}}}{\frac{1 \text{ mol glycerol}}{92.11 \text{ g glycerol}}} \times \underset{\textit{calculated above}}{\frac{1}{\text{kg } H_2O}} \times \underset{\textit{freezing-point depression constant}}{\frac{-1.86°C}{\text{mol/kg}}} = \Delta t_f$$

$$\underset{\textit{freezing point of } H_2O}{0.00°C} + \underset{\textit{calculated above}}{\Delta t_f} = t_f$$

3. *COMPUTE*

$$350. \text{ g } H_2O \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.350 \text{ kg } H_2O$$

$$210.0 \text{ g glycerol} \times \frac{1 \text{ mol glycerol}}{92.11 \text{ g glycerol}} \times \frac{1}{0.350 \text{ kg } H_2O} \times \frac{-1.86°C}{\text{mol/kg}} = -12.1°C$$

$$0.00°C + (-12.1°C) = -12.1°C$$

4. *EVALUATE*

- *Are the units correct?* Yes; units canceled to give Celsius degrees.
- *Is the number of significant figures correct?* Yes; three significant figures is correct because the data had a minimum of three significant figures.
- *Is the answer reasonable?* Yes; the calculation can be approximated as $200 \div [90 \times 3(350 \div 1000)] \times -2 \approx -400/30 = -13$, which is close to the calculated value.

PRACTICE

1. Determine the freezing point of a solution of 60.0 g of glucose, $C_6H_{12}O_6$, dissolved in 80.0 g of water. *ans:* −7.74°C

2. What is the freezing point of a solution of 645 g of urea, H_2NCONH_2, dissolved in 980. g of water? *ans:* −20.4°C

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SAMPLE PROBLEM 2

What is the boiling point of a solution containing 34.3 g of the ionic compound magnesium nitrate dissolved in 0.107 kg of water?

SOLUTION

1. *ANALYZE*

- *What is given in the problem?* — the formula and mass of solute, and the mass of water used
- *What are you asked to find?* — the boiling point of the solution

Items	Data
Identity of solute	magnesium nitrate
Equation for the dissociation of the solute	$Mg(NO_3)_2 \rightarrow Mg^{2+} + 2NO_3^-$
Amount of ions per mole of solute	3 mol
Identity of solvent	water
Boiling point of solvent	100.0°C
Mass of solvent	0.107 kg H_2O
Mass of solute	34.3 g
Molar mass of solute	148.32 g/mol
Molal concentration of solute particles	**?** *m*
Molal boiling-point constant for solvent	0.51°C/*m*
Boiling-point depression	**?**°C
Boiling point of solution	**?**°C

2. *PLAN*

- *What steps are needed to calculate the boiling point of the solution?* — Use the molar mass to calculate the amount of solute in moles. Multiply the amount of solute by the number of moles of ions produced per mole of solute. Use the amount of ions with the mass of solvent to compute the molality of particles in solution. Use this effective molality to determine the boiling-point elevation and the boiling point of the solution.

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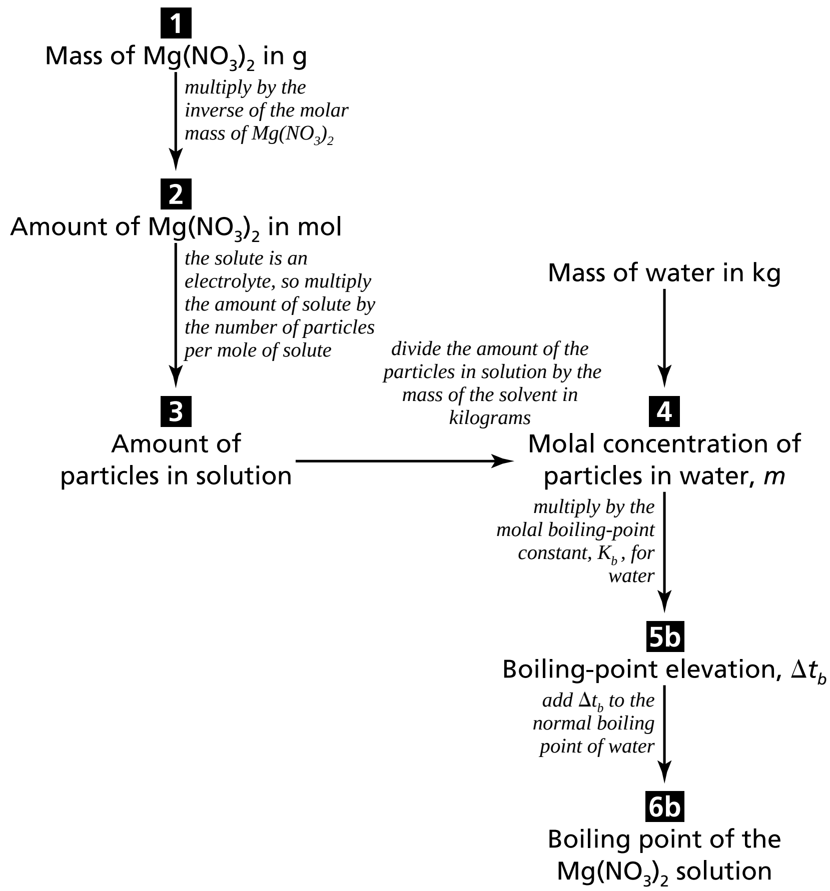

$$\underset{\textit{given}}{\text{g } Mg(NO_3)_2} \times \overset{\frac{1}{\textit{molar mass of } Mg(NO_3)_2}}{\frac{1 \text{ mol } Mg(NO_3)_2}{148.32 \text{ g } Mg(NO_3)_2}} \times \frac{3 \text{ mol particles}}{1 \text{ mol } Mg(NO_3)_2} \times \overset{\textit{given}}{\frac{1}{\text{kg } H_2O}}$$

$$\times \overset{\textit{molal boiling-point constant for water}}{\frac{0.51°C}{\text{mol/kg}}} = \Delta t_b$$

$$\underset{\textit{boiling point of } H_2O}{100.0°C} + \underset{\textit{calculated above}}{\Delta t_b} = t_b$$

3. *COMPUTE*

$$34.3 \text{ g } Mg(NO_3)_2 \times \frac{1 \text{ mol } Mg(NO_3)_2}{148.32 \text{ g } Mg(NO_3)_2} \times \frac{3 \text{ mol particles}}{1 \text{ mol } Mg(NO_3)_2} \times \frac{1}{0.107 \text{ kg } H_2O} \times \frac{0.51°C}{\text{mol/kg}} = 3.31°C$$

$$100.0°C + 3.31°C = 103.3°C$$

4. *EVALUATE*

- *Are the units correct?* Yes; units canceled to give Celsius degrees.
- *Is the number of significant figures correct?* Yes; the number of significant figures is correct because the boiling point of water was given to one decimal place.
- *Is the answer reasonable?* Yes; the calculation can be approximated as $[(35 \times 3)/150] \times 5 = (7/10) \times 5 = 3.5$, which is close to the calculated value for the boiling-point elevation.

PRACTICE

1. What is the expected boiling point of a brine solution containing 30.00 g of KBr dissolved in 100.00 g of water? *ans:* 102.6°C

2. What is the expected boiling point of a $CaCl_2$ solution containing 385 g of $CaCl_2$ dissolved in 1.230×10^3 g of water? *ans:* 104.3°C

SAMPLE PROBLEM 3

A solution of 3.39 g of an unknown compound in 10.00 g of water has a freezing point of −7.31°C. The solution does not conduct electricity. What is the molar mass of the compound?

SOLUTION

1. *ANALYZE*

- *What is given in the problem?* the freezing point of the solution, the mass of the dissolved compound, the mass of solvent, and the fact that the solution does not conduct electricity
- *What are you asked to find?* the molar mass of the unknown compound

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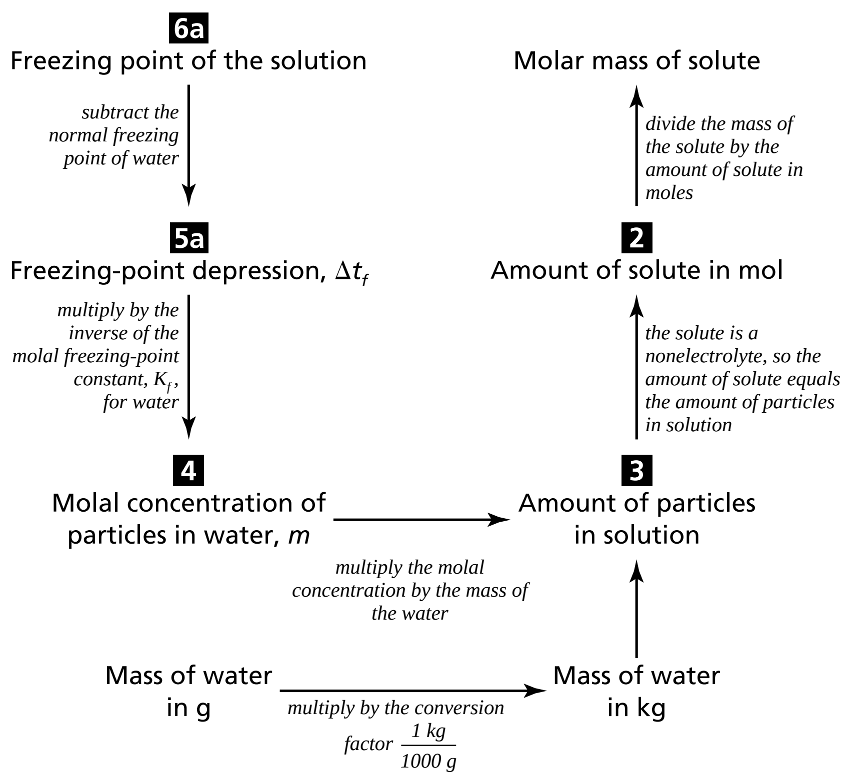
Items	Data
Mass of solute	3.39 g
Molar mass of solute	? g/mol
Identity of solvent	water
Freezing point of solvent	0.00°C
Mass of solvent	10.00 g
Molal freezing-point constant for solvent	− 1.86°C/*m*
Freezing-point depression	?°C
Freezing point of solution	− 7.31°C
Molal concentration of solute particles	? *m*

2. *PLAN*

- *What steps are needed to calculate the molar mass of the unknown solute?*

Determine the molality of the solution from the freezing-point depression. Use the molality and the solute and solvent masses to calculate the solute molar mass.



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$$\underset{given}{t_f} - \underset{\substack{freezing\ point\\ of\ water}}{0.00°C} = \Delta t_f$$

$$\underset{given}{g\ H_2O} \times \frac{1\ kg}{1000\ g} = kg\ H_2O$$

$$\underset{\substack{calculated\\ above}}{\Delta t_f} \times \underset{\substack{\frac{1}{molal\ freezing\text{-}point\ constant\ for\ water}}}{\frac{mol/kg}{-1.86°C}} \times \underset{\substack{calculated\\ above}}{kg\ H_2O} = mol\ solute$$

$$\frac{\overset{given}{g\ solute}}{\underset{calculated\ above}{mol\ solute}} = molar\ mass\ of\ solute$$

3. *COMPUTE*

$$-7.31°C - 0.00°C = -7.31°C$$

$$10.00\ \cancel{g}\ H_2O \times \frac{1\ kg}{1000\ \cancel{g}} = 0.010\ 00\ kg\ H_2O$$

$$-7.31\cancel{°C} \times \frac{mol/\cancel{kg}}{-1.86\cancel{°C}} \times 0.010\ 00\ \cancel{kg\ H_2O} = 0.039\ 30\ mol\ solute$$

$$\frac{3.39\ g\ solute}{0.039\ 30\ mol\ solute} = 86.3\ g/mol$$

4. *EVALUATE*

- *Are the units correct?* Yes; molar mass has units of g/mol.
- *Is the number of significant figures correct?* Yes; the number of significant figures is correct because the data had a minimum of three significant figures.
- *Is the answer reasonable?* Yes; the calculation can be approximated as (4/1) × (1/100) = 0.04, which is close to the value of 0.0393 for the amount of solute.

PRACTICE

1. A solution of 0.827 g of an unknown nonelectrolyte compound in 2.500 g of water has a freezing point of − 10.18°C. Calculate the molar mass of the compound. *ans:* 60.4 g/mol