Concentration of Solutions and Molarity

The **concentration** of a solution is a measure of the amount of solute that is dissolved in a given quantity of solvent.

- A **dilute solution** is one that contains a small amount of solute.
- A **concentrated** solution contains a large amount of solute.

What we need is a way of quantifying the concentration of a solution!

Molarity (M) is the number of moles of solute dissolved in one liter of solution.

- To calculate the molarity of a solution, divide the moles of solute by the volume of the solution. *Remember that volume is ALWAYS in LITERS!*

$$\text{Molarity}\ (M) = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Molarity Example

If 5 liters of water is added to two moles of glucose to make a solution, the concentration (molarity) is said to be 0.4 M

$$\frac{\text{2 mol of glucose}}{\text{5 liters of soln.}} = \mathbf{0.4\ M}$$

*Remember that solution is always in liters!

Molarity Example

What is the molarity of 600. mL of potassium iodide solution that contains 5.50 moles of the solute?

M = mol solute / L soln.

M = 5.50 mol / .600 L

M = 9.16 molar

Finding the Moles of Solute in a Solution

Household laundry bleach is a dilute aqueous solution of sodium hypochlorite (NaClO). How many moles of solute are present in 1.5 L of 0.70*M* NaClO?

$$M = \frac{mol}{L}$$

$$0.7 = \frac{x}{1.5}$$

$$x = 1.05\,\text{mol\_NaClO}$$

Molarity Example

A saline solution contains 0.90 g of NaCl per 100 mL of solution. What is its molarity?

1) convert grams to moles . . .

0.90 g NaCl / 58.5 g/mol = 0.015 mol NaCl

2) convert mL to L and solve . . .

0.015 mol / .100 L = **0.15 M**

Molarity Example

What volume of a 4.0 M solution would contain 15.5 moles of sodium thiosulfate?

M = mol solute / L solution . . . so . . .

L = mol / M

L = 15.5 mol / 4.0 M

L = 3.9 liters of solution

2. What mass of sodium iodide (NaI) is contained in 250 mL of a 0.500M solution?

a) 150 g

b) 75.0 g

c) 18.7 g

d) 0.50 g

$$0.5\text{M} = \frac{\text{x}}{0.250\text{L}}$$

$$\text{x} = 0.125\_\text{mol}\_\text{NaI}$$

$$(0.125\text{mol})\frac{149.89\text{g}}{\text{mol}} = 18.7\text{g}$$

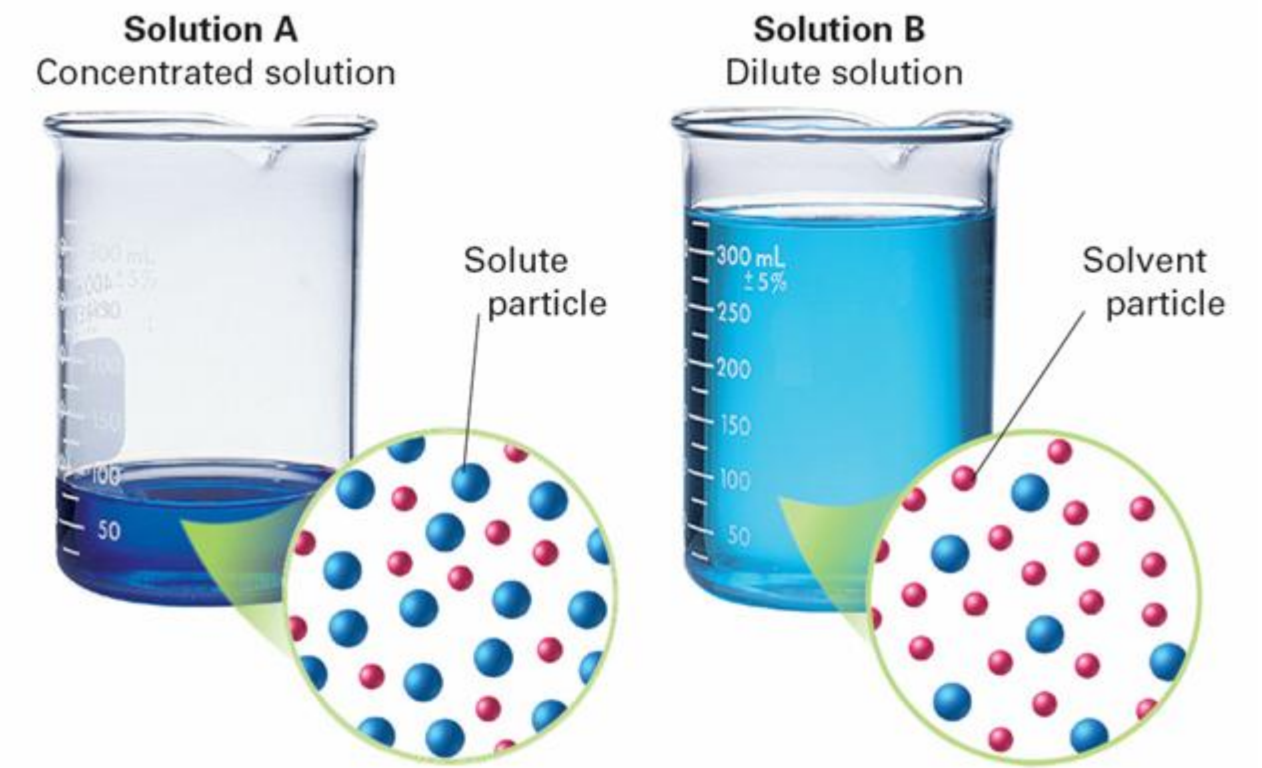
Making Dilutions

– Diluting a solution reduces the number of moles of solute per unit volume, but the total number of moles of solute in solution does not change.
  - The total number of moles of solute remains unchanged upon dilution, so you can write this equation.

$$\text{Moles of solute} = M_1 \times V_1 = M_2 \times V_2$$

  - M_1 and V_1 are the molarity and volume of the initial solution, and M_2 and V_2 are the molarity and volume of the diluted solution.

Making a Dilute Solution



Preparing a Dilute Solution

How many milliliters of aqueous 2.00*M* $MgSO_4$ solution must be diluted with water to prepare 100.0 mL of aqueous 0.400*M* $MgSO_4$?

Analyze ***List the knowns and the unknown.***

Knowns

- $M_1 = 2.00M\ MgSO_4$
- $M_2 = 0.400M\ MgSO_4$
- $V_2 = 100.0$ mL of $0.400M\ MgSO_4$
- $M_1 \times V_1 = M_2 \times V_2$

Unknown

- $V_1 = ?$ mL of $2.00M\ MgSO_4$

Calculate ***Solve for the unknown.***

Solving for V_1 yields:

$$V_1 = \frac{M_2 \times V_2}{M_1} = \frac{0.400\cancel{M} \times 100.0\ \text{mL}}{2.00\cancel{M}}$$

$$= 20.0\ \text{mL}$$

Thus 20.0 mL of the initial solution must be diluted by adding enough water to increase the volume to 100.0 mL.

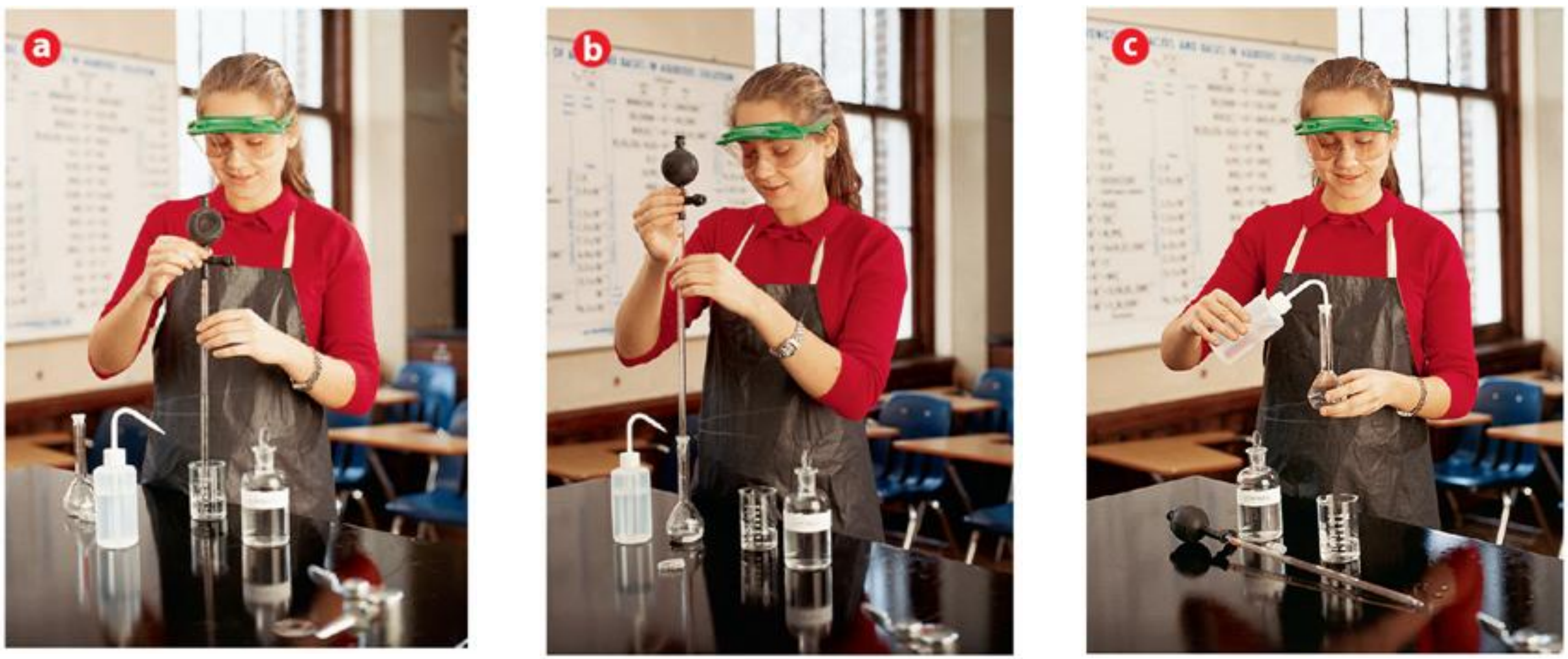
Evaluate ***Does the result make sense?***

The concentration of the initial solution is five times larger than the concentration of the diluted solution. Because the moles of solute in each solution are the same, the volume of the solution to be diluted (20.0 mL) should be one-fifth the final volume of the diluted solution. The answer is correctly expressed to three significant figures.

a) To prepare 100 ml of 0.40*M* $MgSO_4$ from a stock solution of 2.0*M* $MgSO_4$, a student first measures 20 mL of the stock solution with a 20-mL pipet.

b) She then transfers the 20 mL to a 100-mL volumetric flask.

c) Finally she carefully adds water to the mark to make 100 mL of solution.



- **Volume-Measuring Devices**

buret

graduated
cylinder

volumetric
flask

pipette

12. How many milliliters of a solution of 4.00*M* KI are needed to prepare 250.0 mL of 0.760*M* KI?

$$M_1V_1 = M_2V_2$$

$$(4.00)(x) = (0.76)(250)$$

$$x = 47.5\text{mL\_4.00M\_KI}$$

3. Diluting a solution does NOT change which of the following?

a) concentration

b) volume

c) milliliters of solvent

d) moles of solute

Colligative Properties of Solutions

The wood frog is a remarkable creature because it can survive being frozen. Scientists believe that a substance in the cells of this frog acts as a natural antifreeze, which prevents the cells from freezing. You will discover how a solute can change the freezing point of a solution.

Colligative Properties

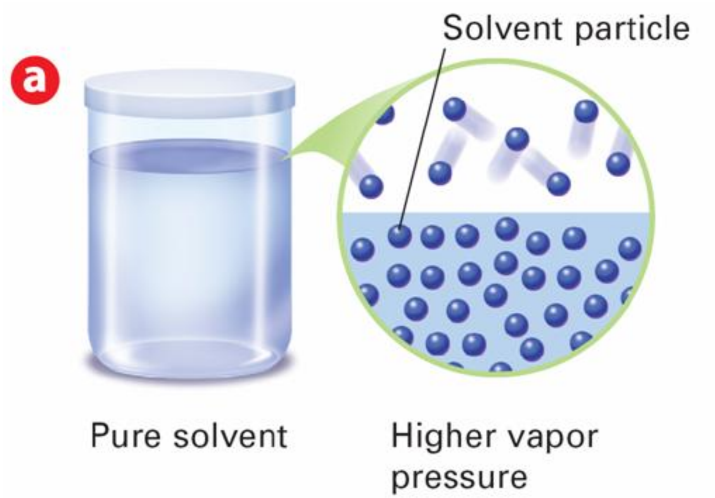
- A property that depends only upon the number of solute particles, and not upon their identity, is called a **colligative property**.

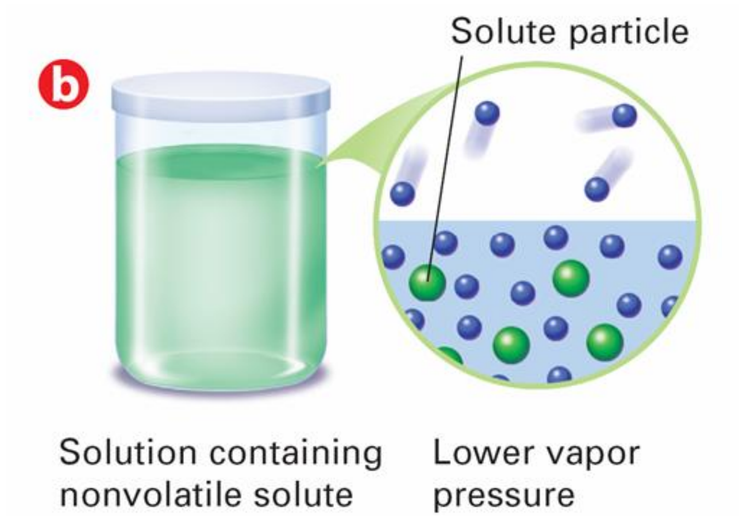
Three important colligative properties of solutions are

- **vapor-pressure lowering**
- **boiling-point elevation**
- **freezing-point depression**

a) In a pure solvent, equilibrium is established between the liquid and the vapor.

b) In a solution, solute particles reduce the number of free solvent particles able to escape the liquid. Equilibrium is established at a lower vapor pressure.

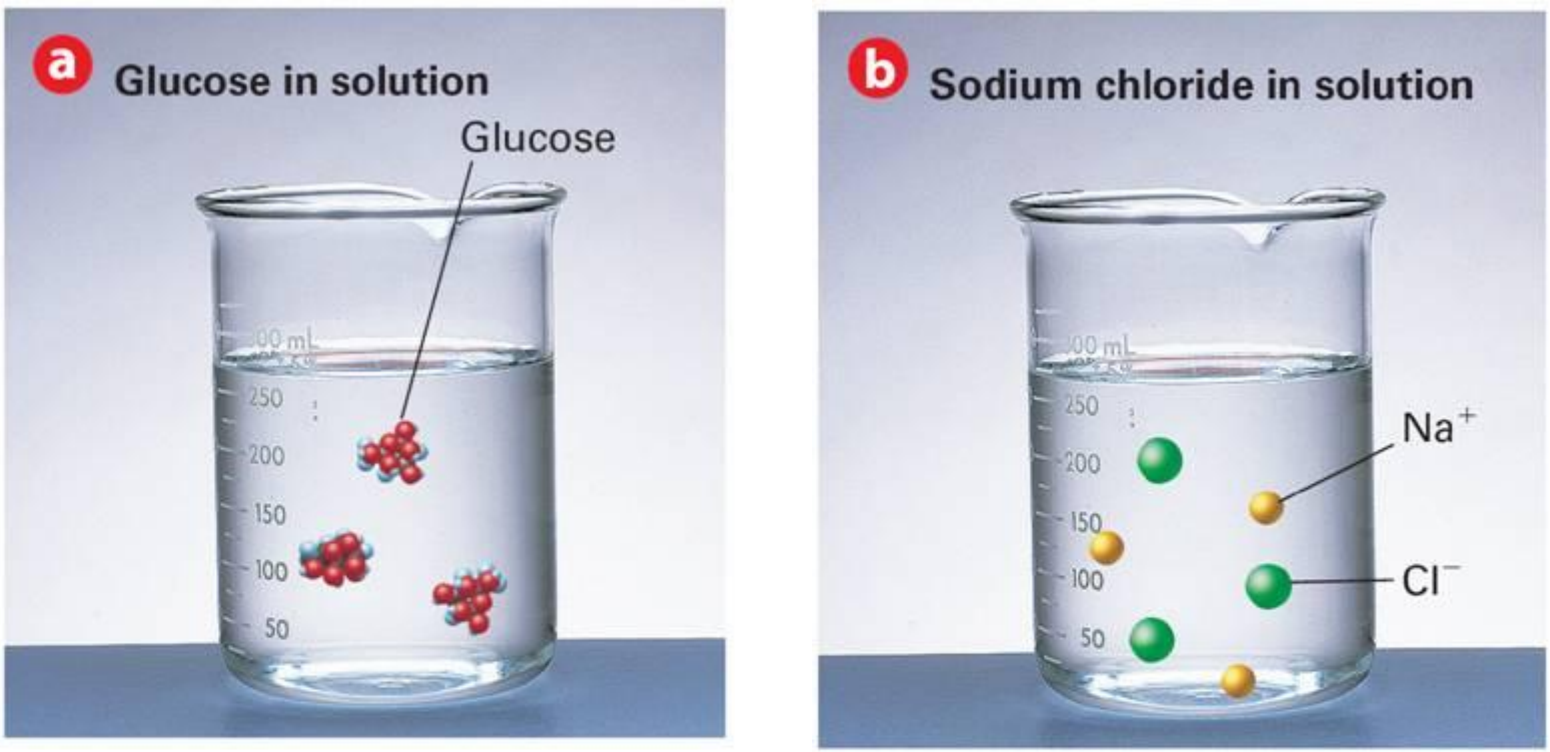




Vapor pressure lowering--The decrease in a solution’s vapor pressure is proportional to the number of particles the solute makes in solution.

a) Three moles of glucose dissolved in water produce 3 mol of particles because glucose does not dissociate.

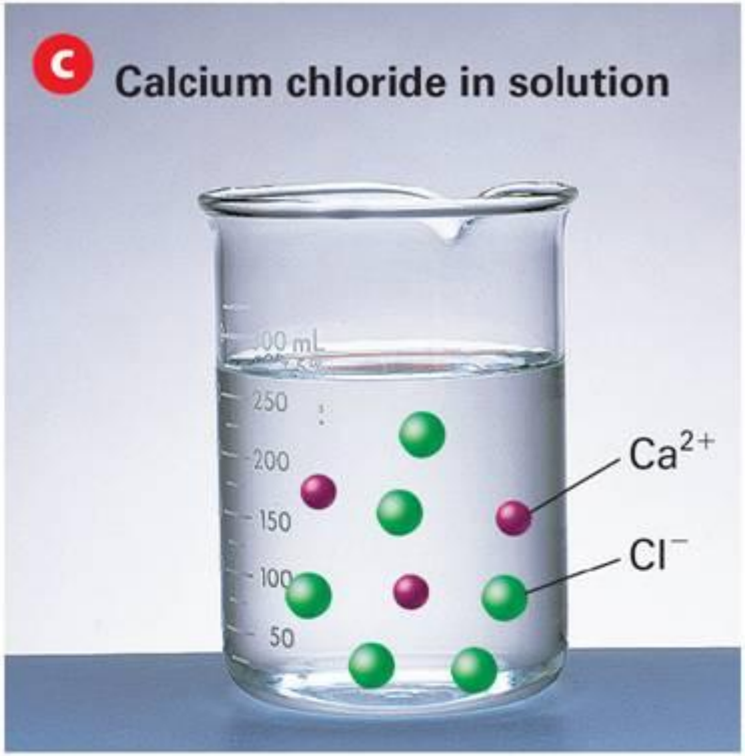
b) Three moles of sodium chloride dissolved in water produce 6 mol of particles because each formula unit of NaCl dissociates into two ions.



3 moles Na+ and 3 moles Cl-

c) Three moles of calcium chloride dissolved in water produce 9 mol of particles because each formula unit of $CaCl_2$ dissociates into three ions.

3 moles Ca^{2+} and 3 moles 2 Cl^- which is 3 moles Ca^{2+} and 6 moles Cl^-



Freezing-Point Depression

- The difference in temperature between the freezing point of a solution and the freezing point of the pure solvent is the **freezing-point depression.**
- The magnitude of the freezing-point depression is proportional to the number of solute particles dissolved in the solvent and does not depend upon their identity.

The freezing-point depression of aqueous solutions makes walks and driveways safer when people sprinkle salt on icy surfaces to make ice melt. The melted ice forms a solution with a lower freezing point than that of pure water.

Boiling-Point Elevation

- The difference in temperature between the boiling point of a solution and the boiling point of the pure solvent is the **boiling-point elevation.**
- The same antifreeze added to automobile engines to prevent freeze-ups in winter, protects the engine from boiling over in summer.
- The magnitude of the boiling-point elevation is proportional to the number of solute particles dissolved in the solvent.
- The boiling point of water increases by 0.512°C for every mole of particles that the solute forms when dissolved in 1000 g of water.

16.3 Review

1. Which of the following is NOT a colligative property of
   - a) vapor-pressure lowering
   - b) freezing-point depression
   - c) boiling-point elevation
   - d) solubility elevation

2. Choose the correct word for the space: The magnitude of each colligative property of solutions is proportional to the ____________ solute dissolved in the solution.

a) type of

b) number of particles of

c) molar volume of

d) particle size of the

3. The decrease in vapor pressure when a solute is added to a liquid is due to

a) attractive forces between solvent particles.

b) repulsion of the solute particles by the solvent particles.

c) dissociation of the solvent particles.

d) attractive forces between solvent and solute particles.

4. You have 500 mL of 1*M* solutions of NaCl, Na_2SO_4, Na_3PO_4, and $Al_2(SO_4)_3$. Which solution will have the highest boiling point?

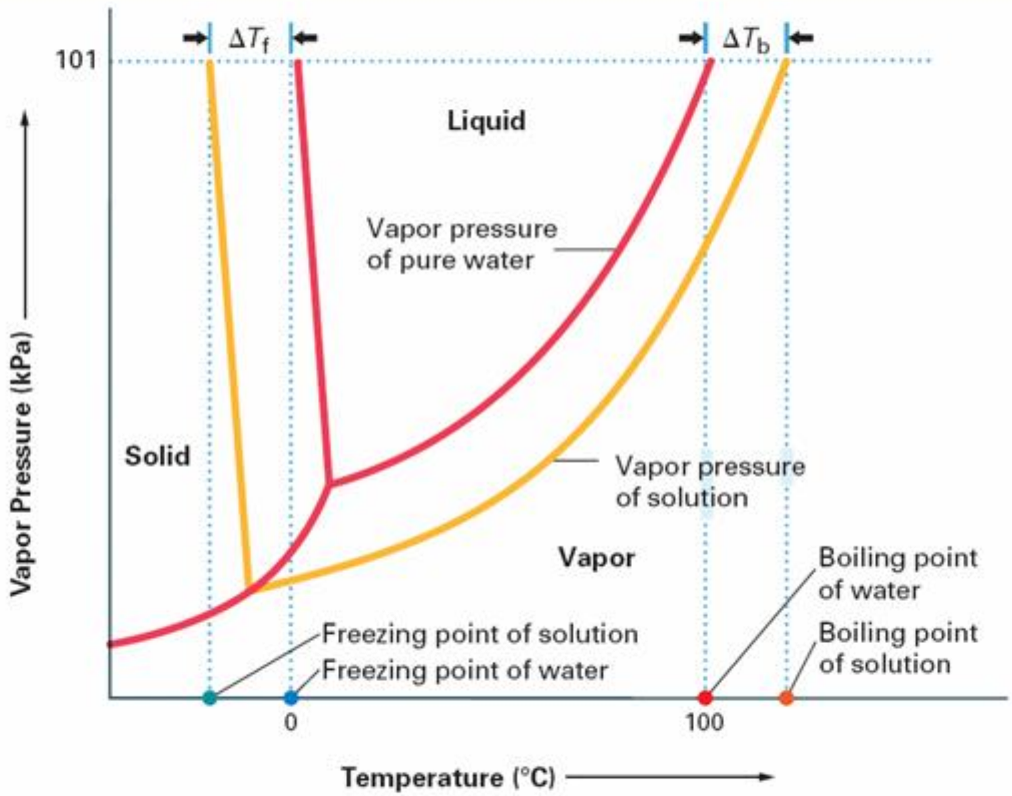
a) NaCl(*aq*)

b) Na_2SO_4(*aq*)

c) Na_3PO_4(*aq*)

d) $Al_2(SO_4)_3$(*aq*)

Vapor Pressure versus Temperature



Calculating the Freezing-Point Depression of a Solution

Antifreeze protects a car from freezing. It also protects it from overheating. Calculate the freezing-point depression and the freezing point of a solution containing 100 g of ethylene glycol ($C_2H_6O_2$) antifreeze in 0.500 kg of water.

Analyze ***List the knowns and the unknowns.***

Knowns

- mass of solute = 100 g $C_2H_6O_2$
- mass of solvent = 0.500 kg H_2O
- K_f for H_2O = 1.86°C/m
- $\Delta T_f = K_f \times m$

Unknown

- ΔT_f = ?°C
- freezing point = ?°C

Calculate the number of moles of solute and the molality. Then calculate the freezing-point depression and freezing point.

Calculate ***Solve for the unknown.***

$$\text{moles } C_2H_6O_2 = 100 \cancel{\text{g } C_2H_6O_2} \times \frac{1 \text{ mol}}{62.0 \cancel{\text{g } C_2H_6O_2}} = 1.61 \text{ mol}$$

$$m = \frac{\text{mol solute}}{\text{kg solvent}} = \frac{1.61 \text{ mol}}{0.500 \text{ kg}} = 3.22m$$

$$\Delta T_f = K_f \times m = 1.86°\text{C}/m \times 3.22m = 5.99°\text{C}$$

The freezing point of the solution is 0.00°C − 5.99°C = −5.99°C.

Evaluate ***Does the result make sense?***

A 1-molal solution reduces the freezing temperature by 1.86°C, so a decrease of 5.99°C for an approximately 3-molal solution is reasonable. The answer is correctly expressed with three significant figures.

Calculating the Boiling Point of a Solution

What is the boiling point of a 1.50m NaCl solution?

Analyze ***List the knowns and the unknown.***

Knowns

- concentration = 1.50m NaCl
- K_b for H_2O = 0.512°C/m
- $\Delta T_b = K_b \times m$

Unknown

- boiling point = ?°C

Each formula unit of NaCl dissociates into two particles, Na^+ and Cl^-. Based on the total number of dissociated particles, the effective molality is $2 \times 1.50m = 3.00m$. Calculate the boiling-point elevation and then add it to 100°C.

Calculate ***Solve for the unknown.***

$$\Delta T_b = K_b \times m = \frac{0.512°C}{\cancel{m}} \times 3.00\cancel{m} = 1.54°C$$

The boiling point of the solution is 100°C + 1.54°C = 101.54°C

Evaluate ***Does the result make sense?***

The boiling point increases about 0.5°C for each mole of solute particles, so the total change is reasonable. Because the boiling point of water is defined as exactly 100°C, this value does not limit the number of significant figures in the solution of the problem.