

Unit 10: Solutions

Solution Definitions

solution: a homogeneous mixture

-- evenly mixed at the particle level

-- e.g., salt water

alloy: a solid solution of metals

-- e.g., bronze = Cu + Sn; brass = Cu + Zn

solvent: the substance that dissolves the solute

water salt

soluble: “will dissolve in”

miscible: refers to two gases or two liquids that form

a solution; more specific than “soluble”

-- e.g., food coloring and water



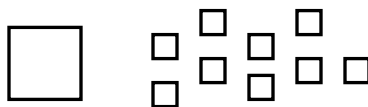
Factors Affecting the Rate of Dissolution

1. temperature



As $T^{\circ} \uparrow$, rate \uparrow

2. particle size



As size \downarrow , rate \uparrow

3. mixing



More mixing, rate \uparrow

4. nature of solvent or solute

Classes of Solutions

aqueous solution: solvent = water

water = “the universal solvent”



amalgam: solvent = Hg

e.g., dental amalgam



tincture: solvent = alcohol

e.g., tincture of iodine (for cuts)



organic solution: solvent contains carbon

e.g., gasoline, benzene, toluene, hexane



Non-Solution Definitions

insoluble: “will NOT dissolve in”

e.g., sand and water

immiscible: refers to two gases or two liquids that will NOT form a solution

e.g., water and oil

suspension: appears uniform while being stirred, but settles over time

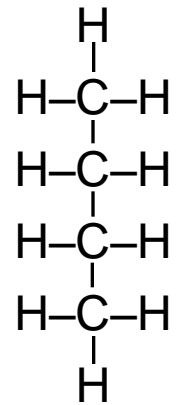
Molecular Polarity

nonpolar molecules:

-- e⁻ are shared equally

-- tend to be symmetric

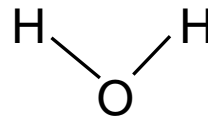
e.g., fats and oils



polar molecules:

-- e⁻ NOT shared equally

e.g., water



“Like dissolves like.”

polar + polar = solution

nonpolar + nonpolar = solution

polar + nonpolar = suspension (won't mix evenly)

Using Solubility Principles

Chemicals used by body obey solubility principles.

-- water-soluble vitamins: e.g., vit. C

-- fat-soluble vitamins: e.g., vits. A, D

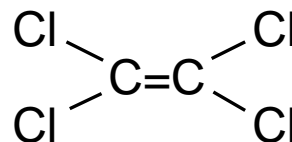


Dry cleaning employs nonpolar liquids.

-- polar liquids damage wool, silk

-- also, dry clean for stubborn stains (ink, rust, grease)

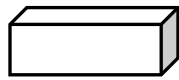
-- *tetrachloroethylene* is in
common use



emulsifying agent (emulsifier):

- molecules w/both a polar AND a nonpolar end
- allows polar and nonpolar substances to mix

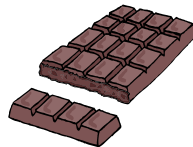
e.g., soap



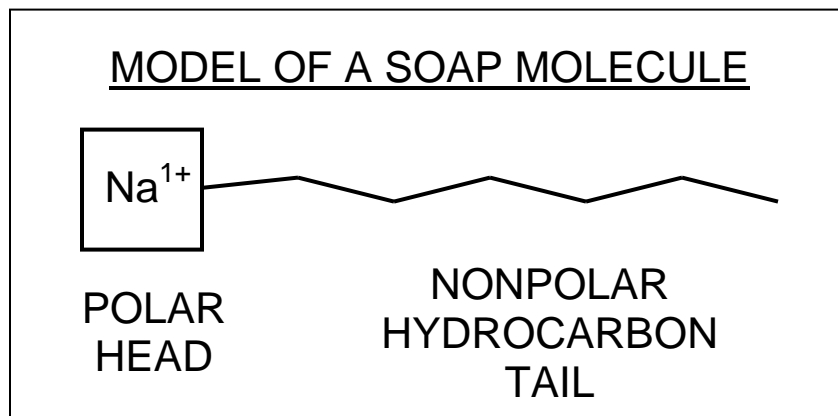
detergent



lecithin



eggs



soap

vs.

detergent

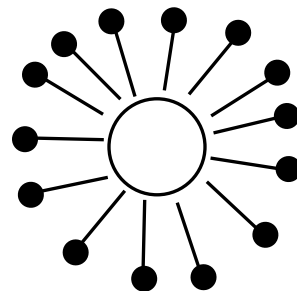
-- made from animal and vegetable fats

-- made from petroleum

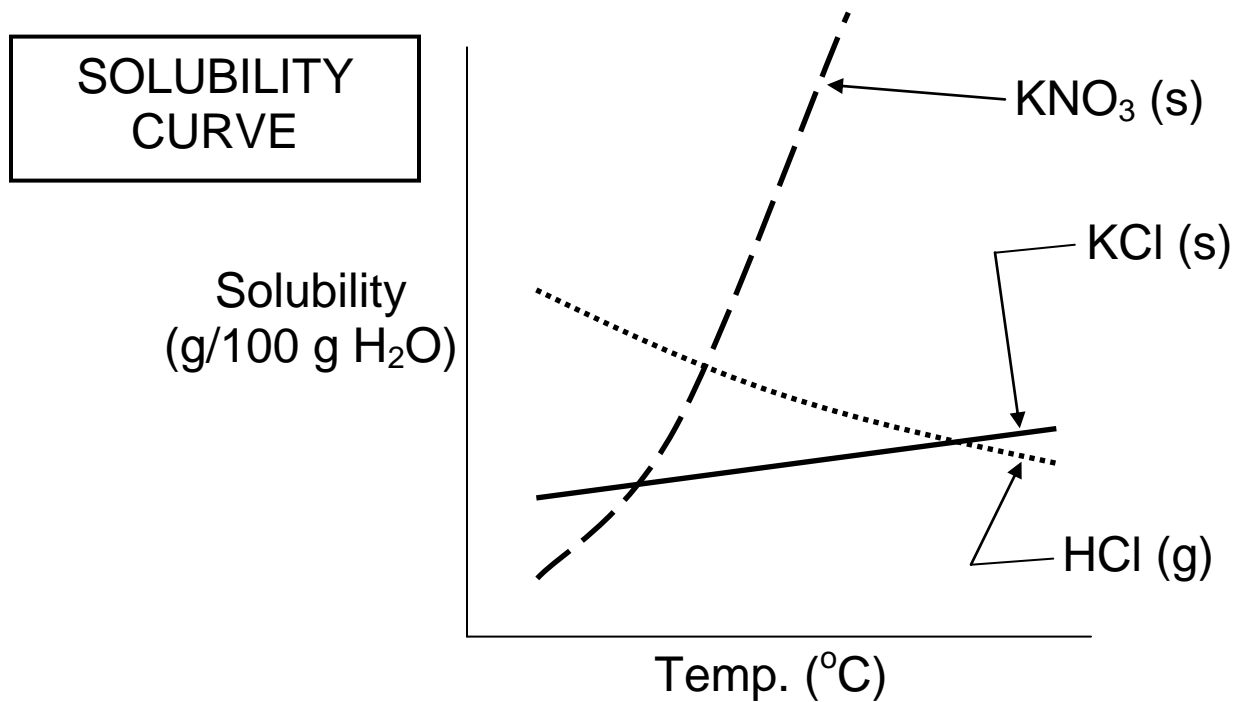
-- works better in hard water

Hard water contains minerals w/ions like Ca²⁺, Mg²⁺, and Fe³⁺ that replace Na¹⁺ at polar end of soap molecule. Soap is changed into an insoluble precipitate (i.e., soap scum).

micelle: a liquid droplet covered w/soap or detergent molecules



Solubility → how much solute dissolves in a given amt. of solvent at a given temp.

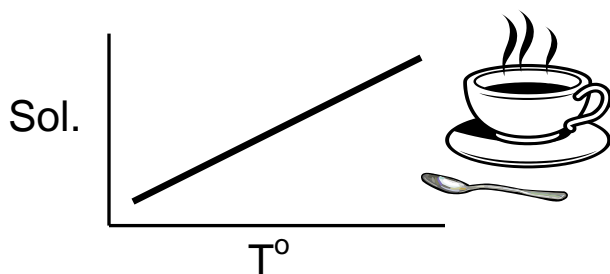


unsaturated: sol'n could hold more solute; below line

saturated: sol'n has "just right" amt. of solute; on line

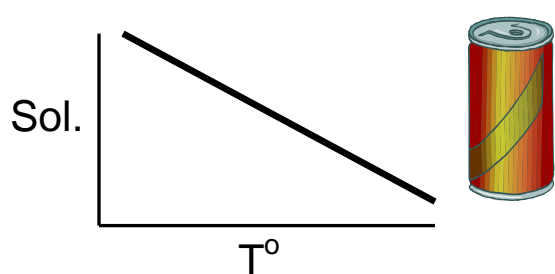
supersaturated: sol'n has "too much" solute dissolved in it; above the line

Solids dissolved in liquids



As T° ↑, solubility ↑

Gases dissolved in liquids



As T° ↑, solubility ↓

Classify as unsaturated, saturated, or supersaturated.

per 100 g H ₂ O	{	80 g NaNO ₃ @ 30°C	unsaturated
		45 g KCl @ 60°C	saturated
		50 g NH ₃ @ 10°C	unsaturated
		70 g NH ₄ Cl @ 70°C	supersaturated

Per 500 g H₂O, 120 g KNO₃ @ 40°C

saturation point @ 40°C for 100 g H₂O = 66 g KNO₃

So sat. pt. @ 40°C for 500 g H₂O = 5 x 66 g = 330 g

120 g < 330 g → unsaturated

Describe each situation below.

(A) Per 100 g H₂O, 100 g
NaNO₃ @ 50°C.

→ Unsaturated; all solute
dissolves; clear sol'n.

(B) Cool sol'n (A) very
slowly to 10°C.

→ Supersaturated; extra
solute remains in sol'n;
still clear.

(C) Quench sol'n (A) in an
ice bath to 10°C.

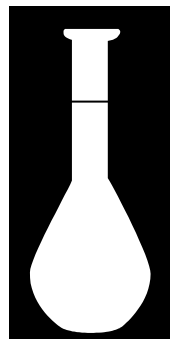
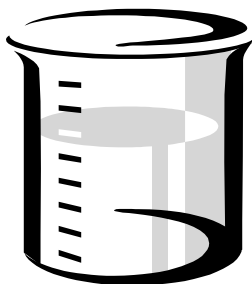
→ Saturated; extra solute
(20 g) can't remain in
sol'n, becomes visible.

Glassware – Precision and Cost

beaker
1000 mL \pm 5%

vs.

volumetric flask
1000 mL \pm 0.30 mL



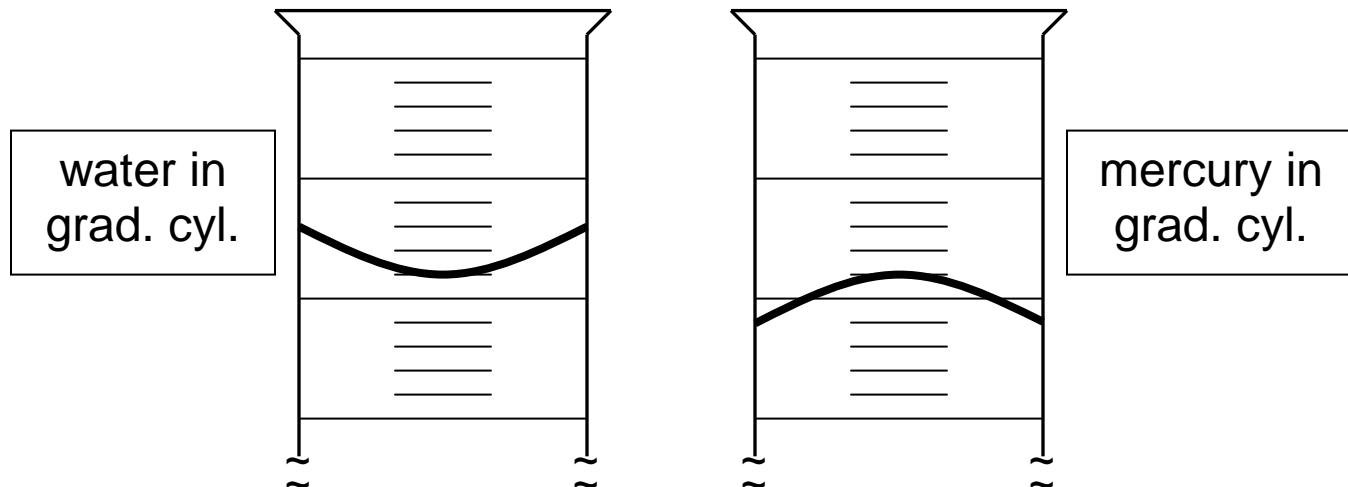
When filled to 1000 mL line, how much liquid is present?

beaker
5% of 1000 mL = 50 mL
Range: 950 mL – 1050 mL

imprecise; cheap

volumetric flask
Range: 999.70 mL
– 1000.30 mL

precise; expensive



Measure to part of meniscus ^w/zero slope.

Concentration...a measure of solute-to-solvent ratio

concentrated

“lots of solute”

dilute

“not much solute”

“watery”

Add water to dilute a sol'n; boil water off to concentrate it.

Selected
units:

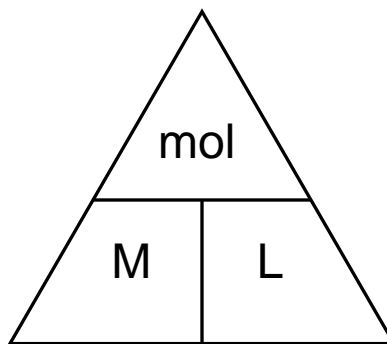
A. mass % = $\frac{\text{mass of solute}}{\text{mass of sol'n}}$

B. parts per million (ppm) → also, ppb and ppt
-- commonly used for minerals or
contaminants in water supplies

C. molarity (M) = $\frac{\text{moles of solute}}{\text{L of sol'n}}$

-- used most often in this class

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



D.
$$\text{molality (m)} = \frac{\text{moles of solute}}{\text{kg of solvent}}$$

7.85 kg KCl are dissolved in 2.38 L of sol'n. Find molality.

$$m = \frac{\text{kg solute}}{\text{L sol'n}} = \frac{7.85 \text{ kg}}{2.38 \text{ L}} = \boxed{3.30 \text{ m KCl}}$$

24.8 g table sugar (i.e., sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$) are mixed into 450 g water. Find molality.

$$m = \frac{\text{kg solute}}{\text{L sol'n}} = \frac{0.0248 \text{ kg}}{0.450 \text{ L}} = \boxed{0.055 \text{ m C}_{12}\text{H}_{22}\text{O}_{11}}$$

What mass of CaF_2 must be added to 1,000 L of water so that fluoride atoms are present at a conc. of 1.5 ppm?

$$X \text{ m'cule H}_2\text{O} = 1000 \text{ L} \left(\frac{1000 \text{ mL}}{1 \text{ L}} \right) \left(\frac{1 \text{ g}}{1 \text{ mL}} \right) \left(\frac{1 \text{ mol}}{18 \text{ g}} \right) \left(\frac{6.02 \times 10^{23} \text{ m'cule}}{1 \text{ mol}} \right)$$

$$= 3.34 \times 10^{28} \text{ m'cules H}_2\text{O}$$

$$\frac{1.5 \text{ atom F}}{1,000,000 \text{ m'cule H}_2\text{O}} = \frac{X \text{ atoms F}}{3.34 \times 10^{28} \text{ m'cule H}_2\text{O}}$$

$$X = 5.01 \times 10^{22} \text{ at. F} \rightarrow \text{times} \left(\frac{1 \text{ m'c CaF}_2}{2 \text{ at. F}} \right) = 2.505 \times 10^{22} \text{ m'c CaF}_2$$

$$X \text{ g CaF}_2 = 2.505 \times 10^{22} \text{ m'c} \left(\frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ m'c}} \right) \left(\frac{78.1 \text{ g}}{1 \text{ mol}} \right) = \boxed{3.25 \text{ g CaF}_2}$$

1: How many mol solute are req'd to make 1.35 L of 2.50 M sol'n?

$$\text{mol} = M L = 2.50 M (1.35 L) = \boxed{3.38 \text{ mol}}$$

A. What mass sodium hydroxide is this?

$$X \text{ g NaOH} = 3.38 \text{ mol} \left(\frac{40.0 \text{ g}}{1 \text{ mol}} \right) = \boxed{135 \text{ g NaOH}}$$

B. What mass magnesium phosphate is this?

$$X \text{ g Mg}_3(\text{PO}_4)_2 = 3.38 \text{ mol} \left(\frac{262.9 \text{ g}}{1 \text{ mol}} \right) = \boxed{889 \text{ g Mg}_3(\text{PO}_4)_2}$$

2: Find molarity if 58.6 g barium hydroxide are in 5.65 L sol'n.

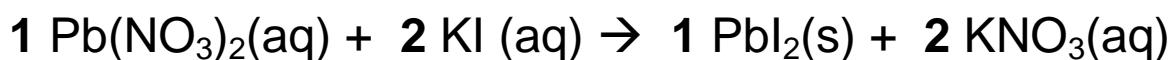
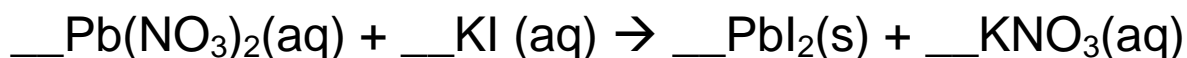
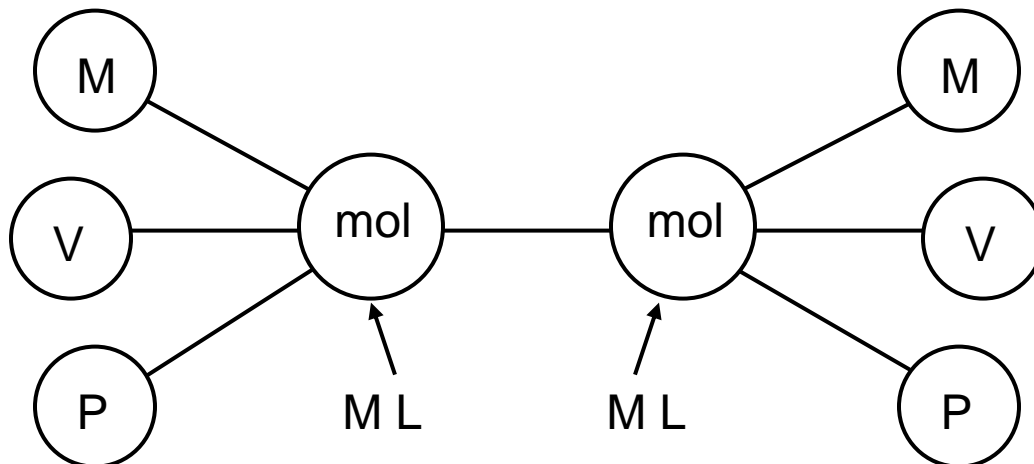
$$X M = \frac{58.6 \text{ g Ba(OH)}_2 \left(\frac{1 \text{ mol Ba(OH)}_2}{171.3 \text{ g Ba(OH)}_2} \right)}{5.65 \text{ L}} = \boxed{0.061 \text{ M Ba(OH)}_2}$$

3: You have 10.8 g potassium nitrate. How many mL of sol'n will make this a 0.14 M sol'n?

$$X L = \frac{10.8 \text{ g KNO}_3 \left(\frac{1 \text{ mol}}{101.1 \text{ g}} \right)}{0.140 \text{ M}} = 0.763 \text{ L} \left(\frac{1000 \text{ mL}}{1 \text{ L}} \right) = \boxed{763 \text{ mL}}$$

↙ convert to mL

Molarity and Stoichiometry



What volume of 4.0 M KI sol'n is req'd to yield 89 g PbI_2 ?

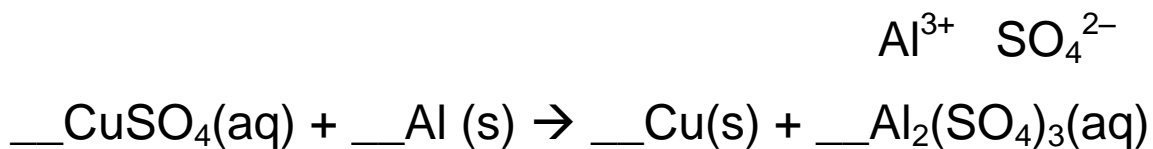
Strategy: (1) Find mol KI needed to yield 89 g PbI_2 .

(2) Based on (1), find volume of 4.0 M KI sol'n.

$$X \text{ mol KI} = 89 \text{ g PbI}_2 \left(\frac{1 \text{ mol PbI}_2}{461 \text{ g PbI}_2} \right) \left(\frac{2 \text{ mol KI}}{1 \text{ mol PbI}_2} \right) = 0.39 \text{ mol KI}$$

$$M = \frac{\text{mol}}{\text{L}} \rightarrow \text{L} = \frac{\text{mol}}{M} = \frac{0.39 \text{ mol KI}}{4.0 \text{ M KI}} = \boxed{0.098 \text{ L of 4.0 M KI}}$$

How many mL of a 0.500 M CuSO_4 sol'n will react
w/excess Al to produce 11.0 g Cu?



$$X \text{ mol CuSO}_4 = 11 \text{ g Cu} \left(\frac{1 \text{ mol Cu}}{63.5 \text{ g Cu}} \right) \left(\frac{3 \text{ mol CuSO}_4}{3 \text{ mol Cu}} \right)$$

$$= 0.173 \text{ mol CuSO}_4$$

$$M = \frac{\text{mol}}{\text{L}} \rightarrow L = \frac{\text{mol}}{M} = \frac{0.173 \text{ mol CuSO}_4}{0.500 \text{ M CuSO}_4} = 0.346 \text{ L}$$

$$0.346 \text{ L} \left(\frac{1000 \text{ mL}}{1 \text{ L}} \right) = \boxed{346 \text{ mL}}$$

Dilutions of Solutions → Acids (and sometimes bases) are purchased in concentrated form (“concentrate”) and are easily diluted to any desired concentration.

**Safety Tip: When diluting, add acid or base to water.

Dilution Equation:

$$M_C V_C = M_D V_D$$

C = conc.

D = dilute

Conc. H_3PO_4 is 14.8 M. What volume of concentrate is req'd to make 25.00 L of 0.500 M H_3PO_4 ?

$$M_C V_C = M_D V_D \rightarrow 14.8 \text{ M}(V_C) = 0.500 \text{ M}(25.00 \text{ L})$$

$$V_C = 0.845 \text{ L} = 845 \text{ mL}$$

How would you mix the above sol'n?

1. Measure out 0.845 L of conc. H_3PO_4 .
2. In separate container, obtain ~20 L of cold H_2O .
3. In fume hood, slowly pour H_3PO_4 into cold H_2O .
4. Add enough H_2O until 25.00 L of sol'n is obtained.

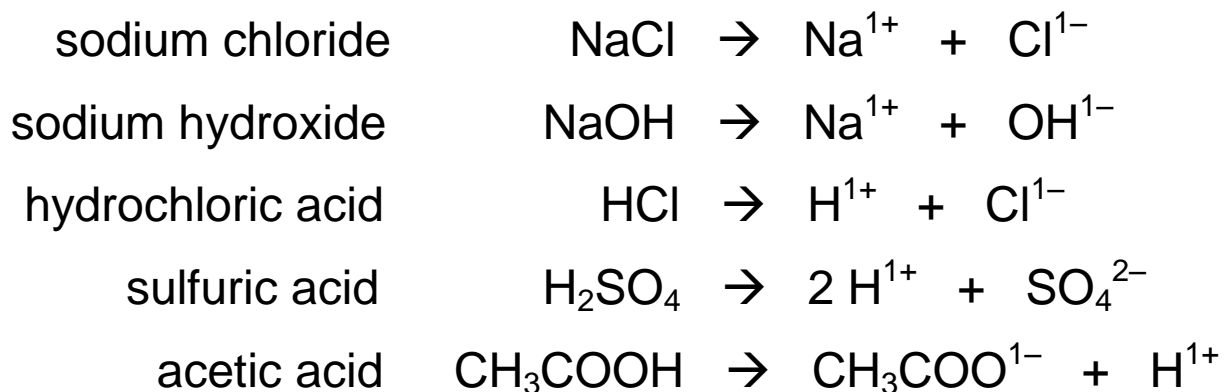
You have 75 mL of conc. HF (28.9 M); you need 15.0 L of 0.100 M HF. Do you have enough to do the experiment?

$$M_C V_C = M_D V_D \rightarrow 28.9 \text{ M}(0.075 \text{ L}) = 0.100 \text{ M}(15.0 \text{ L})$$

Yes;
we're OK.

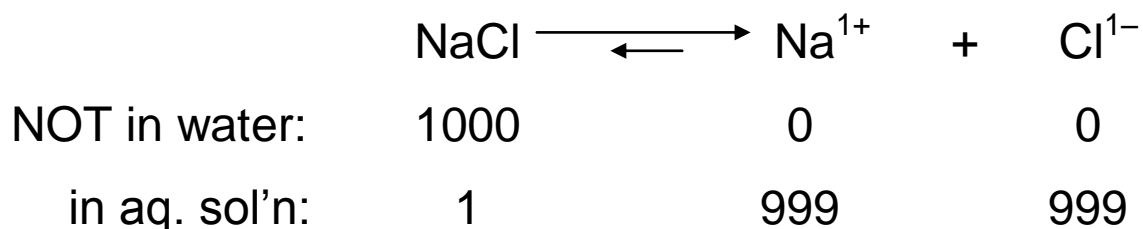
2.1675 mol HAVE > 1.50 mol NEED

Dissociation occurs when neutral combinations of particles separate into ions while in aqueous solution.

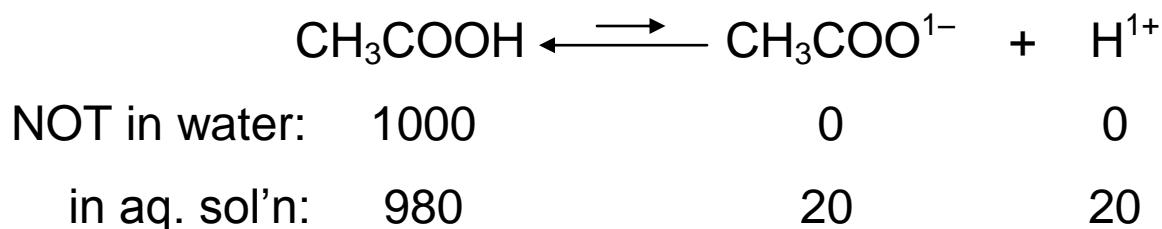


In general, acids yield hydrogen (H^{1+}) ions in aqueous solution; bases yield hydroxide (OH^{1-}) ions.

Strong electrolytes exhibit nearly 100% dissociation.



Weak electrolytes exhibit little dissociation.



“Strong” or “weak” is a property of the substance.

We can't change one into the other.

electrolytes: solutes that dissociate in sol'n

- conduct elec. current because of free-moving ions
- e.g., acids, bases, most ionic compounds
- are crucial for many cellular processes
- obtained in a healthy diet
- For sustained exercise or a bout of the flu, sports drinks ensure adequate electrolytes.

nonelectrolytes: solutes that DO NOT dissociate

- DO NOT conduct elec. current (not enough ions)
- e.g., any type of sugar



Colligative Properties → depend on conc. of a sol'n

Compared to solvent's... a sol'n w/that solvent has a...

...normal freezing point (NFP)

...lower FP

FREEZING PT. DEPRESSION

...normal boiling point (NBP)

...higher BP

BOILING PT. ELEVATION

Applications (NOTE: Data are fictitious.)

1. salting roads in winter

	FP	BP
water	0°C (NFP)	100°C (NBP)
water + a little salt	-11°C	103°C
water + more salt	-18°C	105°C

2. antifreeze (AF) /coolant

	FP	BP
water	0°C (NFP)	100°C (NBP)
water + a little AF	-10°C	110°C
50% water + 50% AF	-35°C	130°C

3. law enforcement

white powder	starts melting at...	finishes melting at...	penalty, if convicted
A	120°C	150°C	comm. service
B	130°C	140°C	2 years
C	134°C	136°C	20 years

Calculations for Colligative Properties

The change in FP or BP is found using...

$$\Delta T_x = K_x m i$$

ΔT_x = change in T° (below NFP or above NBP)

K_x = constant depending on... (A) solvent

(B) freezing or boiling

m = molality of solute = mol solute / kg solvent

i = integer that accounts for any solute dissociation

any sugar (all nonelectrolytes)..... $i = 1$

table salt, $\text{NaCl} \rightarrow \text{Na}^{1+} + \text{Cl}^{1-}$ $i = 2$

barium bromide, $\text{BaBr}_2 \rightarrow \text{Ba}^{2+} + 2 \text{Br}^{1-}$ $i = 3$

Freezing Point Depression

$$\Delta T_f = K_f m i$$

Boiling Point Elevation

$$\Delta T_b = K_b m i$$

Then use these in conjunction with the NFP and NBP to find the FP and BP of the mixture.

168 g glucose ($C_6H_{12}O_6$) are mixed ^w/2.50 kg H_2O . Find BP and FP of mixture. For H_2O , $K_b = 0.512$, $K_f = -1.86$.

$$i = 1 \quad m = \frac{\text{mol } C_6H_{12}O_6}{\text{kg } H_2O} = \frac{168 \text{ g} / 180 \text{ g}}{2.50 \text{ kg}} = 0.373 \text{ m}$$

(NONELECTROLYTE)

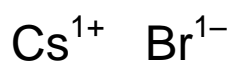
$$\Delta T_b = K_b m i = 0.512 (0.373) (1) = 0.19^\circ\text{C}$$

$$BP = (100 + 0.19)^\circ\text{C} = \boxed{100.19^\circ\text{C}}$$

$$\Delta T_f = K_f m i = -1.86 (0.373) (1) = -0.69^\circ\text{C}$$

$$FP = (0 + -0.69)^\circ\text{C} = \boxed{-0.69^\circ\text{C}}$$

168 g cesium bromide are mixed ^w/2.50 kg H_2O . Find BP and FP of mixture. For H_2O , $K_b = 0.512$, $K_f = -1.86$.



$$m = \frac{\text{mol } CsBr}{\text{kg } H_2O} = \frac{168 \text{ g} / 212.8 \text{ g}}{2.50 \text{ kg}} = 0.316 \text{ m}$$

$$\Delta T_b = K_b m i = 0.512 (0.316) (2) = 0.32^\circ\text{C}$$

$$BP = (100 + 0.32)^\circ\text{C} = \boxed{100.32^\circ\text{C}}$$

$$\Delta T_f = K_f m i = -1.86 (0.316) (2) = -1.18^\circ\text{C}$$

$$FP = (0 + -1.18)^\circ\text{C} = \boxed{-1.18^\circ\text{C}}$$