Objective 3: Identify the chemical forces in ionic and molecular solutions, concentration.

## Quiz Practice problems:

## Key ideas:

Skills:
Draw structures. Determine IM forces between solute and solvent.
a. What does "like dissolves like" mean?
b. Why is NaCl soluble in water whereas AgCl is not?
c. Why is ethanol soluble in water whereas oil is not?

1. Water is called the universal solvent.
a. Draw the Lewis structure of water. Is water polar or non-polar? Identify the intermolecular forces between water molecules. If H bonds exist, use a dotted line to represent H bonds between water molecules.
b. Acetic acid $\left(\mathrm{CH}_{3} \mathrm{COOH}\right)$ is soluble in water. Draw the Lewis structure of acetic acid. Identify the intermolecular forces between acetic acid molecules. Draw a picture that shows the intermolecular forces between acetic acid and water.
c. One way to soften water (remove $\mathrm{Ca}^{2+}$ and $\mathrm{Mg}^{2+}$ ions) is to use lime, $\mathrm{Ca}(\mathrm{OH})_{2}$. The lattice energy between $\mathrm{Ca}(\mathrm{OH})_{2}$ is greater than the hydration energy. Is lime soluble in water?
d. Motor oil is an alkane with a chemical formula, $\mathrm{C}_{20} \mathrm{H}_{42}$. Draw the skeletal structure of motor oil. Identify the intermolecular forces between motor oil molecules. Use chemical forces to explain why oil doesn't mix with water. e. In Lab 1, Part C, you made crude (impure) banana ester. Isoamyl alcohol and sulfuric acid are the impurities. You purified the ester by doing a liquid-liquid extraction. The Isoamy alcohol and sulfuric acid are $\qquad$ soluble in water than in the ester because $\qquad$ -.

Draw the structures of isoamyl acetate (banana ester), isoamyl alcohol, and water.
Show any hydrogen bonds between isoamyl alcohol and water.
Show any hydrogen bonds between isoamyl alcohol and isoamyl acetate.
Based on the number of hydrogen bonds you showed, explain why isoamyl alcohol is more soluble in water than in isoamyl acetate.
f. When drug companies make drugs, the drug is usually soluble in water. If the drug is not soluble enough in water, bonding -OH groups to the drug makes it more soluble. Explain why bonding -OH groups to the drug makes it more soluble.
Answers:
a. Structure of water is shown in (b).

Water is polar.
Intermolecular forces between water molecules are London forces, dipole-dipole forces, and hydrogen bonds. b. Intermolecular forces between acetic acid molecules are London forces, dipole-dipole forces, and hydrogen bonds. Intermolecular forces between water and acetic acid molecules are London forces, dipole-dipole forces, and hydrogen bonds.

c. Lime is not soluble in water.
d. Motor oil is a hydrocarbon and is non-polar.


The intermolecular forces between motor oil molecules are London forces.
Oil does not mix (not soluble) in water because the weak London forces are not strong enough to break the stronger hydrogen bonds between water molecules.
e. The Isoamy alcohol and sulfuric acid are more soluble in water than in the ester because these compounds form more hydrogen bonds to water than the ester does.
isoamyl acetate

f. Bonding -OH groups to a drug makes it more soluble because the alcohol group can form hydrogen bonds to water.
2. Is gasoline $\left(\mathrm{C}_{8} \mathrm{H}_{18}\right)$ soluble in motor oil $\left(\mathrm{C}_{20} \mathrm{H}_{42}\right)$ ? Draw the structure of each compound. Draw a picture that shows the intermolecular forces between motor oil and gasoline.
Answers:
motor oil


Non-polar gasoline $\left(\mathrm{C}_{8} \mathrm{H}_{18}\right)$ is soluble in non-polar motor oil $\left(\mathrm{C}_{20} \mathrm{H}_{42}\right)$ because gasoline can form London forces to motor oil and vice versa. Two isomers of $\mathrm{C}_{8} \mathrm{H}_{18}$ are shown: octane and isooctane. Isooctane has a higher octane number (see label on gas pump at gas station) than octane.
3. a. In general, solids are more soluble in water as temperature increases. When temperature increases, atoms/molecules move faster. Use chemical forces to explain why NaCl is more soluble in hot water than cold water. b. Caffeine is moderately soluble in room temperature water ( 2 g caffeine in 100 ml water) but very soluble in boiling water ( 66 g caffeine in 100 ml water) (https://en.wikipedia.org/wiki/Caffeine). Draw the structure of caffeine. Use chemical forces to explain why caffeine is soluble in water. If H bonds exist, use a dotted line to represent H bonds between water molecules.
c. As Pepsi is heated, it loses mass. Explain this observation.
d. When a can of soda is opened, gas escapes. Explain this observation. Draw a picture that shows how pressure affects the gas dissolved in soda.
Answers:
a. The chemical force between $\mathrm{Na}^{+}$and $\mathrm{Cl}^{-}$ions is ionic bonds. Lattice energy is the amount of energy required (endothermic) to break the ionic bonds between these ions. When water molecules surround $\mathrm{NaCl}(\mathrm{s})$, intermolecular forces form (energy released) between water and $\mathrm{Na}^{+}$and $\mathrm{Cl}^{\text {l }}$ ions. The energy released is called hydration energy. NaCl is more soluble in hot water than cold water because the water molecules and NaCl collide with with more energy at higher temperature $\qquad$ -.
b.

Hydrogen bonds exist between water molecules. Hydrogen bonds exist between caffeine molecules. Hydrogen bonds form between caffeine and water. In oher words, hydrogen bonds are strong enough to break the hydrogen bonds between water molecules.
c. Pepsi loses mass when it is heated because $\mathrm{CO}_{2}(\mathrm{~g})$ escapes from the liquid $==>$ mass of liquid decreases.
d. Soda is canned under high pressure to carbonate the soda (gas is more soluble in a liquid at high pressure). When the can is opened, the pressure inside the can decreases (drops) ==> gas solubility decreases ==> gas escapes. Picture
4. Concentration: there are several ways to quantify the amount of solute in a solution.

Molarity $=$ moles of solute/liter of solution. Very common unit for solutions, e.g., 0.9 M acetic acid is vinegar $\%$ by mass $=\mathrm{g}$ of solute $/ 100 \mathrm{~g}$ of solution
$\%$ by volume $=\mathrm{ml}$ of solute $/ 100 \mathrm{ml}$ of solution. Used when a liquid solute is dissolved in a liquid solvent, e.g., ethanol in water.
$\%$ (mass/volume) $=\mathrm{g}$ of solute $/ 100 \mathrm{ml}$ of solution. Used when a solid solute is dissolved in a liquid solvent, e.g., NaCl in water.
molality = moles of solute/kg of solvent. Not a common unit but used in boiling point elevation and freezing point depression. See Objective 4.
a. Wine is approximately $13 \%$ ethanol by volume ( 13 ml ethanol/ 100 ml of solution). The Molar concentration of this solution is 2.2 M ( 2.2 moles ethanol//iter of solution). Show how to convert from \% by volume to Molarity. Hint: use density of ethanol $=0.78 \mathrm{~g} / \mathrm{ml}$.
b. A bottle of vinegar states " $5 \%$ acid". This is a $\%$ by volume which means 5 ml acetic acid $/ 100 \mathrm{ml}$ solution. $5 \%$ acid $=0.9$ M. Show how to convert from Molarity to $\%$ by volume. Hint: use density of acetic acid $=1.05 \mathrm{~g} / \mathrm{ml}$.
c. 25 g of salt (sodium chloride) is dissolved in enough water to make 250 ml of solution. The concentration of this solution is 1.7 M . Show how this concentration is calculated.
d. Sea water is 0.6 M or $3.5 \% \mathrm{NaCl}$ (mass/volume). $3.5 \% \mathrm{NaCl}$ (mass/volume) $=3.5 \mathrm{~g} \mathrm{NaCl} / 100 \mathrm{ml}$ solution. Starting from 0.6 M , convert to \% ( $\mathrm{m} / \mathrm{V}$ ).
e. Sea water ( 0.6 M NaCl ) has an average density of $1.027 \mathrm{~g} / \mathrm{ml}$. In 1 liter of sea water, there 992 g of water and 35 g

NaCl . Show how these masses were determined. Then, calculate the molality of seat water.
Answers:
a. ethanol $=\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}$. molar mass $=46 \mathrm{~g} / \mathrm{mole}$
convert ml ethanol --> g ethanol --> mole ethanol
$(13 \mathrm{ml}$ ethanol $/ 100 \mathrm{ml}$ solution $)(0.78 \mathrm{~g}$ ethanol $/ 1 \mathrm{ml}$ ethanol $)(1$ mole ethanol $/ 46 \mathrm{~g}$ ethanol $)(1000 \mathrm{ml} / 1 \mathrm{I})=2.2$ moles ethanol/liter $=2.2 \mathrm{M}$
b. acetic acid $=\mathrm{CH}_{3} \mathrm{COOH}$. molar mass $=60 \mathrm{~g} / \mathrm{mole}$
convert moles acetic acid --> g acetic acid --> ml acetic acid
$(0.9$ moles acetic acid/I solution)(60 g acetic acid/1 mole acetic acid)(1 ml acetic acid $/ 1.05 \mathrm{~g}$ acetic acid)(1 $/ / 1000 \mathrm{ml})(100)$
$=5.1 \%$ acetic acid
c. $25 \mathrm{~g} \mathrm{NaCl}(1$ mole $\mathrm{NaCl} / 58.5 \mathrm{~g} \mathrm{NaCl})(1 / 0.250 \mathrm{I})=1.7$ moles $\mathrm{NaCl} / \mathrm{I}$ solution $=1.7 \mathrm{M}$
d. $0.6 \mathrm{M} \mathrm{NaCl}=(0.6$ moles $\mathrm{NaCl} / 1 \mathrm{I}$ solution $)(58.5 \mathrm{~g} \mathrm{NaCl} / 1 \mathrm{~mole} \mathrm{NaCl})(1 \mathrm{l} / 1000 \mathrm{ml})(100)=3.5 \%(\mathrm{~m} / \mathrm{V})$
e. From part d: $0.6 \mathrm{M} \mathrm{NaCl}=3.5 \%(\mathrm{~m} / \mathrm{V})=3.5 \mathrm{~g} \mathrm{NaCl} / 100 \mathrm{ml}$ solution

So in $1000 \mathrm{ml}=1 \mathrm{I}$ solution: $(3.5 \mathrm{~g} \mathrm{NaCl} / 100 \mathrm{ml}$ solution $) \times(1000 \mathrm{ml})=35 \mathrm{~g} \mathrm{NaCl}$
Seawater density $=1.027 \mathrm{~g} / \mathrm{ml}$ means 1.027 g solution in 1 ml solution
In 1000 ml solution: $1.027 \mathrm{~g} / \mathrm{ml} \times 1000 \mathrm{ml}=1027 \mathrm{~g}$ solution
1027 g solution $=$ mass of $\mathrm{NaCl}+$ mass of water
1027 g solution $=35 \mathrm{~g} \mathrm{NaCl}+$ mass of water
So mass of water $=1027 \mathrm{~g}-35 \mathrm{~g}=992 \mathrm{~g}$ water.
Molarity $\mathrm{NaCl}=$ moles $\mathrm{NaCl} / \mathrm{l}$ solution
$=35 \mathrm{~g} \mathrm{NaCl}(1 \mathrm{~mole} \mathrm{NaCl} / 58.5 \mathrm{~g} \mathrm{NaCl}) / 1 \mathrm{I}=0.6$ moles $\mathrm{NaCl} / \mathrm{I}=0.6 \mathrm{M}$
5. a. 25 g of sugar (sucrose, $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11}$ ) is dissolved in enough water to make 250 ml of solution. Useful information:
density of this sugar-water solution is $1.04 \mathrm{~g} / \mathrm{ml}$.
Calculate the concentration in:
(i) Molarity
(ii) \% (mass/volume)
(iii) molality
b. The physiological concentration of NaCl and glucose is $0.9 \%(\mathrm{~m} / \mathrm{V})$ and $5 \%(\mathrm{~m} / \mathrm{V})$, respectively. $0.9 \%(\mathrm{~m} / \mathrm{V}) \mathrm{NaCl}$ has a ___ (higher/lower/same) Molarity than $5 \%(\mathrm{~m} / \mathrm{V})$ glucose. Calculate the Molarity of each solution to support your

## answer.

Answers:
(i) Molarity $=$ moles sugar/I $=25 \mathrm{~g}$ sugar ( 1 mole sugar $/ 342 \mathrm{~g}$ sugar) $/ 0.250 \mathrm{I}=0.29 \mathrm{M}$
(ii) $\%($ mass $/ v o l u m e)=(25 \mathrm{~g}$ sugar $/ 250 \mathrm{ml}) \times 100=10 \%(\mathrm{~m} / \mathrm{V})$
(iii) molality $=$ moles sugar/kg solvent

250 ml solution $\times 1.04 \mathrm{~g} / \mathrm{ml}=260 \mathrm{~g}$ solution
mass of solution = mass of sugar + mass of water
260 g solution $=25 \mathrm{~g}$ sugar + mass of water
mass of ware $=260 \mathrm{~g}-25 \mathrm{~g}=235 \mathrm{~g}$ water $=0.235 \mathrm{~kg}$
molality $=25 \mathrm{~g}$ sugar ( 1 mole sugar $/ 342 \mathrm{~g}$ sugar $) / 0.235 \mathrm{~kg}=0.31 \mathrm{M}$
NOTE: Molarity is approximately equal to molality for dilute solutions.
b. $0.9 \% \mathrm{NaCl}(\mathrm{m} / \mathrm{V})=(0.9 \mathrm{~g} \mathrm{NaCl} / 100 \mathrm{ml}$ solution $)(1000 \mathrm{ml} / 1$ liter $)(1$ mole $\mathrm{NaCl} / 58.5 \mathrm{~g} \mathrm{NaCl})=0.15 \mathrm{M} \mathrm{NaCl}$
b. $5 \%$ glucose $(\mathrm{m} / \mathrm{V})=\left(5 \mathrm{~g} \mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6} / 100 \mathrm{ml}\right.$ solution $)(1000 \mathrm{ml} / 1$ liter $)\left(1\right.$ mole $\left.\mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6} / 180 \mathrm{~g} \mathrm{C} \mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{6}\right)=0.28 \mathrm{M}$ glucose $0.9 \%(\mathrm{~m} / \mathrm{V}) \mathrm{NaCl}$ has a lower Molarity than $5 \%(\mathrm{~m} / \mathrm{V})$ glucose.

