Chemistry 11 - Week 7: May 24 – May 29

Anticipated time required: 3 hours

New learning objective: **Solution Chemistry**

Goals to be completed:

1. Revisit the concepts of molecular polarity
2. Discuss how polarity of molecules influences their ability to dissolve in solutions
3. Ionization and dissociations calculations

This PDF package contains several notes, examples and practice problems. The only formal portion that you are required to submit is the section titled "Formal Assignment to be Submitted". This can be sent to Charlie.feht@yesnet.yk.ca either as a scanned and uploaded PDF attachment to email, or as a jpeg image file. Midterm assignments will be scored and sent back to you as I receive them.

Upcoming next week:

Basic Organic Chemistry Independent Study Unit Booklet

Solutions and Solubility

Solution chemistry is the study of chemical reactions that occur in a solution. When dealing with solutions where a solute of some sort is dissolved in water (the solvent), this is referred to as an **aqueous solution.** For example, If solid NaCl is dissolved in water, we refer to it as *aqueous sodium chloride* and denote its chemical formula as $NaCl_{(aq)}$.

Recall:

Solution → A homogenous mixture
Solvent → The component in a solution which exists in the greater quantity (water is known as the universal solvent)
Solute → The component in a solution which exists in the lesser quantity

A **solute** is soluble in a **solvent** is they mix to form a homogenous mixture known as a **solution**. We will deal with solid and liquid solutes dissolved in solvents, but know that gaseous solutes exist as well.

Definitions:

Insoluble – When little or no solute dissolves in a solvent
Saturated – When the solvent has dissolved as much solvent as possible
Unsaturated – When the solvent can possibly dissolve more solute
Solubility – The maximum amount of solute which can be dissolved in a given solvent. This is the amount of a substance needed to saturate a solution.

In order to solve a solutions solubility, we need to know the following:

1. What is the solute used?
2. How much of the solute is used?
3. What is the solvent used?
4. How much of the solvent is used?
5. What is the temperature of the solution?

More on this at the end of the package.

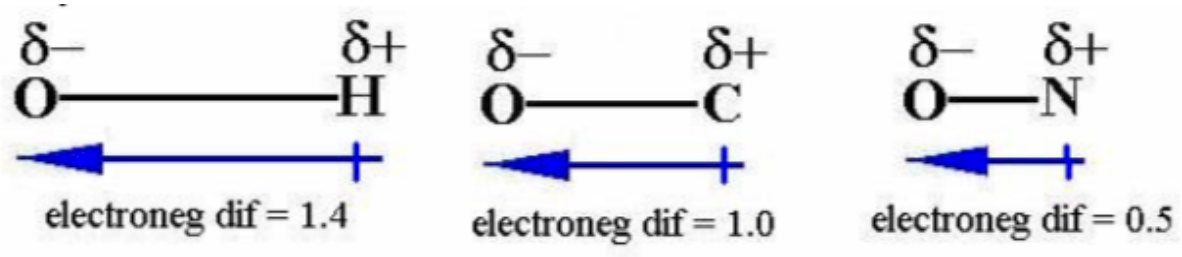
Additionally, some solutions are conductive. If they are conductive, that means that ions are present and have been dissolved in the solution. The more ions present in solution, the greater the conductivity.

Conductive solutes in aqueous solutions	**Non-conductive solutes in aqueous solutions**
Ionic compounds	Covalent compounds
Aqueous metallic solutions	Solid metallic solutes
Acids and Bases	Organic compounds (exception: acetic acid)

So how do know if a solute will dissolve in a solvent? Consider the phrase “like dissolves like”. This means that molecules with like charges and resulting polarity will only dissolve other molecules of matching charge and polarity. For example, a polar molecule will dissolve other polar molecules, but not dissolve non-polar molecules, while nonpolar molecules will dissolve other nonpolars but not polar molecules.

Let’s review molecular polarity:

Bond polarities originate from bonds between atoms of different electronegativity and molecular polarities result from the sum of bond polarities. Polar ponds are treated as vectors (both direction and magnitude) pointing from the positively charges atom to the negatively charged atom. The size of the vector is proportional to the difference in electronegativity of the two atoms. If the two atoms are identical, the magnitude of the vector is zero and the bond is nonpolar.



Recall from atomic theory, elements on the PT have different electronegativity values based on the atoms desire to attract electrons

A greater EN difference between atoms results in a more polar molecule, because one atom has attracted an additional electron, becoming more negative

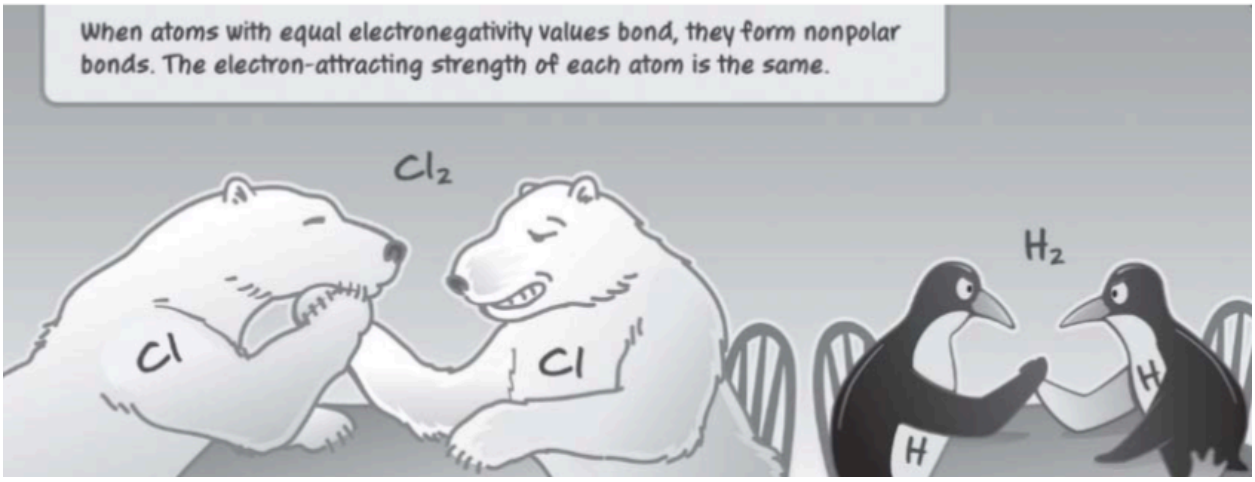
Electronegativity of the Elements

1 H 2.20																	2 He no data
3 Li 0.98	4 Be 1.57											5 B 2.04	6 C 2.55	7 N 3.04	8 O 3.44	9 F 3.98	10 Ne no data
11 Na 0.93	12 Mg 1.31											13 Al 1.61	14 Si 1.90	15 P 2.19	16 S 2.58	17 Cl 3.16	18 Ar no data
19 K 0.82	20 Ca 1.00	21 Sc 1.36	22 Ti 1.54	23 V 1.63	24 Cr 1.66	25 Mn 1.55	26 Fe 1.83	27 Co 1.88	28 Ni 1.91	29 Cu 1.90	30 Zn 1.65	31 Ga 1.81	32 Ge 2.01	33 As 2.18	34 Se 2.55	35 Br 2.96	36 Kr 3.00
37 Rb 0.82	38 Sr 0.95	39 Y 1.22	40 Zr 1.33	41 Nb 1.6	42 Mo 2.16	43 Tc 1.9	44 Ru 2.2	45 Rh 2.28	46 Pd 2.20	47 Ag 1.93	48 Cd 1.69	49 In 1.78	50 Sn 1.96	51 Sb 2.05	52 Te 2.1	53 I 2.66	54 Xe 2.6
55 Cs 0.79	56 Ba 0.89	57-71	72 Hf 1.3	73 Ta 1.5	74 W 2.36	75 Re 1.9	76 Os 2.2	77 Ir 2.2	78 Pt 2.28	79 Au 2.54	80 Hg 2.00	81 Tl 1.62	82 Pb 2.33	83 Bi 2.02	84 Po 2.0	85 At 2.2	86 Rn no data
87 Fr 0.7	88 Ra 0.89	89-103	104 Rf no data	105 Db no data	106 Sg no data	107 Bh no data	108 Hs no data	109 Mt no data	110 Ds no data	111 Rg no data	112 Cn no data	113 Nh no data	114 Fl no data	115 Mc no data	116 Lv no data	117 Ts no data	118 Og no data

Low — High

57 La 1.10	58 Ce 1.12	59 Pr 1.13	60 Nd 1.14	61 Pm 1.13	62 Sm 1.17	63 Eu 1.2	64 Gd 1.2	65 Tb 1.22	66 Dy 1.23	67 Ho 1.24	68 Er 1.24	69 Tm 1.25	70 Yb 1.1	71 Lu 1.27
89 Ac 1.1	90 Th 1.3	91 Pa 1.5	92 U 1.38	93 Np 1.36	94 Pu 1.28	95 Am 1.3	96 Cm 1.3	97 Bk 1.3	98 Cf 1.3	99 Es 1.3	100 Fm 1.3	101 Md 1.3	102 No 1.3	103 Lr no data

- When electronegativity differences are zero, the bond is a nonpolar covalent.



- When the electronegativity is greater than zero but less than 1.4, the bond is polar covalent.

- When the electronegativity is greater than 1.4, the bond is ionic.

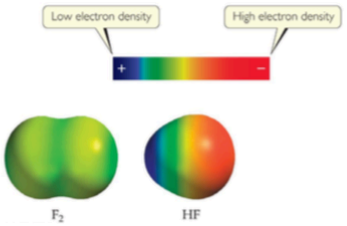
We are only going to focus on polar vs nonpolar molecules for solubility at this point. We will visit ionic compounds shortly.

Check out the computer interactive link below. Click on the 2 atom and 3 atom molecule sessions to see how the bond polarity, resulting molecular polarity, and electron dispersion changes as you alter the attractive force of the molecules.

https://phet.colorado.edu/sims/html/molecule-polarity/latest/molecule-polarity_en.html

Polar Covalent Bonds

(unequal sharing of e^-)



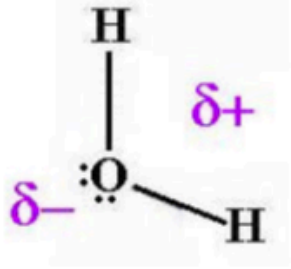
- Electrons tend to spend more time around the **more** electronegative atom. The result is a partial negative charge, δ–.
- The other atom is "more positive," or δ+.
- The greater the difference in electronegativity, the more polar the bond

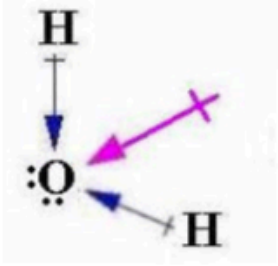
$\delta+ \quad \delta- \quad \longrightarrow$

H_2O

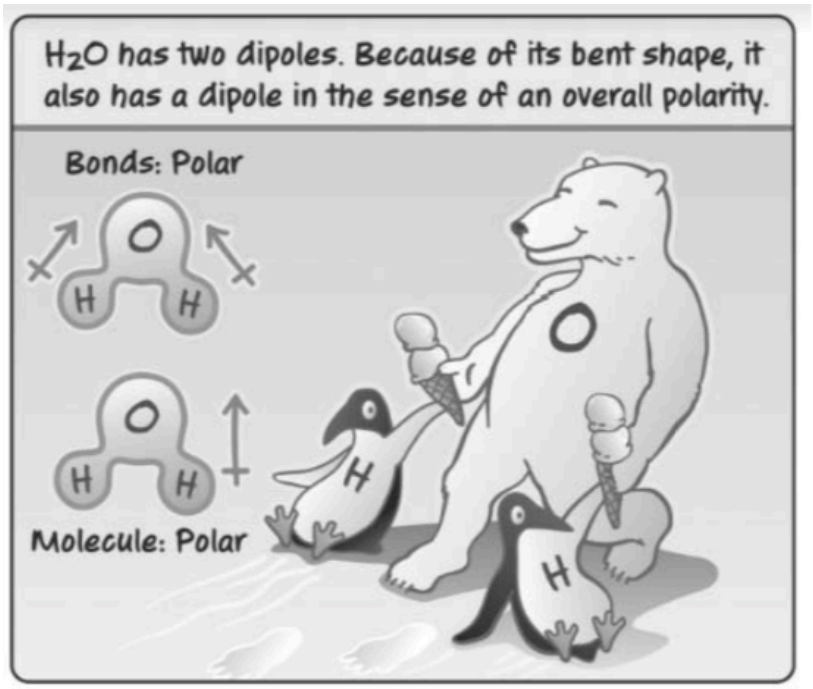
The 2 O-H bonds are polar and the bent geometry makes the distribution of these polar bonds asymmetrical. The part of the water molecule containing the more electronegative oxygen atom is partially negative while the part containing the less electronegative hydrogen atoms is partially positive.

The polarity of water can be represented using δ– /δ+ or arrows.



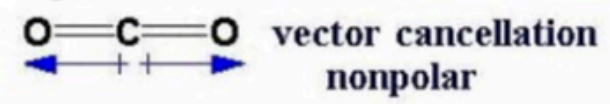


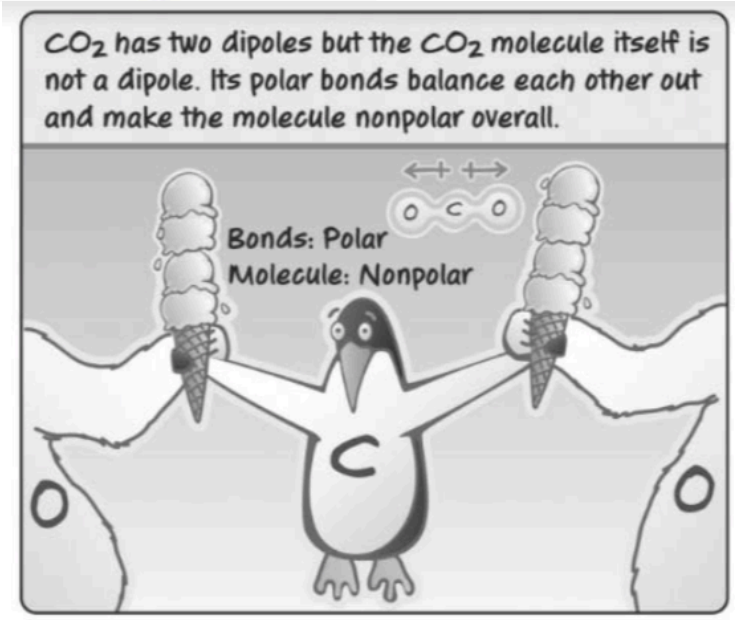
Polar



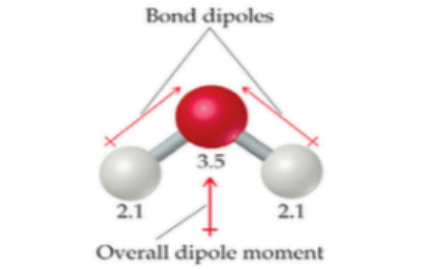
CO_2

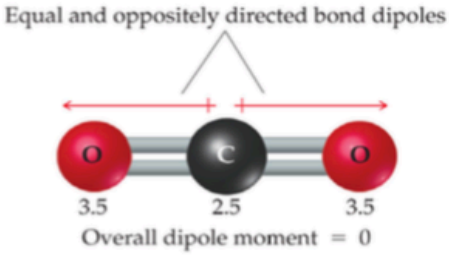
Each C=O bond has vector arrow pointing from the carbon to the oxygen. Since the vectors are equal and pointing in opposite directions, the sum of these two vectors is zero and nonpolar molecule results.

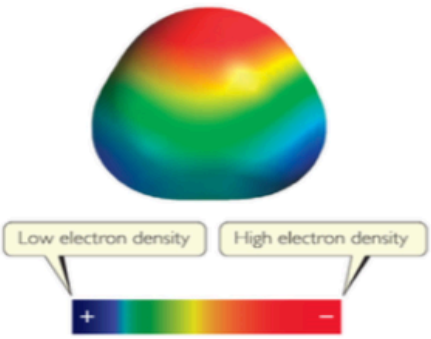


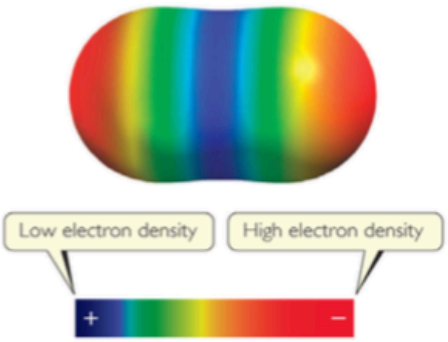


Comparison of the Polarity of Two Molecules



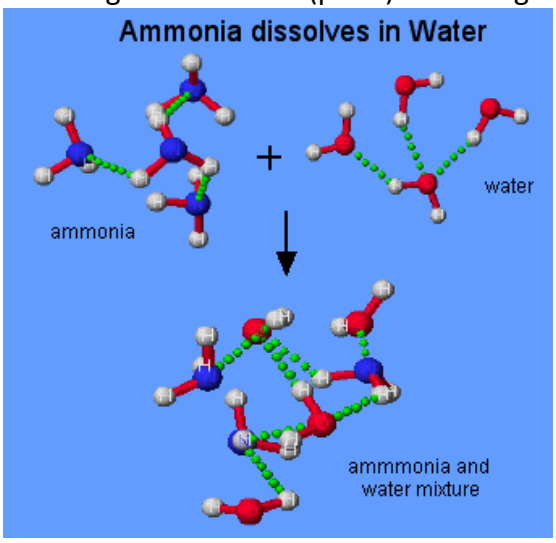




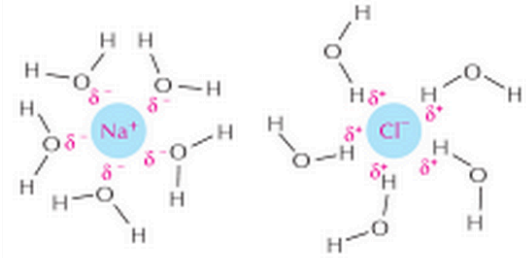


So now that we understand the differences between polar and nonpolar molecules, why is it that polar only dissolves in polar, and nonpolar only dissolves in polar? <u>Why does like dissolves like exist?</u>

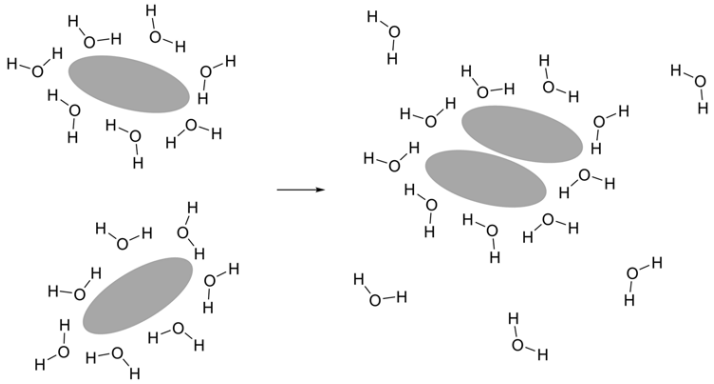
- The slightly more negative end of a polar molecule will be attracted to the slightly more positive end of a molecule. So if two different polar molecules interact, they will bind in this way, as seen in the image of ammonia (polar) dissolving in water (polar)



- Ionic compounds also dissolve in this way, where an anion will be attracted to the positive end of a polar molecule, and a cation will be attracted to the negative end of a polar molecule



- When a nonpolar interacts with a polar molecule, the forces of interaction are too weak for the molecules to dissolve because of common charges. Non polar molecules are referred to as hydrophobic, because they will not dissolve in water.



- When two nonpolar molecules interact, there is enough energy for the two molecules to separate and bond with each other.

Check out the YouTube video below that helps to explain polar vs nonpolar molecules and how they interact:

https://www.youtube.com/watch?v=PVL24HAesnc

Practice Problems – Not for Marks

Bond Polarity

1. What requirement must be met for a single bond to be polar?

2. In the compound CH_3OH, is the O-H bond polar or nonpolar?

3. Determine if each of the following bonds is polar or nonpolar:
   a. Se-Cl b. Al-Cl c. I-F d. Cl-Cl

4. List the following bonds in order of increasing polarity:
   a. C-O b. C-H c. O-H

Molecular Polarity

5. What requirements must be met for an entire molecule to be polar?

6. Determine whether each of the following molecules is polar or nonpolar:
   a. HCl b. H_2CO c. CCl_4 d. PF_3 e. Cl_2O

7. Determine whether each of the following molecules is polar or nonpolar:
   a. CO_2 b. CH_3OCH_3 c. H_2S d. H_2O e. ClF

8. Choose the best answer to complete the sentence. In a water molecule…
   a. the bonds are polar, but the molecule is nonpolar.
   b. the bonds are nonpolar.
   c. the bonds are polar and the molecule is polar.

Ionization and Dissociation

When **ionic compounds** dissolve in solvents, a process called **dissociation** occurs. Dissociation involves separating previously existing ions from an ionic solid. When a **neutral molecule** is broken down into ions, the process is referred to as **ionization.**

Ex. Dissociation

$NaCl_{(s)}$ is an ionic solid made of existing ions and will break down into $Na^{+}_{(aq)}$ and $Cl^{+}_{(aq)}$

Ex. Ionization

$CH_3COOH_{(l)}$ Acetic acid is a neutral molecule (not an ionic compound) that can break down into a polyatomic ion acetate $CH_3COO^{-}_{(aq)}$ and hydrogen ions $H^{+}_{(aq)}$.

Practice:

Show what the ionization/dissociation of the following molecules might look like:

1. $KBr_{(s)}$
2. $Na_2SO_{4(s)}$
3. $HCl_{(g)}$
4. $(NH_4)_2S_{(s)}$

Calculating ions in solution

We know how to calculate concentration of substances after a dilution has occurred, but what we haven't done is also calculate the ions in those solutions. For example, can we solve the molar concentration of chloride ions in 0.25 M $AlCl_3$?

Step 1. We know $AlCl_3 \rightarrow Al^{3+} + 3Cl^{-}$ (of course, the dissociation must be balanced)

Step 2. We see the ratio of chloride ions to $AlCl_3$ molecules is 3:1, so the concentration of chloride ions is 3x greater than the concentration of aluminum chloride.

0.25M $AlCl_3$ x 3 = 0.75M (the concentration of chloride ions is 0.75M after dissociation)

Sample Problem #2

What is the concentration of each ion type in the solution made by mixing 50ml of 0.240M $AlBr_3$ and 25ml of 0.300M $CaBr_2$

$AlBr_3 \rightarrow Al^{3+} + 3Br^{1-}$
$CaBr_2 \rightarrow Ca^{2+} + 2\ Br^{1-}$

Start with writing the ionization/dissociation equation for each solution, and balance it

Solve the dilution problem for each solution

$C_1V_1 = C_2V_2$

$C_2 = \frac{C_1V_1}{V_2}$

> Remember your V_2 value is the sum of the two individual volumes because they have been added together

$[AlBr_2]_{dil} = \frac{0.240M \times 0.050\ L}{0.075L}$

$[AlBr_2]_{dil} = 0.160\ M$

$[CaBr_3]_{dil} = \frac{0.300M \times 0.025\ L}{0.075L}$

$[CaBr_3]_{dil} = 0.100M$

Solve the ion concentration based on the balanced ratios

$AlBr_3 \rightarrow Al^{3+} + 3\ Br^{1-}$
$[0.160] \rightarrow [0.160] + 3\ [0.160]$
$[0.480]$

$CaBr_2 \rightarrow Ca^{2+} + 2\ Br^{1-}$
$[0.100] \rightarrow [0.100] + 2\ [0.100]$
$[0.200]$

Solve the ion totals:

$Al^{3+} = 0.160\ M$
$Ca^{2+} = 0.100\ M$
$Br^{1-} = 0.480\ M + 0.200\ M = 0.680\ M$

Check out the following Youtube video that helps to clarify these calculations:
https://www.youtube.com/watch?v=7fHA17DOrBg

Practice Problems

1. What is the concentration of SO_4^{2-} present in 0.135M $Al_2(SO_4)_3$?

2. What is the $[Cl^-]$ formed when 10g of $BaCl_2$ is dissolved and diluted to 0.600L?

3. What is the concentration of Cl^- produced when 55ml of 0.300 M HCl is mixed with 8- ml of 0.550 M $CaCl_2$?

4. If 75 ml of 0.200 M Na_3PO_4 is added to 25 ml of 0.800 M K_3PO_4, what is the final concentration of each ion in solution?

Week 7 Assignment to Submit

1. Explain what is meant by “like dissolves like”.

2. What is the difference between a polar covalent and a non polar covalent molecule?

3. Label the following substances as either polar covalent, non polar covalent or ionic.

    a. NaCl

    b. H – O

    c. O – Cl

    d. Cl – Cl

4. Sketch a diagram indicating the dipole moment of linear CO_2 and bent H_2O. Label the charges and describe as either polar or non polar.

5. A mystery solute labeled “Solute X” fully dissolves in water but does not dissolve in a second solvent labeled as “Solvent Y”. Describe the polarity of Solvent Y and Solute X.

6. Show how K_2CrO_4 will break down in solution.

7. What is the concentration of all the ions in a solution produced by mixing 15.0 ml of 0.325 M Na_3PO_4 with 35.0 ml of 0.225 M K_2SO_4?