You should show all of your work, perform all calculations correctly, and report all answers to the correct number of significant figures. Compose written responses in complete and concise sentences.

(14 points)
1. a. Find the mass percent of ethanol in the solution when 100.00 mL of ethanol (d = 0.789 g/cm³) is added to 4,900.0 mL of water (d = 1.00 g/cm³).

\[
\% \left( \frac{m}{m} \right) = \frac{\text{mass}_{\text{EtOH}}}{\text{total mass}} \times 100 = \left( \frac{0.789 \text{ g/cm}^3}{4,900 \text{ g of water + 78.9 g of EtOH}} \right) \times 100 = 1.585 \% \left( \frac{m}{m} \right)
\]

b. What is the concentration of the solution in part “a” in ppt AND ppm?

Unfortunately, the abbreviation “ppt” is used by some people to mean parts-per-thousand, and by others to indicate parts-per-trillion. In this case I intended “ppt” to be parts-per-thousand (for which some people use “ppth”) not parts-per-trillion (for which some people use “pptr”).

\[
ppt = \frac{\text{mass}_{\text{EtOH}}}{\text{total mass}} \times 1,000 = \left( \frac{0.789 \text{ g/cm}^3}{4,900 \text{ g of water + 78.9 g of EtOH}} \right) \times 1,000 = 15.85 \text{ ppt}
\]

\[
ppm = \frac{\text{mass}_{\text{EtOH}}}{\text{total mass}} \times 10^6 = \left( \frac{0.789 \text{ g/cm}^3}{4,900 \text{ g of water + 78.9 g of EtOH}} \right) \times 10^6 = \% \left( \frac{m}{m} \right) \times 10^4 = (ppt) \times 10^3 = 1.585 \times 10^4 \text{ ppm}
\]

c. A typical commercial-grade phosphoric acid is 75% (mass/mass) phosphoric acid and has d = 1.57 g/cm³. What is the molarity of this solution?

\[
M = \frac{\text{mole}}{L} = \left( \text{MM}^{-1} \right) \times \% \left( \frac{m}{m} \right) \times (\text{density}) = \frac{\text{1 mole } H_3PO_4}{97.99 \text{ g}} \times \frac{75 \text{ g } H_3PO_4}{100 \text{ g sol}} \times \frac{1.57 \times 10^3 \text{ g}}{L} = 12.02 \text{ mol/L}
\]

(3 points each for numbers 2 - 7, 18 points total)
2. Which of the statements a to d is INCORRECT?

- molecular solids generally have low melting points
- the binding forces in polar molecular solids include dispersion forces
- ionic solids generally have high melting points
- ionic liquids are electrical conductors
- all of the statements a to d are correct

e. all of the statements a to d are correct

3. A solid does not conduct electricity, but its melt does. The crystal is brittle and hard, and it is soluble in water. Thus, it is:

- an ionic crystal
- a network covalent solid
- a molecular crystal
- a metallic crystal
- not enough data given

d. an ionic crystal

4. The melting points of the chlorides decrease going from SnCl₄ to GeCl₄ to SiCl₄ to CCl₄. What type of intermolecular forces are responsible for this trend?

- permanent dipole
- hydrogen bonding
- ion-ion attraction
- London dispersion forces
- ion-dipole attraction

d. London dispersion forces
5. Which of the following will DECREASE as intermolecular forces INCREASE?
   a. melting point  
   b. vapor pressure  
   c. surface tension  
   d. boiling point  
   e. none of the above

6. One of the following processes will release heat as it occurs. Which one is it?
   a. sublimation  
   b. evaporation  
   c. condensation  
   d. melting

7. Which of the following species would you expect to have the highest melting point.
   a. Ne  
   b. CH4  
   c. H2S  
   d. Cl2  
   e. H2O

8. Indicate which substance in each pair below will have the higher melting point (circle your selection) AND explain your choice (using descriptions of the forces involved).
   a. NaCl or CsBr . . . both of these ionic compounds have (+1/-1) ions. The difference in the electrostatic attraction is caused ionic size differences. Na+ is smaller than Cs+ and Cl− is smaller than Br−. The ions will experience higher attractive forces in NaCl. [fast fact: m.p. NaCl = 801°C, m.p. CsBr = 636°C]
   b. NO or O2 . . . both of these are diatomic molecular species of similar size. The intermolecular dispersion forces will therefore be very similar. However, NO is a polar molecule and will experience intermolecular dipole-dipole attractive forces (since O2 is nonpolar it will not). [fast fact: m.p. NO = −164°C, m.p. O2 = −219°C]
   c. CH4 or Cu . . . copper (Cu) is a metallic solid at Room Temp. (RT) while methane (CH4) is a small non-polar molecular species. The metallic bonding in copper is substantially stronger than the very weak dispersion forces in methane. [fast fact: m.p. CH4 = −182.5°C, m.p. Cu = 1,085°C]
   d. NH3 or PH3 . . . both of these molecules are polar and although the PH3 is larger (and will thus have stronger dispersion forces), the ammonia (NH3) is capable of H-bonding and therefore will have quite strong IMF. [fast fact: m.p. NH3 = −78°C, m.p. PH3 = −134°C]
   f. acetic acid, CH3COOH (MM = 60) or butane, C4H10 (MM = 58) . . . both of these are molecular species of about the same size and thus similar dispersion forces. The butane is essentially non-polar and has only the dispersion forces, while acetic acid can H-bond. [fast fact: m.p. CH3COOH = 16.5°C, m.p. C4H10 = −138°C]

9. a. Which should exhibit a higher solubility in water; NO or O2? Explain your choice! (3 points)
   NO because it is polar while O2 is nonpolar and will not interact as well with the dipole moment in the molecules of water. [fast fact: solubility (at ~298K) in water in mg/L = 8.5 mg O2/L and ~56 mg NO/L]
   b. Occasionally, Dr. Mencer likes to have a rum and Coke®. When Coke® is poured over ice, it “fizzes” and produces a large amount of “foam”. However, when he adds the rum, the bubbles quickly collapse. Explain both processes (the fizzing and the collapse of the foam) using the concepts of intermolecular forces. (7 points)
   The fizzing is caused by CO2 escaping from the Coke due to the great reduction in P_{CO2} over the coke after the can (or bottle) is opened. The foaming is due to the large amount of sugar in the Coke. The strong IMF between water and sugar stabilizes bubbles (foam). The rum has a large amount of ethanol in it, the ethanol is more NON-polar than water and/or sugar – adding EtOH reduces the stability of the foam.
   Fast Facts: Coke is “bottled” at about 3 atm P_{CO2} in air P_{CO2} is ~ 0.28 mmHg. Corn syrup can be used to stabilize soap bubbles.
10. If $\Delta H_{vap} = 2.49 \text{ kJ/g (correction)}$ and the specific heat of the liquid phase is $= 1.84 \text{ J/g}^\circ\text{C},$ then how much heat will be required when 50.0 g of the liquid (at 45$^\circ\text{C}$) is heated to liquid (at 55$^\circ\text{C}$) which then vaporizes at 55$^\circ\text{C}$? [assume this all occurs at a constant pressure of 1.00 atm]

heat needed to warm the liquid: $\frac{1.84 \text{ J}}{\text{g}^\circ\text{C}} \times 50.0 \text{ g}(55 - 45)^\circ\text{C} = 920 \text{ J} = 0.920 \text{ kJ}$

heat needed to vaporize the liquid: $\frac{2.49 \text{ kJ}}{\text{g}} \times 50.0 \text{ g} = 124.5 \text{ kJ}$

11. At 20.0$^\circ\text{C}$ hexane has a vapor pressure of 121 mm Hg and pentane has a vapor pressure of 441 mm Hg.

(a) Which has the LOWER boiling point? Explain your choice.

**pentane** - (lower $P_{vap}$ at 20.0$^\circ\text{C}$) and smaller nonpolar hydrocarbon (weaker dispersion forces)

(b) Which has the LARGER heat of vaporization? Explain your choice.

**hexane** - (higher $P_{vap}$ at 20.0$^\circ\text{C}$) and larger nonpolar hydrocarbon (greater dispersion forces)

(c) If a mixture contains 1 mole of pentane and 4 moles of hexane, find the total vapor pressure ($P_{tot}$) and the individual vapor pressures ($P_{pent}$ and $P_{hex}$) above the mixture at 20.0$^\circ\text{C}$.

\[
P_{tot} = P_{hex} + P_{pent} = X_{hex}P_{hex}^o + X_{pent}P_{pent}^o = \frac{4\text{ mole}}{5\text{ mole}} \times 121\text{mmHg} + \frac{1\text{ mole}}{5\text{ mole}} \times 441\text{mmHg} \text{ so } P_{tot} = 185\text{mmHg}
\]

\[
P_{hex} = 96.8\text{ mmHg} \text{ and } P_{pent} = 88.2\text{ mmHg}
\]

(d) What are the mole fractions of pentane and hexane in the vapor phase above the mixture described in part (c)?

In the vapor the mole fractions are the same as the partial pressure fractions:

\[
X_{pent} = \frac{P_{pent}}{P_{total}} = \frac{88.2\text{mmHg}}{185\text{mmHg}} = 0.477 \text{ and } X_{hex} = \frac{P_{hex}}{P_{total}} = \frac{96.8\text{mmHg}}{185\text{mmHg}} = 0.523
\]

check to find $X_{tot} = 1.00, X_{tot} = 0.477 + 0.523 = 1.000$ ..... check is correct

(e) Which liquid, pentane or hexane, would be collected from the condenser in a distillation of a hexane/pentane mixture. Explain supporting your answer with numbers found above.

The pentane will be collected from the condenser. The higher vapor pressure liquid is enriched in the vapor phase. Compare the mole fraction of pentane in the vapor (part d, 0.523) vs. the original liquid mole fraction (1/5 or 0.20). After a single vaporization step the vapor is greatly enriched in the higher vapor pressure substance (the pentane) ... subsequent condensation and re-vaporization steps will enhance this enrichment and nearly “pure” pentane can be collected from the “still head”.

41
12. For benzene, $K_f = 5.12^\circ C/m$. When 3.010 g of an unknown compound with an empirical formula of $C_2HNO_2$ is dissolved in 100.0 g of benzene, the freezing point of benzene is lowered by 0.73$^\circ C$. What are the molar mass AND the molecular formula of this compound? Assume the compound DOES NOT ionize in benzene.

$\Delta T_f = (K_f)(m)(i)$, with $i = 1$, $\Delta T_f = 0.73^\circ C$, and $K_f = 5.12^\circ C/m$ solve to find $(m)$

$m = \frac{\Delta T_f}{K_f}$ so, $m = \frac{(0.73^\circ C)(5.12^\circ C/m)}{0.14_3$ mole/kg$} = 0.014_3$ mole/kg

$m$ mole solute $= (0.14_3$ mole/kg$)(0.1000 kg) = 0.014_3$ mole solute

$MM$ solute $= \frac{3.010 g$ solute$}{0.014_3$ mole solute$} = 210 g/mol = 2.10 \times 10^2 g/mol$.

$C_2HNO_2$ has an empirical mass ~71 which is ~1/3 of the molar mass. So 3 empirical units = 1 molecule, giving $C_6H_3N_3O_6$ as the molecular formula.

13. The maximum solubility of CO$_2$ in water at 20.0$^\circ C$ under a pressure of 1 atm CO$_2$(g) is 149 mg CO$_2$ per 100 g H$_2$O. Find the concentration of CO$_2$ in water when exposed to air at 1 atm pressure (note: CO$_2$ is 0.037% by volume . . . or by mole). Express the concentration in mg CO$_2$ per 100 g H$_2$O and in ppm.

$C_{CO_2} = k P_{CO_2}$ . . . so we can find $k = \frac{C}{P}$ from the given conditions and then solve for $C$ at new the new value of $P$ which is 0.037% of 1 atm (3.7x10$^{-4}$ atm)

$C_{CO_2} = \frac{(149 mg/100 g)}{3.7x10^{-4} atm} = 0.055 mg/100 g H_2O$

now . . . ppm is (parts/whole)x106

$ppm = \frac{0.055 mg CO_2}{100,000 mg H_2O} \times 10^6 = 0.55 ppm \approx \frac{0.055 mg CO_2}{0.100 L H_2O} = 0.55 mg/L$

BONUS (for up to 5 points respond correctly to the following)

A compound has $\Delta H_{vap}$ of 2.80 kJ/g and $\Delta H_{fus}$ of 1.69 kJ/g.

(a) Explain, using molecular level concepts, why it makes sense for heat of vaporization to be larger than heat of fusion. When a molecular substance melts, the molecules that were held together by IMF in the solid are still in very close proximity to one another and still experience nearly the same attractive IMF. As a result, the energy needed to melt the solid is small. If that were not the case, then liquids would be MUCH less dense than solids (and we would not refer to liquids AND solids both as condensed phases of matter). When the same substance vaporizes, the resulting gas phase of the molecules has distances separating the molecules that are much greater than the size of the molecules. Thus, the IMF in the vapor (gas) phase are ~zero. Essentially ALL IMF present in the liquid must be overcome to vaporize the liquid and this requires a substantial investment of energy (when compared to merely melting the solid).

and

(b) Find the heat of sublimation ($\Delta H_{sub}$) for this compound using the data given above (in kJ/g).

$\Delta H_{sub} = \Delta H_{vap} + \Delta H_{fus} = 2.80 kJ/g + 1.69 kJ/g = 4.49 kJ/g$

and

(c) Explain the principle upon which the calculation in part (b) relies. Hess’ Law

<table>
<thead>
<tr>
<th>melting</th>
<th>$X_s(g) \rightarrow X_l(l)$</th>
<th>$\Delta H_{fus}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ vaporizing</td>
<td>$X_l(l) \rightarrow X_g(g)$</td>
<td>$\Delta H_{vap}$</td>
</tr>
<tr>
<td>= sublimation</td>
<td>$X_s(g) \rightarrow X_g(g)$</td>
<td>$\Delta H_{sub}$</td>
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