Dr. Zellmer | Chemistry 1220 | All Sections
Time: 7 PM Sun. | Spring Semester 2023 | January 22, 2023
40 min | Quiz I

Name KEY Rec. TA/time

1. (10 pts) Answer the following questions regarding the enthalpy and entropy changes when a solution forms.

a) What is the sign for the change in enthalpy for the separation of solute particles? **Explain!**

See diagram below. ΔH_1 ($\Delta H_{\text{sep solute}}$) > 0. It is **positive**. **Endothermic** (**energy required** to **break** the **attractive forces** and **separate** the solute **particles**). Energy is always required to break AF.

b) What is the sign for the change in enthalpy of mixing (solvation)? **Explain!**

See diagram below. ΔH_3 ($\Delta H_{\text{solvation}}$ or ΔH_{mixing}) < 0. It is **negative**. **Exothermic** (**energy released** when **AF form** and **particles** are **attracted** to each other). Energy is always given off for this step.

c) If the $\Delta H_{\text{soln}} > 0$ what does this mean about the overall relative strengths of attractive forces between solute and solvent particles when they mix compared to the attractive forces between the solute particles themselves and those between the solvent particles themselves? (i.e. Overall, are the attractive forces between unlike particles stronger or weaker than those between like particles?) **Explain!**

See diagram below. When $\Delta H_{\text{soln}} > 0$ the overall solution process is **endothermic** and energy is **required** to form the solution (go from solute and solvent to solution). This occurs when not as much energy is given off when the solute-solvent (unlike particles) AF forces form as required to break the solute-solute and solvent-solvent (like particles in both cases) AF. This means **overall** the **solute-solvent AF** are <u>**weaker**</u> than the **solute-solute** and **solvent-solvent AF** (unlike AF < like AF).

$\Delta H_1 + \Delta H_2 > |\Delta H_3|$

$\Delta H_{\text{soln}} = \Delta H_1 + \Delta H_2 + \Delta H_3 > 0$ since ΔH_3 is neg. but not as large as the other two combined

d) Is the solution process in part (c) ideal, endothermic or exothermic? (circle one)

endothermic $\Delta H_{\text{soln}} = \Delta H_f - \Delta H_i$ (**final** state **higher** in **energy** than **initial** state)

e) Is an increase in disorder (entropy) necessary for this solution process? **Explain!**

An endothermic process does not tend to be spontaneous (doesn't occur on its own without outside help - moving "uphill") but could be. In order for the solution to form, the **disorder** (**entropy**, S) **MUST INC** ($\boldsymbol{\Delta S_{\text{soln}} > 0}$). An **increase** in **disorder tends** to lead to a **spontaneous process** (but it doesn't automatically mean it would be spont.) At a given temperature, if this inc in disorder is large enough to overcome the increase in enthalpy (the ΔH_{soln}) the process will be spont. Most of the time when things mix there is an inc. in disorder (entropy), $\Delta S_{\text{soln}} > 0$ (but not always, such as a gas or acid mixing in a liquid).

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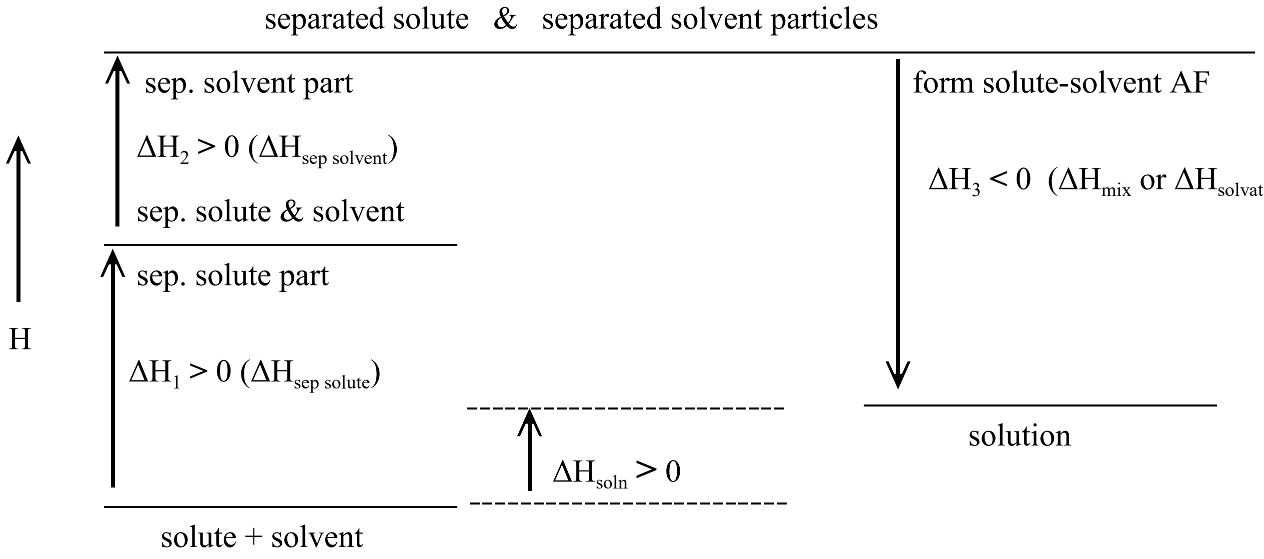
1. (Cont.)

f) Sketch an enthalpy change diagram (as done in lecture or the book) corresponding to $\Delta H_{soln} > 0$. Label all ΔH's (being more specific than something like ΔH_1), including the ΔH_{soln}, on the diagram.

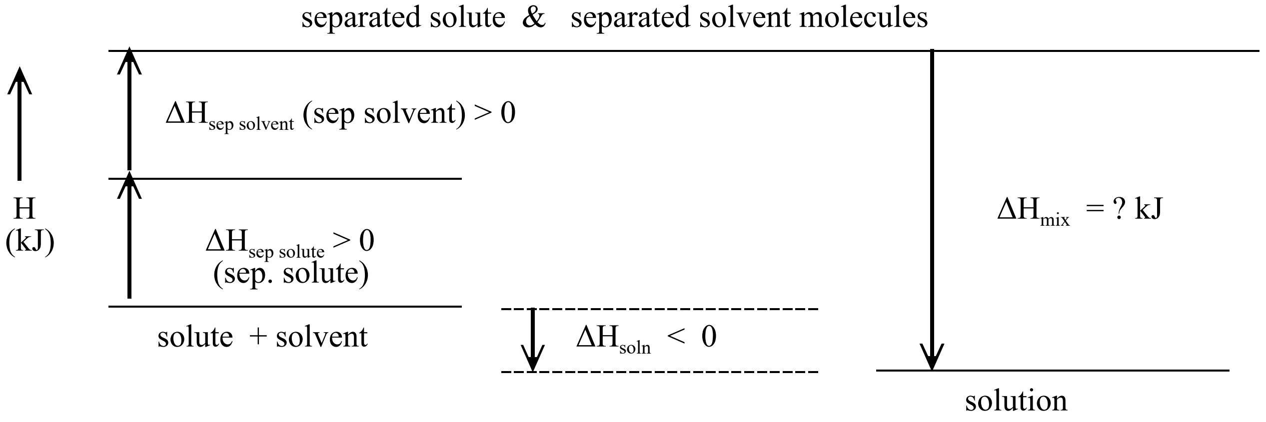


endothermic, $\Delta H_{soln} > 0$; product (solution) has a higher energy than reactants (solute & solvent).

See https://www.asc.ohio-state.edu/zellmer.1/chem1220/notes/ch13_soln_formation.pdf for more info. about the various types of solution formation.

2. (3 pts) The **heat of solution**, ΔH_{soln}, for a substance in water is -10.5 kJ/mol. The heat required to separate the solute particles is 155.0 kJ/mol. The heat required to separate the solvent particles is 210.0 kJ/mol. Estimate the **heat of mixing**, ΔH_{mix}, (also called the **heat of solvation**, $\Delta H_{solvation}$), for the solution process (kJ/mol)?

$\Delta H_{soln} = -10.5$ kJ/mol **exo**thermic soln. process (see two previous pages) - releases heat



$$\Delta H_{soln} = \Delta H_{sep\ solute} + \Delta H_{sep\ solvent} + \Delta H_{mix}$$

$$\Delta H_{mix} = \Delta H_{solutionn} - (\Delta H_{sep.\ solute} + \Delta H_{sep.\ solvent})$$

$$\Delta H_{mix} = -10.5 - (155.0 + 210.0) = -375.5 \text{ kJ/mol}$$

3. (2 pts) The solubility of a solid solute is 32.3 g solute/100 g H_2O at 20 °C. What minimum mass (in grams) of solute would need to be added to 13.1 g H_2O at 20 °C to make the solution saturated?

Use solubility as a conversion factor to figure out how much solute would need to be in 13.1 g H_2O to make it saturated.

$$? \text{ g solute} = 13.1 \text{ g } H_2O \times \frac{32.3 \text{ g solute}}{100 \text{ g } H_2O} = 4.23 \text{ g solute}$$

Thus, 4.23 g solute would be the amount of solute which could dissolve in 13.1 g H_2O to give a saturated soln.

(**Note:** the **denominator** is **mass** of **solvent only** - don't confuse this with percent conc.)

Saturated soln. (see below).

A **saturated** solution occurs when the solution is in equilibrium with undissolved solute. Additional solute will not dissolve when added to a saturated solution. The solution contains the maximum amount of solute which can be dissolved in the solvent (it won't "hold" anymore solute). **Solubility** is the conc. of solute in a **saturated** soln. (the **maximum amount** that will dissolve, in (g solute)/(100 g solvent)). Even if you filter off the solution and get rid of the excess solid you still have a saturated solution. If you were to add more solid solute to the solution the solid will not dissolve.

An **unsaturated** solution has less than the maximum amount of solute dissolved in the solution (less solute than that needed to form a saturated solution). When you add more solute it will dissolve (i.e. an unsaturated solution can dissolve more solute).

A solution with a conc of less than 32.3 g/100 g H_2O (a saturated solution) would be unsaturated. In this case less than 4.23 g of solute in 13.1 g H2O would be unsaturated. Alternatively, 4.23 g of solute in more than 13.1 g H2O would also be unsaturated .

A **supersaturated** solution actually has more solute dissolved than the saturated solution for a given temperature. How? Isn't the definition of a saturated solution such that it contains the maximum amount of dissolved solute for a given temp. and no more will dissolve? The answer to this question is yes, for a stable system. However, remember for most solids the conc. (solubility) increases as temperature increases. If you heat the system the solubility increases. Some substances have trouble crystallizing and if you are very careful and slowly cool the solution and don't disturb it you can get it to cool back to room temp. w/o the excess solid (which shouldn't be dissolved at room temp.) crystallizing out of solution. The excess solute and heat added can be "trapped" in the solution. This is a supersaturated solution and it is a **metastable** state. This means it's not the most stable state for the system. It will revert to the more stable state (saturated solution) over time or if disturbed by shaking, scratching the inner surface of the container or adding a "seed" crystal. This gives the excess solid a point of "nucleation" where the excess solute particles can attach and then start crystallizing out. As this happens the excess "trapped" heat is released to the surroundings. These types of solutions are often used in reusable hot packs. When the hot pack is kneaded in your hands the excess solute crystalizes releasing heat. When thrown in boiling water the supersaturated solution is reformed.

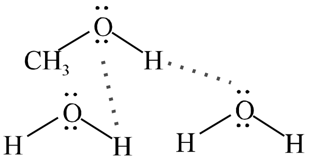
Also, don't confuse the terms concentrated and saturated or dilute and unsaturated. You can have a dilute saturated solution. If the solute is not very soluble then a saturated solution would be dilute. You can have a concentrated unsaturated solution. If the solute is very soluble you can have an unsaturated solution with a lot of solute dissolved which would then be concentrated.

Given a beaker with a liquid in it how could you tell if it's a saturated, unsaturated or supersaturated solution? Add some more solid. If none of it dissolves then the original solution was saturated. If some of it dissolves the original solution was unsaturated. If you add solid to the solution and more solid precipitates the original solution was supersaturated.

4. (4 pts) Which of the following are **<u>soluble</u>** in **water**, H_2O, and **WHY** (give a brief explanation dealing w. IAF & type of compound; ionic, polar, nonpolar for both solute and solvent)? (Circle all that apply.)

[✓ NH_4ClO_3]	C_6H_{12}	[✓ CH_3OH]	CCl_4
ionic (Ion-dipole) in the soln	nonpolar	polar (LF, DD, HB)	nonpolar

H_2O is **polar** (LF, DD, H-bonding)



"Like Dissolves Like"

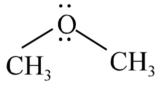
<u>nonpolar</u> solutes dissolve in **<u>nonpolar</u> solvents**
<u>polar</u> & **<u>ionic</u> solutes** dissolve in **<u>polar</u> solvents**

The NH_4ClO_3 is ionic and dissolves in polar H_2O as ions. So you get ion-dipole AF between the ions and the H_2O water molecules.

The CH_3OH is polar and forms LF, DD, HB as a pure substance. H_2O is polar and forms LF, DD, HB as a pure substance. So CH_3OH can form LF, DD, HB to the H_2O molecules.

5. (8 pts) When CH_3OCH_3 dissolves in H_2O forces of attraction are being broken in the solute and in the solvent and attractive forces are formed between the solute and solvent. Answer the following questions concerning this process. (H, C, N and O are in groups 1A, 4A, 5A and 6A, respectively. H, C, N and O have 1, 6, 7 and 8 electrons, respectively.) **Explain your choices!**

a) What forces of attraction are broken between CH_3OCH_3 molecules? (solute-solute AF)

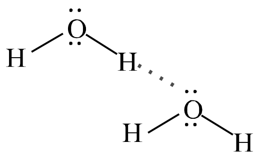


Bent around O (like H_2O) => **polar**

LF (London Dispersion Forces) DD (dipole-dipole AF)

(NO H-bonding in the pure substance between CH_3OCH_3 molecules)

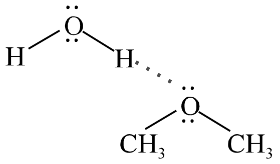
b) What forces of attraction are broken between H_2O molecules? (solvent-solvent AF)



Bent => **polar** and **H on O** (w. lpe$^-$ on O)

LF DD HB (H-bonding)

c) What forces of attraction are formed between CH_3OCH_3 and H_2O in forming the solution? (solute-solvent AF; "unlike" forces)



LF	form between both (only slightly weaker than LF that were broken)
DD	both are polar and can form DD AF to each other
HB	from lpe$^-$ on O in CH_3OCH_3 to H in H_2O

6. (2 pts) What happens to the solubility of a gas in water as temperature increases?

Solubility of a gas in water decreases as temp. increases. We can explain the temp affect on a gas in water in two ways.

We can use Le Châtelier's Principle, as discussed in class. When a gas dissolves in water the ΔH_{soln} is negative, heat is evolved.. When a change is made to a system at equilibrium the system shifts in a way to minimize the change. In a simple way for now (more in Ch 15) when you add something to a system at equilibrium it shifts to try to use up some of what's added. When you remove something from a system at equil. it shifts to try to replace some of what's removed.

$$\text{gas} + H_2O \rightleftarrows \text{Solution} + \text{heat}$$

So, this is at equil. at room temp and we bring a Bunsen burner up to heat and add heat (raise the temp.). Since heat is a product the system shifts away from what's added, in this case toward the reactants to use some of the heat that's being added. As it shifts left you get less solution (gas comes out of solution).

Another way to think about it is what happens to kinetic energy of the molecules when temp. changes. If you add heat to inc. the temp. the KE of everything increases. This is more important for the dissolved gas molecules. Since they have more KE they can escape more easily into the vapor phase above the solution (which leads to an inc. in disorder) and the gases solubility decreases.

7. (3 pts) What volume (in L) of a 133 ppm NH_3 solution with a density of 0.998 g/mL is required to provide 0.0175 grams of NH_3? (Form. wts.: NH_3 = 17.03, H_2O = 18.02)

Use ppm as a conversion factor to get mass of solution required to provide 0.0155 g NH_3 and then convert that to a volume of solution using the density of the solution.

$$\text{ppm} = \frac{\text{g solute}}{\text{g soln}} \times 10^6 \qquad \text{or think of it like pph (\%) where X ppm} = \frac{\text{X g solute}}{10^6 \text{ g solution}}$$

$$\text{? L soln} = 0.0175 \text{ g } NH_3 \times \frac{10^6 \text{ g soln}}{133 \text{ g } NH_3} \times \frac{1 \text{ mL soln}}{0.998 \text{ g soln}} \times \frac{1 \text{ L soln}}{10^3 \text{ mL soln}}$$

$$= 0.13\underline{1}84 \text{ L } NH_3$$

$$= 0.132 \text{ L } NH_3 \text{ soln} \quad \text{(3 s.f.)}$$

8. (10 pts) A 16.0 M nitric acid, HNO_3, solution has a density of 1.42 g/mL.
(Form. wts.: $HNO_3 = 63.01$, $H_2O = 18.02$)

For all these conc. conversion type problems it's best to try to do them using one method or thought process. That way you don't have to worry if you see a problem you may not have worked while studying. I did examples in class. Ultimately, you saw I always wound up assuming I had a beaker containing whatever was in the denominator of the given conc. unit and then worked from there.

a) (5 pts) What is the **molality** of HNO_3?

This part did NOT appear on the actual quiz. It's practice for conc. conversion problems.

A) Write down what you are given and what you are trying to determine

$$16.0\ \text{M HNO}_3 = \frac{16.0\ \text{mol HNO}_3}{1\ \text{L soln}} \qquad D_{\text{soln}} = \frac{1.42\ \text{g soln}}{1\ \text{mL soln}}$$

$$\text{Want:} \quad m = \frac{\text{mol HNO}_3}{1\ \text{kg solvent}}$$

B) **<u>Assume</u>** 1 L soln (i.e. you have a beaker containing 1 L soln) ⇒ 16.0 mol HNO_3

- usually easiest to assume have what's in denominator of given conc. Once you do that it also means you have what's in the numerator.

So now to get molality you need moles solute - already have this
Somehow you have to go from L soln to kg of solvent, water in this case.

C) **Mass of soln** - need to use density of soln

$$?\ \text{g soln} = 1\ \text{L soln} \times \frac{10^3\ \text{mL soln}}{1\ \text{L soln}} \times \frac{1.42\ \text{g soln}}{1\ \text{mL soln}} = 14\underline{\mathbf{2}}0\ \text{g soln}$$

D) **molality of HNO_3**

1) mass of HNO_3 :
$$?\ \text{g HNO}_3 = 16.0\ \text{mol HNO}_3 \times \frac{63.01\ \text{g HNO}_3}{1\ \text{mol HNO}_3} = 10\underline{\mathbf{0}}8.16\ \text{g HNO}_3$$

2) need mass H_2O :
$$?\ \text{g H}_2\text{O} = 14\underline{\mathbf{2}}0\ \text{g soln} - 10\underline{\mathbf{0}}8.16\ \text{g HNO}_3 = 4\underline{\mathbf{1}}1.84\ \text{g H}_2\text{O} \quad (2\ \text{s.f.})$$

3)
$$m\ \text{HNO}_3 = \frac{16.0\ \text{mol HNO}_3}{0.4\underline{\mathbf{1}}184\ \text{kg H}_2\text{O}} = 3\underline{\mathbf{8}}.850\ m\ \text{HNO}_3 = 39\ m\ \text{HNO}_3 \quad (2\text{s.f.})$$

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8. (Cont.)

b) (5 pts) What is the **mole fraction** of HNO_3?

Much of what you need below to solve this was done above but I'm including it here since you didn't do the part above on the quiz.

A) Write down what you are given and what you are trying to determine

$$16.0\text{ M }HNO_3 = \frac{16.0\text{ mol }HNO_3}{1\text{ L soln}} \qquad D_{\text{soln}} = \frac{1.42\text{ g soln}}{1\text{ mL soln}}$$

$$\text{Want:}\quad \chi_{\text{HNO3}} = \frac{\text{mol }HNO_3}{\text{total mol soln}}$$

B) **<u>Assume</u>** 1 L soln (i.e. you have a beaker containing 1 L soln) ⇒ 16.0 mol HNO_3

Usually easiest to assume have what's in denominator of given conc. Once you do that it also means you have what's in the numerator. This was the same assumption made above so you didn't have to do it again.

To get mole fraction you need moles solute (already have this) & moles of solvent. Somehow you have to go from L soln to mass of solvent, water in this case, so you can get moles of solvent.

C) need mass H_2O : subtract mass of HNO_3 from the mass of solution

1) mass of soln : $$?\text{ g soln} = 1\text{ L soln} \times \frac{10^3\text{ mL soln}}{1\text{ L soln}} \times \frac{1.42\text{ g soln}}{1\text{ mL soln}} = 14\underline{\mathbf{2}}0\text{ g soln}$$

2) mass of HNO_3 : $$?\text{ g }HNO_3 = 16.0\text{ mol }HNO_3 \times \frac{63.01\text{ g }HNO_3}{1\text{ mol }HNO_3} = 10\underline{\mathbf{0}}8.16\text{ g }HNO_3$$

3) need mass H_2O : $?\text{ g }H_2O = 14\underline{\mathbf{2}}0\text{ g soln} - 10\underline{\mathbf{0}}8.16\text{ g }HNO_3 = 4\underline{\mathbf{1}}1.84\text{ g }H_2O$ (2 s.f.)

D) need moles of H_2O

$$?\text{ mol }H_2O = 4\underline{\mathbf{1}}1.84\text{ g }H_2O \times \frac{1\text{ mol }H_2O}{18.02\text{ g }H_2O} = 2\underline{\mathbf{2}}.854\text{ mol }H_2O = 2\underline{\mathbf{3}}\text{ mol }H_2O\text{ (2 s.f.)}$$

E) **mole fraction of HNO_3** : have moles of HNO_3 & H_2O

$$\chi_{\text{HNO3}} = \frac{16.0\text{ mol }HNO_3}{(16.0\text{ mol }HNO_3 + 2\underline{\mathbf{2}}.854\text{ mol }H_2O)} = 0.4\underline{\mathbf{1}}179 = 0.4\underline{\mathbf{1}}\text{ (2 s.f.)}$$

$$\chi_{\text{H2O}} = \frac{2\underline{\mathbf{2}}.854\text{ mol }H_2O}{3\underline{\mathbf{8}}.854\text{ mol soln}} = 0.5\underline{\mathbf{8}}820 = 0.5\underline{\mathbf{9}}\text{ (2 s.f.)}$$ no units for mole fraction

9. (5 pts) A 7.69 ***m*** H_2SO_4 solution has a density of 1.329 g/mL. What is the **solubility** of H_2SO_4? (Form. wts.: $H_2SO_4 = 98.08$, $H_2O = 18.02$)

A) Write down what you are given and what you are trying to determine

$$7.69\ m\ \mathrm{H_2SO_4} = \frac{7.69\ \mathrm{mol\ H_2SO_4}}{1\ \mathrm{kg\ H_2O}} \qquad D_{\mathrm{soln}} = \frac{1.329\ \mathrm{g\ soln}}{1\ \mathrm{mL\ soln}}$$

$$\text{Want: solubility} = \frac{\mathrm{g\ H_2SO_4}}{100\ \mathrm{g\ solvent}}$$

Don't confuse this with % (pph), which is g solute/ g solution x 100

B) **Assume** 1 kg H_2O (i.e. have a beaker of soln containing 1 kg H_2O) ⇒ 7.69 mol H_2SO_4

- usually easiest to assume you have what's in denominator of given conc. unit. Once you do that it also means you have what's in the numerator.

So now to get molarity you need g solute - get from moles H_2SO_4
Already have mass of solvent in kg, just need to change to g solvent.

C) **Mass of solute, H_2SO_4**

$$\text{1) mass of } \mathrm{H_2SO_4}\text{:}\quad ?\ \mathrm{g\ H_2SO_4} = 7.69\ \mathrm{mol\ H_2SO_4} \times \frac{98.08\ \mathrm{g\ H_2SO_4}}{1\ \mathrm{mol\ H_2SO_4}} = 75\mathbf{4}.23\ \mathrm{g\ H_2SO_4}$$

D) **solubility of H_2SO_4**

Have mass of H_2SO_4 in 1 kg of water. Now use it to determine mass of H_2SO_4 in 100 g water. Use what we have as a conversion.

$$\text{1) g } \mathrm{H_2SO_4} \text{ in 100 g } \mathrm{H_2O} = \frac{75\mathbf{4}.23\ \mathrm{g\ H_2SO_4}}{1000\ \mathrm{g\ H_2O}} \times 100\ \mathrm{g\ H_2O} = 75.\mathbf{4}23\ \mathrm{g\ H_2SO_4}$$

$$\text{2) solubility } \mathrm{H_2SO_4} = \frac{75.\mathbf{4}\ \mathrm{g\ H_2SO_4}}{100\ \mathrm{g\ H_2O}}$$

While you were given the density of the solution, you did NOT need it. You only need density of the solution when you're going to molarity or from molarity.