

Recitation Worksheet 6: Exam 2 Review

Name

key

MyID

Instructions:

1. This recitation worksheet is for the exam 2 review.
2. You **do not need** to submit it to GradeScope.
3. The answer key has been posted with this worksheet to eLC.
4. The **recitation session in the exam week (Feb 27 – Mar 3) is still mandatory**. The attendance will be recorded.

Chapter 17 – Spontaneity, Entropy, and Free Energy (Thermodynamics)

1. Which of the following processes have a $\Delta S > 0$?

ACD

- gases have a higher entropy than liquids*
- ions in solution have a higher entropy than solids*
- 2 mol of gas are produced $\therefore \Delta S > 0$*
- $\text{CH}_3\text{OH}(\text{l}) \rightarrow \text{CH}_3\text{OH}(\text{g})$
 - $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$
 - $\text{BaF}_2(\text{s}) \rightarrow \text{Ba}^{2+}(\text{aq}) + 2\text{F}^{-}(\text{aq})$
 - $2\text{NaHCO}_3(\text{s}) \rightarrow \text{Na}_2\text{CO}_3(\text{s}) + \text{H}_2\text{O}(\text{g}) + \text{CO}_2(\text{g})$
 - $\text{Mg}(\text{s}) + \text{Cl}_2(\text{g}) \rightarrow \text{MgCl}_2(\text{s})$

2. Which of the following pairs has the member with the greater molar entropy listed first? Select all that apply. All systems are at 25 °C.

BCE

- Ar has a higher molar mass than Ne (\uparrow molar mass \uparrow entropy)*
- gases have higher entropy than ions in solution*
- \uparrow molar mass \uparrow entropy*
- $\text{NO}(\text{g}), \text{N}_2\text{O}_4(\text{g})$
 - $\text{Ar}(\text{g}), \text{Ne}(\text{g})$
 - $\text{H}_2\text{S}(\text{g}), \text{H}_2\text{S}(\text{aq})$
 - $\text{Li}(\text{s}), \text{Pb}(\text{s})$
 - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3(\text{l}), \text{CH}_2=\text{CHCH}=\text{CHCH}_3(\text{l})$

3. Which of the following pairs has the process/member with the lower molar entropy listed first? Select all that apply.

ABD

- Entropy of liquids < Entropy of gases*
- 3 mol produced*
- 5 mol produced*
- \uparrow in ionic charge \therefore ionic bonds \therefore \uparrow lattice energy \therefore lower entropy*
- 0.01 mole H_2 liquid at -253 °C and 1 atm and 0.01 mole H_2 gas at 25 °C and 1 atm
 - $\text{MgCl}_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq})$ at 25 °C and 1 atm and $\text{Mg}_3(\text{PO}_4)_2(\text{s}) \rightarrow 3\text{Mg}^{2+}(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq})$ at 25 °C and 1 atm
 - $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3(\text{l})$ at 25 °C and 1 atm and $\text{CH}_3\text{OCH}_3(\text{l})$ at 25 °C and 1 atm
 - $\text{MgO}(\text{s})$ at 25 °C and 1 atm and $\text{NaCl}(\text{s})$ at 25 °C and 1 atm

4. A sample of water is heated at a constant pressure of one atmosphere. Initially, the sample is ice at 260 K, and at the end the sample consists of steam at 400 K. In which of the following 5K temperature intervals would there be the greatest increase in the entropy of the sample?

D

- \rightarrow water starts boiling at 373 K (liquid water \rightarrow steam)*
- From 260 K to 265 K
 - From 275 K to 280 K
 - From 360 K to 365 K
 - From 370 K to 375 K

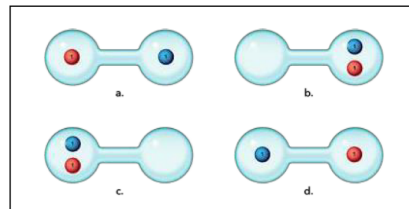
Recitation Worksheet 6: Exam 2 Review

5. Imagine two different gases, for simplicity represented as red and blue spheres, in separate containers. Imagine starting with one red gas atom and one blue gas atom in separate containers. Once the containers are connected, the gases mix between the two containers in 4 possible ways as shown in the accompanying image. If one additional blue atom is added to the mixture, how many different combinations are possible?

8

- A. 4
B. 6
C. 8
D. 12
E. 16

to calculate # of possible combinations or microstates
 $2^n \rightarrow$ number of molecules
 \downarrow
 # of containers
 $2^3 = 8$

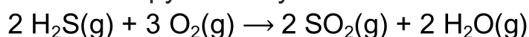


6. Which of the following statements are false? Select all apply

A0

- A. The change in entropy in a system depends on the initial and final states of the system and the path taken from one state to the other. **F** (Entropy is a state not a path function)
 B. The entropy of the universe is continuously increasing **T**
 C. Any irreversible process results in an overall increase in entropy. **T**
 D. When a system is at equilibrium, the reaction is spontaneous in forward direction **F**
 E. Entropy increases with the number of microstates of the system. **T**

7. Sulfur dioxide, SO_2 , is a colorless gas or liquid with a strong, choking odor. The combustion of H_2S produces SO_2 releasing energy to the environment. The entropy of the system is -153.2 J/K at 25°C .



ΔH°_f (kJ/mol)	-20.6	-296.8	-241.8
-----------------------------	-------	--------	--------

- A. Calculate the ΔS_{univ} at 25°C using the given information. Assume the temperature and pressure is constant.

3323.3

J/K

$$\Delta S_{\text{univ}} = \Delta S_{\text{sys}} + \Delta S_{\text{surroundings}}$$

$$\Delta S_{\text{sys}} = -153.2 \text{ J/K}$$

$$\Delta S_{\text{surroundings}} = ?$$

$$\Delta S_{\text{surroundings}} = - \frac{\Delta H_{\text{sys}}}{T}$$

$$\begin{aligned} \Delta H_{\text{sys}} = \Delta H_{\text{rxn}} &= \sum n H_f^\circ \text{ products} - \sum n H_f^\circ \text{ reactants} \\ &= [-4.836 \times 10^2 - 5.936 \times 10^2 - 0.0412 \times 10^3] - [(2 \times -20.6) + (3 \times 0)] = \\ &= [(2 \times -241.8) + (2 \times -296.8)] - [(2 \times -20.6) + (3 \times 0)] = \\ &= [-1.0772 \times 10^3] - [-0.0412 \times 10^3] \\ &= -1.036 \times 10^3 \text{ kJ/mol} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \\ &= -1.036 \times 10^6 \text{ J} \end{aligned}$$

$$\Delta S_{\text{surroundings}} = - \frac{\Delta H_{\text{sys}}}{T} = \frac{-(-1.036 \times 10^6 \text{ J})}{(25 + 273)} = 3.4765 \times 10^3 \frac{\text{J}}{\text{K}}$$

- B. Is this reaction spontaneous or non-spontaneous?

I

- I. Spontaneous
II. Non-spontaneous

$$\Delta S_{\text{univ}} > 0$$

$$\begin{aligned} \Delta S_{\text{univ}} &= (-153.2 \frac{\text{J}}{\text{K}}) + (3476.5 \frac{\text{J}}{\text{K}}) \\ &= 3323.3 \frac{\text{J}}{\text{K}} \end{aligned}$$

Recitation Worksheet 6: Exam 2 Review

8. The combustion of acetylene in the presence of excess oxygen yields carbon dioxide and water:
 $2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$ $\Delta S_{\text{sys}} = -432.4 \text{ J/mol}\cdot\text{K}$

Calculate the molar entropy change when 0.256g CO_2 produced.

-0.629

J/mol·K

molar mass of $\text{CO}_2 = 44.01 \text{ g/mol}$

$$0.256 \text{ g CO}_2 \times \frac{1 \text{ mol CO}_2}{44.01 \text{ g CO}_2} \times \frac{-432.4 \text{ J}}{4 \text{ mol CO}_2} = -0.629 \text{ J/mol}$$

9. Assume that substance X has the enthalpy of vaporization of 5.2 kJ/mol at its normal boiling point (456 °C). If 2 moles of X condense by releasing heat to the surroundings at 456 °C, what is the entropy change in the surroundings?

14 or 1.4

J/K

→ Condensation is exothermic

$$\Delta S_{\text{sur}} = \frac{q_{\text{sur}}}{T} = -\frac{q_{\text{sys}}}{T} = \frac{\Delta H_{\text{phase change}} \times \text{mole}}{T}$$

→ $\Delta H_{\text{vap}} = -\Delta H_{\text{cond.}} = -5.2 \text{ kJ/mol}$

$$= -\left(-5.2 \frac{\text{kJ}}{\text{mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \times 2\right) \div (456 + 273.15 \text{ K})$$

$$= 14.266 \text{ J/K}$$

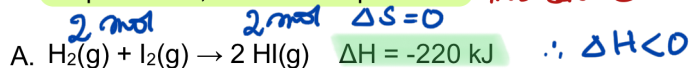
~ 14 J/K

10. Which of the following processes have a positive entropy change?

BCD

- A. Condensation of a liquid Condensation = liquid → solid ∴ $\Delta S < 0$
 B. Increasing the volume of 1.0 mol of an ideal gas at constant temperature dispersal of gas molecules over a large volume ∴ $\Delta S > 0$
 C. Dissolving sugar in water solid dispersed in a larger volume of liquid ∴ $\Delta S > 0$
 D. Heating 1.0 mol of an ideal gas at constant volume

11. Predict whether the reactions will tend to be spontaneous at either high or low temperatures, at all temperatures, or at no temperature



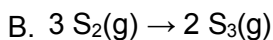
$\Delta G = \Delta H - T\Delta S$
 (-) 0

Spontaneous at all temperatures

A) For this reaction $\Delta H < 0$ & the entropy of the system does not change as there are two moles of gas on the reactant & product side ∴ $\Delta S = 0$ & $-T\Delta S = 0$. If ΔH is a negative value ∴ $\Delta G < 0$ → spontaneous at all temperatures

Recitation Worksheet 6: Exam 2 Review

$$3 \text{ mol} \quad 2 \text{ mol} \quad \therefore \Delta S < 0$$



$$\Delta H = +227 \text{ kJ}$$

Non-spontaneous at all temperatures

$$\Delta G = \Delta H - T\Delta S$$

ΔH (+) $-T\Delta S$ (-) $\therefore \Delta G > 0$

the term $-T\Delta S$ becomes positive

The system goes from 3 mol of gas to 2 mol of gas \therefore entropy of the system decreases $\therefore \Delta S < 0$
 $\Delta H_{\text{sys}} > 0$ or endothermic



$$\Delta H = +44 \text{ kJ}$$

$$\Delta H > 0$$

Spontaneous only at high temperatures

At high temperatures the term $-T\Delta S$ is negative & has a larger magnitude than their ΔH $\therefore \Delta G < 0$ & the reaction is spontaneous at high temperatures

$$\Delta G = \Delta H - T\Delta S$$

ΔH (+) $-T\Delta S$ (+) $\therefore \Delta G < 0$

the term $-T\Delta S$ becomes negative

*Note: when the signs for ΔH & ΔS are the same, spontaneity is temperature dependent



$$\Delta H = -247 \text{ kJ}$$

$$\Delta H < 0$$

Phase change occurs from gas to liquid $\therefore \Delta S < 0$

$$\Delta G = \Delta H - T\Delta S$$

ΔH (-) $-T\Delta S$ (-) $\therefore \Delta G < 0$

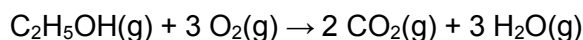
the term $-T\Delta S$ becomes positive

the term $-T\Delta S$ becomes positive

Spontaneous only at low temperatures

At low temperatures the term $-T\Delta S$ is positive & has a smaller magnitude than the negative value for the enthalpy $\therefore \Delta G < 0$ & the reaction is spontaneous at low temperatures

12. Using values for the standard enthalpies of formation (ΔH_f°) and standard molar entropy (ΔS°) shown, calculate the thermodynamic values for the complete combustion of ethanol:



Compound	ΔH_f° (kJ/mol)	ΔS° (J/mol K)
$\text{C}_2\text{H}_5\text{OH}(\text{g})$	-234	283
$\text{CO}_2(\text{g})$	-394	214
$\text{H}_2\text{O}(\text{g})$	-242	189
$\text{O}_2(\text{g})$	0	205

A. The standard enthalpy change (ΔH°)

$$-1280$$

kJ/mol

$$\Delta H^\circ = \sum n \Delta H_f^\circ \text{ products} - \sum n \Delta H_f^\circ \text{ reactants}$$

$$= [(2 \times -394) + (3 \times -242)] - [(1 \times -234) + (3 \times 0)]$$

$$= (-1614) - (-234)$$

$$= -1280 \text{ kJ/mol}$$

B. The standard entropy change (ΔS°)

$$97$$

J/mol·K

$$\Delta S^\circ = \sum n \Delta S^\circ \text{ products} - \sum n \Delta S^\circ \text{ reactants}$$

$$= [(2 \times 214) + (3 \times 189)] - [(1 \times 283) + (3 \times 205)]$$

$$= 995 - 898$$

$$= 97$$

Recitation Worksheet 6: Exam 2 Review

C. Calculate ΔG° at 298 K

-1.3×10^3 kJ/mol

$$\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ$$

$$\Delta G^\circ = -1280 \frac{\text{kJ}}{\text{mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} - \left(298 \text{ K} \times 97 \frac{\text{J}}{\text{mol} \cdot \text{K}} \right)$$

$$= -1.308906 \times 10^6 \frac{\text{J}}{\text{mol}}$$

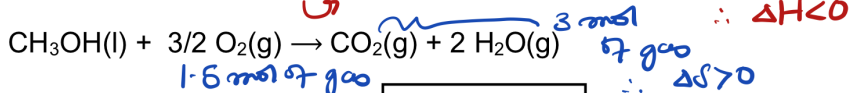
$$\sim -1.3 \times 10^3 \frac{\text{kJ}}{\text{mol}}$$

D. Is this reaction spontaneous or non-spontaneous at 298K under standard conditions?

I

- i. Spontaneous
ii. Non-spontaneous

13. Methanol(CH_3OH) is used a rocket fuel. Using only the signs of ΔH° and ΔS° , predict the signs and temperature dependence for the combustion of methanol



A. ΔS° > 0 (Insert > 0 or < 0)

ΔH° < 0 (Insert > 0 or < 0)

B. Is the sign of ΔG° for this reaction temperature dependent?

ii

- i. The sign of ΔG° for this reaction is temperature dependent because $\Delta S^\circ > 0$ and $\Delta H^\circ < 0$
 ii. The sign of ΔG° for this reaction is not temperature dependent because $\Delta S^\circ > 0$ and $\Delta H^\circ < 0$
 iii. The sign of ΔG° for this reaction is temperature dependent because $\Delta S^\circ < 0$ and $\Delta H^\circ > 0$
 iv. The sign of ΔG° for this reaction is not temperature dependent because $\Delta S^\circ < 0$ and $\Delta H^\circ > 0$

Tip: if the spontaneity of a reaction is temperature dependent!

14. A reaction with a low enthalpy of reaction value is not spontaneous at low temperature but becomes spontaneous at high temperature. What are the signs for ΔH° and ΔS° , respectively?

D

- A. +, -
B. -, -
C. -, +
D. +, +
E. Insufficient data is provided to answer this question

$$\Delta G = \Delta H - T \Delta S$$

(+) (+)

the sign for ΔH & ΔS must be the same

15. Given the following data, determine the molar free energy of combustion of propane gas (C_3H_8)

$\Delta G(\text{C}_3\text{H}_8, \text{g})$	-23.5 kJ/mol
$\Delta G(\text{CO}_2, \text{g})$	-394.4 kJ/mol
$\Delta G(\text{H}_2\text{O}, \text{g})$	-105.6 kJ/mol

-1582.1

kJ/mol



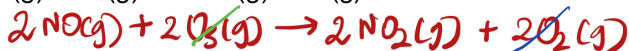
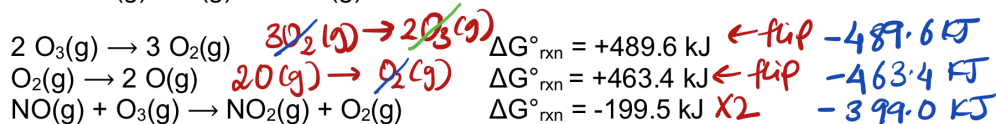
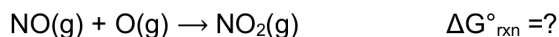
$$\Delta G = \sum n G_{\text{products}} - \sum n G_{\text{reactants}}$$

$$[(3 \times -394.4) + (4 \times -105.6)] - [(1 \times -23.5) + (5 \times 0)]$$

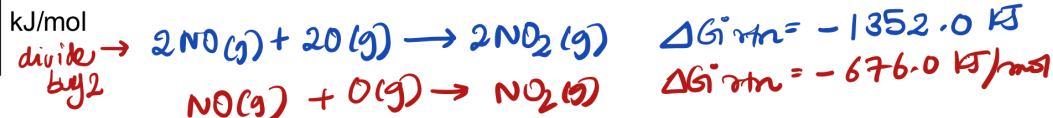
$$= -1582.1 \text{ kJ/mol}$$

Recitation Worksheet 6: Exam 2 Review

16. Calculate $\Delta G^\circ_{\text{rxn}}$ using the following information.



-676.0



17. Indicate which of the following has the highest entropy at 298 K.

C

- A. 0.5 g of HCN
- B. 1 mol of HCN
- ☒ C. 2 kg of HCN
- D. 2 mol of HCN
- E. All of the above have the same entropy at 298 K

Entropy is an extensive property \therefore depends on the amount of matter in the substance

18. The dissolution of ammonium nitrate in water is a spontaneous endothermic process. It is spontaneous because the system undergoes _____.

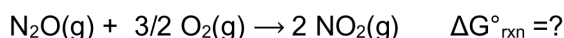
B

- A. A decrease in enthalpy
- ☒ B. An increase in entropy
- C. An increase in enthalpy
- D. A decrease in entropy
- E. An increase in free energy

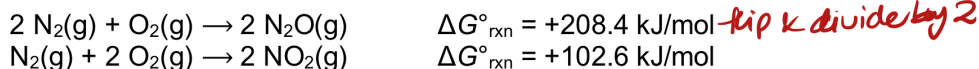
$$\Delta G = \Delta H - T\Delta S$$

• there is an increase in entropy with the dissolution process
 $\text{NH}_4\text{NO}_3\text{(s)} \rightarrow \text{NH}_4^+\text{(aq)} + \text{NO}_3^-\text{(aq)} \quad \Delta S > 0$
 • the reaction is endothermic $\therefore \Delta H > 0$

Find $\Delta G^\circ_{\text{rxn}}$ for the reaction below

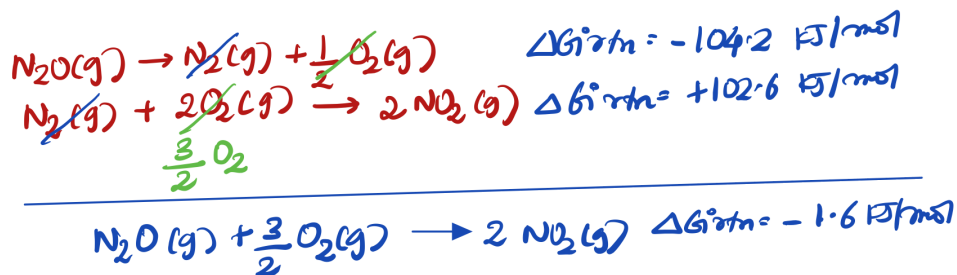


19. Using the following information



-1.6

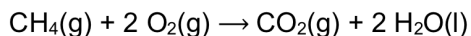
kJ/mol



Recitation Worksheet 6: Exam 2 Review

this is a limiting reactant problem. to solve this problem you need to determine the standard entropy changes that occur when a certain amount of limiting reactants in grams is used.

20. What is the standard entropy change when **10.0 g of methane** reacts with **10.0 g of oxygen**?



Substance	S° (J/mol · K)
CH ₄ (g)	186.2
O ₂ (g)	205.0
H ₂ O (l)	70.0
CO ₂ (g)	213.6

① determine the limiting reactant

-37.9

J/K

$$\text{CO}_2 \text{ produced from CH}_4$$

$$10.0 \text{ g CH}_4 \times \frac{1 \text{ mol CH}_4}{16.05 \text{ g CH}_4} \times \frac{1 \text{ mol CO}_2}{1 \text{ mol CH}_4} \times \frac{44.01 \text{ g CO}_2}{1 \text{ mol CO}_2} = 27.4 \text{ g}$$

$$\text{CO}_2 \text{ produced from O}_2$$

$$10.0 \text{ g O}_2 \times \frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2} \times \frac{1 \text{ mol CO}_2}{2 \text{ mol O}_2} \times \frac{44.01 \text{ g CO}_2}{1 \text{ mol CO}_2} = 6.88 \text{ g}$$

✓ O₂ is the limiting reactant

② determine $\Delta S_{\text{rxn}} = \sum n S^\circ_{\text{products}} - \sum n S^\circ_{\text{reactants}}$

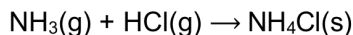
$$= [(1 \times 213.6) + (2 \times 70.0)] - [(1 \times 186.2) + (2 \times 205.0)]$$

$$= -242.6 \text{ J/K}$$

③ standard entropy changes that occur when 10.0g of O₂ are used

$$10.0 \text{ g O}_2 \times \frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2} \times \frac{-242.6 \text{ J/K}}{2 \text{ mol O}_2} = -37.9 \text{ J/K}$$

21. From the data given in the following table, determine $\Delta_r S^\circ$ for the reaction below. All data below are at 298K



Compound	$\Delta_f H^\circ$, kJ/mol	$\Delta_f G^\circ$, kJ/mol
NH ₃ (g)	-46.11	-16.48
HCl (g)	-92.31	-95.30
NH ₄ Cl (s)	-314.4	-202.9

-285

J/mol·K

$$\Delta G = \Delta H - T \Delta S$$

$$\Delta S = \frac{\Delta H - \Delta G}{T}$$

① $\Delta_r H = \sum n H_f^\circ \text{ products} - \sum n H_f^\circ \text{ reactants}$

$$[(1 \times -314.4)] - [(1 \times -46.11) + (1 \times -92.31)]$$

$$= -176.0 \text{ kJ/mol}$$

② $\Delta_r G = \sum n G_f^\circ \text{ products} - \sum n G_f^\circ \text{ reactants}$

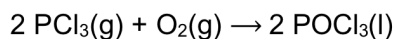
$$[(1 \times -202.9)] - [(1 \times -16.48) + (1 \times -95.30)]$$

$$= -91.1 \text{ kJ/mol}$$

③ $\Delta S = \frac{-176.0 - (-91.1)}{298} = -0.285 \frac{\text{kJ}}{\text{mol} \cdot \text{K}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} = -285 \frac{\text{J}}{\text{mol} \cdot \text{K}}$

Recitation Worksheet 6: Exam 2 Review

22. At 298 K, for the reaction



$\Delta_r H^\circ = -620.2 \text{ kJ/mol}$ and the standard molar entropies, in $\text{J/mol}\cdot\text{K}$ are $\text{PCl}_3(\text{g}) = 311.8$, $\text{O}_2(\text{g}) = 205.1$, and $\text{POCl}_3(\text{l}) = 222.4$.

A. Determine $\Delta_r G^\circ$ at 298 K in kJ/mol

-505.8

kJ/mol

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta S_{\text{rxn}} = \sum n S^\circ_{\text{products}} - \sum n S^\circ_{\text{reactants}}$$

$$[(2 \times 222.4)] - [(2 \times 311.8) + (1 \times 205.1)]$$

$$= -383.9 \text{ J/K}$$

$$\Delta G_{\text{rxn}} = \left(\frac{-620.2 \text{ kJ}}{\text{mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \right) - \left(298 \text{ K} \times -383.9 \frac{\text{J}}{\text{K}} \right)$$

$$= -505797.8 \text{ J/mol} = -505.8 \text{ kJ/mol}$$

B. Is this reaction spontaneous in the forward or the reverse direction when the reactants and products are in their standard states?

ii

- i. The reaction is spontaneous in the forward direction because $\Delta_r G^\circ$ has a positive value
- ii. The reaction is spontaneous in the forward direction because $\Delta_r G^\circ$ has a negative value
- iii. The reaction is spontaneous in the reverse direction because $\Delta_r G^\circ$ has a negative value
- iv. The reaction is spontaneous in the reverse direction because $\Delta_r G^\circ$ has a positive value
- v. The direction of spontaneity cannot be determined

$\Delta G < 0 \therefore$ spontaneous in the forward direction

Chapter 11 – Solutions

23. 15.2 g of methanol (CH_3OH) is added to 19.2 L of ethanol. What is the molality of the methanol in the ethanol? (Note: assume the density of the ethanol is 0.987 g/ml)

**0.0250 or
 2.50×10^{-2}**

m

$$\text{molality} = \frac{\text{mol of solute}}{\text{kg of solvent}}$$

$$= \frac{15.2 \text{ g CH}_3\text{OH} \times \frac{1 \text{ mol CH}_3\text{OH}}{32.04 \text{ g CH}_3\text{OH}}}{19.2 \text{ L ethanol} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{0.987 \text{ g}}{\text{mL}} \times \frac{1 \text{ kg}}{1000 \text{ g}}}$$

$$= 0.02503414 \sim 0.0250 \text{ m or } 2.50 \times 10^{-2} \text{ m}$$

24. A sample of mineral water contains $5.24 \times 10^{-2} \text{ g}$ of NaCl in 2.88 L . If the density of the water is 1.00 g/ml , how many ppm of NaCl is this equal to?

18.2

ppm

$$\text{ppm} = \frac{\text{mg of solute}}{\text{kg of solution}}$$

$$= \frac{5.24 \times 10^{-2} \text{ g NaCl} \times \frac{1000 \text{ mg}}{1 \text{ g}}}{2.88 \text{ L} \times \frac{1000 \text{ mL}}{1 \text{ L}} \times \frac{1.00 \text{ g}}{1 \text{ mL}} \times \frac{1 \text{ kg}}{1000 \text{ g}}} = 18.19444 \sim 18.2 \text{ ppm}$$

Recitation Worksheet 6: Exam 2 Review

25. A solution of glucose ($C_6H_{12}O_6$) is made by adding 4.88 g of glucose with H_2O to yield a total volume of 533 ml. What is the resulting molarity of the glucose in this solution?

0.0508

M

or 5.08×10^{-2}

$$\text{Molarity} = \frac{\text{mol of solute}}{\text{L of solution}}$$

$$= \frac{4.88 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.16 \text{ g } C_6H_{12}O_6}}{533 \text{ mL solution} \times \frac{1 \text{ L}}{1000 \text{ mL}}}$$

$$= 0.05081995 \sim 0.0508 \text{ M}$$

26. What is the freezing point and boiling point of an aqueous solution of LiCl that contains 2.58 g of LiCl and 10.0 ml of water (assume density of H_2O is 1 g/ml)? $K_f(H_2O) = 1.86^\circ\text{C}/m$ and $K_b(H_2O) = 0.512^\circ\text{C}/m$.

Freezing point

-22.6

$^\circ\text{C}$

$$\Delta T_f = T_f(\text{solution}) - T_f(\text{solvent}) = K_f m_{LiCl} i$$

$$= -1.86^\circ\text{C} \times 6.08634118 \text{ m} \times 2 = -22.641189^\circ\text{C}$$

$$\sim -22.6^\circ\text{C}$$

$$m_{LiCl} = \frac{2.58 \text{ g } LiCl \times \frac{1 \text{ mol } LiCl}{42.39 \text{ g } LiCl}}{10.0 \text{ mL } H_2O \times \frac{1 \text{ g}}{\text{mL}} \times \frac{1 \text{ L}}{1000 \text{ g}}} = 6.08634118 \text{ m}$$

$$\therefore T_f(\text{solution}) = \Delta T_f + T_f(\text{solvent})$$

$$= -22.6^\circ\text{C} + 0.0^\circ\text{C}$$

$$= -22.6^\circ\text{C}$$

Boiling point

106.23

$^\circ\text{C}$

$$\Delta T_b = T_b(\text{solution}) - T_b(\text{solvent}) = K_b m_{LiCl} i$$

$$= 0.512^\circ\text{C} \times 6.08634118 \text{ m} \times 2$$

$$= 6.23241331$$

$$\sim 6.23^\circ\text{C}$$

$$T_b(\text{solution}) = \Delta T_b + T_b(\text{solvent})$$

$$= 6.23 + 100.00^\circ\text{C} = 106.23^\circ\text{C}$$

27. A 555 g sample of an aqueous solution contains 92.1 g of glucose. The vapor pressure of pure water at 20.0°C is 17.5 mm Hg. What is the vapor pressure of the water in the glucose solution at 20.0°C ?

17.2

mmHg

$$\text{Raoult's Law } P_{H_2O} = \chi_{H_2O} \times P_{H_2O}^0$$

$$\chi_{H_2O} = \frac{n_{H_2O}}{n_{H_2O} + n_{C_6H_{12}O_6}}$$

n_{H_2O} :

$$\text{Mass of } H_2O = \text{Mass of aqueous solution} - \text{Mass of glucose}$$

$$= 555 \text{ g} - 92.1 \text{ g} = 462.9 \text{ g}$$

$$462.9 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.01 \text{ g } H_2O} = 25.702388$$

$n_{C_6H_{12}O_6}$

$$\frac{92.1 \text{ g } C_6H_{12}O_6 \times \frac{1 \text{ mol } C_6H_{12}O_6}{180.16 \text{ g } C_6H_{12}O_6}}{180.16 \text{ g } C_6H_{12}O_6} = 0.5112123$$

$$\chi_{H_2O} = \frac{25.702388}{25.702388 + 0.5112123}$$

$$= 0.9804982$$

$$P_{H_2O} = \chi_{H_2O} \times P_{H_2O}^0$$

$$= 0.9804982 \times 17.5 \text{ mmHg}$$

$$= 17.15872$$

$$\sim 17.2 \text{ mmHg}$$

Recitation Worksheet 6: Exam 2 Review

$$\text{molar mass} = 58.44 \text{ g/mol}$$

$$\text{molar mass} = 180.16 \text{ g/mol}$$

28. A sports drink contains 1.22 g of NaCl and 23.5 g Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) in 250 ml of the drink. What are the mole fractions of the NaCl and glucose in the sports drink? (Note: assume that the density of the sports drink is identical to pure water). 1.0 g/mL

A. Mole fraction of NaCl

$$0.0016 \text{ or } 1.6 \times 10^{-3}$$

$$\text{Mass of drink} = 250 \text{ mL} \times 1.0 \text{ g/mL} = 250 \text{ g}$$

$$\text{Mass of solvent} = 250 \text{ g} - (1.22 + 23.5) \text{ g} = 225.28 \text{ g}$$

$$n_{\text{NaCl}} = 1.22 \text{ g NaCl} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} = 0.020876$$

$$n_{\text{C}_6\text{H}_{12}\text{O}_6} = 23.5 \text{ g C}_6\text{H}_{12}\text{O}_6 \times \frac{1 \text{ mol C}_6\text{H}_{12}\text{O}_6}{180.16 \text{ g C}_6\text{H}_{12}\text{O}_6} = 0.1304396$$

$$n_{\text{H}_2\text{O}} = 225.28 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.01 \text{ g H}_2\text{O}} = 12.508606$$

$$x_{\text{NaCl}} = \frac{n_{\text{NaCl}}}{n_{\text{NaCl}} + n_{\text{C}_6\text{H}_{12}\text{O}_6} + n_{\text{H}_2\text{O}}} = \frac{0.020876}{0.020876 + 0.1304396 + 12.508606} = 0.00164899 \sim 0.0016$$

B. Mole fraction of Glucose

$$0.010$$

$$x_{\text{C}_6\text{H}_{12}\text{O}_6} = \frac{n_{\text{C}_6\text{H}_{12}\text{O}_6}}{n_{\text{NaCl}} + n_{\text{C}_6\text{H}_{12}\text{O}_6} + n_{\text{H}_2\text{O}}} = \frac{0.1304396}{0.020876 + 0.1304396 + 12.508606} = 0.0103034$$

29. An aqueous solution of NaCl is 4.43% by mass. 15.7 ml of this solution is added to 185 ml of H_2O . What is the mass % of NaCl in this new solution?

$$0.347$$

%

$$\frac{4.43 \text{ g NaCl}}{100.0 \text{ g solution}} \times \frac{1.00 \text{ g solution}}{1 \text{ mL}} =$$

$$\frac{4.43 \text{ g NaCl}}{100.0 \text{ mL solution}} \times 15.7 \text{ mL} = 0.6955 \text{ g NaCl}$$

$$\text{Final volume of new solution} = 185 \text{ mL} + 15.7 \text{ mL} = 200.7 \text{ mL}$$

New concentration of diluted solution

$$= \frac{0.6955 \text{ g NaCl}}{200.7 \text{ mL}} \times \frac{1 \text{ mL}}{1.00 \text{ g}} = \frac{0.6955 \text{ g NaCl}}{200.7 \text{ g solution}} \times 100 = 0.347 \%$$



30. A 778 g sample of aqueous solution contains 133.0 g of RbBr. The vapor pressure of pure water at 20.0 °C is 17.5 mm Hg. What is the vapor pressure of the water in the RbBr solution at 20.0 °C?

$$16.7$$

mmHg

$$\text{Raoult's Law } P_{\text{H}_2\text{O}} = x_{\text{H}_2\text{O}} \times P_{\text{H}_2\text{O}}^0$$

$$x_{\text{H}_2\text{O}} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{H}_2\text{O}} + (i \times n_{\text{RbBr}})}$$

$$n_{\text{H}_2\text{O}} = \frac{\text{mass of H}_2\text{O}}{\text{molar mass of H}_2\text{O}}$$

$$n_{\text{H}_2\text{O}} : \text{Mass of H}_2\text{O} = \text{mass of solution} - \text{mass of RbBr} = 778 \text{ g} - 133.0 \text{ g} = 645 \text{ g H}_2\text{O}$$

$$645 \text{ g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18.01 \text{ g H}_2\text{O}} = 35.813437$$

$$n_{\text{RbBr}} : 133.0 \text{ g RbBr} \times \frac{1 \text{ mol RbBr}}{165.37 \text{ g RbBr}} = 0.8042571$$

$$x_{\text{H}_2\text{O}} = \frac{35.813437}{35.813437 + (0.8042571) \times 2} = 0.9570168$$

$$P_{\text{H}_2\text{O}} = 0.9570168 \times 17.5 \text{ mmHg} = 16.74779 \sim 16.7 \text{ mmHg}$$

Recitation Worksheet 6: Exam 2 Review

31. An aqueous solution of an unknown solute is made by adding 43.8 g of the solute to 325 g of water. This solution lowers the freezing point of the water by 0.935 °C. What is the molecular mass of the unknown solute? $K_f(\text{H}_2\text{O}) = 1.86 \text{ } ^\circ\text{C}/\text{m}$.

268

g/mol

$$T_f(\text{solution}) - T_f(\text{solvent}) = -K_f \times \frac{\text{mol of solute}}{\text{kg of solvent}} \times i$$

$$\text{mol of solute} = \frac{[T_f(\text{solution}) - T_f(\text{solvent})] \times \text{kg of solvent}}{-K_f \times i}$$

$$= \frac{[-0.935^\circ\text{C} - 0^\circ\text{C}] \times 325 \text{ g H}_2\text{O} \times \frac{1 \text{ kg}}{1000 \text{ g}}}{-1.86^\circ\text{C}/\text{m}} = 0.16337366 \text{ mol}$$

$$\text{Molecular mass} = \frac{\text{mass of solute (g)}}{\text{mol of solute}} = \frac{43.8 \text{ g}}{0.16337366 \text{ mol}} = 268.09707 \sim 268 \text{ g/mol}$$

32. A sample of drinking water is found to contain 5.83×10^{-11} moles of mercury in a 75 ml sample. How many parts per billion of mercury is this? (Assume density of the solution is equal to pure water).

0.16

ppb

$$\text{ppb} = \frac{\mu\text{g of solute}}{\text{kg of solution}}$$

$$\frac{5.83 \times 10^{-11} \text{ mol Hg} \times \frac{200.59 \text{ g Hg}}{1 \text{ mol Hg}} \times \frac{10^6 \mu\text{g}}{1 \text{ g}}}{75 \text{ mL solution} \times \frac{1.0 \text{ g solution}}{1 \text{ mL}} \times \frac{1 \text{ kg}}{1000 \text{ g}}} = 0.15592529 \sim 0.16$$

33. A sample of homemade whiskey from a cheap backyard still has a mole fraction of ethanol of 0.35. What would be the mole fraction of the ethanol and water in the vapor of this sample at 40 °C? (At 40 °C the vapor pressure of H₂O is 55 mm Hg and ethanol: 135 mm Hg).

A. X_{EtOH}

0.57

Using Raoult's law to determine the partial pressures of ethanol & H₂O in the vapor

$$P_{\text{EtOH}} = X_{\text{EtOH}} \times P_{\text{EtOH}}^\circ = 0.35 \times 135 = 47.25 \text{ mmHg}$$

$$P_{\text{H}_2\text{O}} = X_{\text{H}_2\text{O}} \times P_{\text{H}_2\text{O}}^\circ = (1 - 0.35) \times 55 = 35.75 \text{ mmHg}$$

Using Dalton's law of partial pressures

$$X_{\text{EtOH}} = \frac{n_{\text{EtOH}}}{n_{\text{EtOH}} + n_{\text{H}_2\text{O}}} = \frac{P_{\text{EtOH}}}{P_{\text{EtOH}} + P_{\text{H}_2\text{O}}}$$

$$= \frac{47.25}{47.25 + 35.75} = 0.569277$$

B. $X_{\text{H}_2\text{O}}$

0.43

$$X_{\text{H}_2\text{O}} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{EtOH}} + n_{\text{H}_2\text{O}}} = \frac{P_{\text{H}_2\text{O}}}{P_{\text{EtOH}} + P_{\text{H}_2\text{O}}}$$

$$= \frac{35.75}{47.25 + 35.75} = 0.430722$$

$$\text{or simply } X_{\text{H}_2\text{O}} = 1 - X_{\text{EtOH}} = 1 - 0.57 = 0.43$$

non-volatile
solute $\therefore i=1$

Recitation Worksheet 6: Exam 2 Review

34. The concentration of ethanol (C_2H_6O) in some wines is as high as 13% by mass. At what temperature will this 3.2 m ethanol solution freeze? $K_f(H_2O) = -1.86^\circ C/m$

-6.0

$^\circ C$

$$\Delta T_f = T_f(\text{solution}) - T_f(\text{solvent}) = K_f \times m \times i$$

$$T_f(\text{solution}) - 0^\circ C = -1.86 \frac{^\circ C}{m} \times 3.2 m \times 1$$

$$T_f(\text{solution}) = -5.952^\circ C$$

$$\sim -6.0^\circ C$$

35. An experiment was performed to determine the molar mass of an unknown solid. A solution of 2.016 g of the unknown solid dissolved in 50.00 g of the nonpolar solvent benzene was prepared, and the freezing point of the resulting solution was determined to be $4.35^\circ C$. What is the molar mass of the unknown solid? The freezing point of pure benzene is $5.50^\circ C$ and $K_f(\text{benzene}) = 5.12^\circ C/m$.

180. or
 1.80×10^2

g/mol

$$T_f = K_f m i$$

$$T_f(\text{solution}) - T_f(\text{solvent}) = -K_f \times \frac{\text{mol of solute}}{\text{kg of solvent}} \times i$$

$$\text{mol of solute} = \frac{[T_f(\text{solution}) - T_f(\text{solvent})] \times \text{kg of solvent}}{-K_f \times i}$$

$$= \frac{[(4.35) - (5.50^\circ C)] \times 50.00 \text{ g benzene} \times \frac{1 \text{ kg}}{1000 \text{ g}}}{-5.12 \frac{^\circ C}{m} \times 1} = 0.0112304 \text{ mol}$$

$$\text{Molar mass} = \frac{\text{mass of solute (g)}}{\text{mol of solute}} = \frac{2.016 \text{ g}}{0.0112304 \text{ mol}} = 179.5116622 = 180. \text{ g/mol}$$

$$\text{or } 1.80 \times 10^2 \text{ g/mol}$$

36. The osmotic pressure of a solution of 20.00 g NaOH dissolved in a total volume of 500.0 mL was compared to the osmotic pressure of a solution of 14.61 g of NaCl dissolved in a total volume of 250.0 mL. Is the osmotic pressure of the NaOH solution higher, lower, or the same as the osmotic pressure of the NaCl solution?

C

- A. Higher
B. Lower
C. The same

Osmotic pressure $\leftarrow \Pi = MRTi$

$\frac{\text{mol}}{L} \times \frac{L \cdot \text{atm}}{\text{mol} \cdot K} \times K = 0.08206 \frac{L \cdot \text{atm}}{\text{mol} \cdot K}$

$$\Pi_{\text{NaOH}} = \frac{20.00 \text{ g NaOH} \times \frac{1 \text{ mol NaOH}}{40.00 \text{ g NaOH}}}{500.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}} \times 0.08206 \frac{L \cdot \text{atm}}{\text{mol} \cdot K} \times (25 + 273) \times 2 = 4.89077$$

$$\Pi_{\text{NaCl}} = \frac{14.61 \text{ g NaCl} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}}}{250.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}} \times 0.08206 \frac{L \cdot \text{atm}}{\text{mol} \cdot K} \times (25 + 273) \times 2 = 4.89077$$

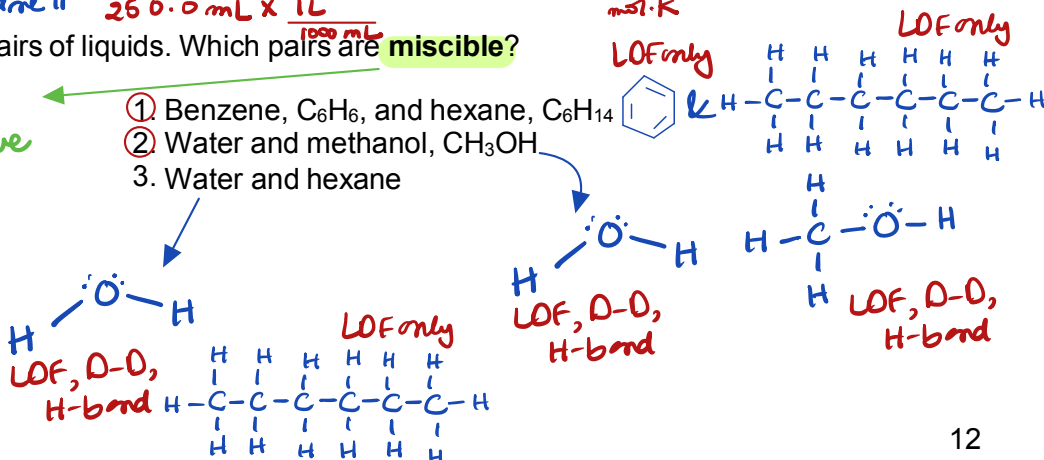
37. Consider the following pairs of liquids. Which pairs are miscible?

Use the concept
of "likes dissolve
likes"

- ① Benzene, C_6H_6 , and hexane, C_6H_{14}
② Water and methanol, CH_3OH
3. Water and hexane

A

- A. 1, 2 only
B. 2 only
C. 1 only
D. 1, 2, 3
E. 2, 3 only



Recitation Worksheet 6: Exam 2 Review

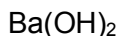
38. The vapor pressure of a solution containing a nonvolatile solute is directly proportional to the

D

- A. Molality of the solvent.
- B. Osmotic pressure of the solute.
- C. Molarity of the solvent.
- ☒ D. Mole fraction of solvent.
- E. Mole fraction of solute.

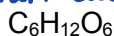
Raoult's Law: $P_{\text{solution}} = \chi_{\text{solvent}} \times P^{\circ}_{\text{solvent}}$
Proportion of χ_{solvent}

39. What are the ideal Van't Hoff factors for these compounds?



3

non-electrolyte



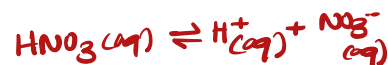
1



4



2



40. Which of the following concentration measures will change in value as the temperature of a solution changes?

D

- A. Mass percent
- B. Mole fraction
- C. Molality
- ☒ D. Molarity
- E. All of these

Molarity = $\frac{\text{mol of solute}}{\text{Liters of solution}}$

↓ volume changes with temperature

41. Rank the following compounds according to increasing solubility in water.

I < II < III

- I. CH₃-CH₂-CH₂-CH₃ *LOF only*
- II. CH₃-CH₂-O-CH₂-CH₃ *LOF & D-O*
- III. CH₃-CH₂-CH₂-CH₂-OH *LOF, D-O, H-bond*

smallest to largest

42. Which of the following favors the solubility of an ionic solid in a liquid solvent?

D

- A. A large magnitude of the solvation energy of the ions
- B. A small magnitude of the lattice energy of the solute
- C. A large polarity of the solvent
- ☒ D. All of the above
- E. None of the above

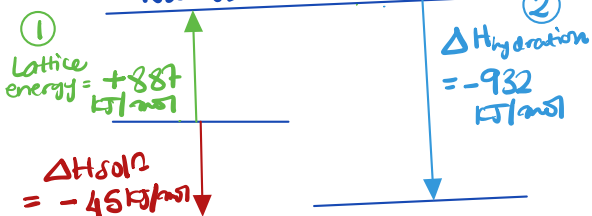
Example: NaOH

more exothermic and larger than $\Delta H_{\text{lattice}}$ step 2

ionic solutes are more soluble in polar solvent
less endothermic in step 1

$\Delta H_{\text{soln}} = \Delta H_{\text{solute}}^{(+)} + \Delta H_{\text{hydration}}^{(-)}$

($\Delta H_{\text{solute}} = -\Delta H_{\text{lattice}}$)



43. What partial pressure of oxygen gas is required in order for 0.00316 g of the gas to dissolve in 16.8 mL of pure water? The Henry's law constant for oxygen gas is $1.3 \times 10^{-3} \text{ M} \cdot \text{atm}^{-1}$.

4.52

density = 1.00g/mL *Henry's Law* *$C_{\text{O}_2} = k_H \times P_{\text{O}_2}$*
 $\frac{\text{mol of O}_2}{\text{L of solution}} = k_H \times P_{\text{O}_2}$

Mass of solution = $0.00316 \text{ g} + (16.8 \text{ mL} \times \frac{1.00 \text{ g}}{\text{mL}}) = 16.80316 \text{ g}$

Volume of solution = $16.80316 \text{ g} \times \frac{1 \text{ mL}}{1.00 \text{ g}} = 16.80316 \text{ mL}$

$\frac{0.00316 \text{ g O}_2 \times \frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2}}{16.80316 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}}} = 1.3 \times 10^{-3} \frac{\text{M}}{\text{atm}} \times P_{\text{O}_2}$
 $\therefore P_{\text{O}_2} = 4.52 \text{ atm}$

Recitation Worksheet 6: Exam 2 Review

44. The molar mass of a solid as determined by freezing point depression is 10% higher than the true molar mass. Which of the following experimental errors could not account for this discrepancy?

C

- A. Not all the solid was dissolved. *if not all solid is dissolved $\therefore \Delta T_f$ is small $\therefore \uparrow$ in molar mass*
 B. More than the recorded amount of solvent was pipetted into the solution. *\downarrow in molality of solute $\therefore \Delta T_f$ is smaller*
 C. The solid dissociated slightly into two particles when it dissolved. *if $i > 1 \therefore \Delta T_f \uparrow \therefore$ molar mass \downarrow*
 D. Some solid was left on the weighing paper *ΔT_f is small $\therefore \uparrow$ in molar mass*
 E. Before the solution was prepared, the container was rinsed with solvent and not dried. *$\downarrow \downarrow$ molality of solute $\downarrow \Delta T_f$*

$$\Delta T_f = K_f \times m \times i = K_f \times \frac{\text{mass of solute (g)}}{\text{molar mass of solute (g/mol)} \times \text{mass of solvent (kg)}} \times i$$

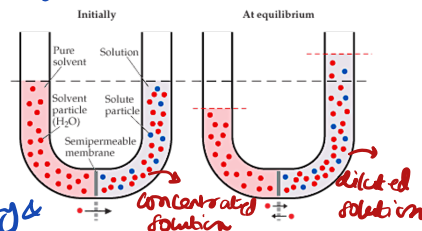
\downarrow
rearranging in terms of molar mass

$$\uparrow \downarrow \text{ molar mass of solute} = \frac{K_f \times \text{mass of solute} \times i}{\uparrow \downarrow \Delta T_f \times \text{mass of solvent}}$$

45. Consider pure water separated from an aqueous sugar solution by a semipermeable membrane, which allows water to pass freely but not sugar. After some time has passed, the concentration of sugar solution:

B

- A. Will have increased
 B. Will have decreased *Osmosis is the flow of solvent from region of higher solvent concentration to a region of lower solvent concentration*
 C. Will not have changed
 D. Might have increased or decreased depending on other factors
 E. Will be the same on both sides of the membrane



46. Which of the following solutions would have the highest osmotic pressure?

B

- A. 0.15 M NaCl, sodium chloride *$0.15 \text{ mol} \times 2 = 0.30 \text{ mol}$*
 B. 0.15 M CaCl_2 , calcium chloride *$0.15 \text{ mol} \times 3 = 0.45 \text{ mol}$*
 C. 0.2 M CH_3OH , methanol *$0.2 \text{ mol} \times 1 = 0.2 \text{ mol}$*
 D. 0.2 M $\text{C}_6\text{H}_{12}\text{O}_6$, glucose *$0.2 \text{ mol} \times 1 = 0.2 \text{ mol}$*
 E. 0.2 M $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, sucrose *$0.2 \text{ mol} \times 1 = 0.2 \text{ mol}$*

$\pi = MRTi$ if temperature is constant \therefore determined by molarity & Van't Hoff factor

47. When 22.5 g of an unknown compound is added to 250.0 g water, the freezing point is -0.930°C . If the empirical formula of this unknown compound is CH_2O , what is the molecular formula? $K_f(\text{H}_2\text{O}) = 1.86^\circ\text{C/m}$.

$\text{C}_6\text{H}_{12}\text{O}_6$

$$T_f = K_f m i$$

$$T_f(\text{solution}) - T_f(\text{solvent}) = -K_f \times \frac{\text{mol of solute}}{\text{kg of solvent}} \times i$$

$$\text{mol of solute} = \frac{[T_f(\text{solution}) - T_f(\text{solvent})] \times \text{kg of solvent}}{-K_f \times i}$$

$$= \frac{(-0.930^\circ\text{C} - 0^\circ\text{C}) \times 250\text{g} \times \frac{1\text{kg}}{1000\text{g}}}{-1.86^\circ\text{C/m} \times 1}$$

$$= 0.125 \text{ mol}$$

$$\text{Molar mass of molecular formula} = \frac{\text{mass of solute (g)}}{\text{mol of solute}} = \frac{22.5 \text{ g}}{0.125 \text{ mol}} = 180. \text{ g/mol}$$

$$\text{Mass of empirical formula} = (1 \times 12.01) + (2 \times 1.01) + 16.00 = 30.03 \text{ g/mol}$$

$$\text{Molecular formula} = \text{empirical formula} \times \frac{\text{molar mass of molecular formula}}{\text{molar mass of empirical formula}}$$

$$= (\text{CH}_2\text{O}) \times \frac{180. \text{ g/mol}}{30.03 \text{ g/mol}} = (\text{CH}_2\text{O}) \times 5.994$$

$$= \text{C}_6 \text{H}_{12} \text{O}_6$$