

CH302 Spring 2009 Answer Key—

10 Questions on Colligative Properties and 10 Questions to Introduce Chemical Equilibria

All of this is intended to be done without the aid of a calculator. All of the calculations are designed such that approximating should be straight-forward and produce a correct result.

1. Based on the physical constants involved, which colligative property has the greatest magnitude for a solution of a given concentration? Which can't be compared in this way? Why?

Osmotic pressure - except at extremely low temperatures - the RT term is going to be much larger than the value of k_b or k_f . It is difficult to compare Raoult's Law in these terms because it uses no physical constants.

2. Which colligative properties have a linear concentration dependence? Write their equations.

All colligative properties have a linear concentration dependence.

Osmotic pressure ($\Pi = i \cdot M \cdot R \cdot T$)

Boiling point elevation ($\Delta T_b = i \cdot m \cdot K_b$)

Freezing point depression ($\Delta T_f = -i \cdot m \cdot K_f$)

Vapor pressure lowering ($P = P^\circ \cdot x$)

3. Rank the following aqueous solutions in terms of increasing boiling point: 3 *m* sugar, 2 *m* NaCl, 0.5 *m* Mg(OH)₂, 5 *m* AlN, 1 *m* urea.

5 *m* AlN < 1 *m* urea < 0.5 *m* Mg(OH)₂ < 3 *m* sugar < 2 *m* NaCl

4. Assuming a cell wall can withstand an osmotic pressure of 1 atmosphere and the concentration of Na⁺ in a cell is 50 mM, approximate the [Na⁺] outside the cell that would cause lysis.

The product of 0.0821 L·atm·mole⁻¹·K⁻¹ and 298 K is roughly 25 L·atm·mol⁻¹ (or atm·M⁻¹).

1 atmosphere of pressure would thus be produced by roughly 40 mM Na⁺.

Therefore an exterior concentration of approximately 10 mM Na⁺ (or less) would be required.

5. If you dissolved 58 grams of NaCl in 90 grams of pure H₂O hot enough to have a vapor pressure of 30 torr, what will the new vapor pressure be?

The molecular weight of NaCl is roughly 58 g·mol⁻¹, so we have about 1 mol of NaCl.

The molecular weight of H₂O is roughly 18 g·mol⁻¹, so we have about 5 mol of water.

The mol fraction of water is therefore 5/6, times a vapor pressure 30 torr for pure water, is roughly 25 torr for the new solution.

6. Assuming standard conditions and a $K_f = 0.2 \text{ K} \cdot m^{-1}$ and a $K_b = 0.5 \text{ K} \cdot m^{-1}$ for water, what would be the freezing point of a solution that boiled at 375.5 K? Express your answer in both K and °C.

The normal boiling point of water is 373 K, so we have a $\Delta T_b = 2.5 \text{ K}$, which equates to an effective molality of $m = 5$, resulting in a $\Delta T_f = -1 \text{ K}$, so our solution will freeze at 272 K, or -1 °C.

7. Based on the question above and assuming 1 kg of water, how many moles of NaCl would be needed to produce this effect? What about sugar?

Accounting for the van't Hoff coefficient, 2.5 moles of NaCl would produce a 5 *m* solution.

It would take 5 moles of sugar to produce the same effect.

8. Based on your understanding of boiling point elevation, why **doesn't** salting water help food to cook faster?

The effects involved are very small. Given the magnitude of the boiling point elevation constant as well as the amount of salt required to achieve even a 1 *m* solution, the change in boiling point resulting from salting food is too small to substantially effect cooking times.

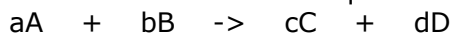
9. Vapor pressure is often described as a "surface phenomenon." Define this term in your own words to the best of your ability.

A surface phenomenon is simply a process (such as evaporation/condensation) that takes place at a surface where two phases meet. This makes sense, as the only place a water molecule could switch between two phases is the place where they meet, just as the only place a person can go from inside to outside is at a doorway that connects the two.

10. Raoult's can be used to calculate the decrease in vapor pressure when a non-volatile substance (like salt) is dissolved in a volatile substance (like water). Explain this phenomenon.

Since evaporation is a surface phenomenon, by adding something like salt to water, part of the surface area is now occupied by salt ions instead of water molecule, diminishing the probability that a water molecule will escape the surface.

11. Write a mass action quotient (aka mass action expression) for the general equation below:



$$Q = [C]^c \cdot [D]^d / [A]^a \cdot [B]^b$$

12. What sort of mathematical relationship exists between ΔG and K ? Which of these terms should have a wider range of possible values?

There is a log-linear (aka exponential) relationship between ΔG and K - when ΔG increases, K increases exponentially. K should have a wider range of values, since it is proportional to the base e exponent of ΔG , i.e. if ΔG is doubled, K will increase by a factor equal to e^2 .

13. What is the difference between Q and K ?

Q can have any value depending on the concentrations of reactants and products, and it can describe any and all non-equilibrium states for a system. K , on the other hand, can have only one value at a given temperature and pressure and that value is always equal to the mass action quotient when the system is at equilibrium.

14. What can you for certain about ΔG when K is less than 1, equal to 1 or greater than 1?

You know that ΔG is positive, zero or negative, respectively.

15. Based on your answer to question 14, what does the value of K tell you about the spontaneity of a reaction?

The value of K tells you whether a given reaction is spontaneous ($K > 1$), non-spontaneous ($K < 1$) or at equilibrium ($K = 1$)

16. If a given reaction has $K = 10$, and presently has a $Q = 5$, what must happen in order for the reaction to reach equilibrium?

The reaction must proceed in the forward direction, producing more products (the numerator in our mass action quotient) until the value of Q is also 10.

17. Based on your understanding of reaction stoichiometry, complete the RICE diagram below by filling in the blank regions.

| | | | | |
|--------------------|---------------------------|--------------------------------------|---------------------------|----------------------------------|
| Reaction | $\text{CH}_4(\text{g}) +$ | $2 \text{O}_2(\text{g}) \rightarrow$ | $\text{CO}_2(\text{g}) +$ | $2 \text{H}_2\text{O}(\text{g})$ |
| Initial | 10 moles | 19 moles | 1 moles | 7 moles |
| Change | -9 moles | -18 moles | + 9 moles | +18 moles |
| Equilibrium | 1 mol | 1 mol | 10 moles | 25 moles |

18. Write a mass action quotient and determine K for the reaction in question 17.

$$K = [\text{CO}_2] \cdot [\text{H}_2\text{O}]^2 / [\text{CH}_4] \cdot [\text{O}_2]^2 = 10 \cdot 25^2 / 1 \cdot 1^2 = 6,250$$

19. If the equilibrium established in question 17 were disturbed by the addition of 90 moles of CO_2 , what would the value of Q then be? Fill in a new RICE diagram, using X for unknown values.

| | | | | |
|-----------------|---------------------------|--------------------------------------|---------------------------|----------------------------------|
| Reaction | $\text{CH}_4(\text{g}) +$ | $2 \text{O}_2(\text{g}) \rightarrow$ | $\text{CO}_2(\text{g}) +$ | $2 \text{H}_2\text{O}(\text{g})$ |
| Initial | 1 mol | 1 mol | 100 moles | 25moles |

| | | | | |
|-------------|--------------------|---------------------|----------------------|----------------------|
| Change | +X moles | +2X moles | -X moles | -2X moles |
| Equilibrium | 1 + X moles | 1 + 2X moles | 100 - X moles | 25 - 2X moles |

$$Q = [\text{CO}_2] \cdot [\text{H}_2\text{O}]^2 / [\text{CH}_4] \cdot [\text{O}_2]^2 = 100 \cdot 25^2 / 1 \cdot 1^2 = 62,500$$

20. How will the system respond to the stress in question 19 in order to re-establish equilibrium?

The reaction will have to shift back toward the product side in order to increase the denominator in the mass action expression and make Q once again equal to K.