

Guide to Chapter 4. Reactions in Aqueous Solutions

We will spend three lecture days on this chapter and one review day. In this chapter we will learn to predict several fundamental chemical reactions. This chapter is so important that Exam 3 will cover only this chapter!

This is a chapter study guide, given section-by-section. Work problems on separate sheets of paper and keep them with this guide. *When working problems, use plenty of space and when appropriate, show all work.*

You will need to memorize the solubility rules. You will be given flashcards to cut out and start learning. Do this as soon as possible.

□ Read the introductory paragraph to Chapter 4. Reactions in Aqueous Solution

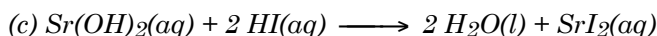
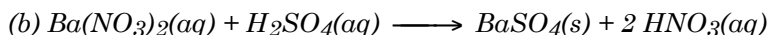
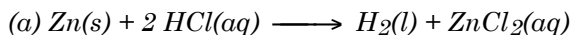
□ Read Section 4.1 Some Ways that Chemical Reactions Occur.

□ □ Learning Objective 1: In this section we will learn three important reasons why reactions occur. You must be able to identify these possible “driving forces” in aqueous solutions.

□ Do Problem 1 at the end of the section.

□ Do the following end-of-chapter problem: 30

□ *Problem Club Question A. Classify each of the following reactions according to type (acid base, precipitation, oxidation-reduction or “none of the above”)*



Answer: (a) oxidation-reduction; (b) precipitation; (c) acid-base

□ Read Section 4.2 Electrolytes in Aqueous Solution

□ □ Learning Objective 2: In this section, we will draw beakers and fill them with reactants and products, separated into ions, if appropriate. Your beakers do not need to be as fancy as the one at right, but do use drawings! This will start you thinking along the lines of always asking yourself, **“What’s in the beaker?”**

□ □ Learning Objective 3: Classify solutes dissolved in water as strong electrolyte (soluble salts, strong acids, or strong bases), weak electrolyte (weak acids or ammonia) or non-electrolyte (a covalent molecular compound).

□ □ Learning Objective 4: Know how to write chemical equilibria for strong and weak electrolytes. Know how strong and weak electrolytes break apart in aqueous solutions.



□ □ Learning Objective 5: Know how strong-electrolytes behave in water and write simple chemical equations using an arrow (\longrightarrow).

□ □ Learning Objective 6: Know how weak-electrolytes behave in water and write simple chemical equations using an “arrow to the left” (\longleftarrow).

□ □ Learning Objective 7: Know how non-electrolytes behave in water.

□ □ Learning Objective 8: Concentration. Given the molar concentration of a strong electrolyte solution (or the information necessary to determine this), calculate the molar concentration (mol/L) of each ion in the solution.

□ Do Problems 2 and 3 at the end of the section.

□ Do the following end-of-chapter problems: 36, 38

□ *Problem Club Question B. Write the equation to show how each of these strong electrolytes dissolves in water. Sketch four beakers and then sketch exactly what ions or molecules are present in each beaker. Create your own key such as a solid sphere means Na^+ , etc.*

a. HCl

b. CaBr_2

c. Na_2SO_4

d. NH_4Cl

Answer: (a) your beaker should show one H^+ (or H_3O^+) cation for every Cl^- anion;

(b) (a) your beaker should show one Ca^{+2} cation for every two Br^- anions;

(c) (a) your beaker should show two Na^+ cations for every SO_4^{-2} anion;

(d) (a) your beaker should show one NH_4^+ cation for every Cl^- anion

□ *Problem Club Question C. If 1.0 mmol of each of the following solutes is dissolved in the same amount of water, which solute would produce the largest number of ions? (a) NaCl; (b) $\text{Al}_2(\text{SO}_4)_3$; (c) CaCl_2 ; (d) AlCl_3*

Answer: (a) 2 mmol ions; (b) 5 mmol ions; (c) 3 mmol ions; (d) 4 mmol ions

□ *Problem Club Question D. Corn syrup is a mixture of sugar and water. Which is the solute and which is the solvent?*

Answer: water is the solvent and corn syrup is the solute

□ *Problem Club Question E. Identify each of the following solutes as being a strong, weak or non electrolyte. If you didn't know, how might you test this? (a) NaCl; (b) H_2S ; (c) HBr; (d) NaOH; (e) NiS; (f) $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ (sugar); (g) NaNO_3 ; (h) HNO_3 ; (i) NH_4Cl*

Answer: (a) strong; (b) weak; (c) strong; (d) strong; (e) non; (f) non; (g) strong; (h) strong; (i) strong

□ *Problem Club Question F. How many grams of MgCl_2 are contained in 350 mL of a 0.250 M solution? What is the concentration of each ion?*

Answer: (a) 0.0875 mol $\text{MgCl}_2 = 8.3$ g MgCl_2 ; (b) $[\text{Mg}^{+2}] = 0.25$ M and $[\text{Cl}^-] = 0.50$ M

□ *Problem Club Question G. In order to prepare a 500.0 mL of a 0.24 M sodium sulfate solution: (a) What mass of sodium sulfate is needed? (b) How much water? (c) What glassware is a must for this job?*

Answer: (a) 17 g; (b) enough water to make 500 mL; (c) volumetric flask

□ *Problem Club Question H. A 9.36 g sample of ferric nitrite hexahydrate is dissolved in enough water to make a total volume of 1.000-L. What is the concentration of the resulting solution and of each ion?*

Answer: Note: MM of $\text{Fe}(\text{NO}_3)_3 \cdot 6 \text{H}_2\text{O} = 350 \text{ g/mol}$; (a) 0.027 M $\text{Fe}(\text{NO}_3)_3 \cdot 6 \text{H}_2\text{O}$; (b) 0.027 M Fe^{+3} and 0.080 M NO_3^-

□ Read Sections 4.3. Aqueous Reactions and Net Ionic Equations

□ □ Learning Objective 9: Write a balanced molecular equation, ionic equation, and net ionic equation for a reaction involving ionic reagents.

□ Do Problem 4 at the end of the section.

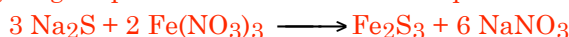
□ Do the following end-of-chapter problem: 32

□ *Problem Club Question I. Sketch a beaker. Suppose 75 mL 0.50 M $\text{Ca}(\text{NO}_3)_2$ and 125 mL 0.47 M NaNO_3 are mixed. What is the concentration of each ion in the resulting solution? Hint: Do these compounds react? Or is it a simple dilution? Sketch the resulting ions in beaker.*

Answer: Note: MM of $\text{Ca}(\text{NO}_3)_2 = 164 \text{ g/mol}$; MM of $\text{NaNO}_3 = 85 \text{ g/mol}$; Note #2: The new total volume is 200 mL; (a) $[\text{Ca}^{+2}] = 0.1875 \text{ M}$ Ca^{+2} ; $[\text{Na}^+] = 0.2938 \text{ M}$ Na^+ and $[\text{NO}_3^-] = 0.6688 \text{ M}$

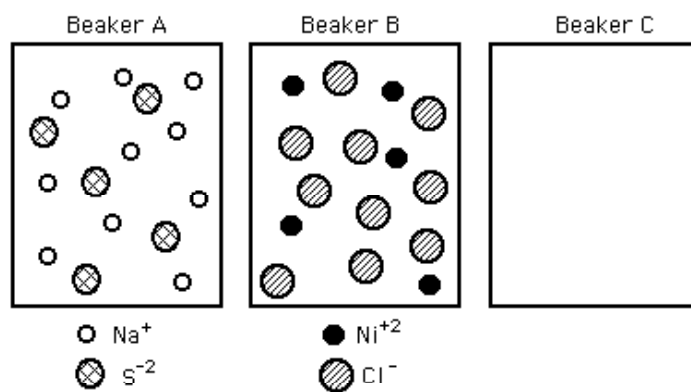
□ *Problem Club Question J. Sketch a beaker. Suppose 85 mL 0.92 M Na_2S and 65 mL 0.48 M $\text{Fe}(\text{NO}_3)_3$ are mixed. What is the concentration of each ion in the resulting solution? Hint: Do these compounds react? If so, is there a limiting reagent? Start with a balanced chemical equation. Sketch the resulting ions in beaker.*

Answer: This is a limiting reagent problem and the balanced equation is:

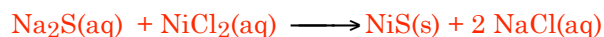


The moles of each reagent: 0.0782 mol Na_2S and 0.0312 mol $\text{Fe}(\text{NO}_3)_3$; Theoretical yield of Fe_2S_3 is 0.0156 mol Fe_2S_3 . After the reaction is over, the solution contains $2 \times 0.0782 = 0.1564 \text{ mol Na}^+$; $0.0782 - (3/2) \times 0.0312 = 0.0314 \text{ mol S}^{-2}$; 0 mol Fe^{+3} ; and $3 \times 0.0312 = 0.0936 \text{ mol NO}_3^-$; the new volume of the solution is 0.150 L so the concentrations of ions in solution are: $[\text{Na}^+] = 1.04 \text{ M}$; $[\text{S}^{-2}] = 0.209 \text{ M}$; $[\text{Fe}^{+3}] = 0 \text{ M}$; and $[\text{NO}_3^-] = 0.624 \text{ M}$

□ *Problem Club Question K. Sketch a beaker. Suppose the contents of Beakers A and B are combined into Beaker C. The number of circles represent the relative number of moles of each ion. The volumes are not to scale (making it possible for all of Beaker A + Beaker B to mysteriously fit into Beaker C!) Sketch the contents of Beaker C using circles. Write a balanced chemical reaction for what happens.*



Answer: The balanced reaction is:



There was no single limiting reagent the number of Ni^{+2} and S^{-2} ions were equal (5) and formed a precipitate that you may have shown on the bottom of Beaker C. Beaker C should show ten Na^+ and ten Cl^-

□ Problem Club Question L. Sketch a beaker. The solution used to treat burns is made by dissolving 8.6 g sodium chloride, 0.30 g potassium chloride and 0.33 g calcium chloride per 1.0 L of solution. What is the molarity of each ion?

Answer: First, determine moles of each: 0.147 mol NaCl (0.147 mol Na^+ + 0.147 mol Cl^-); 0.004 mol KCl (0.004 mol K^+ + 0.004 mol Cl^-); and 0.1003 mol CaCl_2 (0.003 mol Ca^{+2} + 0.006 mol Cl^-); Volume = 1.00 L; $[\text{Na}^+] = 0.147 \text{ M}$; $[\text{K}^+] = 0.004 \text{ M}$, $[\text{Ca}^{+2}] = 0.003 \text{ M}$; and $[\text{Cl}^-] = (0.147 + 0.004 + 0.006)\text{mol}/1 \text{ L} = 0.157 \text{ M Cl}^-$

□ Problem Club Question M. Sketch a beaker. What is the concentration of K^+ in the solution that results when 25 mL of 0.20 M potassium sulfate and 50 mL of 0.40 M potassium hydroxide are mixed?

Answer: 0.40 M K^+

□ Problem Club Question N. What is the molarity of chloride ion in 120 mL of 5.7 M calcium chloride solution? Is molarity an intensive or extensive property?

Answer: (a) 11.4 M; (b) intensive

□ Read Section 4.4 Precipitation Reactions and the Solubility Rules

□ □ Learning Objective 10: Memorize the solubility rules given on the flash cards. You will use these rules several times throughout the rest of the year.

□ □ Learning Objective 11: Given the formula of a salt, predict if it is "soluble" or "insoluble" in water.

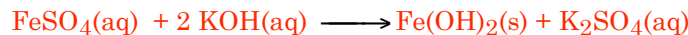
□ Do Problems 5 — 8 at the end of the section

□ Do the following end-of-chapter problems: 40, 42, 44, 48

□ Problem Club Question O. Sketch a beaker. Aqueous ferrous sulfate reacts with aqueous potassium hydroxide to form a precipitate. Write the overall equation and the net ionic

equation for the reaction. Sketch the resulting solution in the beaker. Indicate ions with labeled circles.

Answer: The overall reaction is:



and the net ionic equation is:



The beaker should show sulfate ions and potassium ions in solution and iron(II) hydroxide on the bottom as a precipitate. We were not given quantities, so we cannot predict if either reagent were in excess, so we will assume the reaction was done stoichiometrically.

□ Problem Club Question P. Sketch a beaker. Aqueous solutions of sodium sulfide and copper(II) chloride are mixed. Does a precipitate form? If so, what is it? Sketch the resulting solution in the beaker.

Answer: (a) Yes, CuS. (b) The beaker should show sodium ions and chloride ions in solution and copper(II) sulfide on the bottom as a precipitate. We were not given quantities, so we cannot predict if either reagent were in excess, so we will assume the reaction was done stoichiometrically.

□ Problem Club Question Q. Sketch a beaker. Aqueous solutions of potassium nitrate and ammonium chloride are mixed. Does a precipitate form? If so, what is it? Sketch the resulting solution in the beaker.

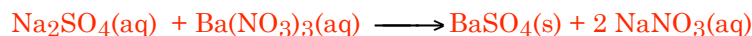
Answer: no precipitate, they just mix, show all ions in solution

□ Problem Club Question R. Which of the following salts is/are insoluble in water? (a) Na_2S ; (b) PbCl_2 ; (c) CaCl_2 ; (d) $\text{Pb}(\text{NO}_3)_2$; (e) K_3PO_4

Answer: (a) sol; (b) insol; (c) sol; (d) sol; (e) sol

□ Problem Club Question S. When 0.1 M sodium sulfate and 0.1 M barium nitrate are mixed, a white precipitate is formed. What is the overall equation and the net ionic equation?

Answer: The overall reaction is:



and the net ionic equation is:

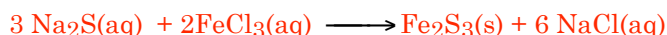


□ Problem Club Question T. A chemist wishes to prepare 25 g BaSO_4 from a solution of sodium sulfate and solid barium nitrate. What volume of 1.2 M sodium sulfate and what mass of barium nitrate should he/she use? Write the reaction and the net ionic reaction.

Answer: 25 g BaSO_4 is 0.107 mol BaSO_4 ; this corresponds to 0.107 mol Ba^{2+} and 0.107 mol SO_4^{2-} . Use 89 mL sodium sulfate solution and 28.0 g barium nitrate.

□ *Problem Club Question U. What volume of 0.500 M sodium sulfide solution is needed to react completely with 300 mL of 0.400 M ferric chloride(aq)?*

Answer: first the balanced equation:



One would need 360 mL $\text{Na}_2\text{S}(\text{aq})$

□ *Problem Club Question V. An unknown material, thought to be a metal chloride is tested as follows: A sample of the unknown with mass of 5.000-g is dissolved in water. The solution is reacted with 0.2010 M $\text{AgNO}_3(\text{aq})$ which reacts with the chloride to form AgCl precipitate. If it takes 70.90 mL of this silver nitrate solution to precipitate all of the chloride in the unknown, what is the percent chloride in the unknown?*

Answer: 10.1%

□ *Problem Club Question W. When 50.0 mL of 0.10 M silver nitrate is added to 50.0 mL of 0.20 M calcium chloride, a white precipitate forms. After the reaction is complete, calculate the amount of precipitate that formed.*

Answer: limiting reagent problem; 0.72 g $\text{AgCl}(\text{s})$

Advice from a former student:

I was definitely not one of the lucky students who came to college with a good chemistry background. The things that have helped me the most have been: (1) paying close attention in class and taking good notes, (2) doing all of the problem clubs and paying especially close attention to the things I had trouble with, (3) using all of your little word hints and such(LEO says GER, the "daycare"), and (4) doing problem clubs, reviews, etc. with other people to bounce questions off each other (most of the time if one person doesn't know the answer, someone else does)

□ **Read Section 4.5 Acids, Bases and Neutralization Reactions**

□ □ Learning Objective 12: Be able to identify an acid.

□ □ Learning Objective 13: Know the list of six strong acids and what the word "strong" means.

□ □ Learning Objective 14: Know how strong acids (strong-electrolytes) behave in water and write simple chemical equations using an arrow (\longrightarrow).

□ □ Learning Objective 15: Know how weak-acids (weak-electrolytes) behave in water and write simple chemical equations using an "arrow to the left" (\longleftarrow).

□ □ Learning Objective 16: Be able to identify a base.

□ □ Learning Objective 17: Know which bases are strong bases.

□ □ Learning Objective 18: Know that ammonia is a weak base.

- □ Learning Objective 19: Identify acid-base neutralization reactions.
- □ Learning Objective 20: Know what the word “neutralization” means.
- □ Learning Objective 21: Know what the word “hydronium ion” means..
- □ Learning Objective 22: Given a balanced chemical equation for an acid-base neutralization reaction, calculate the number of moles or the mass of either reactant (acid or base) required to neutralize a specific amount of the other reactant.
- Do Problems 9 and 10 at the end of the section
- Do the following end-of-chapter problems: 50, 52, 54

□ *Problem Club Question X. This question explores the difference between a strong and a weak acid. (a) Sketch a beaker! A 22.0 g sample of HCl is dissolved in water to give a 200 mL solution. What is the molar concentration of the solution? (b) What happens to the HCl molecules in solution? Do they dissociate into $H^+(aq)$ and $Cl^-(aq)$ or do they remain associated as $HCl(aq)$? (c) Use arrows (either \longrightarrow or \longleftarrow) to describe the relationship between $HCl(aq)$ and $H^+(aq)$ and $Cl^-(aq)$. Sketch the species present in the beaker.*

Answer: (a) $[HCl] = 3.0\text{ M}$; (b) HCl dissociates 100% to give H_3O^+ and Cl^- ; (c) \longrightarrow . Your drawing should show an equal number of H_3O^+ and Cl^- ions and no HCl molecules.

□ *Problem Club Question Y. This problem continues along the same lines as the previous problem. (a) Sketch a beaker! A 22.0 g sample of HF is dissolved in water to give a 200 mL solution. What is the molar concentration of the solution? (b) What happens to the HF molecules in solution? Do they dissociate into $H^+(aq)$ and $F^-(aq)$ or do they remain associated as $HF(aq)$? (c) Use arrows (either \longrightarrow or \longleftarrow) to describe the relationship between $HF(aq)$ and $H^+(aq)$ and $F^-(aq)$. Sketch the species present in the beaker.*

Answer: (a) $[HF] = 5.5\text{ M}$; (b) HF does not dissociates very much — a few percent to give H_3O^+ and F^- ; (c) \longleftarrow . Your drawing should show a few, but an equal number of H_3O^+ and F^- ions but mostly HF molecules.

□ *Problem Club Question Z. What volume of 0.2267 M NaOH(aq) is necessary to neutralize a solution made by dissolving 5.0 g HCl in water?*

Answer: 605 mL

□ *Problem Club Question AA. Sketch three beakers. In the left beaker, sketch a pictorial representation of NaOH(aq). In the middle beaker sketch HCl(aq). React the two and draw the results in the righthand beaker.*

Answer: left beaker should show Na^+ and OH^- ; middle beaker should show H_3O^+ and Cl^- ; right beaker should show Na^+ and Cl^-

□ *Problem Club Question BB. What volume of 0.25 M nitric acid is necessary to react completely with 7.4 g of calcium hydroxide?*

Answer: 800 mL

□ Problem Club Question CC. A 6.50 g sample of an acid, HX, requires 137.5 mL of a 0.750 M NaOH solution for complete reaction. Calculate the molar mass of the acid.

Answer: 63 g/mol

□ Problem Club Question DD. (ACS-style) Answer: I like both A and C. Hmmm?

□ Problem Club Question EE. (ACS-style) Answer: B

□ Problem Club Question FF. (ACS-style) Answer: D

□ Read Section 4.6 Oxidation-Reduction (Redox) Reactions

□ □ Learning Objective 23: Given the formula of a compound, assign oxidation numbers to each element.

□ □ Learning Objective 24: Be able to assign oxidation numbers to each element in a polyatomic ion.

□ Do Problem 11 at the end of the section.

□ Do the following end-of-chapter problem: 56, 60, 62,

□ Problem Club Question GG. What is the oxidation state of nitrogen in each of the following compounds? (a) HNO_3 ; (b) NO_2 ; (c) N_2O ; (d) NH_4Cl ; (e) NaNO_2

Answer: (a) +5; (b) +4; (c) +1; (d) -3; (e) +3

□ Problem Club Question HH. What is the oxidation state of chromium in each of the following compounds? (a) Cr_2O_3 ; (b) $\text{K}_2\text{Cr}_2\text{O}_7$; (c) K_2CrO_4

Answer: (a) +3; (b) +6; (c) +6

□ Problem Club Question II. What is the oxidation state of chlorine in each of the following compounds? (a) HCl ; (b) HClO ; (c) HClO_2 ; (d) HClO_3 ; (e) HClO_4

Answer: (a) -1; (b) +1; (c) +3; (d) +5; (e) +7

□ Problem Club Question JJ. (ACS-style) Answer: A

Advice from a former student:

In terms of advice for next year's class, the best advice that I can give is really very simple. I think that what has helped me the most is to go to class every day and to do as many problems as possible. While attendance is not required, I do feel that the actual lectures are what help me the most to understand the concepts. I also feel that by completing all of the problem clubs and the practice tests also help. I have found that working with other people can also help even if you are just attempting to explain the concepts to them. In doing so, the concepts are reinforced for me so I also benefit. For the tests, I try and start studying at least two days in advance and go over all of the problem clubs. On the night before the test, I usually review the practice tests. This is what has helped me, but I am afraid it is nothing very original. I hope that this helps.

□ Problem Club Question KK. (ACS-style) Answer: D

□ **Read Section 4.7 Identifying Redox Reactions**

□ □ Learning Objective 25: Given a redox reaction, be able to determine (a) the reducing agent (the reactant that is oxidized); (b) the oxidizing agent (the reactant that is reduced)

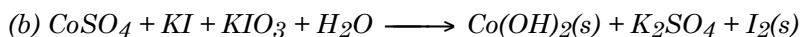
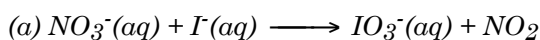
□ □ Learning Objective 26: Know that the reactant that is being reduced gains electrons and the the reactant that loses electrons is being oxidized.

□ □ Learning Objective 27: Remember that chemical reactions that we have studied so far all proceed from left (reactants) to right (products). We called the left side “before” and the right side “after”. Given that, when asked for the oxidizing agent, reducing agent, what is being oxidized, or what is being reduced, your choices are only on the LEFT side (the reactants).

□ Do Problems 12 and 13 at the end of this section.

□ Do the following end-of-chapter problems: 58, 64,

□ *Problem Club Question LL. What is being oxidized and reduced in the following reaction? What is the oxidizing agent? The reducing agent?*



Answer: (a) NO_3^- is being reduced + I^- is being oxidized; (b) KI is being oxidized and KIO_3 is being reduced

□ *Problem Club Question MM. (ACS-style) Answer: C?*

□ *Problem Club Question NN. (ACS-style) Answer: A*

□ □ **Read Section 4.8 The Activity Series of the Elements**

□ □ Learning Objective 28: Use the activity series to predict if a redox reaction will occur or not occur. If the redox reaction is predicted to occur, write the balanced net ionic equation for the reaction.

□ Do Problems 14 and 15 at the end of the section

□ Do the following end-of-chapter problems: 66,

□ **Skip Sections 4.9 and 4.10 on balancing redox equations (we will do this next semester in Chapter 18)**

□ □ **Read Section 4.11 Redox Titrations**

□ □ Learning Objective 29: Be able to work problems involving redox titrations using the skills learned in Chapter 3.

□ Do Problem 21 at the end of this section

□ Do the following end-of-chapter problems: 82, 84, 86, 88

□ *Problem Club Question OO. With what volume of 5.0 M hydrofluoric acid will 4.0 g of calcium react completely to yield calcium fluoride (a precipitate) and hydrogen gas? Hint: Balance the equation first!*

Answer: $2 \text{HF(aq)} + \text{Ca(s)} \longrightarrow \text{CaF}_2\text{(s)} + \text{H}_2\text{(g)}$; 0.10 mol Ca requires 0.20 mol HF; use 40.0 mL HF(aq) solution

□ *Problem Club Question PP. Zinc reacts with hydrochloric acid to produce zinc(II) chloride and hydrogen gas. What volume of 0.470 M the acid is required to produce 1.50 g zinc(II) chloride?*

Answer: $2 \text{HCl(aq)} + \text{Zn(s)} \longrightarrow \text{ZnCl}_2\text{(s)} + \text{H}_2\text{(g)}$; 0.011 mol ZnCl_2 requires 0.22 mol HCl; use 46.8 mL HCl(aq) solution

□ *Problem Club Question QQ. (ACS-style) Answer: B*

□ □ **Read Section 4.12 Some Applications of Redox Reactions**