Chapter 8.2
Strong and Weak Acids and Bases

Learning Goals: I will be able to …

1. **compare** the properties of strong and weak acids, and strong and weak bases, using the concept of dynamic equilibrium
2. **identify** common equilibrium constants, including K_b, and K_w, and write the expressions for each
3. **solve** problems related to equilibrium by **performing** calculations involving concentrations of reactants and products (K_a, pH, pOH, K_w, K_b)

Recall… Grade 11

- A **strong acid** is an acid that *ionizes* almost 100% in water, producing hydrogen ions

- A **weak acid** is an acid that only partly *ionizes* in water, producing hydrogen ions

Now…

- A **strong acid** is an acid for which the equilibrium position in an aqueous solution lies *far to the right*.
  - At equilibrium, almost all the HA molecules have broken apart to produce ions.
- A **weak acid** is one for which the equilibrium position is *far to the left*.
  - Most of the acid originally placed in the solution is HA molecules at equilibrium.

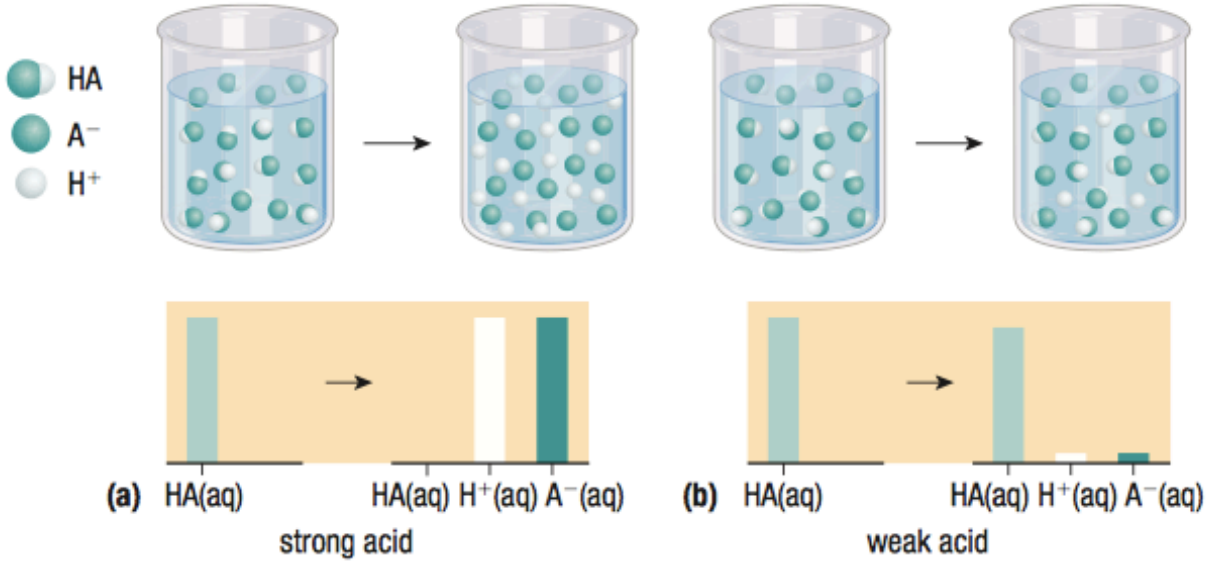
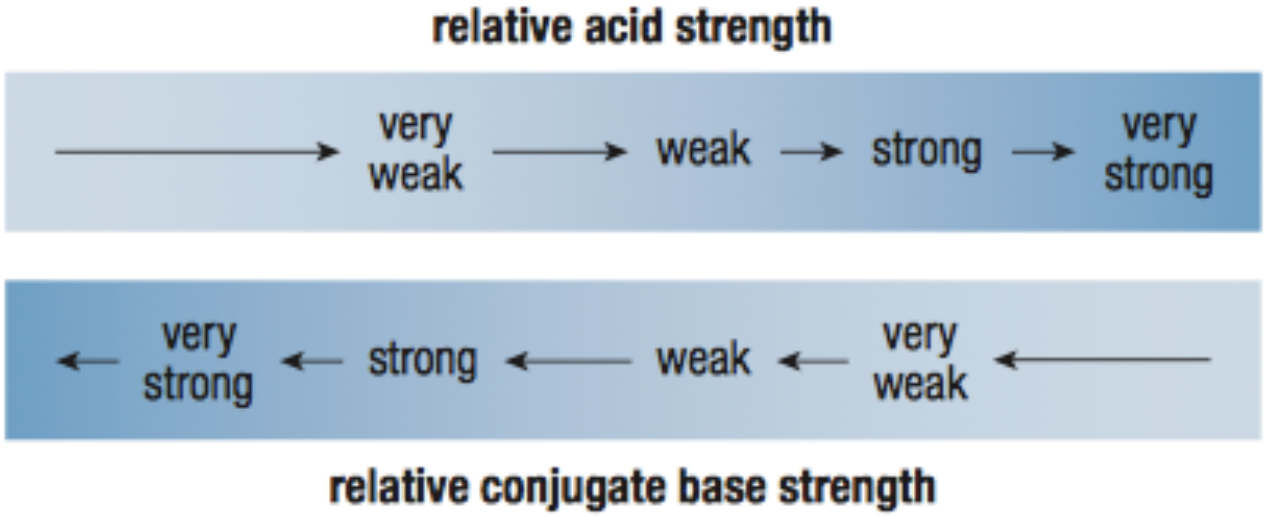


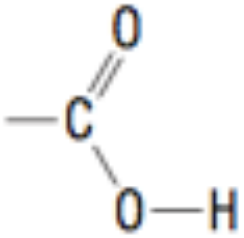
Table 1 Various Ways to Describe Acid Strength

Property	Strong acid	Weak acid
Value of acid ionization constant, K_a	K_a is large	K_a is small
Position of the ionization equilibrium	far to the right	far to the left
Equilibrium concentration of $H^+(aq)$ compared with original concentration of HA	$[H^+(aq)]_{equilibrium} \approx [HA(aq)]_{initial}$	$[H^+(aq)]_{equilibrium} << [HA(aq)]_{initial}$

The stronger an acid, the weaker its conjugate base, and conversely, the weaker an acid, the stronger its conjugate base.



Oxyacids and Organic Acids



- An **oxyacid** is an acid in which the acidic hydrogen atom is attached to an oxygen atom.
  - Example:
    - Strong oxyacid: sulfuric acid, H_2SO_4
    - Weak oxyacid: phosphoric acid, H_3PO_4; nitrous acid, HNO_2; and hypochlorous acid, HClO
- An **organic acid** is an acid containing carbon, oxygen, and hydrogen carbons (except carbonic acid, H_2CO_3); also called carboxylic acid
  - Most are weak acids
  - Examples: ethanoic acid, $HC_2H_3O_2$; benzoic acid, $HC_7H_5O_2$

Recall… Grade 11

- A **strong base** is a base that *dissociates* completely in water, producing hydroxide ions

- A **weak base** is a base that only partially reacts with water to produce hydroxide ions

Now…

- A **strong base** forms an equilibrium that lies farther to the *right* (toward products) when it reacts with water.

- A **weak base** forms an equilibrium that lies farther to the *left* (toward reactants) when it reacts with water.

Base Ionization Constant (K_b)

- **Base ionization constant (K_b)** is the equilibrium constant for the ionization of a base; also called the base dissociation constant
- General equation for the reaction of a base, B, with water:

$$\underset{\text{base}}{B(aq)} + \underset{\text{acid}}{H_2O(l)} \rightleftharpoons \underset{\text{conjugate acid}}{BH^+(aq)} + \underset{\text{conjugate base}}{OH^-(aq)}$$

$$K = \frac{[OH^-(aq)][BH^+(aq)]}{[B(aq)][H_2O(l)]} \qquad K_b = \frac{[BH^+(aq)][OH^-(aq)]}{[B(aq)]}$$

$$NH_3(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + NH_4^+(aq)$$

Water as an Acid and a Base

- Recall, water is the most common amphiprotic substance (behave as either an acid or a base).
- Water can behave as both a acid and a base in the same reaction called the **autoionization of water**.
  - Involves the transfer of a hydrogen ion from one water molecule to another water molecule.

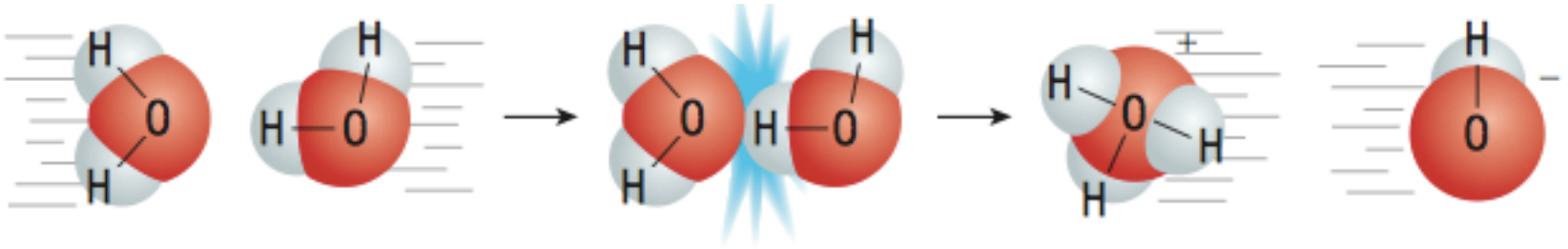


Figure 7 Two water molecules must collide in exactly the right orientation to form a hydronium ion and a hydroxide ion.

Ion-product Constant for Water (K_w)

- **Ion-product constant for water (K_w)** is the equilibrium constant for the autoionization of water

$$2\,H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

$$K = \frac{[H_3O^+(aq)][OH^-(aq)]}{[H_2O(l)]^2} \qquad K = [H_3O^+(aq)][OH^-(aq)]$$

$$K_w = [H^+(aq)][OH^-(aq)]$$

Ion-product Constant for Water (K_w)

- The value of K_w at 25°C is 1.0×10^{-14}
- This means in any aqueous solution at 25°C, no matter what the solution contains, the product of $[H^+_{(aq)}]$ and $[OH^-_{(aq)}]$ must always equal 1.0×10^{-14}
- There are 3 possible situations:
  - A neutral solution, $[H^+_{(aq)}] = [OH^-_{(aq)}]$
  - An acidic solution, $[H^+_{(aq)}] > [OH^-_{(aq)}]$
  - A basic solution, $[H^+_{(aq)}] < [OH^-_{(aq)}]$

The Relationship between K_w, K_a, and K_b

$$HA(aq) + H_2O(l) \rightleftharpoons A^-(aq) + H_3O^+(aq) \qquad K_a = \frac{[H_3O^+(aq)][A^-(aq)]}{[HA(aq)]}$$

A^-, the conjugate base of HA

$$A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq) \qquad K_b = \frac{[HA][OH^-]}{[A^-]}$$

Hess's law

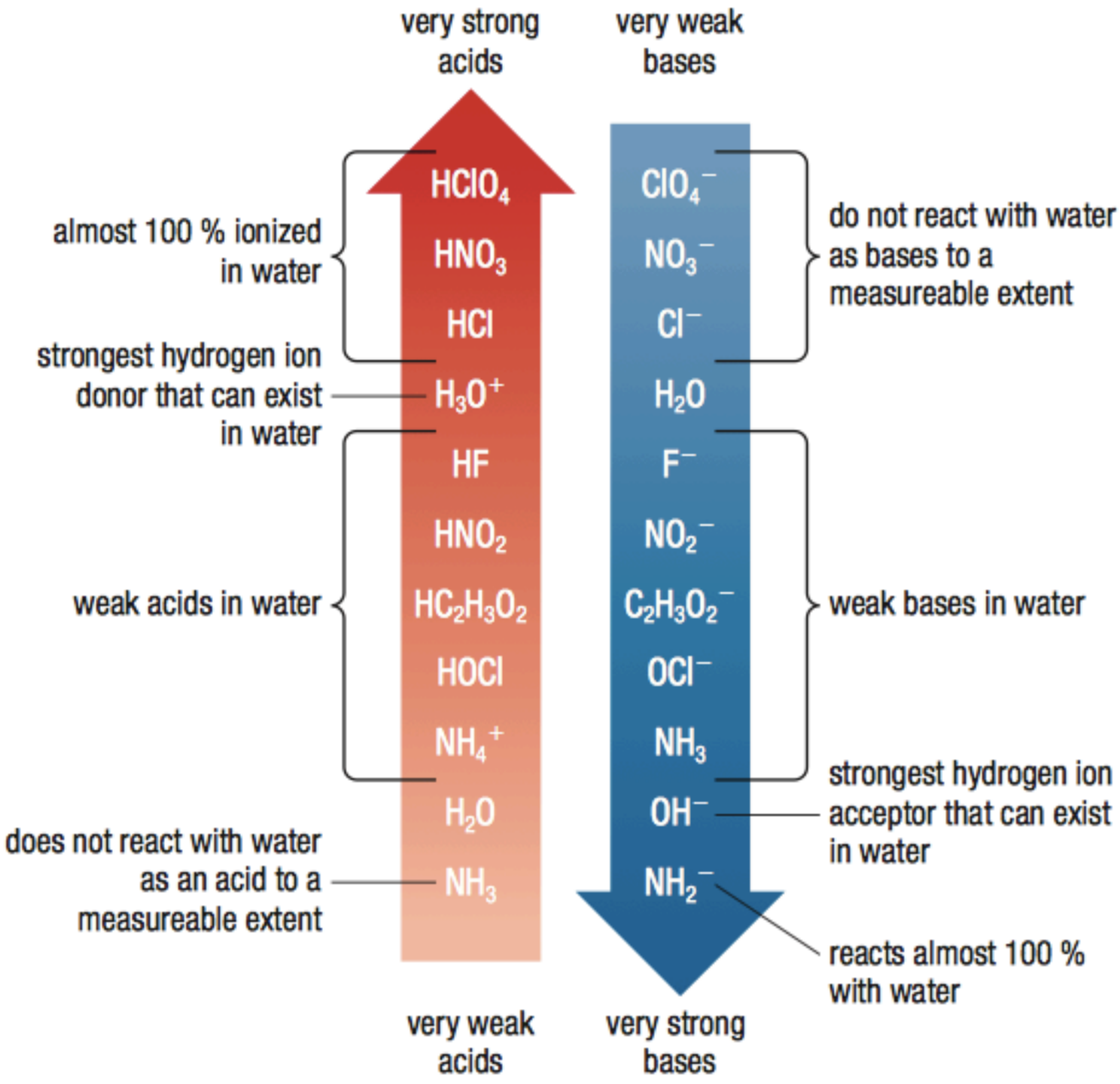
$$\begin{aligned} \cancel{HA(aq)} + H_2O(l) &\rightleftharpoons \cancel{A^-(aq)} + H_3O^+(aq) \\ \cancel{A^-(aq)} + H_2O(l) &\rightleftharpoons \cancel{HA(aq)} + OH^-(aq) \\ \hline 2\,H_2O(l) &\rightleftharpoons H_3O^+(aq) + OH^-(aq) \end{aligned} \qquad K_w = [H_3O^+(aq)][OH^-(aq)]$$

$$K_aK_b = \frac{[H_3O^+(aq)][\cancel{A^-(aq)}]}{[\cancel{HA(aq)}]} \times \frac{[\cancel{HA(aq)}][OH^-(aq)]}{[\cancel{A^-(aq)}]}$$

$$= [H_3O^+(aq)][OH^-(aq)]$$

$$K_aK_b = K_w$$

$$\boxed{K_aK_b = K_w}$$


very strong acids
very weak bases
$HClO_4$
HNO_3
HCl
H_3O^+
HF
HNO_2
$HC_2H_3O_2$
HOCl
NH_4^+
H_2O
NH_3
ClO_4^-
NO_3^-
Cl^-
H_2O
F^-
NO_2^-
$C_2H_3O_2^-$
OCl^-
NH_3
OH^-
NH_2^-
almost 100 % ionized in water
strongest hydrogen ion donor that can exist in water
weak acids in water
does not react with water as an acid to a measureable extent
do not react with water as bases to a measureable extent
weak bases in water
strongest hydrogen ion acceptor that can exist in water
reacts almost 100 % with water
very weak acids
very strong bases

Assumptions

- A strong acid or base has a very weak conjugate.
- A weak acid or base has a weak conjugate.
- A very weak acid or base has a strong conjugate

Example 1

The hydrogen phosphate ion, $HPO_4^{2-}{}_{(aq)}$, has a K_a of 1.3×10^{-13} at SATP. What is the base ionization constant, K_b, for the phosphate ion, $PO_4^{3-}{}_{(aq)}$?

pH and pOH

$$pH = -\log[H^+(aq)] \quad \text{and} \quad pOH = -\log[OH^-(aq)]$$

$$pH + pOH = 14$$

In neutral solutions,

- $[H^+(aq)] = 1.0 \times 10^{-7}$ mol/L and $pH = 7$
- $[OH^-(aq)] = 1.0 \times 10^{-7}$ mol/L and $pOH = 7$

In acidic solutions,

- $[H^+(aq)] > 1.0 \times 10^{-7}$ mol/L and $pH < 7$
- $[OH^-(aq)] < 1.0 \times 10^{-7}$ mol/L and $pOH > 7$

In basic solutions,

- $[H^+(aq)] < 1.0 \times 10^{-7}$ mol/L and $pH > 7$
- $[OH^-(aq)] > 1.0 \times 10^{-7}$ mol/L and $pOH < 7$

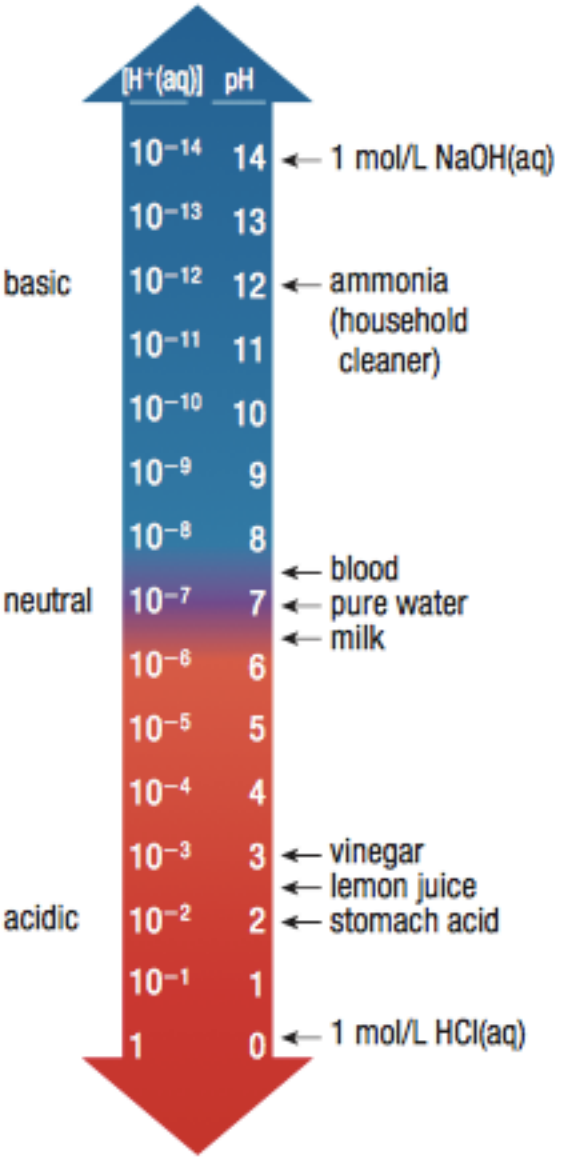


Figure 9 The pH scale showing hydrogen ion concentrations and the pH values of some common substances

Example 2

A solution of NaOH has a $[H^+_{(aq)}]$ of 5.2×10^{-11} mol/L.

a) What is the pH of the solution?

b) What is the pOH of the solution?

c) Is the solution acidic or basic?

Example 3

A solution of ethanoic acid has a pH or 5.30.

a) What is the concentration of hydrogen ions in the solution in mol/L?

b) What is the concentration of hydroxide ions in the solution in mol/L?

Measuring pH

- A **pH meter** is a device that measure the acidity or alkalinity of a solution electronically and displays the result as a pH value.

Figure 10 A pH meter shows the pH of a solution.

- Another common way to determine the pH of a solution is to use an **acid-base indicator** (a substance that has different colours in solutions with different pH values).

Figure 11 These beakers contain solutions with pH values ranging from 1 on the far left to 13 on the far right, along with a little boiled red cabbage and its juice.

Did You Learn?

- A strong acid or base completely ionizes or dissociates in water.
  - Its K_a or K_b value is very large.
- A weak acid or base ionizes or dissociates only slightly in water.
  - Its K_a or K_b value is relatively small.
- Water undergoes autoionization. The ion-product constant for the autoionization of water, K_w, is related to the concentration of hydrogen and hydroxide ions by the equation $K_w=[H^+_{(aq)}][OH^-_{(aq)}]$.
- K_w, K_a, and K_b are related by the equation $K_w=K_aK_b$.
- pH can be determined from the hydrogen ion concentration of a solution using the equation $pH= - \log[H^+_{(aq)}]$.
  - Similarly, $pOH = - \log[OH^-_{(aq)}]$.
- pH and pOH are related by the equation pH + pOH = 14.
- The pH scale is used to describe the acidity or alkalinity of a solution.
- pH meters and acid-base indicators can be used to measure the pH of a solution.

HOMEWORK

Required Reading:

p. 495 – 509

(remember to supplement your notes!)

Questions:

P. 505 #1-3

P. 508 #1-4

P. 509 #1-9