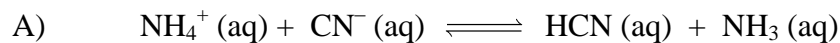


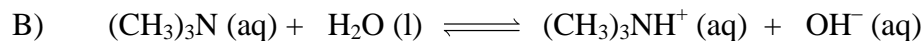
REVIEW QUESTIONS

## Chapter 16

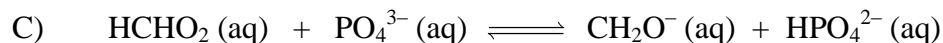
1. For each reaction below, identify the Brønsted-Lowry acid and base and their conjugates:



acid      base      conj acid      conj base

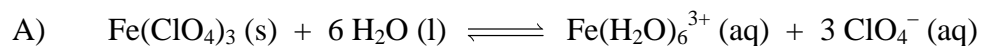


base      acid      conj acid      conj base

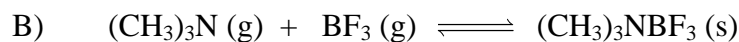


acid      base      conj base      conj acid

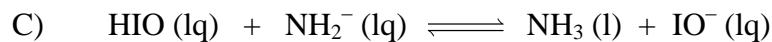
2. Identify the Lewis acid and base in each of the following reactions:



**Acid**      **Base**



**Base**      **Acid**

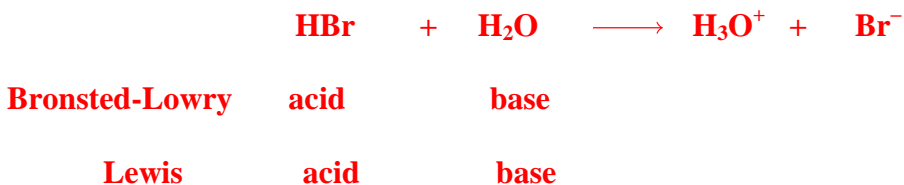


(lq denotes liquid ammonia as solvent)

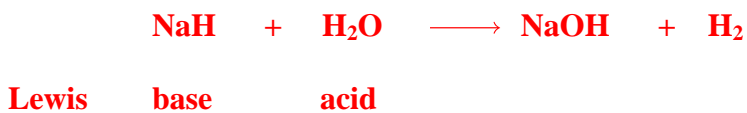
**Acid**      **Base**

3. For each of the following descriptive statements, provide an interpretation in terms of the Bronsted-Lowry, the Lewis theory, or both, as appropriate.

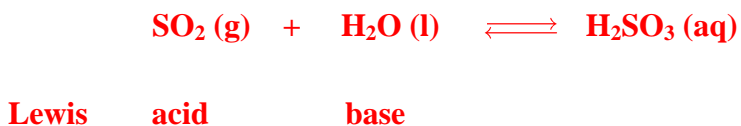
a) Hydrogen bromide, HBr, dissolves in water to form an acidic solution.



b) Sodium hydride, NaH, reacts with water to form a basic solution.



c) Sulfur dioxide, SO<sub>2</sub>, dissolves in water to form an acidic solution.



4. Complete the table below by calculating the missing entries and indicating whether each solution is acidic or basic:

[H <sup>+</sup> ]	[OH <sup>-</sup> ]	pH	pOH	acidic or basic?
2.5x10 <sup>-4</sup> M	<b>4.0x10<sup>-11</sup> M</b>	<b>3.60</b>	<b>10.40</b>	<b>acidic</b>
<b>1.4x10<sup>-7</sup> M</b>	6.9x10 <sup>-8</sup> M	<b>6.84</b>	<b>7.16</b>	<b>acidic</b>
<b>6.3x10<sup>-4</sup> M</b>	<b>1.6x10<sup>-11</sup> M</b>	3.20	<b>10.80</b>	<b>acidic</b>
<b>5.6x10<sup>-9</sup> M</b>	<b>1.8x10<sup>-6</sup> M</b>	<b>8.25</b>	5.75	<b>basic</b>

5. For each pair shown below, choose the stronger base:

a)  $\text{F}^-$  or  $\text{Cl}^-$

**HF is a weaker acid than HCl. Therefore, its conjugate base ( $\text{F}^-$ ) is a stronger base than  $\text{Cl}^-$ .**

b)  $\text{Cl}^-$  or  $\text{H}_2\text{O}$

**The conjugate acid of water ( $\text{H}_3\text{O}^+$ ) is a weaker acid than HCl. Therefore, water is a stronger base than  $\text{Cl}^-$ .**

c)  $\text{ClO}_4^-$  or  $\text{ClO}_2^-$

**$\text{HClO}_2$  is weaker acid than  $\text{HClO}_4$ . Therefore, its conjugate base ( $\text{ClO}_2^-$ ) is a stronger base than  $\text{ClO}_4^-$ .**

6. Calculate the  $[\text{H}^+]$  and  $[\text{OH}^-]$  for each of the following strong acid or base solution:

a)  $1.8 \times 10^{-4} \text{ M HBr}$

$$[\text{H}^+] = [\text{HBr}] = 1.8 \times 10^{-4} \text{ M} \quad [\text{OH}^-] = \frac{K_w}{[\text{H}^+]} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-4}} = 5.6 \times 10^{-11} \text{ M}$$

b)  $0.0895 \text{ M HClO}_4$

$$[\text{H}^+] = [\text{HClO}_4] = 0.0895 \text{ M} \quad [\text{OH}^-] = \frac{K_w}{[\text{H}^+]} = \frac{1.0 \times 10^{-14}}{0.0895} = \text{M}$$

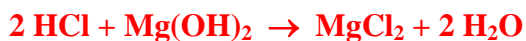
c)  $3.2 \times 10^{-3} \text{ M KOH}$

$$[\text{OH}^-] = [\text{KOH}] = 3.2 \times 10^{-3} \text{ M} \quad [\text{H}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{3.2 \times 10^{-3}} = 3.1 \times 10^{-12} \text{ M}$$

d)  $0.0075 \text{ M Ca(OH)}_2$

$$[\text{OH}^-] = 2 \times [\text{Ca(OH)}_2] = 1.5 \times 10^{-2} \quad [\text{H}^+] = \frac{K_w}{[\text{OH}^-]} = \frac{1.0 \times 10^{-14}}{1.5 \times 10^{-2}} = 6.7 \times 10^{-13} \text{ M}$$

7. People often take milk of magnesia to reduce the discomfort associated with acid stomach or heartburn. The recommended dose is 1 teaspoon, which contains 400 mg of  $\text{Mg}(\text{OH})_2$ . What volume of HCl solution with a pH of 1.3 can be neutralized by one dose of milk of magnesia? (Calculate answer to 2 sig figs).



$$[\text{HCl}] = [\text{H}_3\text{O}^+] = 10^{-1.3} = 0.050 \text{ M}$$

$$400 \text{ mg Mg}(\text{OH})_2 \times \frac{1 \text{ g}}{10^3 \text{ mg}} \times \frac{1 \text{ mol}}{58.32 \text{ g}} \times \frac{2 \text{ mol HCl}}{1 \text{ mol Mg}(\text{OH})_2} \times \frac{1 \text{ L}}{0.050 \text{ mol HCl}} \times \frac{10^3 \text{ mL}}{1 \text{ L}} = 270 \text{ mL HCl}$$

8. Calculate the  $[\text{H}_3\text{O}^+]$  and  $[\text{OH}^-]$  for solutions with the following pH values:

a) 2.63

$$[\text{H}_3\text{O}^+] = 10^{-2.63} = 2.3 \times 10^{-3} \text{ M}$$

$$[\text{OH}^-] = \frac{K_w}{[\text{H}_3\text{O}^+]} = \frac{1.0 \times 10^{-14}}{2.3 \times 10^{-3}} = 4.3 \times 10^{-12} \text{ M}$$

b) 14.25

$$[\text{H}_3\text{O}^+] = 10^{-14.25} = 5.6 \times 10^{-15} \text{ M}$$

$$[\text{OH}^-] = \frac{K_w}{[\text{H}_3\text{O}^+]} = \frac{1.0 \times 10^{-14}}{5.6 \times 10^{-15}} = 1.8 \text{ M}$$

9. Using values of  $K_a$  in your textbook, arrange the following acids in order of (a) increasing acid strength, and (b) decreasing percent ionization:

	$\text{C}_6\text{H}_5\text{OH}$	$\text{HNO}_2$	$\text{CH}_3\text{CO}_2\text{H}$	$\text{HOCl}$
$K_a$	$1.3 \times 10^{-10}$	$4.6 \times 10^{-4}$	$1.8 \times 10^{-5}$	$2.9 \times 10^{-8}$

a) The larger  $K_a$  value, the stronger the acid. Therefore,



b) The larger  $K_a$  value, the greater the ionization. Therefore,



10. A 0.10 M solution of lactic acid ( $\text{HC}_3\text{H}_5\text{O}_3$ ) has a pH of 2.44. Calculate  $K_a$  for lactic acid.

$$\begin{aligned}[\text{H}^+] &= 10^{-2.44} = 3.6 \times 10^{-3} \text{ M} \\ [\text{C}_3\text{H}_5\text{O}_3^-] &= [\text{H}^+] = 3.6 \times 10^{-3} \text{ M} \\ [\text{HC}_3\text{H}_5\text{O}_3] &= 0.10 - (3.6 \times 10^{-3}) \approx 0.10 \\ K_a &= \frac{[\text{H}^+][\text{C}_3\text{H}_5\text{O}_3^-]}{[\text{HC}_3\text{H}_5\text{O}_3]} = \frac{(3.6 \times 10^{-3})^2}{0.10} = 1.3 \times 10^{-4}\end{aligned}$$

11. A 0.200 M solution of a weak acid HX is 9.4% ionized. Calculate the pH and  $K_a$  for this acid.

$$\begin{aligned}[\text{H}^+] &= [\text{A}^-] = 0.200 \times 0.094 = 0.019 \text{ M} \\ \text{pH} &= -\log(0.019) = 1.72 \\ [\text{HA}] &= 0.200 - 0.019 = 0.181 \\ K_a &= \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = \frac{(0.019)^2}{0.181} = 2.0 \times 10^{-3}\end{aligned}$$

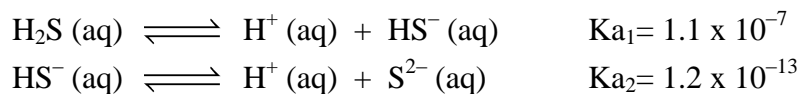
12. Calculate the pH of a 0.050 M solution of ethylamine ( $\text{C}_2\text{H}_5\text{NH}_2$ ,  $K_b = 6.4 \times 10^{-4}$ ).

$$\begin{aligned}\text{C}_2\text{H}_5\text{NH}_2 + \text{H}_2\text{O} &\rightleftharpoons \text{C}_2\text{H}_5\text{NH}_3^+ + \text{OH}^- \\ K_b &= \frac{[\text{C}_2\text{H}_5\text{NH}_3^+][\text{OH}^-]}{[\text{C}_2\text{H}_5\text{NH}_2]} = \frac{x^2}{0.050 - x} = 6.4 \times 10^{-4} \\ x = [\text{OH}^-] &= \sqrt{(0.050)(6.4 \times 10^{-4})} = 5.7 \times 10^{-3} \text{ M} \\ \text{pOH} &= -\log(5.7 \times 10^{-3}) = 2.24 \\ \text{pH} &= 14.00 - 2.24 = 11.76\end{aligned}$$

13. The  $K_a$  for hydrocyanic acid, HCN, is  $5.0 \times 10^{-10}$ . What is the  $K_b$  for  $\text{CN}^-$ ?

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{5.0 \times 10^{-10}} = 2.0 \times 10^{-5}$$

14. Hydrosulfuric acid is a polyprotic acid with the following equilibria:



a) Calculate the pH of a 0.100 M H<sub>2</sub>S solution.

$$\begin{aligned} K_{a1} &= \frac{[\text{H}^+][\text{HS}^-]}{[\text{H}_2\text{S}]} = \frac{x^2}{0.100 - x} = 1.1 \times 10^{-7} \\ x = [\text{H}^+] &= [\text{HS}^-] = \sqrt{(0.100)(1.1 \times 10^{-7})} = 1.0 \times 10^{-4} \text{ M} \\ \text{pH} &= -\log(1.0 \times 10^{-4}) = 4.00 \end{aligned}$$

b) Calculate the [S<sup>2-</sup>] for the solution above.

$$\begin{aligned} K_{a2} &= \frac{[\text{H}^+][\text{S}^{2-}]}{[\text{HS}^-]} = \frac{(1.0 \times 10^{-4} + y)(y)}{(1.0 \times 10^{-4}) - y} = 1.2 \times 10^{-13} \\ y = [\text{S}^{2-}] &= 1.2 \times 10^{-13} \text{ M} \end{aligned}$$

15. Sodium benzoate, C<sub>6</sub>H<sub>5</sub>CO<sub>2</sub>Na, is the salt of the weak acid, benzoic acid (C<sub>6</sub>H<sub>5</sub>CO<sub>2</sub>H). A 0.10 M solution of sodium benzoate has a pH of 8.60 at room temperature.

a) Calculate the K<sub>b</sub> value for benzoate ion (C<sub>6</sub>H<sub>5</sub>CO<sub>2</sub><sup>-</sup>).

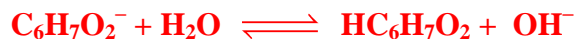
$$\begin{aligned} \text{C}_6\text{H}_5\text{CO}_2^- + \text{H}_2\text{O} &\rightleftharpoons \text{C}_6\text{H}_5\text{CO}_2\text{H} + \text{OH}^- \\ \text{pOH} &= 14.00 - 8.60 = 5.40 \\ [\text{OH}^-] &= [\text{C}_6\text{H}_5\text{CO}_2\text{H}] = 10^{-5.40} = 4.0 \times 10^{-6} \\ [\text{C}_6\text{H}_5\text{CO}_2^-] &= 0.10 - (4.0 \times 10^{-6}) \approx 0.10 \\ K_b &= \frac{[\text{C}_6\text{H}_5\text{CO}_2\text{H}][\text{OH}^-]}{[\text{C}_6\text{H}_5\text{CO}_2^-]} = \frac{(4.0 \times 10^{-6})^2}{0.10} = 1.6 \times 10^{-10} \end{aligned}$$

b) Calculate the K<sub>a</sub> value for benzoic acid.

$$K_a = \frac{K_w}{K_b} = \frac{1.0 \times 10^{-14}}{1.6 \times 10^{-10}} = 6.3 \times 10^{-5}$$

16. Potassium sorbate ( $\text{KC}_6\text{H}_7\text{O}_2$ ) is the salt of the weak acid, sorbic acid ( $\text{HC}_6\text{H}_7\text{O}_2$ ) with  $K_a = 1.7 \times 10^{-5}$ , and is commonly added to cheese to prevent mold. What is the pH of a solution containing 4.93 g of potassium sorbate in 500 mL of solution?

$$4.93 \text{ g} \times \frac{1 \text{ mol}}{150.1 \text{ g}} \times \frac{1}{0.500 \text{ L}} = 0.0657 \text{ M}$$



$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.7 \times 10^{-5}} = 5.9 \times 10^{-10}$$

$$K_b = \frac{[\text{HC}_6\text{H}_7\text{O}_2][\text{OH}^-]}{[\text{C}_6\text{H}_7\text{O}_2^-]} = \frac{x^2}{0.0657 - x} = 5.9 \times 10^{-10}$$

$$x = [\text{OH}^-] = \sqrt{(0.0657)(5.9 \times 10^{-10})} = 6.2 \times 10^{-6} \text{ M}$$

$$\text{pOH} = -\log(6.2 \times 10^{-6}) = 5.21 \quad \text{pH} = 14.00 - 5.21 = 8.79$$

17. Calculate the pH of solutions prepared by:

- a) Diluting 75 mL of 0.10 M  $\text{HClO}_4$  to a volume of 350 mL.

$$[\text{H}^+] = [\text{HClO}_4] = \frac{(0.10 \text{ M})(75 \text{ mL})}{350 \text{ mL}} = 2.14 \times 10^{-2} \text{ M}$$

$$\text{pH} = -\log(2.14 \times 10^{-2}) = 1.67$$

- b) Dissolving 4.8 g of  $\text{Ca}(\text{OH})_2$  in 250 mL of solution.

$$[\text{OH}^-] = 2x[\text{Ca}(\text{OH})_2] = 2\left(\frac{4.8 \text{ g}}{74.10 \text{ g/mol}} \times \frac{1}{0.250 \text{ L}}\right) = 0.518 \text{ M}$$

$$\text{pOH} = -\log 0.518 = 0.29$$

$$\text{pH} = 14.00 - 0.29 = 13.71$$

- c) Dissolving 3.25 g of  $\text{NH}_4\text{Cl}$  in 125 mL of solution.



$$[\text{NH}_4^+] = [\text{NH}_4\text{Cl}] = 3.25 \text{ g} \times \frac{1 \text{ mol}}{53.50 \text{ g}} \times \frac{1}{0.125 \text{ L}} = 0.486 \text{ M}$$

$$K_a = \frac{[\text{NH}_3][\text{H}_3\text{O}^+]}{[\text{NH}_4^+]} = \frac{x^2}{0.486 - x} = 5.6 \times 10^{-10}$$

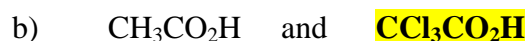
$$x = [\text{H}_3\text{O}^+] = \sqrt{(0.486)(5.6 \times 10^{-10})} = 1.65 \times 10^{-5} \text{ M}$$

$$\text{pH} = -\log(1.65 \times 10^{-5}) = 4.78$$

18. For each pair, determine which is the stronger acid, and provide a brief explanation for your choice.



**H<sub>2</sub>SO<sub>4</sub> since sulfur is more electronegative than selenium causing the O—H bond to become more polar.**

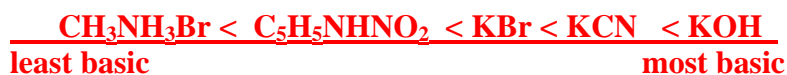


**The more electronegative Cl atoms in CCl<sub>3</sub>CO<sub>2</sub>H cause the O—H bond to become more polar and trichloroacetic acid to have greater acidity.**



**Acidic hydrogens are easier lost from a less negatively charged species, therefore H<sub>2</sub>PO<sub>4</sub><sup>-</sup> is more acidic.**

19. Arrange the solutions below in order of increasing basicity (assume concentrations to be the same):



**CH<sub>3</sub>NH<sub>3</sub>Br (cation is weakly acidic; anion is pH neutral)**

**C<sub>5</sub>H<sub>5</sub>NHNO<sub>2</sub> (cation is weakly acidic; anion is weakly basic)**

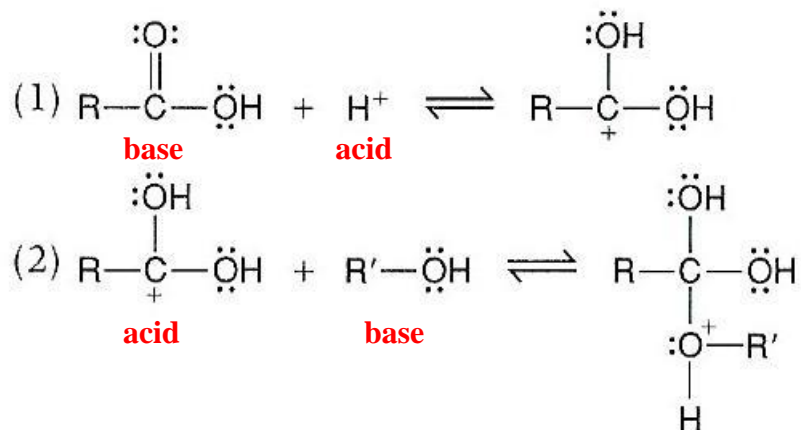
**KBr (both cation and anion are pH neutral)**

**KCN (cation is pH neutral; anion is weakly basic)**

**KOH (strong base)**



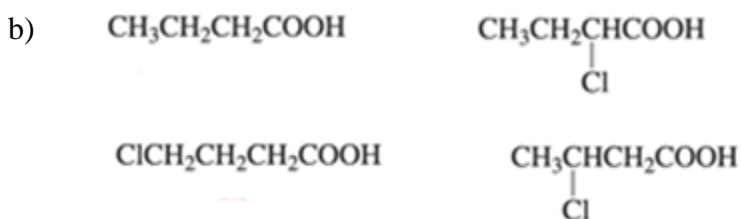
20. Esters, RCOOR', are important organic compounds that are active ingredients in the odors of fruits, and have important uses in the food and cosmetics industries. Shown below are the first two steps in the mechanism for synthesis of these compounds. Identify the Lewis acids and bases in these two steps:



21. For each list below, rank in order of decreasing acid strength (highest to lowest):



**(the increasing number of electronegative groups on the neighboring carbon atom makes the acidic bond more polar through inductive effect, and the acid stronger)**

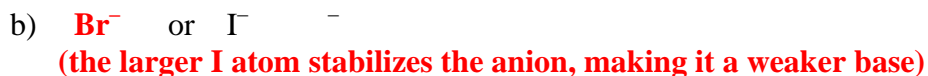
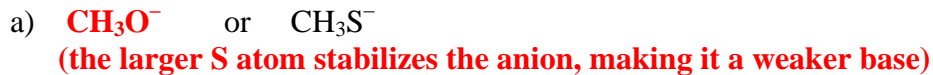


**(the closer the electronegative Cl atom to the acidic bond, the more polar the bond, and the stronger the acid)**

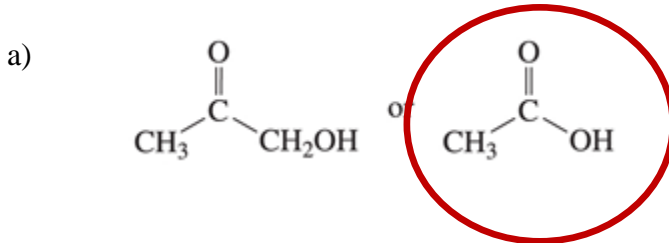


**(the more electronegative the atom forming the acidic bond, the more polar the bond and the stronger the acid)**

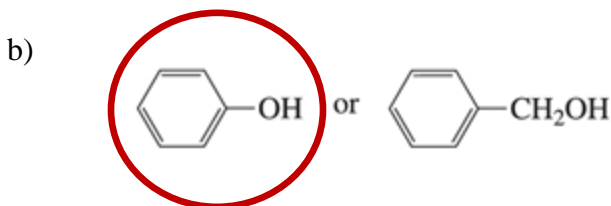
22. In each pair shown below, determine which is the stronger base:



23. For each pair shown below, determine which is the stronger acid:

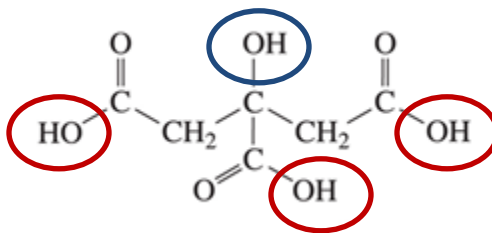


The anion of acetic acid ( $\text{CH}_3\text{CO}_2^-$ ) is stabilized through resonance with the neighboring C=O group, making it a stronger acid.



The anion of phenol is stabilized through resonance with the neighboring pi bonds in the ring, making it a stronger acid.

24. Citrus fruits are rich in citric acid, a compound with four acidic hydrogens:



a) Identify the acidic hydrogen in this molecule. Which is the weakest? Why?

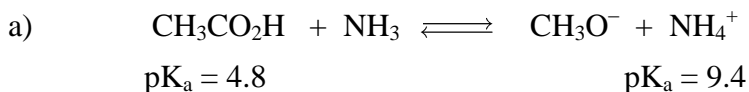
**The acidic hydrogens are circled in the structure above.**

**The H indicated by the blue circle is the weakest acid since its anion is not stabilized by any resonance structures, contrary to the other 3 hydrogens indicated by the red circles.**

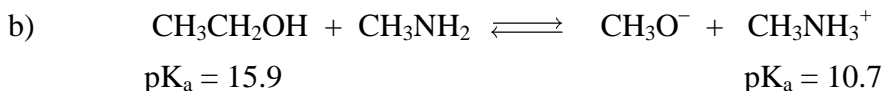
b) Explain why the  $pK_a$  for the COOH group in the center of the molecule is lower than the  $pK_a$  of acetic acid.

**The  $pK_a$  of the COOH group in the center of the molecule is lower than the  $pK_a$  of acetic acid because of a neighboring oxygen-containing group that withdraws electrons inductively and thereby stabilizes the conjugate base.**

25. Using the information given, determine if reactants or products are favored in each equilibrium below:

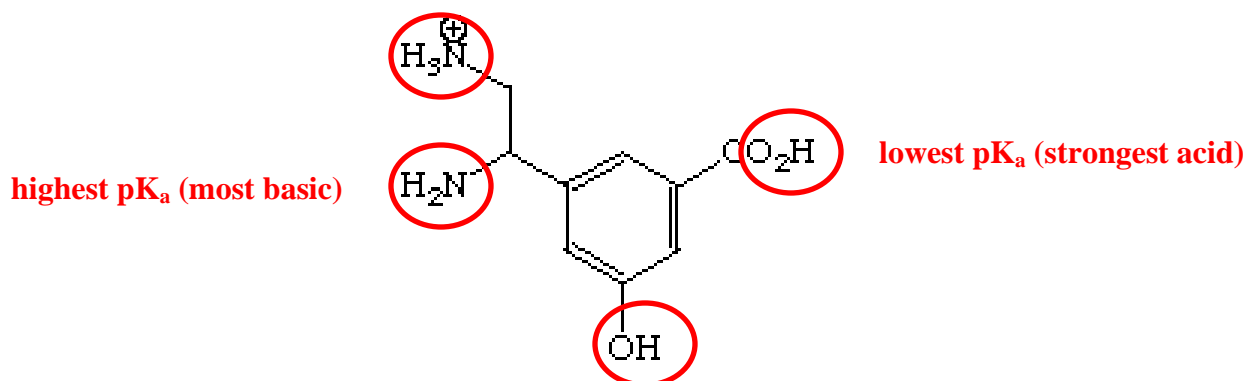


**Products are favored. The lower  $pK_a$  for the acid on the reactant side indicates that it is a stronger acid. Reactions favor the weaker acid and base.**



**Reactants are favored. The lower  $pK_a$  for the acid on the product side indicates that it is a stronger acid. Reactions favor the weaker acid and base.**

26. Identify the highest and lowest  $pK_a$  values for the hydrogens circled below:



27. Identify the more acidic hydrogen in each pair shown below:

