ChemQuest 68

Intro to Acids and Bases

Name: _____

Date: _____

Hour: _____

Information: Definitions of Acids and Bases

Arrhenius definitions

1) acid: substance that when dissolved in water increases $[H^+]$; (note: H^+ exists bonded to water as the hydronium ion, H_3O^+, so $[H^+]$ and $[H_3O^+]$ are equivalent expressions)
2) base: substance that when dissolved in water increases $[OH^-]$

Bronsted-Lowry definitions

1) acid: substance that donates a proton, H^+, in a reaction
2) base: substance that accepts a proton, H^+, in a reaction

Critical Thinking Questions

1. Using the Bronsted-Lowry definitions, explain why $C_2H_3O_2^-$ acts like a base in the following reaction: $C_2H_3O_2^- + H_2O \rightarrow HC_2H_3O_2 + OH^-$

   A H^+ ion (which is the same as a proton) is transferred from H_2O to $C_2H_3O_2^-$ in the reaction.

2. Using Arrhenius definitions, explain why $C_2H_3O_2^-$ acts like a base in the reaction given in question 1.

   When placed in water, $C_2H_3O_2^-$ increases the amount of OH^-.

3. Given the following reaction, explain why HCN is an acid according to Bronsted-Lowry, but not according to Arrhenius: $HCN + SO_4^{2-} \rightarrow HSO_4^- + CN^-$

   HCN donates a H^+ in the reaction, but it does not increase the amount of H^+ ions in solution.

4. Given the following reaction, identify the acid or base: $H_2CO_3 + H_2O \rightarrow H_3O^+ + HCO_3^-$
   Acid Base

Information: Acid-Base Equilibrium

Table 1: Equilibrium constants (at 25°C) for some acid-base equilibrium reactions.

Reaction	K_c
1. $C_2H_3O_2^- + H_2O \leftrightarrow HC_2H_3O_2 + OH^-$	1.07×10^{-11}
2. $HCN + SO_4^{2-} + H_2O \leftrightarrow HSO_4^- + CN^- + H_2O$	4.9×10^{-11}
3. $HC_2H_3O_2 + H_2O \leftrightarrow H_3O^+ + C_2H_3O_2^-$	3.09×10^{-7}
4. $H_2CO_3 + H_2O \leftrightarrow H_3O^+ + HCO_3^-$	7.82×10^{-9}
5. $HCl + H_2O \leftrightarrow H_3O^+ + Cl^-$	2.0×10^{4}

Critical Thinking Questions

5. List all of the reactants in Table 1 that are Arrhenius acids.
   $HC_2H_3O_2$, H_2CO_3, and HCl

6. a) What is the strongest acid among the reactants in reactions 3-5 inTable 1? Explain.
   HCl because it acts like an acid and it has the largest equilibrium constant.

   b) What is the weakest acid among the reactants in reactions 3-5 inTable 1? Explain.
   HCN because it has the smallest equilibrium constant out of all the substances acting like an acid. ($C_2H_3O_2^-$ has a smaller constant, but it is a base, not an acid.)

7. Consider Reaction 3.
   a) What substance is formed (by the acid) after the acid loses a proton?
   $C_2H_3O_2^-$

   b) Is this substance an acid or a base? (Hint: look at reaction 1.)
   Base

8. Drawing a conclusion from question 7, what can be said about a substance after it loses a proton? Is the substance formed acidic or basic?
   After losing a proton, the resultant substance is basic.

Information: Conjugate Acid-Base Pairs

After an acid loses a proton in a reaction, the substance formed behaves like a base. Verify this by examining Reactions 3 and 1 in Table 1. Notice from reaction 3 that $HC_2H_3O_2$ is an acid. After it loses a proton it becomes the acetate ion, $C_2H_3O_2^-$. The acetate ion is a base, as seen in reaction 1; there is a special name for this base: it is a conjugate base. So, $C_2H_3O_2^-$ is the conjugate base of $HC_2H_3O_2$. Similarly, HSO_4^- is the conjugate acid of SO_4^{2-}. Verify this by examining Reaction 2.

Critical Thinking Questions

9. Describe how a conjugate base is formed.
   It is formed by an acid losing a H^+.

10. How is a conjugate acid formed?

It is formed by a base gaining a H^+.

11. For each of the acids below, write the reaction of the acid with water and circle the formula of the conjugate base in your reaction.

a) H_2SO_4 $H_2SO_4 + H_2O \leftrightarrow H_3O^+ + HSO_4^-$

b) HCO_3^- $HCO_3^- + H_2O \leftrightarrow H_3O^+ + CO_3^{2-}$

c) HF $HF + H_2O \leftrightarrow H_3O^+ + F^-$

12. For each of the bases below, write the reaction of the base with water and circle the formula of the conjugate acid in your reaction.

a) NH_3 $NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$

b) OH^- $OH^- + H_2O \leftrightarrow H_2O + OH^-$

c) NO_3^- $NO_3^- + H_2O \leftrightarrow HNO_3 + OH^-$

ChemQuest 69

pH and pOH

Name: _____

Date: _____

Hour: _____

Introduction Questions

1. Now we're going to get ready to learn about pH. We're going to practice taking the negative log of a number. Follow the steps to calculate –log (0.75)
   a) Take the log of 0.75 on your calculator. You should get –0.125.

   b) Now take the negative of the answer you got. So the –log(0.75) = 0.125.

2. Verify on your calculator that –log(0.390) = 0.409.

3. Calculate the following logs:
   a) –log(0.0036) 2.44
   b) –log(0.073) 1.14
   c) –log(0.65) 0.19

Information: Calculating pH

Many people have heard of "pH", and many people know that it probably refers to acidity, but not very many understand what exactly it measures. The pH is a measure of the concentration of hydrogen ions (H^+) in a solution.

The pH of a solution can range from 0-14. The equation for calculating pH is:

$$pH = -\log[H^+]$$

The square brackets are a symbol for the concentration. "$[H^+]$" means molarity of H^+. A pH of 7 is considered neutral. Below 7 is acidic and above 7 is basic.

Critical Thinking Questions

4. A certain solution has a concentration of hydrogen ions of 2.5×10^{-3} M. What is the pH?
   $pH = -\log[H^+] = -\log(2.5 \times 10^{-3}) = 2.60$

5. A certain solution has a concentration of HNO_3 of 0.057 M.
   a) What is the concentration of H^+ ions?
      0.057 M
   b) Calculate the pH of this solution.
      -log(0.057) = 1.24

6. What is the pH of a 0.0085 M solution of HCl?
   -log(0.0085) = 2.07

Information: pOH

As you know, when an acid is placed in water, H^+ ions are produced. A base will produce OH^- ions. If pH equals the negative log of the H^+ concentration, it should make sense that pOH equals the –log of the OH^- ions.

$$pOH = -\log[OH^-]$$

Critical Thinking Questions

7. The solution from question 4 had a $[H^+]$ of 0.0025 M. The very same solution has a concentration of hydroxide ions $[OH^-]$ of 4.0×10^{-12} M. What is the pOH of this solution?
   $pOH = -\log[OH^-] = -\log(4.0 \times 10^{-12}) = 11.40$

8. Given your answers to questions 4 and 7, which of the following equations is true?

   A) pH + pOH = 20 B) pH x pOH = 12 C) pH + pOH = 14 D) pH ÷ pOH = 0.85

9. Given the equation you chose from the previous question, calculate the pOH of a solution that has a pH of 4.2.
   14 – 4.2 = 9.8

10. Calculate the pH of a 0.025 M solution of $Ca(OH)_2$. You can follow these steps…
    a) First remember that the OH^- concentration is twice the $Ca(OH)_2$ concentration. Calculate the pOH.
       $[OH^-] = 0.025 \times 2 = 0.05$ M → $-\log(0.05) = 1.3$

    b) Now use the pOH to calculate the pH (use the equation from question 8).
       pH = 14 – 1.3 = 12.7

11. Next you can follow these steps to find the H^+ concentration from the pH. The equation you use is $[H^+] = 10^{-pH}$. Use the following steps to find the $[H^+]$ if the pH of a solution is 2.45.

    a) First, take the negative of the pH.
       -2.45
    b) Now, use your calculate and hit the "2^{nd}" or "inv" button and then the log button which should be the 10^x function. Your answer should be 0.00355.
       $10^{-2.45} = 0.0035$ M

12. A certain solution has a pH of 5.2. What is the concentration of hydrogen ions $[H^+]$? (Hint: follow the steps from the previous question.)
    $[H^+] = 10^{(-pH)} = 10^{(-5.2)} = 6.3 \times 10^{-6}$ M

13. a) Find the pOH of the solution from question 12.

pOH = 14 – 5.2 = 8.8

b) What is the concentration of hydroxide ions [OH^-] in this solution?

[OH^-] = $10^{-8.8}$ = $1.58x10^{-9}$ M

14. Given your answers to questions 12 and 13b, which of the following is true:

A) [H^+] + [OH^-] = 1 B) [H^+][OH^-] = $1x10^{-14}$ C) [H^+]÷[OH^-] = 1

Use what you've learned so far to answer the following questions.

15. Calculate the pH of a 0.0078 M solution of $Mg(OH)_2$.

0.0078 x 2 = 0.0156 M → pOH = -log(0.0156) = 1.8 → pH = 14 – 1.8 = **12.2**

16. Consider a 0.00475 M solution of HNO_3…

a) Calculate the pH. pH = -log(0.00475) = 2.32

b) Calculate the pOH. pOH = 14 – 2.32 = 11.68

c) Calculate the [H^+] 0.00475 M

d) Calculate the [OH^-] $10^{-11.68}$ = $2.09x10^{-12}$ M

17. A certain solution of HCl has a pH of 1.96. What is the concentration of the acid?

[HCl] = [H^+] = $10^{-1.96}$ = 0.0109 M

18. A certain solution of $Ca(OH)_2$ has a pH of 12.58. What is the concentration of the $Ca(OH)_2$?

[OH^-] = 10^{-pOH} = $10^{-1.42}$ = 0.038 M

[$Ca(OH)_2$] = 0.038 ÷ 2 = **0.019 M**

ChemQuest 70

Acid/Base Applications

Name: _____

Date: _____

Hour: _____

Information: Common Acids and Bases

As you know, the pH measures how acidic or basic a solution is. The pH scale ranges from 0-14. Here is a table of common acids and bases:

Acids (pH less than 7)	Bases (pH higher than 7)
Nitric acid: HNO_3	Lithium hydroxide: LiOH
Sulfuric acid: H_2SO_4	Sodium hydroxide: NaOH
Hydrochloric acid: HCl	Potassium hydroxide: KOH
Hydrobromic acid: HBr	Calcium hydroxide: $Ca(OH)_2$
Hydroiodic acid: HI	Strontium hydroxide: $Sr(OH)_2$

Critical Thinking Questions

1. What do all of the acids in the above table have in common?
   Their formulas begin with hydrogen.

2. What do all of the bases in the above table have in common?
   They are all hydroxides.

3. A certain solution has a pH of 2.75. Which of the following is probably dissolved in the solution?
   A) NaOH B) H_2SO_4 C) NaCl

   Explain your answer:
   The pH is less than 7 so it must be an acid. H_2SO_4 is the only acid listed as a choice.

4. If a certain man's pool had a pH that was too low and his plan was to add a little H_2SO_4 to the water to fix the problem, what advice would you give him?

   H_2SO_4 would lower the pH further. Better choose a base instead!

5. Factories often let out pollutants such as sulfur oxides and nitrogen oxides into the air. The pollutants being released into the air are a leading cause of acid rain. Offer a hypothesis as to why those two gases in the atmosphere could lead to acid rain.

   Nitrogen oxides combine with H_2O to make HNO_3 and sulfur oxides make H_2SO_4.

6. Acids and bases react together to neutralize each other. An acid will react with a base in a double replacement reaction. When an acid reacts with a base, water is formed as one of the products along with another compound. Write the balanced equation for the reaction between HCl and NaOH.

   $HCl + NaOH \rightarrow H_2O + NaCl$

7. Write the balanced chemical equation for the reaction between nitric acid and calcium hydroxide.

   $2\ HNO_3 + Ca(OH)_2 \rightarrow 2\ H_2O + Ca(NO_3)_2$

8. Compounds that contain carbonate (CO_3^{-2}) react with acids to form carbon dioxide (CO_2) and water and another compound. Complete and then balance the following equations:

   a) $CaCO_3 + 2\ HNO_3 \rightarrow$ CO_2 + H_2O + $Ca(NO_3)_2$

   b) $CaCO_3 + 2\ HCl \rightarrow CO_2 + H_2O + CaCl_2$

   c) $Na_2CO_3 + 2\ HBr \rightarrow CO_2 + H_2O + 2\ NaBr$

9. Some lakes have a lot of limestone at the bottom. Limestone is primarily $CaCO_3$. Given what you learned in the previous question, why would lakes that contain limestone not be affected very much by acid rain. Give it your best hypothesis.

   Carbonates neutralize acids.

Skill Practice Questions

10. Write the balanced equation for the reaction of hydrobromic acid and calcium hydroxide.
    $2\ HBr + Ca(OH)_2 \rightarrow 2\ H_2O + CaBr_2$

11. Vinegar (acetic acid, $HC_2H_3O_2$) reacts with baking soda and lots of bubbles are produced.

    a) Which of the following is a possible formula for baking soda?
       A) $CaCl_2$ B) $NaHCO_3$ C) $NaOH$ D) Na_2SO_4

    b) Production of bubbles is a sign that a gas is generated. Which gas?
       CO_2

    c) Some baking soda was dissolved in water. What is the pH of the solution?

       A) 2.5 B) 9.8 C) 7.0

12. Write the balanced equation for the reaction of Na_2CO_3 with nitric acid.

    $Na_2CO_3 + 2\ HNO_3 \rightarrow CO_2 + H_2O + 2\ NaNO_3$

13. Calculate the molarity of a solution formed by dissolving 23.4g of $CaCl_2$ in 235 mL of solution.

23.4 ÷111g/mol = 0.211 mol
0.211 mol ÷ 0.235 L = **0.897 M**

14. What is the concentration of a solution formed by dissolving 25g of $Al(NO_3)_3$ in 120 mL of solution?

25g ÷ 212.98g/mol = 0.117 mol
0.117 mol ÷ 0.120L = **0.978 M**

15. For the solution in the previous question, calculate the molarity of NO_3^- ions.

0.978 x 3 = 2.93 M

16. Calculate the following for a 0.0079 M solution of HNO_3…

$[H^+]$ = 0.0079 M

$[OH^-]$ = $1.27x10^{-12}$ M

pOH = 11.90

pH = 2.10

17. Calculate the pH of a 0.0047 M solution of $Mg(OH)_2$.

11.97

18. A solution is formed by dissolving 1.25g of NaOH in 200 mL of solution. Calculate…

$[H^+]$ = $6.4x10^{-14}$ M

$[OH^-]$ = 0.156 M

pOH = 0.806

pH = 13.19

ChemQuest 71

Acid/Base Calculations

Name: _____

Date: _____

Hour: _____

Information: Constants and Equations

You have discovered two fundamental constants represented by the following equations:

1. $pH + pOH = 14$
2. $[OH^-][H^+] = 1x10^{-14}$

A third equation is related to equation 2 above:

3. $(K_a)(K_b) = 1x10^{-14}$

This equation holds true for any conjugate acid-base pair. The K_a for the acid multiplied by the K_b for the conjugate base will always equal $1x10^{-14}$.

The following questions will give you some practice using the above three relationships combined with the equations for pH and pOH that you should already be familiar with.

Critical Thinking Questions

1. The K_a for a certain weak acid is $1.8x10^{-9}$. What is the K_b for the conjugate base of this acid?
   $K_b = 1x10^{-14} \div K_a = 1x10^{-14} \div 1.8x10^{-9} = 5.6x10^{-6}$
2. The K_b for NH_3 is $1.8x10^{-5}$. Write the formula for and calculate the K_a for the conjugate acid of NH_3.
   The formula is NH_4^+ since conjugate acids are formed when a base gains a H^+.
   $K_a = 1x10^{-14} \div 1.8x10^{-5} = 5.6x10^{-10}$
3. The pH of a certain solution was 1.45. What was the pOH?
   $pOH = 14 - 1.45 = 12.55$
4. If the hydroxide ion concentration of a certain solution was $2.6x10^{-4}$ M, what is the pH?
   $pOH = -\log(2.6x10^{-4}) = 3.59 \rightarrow pH = 14 - 3.59 = 10.41$

Information: Strong Acids and Bases

Acids and bases are called "strong" if they dissociate completely (or almost completely) in water. For example, hydrochloric acid (HCl) exists almost completely as H^+ ions and Cl^- ions in water. Therefore HCl is a strong acid. If you put 2.0 moles of HCl in water, the HCl will dissociate and you will end up having about 2.0 moles of H^+ and 2.0 moles of Cl^- in the water. Each HCl molecule breaks up into two ions when dissolved: $HCl \rightarrow H^+ + Cl^-$. For every mole of HCl added to water, you will get one mole of H^+.

Critical Thinking Questions

5. Consider a strong acid like HCl. If the concentration of the acid is 0.025 M, what is the concentration of hydrogen ions? Explain your reasoning.
   0.025 M because all of the HCl breaks up into H^+ and Cl^- ions.

6. Consider a strong base such as NaOH. If the concentration of the base is 0.75 M, what is the concentration of the hydroxide ions? Explain.
   For a strong base, $[OH^-]$ = [base]. Therefore, here the $[OH^-]$ = 0.75 M

7. What is the pH of a solution that has a concentration of HCl equal to 0.0049 M?
   $[H^+]$ = [HCl] = [0.0049]; pH = -log(0.0049) = 2.31

8. If 2.5 moles of HCl were dissolved in 42 L of water, what would the pH be? What would the pOH be?
   $[H^+]$ = [HCl] = 2.5mol ÷ 42L = 0.595 M
   pH = -log(0.595) = 0.23
   pOH = 14 – 0.23 = 13.77

9. The strong base, NaOH, was dissolved in water. If 4.2 moles of NaOH was dissolved in 245 L of water, what is the pH of the solution?
   $[OH^-]$ = [NaOH] = 4.2mol ÷ 245L = 0.017 M; pOH = -log(0.017) = 1.77
   pH = 14 – 1.77 = 12.23

Information: Weak Acids and Bases

Weak acids and bases do not dissociate completely in water. For example, consider acetic acid ($HC_2H_3O_2$):

$$HC_2H_3O_2 \leftrightarrow H^+ + C_2H_3O_2^- ;\ K_a = 1.7x10^{-5}$$

For HCl, the concentration of HCl equaled the concentration of H^+ so finding the pH was easy. However, for acetic acid, $[HC_2H_3O_2]$ does not equal $[H^+]$ because not all of the $HC_2H_3O_2$ dissociates into H^+ ions. To find the pH of a solution of acetic acid, you first must calculate the $[H^+]$ using the K_a. This will be an equilibrium problem! Once you know $[H^+]$, you calculate pH using pH = -log$[H^+]$.

Critical Thinking Questions

10. What is the pH of a solution that was 0.75 M acetic acid? (Note: 0.75 M is the initial concentration of acetic acid.)
    a) Find the equilibrium concentration of H^+ using the equilibrium constant, K_a, as shown below. Recall that $[C_2H_3O_2^-]$ and $[H^+]$ will equal "x" and $[HC_2H_3O_2]$ will equal 0.75-x.

$$K_a = \frac{[C_2H_3O_2^-][H^+]}{[HC_2H_3O_2]}$$

$$1.7x10^{-5} = \frac{[x][x]}{[0.75 - x]} \rightarrow 1.7x10^{-5} = \frac{x^2}{0.75} \rightarrow x = 0.036 = [H^+]$$

    b) Now that you know the equilibrium concentration of H^+, calculate the pH.
       pH = -log(0.036) = **2.45**

11. Find the pH of a 0.85 M solution of hydrocyanic acid, HCN, whose $K_a = 4.9x10^{-10}$.

pH = 4.69

$$K_a = \frac{[CN^-][H^+]}{[HCN]} = \frac{(x)(x)}{(0.85-x)}$$

$$4.9x10^{-10} = \frac{x^2}{0.85} \rightarrow x = 2.04x10^{-5} = [H^+]$$

$$pH = -\log(2.04x10^{-5}) = 4.69$$

12. Find the pH of a 0.5 M solution of ammonia, NH_3, whose K_b is $1.8x10^{-5}$.

pH = 11.48

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} \rightarrow 1.8x10^{-5} = \frac{(x)(x)}{(0.5 - x)} \rightarrow x = 0.003\ M = [OH^-]$$

$$pOH = -\log(0.003) = 2.52$$
$$pH = 14 - 2.52 = 11.48$$