Math Tutor — Using Logarithms and pH

When you work with acids and bases, you often need to state the hydronium ion concentration, $[H_3O^+]$, of a solution. One common practice is to use the negative logarithm of $[H_3O^+]$. This quantity is called *pH*. For example, pure water has a $[H_3O^+]$ of 1.0×10^{-7} M. So the pH of pure water is $-\log(1.0 \times 10^{-7}\ M) = 7.00$. A solution of 0.10 M HCl has a pH of 1.00, or $pH = -\log(1.0 \times 10^{-1}) = 1.00$. The term *pOH* is also used for the negative logarithm of the hydroxide ion concentration, $[OH^-]$. The pOH of pure water is also 7.00.

Problem-Solving TIPS

- For pure water at 25°C, $[H_3O^+] = [OH^-] = 1.00 \times 10^{-7}$ M.
- The ionization constant of water, K_w, is the product of $[H_3O^+]$ and $[OH^-]$, so $K_w = [H_3O^+][OH^-] = (1.00 \times 10^{-7})(1.00 \times 10^{-7}) = 1.00 \times 10^{-14}$ at 25°C.
- If you know either $[H_3O^+]$ or $[OH^-]$, you can determine the other concentration.
- In terms of pH and pOH, $pH + pOH = 14.00$ for an aqueous solution at 25°C.
- Because pH calculations involve scientific notation and changes in signs, you should always check to see if answers make sense.

Sample Problem

What is the pH of a 0.0046 M solution of KOH?

KOH is completely dissociated into equal numbers of $K^+(aq)$ and $OH^-(aq)$. The concentration of OH^- is the same as the concentration of dissolved KOH, 0.0046 M. So $[OH^-] = 4.6 \times 10^{-3}$ M, and $pOH = -\log(4.6 \times 10^{-3}\ M) = 2.34$.
For an aqueous solution at 25°C, $pH + pOH = 14.00$, so $pH + 2.34 = 14.00$.
Therefore, the pH of 0.0046 M KOH solution $= 14.00 - 2.34 = 11.66$.

What is the hydronium ion concentration, $[H_3O^+]$, of a solution with a pH of 4.08? What is the pOH of the solution?

In this solution, $\log [H_3O^+] = -4.08$

$[H_3O^+] = \text{antilog}(-4.08) = 0.000\,083\ M = 8.3 \times 10^{-5}\ M$

The pOH of the solution is $14.00 - pH = 14.00 - 4.08 = 9.92$.

Practice

Answers in Appendix E

1. What is the pH of a 0.000 85 M solution of nitric acid, HNO_3, which is a strong acid?
2. What is the hydroxide ion concentration of an aqueous solution that has a pH of 9.95?

CHAPTER 15 Summary

BIG IDEA A solution's pH is a measure of its hydronium ion concentration and is used to rate its acidity.

SECTION 1 Aqueous Solutions and the Concept of pH

- Pure water undergoes self-ionization to give 1.0×10^{-7} M H_3O^+ and 1.0×10^{-7} M OH^- at 25°C.
- $pH = -\log[H_3O^+]$; $pOH = -\log[OH^-]$; at 25°C, pH + pOH = 14.0.
- At 25°C, acids have a pH of less than 7, bases have a pH of greater than 7, and neutral solutions have a pH of 7.
- If a solution contains a strong acid or a strong base, the $[H_3O^+]$, $[OH^-]$, and pH can be calculated from the molarity of the solution. If a solution contains a weak acid or a weak base, the $[H_3O^+]$ and the $[OH^-]$ must be calculated from an experimentally measured pH.

KEY TERMS

self-ionization of water
pH
pOH

SECTION 2 Determining pH and Titrations

- The pH of a solution can be measured using either a pH meter or acid-base indicators.
- Titration uses a solution of known concentration to determine the concentration of a solution of unknown concentration.
- To determine the end point of a titration, one should choose indicators that change color over ranges that include the pH of the equivalence point.
- When the molarity and volume of a known solution used in a titration are known, then the molarity of a given volume of an unknown solution can be found.

KEY TERMS

acid-base indicators
transition interval
pH meter
titration
equivalence point
end point
standard solution
primary standard

CHAPTER 15 Review

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SECTION 1

Aqueous Solutions and the Concept of pH

REVIEWING MAIN IDEAS

1. Why is pure water a very weak electric conductor?

2. What does it mean when the formula of a particular ion or molecule is enclosed in brackets?

3. **a.** What is the $[H_3O^+]$ of pure water at 25°C?
   b. Is this true at all temperatures? Why or why not?

4. **a.** What is always true about the $[H_3O^+]$ value of acidic solutions?
   b. What is true about the $[H_3O^+]$ value of acidic solutions at 25°C?

5. **a.** Describe what is meant by the pH of a solution.
   b. Write the equation for determining pH.
   c. Explain and illustrate what is meant by the common logarithm of a number.

6. Identify each of the following solutions that are at 25°C as acidic, basic, or neutral:
   a. $[H_3O^+] = 1.0 \times 10^{-7}$ M
   b. $[H_3O^+] = 1.0 \times 10^{-10}$ M
   c. $[OH^-] = 1.0 \times 10^{-7}$ M
   d. $[OH^-] = 1.0 \times 10^{-11}$ M
   e. $[H_3O^+] = [OH^-]$
   f. pH = 3.0
   g. pH = 13.0

7. Arrange the following common substances in order of increasing pH:
   a. eggs
   b. apples
   c. tomatoes
   d. milk
   e. bananas
   f. potatoes
   g. lemons
   h. milk of magnesia
   i. seawater

PRACTICE PROBLEMS

8. Calculate the $[H_3O^+]$ and $[OH^-]$ for each of the following. (Hint: See Sample Problem A.)
   a. 0.030 M HCl
   b. 1.0×10^{-4} M NaOH
   c. 5.0×10^{-3} M HNO_3
   d. 0.010 M $Ca(OH)_2$

9. Determine the pH of each of the following solutions. (Hint: See Sample Problem B.)
   a. 1.0×10^{-2} M HCl
   b. 1.0×10^{-3} M HNO_3
   c. 1.0×10^{-5} M HI
   d. 1.0×10^{-4} M HBr

10. Given the following $[OH^-]$ values, determine the pH of each solution.
   a. 1.0×10^{-6} M
   b. 1.0×10^{-9} M
   c. 1.0×10^{-2} M
   d. 1.0×10^{-7} M

11. Determine the pH of each solution.
   a. 1.0×10^{-2} M NaOH
   b. 1.0×10^{-3} M KOH
   c. 1.0×10^{-4} M LiOH

12. Determine the pH of solutions with each of the following $[H_3O^+]$. (Hint: See Sample Problem C.)
   a. 2.0×10^{-5} M
   b. 4.7×10^{-7} M
   c. 3.8×10^{-3} M

13. Given the following pH values, determine the $[H_3O^+]$ for each solution. (Hint: See Sample Problem D.)
   a. 3.0
   b. 7.00
   c. 11.0
   d. 5.0

14. Given the following pH values, determine the $[OH^-]$ for each solution.
   a. 7.00
   b. 11.00
   c. 4.00
   d. 6.00

15. Determine $[H_3O^+]$ for solutions with the following pH values. (Hint: See Sample Problem E.)
   a. 4.23
   b. 7.65
   c. 9.48

16. A nitric acid solution is found to have a pH of 2.70. Determine each of the following:
   a. $[H_3O^+]$
   b. $[OH^-]$
   c. the number of moles of HNO_3 required to prepare 5.50 L of this solution
   d. the mass of HNO_3 in the solution in part (c)
   e. the milliliters of concentrated acid needed to prepare the solution in part (c) (Concentrated nitric acid is 69.5% HNO_3 by mass and has a density of 1.42 g/mL.)

SECTION 2

Determining pH and Titrations

REVIEWING MAIN IDEAS

17. What is meant by the transition interval of an indicator?

18. Explain how changes in pH affect the color of an indicator.

19. **a.** Without using an indicator, how can you determine the equivalence point of a titration experiment or the pH of a solution?
b. What can be observed about the rate of change of the pH of a solution near the end point of a titration?

20. **a.** What is meant by the end point of a titration?
b. What is the role of an indicator in the titration process?
c. On what basis is an indicator selected for a particular titration experiment?

21. For each of the four possible types of acid-base titration combinations (strong-strong, strong-weak, etc.), indicate the approximate pH at the end point. Also name a suitable indicator for detecting that end point.

22. Use **Figures 2.7a** and **2.7b** to sketch the pH curve of a strong acid being titrated by a weak base.

23. An unknown solution is colorless when tested with phenolphthalein but causes the indicator phenol red to turn red. Use this information to find the approximate pH of this solution.

PRACTICE PROBLEMS

24. For each of the following acid-base titration combinations, determine the number of moles of the first substance listed that would be the chemically equivalent amount of the second substance.
a. NaOH with 1.0 mol HCl
b. HNO_3 with 0.75 mol KOH
c. $Ba(OH)_2$ with 0.20 mol HF
d. H_2SO_4 with 0.90 mol $Mg(OH)_2$

25. Suppose that 15.0 mL of 2.50×10^{-2} M aqueous H_2SO_4 is required to neutralize 10.0 mL of an aqueous solution of KOH. What is the molarity of the KOH solution? (Hint: See Sample Problem F.)

26. In a titration experiment, a 12.5 mL sample of 1.75×10^{-2} M $Ba(OH)_2$ just neutralized 14.5 mL of HNO_3 solution. Calculate the molarity of the HNO_3 solution.

Mixed Review

REVIEWING MAIN IDEAS

27. **a.** What is the $[OH^-]$ of a 4.0×10^{-4} M solution of $Ca(OH)_2$?
b. What is the $[H_3O+]$ of the solution?

28. Given the following $[H_3O^+]$ values, determine the pH of each solution.
a. 1.0×10^{-7} M
b. 1.0×10^{-3} M
c. 1.0×10^{-12} M
d. 1.0×10^{-5} M

29. What is the $[H_3O^+]$ for a solution that has a pH of 6.0?

30. Suppose that a 5.0×10^{-5} M solution of $Ba(OH)_2$ is prepared. What is the pH of the solution?

31. **a.** Calculate the pH of a solution that has an $[H_3O^+]$ of 8.4×10^{-11} M.
b. Calculate the $[H_3O^+]$ of a solution that has a pH of 2.50.

32. **a.** What is the concentration of OH^- in a 5.4×10^{-5} M solution of magnesium hydroxide, $Mg(OH)_2$?
b. Calculate the concentration of H_3O+ for this solution.

33. **a.** Calculate the molarity of H_3O^+ in a solution that has a pH of 8.90.
b. Calculate the concentration of OH^- for this solution.

34. What is the pH of a solution in which $[OH^-]$ equals 6.9×10^{-10} M?

35. In a titration, 25.9 mL of 3.4×10^{-3} M $Ba(OH)_2$ neutralized 16.6 mL of HCl solution. What is the molarity of the HCl solution?

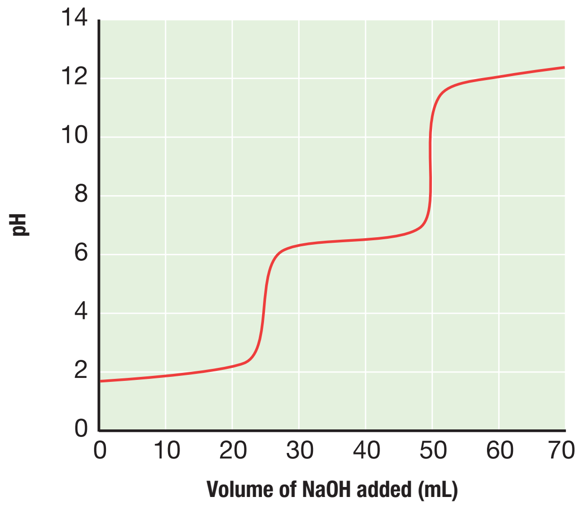
36. Find the molarity of a $Ca(OH)_2$ solution given that 428 mL of the solution is neutralized in a titration by 115 mL of 6.7×10^{-3} M HNO_3.

37. Suppose that 10.1 mL of HNO_3 is neutralized by 71.4 mL of a 4.2×10^{-3} M solution of KOH in a titration. Calculate the concentration of the HNO_3 solution.

CRITICAL THINKING

38. **Interpreting Graphics** The following titration curve resulted from the titration of an unknown acid with 0.10 M NaOH. Analyze the curve. Make inferences related to the type of acidic solution titrated.

Titration of an Unknown Acid



USING THE HANDBOOK

39. The normal pH of blood is about 7.4. When the pH shifts above or below that level, the results are acidosis or alkalosis. Review the section on blood pH in Group 14 of the *Elements Handbook* (Appendix A), and answer the following.
    a. What chemical species keep H_3O^+ in blood at the appropriate pH?
    b. What condition results when there is an excess of CO_2 in the blood?
    c. What is hyperventilation, and how does it affect blood pH?

RESEARCH AND WRITING

40. Examine the labels of at least five brands of shampoo. Note what is written there, if anything, regarding the pH of the shampoo. Do library research to find out why such pH ranges are chosen and why other ranges might be harmful to hair or eyes.

41. Acid rain is an environmental issue that crosses state and national boundaries. Conduct library research on this topic, and write a brief report. Include a description of the areas in the United States affected by acid rain and the geographical source of the sulfur and nitrogen oxides that are responsible for acid rain in each region.

ALTERNATIVE ASSESSMENT

42. **Performance** Use pH paper to determine the approximate pH of various brands of orange juice, which contains citric acid.

43. **Performance** Design and conduct an experiment to extract possible acid-base indicators from sources such as red cabbage, berries, and flower petals. Use known acidic, basic, and neutral solutions to test the action of each indicator that you are able to isolate.