Calculating pH

How is pH related to the concentration of hydronium ions?

Why?

In biology and other science courses pH is introduced as a way to quantify the acidity or basicity of a solution. This property can be measured using a pH probe or with an indicator paper strip that changes color at different pH values. But, what is actually being measured? We know that a pH of 7 is neutral, below 7 is acid, and above 7 is base, but why? What in the solution is the paper strip or probe actually reacting with?

Model 1 – Ion Concentrations for Acids and Bases

Beaker	Solution	Acidic, Basic or Neutral?	$[H_3O^+]$	$[OH^-]$	$[H_3O^+] \times [OH^-]$
1	0.10 M HCl(aq)	Acidic	1.0×10^{-1} M	1.0×10^{-13} M	
2	0.0010 M HCl(aq)	Acidic	1.0×10^{-3} M	1.0×10^{-11} M	
3	0.000010 M HCl(aq)	Acidic	1.0×10^{-5} M	1.0×10^{-9} M	
4	0.0000010 M HCl(aq)	Acidic	1.0×10^{-6} M	1.0×10^{-8} M	
5	0.00000010 M HCl(aq)	Neutral	1.0×10^{-7} M	1.0×10^{-7} M	
6	0.00000010 M NaOH(aq)	Neutral	1.0×10^{-7} M	1.0×10^{-7} M	
7	0.0000010 M NaOH(aq)	Basic	1.0×10^{-8} M	1.0×10^{-6} M	
8	0.00010 M NaOH(aq)	Basic	1.0×10^{-10} M	1.0×10^{-4} M	
9	0.010 M NaOH(aq)	Basic	1.0×10^{-12} M	1.0×10^{-2} M	
10	0.10 M NaOH(aq)	Basic	1.0×10^{-13} M	1.0×10^{-1} M	

1. What does the symbol $[H_3O^+]$ in Model 1 indicate?

2. In Beaker 2, which ion has a higher concentration, hydronium ion or hydroxide ion?

3. Describe how the concentration of hydronium ion was calculated for Beaker 3 in Model 1 from the concentration of the acid.

4. Describe how the concentration of hydroxide ion was calculated for Beaker 8 in Model 1 from the concentration of the base.

5. Which ion, hydronium or hydroxide, has a higher concentration in an acidic solution?

6. Which ion, hydronium or hydroxide, is more concentrated in a neutral solution?

7. Which statement is true for basic solutions?
   a. The hydroxide ion concentration must be less than 1.0×10^{-7} M.
   b. The hydroxide ion concentration must be more than 1.0×10^{-7} M.
   c. The hydroxide ion concentration must be more than or equal to 1.0×10^{-7} M.

8. A student makes the following statement on an exam: "Acidic solutions contain hydronium ions, while basic solutions contain hydroxide ions." Is the student's statement correct based on the information in Model 1? Explain.

9. Calculate the quantity $[H_3O^+] \times [OH^-]$ for each of the 10 beakers in Model 1. Divide the work among the members in your group.

10. If you know the hydronium ion concentration, $[H_3O^+]$, of a solution, how could you determine the hydroxide ion concentration, $[OH^-]$?

11. A solution has a hydroxide ion concentration of 1.0×10^{-3} M.
    a. What is the hydronium ion concentration in the solution? (Show your work.)

    b. Is the solution acidic, neutral or basic? How do you know?

12. A solution has a hydroxide ion concentration of 4.79×10^{-3} M.
    a. What is the hydronium ion concentration in the solution? (Show your work.)

    b. Is the solution acidic, neutral or basic? How do you know?

Read This!

The value 1.0×10^{-14} is the equilibrium constant for the autoionization of water (K_w).

$$H_2O \ + \ H_2O \rightleftarrows H_3O^+(aq) \ + \ OH^-(aq) \qquad\qquad K_w = 1.0\times10^{-14}$$

This equilibrium occurs in all aqueous solutions (acidic, basic, and neutral). The results of this equilibrium are as follows:

1. All aqueous solutions have some detectable concentration of both hydronium and hydroxide ions.
2. The product of these ion concentrations is always K_w.

$$K_w = [H_3O^+] \times [OH^-] = 1.0\times10^{-14}$$

Model 2 – A Crash Course in Logarithms

log 1	= 0	log 0.1	= –1
log 10	= 1	log 0.01	= –2
log 100	= 2	log 0.001	= –3
log 1000	= 3	log (1.0×10^{-4})	= –4
log (1.0×10^{4})	= 4	log (1.0×10^{-8})	= –8

13. Using the examples in Model 2, explain how logarithms are calculated in terms of "factors of ten."

14. What would be the logarithm of one million? (Do NOT use your calculator.)

15. Take out your scientific calculator.

    a. Enter at least three of the examples shown in Model 2 into your calculator to verify that you know how to find the logarithm of a number.

    b. Use your calculator to find the logarithm of 250.

    c. The number 250 is between 100 and 1000. Explain why your calculator gave you an answer between 2 and 3 for the log of 250. *Hint:* Think about "factors of ten."

16. First estimate the answer for each of the following. Then, find the answer using your calculator to check your estimate.

    a. 7800 *b.* 0.045 *c.* 3.4×10^{9} *d.* 7.2×10^{-4}

Model 3 – Logarithms and pH

	1	2	3	4
Solution	**$[H_3O^+]$ (Decimal notation)**	**$[H_3O^+]$ (Scientific notation)**	**log $[H_3O^+]$**	**pH**
A	0.010 M	1.0×10^{-2} M	$\log (1.0 \times 10^{-2}) = -2.0$	2.0
B	0.0055 M	5.5×10^{-3} M	$\log (5.5 \times 10^{-3})$	
C		1.0×10^{-3} M	$\log (1.0 \times 10^{-3}) = -3.0$	3.0
D	0.00010 M		$\log (1.0 \times 10^{-4}) = -4.0$	4.0
E	0.000027 M	2.7×10^{-5} M	$\log (2.7 \times 10^{-5})$	

17. Columns 1 and 2 in Model 3 both give the molar concentration of hydronium ion in solution.

    a. What is the difference in the way the first two columns express this data?

    b. Fill in the missing values in columns 1 and 2 of Model 3.

18. Estimate the missing logarithms for solutions B and E in Model 3. Then verify the answers using a calculator.

19. Using the examples given in Model 3, write a sentence or a mathematical equation that describes how to calculate pH from the hydronium ion concentration of a solution.

20. Fill in the missing pH values in column 4 of Model 3.

21. Calculate the pH of a solution that has a hydronium ion concentration of:

    a. 1×10^{-8} M

    b. 0.007 M

22. Discuss in your group how you would find the hydronium ion concentration in a solution if you were given the pH. Check your procedure using several examples from Model 3.

23. Calculate the hydronium ion concentration in solutions with a pH of:

    a. 6.0

    b. 5.43

24. Why does neutral water have a pH of 7?

25. Which solution has a greater hydronium ion concentration, one that has a pH of 4 or one that has a pH of 8? Explain.

26. A student makes the following statement on an exam:

"A solution with pH = 1 is twice as concentrated in hydronium ions as a solution with pH = 2."

Explain why this statement is not correct, and write a sentence that describes the correct relationship.

Extension Questions

Model 4 – pH and pOH

Solution	$[H_3O^+]$	$[OH^-]$	pH	pOH	pH + pOH
A	1×10^{-3} M	1×10^{-11} M	3.0	11.0	
B	1×10^{-9} M	1×10^{-5} M	9.0	5.0	
C	5.2×10^{-3} M	1.9×10^{-12} M	2.28	11.72	
D				3.68	
E			9.28		
F		3.02×10^{-3} M			

27. Look at the examples in Model 4. If you know the concentration of hydroxide ion, $[OH^-]$, in a solution, how can you determine the pOH?

28. Consider the data in Model 4.

    a. Calculate pH + pOH for solutions A, B and C.

    b. How could you determine the pH of a solution if you know the pOH?

29. Fill in all of the missing values in Model 4 .

30. Calculate the $[OH^-]$ and pOH of a solution that has a $[H_3O^+]$ of 1×10^{-4} M.