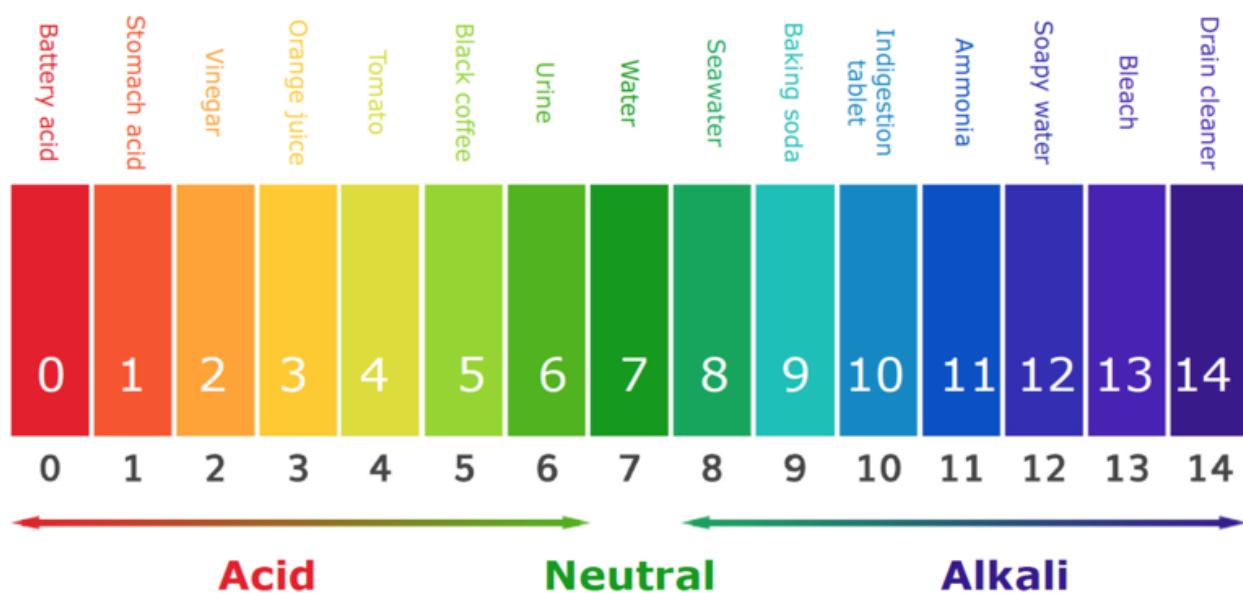


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Chapter3: Acids and Bases

Section 3: Hydrogen Ions and pH

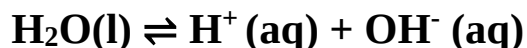


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Section 3: Hydrogen Ions and pH

Ion Product Constant for Water

- Pure water contains equal concentrations of H^+ and OH^- ions produced by self-ionization.



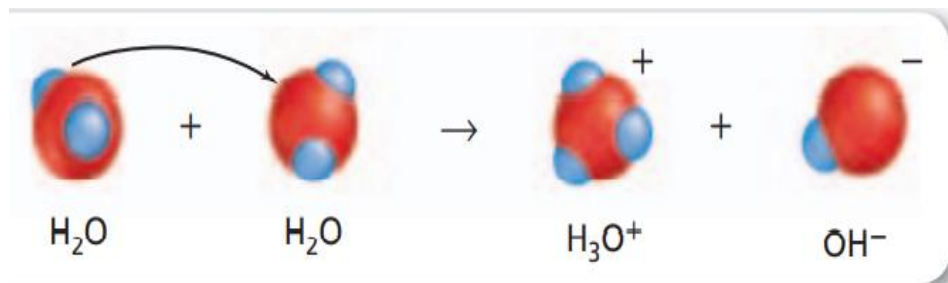
- **Writing K_w (The Ion Product Of Water)**

- The double arrow indicates that this is an equilibrium.
- The equilibrium constant expression is written by placing the concentrations of the products in the numerator and the concentrations of the reactants in the denominator.
- The concentration of pure water is constant, so $[\text{H}_2\text{O}]$ does not appear in the denominator.
- **$K_w = [\text{H}^+][\text{OH}^-]$**
- In dilute aqueous solutions, the product of the concentrations of the hydrogen ion and the hydroxide ion equals K_w .
- The ion product constant for water is the value of the equilibrium constant expression for the self-ionization of water.
- Experiments show that in pure water at 298 K, $[\text{H}^+]$ and $[\text{OH}^-]$ are both equal to $1.0 \times 10^{-7} \text{M}$. Therefore, at 298 K, the value of K_w is 1.0×10^{-14} .

$$K_w = [\text{H}^+][\text{OH}^-] = (1.0 \times 10^{-7})(1.0 \times 10^{-7})$$

$$K_w = 1.0 \times 10^{-14}$$

■ **Figure 18.13** In the self-ionization of water, one water molecule acts as an acid, and the other acts as a base.



K_w and Le Châtelier's Principle

- The product of $[\text{H}^+]$ and $[\text{OH}^-]$ always equals 1.0×10^{-14} at 298 K.
- This means that if the concentration of H^+ ions increases, the concentration of OH^- ions must decrease.

- Similarly, an increase in the concentration of OH⁻ ions causes a decrease in the concentration of H⁺ ions.
- According to Le Châtelier's principle adding extra hydrogen ions to water at equilibrium is a stress on the system.
- The system reacts in a way to relieve the stress. The added H⁺ ions react with OH⁻ ions to form more water molecules.
- Thus, the concentration of OH⁻ ions decreases.

For solving problems, you must use this relation.

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$$

$$[OH^-] = \frac{K_w}{[H^+]}$$

$$[H^+] = \frac{K_w}{[OH^-]}$$

1- Explain why Kw does not change when the concentration of hydrogen ions increases.

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2- Calculate [H⁺] and [OH⁻] Using Kw At 298 K, the H⁺ ion concentration in a cup of coffee is $1.0 \times 10^{-5} \text{M}$. What is the OH⁻ ion concentration in the coffee? Is the coffee acidic, basic, or neutral?

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3- The concentration of either the H⁺ ion or the OH⁻ ion is given for four aqueous solutions at 298 K. For each solution, calculate [H⁺] or [OH⁻]. State whether the solution is acidic, basic, or neutral.

a. $[H^+] = 1.0 \times 10^{-13} \text{M}$

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b . $[\text{OH}^-] = 1.0 \times 10^{-3} \text{ M}$

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c . $[\text{OH}^-] = 1.0 \times 10^{-7} \text{ M}$

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d. $[\text{H}^+] = 4.0 \times 10^{-5} \text{ M}$

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4- Challenge Calculate the number of H^+ ions and the number of OH^- ions in 300 mL of pure water at 298 K.

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pH and pOH

why do chemists express about concetration of H^+ ions by PH ?

- Concentrations of H^+ ions are often small numbers expressed in scientific notation.
- Because these numbers are cumbersome, chemists adopted an easier way to express H^+ ion concentrations.
- **What is pH?** Chemists express the concentration of hydrogen ions using a pH scale based on common logarithms.

- **The pH of a solution** is the negative logarithm of the hydrogen ion concentration.

$$\text{pH} = -\log [\text{H}^+]$$

- At 298 K, **acidic solutions** have pH values below 7.
- **Basic solutions** have pH values above 7.
- **Neutral solutions** have pH values equal to 7.
- Thus, a solution with a pH of 0.0 is strongly acidic; a solution with a pH of 14.0 is strongly basic.
- The logarithmic nature of the pH scale means that a change of one pH unit represents a tenfold change in ion concentration.
- A solution having a pH of 3.0 has ten times the hydrogen ion concentration of a solution with a pH of 4.0.
- **The pH scale and pH values of some common substances are shown in Figure.**

5- Determine whether seawater or detergent has a higher concentration of H^+ ions. How many times higher?

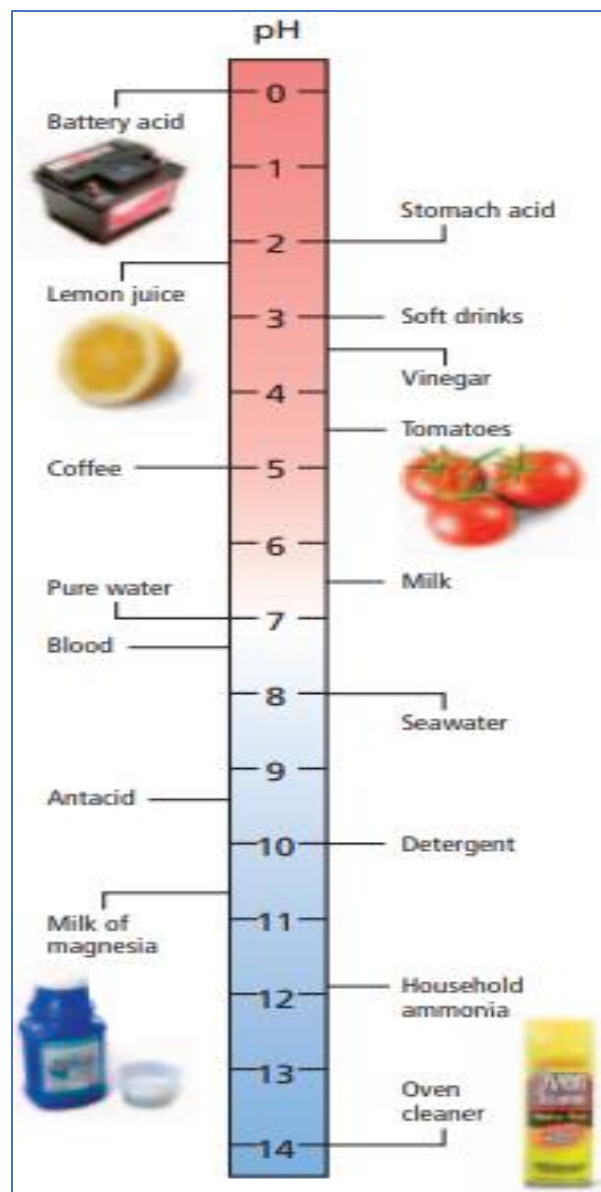
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6- How many times is the acidity of a solution of a pH of 5 more acidic than a solution of a pH of 6?

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What is pOH?

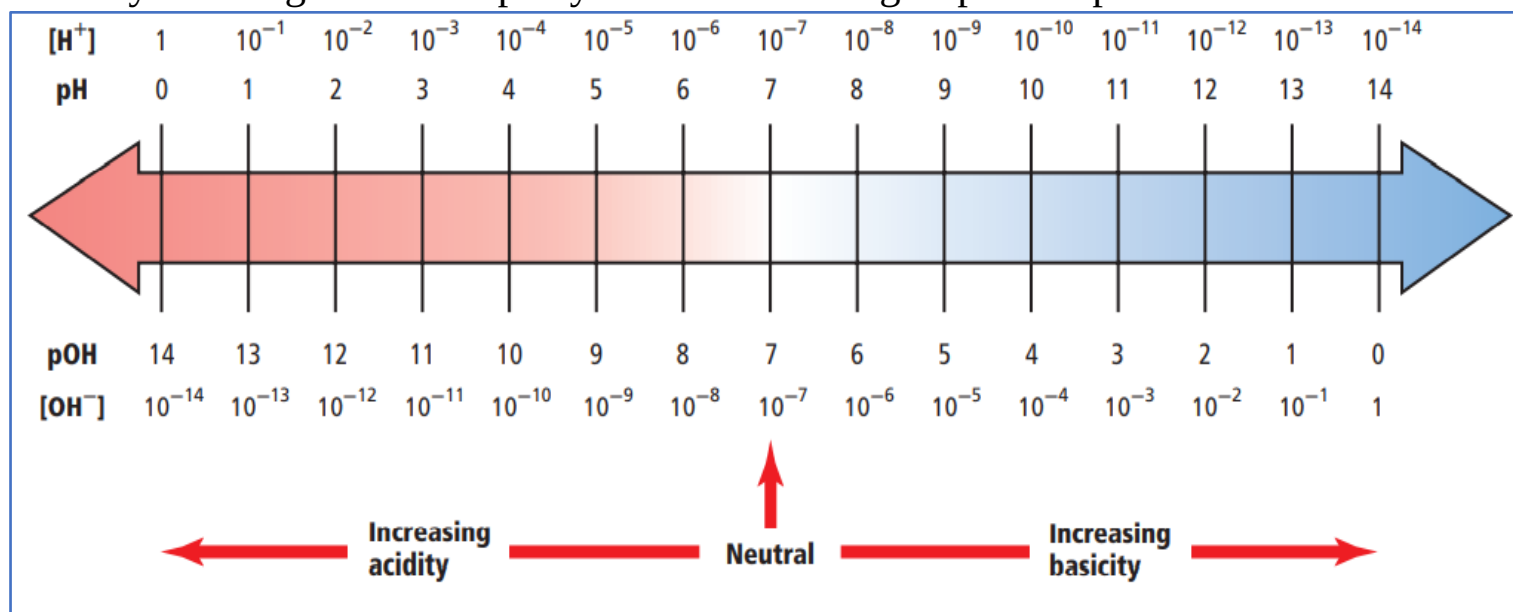
- Sometimes it is convenient to express the basicity or alkalinity of a solution on a pOH scale that mirrors the relationship between pH and $[\text{H}^+]$.
- **The pOH of a solution** is the negative logarithm of the hydroxide ion concentration.

$$\text{pOH} = -\log [\text{OH}^-]$$

- At 298 K, a solution with a pOH less than 7.0 is basic.
- A solution with a pOH of 7.0 is neutral.
- A solution with a pOH greater than 7.0 is acidic.
- The pH scale, a change of one pOH unit expresses a tenfold change in ion concentration.
- A simple relationship between pH and pOH makes it easy to calculate either quantity if the other is known.
- **How pH and pOH Are Related**
- **pH + pOH = 14.00**
- pH represents $-\log [H^+]$. pOH represents $-\log [OH^-]$.

7- How many times more basic is a solution with a pH of 11 greater than a solution of a pH of 9?

- The figure illustrates the relationship between pH and the H^+ concentration and the relationship between pOH and OH^- concentration at 298 K.
- Study this diagram to sharpen your understanding of pH and pOH.



- Note that at each vertical position, the sum of pH (above the arrow) and pOH (below the arrow) equals 14.
- Also note that at every position, the product of $[H^+]$ and $[OH^-]$ equals 10^{-14} .
- When the concentration of $[H^+]$ increases, the pH decreases.

8- Calculate pH from $[H^+]$ What is the pH of a neutral solution at 298 K?

9- Calculate the pH and pOH of solutions having the following ion concentrations at 298 K. Also calculate the $[OH^-]$

a. $[H^+] = 1.0 \times 10^{-2}M$

b. $[H^+] = 3.0 \times 10^{-6}M$

10- Calculate the pH and pOH of solutions having the following ion concentrations at 298 K. Also calculate the $[OH^-]$.

a. $[H^+] = 0.0055 M$

b. $[H^+] = 0.000084 M$

11- Challenge Calculate the pH and pOH of a solution having $[OH^-] = 8.2 \times 10^{-6}M$. Also calculate the $[H^+]$.

12- Calculate the pH and pOH of aqueous solutions with the following concentrations at 298 K. Also calculate the $[H^+]$ or $[OH^-]$.

a. $[OH^-] = 1.0 \times 10^{-6} \text{ M}$

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b. $[OH^-] = 6.5 \times 10^{-4} \text{ M}$

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c. $[H^+] = 3.6 \times 10^{-9} \text{ M}$

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d. $[H^+] = 2.5 \times 10^{-2} \text{ M}$

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13- Calculate the pH and pOH of aqueous solutions with the following concentration at 298 K. Also calculate the $[H^+]$ or $[OH^-]$.

a. $[OH^-] = 0.000033 \text{ M}$

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b. $[H^+] = 0.0095 \text{ M}$

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14- Challenge Calculate pH and pOH for an aqueous solution containing 1.0×10^{-3} mol of HCl dissolved in 5.0 L of solution. Also calculate the $[\text{OH}^-]$.

Calculating ion concentrations from pH

- Sometimes, you have to calculate the concentration of H^+ ions and OH^- ions from the pH of a solution.
- $\text{pH} = -\log [\text{H}^+]$ similarly $\text{pOH} = -\log [\text{OH}^-]$
- $-\text{pH} = \log [\text{H}^+]$ $-\text{pOH} = \log [\text{OH}^-]$
- $[\text{H}^+] = \text{antilog} (-\text{pH})$ $[\text{OH}^-] = \text{antilog} [\text{OH}^-]$

15- What are $[\text{H}^+]$, $[\text{OH}^-]$ and pOH in a healthy person's blood that has a pH of 7.40? Assume that the temperature of the blood is 298 K.

16- Calculate $[\text{H}^+]$, $[\text{OH}^-]$ and pOH in each of the following solutions.

a. Milk, pH = 6.50.

b. Lemon juice, pH = 2.37

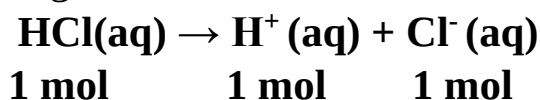
c. Milk of magnesia, pH = 10.50

d. Household ammonia, pH = 11.90

17- Challenge Calculate the $[H^+]$, $[OH^-]$ and pH in a sample of seawater with a pOH = 5.60.

Molarity and the pH of strong acids

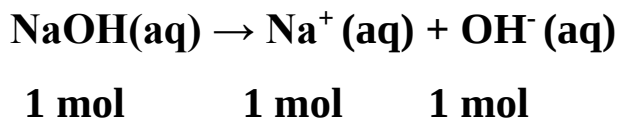
- Molarity is the number of moles of molecules or formula units in 1 L of solution.
- Recall that strong acids and bases are essentially 100% in the form of ions in solution.
- That means that the following reaction for the ionization of HCl goes to completion.



- Every HCl molecule produces one H^+ ion. 0.1M HCl contains 0.1 mol of H^+ ions per liter and 0.1 mol of Cl^- ions per liter.
- For all strong monoprotic acids, the concentration of the acid is the concentration of H^+ ions. Thus, you can use the molarity of the acid to calculate pH .

Molarity and the pH of strong bases

- Similarly, the 0.1M solution of the strong base NaOH is fully ionized.



- One formula unit of NaOH produces one OH^- ion. Thus, the concentration of the OH^- ions is the same as the molarity of the solution, 0.1M.
 - Calcium hydroxide $Ca(OH)_2$, contain two or more OH^- ions in each formula unit.
 - The concentration of OH^- ion in a solution of $Ca(OH)_2$ is twice the molarity of the ionic compound.
- $$\begin{array}{ccccc} \text{Ca(OH)}_2 \text{ (aq)} & \rightarrow & \text{Ca}^{2+} \text{ (aq)} & + & 2\text{OH}^- \text{ (aq)} \\ 1\text{mol} & & 1\text{mol} & & 2\text{mol} \end{array}$$

➤ For example, the concentration of hydroxide ions in a $7.5 \times 10^{-4}\text{M}$ solution of $\text{Ca}(\text{OH})_2$ is $7.5 \times 10^{-4}\text{M} \times 2 = 1.5 \times 10^{-3}\text{ M}$.

18- Calculate the pH of the following solutions.

a. 1.0M HI

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b. 0.050M HNO_3

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c. 1.0M KOH

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d. $2.4 \times 10^{-5}\text{M}$ $\text{Mg}(\text{OH})_2$

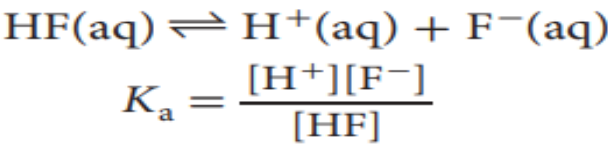
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- Strong acids and strong bases are completely ionized in dilute aqueous solutions.
- Weak acids and weak bases are only partially ionized.
- Therefore, you must use K_a and K_b values to determine the concentrations of H^+ and OH^- ions in solutions of weak acids and bases.
- Explain why you cannot obtain the $[\text{H}^+]$ directly from the molarity of a weak acid solution?

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Calculating Ka from pH

- Suppose you measured the pH of a 0.100M solution of the weak acid HF and found it to be 3.20. Would you have enough information to calculate Ka for HF?



- From the pH, you could calculate [H⁺]. [H⁺] = antilog (-pH)
- [H⁺] =[F⁻]
- That means you know two of the variables in the Ka expression.
- [HF] = (0.100M) – [H⁺].

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19- Calculate Ka , The pH of a 0.100M solution of formic acid (HCOOH) is 2.38. What is Ka for HCOOH?

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20- Calculate the Ka for the following acids using the given information.
a. 0.220M solution of H₃AsO₄, pH = 1.50 .

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b. 0.0400M solution of HClO_2 , $\text{pH} = 1.8033$.

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21- Calculate the K_a of the following acids using the given information.

a. 0.00330M solution of benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$), $\text{pOH} = 10.70$.

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b. 0.100M solution of cyanic acid (HCNO), $\text{pOH} = 11.00$.

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c. 0.150M solution of butanoic acid ($\text{C}_3\text{H}_7\text{COOH}$), $\text{pOH} = 11.18$ 34.

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22- Challenge Calculate the K_a of a 0.0091M solution of an unknown acid (HX) having a pOH of 11.32. Use Table to identify to a cid .

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Measuring pH

- The litmus paper is an example of a kind of pH paper.
- All pH paper is treated with one or more substances called indicators that change color depending on the concentration of hydrogen ions in a solution.
- Phenolphthalein is an example of an indicator. When a strip of pH paper is dipped into an acidic or a basic solution, the color of the paper changes.
- To determine the pH, the new color of the paper is compared with standard pH colors on a chart, as shown in Figure.
- The pH meter in Figure provides a more accurate measure of pH.
- When electrodes are placed in a solution, the meter gives a direct analog or digital readout of pH.

■ **Figure 18.18** The approximate pH of a solution can be obtained by wetting a piece of pH paper with the solution and comparing the color of the wet paper with a set of standard colors as shown in **a**. The portable pH meter in **b**, which is being used to measure the pH of rain water, provides a more accurate measurement in the form of a digital display of the pH.



Revision

1- Explain why the pH of an acidic solution is always a smaller number than the pOH of the same solution.

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2- Describe how you can determine the pH of a solution if you know its pOH.

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3- Explain the significance of K_w in aqueous solutions.

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4- Explain, using Le Châtelier's principle, what happens to the $[H^+]$ of a 0.10M solution of acetic acid when a drop of NaOH solution is added.

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5- List the information needed to calculate the K_a of a weak acid.

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6- Calculate The pH of a tomato is approximately 4.50. What are $[H^+]$ and $[OH^-]$ in a tomato?

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7- Determine the pH of a solution that contains 1.0×10^{-9} mol of OH^- ions per liter.

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8- Calculate the pH of the following solutions.

a. 1.0M HI

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b. 0.050M HNO₃

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c. 1.0M KOH

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d. 2.4×10^{-5} M Mg(OH)₂

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9- What happens to the [H⁺], [OH⁻], pH, and pOH as a neutral solution becomes more acidic? As a neutral solution become more basic?

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10- What is the relationship between the pOH and the OH⁻ ion concentration of a solution?

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11- Solution A has a pH of 2.0. Solution B has a pH of 5.0. Which solution is more acidic? Based on the H^+ ion concentrations in the two solutions, how many times more acidic?

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12- If the concentration of H^+ ions in an aqueous solution decreases, what must happen to the concentration of OH^- ions? Why?

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13- Use Le Châtelier's principle to explain what happens to the equilibrium $H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$ when a few drops of HCl are added to pure water.

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14- Common Acids and Bases Use the data in Table to answer the following questions.

a. Which substance is the most basic?

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b. Which substance is closest to neutral?

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c. Which has a concentration of $H^+ = 4.0 \times 10^{-10} M$?

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d. Which has a pOH of 11.0?

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e. How many times more basic is antacid than blood?

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Table 18.8 pH values	
Substance	pH
Household ammonia	11.3
Lemon juice	2.3
Antacid	9.4
Blood	7.4
Soft drinks	3.0

15- Given two solutions, 0.10M HCl and 0.10M HF, which solution has the greater concentration of H⁺ ions? Calculate pH values for the two solutions, given that [H⁺] = 7.9 × 10⁻³M in the 0.10M HF.

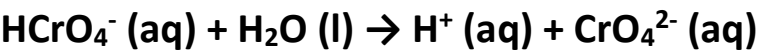
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16- Chromic acid is used as an industrial cleaner for metals. What is Ka for the second ionization of chromic acid (H₂CrO₄) if a 0.040M solution of sodium hydrogen chromate has a pH of 3.946?



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17- What is the pH of a 0.200M solution of hypobromous acid (HBrO)? Ka = 2.8 × 10⁻⁹

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18- Which of the following are polyprotic acids?

- a. H₃BO₃
- b. HNO₃
- c. CH₃COOH
- d. H₂SeO₃

19- The pH probe in Figure is immersed in a 0.200M solution of a monoprotic acid, HA, at 303 K. What is the value of Ka for the acid at 303 K? pH= 3.10



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20- An aqueous solution buffered by benzoic acid (C₆H₅COOH) and sodium benzoate (C₆H₅COONa) is 0.0500M in both compounds. Given that benzoic acid’s Ka equals 6.4 × 10⁻⁵ , what is the pH of the solution?

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21- You have 20.0 mL of a solution of a weak acid, HX, whose Ka equals 2.14 × 10⁻⁶ . The pH of the solution is found to be 3.800. How much distilled water would you have to add to the solution to increase the pH to 4.000?

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22- Choose the correct answer:

1- Hydrogen bromide (HBr) is a strong, highly corrosive acid. What is the pOH of a 0.0375M HBr solution?

- A. 12.574
- B. 12.270
- C. 1.733
- D. 1.433

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2- What is the pH of a 0.40M solution of HB $K_a= 3.55\times10^{-3}$?

- A. 2.06
- B. 2.45
- C. 1.22
- D. 1.42

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23- 5ml of HCl of 6.00 M is added to 95 ml of pure water and the final volume of the solution becomes 100 ml what is the pH of the solution?

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