Chapter 9

Advanced Chemistry

Key Terms

Acids
Alkalis
Anions
Cations
Hydrogen ion
Hydroxide ion
Ions
Logarithm
Oxidation
pH scale
Reduction

Learning Objectives

After completing this chapter, you should be able to:

- Understand acids, alkalis, and pH.
- Describe how pH influences the skin, scalp, and hair.
- Explain oxidation and reduction reactions.
- Describe how to safely handle corrosives and oxidizers.

INTRODUCTION

This chapter builds upon the concepts presented in Chapter 8, General Chemistry. The concepts of pH and oxidation-reduction are essential to haircoloring, permanent waving and chemical hair relaxers.

WATER AND pH

You may already know that the pH scale ranges from 0 to 14. A pH of 7 indicates a neutral solution, a pH below 7 indicates an acidic solution, and a pH above 7 indicates an alkaline solution. Although this says something about how pH is measured, it doesn't say anything about what pH is. You may also know that acids contract and harden the hair and alkalis soften and swell the hair. Although this says something about how the hair reacts to acids and alkalis, it still doesn't say anything about what pH really is.

We can't study pH without first learning a little about ions. An **ion** (EYE-on) is an atom or molecule with an electrical charge. When a molecule ionizes, it splits in two, creating a pair of ions with opposite electrical charges. An ion with a negative electrical charge is an **anion** (AN-eye-on). An ion with a positive electrical charge is a **cation** (KAT-eye-on). The pH scale measures ions.

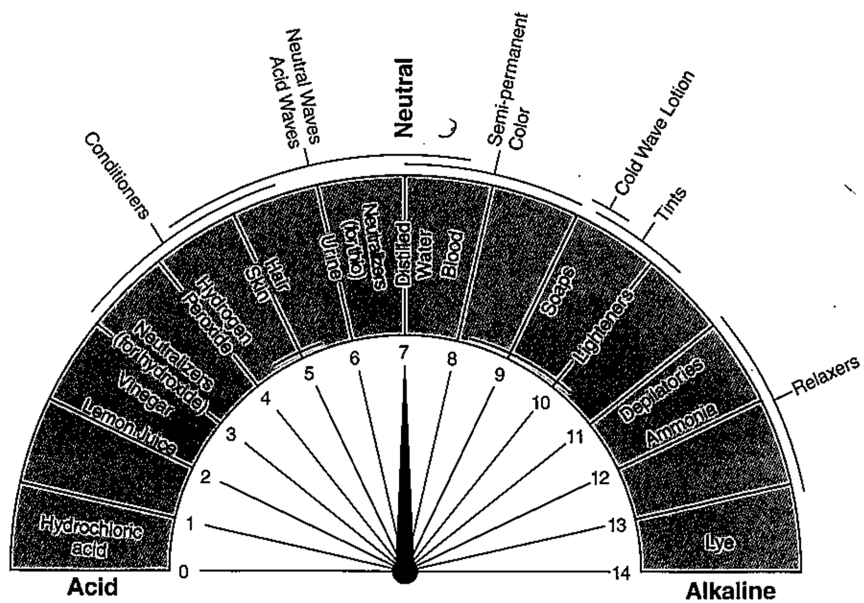


Figure 9-1 *Average pH values.*

Why is the pH of pure water neutral and what does that mean? A water molecule (H_2O) is composed of two hydrogen atoms and one oxygen atom. But some of the water molecules don't stay together as water molecules (H_2O). Because of the natural ionization of water, some of the water molecules (H_2O) ionize (split) into two separate ions: H^+ and OH. (See Fig. 9-2.)

A water molecule can be expressed as H_2O and the natural ionization of water can be expressed as:

$$H_2O \rightarrow H^+ + OH^-$$

That same water molecule can also be expressed as HOH, and the autoionization of water can be expressed as:

$$HOH \rightarrow H^+ + OH^-$$

The H^+ ion is the **hydrogen ion**, which is acidic. The OH^- ion is the **hydroxide ion**, which is alkaline. Every water molecule (H_2O) that ionizes yields one hydrogen ion (H^+) and one hydroxide ion (OH^-). Therefore, in pure water, the concentration of acid and alkaline must be equal, since each time a hydrogen ion is produced, a hydroxide ion is also produced. In pure water, no other combinations are possible. This natural ionization of water explains two important ideas.

1. pH is only possible because of the ionization of water. Only aqueous (water) solutions have pH. Non-aqueous solutions (oil and alcohol) do not have pH. Without water, pH is not possible.
2. Pure water isn't neutral because it's neither acidic nor alkaline. Pure water is neutral because it's an even balance of both. Pure water is neutral because it contains the same number of hydrogen ions (H^+) as hydroxide ions (OH^-). Pure water is 50 percent acidic and 50 percent alkaline.

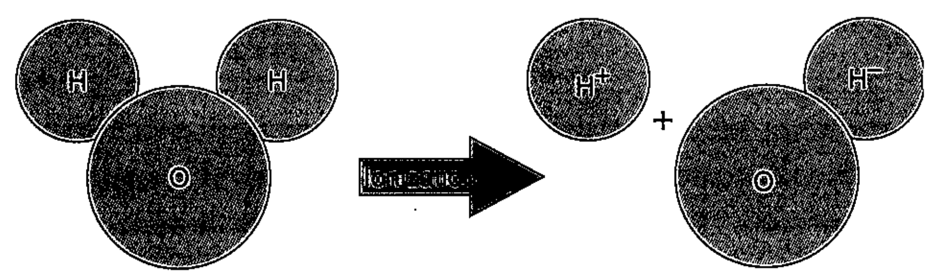


Figure 9-2 *The ionization of water into acid and alkali.*

THE pH SCALE

You may have heard the terms "parts hydrogen" or "potential hydrogen" used to describe the pH scale. Actually, the pH scale originates from the Danish term *potenz hydrogen* or "hydrogen strength" and was first proposed in 1909, by the Danish chemist S. P. L. Sorensen.

Scales are used to measure quantities. A ruler is a scale that is used to measure length. The **pH scale** measures acidity and alkalinity by measuring the concentration of hydrogen ions. The pH is the negative logarithm of the concentration of hydrogen ions. Notice that pH is written with a small "p" (which represents a quantity) and a capital "H". (which represents the hydrogen ion (H^+). The symbol pH represents the quantity of the hydrogen ion concentration.

Scientific notation is used to condense big numbers with many zeros. The number 1×10^{-7} is expressed in scientific notation and is the same number as .0000001, which is expressed as a decimal. Notice that in scientific notation the exponent is a seven. Also notice that the same number, expressed as a decimal, has seven decimal places. In scientific notation, a negative exponent is the same number as the number of decimal places and each decimal place indicates a tenfold change. If we add a dollar sign to numbers expressed as a decimal, $0.01 is a penny (one cent) and $0.10 is a dime (ten cents). One penny times ten equals one dime. (See Fig. 9-3)

The term **logarithm** (LOG-ah-rhythm) means multiples of ten. Since the pH scale is a logarithmic scale, a change of one whole number represents a tenfold change in pH. That means that a pH of 8 is ten times more alkaline than a pH of 7. A change of two whole numbers represents a change of ten times ten, or a one hundredfold change. That means that a pH of 9 is 100 times more alkaline than a pH of 7. A small change on the pH scale indicates a large change in the concentration of hydrogen and hydroxide ions.

The pH scale (Fig. 9-3) shows that the pH is simply the same number as the exponent, but without the minus sign. In scientific notation, the concentration of hydrogen ions in pure water is 1×10^{-7}. Notice that the exponent is seven, which is the pH of pure water. That means that the pH is the same number as the negative exponent in scientific notation. The pH of any solution is the exponent (of the hydrogen ion concentration) without the minus sign. Also notice that there is the same number of hydroxide ions (Fig. 9-3).

Regardless of pH, all aqueous solutions contain both acid (H^+) and alkaline (OH^-) ions. And although a pH of 6 is acidic, it is 10 times more alkaline than a pH of 5. Pure water, with a pH of 7, is 100 times more alkaline than a pH of 5. Since the average pH of hair and skin is also 5, pure water is 100 times more alkaline than your hair and skin, even though it has a neutral pH (Fig. 9-4). Pure water can cause the hair to swell as much as 20 percent.

Alkalinity increases as the pH increases and decreases as the pH decreases. That means that a higher pH (bigger number) is more alkaline than a lower pH

	The pH Scale H^+			
	H^+ Hydrogen Ion		OH^- Hydroxide Ion	
pH	Exponential Notation	With Decimal	Exponential Notation	With Decimal
0	1×10^{-0}	1.	1×10^{-14}	.00000000000001
1	1×10^{-1}	.1	1×10^{-13}	.0000000000001
2	1×10^{-2}	.01	1×10^{-12}	.000000000001
3	1×10^{-3}	.001	1×10^{-11}	.00000000001
4	1×10^{-4}	.0001	1×10^{-10}	.0000000001
5	1×10^{-5}	.00001	1×10^{-9}	.000000001
6	1×10^{-6}	.000001	1×10^{-8}	.00000001
7	1×10^{-7}	.0000001	1×10^{-7}	.0000001
8	1×10^{-8}	.00000001	1×10^{-6}	.000001
9	1×10^{-9}	.000000001	1×10^{-5}	.00001
10	1×10^{-10}	.0000000001	1×10^{-4}	.0001
11	1×10^{-11}	.00000000001	1×10^{-3}	.001
12	1×10^{-12}	.000000000001	1×10^{-2}	.01
13	1×10^{-13}	.0000000000001	1×10^{-1}	.1
14	1×10^{-14}	.00000000000001	1×10^{-0}	1.

Figure 9-3 *The quantities of the pH scale expressed as pH, exponential notation, and with a decimal point.*

(smaller number). On the other hand, acidity increases as pH decreases. That means that a lower pH (smaller number) is more acidic than a higher pH (bigger number).

The pH scale only measures acidity (the hydrogen ion). The pH scale does not measure alkalinity (the hydroxide ion) directly, but it is understood because alkalinity increases as acidity decreases. Adding the exponents or decimal places across at any pH always totals 14 (Fig. 9-3).

ACIDS AND THE HYDROGEN ION (H^+)

All **acids** owe their chemical reactivity to the **hydrogen** (HY-droh-jen) **ion** (H^+). The word acid comes from the Latin acidus, meaning sour or tart. Acids contract and harden the hair (Fig. 9-4). Acids taste sour, turn litmus paper from blue to red, and react with akalis to form water and salts. Acids contract and harden the hair. Hydrochloric acid (HCI), commonly known as muratic acid, is a strong acid.

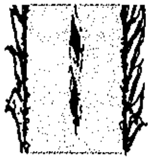
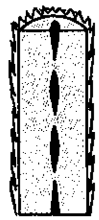
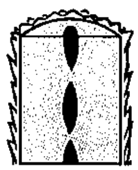
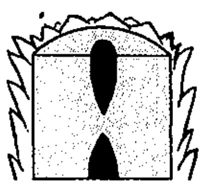
Solution	Effect on Hair		Important Features
Very Strong Acid (pH 0.0 – 1.0)		Dissolves hair completely.	Must not be applied to hair or scalp.
Strong to Mild Acid (pH 1.0 – 4.5)		Hair shrinks and hardens. Body is increased. Cuticle imbrications close up. Porosity is reduced. Sheen of hair is improved. Soap residues are removed. Neutralizes traces of alkalies.	Acid or cream rinses restore body to bleached, porous hair. Conditioners and fillers overcome the excess porosity of damaged hair. Special shampoos reduce tangling and matting of hair and prevent color loss. Hair creams increase sheen. Color rinses provide temporary effect. Neutralizers remove residual waving lotion.
Neutral (pH 4.5 – 5.5)		Hair is normal diameter. Texture and luster standard.	Neutral solutions are designed to prevent excess swelling of normal and damaged hair. Mild shampoos for normal cleaning and manageability of hair.
Mild Alkali (pH 5.5 – 10.0)		Hair swells. Porosity increases as imbrications open. Hair has a dry, drab appearance.	Tints and bleaches penetrate easier and chemical action increases. Cold wave solutions for resistant hair. Soap shampoos to overcome acidity of tap water. Activators for hydrogen peroxide.
Stronger Alkali (pH 10.0 – 14.0)		Dissolves hair completely	Must not be applied to hair or scalp unless used as relaxers or depilatories.

Figure 9-4 *The effect of pH on hair.*

Thioglyocolatic acid is used in permanent waving.

ALKALIS, BASES, AND THE HYDROXIDE ION (OH^-)

All alkalis owe their chemical reactivity to the **hydroxide** (hy-DRAHKS-eyd) *ion* (OH^-). Although cosmetology still uses the term *alkali*, the scientific community usually uses the term *base*. The terms *alkali*, *alkaline*, *base*, and *basic* are interchangeable. Alkalis soften and swell the hair (Fig 9-4). Alkalis taste bitter, turn litmus paper from red to blue, feel slippery and soapy on the skin, and react with acids to form water and salts. Sodium hydroxide (NaOH), commonly known as lye, is a strong alkali used in chemical drain cleaners and chemical hair relaxers (see Chapter 14, Chemical Hair Relaxers and Soft Curl Permanents).

The Strengths of Acids and Alkalis

The hydrogen ion (H^+) is responsible for all acid reactions. The hydroxide ion (OH^-) is responsible for all alkaline reactions. The strength of different acids and alkalis is due to their degree of ionization in water. Strong acids and alkalis ionize almost completely and produce more ions. Weak acids and alkalis do not ionize completely and do not produce as many ions. Regardless of their strength, all acids produce hydrogen ions (H^+) and all alkalis produce hydroxide ions (OH^-). The only difference between strong acids and alkalis and weak acids and alkalis is the number of ions they produce.

Acid-Alkali Neutralization Reactions

When acids and alkalis are mixed together in equal proportions, they neutralize each other to form water and a salt. Although hydrochloric acid is a strong acid and sodium hydroxide is a strong alkali, if they are mixed together in exactly equal proportions, they form a solution of pure water and table salt. The neutralization reaction of hydrochloric acid (HCl) and sodium hydroxide (NaOH) to form salt water is shown below.

$$HCl + NaOH \rightarrow H_2O + \mathbf{NaCl}$$

(or)

$$HCl + NaOH \rightarrow \mathbf{HOH} + NaCl$$

OXIDATION-REDUCTION (REDOX) REACTIONS

The original discovery of **oxidation** reactions involved the chemical combination of any element or compound with oxygen to produce an oxide. When oxygen combines with another element, some heat is almost always produced. Chemical reactions that produce heat are called **exothermic** ("exo" means outside and "thermic" means heat). Exothermic permanent waves produce heat because of an oxidation reaction that results when the activator tube, which contains hydrogen peroxide, is added to the permanent wave solution (see Chapter 13, Permanent Waving).

Slow oxidation occurs in oxidation haircolors and permanent wave neutralizers. If you pay close attention, you will notice an increase in the temperature of oxidation haircolors after the peroxide is added. *Combustion* is a *rapid oxidation* reaction that produces a high quantity of heat and light. Lighting a match is an example of rapid oxidation. Remember, you can't have a fire without oxygen.

When oxygen is combined with a substance, the substance is oxidized. When oxygen is removed from a substance, the substance is **reduced**. Oxidizing agents are substances that readily release oxygen. Hydrogen peroxide is an oxidizing agent because it contains "extra" oxygen. When hydrogen peroxide is mixed with an oxidation haircolor, the haircolor gains oxygen and is oxidized. At the same time, the hydrogen peroxide loses oxygen and the hydrogen peroxide is reduced. In this example, haircolor is the reducing agent.

Oxidation and reduction always occur simultaneously and are referred to as *redox* reactions. Oxidation cannot happen without reduction. In a redox reaction, the oxidizer is always reduced and the reducing agent is always oxidized.

So far, we have considered oxidation only as the addition of oxygen, and reduction only as the loss of oxygen. Although the first known oxidation reactions involved oxygen, many oxidation reactions do not involve oxygen. Oxidation also results from the loss of hydrogen, and reduction also results from the addition of hydrogen.

Permanent waving is an example of this type of redox reaction. Permanent waving solution contains thioglycolic acid. Permanent wave solution breaks the disulfide bonds in the hair through a reduction reaction that adds hydrogen ions (H^+) to the hair. In this reaction, the hair is reduced and the perm solution is oxidized. Neutralizer then oxidizes the hair by removing the hydrogen that was previously added. When the hair is oxidized, the neutralizer is reduced (see Chapter 13, Permanent Waving).

For our purposes, **oxidation** can be defined as either the addition of oxygen or the loss of hydrogen. Conversely, **reduction** can be defined as either the loss of oxygen or the addition of hydrogen.

Review Questions

1. Define pH.
2. How much more acidic is pH 2 than pH 6?
3. What is the pH of an organic solvent that is insoluble in water?
4. Which is most dangerous to the skin or eyes: acids, bases, or corrosives? Why?
5. What is the importance of the skin's acid mantle?
6. What safety precautions should you take when using oxidizers?

Discussion Questions

1. Ask your instructor about the importance placed on safety when she or he attended cosmetology school. Is more importance placed on safety today than there was ten years ago?