Basic Science Concepts

Chapter 2

What Is In This Chapter?

1. Chemical characteristics of water
2. Elements
3. Compounds
4. Constituents in water
5. Biological characteristics of water
6. Disease and disease transmission

Key Words

- Aerobic
- Alkalinity
- Anaerobic
- Anion
- Aquatic
- Bacteria
- Cation
- Chemistry
- Colloidal
- Colloidal Solids
- Covalent Bond
- Disinfection
- Dissolved Solids
- Element
- Electromagnetism
- Facultative
- Fungi
- Gases
- Ion
- Ionization
- Liquids
- Matter
- Microorganisms
- Precipitate
- Protozoa
- Saturated Solution
- Solids
- Solute
- Solvent
- Spores
- Sterilization
- Suspended Solids
- Total Solids
- Turbidity
- Viruses
- Waterborne Pathogens

Introduction

The following material is provided as basic background information necessary to understand the components and processes associated with drinking water systems.

Material Depth

Care has been taken to maintain the depth of the material at the Level I operator. As a result, certain complicated concepts have been greatly simplified. One of the problems with simplification of complicated material is the chance that the reader may be misguided. If this should happen, we apologize.

Lesson Content

This lesson is divided into distinct areas:

- Chemical characteristics of water
- Biological characteristics of water

Chemical Characteristics of Water

Introduction

The Operator as Chemist

When you light a match to start a fire, when you take your first breath of fresh morning air, when you put sugar in a steaming cup of coffee, when you digest that delicious donut, when gasoline explodes to power your car, and when you add chlorine to water to make it safe, a chemical reaction takes place. You are dealing with the substances around you and the way those substances react with one another. You are as much a chemist as the person in a laboratory in a white coat with a test tube in hand. When you treat drinking water, you are also a chemist. You are working with substances and controlling the way they react with one another.

What is Chemistry?

[1] Chemistry – The study of substances and the changes they undergo.

Chemistry[1] can be really quite simple and something with which we all are involved. Chemistry is the study of substances and the changes they undergo. Many things in chemistry are familiar to us and have names with which we are familiar. But some things in the study of chemistry are not familiar, and we must use new words to describe these new things. The vocabulary of chemistry describes the structure and activities of the things with which we work. As we discuss the chemistry of water, you will start to learn this new vocabulary and use the new terms to describe and explain the things that you do every day.

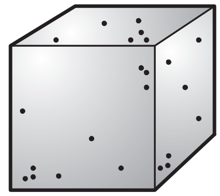
Matter

States of Matter

[2] Matter – Anything that has weight and occupies space.

Every day we come in contact with many kinds of **matter**[2]. Air, coffee, water, gasoline, chlorine, rocks, and paper are all different forms of matter. Matter is anything that has mass (weight) and occupies space. And that's just about everything, isn't it? But it's pretty obvious that all matter is not alike. However, we can put all matter into three large groups that are called the physical states of matter:

- **Solids**[3] have a definite shape with their particles closely packed together and sticking firmly to one another. A solid doesn't change its shape to fit a container. If you put a solid on the table, it would keep its shape and volume.

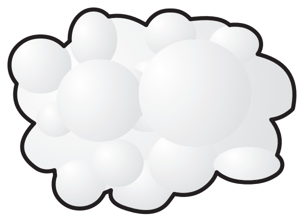


[3] Solids – Substances that maintain definite size and shape.

- **Liquids**[4] maintain a constant volume but will change shape to fit the shape of their container. The particles of the liquid move freely over one another but still stick together enough to maintain a constant volume. Pour water from a glass into a bowl. You have the same volume of water, but a different shape.

[4] Liquids – A definite volume, but not shape, that will fill containers to certain levels and form free-level surfaces.

- **Gases**[5] have no fixed shape and their volume can be expanded or compressed to fill different sizes of containers. The particles of gases do not stick together at all, and they move about freely, filling containers of any shape and size. The air around you and the helium in a balloon are examples of gases.



[5] Gases – Of neither definite volume nor shape, they completely fill any container in which they are placed.

Changing Matter

Matter can change in two different ways:

- **Physical changes** occur when matter changes its physical characteristics, such as its size, shape, density, as well as when it changes its state from a gas, to a liquid, to a solid. When ice melts or when a coffee cup breaks into pieces, a physical change has occurred.
- **Chemical changes** occur when new substances are formed that have entirely different properties and characteristics. When a match burns or iron rusts, a chemical change has occurred.

Review

1. Chemistry is the study of substances and the _______________ they undergo.

2. The three states of matter are:

3. Matter can change in two different ways:

The Elements – The Content of Matter

[6] Element – One of 106 fundamental substances that consist of atoms of only one kind and that singly or in combination constitute all matter.

Basic Building Blocks

All matter on earth is made up of pure basic substances or combinations of these basic substances. The basic substances, which cannot be broken down to simpler substances, are called **elements**[6]. There are 117 known elements, 94 of which occur naturally on earth. They range from simple, lightweight elements to very complex, heavy weight elements. Some of these elements exist in nature in pure form; others are combined. Many of the elements are quite familiar, for example: oxygen, chlorine, gold, carbon, iron, and calcium.

The Atom

If you take a small piece of an element, say aluminum, and subdivide it until you get to a tiny single unit of aluminum that cannot be divided any further and still be aluminum, you have an atom. An atom is the smallest unit of an element.

Element Symbols

For convenience, elements are often identified by one or two letters, called chemical symbols. Most of the time, the symbol is easily recognized as an abbreviation of the element name, such as C for carbon. Some symbols are not as easy to recognize because they refer to the element's Latin name, such as Fe for iron, whose Latin name is ferrum. A properly written element symbol is always capitalized, and if the symbol has two letters (such a Ca), the first letter is upper case and the second is lower case.

Review

1. A(n) _______________ is a basic substance that cannot be broken down any further without changing the nature of the substance.
2. A(n) ______________ is the smallest unit of an element.
3. Abbreviations, called chemical _____________, are used to identify the elements.

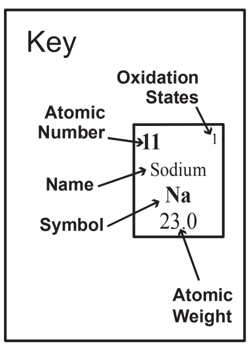
The Periodic Table

The elements are listed together on a chart called the Periodic Table of the Elements. The periodic table shows all the elements arranged in order of increasing atomic number. It also shows the name, symbol, atomic number, and atomic weight of each element and, on some periodic tables, a lot of other information about physical and chemical characteristics. The columns and rows of the periodic table show how the elements are related to one another. Metallic elements are on the left and the nonmetals are on the right. Elements next to each other are about the same size and weight. Elements in the same column have similar chemical reaction characteristics.

Periodic Table of the Elements

Period	Group IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	**1** 1 Hydrogen **H** 1.0																	**2** Helium **He** 4.0
2	**3** 1 Lithium **Li** 6.9	**4** 2 Beryllium **Be** 9.0											**5** 3 Boron **B** 10.8	**6** ±4,2 Carbon **C** 12.0	**7** ±3,5,4,2 Nitrogen **N** 14.0	**8** -2 Oxygen **O** 16.0	**9** -1 Fluorine **F** 19.0	**10** Neon **Ne** 20.2
3	**11** 1 Sodium **Na** 23.0	**12** 2 Magnesium **Mg** 24.3											**13** 3 Aluminum **Al** 27.0	**14** 4,2 Silicon **Si** 28.1	**15** ±3,5,4 Phosphorus **P** 31.0	**16** ±2,4,6 Sulfur **S** 32.1	**17** ±1,3,5,7 Chlorine **Cl** 35.5	**18** Argon **Ar** 39.9
4	**19** 1 Potassium **K** 39.1	**20** 2 Calcium **Ca** 40.1	**21** 3 Scandium **Sc** 45.0	**22** 4,3 Titanium **Ti** 47.9	**23** 5,4,3,2 Vanadium **V** 50.9	**24** 6,3,2 Chromium **Cr** 52.0	**25** 7,6,4,2,3 Manganese **Mn** 54.9	**26** 2,3 Iron **Fe** 55.8	**27** 2,3 Cobalt **Co** 58.9	**28** 2,3 Nickel **Ni** 58.7	**29** 2,1 Copper **Cu** 63.5	**30** 2 Zinc **Zn** 65.4	**31** 3 Gallium **Ga** 69.7	**32** 4 Germanium **Ge** 72.6	**33** ±3,5 Arsenic **As** 74.9	**34** -2,4,6 Selenium **Se** 79.0	**35** ±1,5,7 Bromine **Br** 79.9	**36** 0,2 Krypton **Kr** 83.8
5	**37** 1 Rubidium **Rb** 85.5	**38** 2 Strontium **Sr** 87.6	**39** 3 Yttrium **Y** 88.9	**40** 4 Zirconium **Zr** 91.2	**41** 5,3 Niobium **Nb** 92.9	**42** 6,5,4,3,2 Molybdenum **Mo** 95.9	**43** 7 Technitium **Tc** 98.9	**44** 2,3,4,6,8 Ruthenium **Ru** 101.0	**45** 2,3,4 Rhodium **Rh** 102.9	**46** 2,4 Palladium **Pd** 106.4	**47** 1 Silver **Ag** 107.9	**48** 2 Cadmium **Cd** 112.4	**49** 3 Indium **In** 114.8	**50** 4,2 Tin **Sn** 118.7	**51** ±3,5 Antimony **Sb** 121.8	**52** -2,4,6 Tellurium **Te** 127.6	**53** ±1,5,7 Iodine **I** 126.9	**54** 0,2,4,6 Xenon **Xe** 131.3
6	**55** 1 Cesium **Cs** 132.9	**56** 2 Barium **Ba** 137.3	**57** 3 Lanthanum **La** 138.9	**72** 4 Hafnium **Hf** 178.5	**73** 5 Tantalum **Ta** 180.9	**74** 6,5,4,3,2 Tungsten **W** 183.8	**75** 7,6,4,2,-1 Rhenium **Re** 186.2	**76** 2,3,4,6,8 Osmium **Os** 190.2	**77** 2,3,4,6 Iridium **Ir** 192.2	**78** 2,4 Platinum **Pt** 195.1	**79** 3,1 Gold **Au** 197.0	**80** 2,1 Mercury **Hg** 200.6	**81** 3,1 Thallium **Tl** 204.4	**82** 4,2 Lead **Pb** 207.2	**83** 3,5 Bismuth **Bi** 208.9	**84** 4,2,6 Polonium **Po** (210)	**85** ±1,3,5,7 Astatine **At** (210)	**86** 0,2 Radon **Rn** (222)
7	**87** 1 Francium **Fr** (223)	**88** 2 Radium **Ra** (226)	**89** 3 Actinium **Ac** (227)	**104** Rutherfordium **Rf** 1.0	**105** Dubnium **Db** (262)	**106** Seaborgium **Sg** 263	**107** Bohrium **Bh** 262	**108** Hassium **Hs** 265	**109** Meitnerium **Mt** (266)	**110** ---- -- 0	**111** ---- -- 0	**112** ---- -- 0		**114** ---- -- 0		**116** ---- -- 0		**118** ---- -- 0

Series														
Lanthanide Series 6	**58** 3,4 Cerium **Ce** 140.1	**59** 3,4 Praseodymium **Pr** 140.9	**60** 3 Neodymium **Nd** 144.2	**61** 3 Promethium **Pm** (145)	**62** 3,2 Samarium **Sm** 150.4	**63** 3,2 Europium **Eu** 152.0	**64** 3 Gadolinium **Gd** 157.2	**65** 3,4 Terbium **Tb** 158.9	**66** 3 Dysprosium **Dy** 162.5	**67** 3 Holmium **Ho** 164.9	**68** 3 Erbium **Er** 167.3	**69** 3,2 Thulium **Tm** 168.9	**70** 3,2 Ytterbium **Yb** 173.0	**71** 3 Lutetium **Lu** 175.0
Actinide Series 7	**90** 4 Thorium **Th** 232.0	**91** 5,4 Protactinium **Pa** (231)	**92** 6,5,4,3 Uranium **U** 238.0	**93** 6,5,4,3 Neptunium **Np** (237)	**94** 6,5,4,3 Plutonium **Pu** (242)	**95** 6,5,4,3 Americium **Am** (243)	**96** 3 Curium **Cm** (247)	**97** 4,3 Berkelium **Bk** (249)	**98** Californium **Cf** (251)	**99** 3 Einsteinium **Es** (254)	**100** 3 Fermium **Fm** (253)	**101** 3 Mendelevium **Md** (256)	**102** 2,3 Nobelium **No** (254)	**103** 3 Lawrencium **Lr** (257)



The Operator's Element List

Water operators routinely work with about a third of the elements. A list of these is shown below.

Element	Symbol
Aluminum	Al
Arsenic	As
Barium	Ba
Bromine	Br
Cadmium	Cd
Calcium	Ca
Carbon	C
Chlorine	Cl
Chromium	Cr
Copper	Cu
Fluoride	F
Gold	Au
Helium	He
Hydrogen	H
Iodine	I
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn
Mercury	Hg
Nitrogen	N
Nickel	Ni
Oxygen	O
Phosphorus	P
Potassium	K
Radium	Ra
Radon	Rn
Silicon	Si
Sulfur	S
Tin	Sn
Uranium	U
Zinc	Zn

Review

1. A table of the basic elements is called the ____________ table.

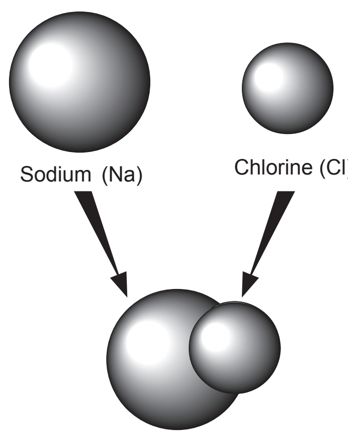
2. Give the symbol for the following elements:

   A. Aluminum _____________
   B. Chlorine _____________
   C. Oxygen _____________
   D. Iron _____________
   E. Lead _____________
   F. Fluoride _____________
   G. Manganese _____________
   H. Magnesium _____________

Compounds

What Are Compounds?

Most forms of matter in nature are composed of combinations of the 94 pure elements. Substances composed of two or more elements are called compounds. Unlike elements, compounds can be broken into simpler substances by chemical changes. A familiar, common compound is table salt, sodium chloride. It is a combination of the two elements sodium and chlorine.



Salt or Sodium Chloride (NaCl)

The Molecule

If you have a small piece of a compound, say a crystal of salt or sodium chloride (NaCl), and you subdivide it and continue to subdivide it until you get one tiny unit of sodium chloride that cannot be further subdivided and still be sodium chloride, you have a molecule.

Formulas for Compounds

A shorthand method for writing the names of compounds is a formula showing the kinds and numbers of different elements in the compound by using the symbols of the elements making up that compound. The shorthand representations of chemical compounds are called chemical formulas. The formula for sodium chloride is NaCl. This formula shows that one atom of sodium combines with one atom of chlorine to form one molecule of sodium chloride. An example of a bit more complex compound is sodium carbonate or soda ash: Na_2CO_3. This formula shows that the compound is made up of three elements: sodium, carbon, and oxygen. And there are two atoms of sodium, one atom of carbon, and three atoms of oxygen in each molecule. Here's the formula for sulfuric acid: H_2SO_4 .

Combining Compounds

Chemical equations are shorthand method of expressing chemical reactions. The following equation shows the reaction that occurs when chlorine gas is added to water. It shows the formulas of the molecules that react together and the formulas of the product molecules.

$$Cl_2 + H_2O \longrightarrow HOCl + HCl$$

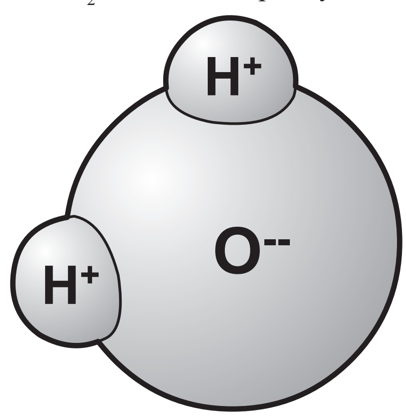
Review

1. A(n) _____________ is the combination of two or more elements.
2. A(n) _____________ is the smallest unit of a compound.
3. A(n) _____________ is the shorthand method of showing the kinds and numbers of elements making up a compound.
4. Chemical _____________ are used to show how chemical react.

Water

Importance of Water

Water, obviously, plays the major role in water chemistry and drinking water treatment. In fact, water is perhaps the most important compound on earth. All life depends on it. Water is really a pretty simple compound: H_2O. But its simplicity is deceiving. It has a number of characteristics that make it unique.



The Water Molecule

Pure water is a colorless, odorless, tasteless liquid. Each molecule of water has two atoms of hydrogen and one atom of oxygen. The two hydrogen atoms are **covalently bonded**[7] to the oxygen atoms. The hydrogen atoms tend to be positively charged, and the oxygen atoms tend to be negatively charged. This gives the water molecule an electrical polarity, one end positively charged and one end negatively charged.

[7] Covalent Bond – a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms.

The Purity of Water

Pure water contains no impurities, but in nature, water contains a number of things besides water. Water is a very good **solvent**[8]. The polarity just described is the main reason water is able to dissolve so many other substances. For those of us interested in making water as pure as possible, this fact makes our job more difficult. It means there are many things dissolved and suspended in the water with which we must deal.

[8] Solvent – The component of a solution that does the dissolving.

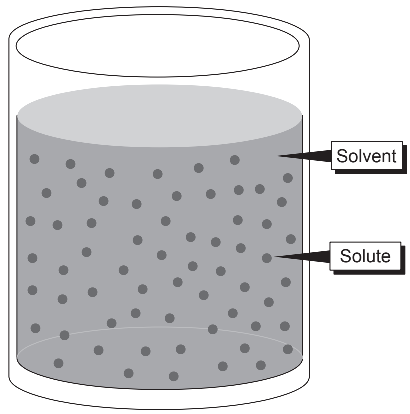
Three States of Water

Water exists in three physical states: ice, liquid, and steam. The temperature at which ice melts is the same as the temperature at which liquid freezes and is called the melting point. The melting point of water is 0°C (32°F). The temperature at which liquid turns to steam or steam condenses into liquid is called the boiling point. The boiling point of water is 100°C (212°F).

Water Solutions

Components of Solutions

A solution is a condition in which substances are uniformly and evenly mixed or dissolved. A solution has two components: a solvent and a **solute**[9]. The solvent is the component that does the dissolving. The solute is the component that is dissolved. In water (**aquatic**[10]) solutions, water is the solvent. Water is an excellent solvent and can dissolve a number of substances (solids, liquids, and gases), many of which must be removed during treatment to make water safe to drink.



[9] Solute – The component of a solution that is dissolved by the solvent.

[10] Aquatic – Pertaining to water.

Solutions and Suspensions

A solution may be colored, but it will be transparent, not cloudy. The solute will remain uniformly distributed throughout the solution and will not settle out with time. If the mixture appears cloudy, the solid particles are not actually dissolved. This situation is referred to as a suspension. The suspended particles will eventually settle out.

How Do We Get Ions?

With many molecules that dissolve in water, the atoms making up the molecules come apart in the water. This dissociation in water is called **ionization**[11]. When the atoms in the molecules come apart, they do so as charged atoms called **ions**[12]. There are always positively charged ions and negatively charged ions when ionization occurs. The positively charge ions are called **cations**[13], and the negatively charged ions are called **anions**[14].

[11] Ionization – The formation of ions by splitting molecules or electrolytes in solution.

[12] Ion – An atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons.

[13] Cation – A positively charged ion.

[14] Anion – A negatively charged ion.

Examples of Ionization

A good example is the ionization that occurs when table salt, sodium chloride, dissolves in water:

$NaCl$ sodium chloride	↔	Na^{+} sodium ion (cation)	+	Cl^{-} chloride ion (anion)

Another example is the ionization of calcium carbonate:

$CaCO_3$ calcium carbonate	↔	Ca^{++} calcium ion (cation)	+	CO_3^{-2} carbonate ion (anion)

The table below shows some of the common ions found in water:

Ion	Symbol
Hydrogen	H^+
Sodium	Na^+
Potassium	K^+
Copper – Cuprous	Cu^+
Silver	Ag^+
Ammonium	NH_4^+
Fluoride	F^-
Chloride	Cl^-
Bromide	Br^-
Iodide	I^-
Hydroxide	OH^-
Nitrate	NO_3^-
Nitrite	NO_2^-
Hypochlorite	OCl^-
Bicarbonate	HCO_3^-
Permanganate	MnO_4^-
Magnesium	Mg^{+2}
Calcium	Ca^{+2}
Copper-Cupric	Cu^{+2}
Iron-Ferrous	Fe^{+2}
Zinc	Zn^{+2}
Oxide	O^{-2}
Sulfide	S^{-2}
Sulfite	SO_3^{-2}
Sulfate	SO_4^{-2}
Carbonate	CO_3^{-2}
Dichromate	$Cr_2O_7^{-2}$
Aluminum	Al^{+3}
Iron-Ferric	Fe^{+3}
Phosphate	PO_4^{-3}

Water's Ability to Dissolve

Since water is a polar substance, it dissolves other polar substances better than non-polar substances. Mineral acids, bases, and salts are polar and easily dissolved. Non-polar substances such as oils, fats, and many organic compounds do not dissolve as easily in water.

Electricity and Water

Pure water will not conduct electrical current. But when compounds release ions into the water, the charged ions make electrolytes that can conduct electrical current. The more ions there are in a solution, the more easily the current flows. The ability to conduct electrical current is called conductivity and can be used to indirectly estimate the amount of total **dissolved solids**[15] in the water.

[15] Dissolved Solids -The material in water that will pass through a glass fiber filter and remain in an evaporating dish after the water has evaporated.

The Impact of Temperature

Polar substances will dissolve in water up to a point. At a given temperature, water will dissolve only so much solute. When that limit is reached, the resulting solution is said to be saturated. If you add more solute to a **saturated solution**[16], it will not dissolve. If a solution contains less solute than required to reach saturation, the solution is unsaturated. In the case of solids dissolved in water, if the temperature of the solution is increased, the amount of solute (solid) required to reach saturation increases. Can you think of some solutions you have made during the last week? What were the solvent and the solute in each case? Were the solutions unsaturated or saturated?

[16] Saturated Solution – The physical state in which a solution will no longer dissolve more of the dissolving substance (solute).

Solution Strength

The strength of a solution is determined by the amount of solute dissolved in a certain amount of water. If you dissolve more solute, you make the solution stronger. We express solution strength is a variety of ways:

- **Parts per million (ppm)** and **milligram per Liter (mg/L)** are essentially equal and used interchangeably. A 1 ppm or 1 mg/L solution contains 1 milligram of solute per Liter of solution.
- **Percent concentration** is parts of the solute dissolved in 100 parts of solution on a weight basis. One gram of solute dissolved in 100 grams of solution is a 1 percent solution.
- **Molarity (M)** and **normality (N)** are solution concentration expressions used almost exclusively in the lab. They are based on the molecular weight of the solute. A 10 M solution is 10 times stronger than a 1 M solution. A 0.1 N solution is four times stronger than a 0.025 N solution.

Review

1. Water is said to be a ___________ molecule because one end is positively charged, and the other end negatively charged.
2. Water exists in what three physical states?
3. A(n) _______________ is formed when water dissolves material.

Constituents in Water

As we can see from the previous discussion, natural water can contain a number of substances. In the waterworks industry, these substances are called constituents or impurities. When a constituent can cause a negative impact to the health of the water user, it is called a contaminant. As you will see in the lesson on regulations, federal and state agencies have set limits on those items considered to be contaminants. The following is a brief discussion of some of the more common constituents of water.

Suspended Solids

Definition

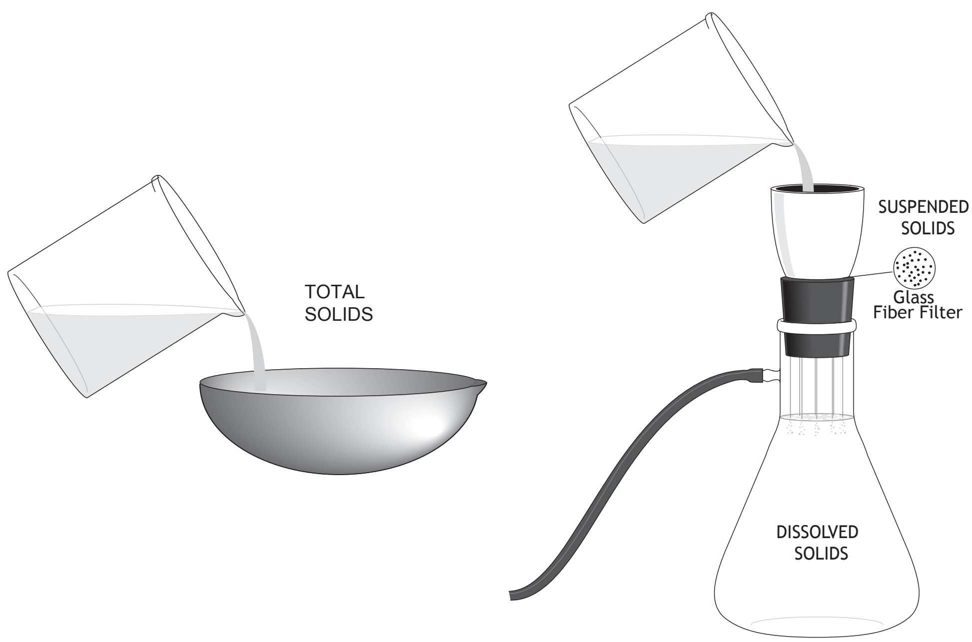
Natural water carries a lot of solids that are not dissolved. These solids are mainly non-polar substances and particles of silt and other in-organic material that just won't dissolve. These solids are referred to as **suspended solids**[17]. If the water is allowed to sit quietly, as it does in a sedimentation basin or clarifier, most of the suspended solids will settle out.

[17] Suspended Solids – The quantity of material deposited when a quantity of water, sewage, or other liquid is filtered through a glass fiber filter.

Types of Solids

In the water business, **total solids**[18] are those solids, both suspended and dissolved, that remain behind when the water is removed by evaporation. Suspended solids are defined as those that can be filtered out in the suspended solids laboratory test. The material that passes through the filter is defined as dissolved solids. These definitions are not technically accurate from a chemical point of view because some finely suspended material can actually pass through the filter.

[18] Total Solids – The solids in water, sewage, or other liquids; it includes the suspended solids (those largely removable by a filter) arid filterable solids (those that are able to pass through a filter).



Colloidal Solids

Definition

Colloidal[19] solids are suspended solids so small they will not settle even if allowed to sit quietly for days or weeks. They are not dissolved, but even though they are extremely tiny, they often make the water cloudy. In general, anything less than one micron (1/ 1000 of a millimeter) is considered a colloidal particle. Fine silt, tiny particles of vegetation, and **bacteria**[20] are examples of colloidal particles.

[19] Colloidal – Any substance in a certain state of fine division in which the particles are less than one micron in diameter.

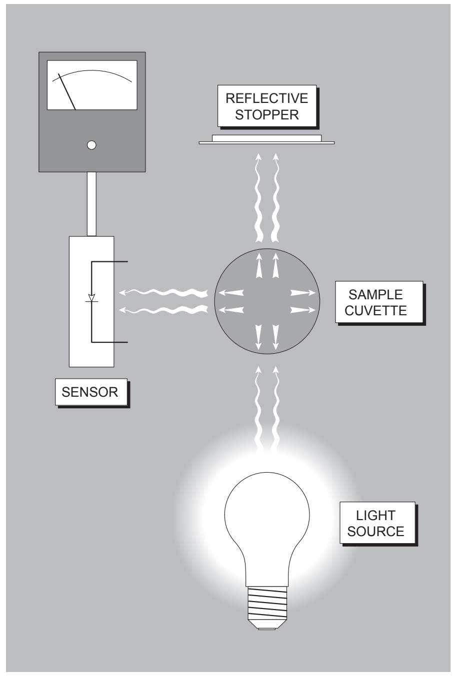
[20] Bacteria – Living organisms, microscopic in size, that consist of a single cell. Most bacteria use organic matter for their food and produce waste products as the result of their life processes.

Turbidity

Definition

Turbidity in water is caused by suspended solids, usually particles of colloidal size. Turbidity is defined as that property of water that causes light to be scattered or absorbed. Whereas high turbidity water appears cloudy, low turbidity water often sparkles with clarity. Water with low turbidity can still have dissolved solids because dissolved solids do not cause light to be scattered or absorbed. Materials that cause turbidity can cause taste and odor in drinking water and can provide a place for **microorganisms**[21] to hide and avoid disinfection.

NEPHELOMETRIC TURBIDIMETER



[21] Microorganisms – Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

Color

Two Types

Color is considered an aesthetic quality in water and has no direct health impact. Color is divided into two general categories:

- **True color** – Color that is the result of dissolved chemicals, such as humic acid (from alder leaves), is called true color. It cannot be removed by passing the water through a filter.
- **Apparent color** – Color that is contributed to the water as a result of suspended material, such as clay, silt, or sand carried in the water. The yellow color in the Yellowstone River is the result of the yellow clay carried by the stream.

Dissolved Gasses

What Gases?

Gases can also be dissolved in water. Gases such as oxygen, carbon dioxide, hydrogen sulfide, and nitrogen are examples of gases that dissolve in water. Not all gases dissolve to the same extent; some dissolve easily and others not as well. Oxygen and carbon dioxide are two dissolved gases important to water operations.

The Impact of Dissolved Oxygen

Dissolved oxygen (D.O.) is important to most aquatic organisms. It is of particular importance in streams and reservoirs as an indicator of water quality. Like other solutions, water at a given temperature can be saturated with the solute: the oxygen. And as with solid solutes, the amount of oxygen that can be dissolved at saturation depends upon temperature of the water. However, the effect is just the opposite: the higher the temperature, the lower the saturation level; the lower the temperature, the higher the saturation level.

The Impact of Carbon Dioxide

Carbon dioxide is important because of the role it plays in pH and alkalinity. Carbon dioxide is released into the water by microorganisms and consumed by algae and aquatic plants. Carbon dioxide is only slightly soluble in water. Most of the carbon dioxide reacts with the water to form carbonic acid. So as dissolved carbon dioxide levels increase, the system becomes more acidic.

$$\underset{\text{(carbon dioxide)}}{CO_2} + \underset{\text{(water)}}{H_2O} \leftrightarrow \underset{\text{(carbonic acid)}}{H_2CO_3}$$

Metals in Water

The Impact of Metals in Water

Water often carries metal impurities. Although most of the metals are not harmful at normal levels, a few metals can cause taste and odor problems or, more seriously, be toxic to humans, animals, and microorganisms. Most of these metals enter the water as part of compounds that ionize to release the metals as positive ions. When someone says they have iron in their water, this really means they have iron ions. Under specific conditions, the metal will come out of solution, and a **precipitate**[22] will be formed. Examples of metal precipitates are the reddish-brown iron rust and bluish-green copper stain. The following table lists some metals commonly found in water and their potential health hazards.

[22] Precipitate – A solid substance that can be dissolved but is separated from solution as a result of a chemical reaction or change in conditions, such as pH or temperature.

Metal	Health Hazard
Barium	Effects circulatory system and increases blood pressure.
Cadmium	Concentrates in the liver, kidneys, pancreas, and thyroid.
Copper	Damages nervous system and effects kidneys, toxic to infants.
Lead	Same as copper.
Mercury	Causes central nervous system disorders and effects the kidneys.
Nickel	Affects nervous system and causes skin sensitization.
Selenium	Affects nervous system.
Silver	Turns the skin gray.
Zinc	Causes taste problems, but not a health hazard.

Review

1. Solids that can be captured on a filter are called ______________ solids, and solids that pass through the filter are called ________________ solids.

2. A solids that is less than 1 μ in size is called a _______________.

3. Turbidity is the property of water that causes light to be ______________ and _______________.

4. There are two categories of color: ______________ color and _______________ color. Color caused by decaying alder leaves is _______________ color.

5. When carbon dioxide dissolves in water, it tends to _____________the pH of the water.

6. Metals dissolving in water can be a nuisance by causing taste and ____________ problems, and sometimes they can be _________________ to humans.

Organic and Inorganic Chemicals

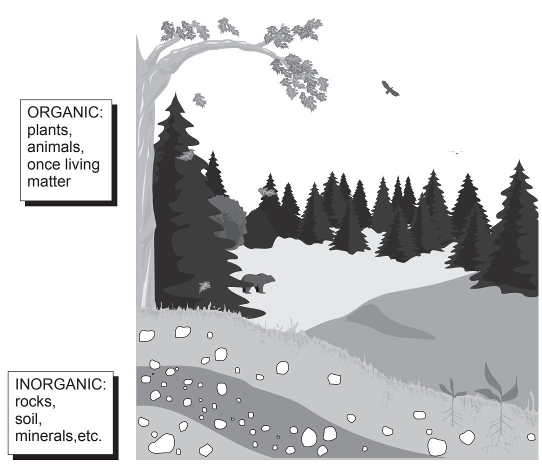
Two Categories

Chemistry divides chemical compounds into two large categories:

- **Organic compounds** are those that contain the element carbon and are derived from material that was once alive.
- **Inorganic compounds** are just the opposite. They do not contain carbon and are not derived from living material. There are a couple exceptions. Carbon dioxide, carbonate ions, and bicarbonate ions, although containing carbon, are considered inorganic.

Organic Compounds

These two large groups of compounds have very different characteristics. Organic compounds are usually large, non-polar molecules that do not dissolve well in water. They often provide large amounts of energy as food for animals and microorganisms. Some synthetic organic compounds, such as pesticides and herbicides, are extremely toxic at very low concentrations. Organics include fats, proteins, carbohydrates, fuels, cotton, wood, plastics, dyes, soaps, rubber products, and explosives.



Inorganic Compounds

Inorganic compounds are usually smaller, polar molecules that dissolve well in water. Although some specialized bacteria can use inorganics as an energy source, they are not considered a high-energy source for as many organisms. The inorganics include the acids, bases, salts, oxides, sulfate, phosphates, etc.

pH

Definition

pH is a measure of the hydrogen ion (H^+) concentration. The pH scale ranges from 0 to 14, with 7 being the center or neutral value. Low pH values are considered acidic, and high pH values are basic. The pH scale is actually an inverse logarithmic scale. What that means is that low pH values are actually high H^+ concentration, while high pH values are low H^+ concentration. It also means that the difference between any two pH values means a ten-fold difference in H^+ concentration.

Importance of pH

The pH of a solution is important to chemical reactions in water. Metal toxicity is also influenced by pH. High or low pH can inhibit growth of microorganisms.

Pure Water pH

Pure water has a neutral pH. Even pure water ionizes slightly, releasing equal numbers of H^+ and OH^- ions.

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

Acids

Acids can be defined as compounds that release hydrogen ions (H^+) when added to water. As an acid is added to the water, additional H^+ ions are released, so the H^+ ion concentration goes up, and the pH value goes down. Hydrochloric acid (HCl) is a good example of an acid:

$$HCl \leftrightarrow H^+ + Cl^-$$

It is easy to recognize acids because their formula starts with hydrogen (H). Some common acids include the following:

Hydrochloric acid	HCl
Sulfuric acid	H_2SO_4
Phosphoric acid	H_3PO_4
Carbonic acid	H_2CO_3
Nitric acid	HNO_3
Hydrofluoric acid	HF
Acetic acid	$HC_2H_3O_2$
Hyphochlorous acid	$HOCl$

Bases

One characteristic of bases is that they release hydroxide ions (OH^-) when added to water. The OH^- ions combine with H^+ ions in the water, which reduces the concentration of free H^+ and raises the pH.

Sodium hydroxide is a good example of a base:

$$NaOH \leftrightarrow H^+ + OH^-$$

It is easy to recognize bases because their formula contains (OH). Some common bases include the following:

Sodium hydroxide	$NaOH$
Calcium hydroxide (hydrated lime)	$Ca(OH)_2$
Ammonium hydroxide	NH_4OH

Salts

Salts are technically defined as the results of a neutralization reaction that combines an acid with a base. Salts are neither acid nor bases because they do not release either hydrogen ions (H+) or hydroxide ions (OH-). Here is an example of a neutralization reaction that produces a salt:

$$2NaOH + H_2SO_4 \leftrightarrow Na_2SO_4 + 2H_2O$$

Alkalinity

Definition

Alkalinity is a measure of waters ability to neutralize an acid. Alkalinity can also be defined as a buffer, a chemical system that tends to stabilize and prevent fluctuations in pH. It is usually beneficial to have significant alkalinity in water because it tends to prevent quick changes in pH. Quick changes in pH interfere with the effectiveness of the common water treatment processes. Low alkalinity contributes to corrosive tendencies of water. When alkalinity is below 80 mg/L, it is considered low.

What Causes Alkalinity?

Alkalinity is the result of carbonate (CO_3^{-2}), bicarbonate (HCO_3^{-1}), and hydroxide (OH^-) ions in the water. Alkalinity should not be confused with pH. Even water with an acid pH can contain alkalinity. Typical water treatment chemicals that can be used to increase alkalinity are quick lime (calcium oxide, CaO), hydrated lime (calcium hydroxide), $Ca(OH)_2$, and soda ash (sodium carbonate, Na_2CO_3).

Hardness

Impact of Hardness

Hardness is caused by the presence of magnesium (Mg) and calcium (Ca) ions in water. Hardness causes soaps and detergents to be less effective and contributes to scale formation in pipes and boilers. Although there are no known health hazards to high hardness, water that contains excessive hardness must often be softened by lime precipitation or ion exchange. Low hardness contributes to the corrosive tendencies of water. Hardness and alkalinity often occur together because some compounds can contribute both alkalinity and hardness ions. However, hardness can be present when the alkalinity is low and visa versa.

Classification	mg/L $CaCO_3$
Soft	0 – 75
Moderately Hard	75 – 150
Hard	150 – 300
Very Hard	Over 300

Review

1. Compounds that are derived from material once living are called ________________ compounds.

2. Compounds that do not contain carbon are called ____________ compounds.

3. The pH scales ranges from _________ to __________.

4. A pH of 4 would be considered _____________.

5. A pH of 7 would be considered _____________.

6. Acids are chemicals that release ___________ ions in water.

7. NaOH is a example of a:

8. Salts are formed by a neutralization reaction between an ____________ and a ______________.

9. ______________ is a measure of a water ability to neutralize and acid.

10. Hardness is caused by _____________ and _____________ ions.

Chlorine and Other Disinfectants

The element chlorine (Cl) is one of the most commonly used chemicals. As a pure element and in compounds, chlorine is the most commonly used disinfectant in water and wastewater treatment. Pure chlorine is a greenish-yellow colored gas at room temperature. It is a dense gas, 2.5 times heavier than air. It has a strong, pungent odor that is very corrosive to moist metals and lethal if inhaled in sufficient quantity.

When chlorine gas is added to water, it reacts with water to form hypochlorous acid (HOCl).

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

The hypochlorous acid immediately ionizes to release hydrogen ions (H^+) and hypochlorite ions (OCl-).

$$HOCl \leftrightarrow H^+ + OCl^-$$

When present in water, hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) are know as free chlorine residual.

Chlorine compounds are also used as disinfectants. Liquid sodium hypochlorite (NaOCl) solution, also known as bleach, and calcium hypochlorite [$Ca(OCl_2)$], a crystal or powder, are common disinfectants. Chlorine dioxide (ClO_2), a gas, is also used as a disinfectant.

Bromine (Br_2) and iodine (I_2), both closely related chemically to chlorine, also have disinfection properties. Bromine is sometimes used to disinfect pools and spas, and iodine is used in tablet form for emergency disinfection of small volumes of drinking water.

Iron and Manganese

Iron (Fe) and manganese (Mn) are present in many water supplies, particularly groundwater. Neither is a health hazard, although both can affect water quality by causing taste and odor problems and by staining sinks, toilet bowls, and other fixtures. Iron and manganese are closely related chemically, and if iron is present, manganese will usually also be present.

Iron and manganese can be soluble (dissolved) or insoluble (undissolved particles), depending upon the conditions. In ground water, both tend to be dissolved. But when exposed to air, they are converted to the insoluble form. Soluble forms of iron are ferrous forms (also noted as Fe^{+2}). When exposed to air (such as a dripping faucet), the soluble form is converted to the insoluble ferric form (noted as Fe^{+3}), and the particles stick to the sink as a reddish-brown, rusty stain. Manganese also has soluble and insoluble forms. The insoluble manganese causes as dark greenish-black stain.

Iron can be removed by ion exchange systems or by chemical precipitation and filtration. Chemical oxidizing agents, such as chlorine and potassium permanganate, can be used to convert the soluble forms of iron and manganese to the insoluble forms.

Be careful not to confuse manganese (Mn) with magnesium (Mg). They have similar names and symbols but quite different chemical properties.

Lead and Copper

Lead (Pb) and copper (Cu) are often mentioned together because their presence in drinking water is usually the result of corrosive water leaching lead and copper out of household plumbing system pipes. Lead can be a health hazard, causing damage to the brain, red blood cells, and kidneys if it builds up in the body over time. Acute exposures to copper can cause nausea and diarrhea. Lead and copper can also cause taste and odor problems.

Corrosive water can leach lead and copper out of copper and lead pipe, out of lead-based solder, and other lead-based materials used in distribution systems. Water systems control the levels of lead and copper by treating drinking water to reduce the corrosive tendency of the water being provided to consumers.

Fluoride

Fluoride is the ion of the element fluorine (F). Fluorine compounds occur naturally in low concentrations in many water supplies. At levels of about 1 mg/L, fluoride has been shown to reduce cavities. Some communities choose to add fluoride to their drinking water to achieve this benefit.

Sodium fluoride (NaF) and sodium fluorosilicate (Na_2SiF_6) are examples of fluoride-containing compounds used as drinking water additives. Fluoride compounds must be handled carefully because the chemical powder is hazardous if inhaled. Carefully controlled addition of fluoride solution to drinking water is critical because overdosing can be toxic to consumers.

Arsenic

Arsenic (As) is a notorious poison that affects a number of organ systems in the body. It is more prevalent in groundwater than surface water, but many water systems must remove the arsenic to be within acceptable limits. A variety of technologies can be used including coagulation/filtration, ion exchange, and nanofiltration.

Lime

Lime is added to water during treatment to raise the pH and to increase alkalinity and hardness. There are two forms of lime:

- **Calcium oxide** – CaO (quick lime)
- **Calcium hydroxide** – $Ca(OH)_2$ (hydrated or slaked lime)

$Ca(OH)_2$ is CaO that has be mixed with water in a process called hydrating or slaking.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Quick lime (CaO) is hazardous to handle because it reacts vigorously with any moisture, including the moisture in your skin. Although cheaper, it must be hydrated before it can be fed into the water system. Dry, hydrated lime [$Ca(OH)_2$] is mixed with water to make a slurry and then fed into the system.

Raising the pH and increasing the alkalinity and hardness by adding lime tends to lower the corrosive tendency of the water to which it is added. Lime is often added to optimize alkalinity levels during the coagulation/flocculation treatment process.

Soda Ash

Soda ash (sodium carbonate – Na_2CO_3) is added to water to raise the pH. It also contributes to alkalinity but does not affect hardness. It does not have as strong an effect on pH as lime.

Coagulants

Coagulants are chemicals added to water to facilitate the removal of very finely suspended particles, such as colloidal particles. Most coagulants are aluminum- and iron-containing compounds. Common coagulants include aluminum sulfate or alum -$Al_2(SO_4)_3$ and ferric sulfate – $Fe_2(SO_4)_3$.

Polymers

Polymers are large, synthetic organic molecules created to optimize coagulation, flocculation, and filtration. Three general types are available:

- Cationic – having a general overall positive charge
- Anionic – having a general overall negative charge
- Non-ionic – having a general overall neutral change

Many proprietary types are available. Each water supply is carefully tested to determine which polymer will be the most effective. Polymers can be used to enhance coagulation by helping colloidal particles stick together. They can be used to help coagulated particles flocculate and become large enough to settle, and they can increase the effectiveness of the filtration process.

Radioactivity

Water supplies may contain material with low levels of radioactivity. These materials may enter the water supply from natural geological deposits or in the waste streams from industrial, research, and medical facilities. Alpha particle, beta particle, and photon radiation are all types of radiation with varying degrees of potential health implications. Different materials emit different types and intensities of radiation. Water systems are now required to monitor for radioactive uranium, radium, gross alpha particle, beta particle, and photon radioactivity.

Radon (Rn) is a colorless, odorless, radioactive gas formed by the natural radioactive decay of uranium in rock, soil, and water. It can be present in drinking water and indoor household air and is of increasing concern for water suppliers.

Review

1. When chlorine gas reacts with water, it forms two acid: hydrochloric acid (HCl) and ____________________ acid.

2. The hypochlorite, also known as bleach, is ________________ hypochlorite.

3. Soluble iron can be converted to an insoluble form by contact with:

4. A reddish-brown stain is most likely caused by insoluble _________________ particles.

5. Lead and copper can enter consumers drinking water from household plumbing because the water is too:

6. CaO is the formula for ________________. $Ca(OH)_2$ is the formula for _________________.

7. Na_2CO_3 is the formula for:

8. _______________ and polymers are used in the coagulation/flocculation/filtration water treatment process.

9. Radioactive material can enter water sources from natural geological formations, from industrial discharges, from research facilities, and from:

Chemical Characteristics of Water Quiz

1. Matter that maintains a constant volume but that will change shape to fit the shape of its container is a:
   A. Gas
   B. Liquid
   C. Solid
   D. Colloid

2. When a change takes place in matter where new substances are formed that have entirely different properties than the original, it is said to be a _____________ change.
   A. Nuclear
   B. Physical
   C. Chemical
   D. Biological

3. All matter is made up of 94 pure substances called:
   A. Molecules
   B. Compounds
   C. Elements
   D. Radicals

4. The smallest piece of an element is called a(n):
   A. Atom
   B. Molecule
   C. Compound
   D. Radical

5. Which is the correct symbol for calcium?
   A. CA
   B. ca
   C. Ca
   D. Cal

6. The Periodic Table:
   A. Shows the pH of all aquatic compounds.
   B. Lists all of the common acids used in water treatment.
   C. Lists the common radicals.
   D. Lists the elements.

7. The smallest piece of an compound is called a(n):
   A. Atom
   B. Molecule
   C. Element
   D. Radical

8. The compound $FeSO_4$ has how many atoms of sulfur?
   A. 1
   B. 2
   C. 3
   D. 4

9. A chemical ___________________ is a shorthand way to show how chemicals react.
   A. Balance
   B. Formula
   C. Equation
   D. Equilibrium

10. The main characteristic of water that makes it an exceptional solvent is its:
   A. Viscosity
   B. Polarity
   C. Surface tension
   D. Clarity

11. In a solution, the substance that is dissolved is called the:
   A. Solvent
   B. Solution
   C. Solute
   D. Colloid

12. When many molecules dissolve in water, they dissociate to release changed particles called:
   A. Atoms
   B. Neutrons
   C. Electrons
   D. Ions

13. Positively charged ions are called:
   A. Radicals
   B. Protons
   C. Anions
   D. Cations

14. Which of the following is not an expression of solution concentration?
   A. mg/L
   B. ppm
   C. Molecular weight
   D. Molarity (M)

15. Solids in water that can be filtered out are called _______________ solids.
    A. Total
    B. Dissolved
    C. Suspended
    D. Colloidal

16. Solids that are so small they won't settle (about 1 µ) but are not actually dissolved are called ______________ solids.
    A. Total
    B. Dissolved
    C. Suspended
    D. Colloidal

17. The property of water that causes light to be scattered or absorbed is called:
    A. Color
    B. Turbidity
    C. Light interference
    D. Clarity

18. Chemical compounds that contain carbon and are derived from material that was once living are called _________________ compounds.
    A. Macro
    B. Inorganic
    C. Organic
    D. Energy

19. Which of the following represents an acid pH?
    A. 12
    B. 9
    C. 7
    D. 5

20. Which of the following compounds is a base?
    A. HCl
    B. NaOH
    C. NaCl
    D. H_2SO_4

21. ____________________ is the result of carbonate, bicarbonate, and hydroxide ions in the water.
    A. pH
    B. Hardness
    C. Alkalinity
    D. Turbidity

22. ________________ is the result of Mg^{+2} and Ca^{+2} ions in the water.
   A. pH
   B. Hardness
   C. Alkalinity
   D. Turbidity

23. When chlorine gas reacts with water, what compound is formed?
   A. Sulfuric acid
   B. Sodium hydroxide
   C. Hypochlorous acid
   D. Chlorine dioxide

24. A reddish-brown stain on a white porcelain sink would likely be caused by ____________ precipitate.
   A. Calcium
   B. Magnesium
   C. Iron
   D. Manganese

25. Unacceptable levels of lead and copper at a consumer's faucet would most likely be caused by:
   A. Lead and copper in the raw water source.
   B. Having chlorine residual levels too high.
   C. Corrosive water.
   D. Bacteriological activity.

26. What is the formula for soda ash?
   A. CaO
   B. $Ca(OH)_2$
   C. Na_2CO_3
   D. $NaCl$