Properties of Water

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CONCEPT 1 Properties of Water

Learning Objectives

- Identify the chemical structure of water.
- Describe a polar molecule.
- Deine hydrogen bond.
- Explain how water's structure related to its unique properties.

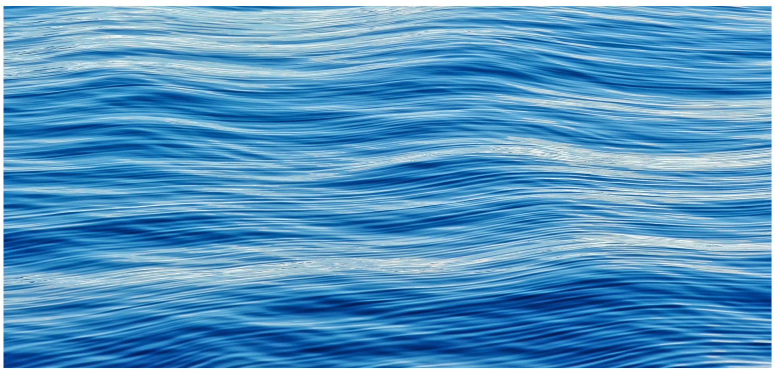

FIGURE 1.1

Ocean Chemistry

The oceans are full of water. Ocean water is not just pure H_2O, though. Ocean water has many different chemicals in it, especially salt.

The salt in sea water is a lot like the salt we sprinkle on food. Table salt is made up of the chemical sodium chloride (NaCl). The salt in ocean water is mostly sodium chloride, too. However, the salt in the oceans has other kinds of salt in it too. The main other chemicals in sea salt are magnesium, sulfate, calcium, and potassium.

Why is the ocean salty? When it rains on land, some of the water dissolves minerals in rocks. That water flows in rivers to the sea. It carries the minerals with it. When water evaporates back out of the ocean, it leaves the minerals behind. The minerals make sea water salty.

Some parts of the ocean are saltier than others. For example, melting glaciers dump lots of fresh water into the ocean. Places in the ocean near melting glaciers aren't as salty as the rest of the ocean.

Some gases are dissolved in sea water too. There is carbon dioxide(CO_2) from the atmosphere dissolved in sea water. That is important because carbon dioxide is a greenhouse gas. Scientists want to know how much CO_2 the oceans can hold. It will help them predict climate change. When carbon dioxide dissolves in water, it makes an acid. Too much acid can harm corals, shellfish, and other creatures that live in the seas.

People and other living things also affect the chemistry of the oceans. If farmers use too much fertilizer, some of it gets washed into the rivers and then on down to the seas. Some tiny creatures in the ocean love the nitrogen from the fertilizer and grow like crazy. As they grow, they use up lots of oxygen. When large areas of the ocean lose oxygen, fish and crabs and other animals die.

How Salty Is Ocean Water?

Have you ever gone swimming in the ocean? If you have, then you probably tasted the salts in the water. By mass, salts make up about 3.5% of ocean water. The table below shows the most common minerals in ocean water (**Table** below). The main components are sodium and chloride. Together they form the salt known as sodium chloride. You may know the compound as table salt or the mineral halite.

TABLE 1.1: Seawater Chemistry

Element	Percent
Oxygen	85.84
Hydrogen	10.82
Chloride	1.94
Sodium	1.08
Magnesium	0.1292
Sulfur	0.091
Calcium	0.04
Potassium	0.04
Bromine	0.0067
Carbon	0.0028

The amount of salts in ocean water varies from place to place. For example, near the mouth of a river, ocean water may be less salty. That's because river water contains less salt than ocean water. Where the ocean is warm, the water may be more salty. Can you explain why? (Hint: More water evaporates when the water is warm.)

Density

Seawater has lots of salts in it. This increases its **density** (mass per volume) over fresh water. Temperature and pressure also affect density.

Water density increases as:

- salinity increases.
- temperature decreases.
- pressure increases.

Differences in water density are responsible for deep ocean currents, as will be discussed in the concept "Deep Ocean Currents."

Summary

- Water moving through rock and soil picks up ions. Those ions end up as salts in large bodies of water.
- Ocean water contains salts and other substances.
- Water density increases as salinity and pressure increase, or as temperature decreases.

Review

1. Streams aren't salty, so why is the ocean salty?
2. Answer and explain the following: If evaporation is high, what happens to seawater density? If freshwater is added to a region, what happens to seawater density? If seawater gets very cold, what happens to its density?

3. What is salinity?

Water may be the most important molecule for life

Some may argue DNA. Some may argue certain proteins. But many would argue water. And what makes water so important? Its properties. The nature of the three atoms and how they interact with each other. This allows water to be a polar molecule, which allows it to interact with many other molecules necessary for life. Most of the substances in a cell are floating around in a water-based cytoplasmic environment.

Chemical Structure and Properties of Water

You are probably already familiar with many of water's properties. For example, you no doubt know that water is tasteless, odorless, and transparent. In small quantities, it is also colorless. However, when a large amount of water is observed, as in a lake or the ocean, it is actually light blue in color. The blue hue of water is an intrinsic property and is caused by selective absorption and scattering of white light. These and other properties of water depend on its chemical structure.

The transparency of water is important for organisms that live in water. Because water is transparent, sunlight can pass through it. Sunlight is needed by water plants and other water organisms for photosynthesis.

Chemical Structure of Water

Each molecule of water consists of one atom of oxygen and two atoms of hydrogen, so it has the chemical formula H_2O. The arrangement of atoms in a water molecule, shown in **Figure** 1.2, explains many of water's chemical properties. In each water molecule, the nucleus of the oxygen atom (with 8 positively charged protons) attracts electrons much more strongly than do the hydrogen nuclei (with only one positively charged proton). This results in a negative electrical charge near the oxygen atom (due to the "pull" of the negatively charged electrons toward the oxygen nucleus) and a positive electrical charge near the hydrogen atoms. A difference in electrical charge between different parts of a molecule is called **polarity**. A **polar molecule** is a molecule in which part of the molecule is positively charged and part of the molecule is negatively charged.

Hydrogen Bonding

Opposite electrical charges attract one another. Therefore, the positive part of one water molecule is attracted to the negative parts of other water molecules. Because of this attraction, bonds form between hydrogen and oxygen atoms of adjacent water molecules, as demonstrated in **Figure** 1.5. This type of bond always involves a hydrogen atom, so it is called a **hydrogen bond**. Hydrogen bonds are bonds between molecules, and they are not as strong as bonds within molecules. Nonetheless, they help hold water molecules together.

Hydrogen bonds can also form within a single large organic molecule. For example, hydrogen bonds that form between different parts of a protein molecule bend the molecule into a distinctive shape, which is important for the protein's functions. Hydrogen bonds also hold together the two nucleotide chains of a DNA molecule.

Sticky, Wet Water

Water has some unusual properties due to its hydrogen bonds. One property is **cohesion**, the tendency for water molecules to stick together. The cohesive forces between water molecules are responsible for the phenomenon known as **surface tension**. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. For example, if you drop a tiny amount of water onto a very smooth surface, the water molecules will stick together and form a droplet,

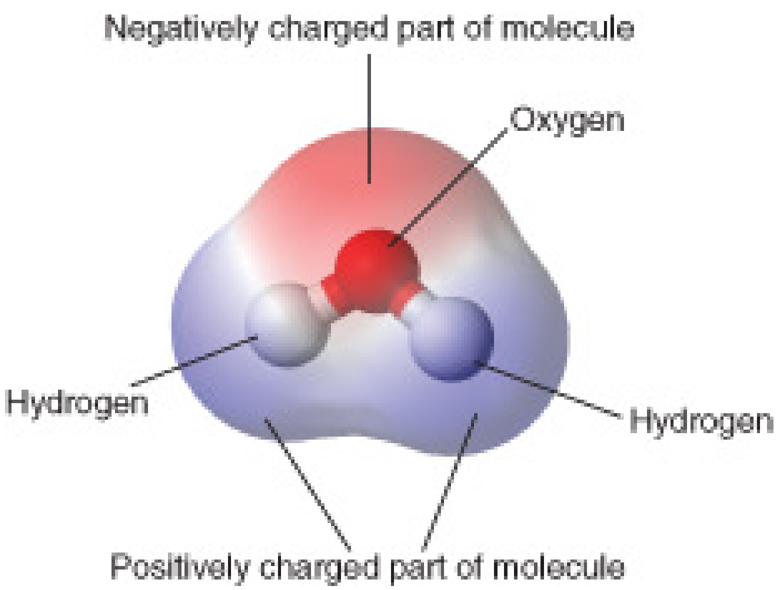

FIGURE 1.2
This model shows the arrangement of oxygen and hydrogen atoms in a water molecule. A water molecule has a bent or angular (non-linear) shape, with an angle of about 105°. The nucleus of the oxygen atom attracts electrons more strongly than do the hydrogen nuclei. As a result, the middle part of the molecule near oxygen has a negative charge, and the other parts of the molecule have a positive charge. In essence, the electrons are "pulled" toward the nucleus of the oxygen atom and away from the hydrogen atom nuclei. Water is a polar molecule, with an unequal distribution of charge throughout the molecule.

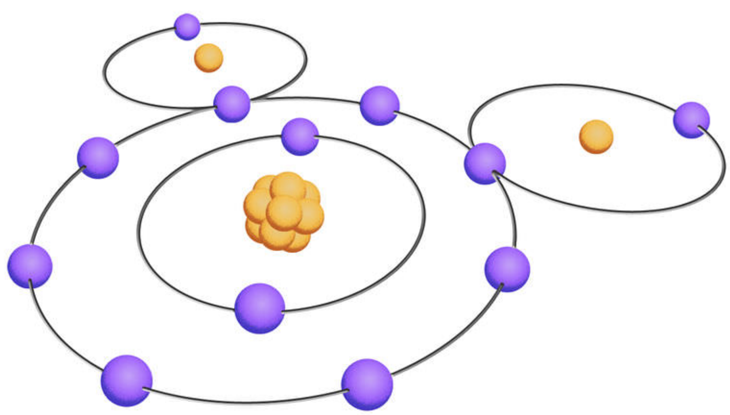

FIGURE 1.3
This model is an atomic diagram of water, showing the two hydrogen atoms and oxygen atom in the center. The protons (red) are in the center (nucleus) of each atom, and the electrons (light blue) circle each nucleus.

rather than spread out over the surface. The same thing happens when water slowly drips from a leaky faucet. The water doesn't fall from the faucet as individual water molecules but as droplets of water. The tendency of water to stick together in droplets is also illustrated by the dew drops in **Figure** 1.6.

Another important physical property of water, is **adhesion**. In terms of water, adhesion is the bonding of a water molecule to another substance, such as the sides of a leaf's veins. This process happens because hydrogen bonds are special in that they break and reform with great frequency. This constant rearranging of hydrogen bonds allows a percentage of all the molecules in a given sample to bond to another substance. This grip-like characteristic that water molecules form causes **capillary action**, the ability of a liquid to flow against gravity in a narrow space. An

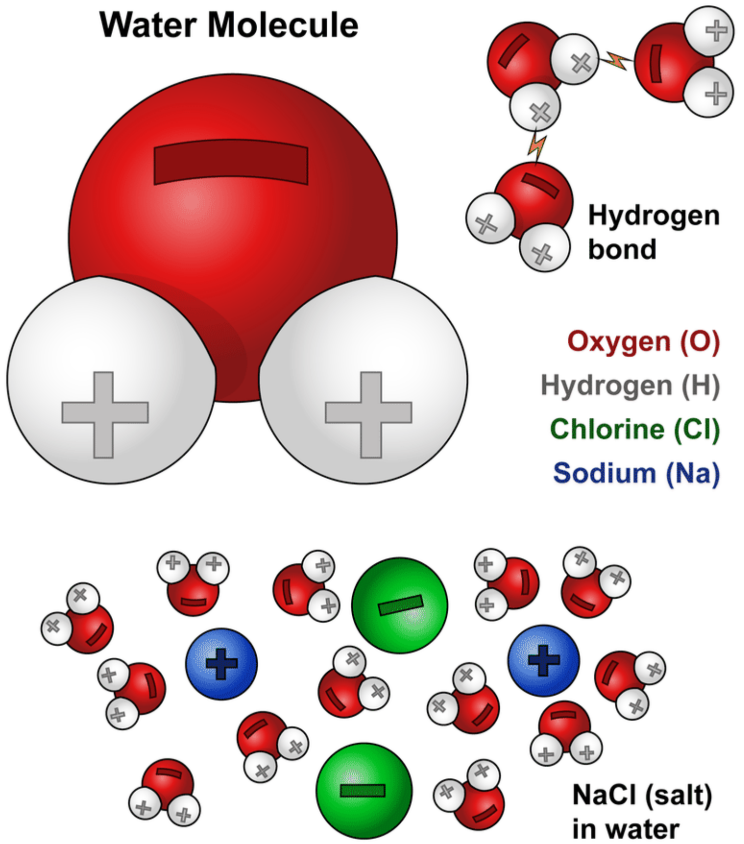

FIGURE 1.4
This diagram shows the positive and negative parts of a water molecule. It also depicts how a charge, such as on an ion (Na or Cl, for example) can interact with a water molecule.

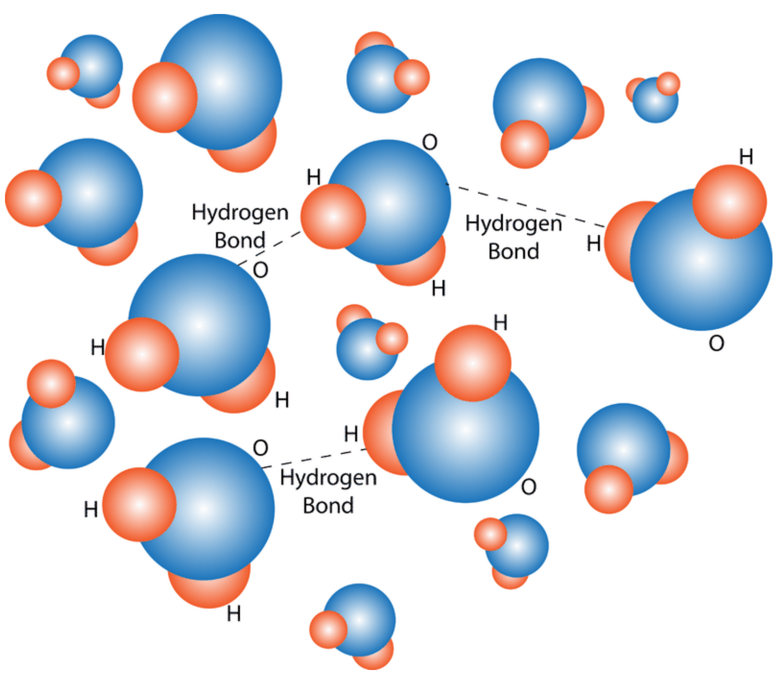

FIGURE 1.5
Hydrogen bonds form between positively and negatively charged parts of water molecules. The bonds hold the water molecules together. How do you think this might affect water's properties?

FIGURE 1.6
Droplets of dew cling to a spider web, demonstrating cohesion, the tendency of water molecules to stick together because of hydrogen bonds.

example of capillary action is when you place a straw into a glass of water. The water seems to climb up the straw before you even place your mouth on the straw. The water has created hydrogen bonds with the surface of the straw, causing the water to adhere to the sides of the straw. As the hydrogen bonds keep interchanging with the straw's surface, the water molecules interchange positions and some begin to ascend the straw.

Adhesion and capillary action are necessary to the survival of most organisms. It is the mechanism that is responsible for water transport in plants through roots and stems, and in animals through small blood vessels.

Hydrogen bonds also explain why water's **boiling point** (100°C) is higher than the boiling points of similar substances without hydrogen bonds. Because of water's relatively high boiling point, most water exists in a liquid state on Earth. Liquid water is needed by all living organisms. Therefore, the availability of liquid water enables life to survive over much of the planet.

Furthermore, water has a high **specific heat** because it takes a lot of energy to raise or lower the temperature of water. As a result, water plays a very important role in temperature regulation. Since cells are made up of water, this property helps to maintain **homeostasis**.

Density of Ice and Water

The **melting point** of water is 0°C. Below this temperature, water is a solid (ice). Unlike most chemical substances, water in a solid state has a lower density than water in a liquid state. This is because water expands when it freezes. Again, hydrogen bonding is the reason. Hydrogen bonds cause water molecules to line up less efficiently in ice than in liquid water. As a result, water molecules are spaced farther apart in ice, giving ice a lower density than liquid water. A substance with lower density floats on a substance with higher density. This explains why ice floats on liquid water, whereas many other solids sink to the bottom of liquid water.

In a large body of water, such as a lake or the ocean, the water with the greatest density always sinks to the bottom. Water is most dense at about 4°C. As a result, the water at the bottom of a lake or the ocean usually has temperature of about 4°C. In climates with cold winters, this layer of 4°C water insulates the bottom of a lake from freezing temperatures. Lake organisms such as fish can survive the winter by staying in this cold, but unfrozen, water at the bottom of the lake.

Summary

- Water molecules are polar, so they form hydrogen bonds. This gives water unique properties, such as a relatively high boiling point, high specific heat, cohesion, adhesion and density.

Review

1. Describe the structure of a water molecule.
2. What is polarity, and why is water polar?
3. Explain how hydrogen bonds cause molecules of liquid water to stick together.
4. What is capillary action? Give an example.
5. What property of water helps to maintain homeostasis and how?

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2. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
3. Mariana Ruiz Villarreal (LadyofHats) for the CK-12 Foundation. Water Molecule . CC BY-NC 3.0
4. Jodi So. Hydrogen Bonding in Water Molecule . CC BY-NC 3.0
5. Courtesy of the US Fish and Wildlife Service. http://commons.wikimedia.org/wiki/File:Water_drops_on_spider_web.jpg . Public Domain

CONCEPT 2 Heat Capacity and Specific Heat

Learning Objectives

- Define heat capacity.
- Define specific heat.
- Perform calculations involving specific heat.


Which pool will warm up faster?

If a swimming pool and wading pool, both full of water at the same temperature were subjected to the same input of heat energy, the wading pool would certainly rise in temperature more quickly than the swimming pool. The heat capacity of an object depends both on its mass and its chemical composition. Because of its much larger mass, the swimming pool of water has a larger heat capacity than the bucket of water.

Heat Capacity and Specific Heat

Different substances respond to heat in different ways. If a metal chair sits in the bright sun on a hot day, it may become quite hot to the touch. An equal mass of water in the same sun will not become nearly as hot. We would say that water has a high **heat capacity** (the amount of heat required to raise the temperature of an object by 1°C.) Water is very resistant to changes in temperature, while metals in general are not. The **specific heat** of a substance is the amount of energy required to raise the temperature of 1 gram of the substance by 1°C. **Table** 2.1 lists the specific heats of some common substances. The symbol for specific heat is c_p, with the p subscript referring to the fact that specific heats are measured at constant pressure. The units for specific heat can either be joules per gram per degree (J/g°C) or calories per gram per degree (cal/g°C). This text will use J/g°C for specific heat.

TABLE 2.1: Specific Heats of Some Common Substances

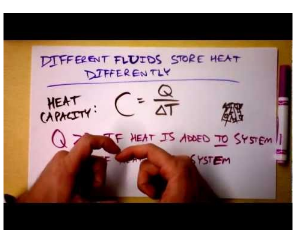
Substance	Specific Heat (J/g°C)
Water (l)	4.18
Water (s)	2.06
Water (g)	1.87
Ammonia (g)	2.09
Ethanol (l)	2.44

TABLE 2.1: (continued)

Aluminum (s)	0.897
Carbon, graphite (s)	0.709
Copper (s)	0.385
Gold (s)	0.129
Iron (s)	0.449
Lead (s)	0.129
Mercury (l)	0.140
Silver (s)	0.233

Notice that water has a very high specific heat compared to most other substances. Water is commonly used as a coolant for machinery because it is able to absorb large quantities of heat (see **Table** 2.1). Coastal climates are much more moderate than inland climates because of the presence of the ocean. Water in lakes or oceans absorbs heat from the air on hot days and releases it back into the air on cool days.

FIGURE 2.1
This power plant in West Virginia, like many others, is located next to a large lake so that the water from the lake can be used as a coolant. Cool water from the lake is pumped into the plant, while warmer water is pumped out of the plant and back into the lake.



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Summary

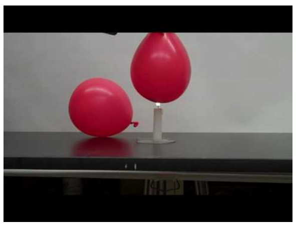
- Heat capacity and specific heat are defined.

Review

1. What is heat capacity?
2. What is specific heat?
3. You have a 10 gram piece of aluminum and a 10 gram piece of gold sitting in the sun. Which metal will warm by ten degrees first?
4. You have a 20 gram piece of aluminum and a 40 gram piece of aluminum sitting in the sun. Which piece will arm by ten degrees first?

Explore More

Use the resource below to answer the questions that follow.



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1. What was in the first balloon?
2. What was in the send balloon?
3. Why did the first balloon not burst?
4. Why did the second balloon burst?

Vocabulary

- **heat capacity:** The amount of heat required to raise the temperature of an object by 1°C.
- **specific heat:** The amount of energy required to raise the temperature of 1 gram of the substance by 1°C.

References

1. Swimming pool: User:Mhsb/Wikimedia Commons; Wading pool: User:Aarchiba/Wikipedia. Swimming pool: http://commons.wikimedia.org/wiki/File:Freshwater_swimming_pool.jpg; Wading pool: http://commons.wikimedia.org/wiki/File:Wading-pool.jpg .
2. User:Raeky/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Mount_Storm_Power_Plant,_-Areial.jpg .

Concept 3 pH Concept

Learning Objectives

- Explain why some acids and bases are stronger than others.
- Define pH.
- Show how to use the pH scale.
- Explain why pH is important to living things.

This scientist is collecting and testing samples of water from the river. One of the properties of the water she is testing is acidity. She wants to know how acidic the water is because water that is too acidic can harm the health of water organisms.

Strength of Acids and Bases

Acids are ionic compounds that produce positively charged hydrogen ions (H^+) when dissolved in water. Acids taste sour and react with metals. Bases are ionic compounds that produce negatively charged hydroxide ions (OH^-) when dissolved in water. Bases taste bitter and do not react with metals. Examples of acids are vinegar and battery acid. The acid in vinegar is weak enough to safely eat on a salad. The acid in a car battery is strong enough to eat through skin. Examples of bases include those in antacid tablets and drain cleaner. Bases in antacid tablets are weak enough to take for an upset stomach. Bases in drain cleaner are strong enough to cause serious burns.

Q: What do you think causes these differences in the strength of acids and bases?

A: The strength of an acid or a base depends on how much of it breaks down into ions when it dissolves in water.

Concentration of Ions

The strength of an acid depends on how many hydrogen ions it produces when it dissolves in water. A stronger acid produces more hydrogen ions than a weaker acid. For example, sulfuric acid (H_2SO_4), which is found in car batteries, is a strong acid because nearly all of it breaks down into ions when it dissolves in water. On the other hand, acetic acid (CH_3CO_2H), which is the acid in vinegar, is a weak acid because less than 1 percent of it breaks down into ions in water.

The strength of a base depends on how many hydroxide ions it produces when it dissolves in water. A stronger base produces more hydroxide ions than a weaker base. For example, sodium hydroxide (NaOH), a base in drain cleaner, is a strong base because all of it breaks down into ions when it dissolves in water. Calcium carbonate ($CaCO_3$), a base in antacids, is a weak base because only a small percentage of it breaks down into ions in water.

The pH Scale

The strength of acids and bases is measured on a scale called the pH scale, which is shown in the **Figure** 3.1. By definition, **pH** represents the **acidity**, or hydrogen ion (H^+) concentration, of a solution. Pure water, which is neutral, has a pH of 7. With a higher the concentration of hydrogen ions, a solution is more acidic and has a lower pH. Acids have a pH less than 7, and the strongest acids have a pH close to zero. Bases have a pH greater than 7, and the strongest bases have a pH close to 14. It's important to realize that the pH scale is based on powers of ten. For example, a solution with a pH of 8 is 10 times more basic than a solution with a pH of 7, and a solution with a pH of 9 is 100 times more basic than a solution with a pH of 7.

Q: How much more acidic is a solution with a pH of 4 than a solution with a pH of 7?

A: A solution with a pH of 4 is 1000 ($10 \times 10 \times 10$, or 10^3) times more acidic than a solution with a pH of 7.

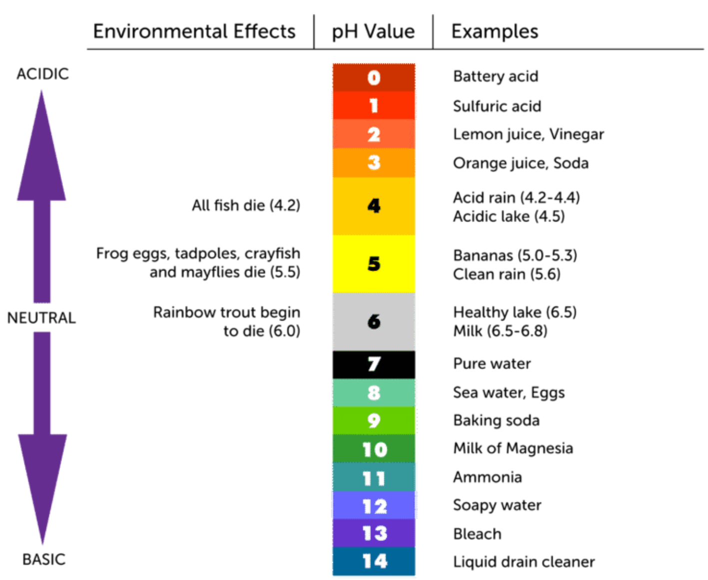

FIGURE 3.1

Q: Which solution on the pH scale in the **Figure** 3.1 is the weakest acid? Which solution is the strongest base?

A: The weakest acid on the scale is milk, which has a pH value between 6.5 and 6.8. The strongest base on the scale is liquid drain cleaner, which has a pH of 14.

Why pH Matters

Acidity is an important factor for living things. For example, many plants grow best in soil that has a pH between 6 and 7. Fish may also need a pH between 6 and 7. Certain air pollutants form acids when dissolved in water droplets in the air. This results in acid fog and acid rain, which may have a pH of 4 or even lower. The pH chart in the **Figure** 3.1 and the **Figure** 3.2 reveal some of the adverse effects of acid fog and rain. Acid rain not only kills trees. It also lowers the pH of surface waters such as ponds and lakes. As a result, the water may become too acidic for fish and other water organisms to survive.

FIGURE 3.2
Acid fog and acid rain killed the trees in this forest.

Even normal (clean) rain is somewhat acidic. That's because carbon dioxide (CO_2) in the air dissolves in raindrops, producing a weak acid called carbonic acid (H_2CO_3), which has a pH of about 5.5. When rainwater soaks into the ground, it can slowly dissolve rocks, particularly those containing calcium carbonate. This is how water forms underground caves.

Q: How do you think acid rain might affect buildings and statues made of stone?

A: Acid rain dissolves and damages stone buildings and statues. The **Figure** 3.3 shows a statue that has been damaged by acid rain.

FIGURE 3.3

Summary

- The strength of an acid or base is called acidity. It depends on how much of the substance breaks down into ions when it dissolves in water.
- Acidity is measured by pH, which is the concentration of hydrogen ions in a solution.
- Acidity is an important factor for living things because most can survive only within a relatively narrow range of acidity.

Review

1. What determines how acidic or basic a solution is?
2. What is pH? What is the pH of a neutral substance?
3. How much more acidic is soapy water than pure water? (*Hint*: See the pH chart in the **Figure** 3.1.)
4. Why is the pH of the environment important for living things?

Acidic Ocean Water Impacts Corals and Other Marine Life

Some of the carbon dioxide that is added to the atmosphere from burning fossil fuels makes its way into the world's oceans. This makes seawater more acidic, which could have a large impact on marine life.

Marine creatures such as corals, clams, snails, and many other types of marine life build their skeletons and shells from calcium carbonate. These creatures get the materials they need to make the calcium carbonate from seawater. As seawater gets more acidic these creatures might have a harder time building their skeletons and shells because calcium carbonate mineral dissolves in acid.

Put a clam shell (one that you don't want to keep) into a container of vinegar and wait. Vinegar is an acid. Within a few hours will notice that your clam shell is disappearing. The calcium carbonate that makes up the shell is dissolving into the acidic vinegar.

Seawater will not become as acidic as vinegar. It has become only slightly more acidic over the past 150 years. It will continue to get more acidic, but very slowly. Scientists suspect that even a small change can make a big difference to the creatures that need to build their shells.

Because corals build reefs from calcium carbonate, and because those reefs become a home to a large amount of marine life, scientists are especially interested in the impact of more acidic water on corals.

Slower growing shells and skeletons can have an impact on the food webs of marine life, possibly changing the number of species of living things in the ocean.

Sometimes a picture is worth a thousand words. The first image shows the link between rising levels of carbon dioxide (CO2) in the atmosphere with rising CO2 levels in the nearby ocean (at Mauna Loa, Hawaii). As more CO2 builds up in the ocean, the pH of the ocean decreases (gets more acidic). The second picture shows one of the devastating affects of ocean acidification.

Picture of Coral Bleaching:

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1. CK-12 Foundation. The pH scale measures acidity . CC BY-NC 3.0

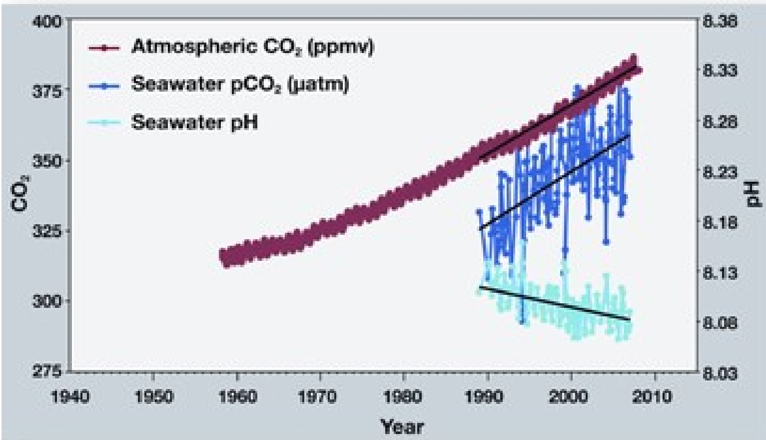

FIGURE 3.4

FIGURE 3.5

2. User:Nipik/Wikimedia Commons. Acid fog and acid rain has killed all the trees in this forest . Public Domain
3. User:Nino Barbieri/Wikimedia Commons. This statue has been damaged by acid rain . CC BY 2.0