

# Water and pH

## Slide 1 Water and pH

**Slide 2** Water covers approximately three-fourths of the earth's surface. While we often think of water in terms of providing great fishing or other recreational opportunities, or just quenching our thirst, it is important to consider how essential water is to the very existence of life. In fact, life first evolved in water, and even today organisms are composed of anywhere from forty-five to ninety-five percent water. Water is often called the universal solvent, and most biological reactions take place in water. Water also takes part directly in many important biological reactions, including the condensation and hydrolysis reactions associated with the synthesis of macromolecules such as carbohydrates and proteins. In addition, the chemical properties of water make it an integral part of many other aspects of life on earth, from regulating organismal and environmental temperatures to transporting nutrients from the soil to the tops of three-hundred feet tall trees.

**Slide 3** Many of the important properties of water stem from its molecular structure, which consists of two hydrogen atoms bound to one oxygen atom. The pairs of electrons that are shared between the hydrogen atoms and the oxygen atom are held more closely to the oxygen atom, since oxygen has higher electronegativity. This results in a slight positive charge on each hydrogen atom. In addition, the other four paired electrons around the oxygen atom create a slightly negative charge. This distribution of charges makes water a polar molecule, and allows an incredible number of polar or charged substances to dissolve in it. Since water is such an effective solvent, it often plays an essential role in the movement of substances, such as dissolved nutrients and minerals, between organisms and their environment.

**Slide 4** The polarity of water is also important because it allows water molecules in liquid and solid water to react with each other through the formation of hydrogen bonds. In liquid water, hydrogen bonds are constantly forming, breaking, and reforming between the hydrogen atoms and oxygen atoms of different water molecules. On average, at any given moment each molecule of liquid water is hydrogen bonded to 3.4 other water molecules. In solid water, or ice, hydrogen bonds are stable, and each water molecule is hydrogen bonded to four other water molecules. In gaseous water, or steam, individual water molecules contain too much energy and are on average too far apart to form hydrogen bonds. While hydrogen bonds individually are weak, the large numbers of hydrogen bonds that occur in a volume of liquid or solid water give them some unique and important properties. For example, liquid water has a high heat capacity, meaning that it takes a relatively large amount of energy to raise its temperature. The reason for this high heat capacity is that a large portion of the energy absorbed by water is used to break the myriad hydrogen bonds it contains. Water also has a high heat of fusion and a high heat of vaporization, meaning that the transitions from solid to liquid water and from liquid to gaseous water, respectively, require a large input of energy.

**Slide 5** The special characteristics of water, such as its high heat capacity and high heat of vaporization, often have significant consequences for organisms. For example, because the temperature of large bodies of water is slow to change under most conditions, water plays an important role in maintaining stable environmental temperatures in oceans, lakes and rivers. Further, bodies of water can affect the temperature of the air that moves over them. Since so much of the earth's surface is covered in water, bodies of water may moderate the air temperatures that organisms experience on land. This is why, for instance, the seasonal temperature fluctuations of Portland, Oregon, are not as extreme as Minneapolis, Minnesota, even though both cities are at similar latitudes. The air temperatures of Portland are moderated by the waters of the adjacent Pacific Ocean, which have a fairly stable year-round temperature. The air masses that move through Minneapolis, on the other hand, travel great distances over land and so are subject to much greater seasonal fluctuations.

The high heat of vaporization of water is important to many organisms because it allows for evaporative cooling. When you sweat on a hot day, for instance, the water on your skin absorbs energy in the form of the heat in your body. Eventually, enough energy is absorbed to cause the water to evaporate into the surrounding air. As this happens, the loss of energy from your body results in a cooling of your body temperature.

**Slide 6** The hydrogen bonds and polarity of water also impart properties of cohesion and adhesion, meaning that not only do water molecules stick to each other, but they also tend to be attracted to other substances. For example, the columns of water that rise from the roots of plants to their leaves are supported by the attraction of the water molecules for each other, and the attraction of the water molecules to the cell walls of the plant's xylem.

The cohesiveness of water molecules also results in surface tension. Some organisms, such as water striders, are able to take advantage of this tension and spend virtually their entire lives walking on the surface of water, without ever getting wet.

**Slide 7** Since water plays many essential roles for life, it is important for scientists to be able to describe solutions of water quantitatively. This can be done in a number of ways, ranging from measuring the temperature or density of water to measuring the concentration of solutes, such as salt, depending on what specific character one is interested in. One of the most common ways to quantify a water solution is to measure its pH. pH is a measure of the acidity or basicity of a solution. More specifically, pH is defined as the negative log of the proton concentration of a solution. For example, if a solution has a proton concentration of  $10^{-9}$  M, its pH is 9. If a solution has a higher proton concentration, say  $10^{-1}$  M, its pH is 1.

**Slide 8** Acidic solutions have higher concentrations of protons, while basic solutions have lower concentrations of protons. On the pH scale, acidic solutions range from just under pH seven, which is very slightly acidic, to pH zero or less, which is strongly acidic. Lemon juice at pH 2, for example, is quite acidic. Basic solutions range from just over pH seven, which is slightly basic, to pH fifteen and over, which is strongly basic. Many household cleaning products, such as ammonia or drain cleaners, are very basic.

Many biological solutions, such as blood or the cytosol inside of cells, have a fairly neutral pH – one that is neither strongly acidic nor strongly basic. Many environments, as well, such as the ocean, lakes and streams, and some soils exhibit fairly neutral pH levels. Many of the enzymes and other macromolecules that organisms depend on for life processes are most stable in neutral solutions, therefore mechanisms to maintain neutral pH levels around these molecules have evolved in many types of organisms. Of course, there are exceptions. The digestive enzymes in your stomach, for instance, are most effective at low pH, corresponding to the acidic conditions in your stomach that contribute to the breakdown of ingested food.