Chapter 3

Water and the Fitness of the Environment

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: The Molecule That Supports All of Life

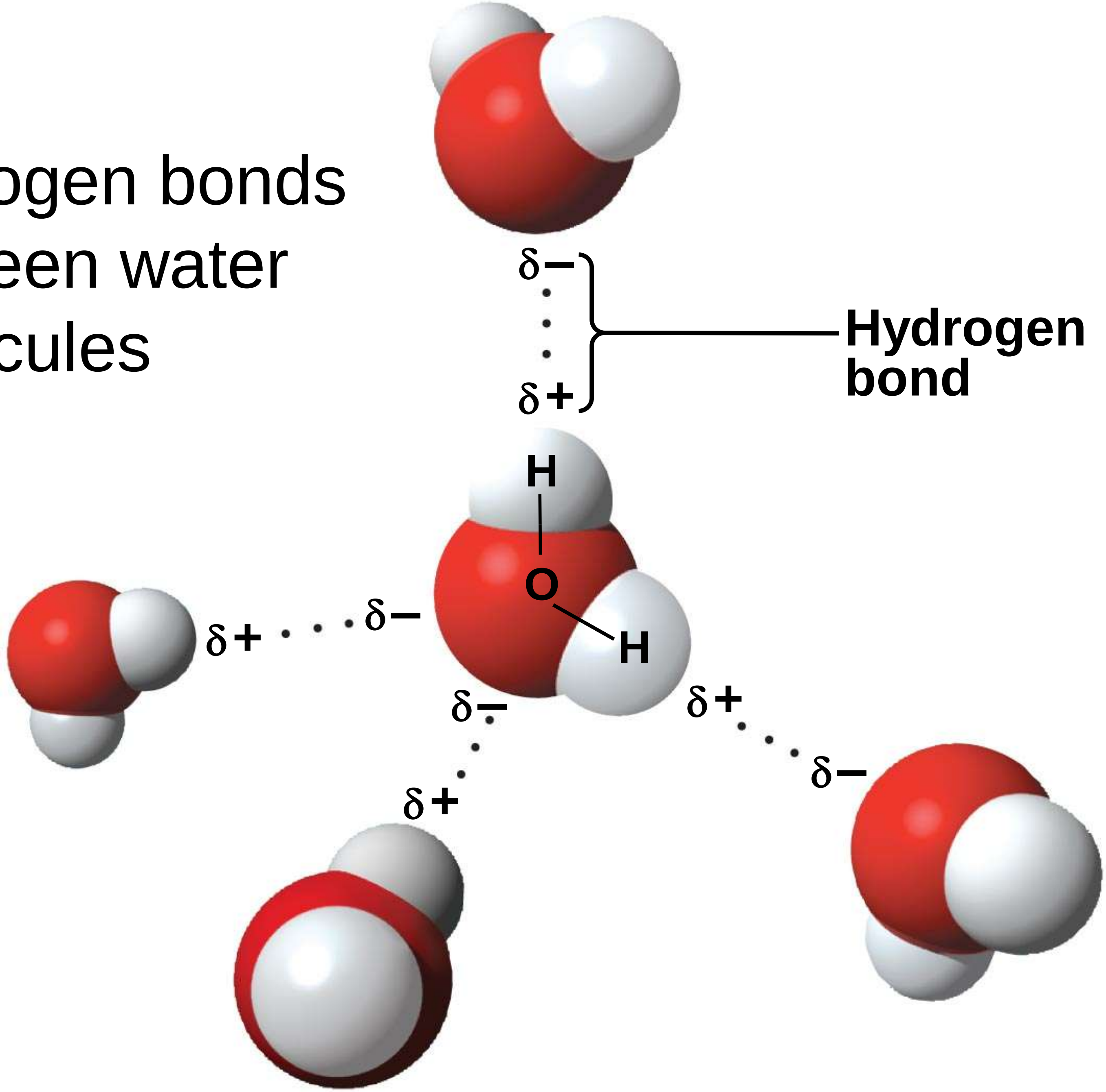
- Water is the **biological medium** on Earth
- All living organisms require water more than any other substance
- Most cells are surrounded by water, and cells themselves are about **70–95% water**
- The abundance of water is the main reason the Earth is habitable

The polarity of water molecules results in hydrogen bonding

- The water molecule is a **polar molecule**: The opposite ends have opposite charges
- Polarity allows water molecules to form hydrogen bonds with each other

PLAY Animation: Water Structure

Hydrogen bonds between water molecules



Four emergent properties of water contribute to Earth's fitness for life

- **Four** of water's properties that facilitate an environment for life are:
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

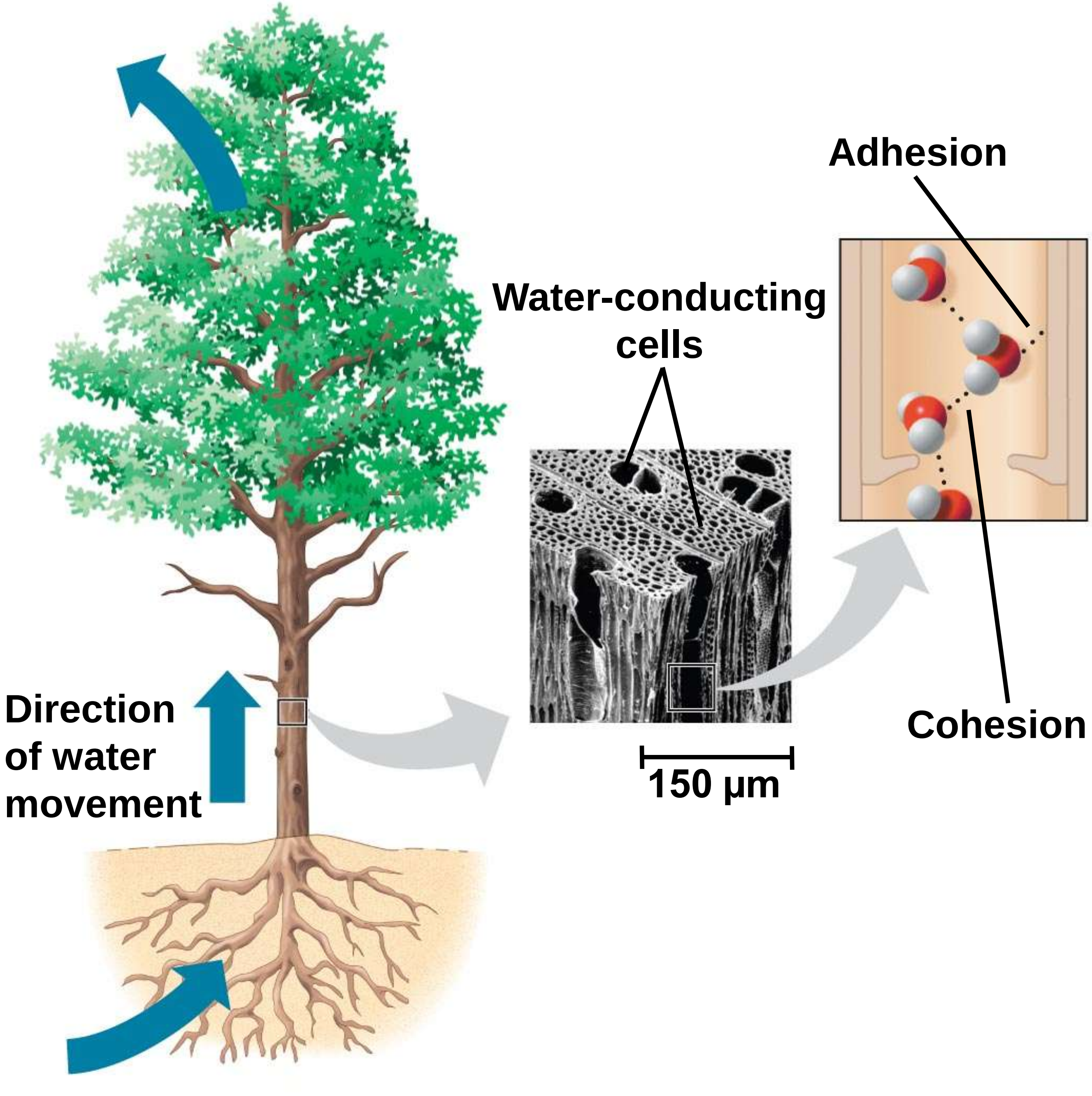
Cohesion

- Collectively, hydrogen bonds hold water molecules together, a phenomenon called **cohesion**

- Cohesion helps the transport of water against gravity in plants

- **Adhesion** is an attraction between **different** substances, for example, between water and plant cell walls

PLAY Animation: Water Transport



Adhesion
Water-conducting cells
Direction of water movement
150 µm
Cohesion

- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion

Moderation of Temperature

- Water absorbs heat from warmer air and releases stored heat to cooler air
- Water can absorb or release a **large amount of heat** with only a **slight change in its own temperature, because of it's high specific heat**

Heat and Temperature

- **Kinetic energy** is the energy of motion
- **Heat** is a measure of the ***total*** amount of kinetic energy due to molecular motion
- **Temperature** measures the intensity of heat due to the ***average*** kinetic energy of molecules

- The **Celsius scale** is a measure of temperature using Celsius degrees (°C)
- A **calorie (cal)** is the amount of heat required to raise the temperature of <u>1 g of water by 1°C</u>
- The **joule (J)** is another unit of energy where 1 J = 0.239 cal, or 1 cal = 4.184 J

Water's High Specific Heat

- The **specific heat** of a substance is the amount of heat that **must be absorbed or lost** for 1 g of that substance to change its temperature by 1ºC
- The specific heat of water is 1 cal/g/ºC
- Water resists changing its temperature because of its high specific heat

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html

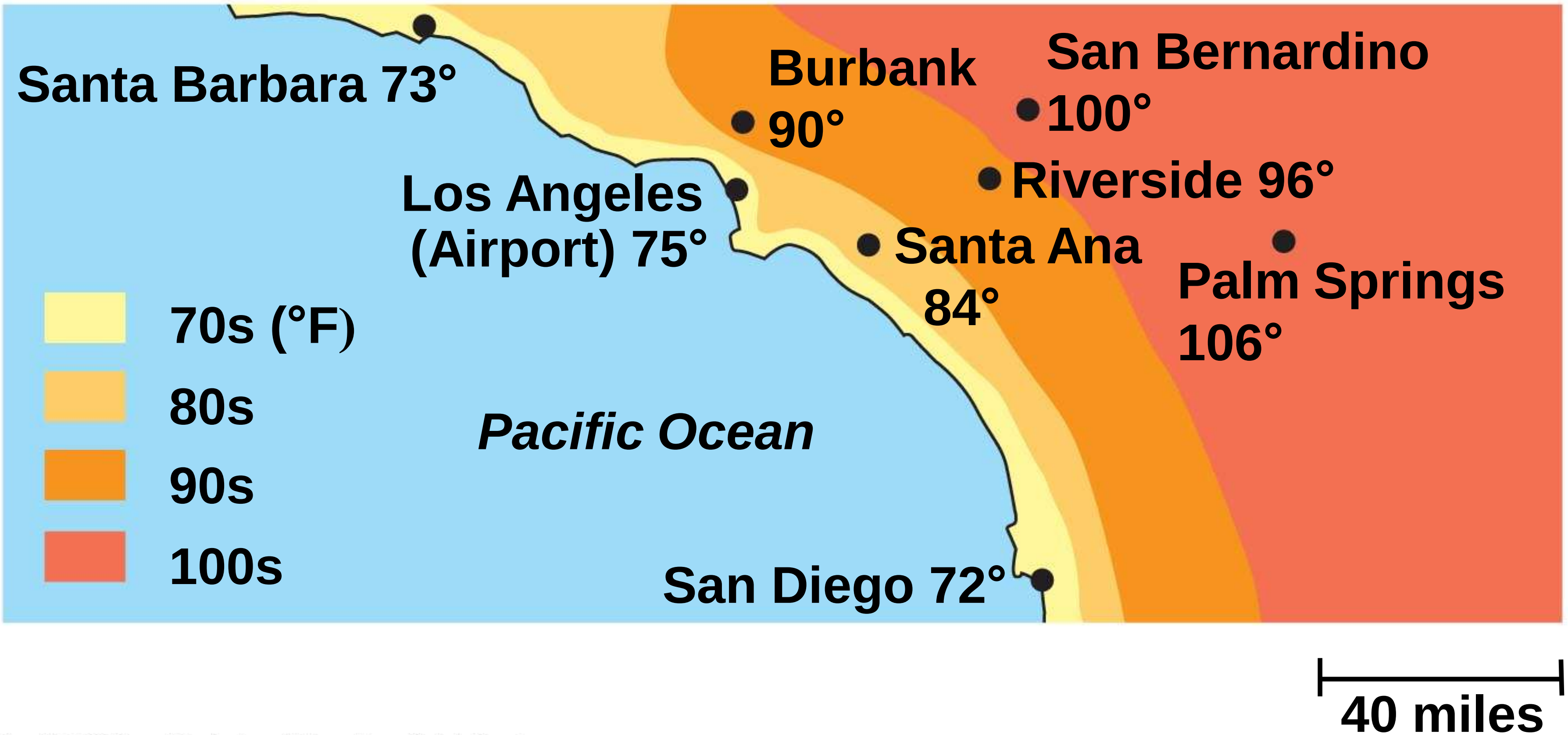
- **$Q = mc\Delta T$**
- *Q* is the amount of heat needed to change the temperature of a substance
- *m* is the mass of the heated substance
- *c* is the specific heat capacity
- ΔT (pronounced *delta T*) is the temperature difference; the difference in temperature before and after you applied the heat

- $Q = m\ c\ \Delta T$
- Now what does that mean?
- Suppose we want to know HOW MUCH HEAT is needed to change the temperature of a substance…this is the equation we use.
- Q= heat. The unit of heat will be either the SI unit of heat energy called JOULES or it may be measured in Calories as well, the older unit of heat.
- M = Mass. The amount of heat needed to change the temperature of a certain amount of a substance depends in part on HOW MUCH of the substance you have. Obviously you must do much more work to change the temperature of a ton of iron than it will take to change the temperature of 1 ounce of iron.
- "c"= is called the "specific heat" of a substance. It turns out that every substance has a characteristic specific heat. We can identify an unknown substance IF we know its specific heat. So when I wish to find out how much heat is needed to change the temperature of a substance it helps to know the mass and the identity of the substance.
- The third piece of info needed is the amount of temperature change (ΔT).
- So it will take more energy, more work, more heat to change the temperature by 50 degrees than to change the temperature by only 10 degrees.
- $Q = mc\Delta T$ If I know the mass and the identity of the substance and the amount by which we wish to change the temperature of a substance then we can calculate the amount of work, energy, heat needed to make the change.

For Your Information

- Water's high specific heat can be traced to hydrogen bonding
  - Heat is absorbed when hydrogen bonds break
  - Heat is released when hydrogen bonds form
- The **high specific heat of water** **minimizes temperature fluctuations to within limits that permit life**

The effect of a large body of water on climate



Evaporative Cooling

- *Evaporation* is transformation of a substance from liquid to gas
- **Heat of vaporization** is the heat a liquid must absorb for 1 g to be converted to gas
- As a liquid evaporates, its remaining surface cools, a process called **evaporative cooling**
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water


How Evaporative Cooling Works
Water
Warm Air
18-25°
Cooler Air!

HyperKewl™ Evaporative Cooling Vest, Khaki, Small

View Larger

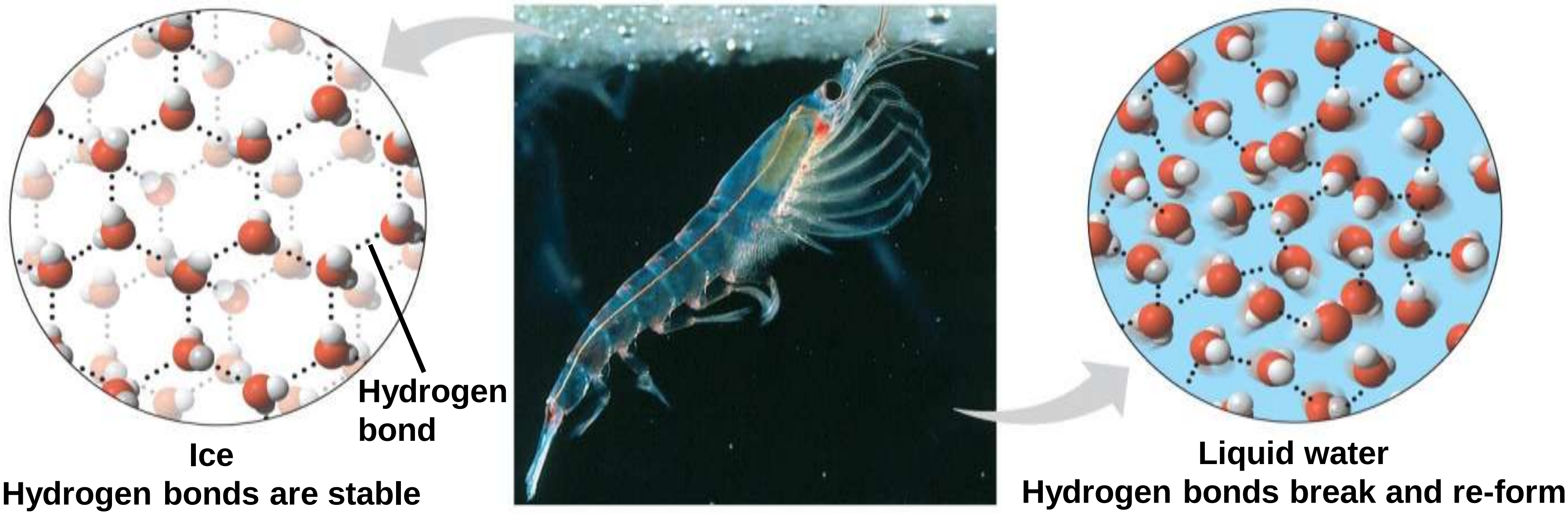
HyperKewl™ Evaporative Cooling Vest, Khaki, Small Close

Lightweight, Durable and Washable

Soak for just two or three minutes for five to 10 hours of cooling relief! V-neck Vest has a zipper closure. Comfortable, quilted nylon outer with HyperKewl polymer-embedded fabric inner and water-repellent nylon liner. Just soak for two minutes and you're ready to go! ANSI complaint with 3M reflective tape to keep you safe. Three large front pockets to stash your gear.***Compliance:*** ANSI 107-2004 Class II. ***Please Specify Men's Size:*** S, M, L, XL, XXL, 3XL.

Ice floats in liquid water because hydrogen bonds in ice are more "ordered," **making ice less dense**

If ice sank, all bodies of water would eventually **freeze solid**, making life impossible on Earth



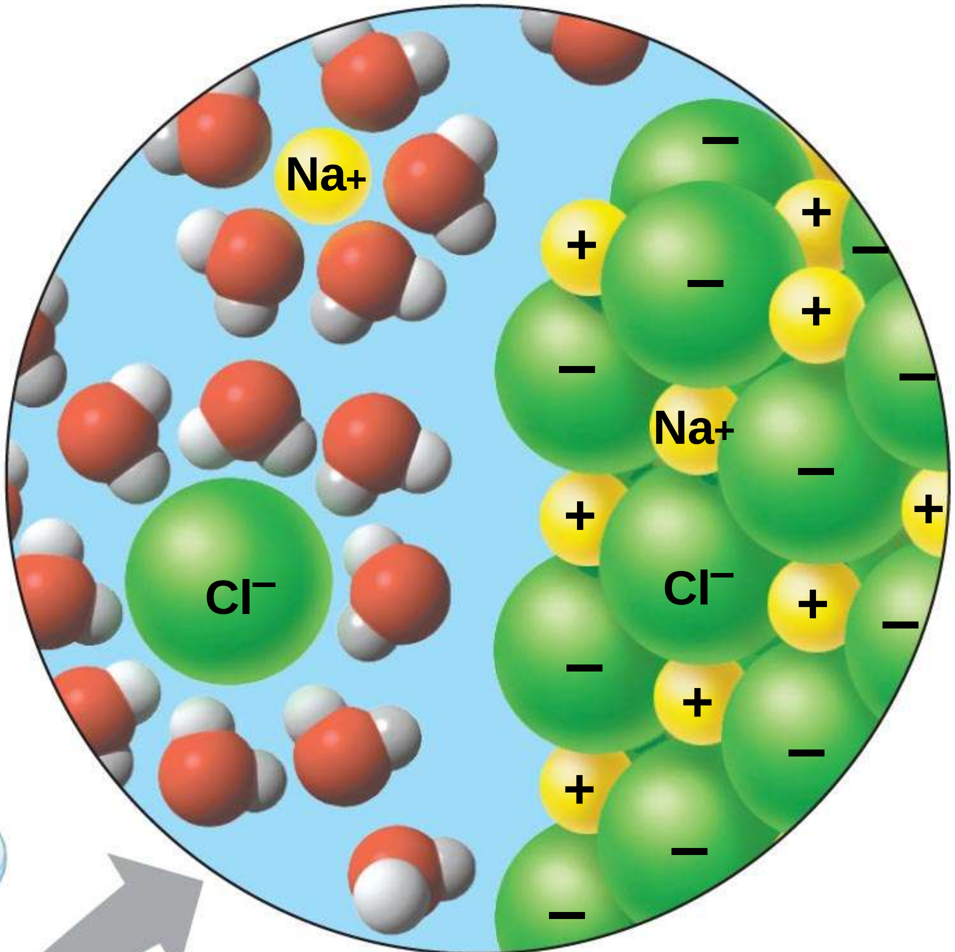
Water reaches its **greatest density** at **4°C**

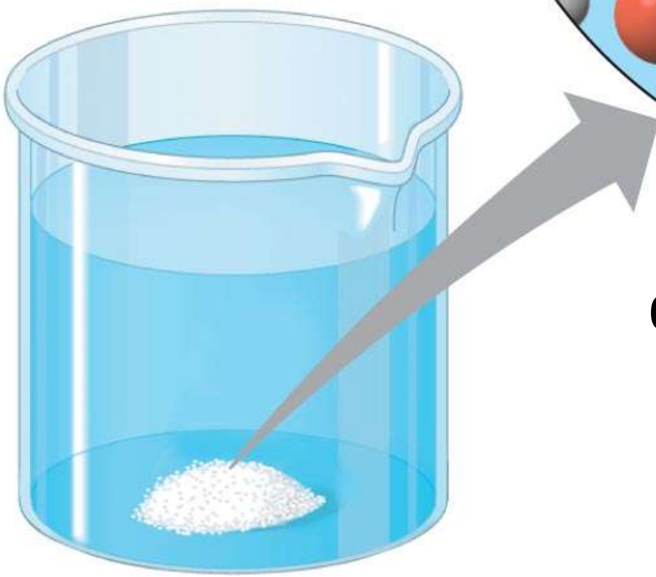
The Solvent of Life

- A **solution** is a liquid that is a homogeneous mixture of substances
- A **solvent** is the dissolving agent of a solution
- The **solute** is the substance that is dissolved
- An **aqueous solution** is one in which water is the solvent

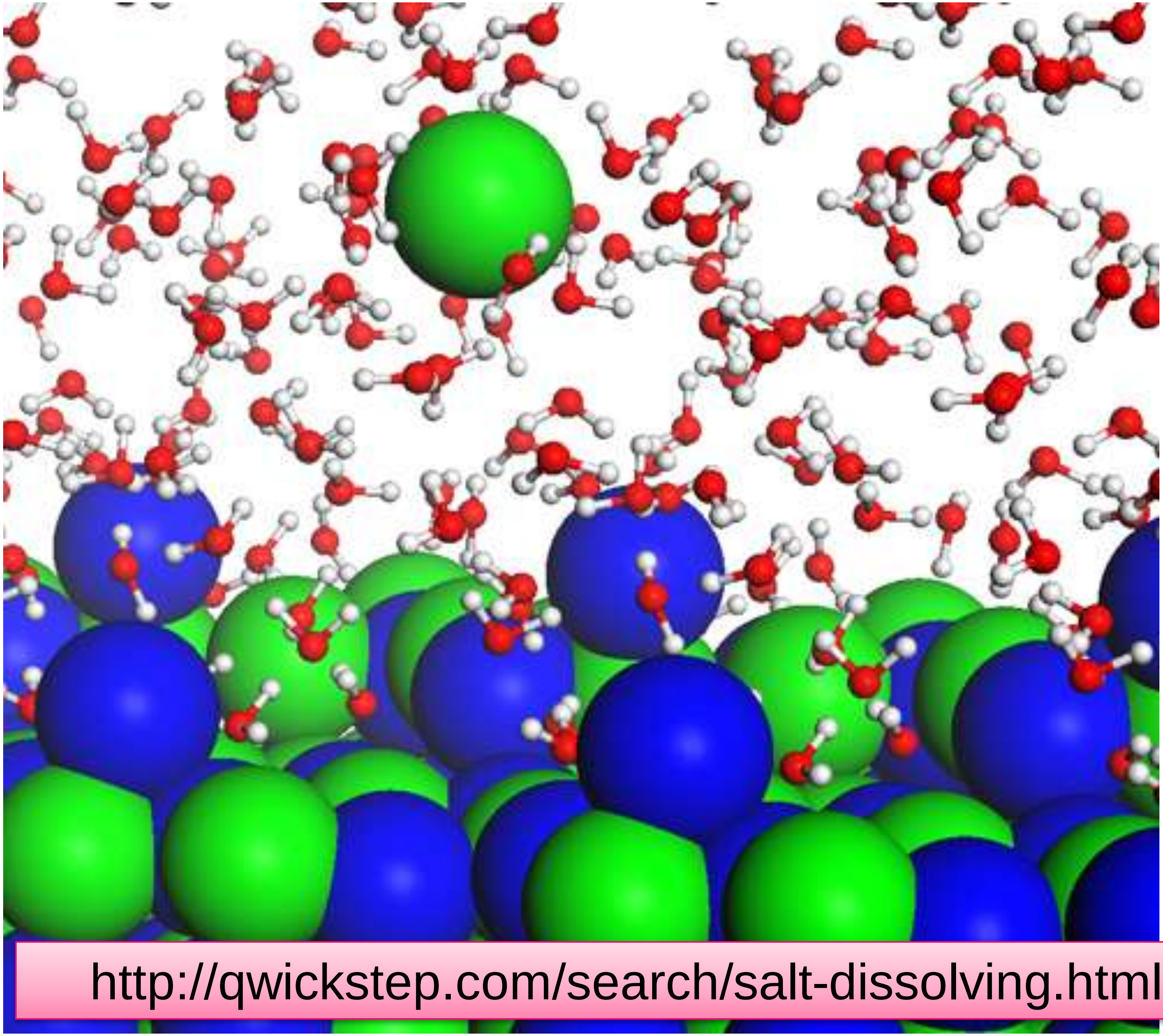
Fig. 3-7

Water is a versatile solvent due to its polarity, which allows it to form hydrogen bonds easily

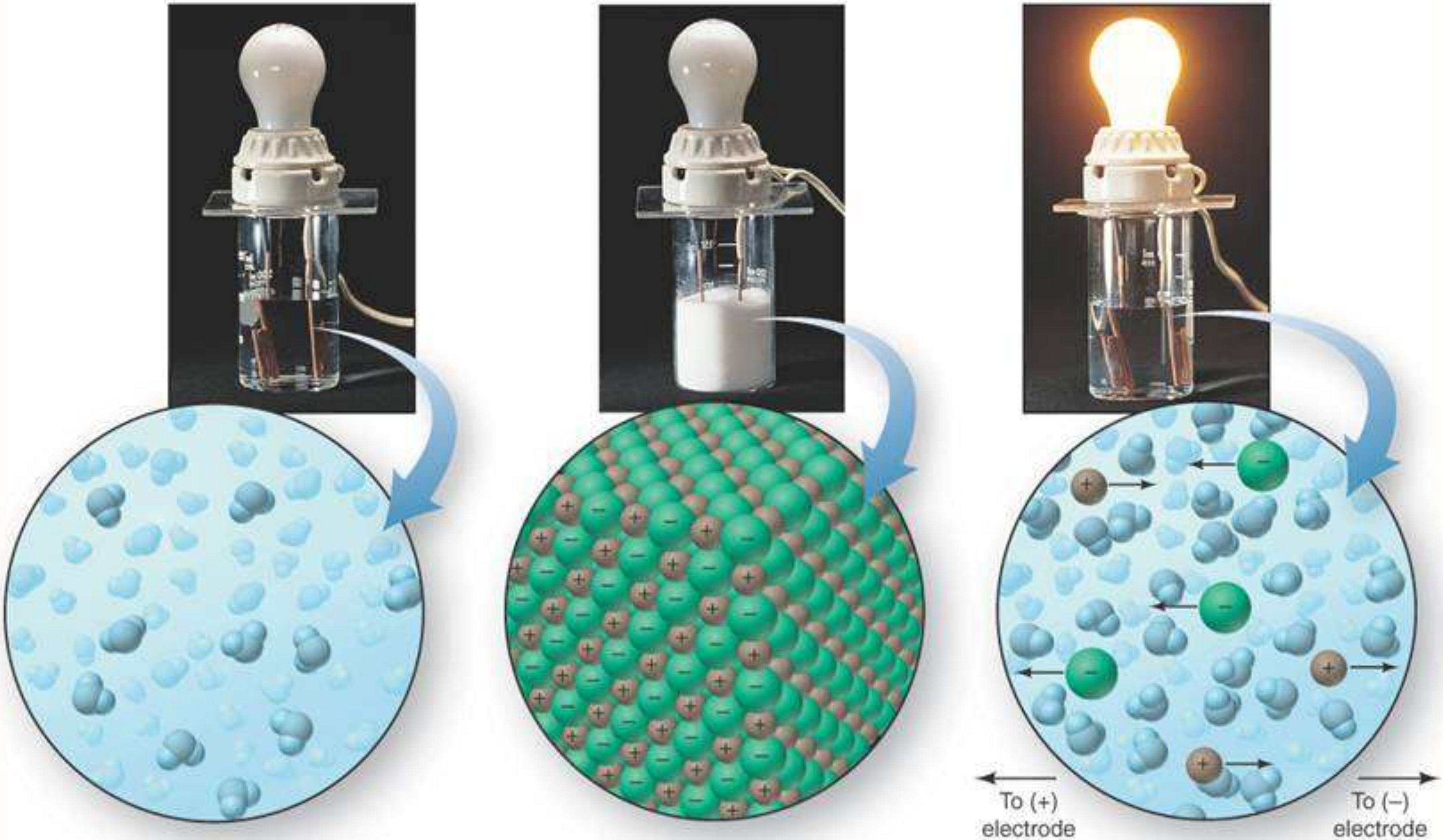




When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**



http://qwickstep.com/search/salt-dissolving.html



A Distilled water does not conduct a current

B Positive and negative ions fixed in a solid do not conduct a current

C In solution, positive and negative ions move and conduct a current

- Water can also dissolve compounds made of nonionic **polar** molecules
- Even large polar molecules such as proteins can dissolve in water if they have ionic and polar regions

Hydrophilic and Hydrophobic Substances

- A **hydrophilic** substance is one that has an affinity for water
- A **hydrophobic** substance is one that does not have an affinity for water
- Oil molecules are hydrophobic because they have relatively nonpolar bonds
- A **colloid** is a <u>stable suspension of fine particles</u>

Solute Concentration in Aqueous Solutions

- **Most biochemical reactions occur in water**
- Chemical reactions depend on collisions of molecules and therefore **on the concentration of solutes** in an aqueous solution

- **Molecular mass** is the sum of all masses of all atoms in a molecule
- Numbers of molecules are usually measured in moles, where 1 **mole (mol)** = 6.02×10^{23} molecules (Avogadro's number)
- **Molarity (*M*)** is the **number of moles of solute per liter of solution**

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<u>EXAMPLE:</u>

- **<u>The solution of C_2H_6O in 1 liter of water</u>**
- Molecular mass of **<u>one</u>** $\mathbf{C_2H_6O}$ molecule is:
- 12×2 = 24; 1×6 = 6; 16×1 = 16; 24+6+16 = 46
- Therefore, if you dissolve 46 grams of $\mathbf{C_2H_6O}$ in 1 liter of water, it would be **<u>1M</u>** solution; if 92 grams – **2M** solution; if 4.6 grams – **0.1M** solution

Concept 3.3: Acidic and basic conditions affect living organisms

- A hydrogen atom in a hydrogen bond between two water molecules can shift from one to the other:
  - The hydrogen atom leaves its electron behind and is transferred as a proton, or **hydrogen ion** (H^+)
  - The molecule that lost the proton is now a **hydroxide ion** (OH^-)

Effects of Changes in pH

- Concentrations of H^+ and OH^- are equal in pure water
- Adding certain solutes, called acids and bases, **modifies** the concentrations of H^+ and OH^-
- Changes in concentrations of H^+ and OH^- can **drastically affect the chemistry of a cell**
- Biologists use something called the **pH scale** to describe whether a solution is acidic or basic (the opposite of acidic)

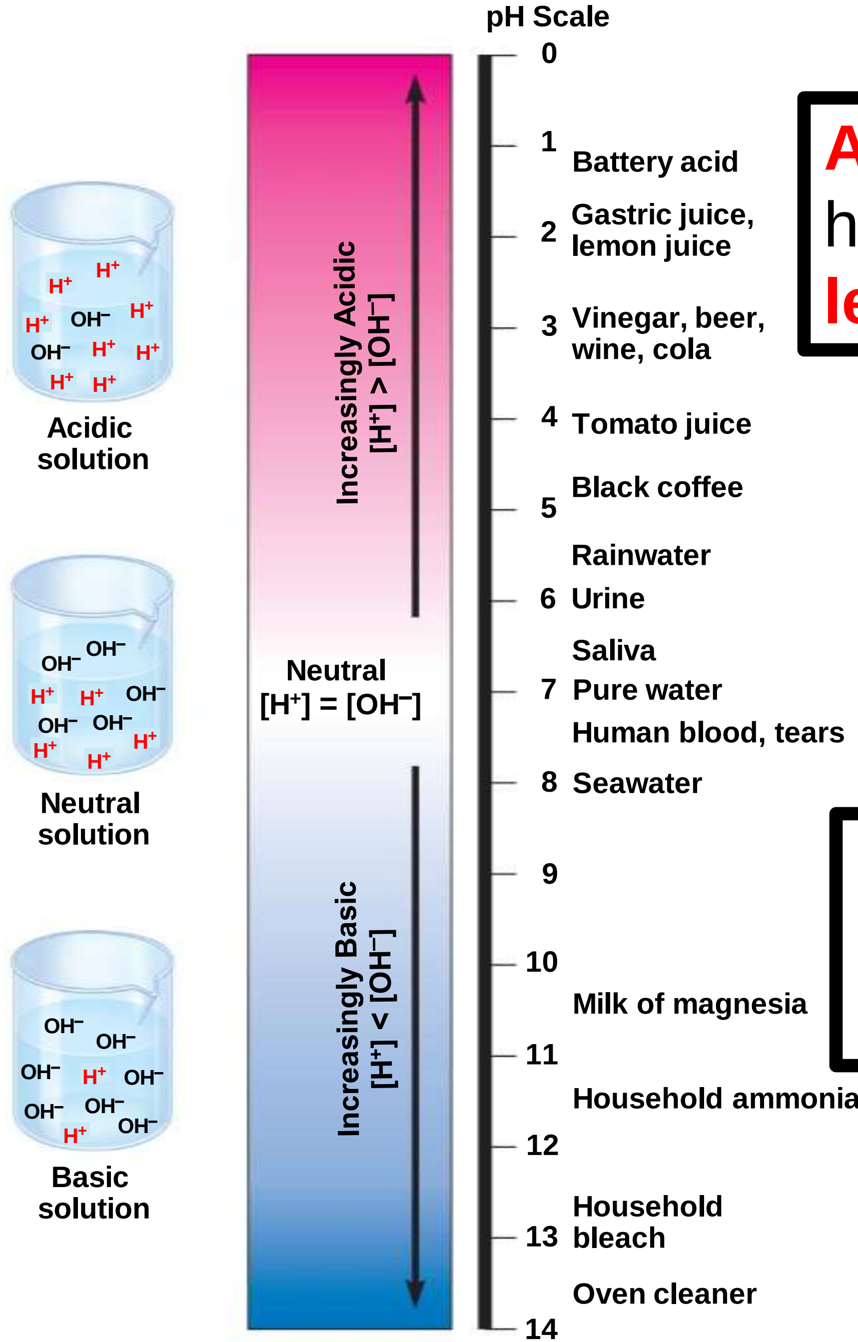
The pH Scale

An **acid** is any substance that increases the H^+ concentration of a solution

Concentration of Hydrogen ions compared to distilled water		Examples of solutions at this pH
10,000,000	pH= 0	Battery acid, Strong Hydrofluoric Acid
1,000,000	pH = 1	Hydrochloric acid secreted by stomach lining
100,000	pH = 2	Lemon Juice, Gastric Acid Vineger
10,000	pH = 3	Grapefruit, Orange Juice, Soda
1,000	pH = 4	Acid rain Tomato Juice
100	pH = 5	Soft drinking water Black Coffee
10	pH = 6	Urine Saliva
1	pH = 7	"Pure" water
1/10	pH = 8	Sea water
1/100	pH = 9	Baking soda
1/1,000	pH = 10	Great Salt Lake Milk of Magnesia
1/10,000	pH = 11	Ammonia solution
1/100,000	pH = 12	Soapy water
1/1,000,000	pH =13	Bleaches Oven cleaner
1/10,000,000	pH = 14	Liquid drain cleaner

A **base** is any substance that reduces the H^+ concentration of a solution

Fig. 3-9



Acidic solutions have pH values **less** than 7

Basic solutions have pH values **greater** than 7

Most biological fluids have pH values in the range of **6 to 8**

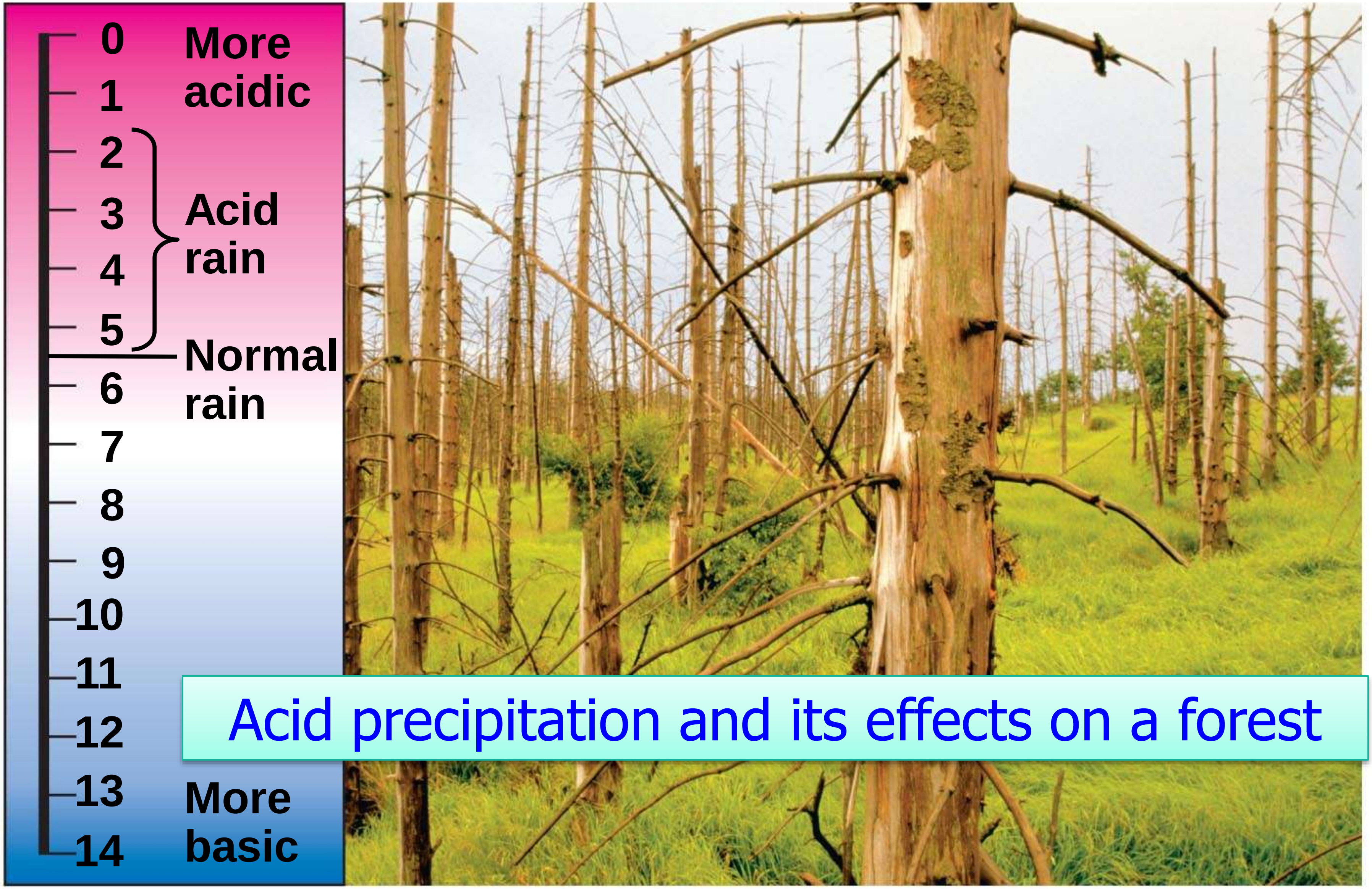
Buffers

- The internal pH of most living cells must remain close to pH 7
- **Buffers** are substances that minimize changes in concentrations of H^+ and OH^- in a solution

A **buffer solution** has the property that the pH of the solution changes very little when a small amount of strong acid or base is added to it. Buffer solutions are used as a means of keeping pH at a nearly constant value in a wide variety of chemical applications. Many life forms thrive only in a relatively small pH range; an example of a buffer solution is blood - http://en.wikipedia.org/wiki/Buffer_solution

Threats to Water Quality on Earth

- **Acid precipitation** refers to rain, snow, or fog with a **pH lower than 5.6**
- Acid precipitation is caused mainly by the **mixing of different pollutants (mainly SO_2, NO_2, CO_2) with water in the air** and can fall at some distance from the source of pollutants
- Acid precipitation can damage life **in aquatic environments** (oceans, lakes, rivers)
- Effects of acid precipitation on soil chemistry are **contributing to the decline of some forests**



Acid precipitation and its effects on a forest

- Human activities such as burning fossil fuels threaten water quality
- CO_2 is released by fossil fuel combustion and contributes to:
  - A warming of earth called the **"greenhouse" effect**
  - Acidification of the oceans; this leads to a decrease in the ability of corals to form calcified reefs

Questions ?

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