Chapter 2

The Chemical Basis of Life

Introduction

- Chemicals are the stuff that make up our bodies and those of other organisms.
- They make up the physical environment as well.
- The ordering of atoms into molecules represents the lowest level of biological organization.
- Therefore, to understand life, it is important to understand the basic concepts of chemistry.

ELEMENTS, ATOMS, AND MOLECULES

Living organisms are composed of about 25 chemical elements

- **Chemicals are at the base level of biological hierarchy .**
- **They are arranged into higher and higher levels of structural organization.**
- **Arrangement eventually leads to formation of living organisms.**

Living organisms are composed of about 25 chemical elements

- **Living organisms are composed of matter, which is anything that occupies space and has mass (weight)**
  - **Matter is composed of chemical elements .**
  - **Element — a substance that cannot be broken down to other substance.**
  - **There are 92 elements in nature — only a few exist in a pure state.**
  - **Life requires 25 essential elements; some are called trace elements.**

TABLE 2.1 ELEMENTS IN THE HUMAN BODY

Element	Symbol	Percentage of Human Body Weight	
Oxygen	O	65.0	96.3
Carbon	C	18.5	
Hydrogen	H	9.56	
Nitrogen	N	3.3	
Calcium	Ca	1.5	
Phosphorus	P	1.0	
Potassium	K	0.4	
Sulfur	S	0.3	
Sodium	Na	0.2	
Chlorine	Cl	0.2	
Magnesium	Mg	0.1	

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

Elements in the Human Body

Essential Elements

S H O P C N

Invariably found in all living organisms

Variable Elements

Na K Ca Mg Fe Cl

Variably found in living organisms

Trace Elements

Cu Zn Mn Se Si F I

Found in trace amounts in some, but not all, organisms

CONNECTION: Trace elements are common additives to food and water

- **Some trace elements are required to prevent disease**
  - **Without iron, your body cannot transport oxygen**
  - **An iodine deficiency prevents production of thyroid hormones, resulting in goiter**

Goiter in a Malaysian woman, a symptom of iodine deficiency

CONNECTION: Trace elements are common additives to food and water

- Several chemicals are added to food for a variety of reasons
  - Help preserve it
  - Make it more nutritious
  - Make it look better
- Check out the "Nutrition Facts" label on foods and drinks you purchase

Elements can combine to form compounds

- **Compound - a substance consisting of two or more different elements combined in a fixed ratio.**
  - **There are many compounds that consist of only two elements.**
    - **Table salt (sodium chloride or NaCl) is an example.**
    - **Sodium is a metal, and chloride is a poisonous gas.**
    - **However, when chemically combined, an edible compound emerges.**

The emergent properties of the edible compound sodium chloride

Sodium

+

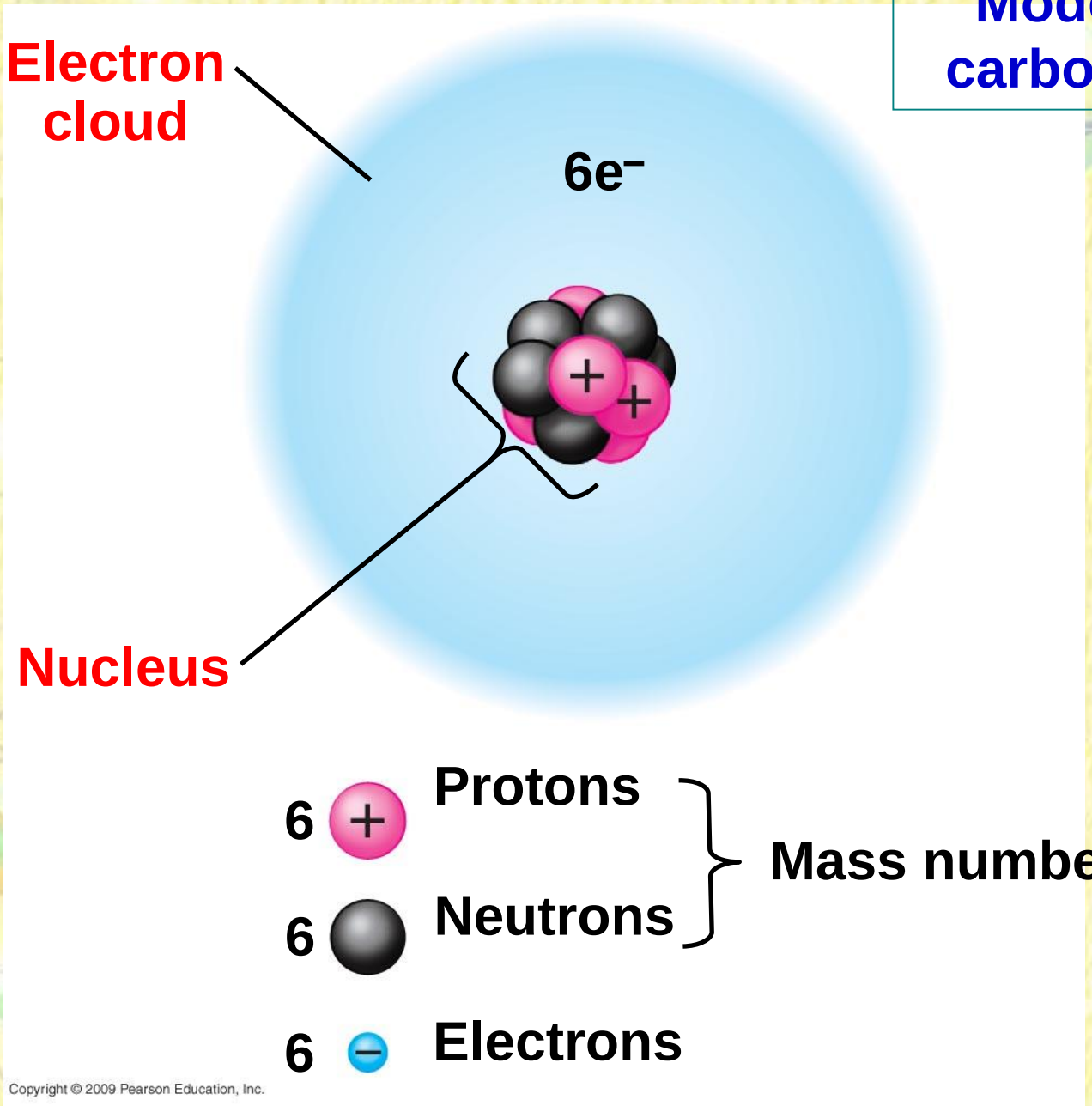
Chlorine

Sodium Chloride

Atoms consist of protons, neutrons, and electrons

- An **atom** is the smallest unit of matter that still retains the properties of an element
- Atoms are made of over a hundred subatomic particles, but only three are important for biological compounds
  - **Proton** — has a single positive electrical charge
  - **Electron** — has a single negative electrical charge
  - **Neutron** — is electrically neutral

Model of a carbon atom



Atoms consist of protons, neutrons, and electrons

- **Although all atoms of an element have the same atomic number, some differ in mass number**
  - **The variations are isotopes, which have the same numbers of protons and electrons but different numbers of neutrons**
    - **One isotope of carbon has 8 neutrons instead of 6 (written ^{14}C)**
    - **Unlike ^{12}C, ^{14}C is an unstable (radioactive) isotope that gives off energy**

TABLE 2.4 ISOTOPES OF CARBON

	Carbon-12	Carbon-13	Carbon-14
Protons	6	6	6
Neutrons	6	7	8
Electrons	6	6	6

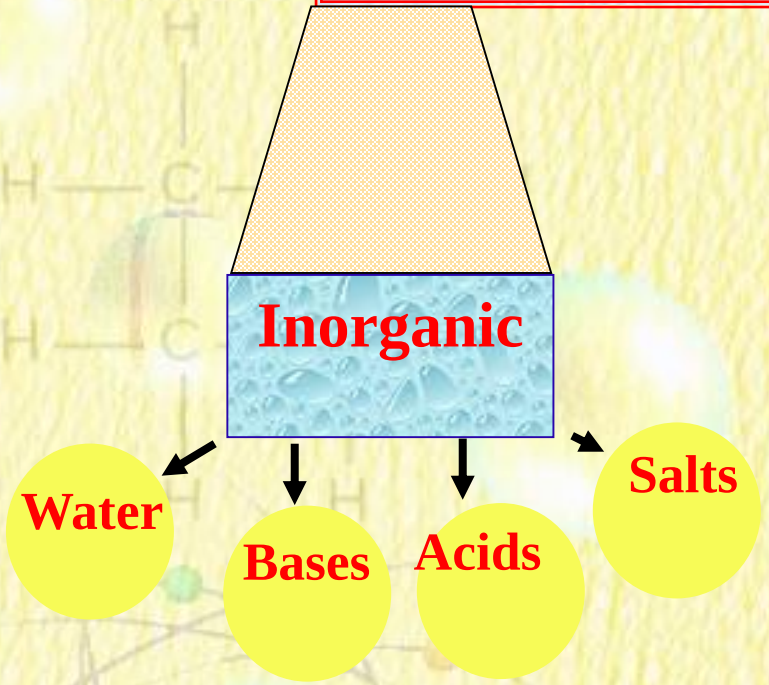
CONNECTION: Radioactive isotopes can help or harm us

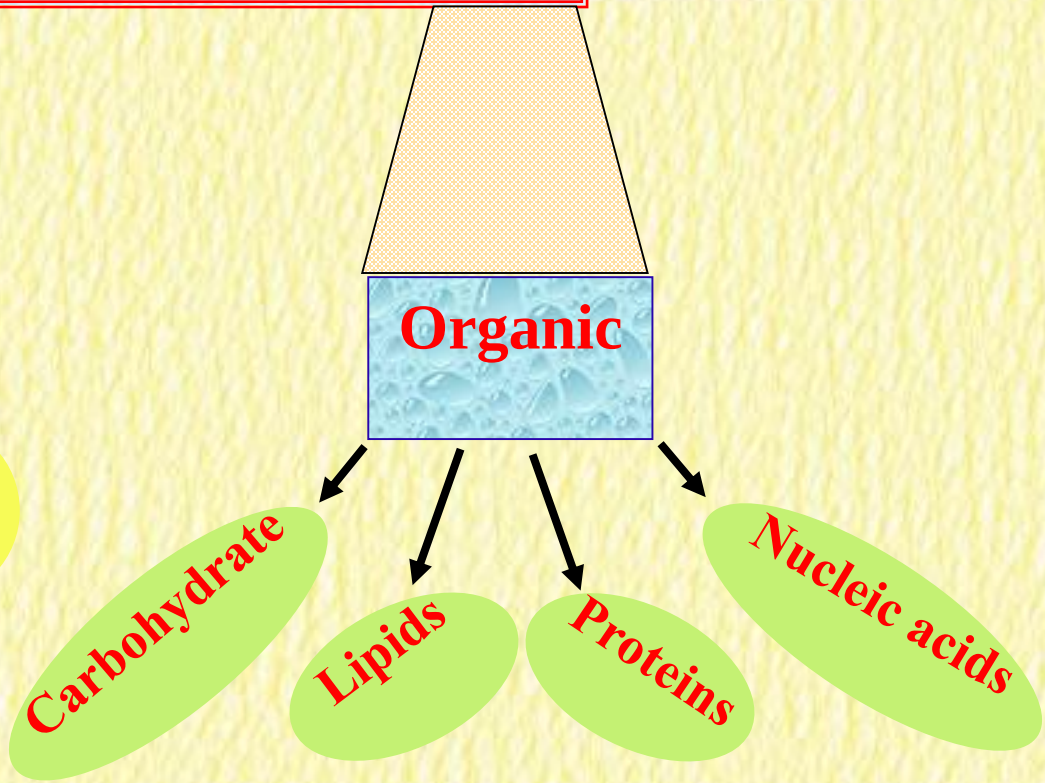
- **Living cells cannot distinguish between isotopes of the same element.**
  - **Therefore, when radioactive compounds are used in metabolic processes, they act as tracers.**
  - **Radioactivity can be detected by instruments.**
- **With instruments, the fate of radioactive tracers can be monitored in living organisms.**
- **Radioactive tracers are frequently used in medical diagnosis.**
- **Sophisticated (advanced) imaging instruments are used to detect them.**

2.5 CONNECTION: Radioactive isotopes can help or harm us

- **In addition to benefits, there are also dangers associated with using radioactive substances**
  - **Uncontrolled exposure can cause damage to some molecules in a living cell, especially DNA**
  - **Chemical bonds are broken by the emitted energy.**

Biological Molecules

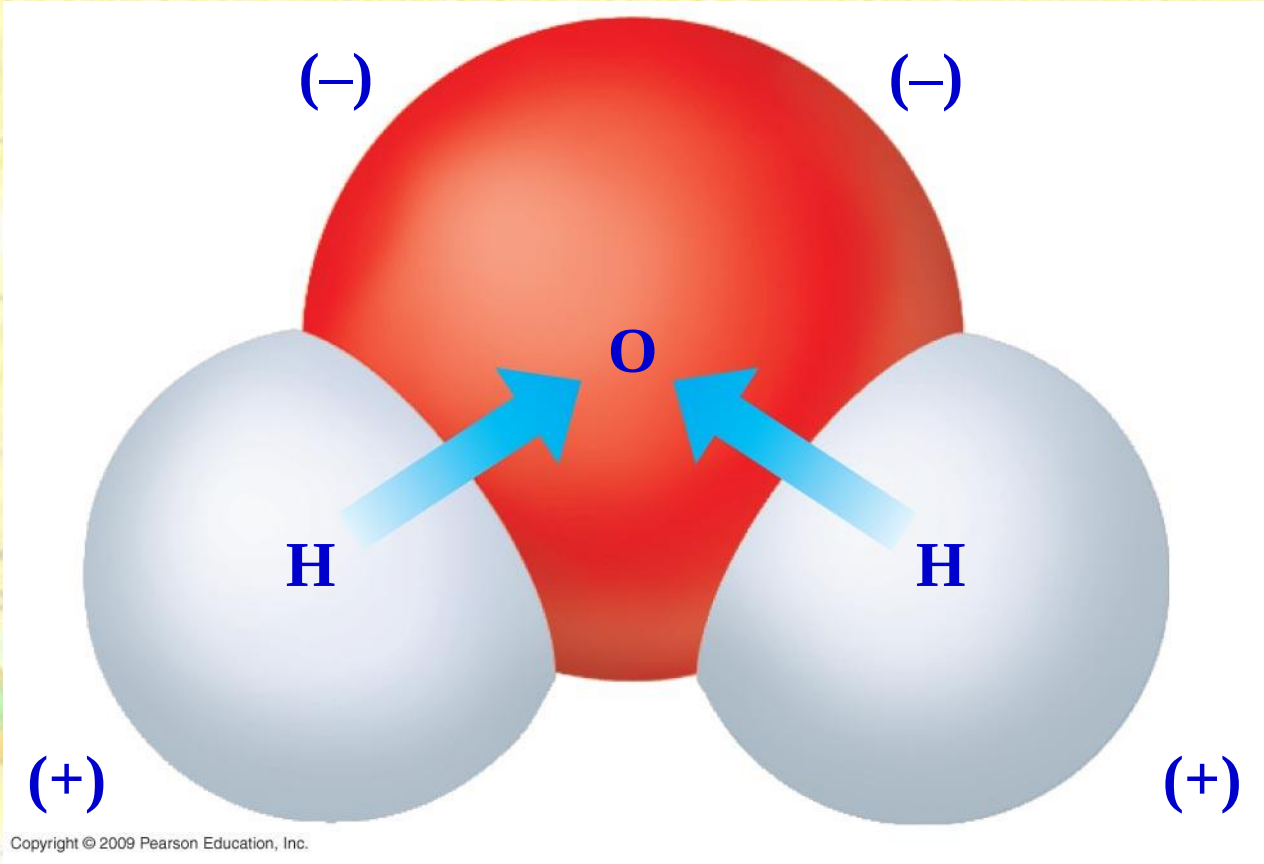




Water properties

- **Water has atoms with different electronegativities**
  - **Oxygen attracts the shared electrons more strongly than hydrogen**
  - **So, the shared electrons spend more time near oxygen**
  - **The result is a polar covalent bond**

A water molecule

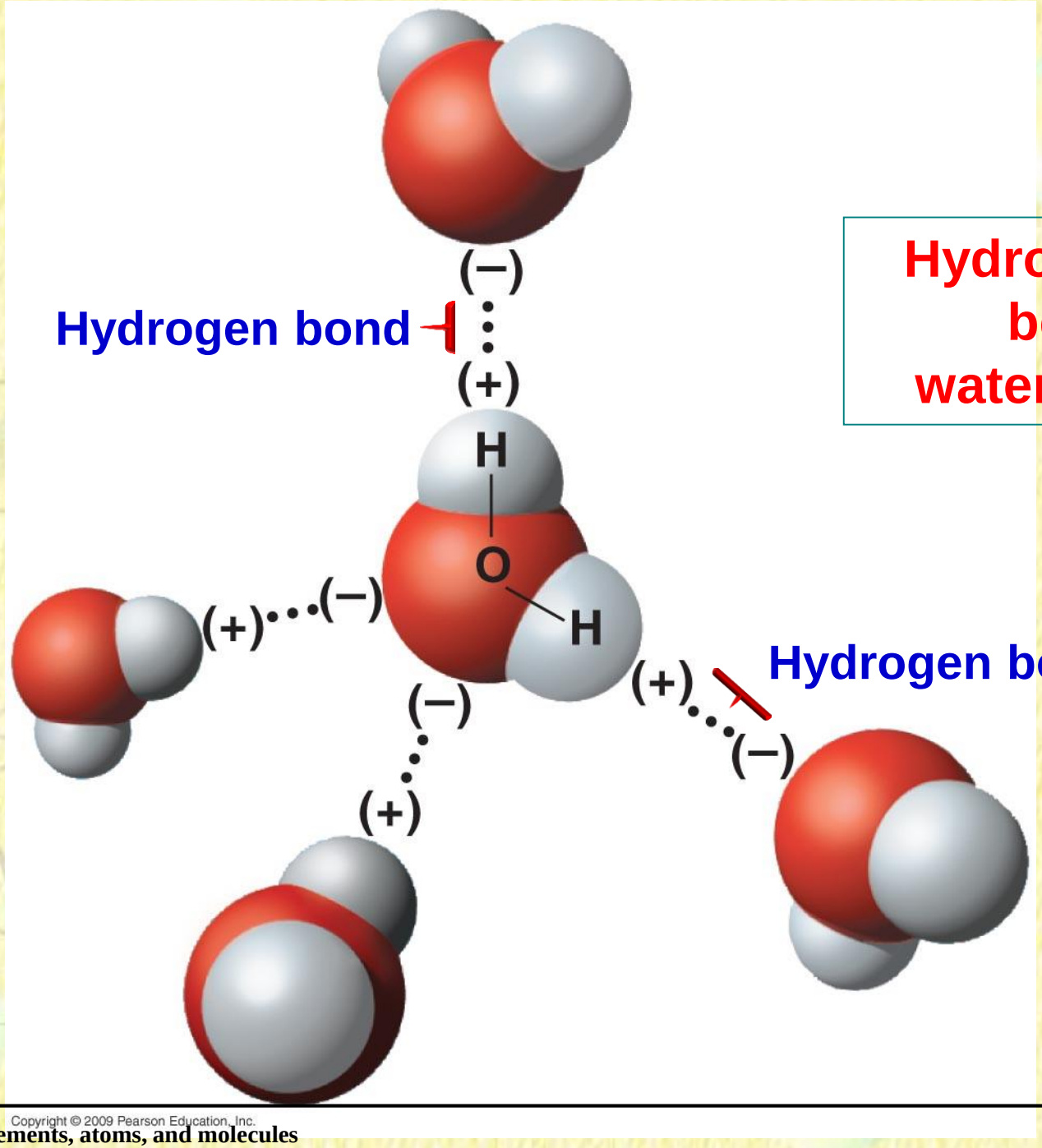


Water is Polar

- In each water molecule, the **oxygen atom attracts more** than its "fair share" of **electrons**
- The **oxygen** end "acts" **negative**
- The **hydrogen** end "acts" **positive**
- Causes the water to be **POLAR**
- However, Water is **neutral** (equal number of e- and p+) --- **Zero Net Charge**

Hydrogen bonds are weak bonds important in the chemistry of life

- Hydrogen, as part of a polar covalent bond, will share attractions with other electronegative atoms
  - Examples are oxygen and nitrogen
- Water molecules are electrically attracted to oppositely charged regions on neighboring molecules
  - Because the positively charged region is always a hydrogen atom, the bond is called a Hydrogen bond



Hydrogen bonds between water molecules

WATER'S LIFE-SUPPORTING PROPERTIES

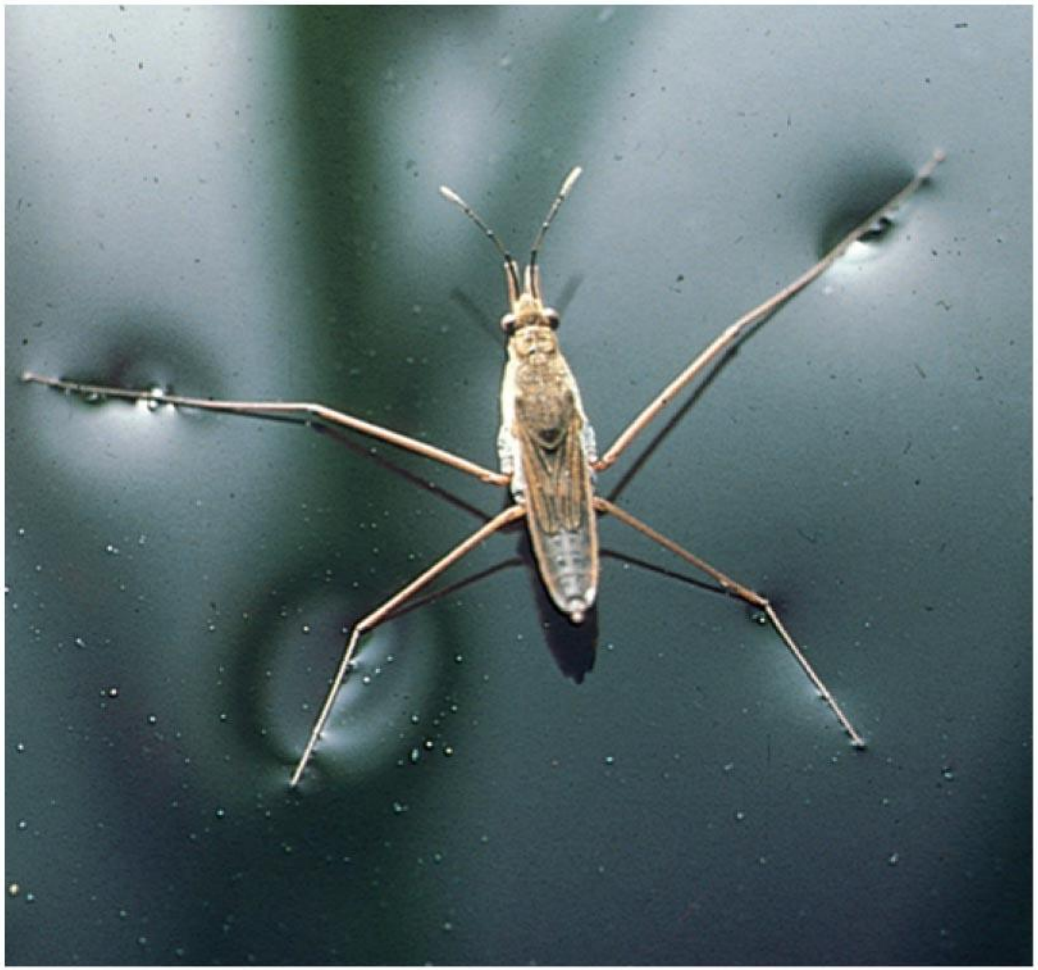
Hydrogen bonds make liquid water cohesive

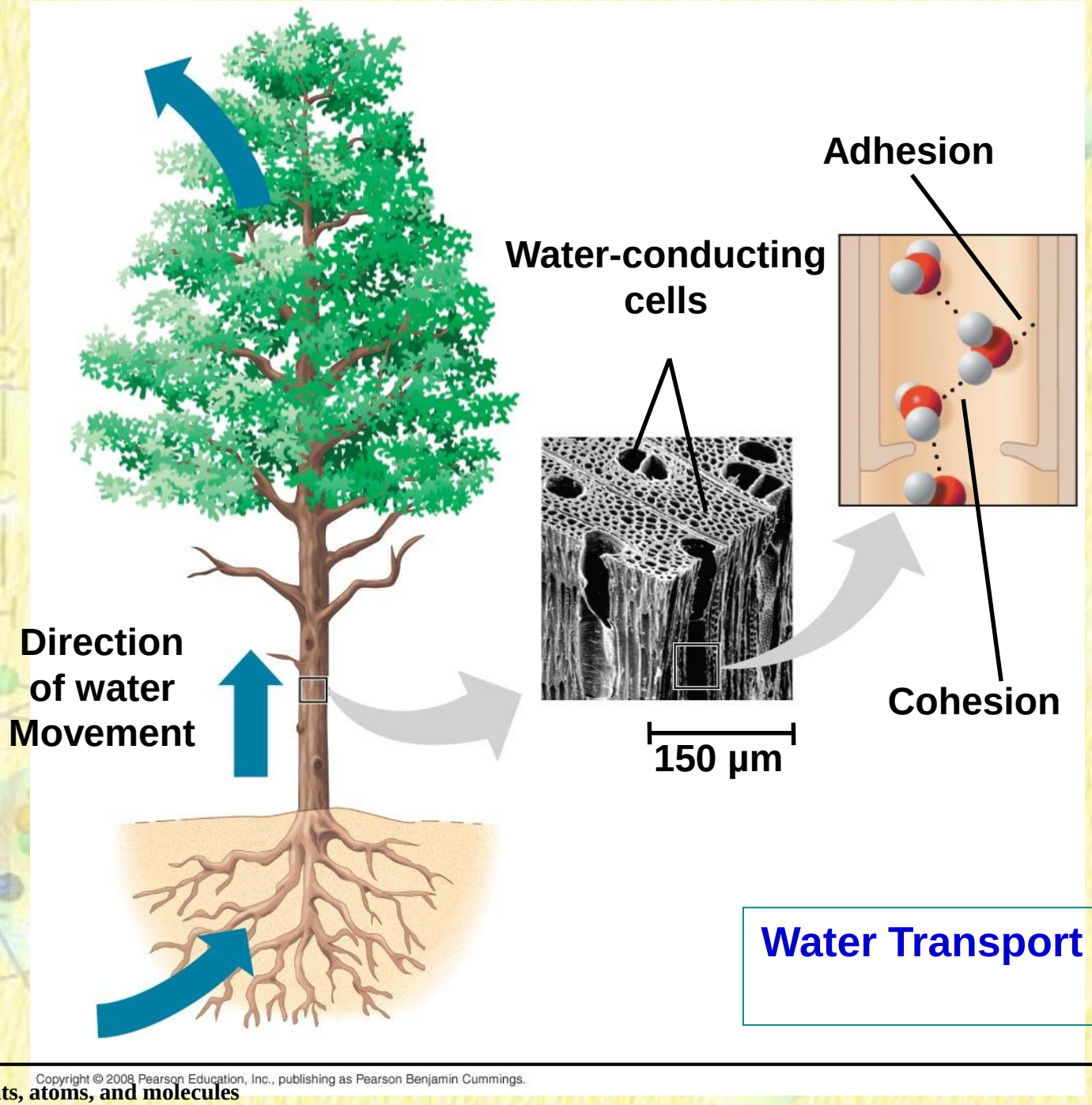
- Hydrogen bonding causes molecules to stick together, a property called cohesion
  - Cohesion is much stronger for water than other liquids.
  - This is useful in plants that depend upon cohesion to help transport water and nutrients up the plant.

Hydrogen bonds make liquid water cohesive

- Cohesion is related to surface tension — a measure of how difficult it is to break the surface of a liquid
  - Hydrogen bonds are responsible for surface tension

Surface tension allows a water strider to walk on water





Water Transport in Plants

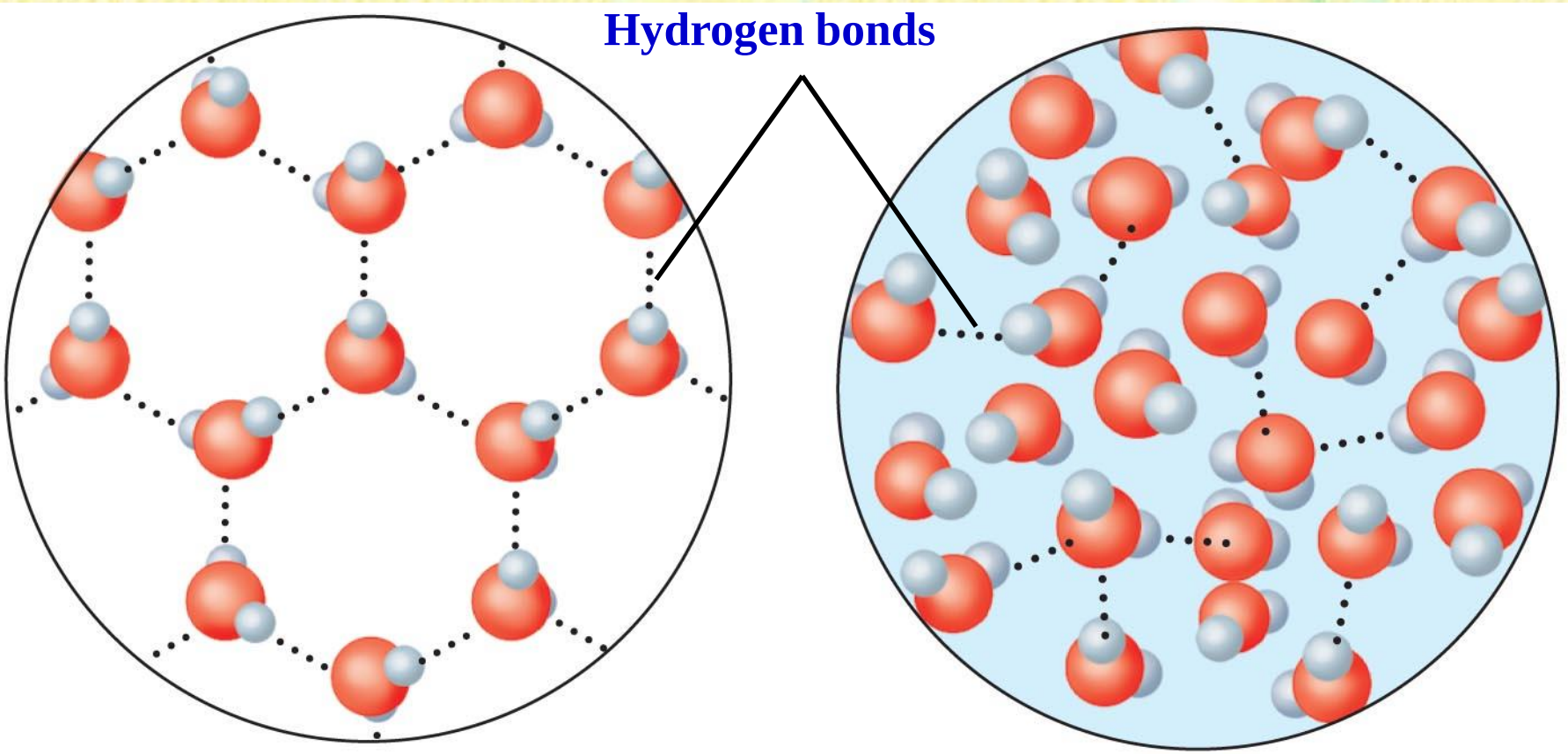
Ice is less dense than liquid water

- **Water can exist as a gas, liquid, and solid**
  - **Water is less dense as a solid, a property due to hydrogen bonding**

Ice is less dense than liquid water

- When water freezes, each molecule forms a stable hydrogen bond with four neighbors
  - A three-dimensional crystal results
  - There is space between the water molecules
- Ice is less dense than water, so it floats

Hydrogen bonds between water molecules in ice and water



Water is the solvent of life

- **Water is a versatile solvent that is fundamental to life processes**
  - **Its versatility results from its polarity**
  - **Table salt is an example of a solute that will go into solution in water**
    - **Sodium and chloride ions and water are attracted to each other because of their charges**

A crystal of table salt (NaCl) dissolving in water

Properties of Water

- Cohesion-Attraction between particles of the same substance.
- Adhesion-Attraction between two different substances.
- Water will make hydrogen bonds with other surfaces such as glass, soil, plant tissues, and cotton.
- Less Dense as a Solid

Acidic and basic conditions

- **A few water molecules can break apart into ions**
  - **Some are hydrogen ions (H^+).**
  - **Some are hydroxide ions (OH^-) .**
    - **Both are extremely reactive.**
    - **A balance between the two is critical for chemical processes to occur in a living organism.**

Acidic and basic conditions

- Chemicals other than water can contribute H^+ to a solution
  - They are called acids
  - An example is hydrochloric acid (HCl)
    - This is the acid in your stomach that aids in digestion
- An acidic solution has a higher concentration of H^+ than OH^-

Acidic and basic conditions

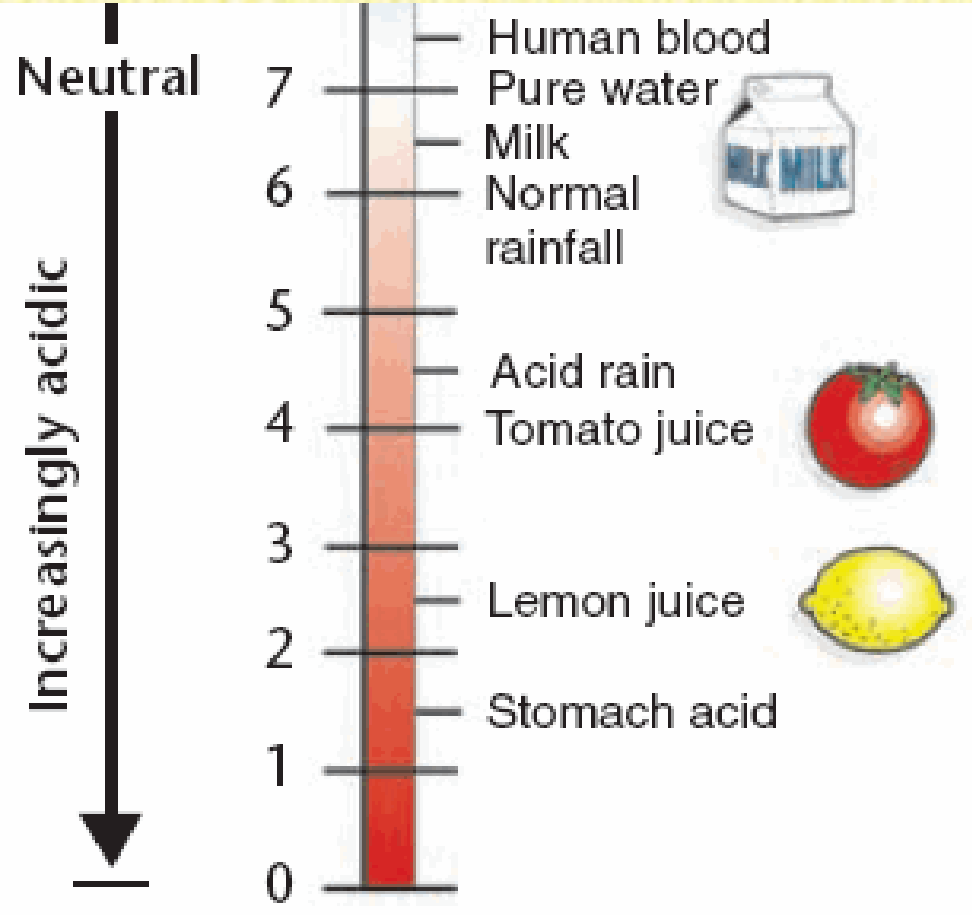
- **A pH scale (pH = potential of hydrogen) is used to describe whether a solution is acidic or basic**
  - **pH ranges from 0 (most acidic) to 14 (most basic)**
  - **A solution that is neither acidic or basic is neutral (pH = 7)**

The pH Scale

- Indicates the concentration of H^+ ions
- Ranges from 0 – 14
- pH of 7 is neutral
- pH 0 up to 7 is acid … H^+
- pH above 7 – 14 is basic… OH^-

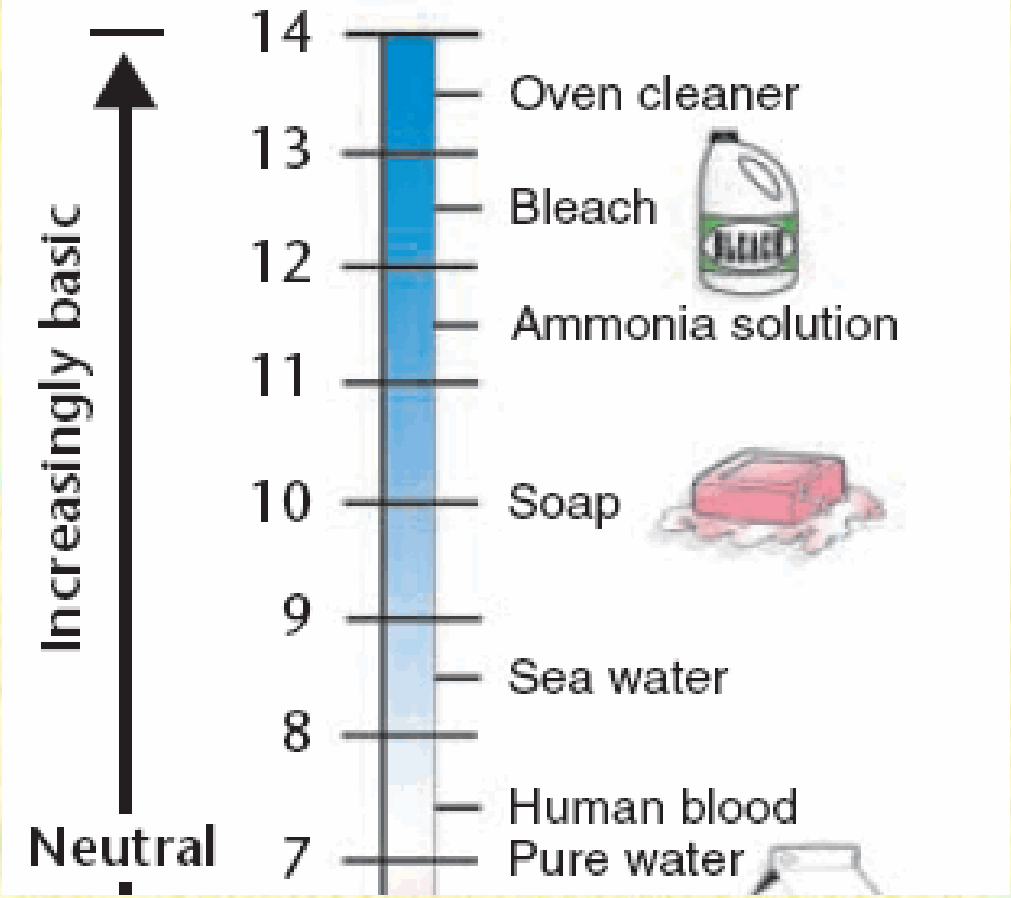
Acids

- **Strong Acids have a pH of 1-3**
- **Produce lots of H^+ ions**



Bases

- **Strong Bases** have a pH of **11 to 14**
- Contain **lots of OH^- ions** and fewer H+ ions

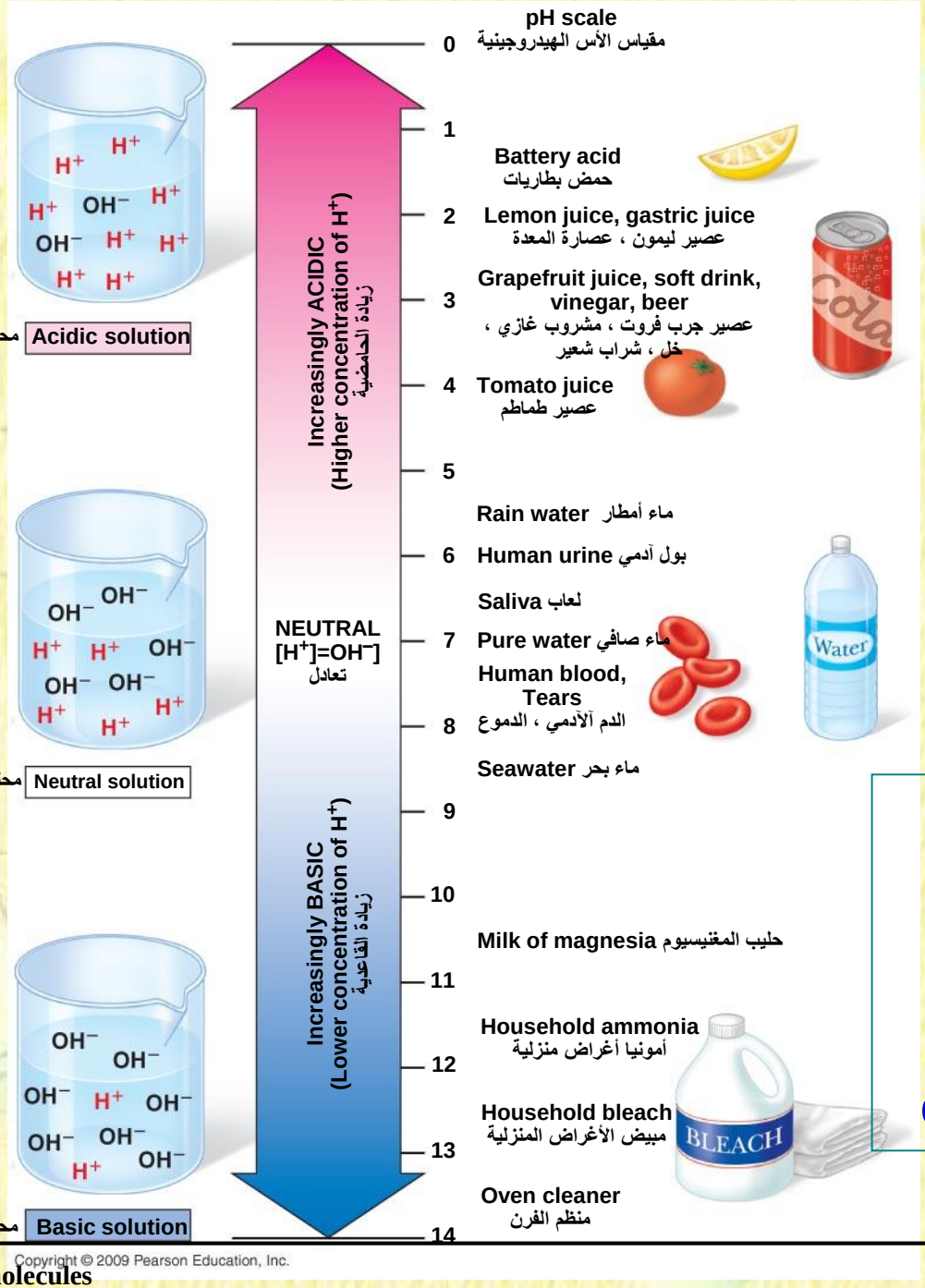


Buffers

- Weak acids or bases that react with strong acids or bases to prevent sharp, sudden changes in pH (neutralization).
- Produced naturally by the body to maintain homeostasis

Weak Acid

Weak Base



The pH scale represents the relative concentration of H^+ and OH^-

CONNECTION: Acid precipitation and ocean acidification threaten the environment

- When we burn fossil fuels (gasoline and heating oil), air-polluting compounds and CO_2 are released into the atmosphere
  - Sulfur and nitrous oxides react with water in the air to form acids
    - These fall to Earth as acid precipitation, which is rain, snow, or fog with a pH lower than 5.6
  - Additional CO_2 in the atmosphere contributes to the "greenhouse" effect and alters ocean chemistry.