Lecture 2

The Chemistry of Life

By Dr.Reem Alruhaimi
Modified by:
Dr. Nada Alharbi
Dr. Mariam Alkhateeb

A Chemical Connection to Biology

- ✓ Biology is a multidisciplinary science
- ✓ Living organisms are subject to basic laws of physics and chemistry

Nature is not neatly packaged into individual sciences—biology, chemistry, physics, and so forth. Biologists specialize in the study of life, but organisms and their environments are natural systems to which the concepts of chemistry and physics apply. Biology is multidisciplinary. This lecture introduces some basic concepts of chemistry that apply to the study of life. We will cross the blurry boundary between nonlife and life somewhere in the transition from molecules to cells. This chapter focuses on the chemical components that make up all matter.

Organisms are composed of **matter**, which **is anything that takes up space and has mass**. Matter exists in many forms. Rocks, metals, oils, gases, and living organisms are a few examples of what seems to be an endless assortment of matter. Elements and Compounds Matter is made up of elements. **An element is a substance that cannot be broken down to other substances by chemical reactions.** Today, chemists recognize 92 elements occurring in nature; gold, copper, carbon, and oxygen are examples. Each element has a symbol, usually the first letter or two of its name. Some symbols are derived from Latin or German; for instance, the symbol for sodium is Na, from the Latin word natrium. **A compound is a substance consisting of two or more different elements combined in a fixed ratio.** Table salt, for example, is sodium chloride (NaCl), a compound composed of the elements sodium (Na) and chlorine (Cl) in a 1:1 ratio. Pure sodium is a metal, and pure chlorine is a poisonous gas. When chemically combined, however, sodium and chlorine form an edible compound. Water (H2O), another compound, consists of the elements hydrogen (H) and oxygen (O) in a 2:1 ratio. These are simple examples of organized matter having emergent properties: *A compound has characteristics different from those of its elements*.

Elements and Compounds

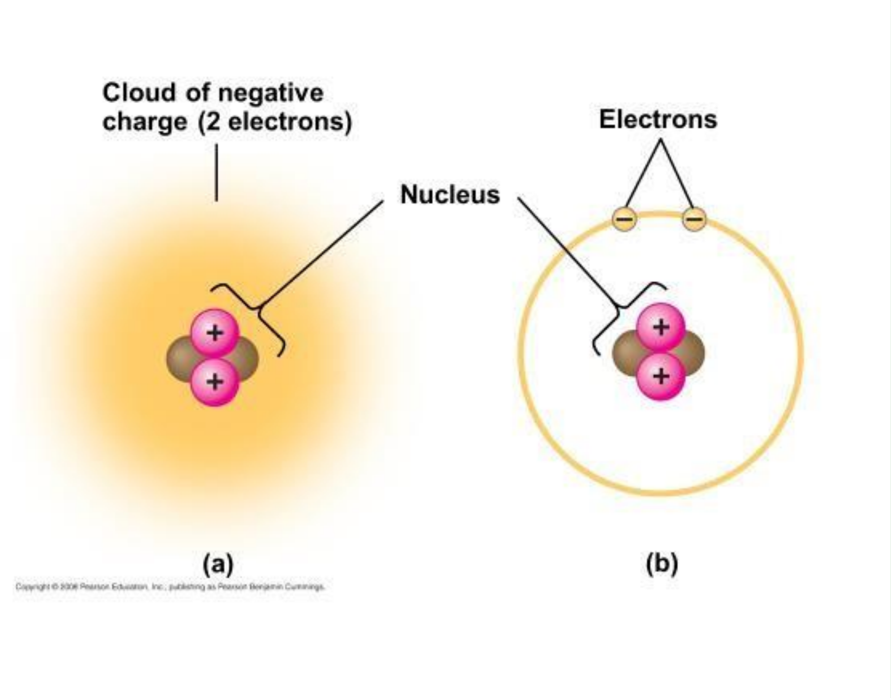
- Organisms are composed of **compounds =matter**
- Matter is <u>anything that takes up space and has mass and made up of elements</u>

An **element** is a substance that cannot be broken down to other substances by chemical reactions

A **compound** is a substance consisting of two or more elements in a fixed ratio, and has characteristics different from those of its elements

The Elements of Life Of the 92 natural elements, about 20–25% are essential elements that an organism needs to live a healthy life and reproduce. The essential elements are similar among organisms, but there is some variation—for example, humans need 25 elements, but plants need only 17. Just four elements—oxygen (O), carbon (C), hydrogen (H), and nitrogen (N)—make up 96% of living matter. Calcium (Ca), phosphorus (P), potassium (K), sulfur (S), and a few other elements account for most of the remaining 4% of an organism's mass. All the elements needed by the human body are listed in Table 1

- Each element consists of unique atoms
- Atoms are composed of subatomic particles
- Relevant subatomic particles include:
  - **Neutrons** (no electrical charge)
  - **Protons** (positive charge)
  - **Electrons** (negative charge)



Essential Elements of Life

About 25 of the 92 elements are essential to life

Carbon, hydrogen, oxygen, and nitrogen make up 96% of living matter

Most of the remaining 4% consists of calcium, phosphorus, potassium, and sulfur

Trace elements are those required by an organism in minute quantities

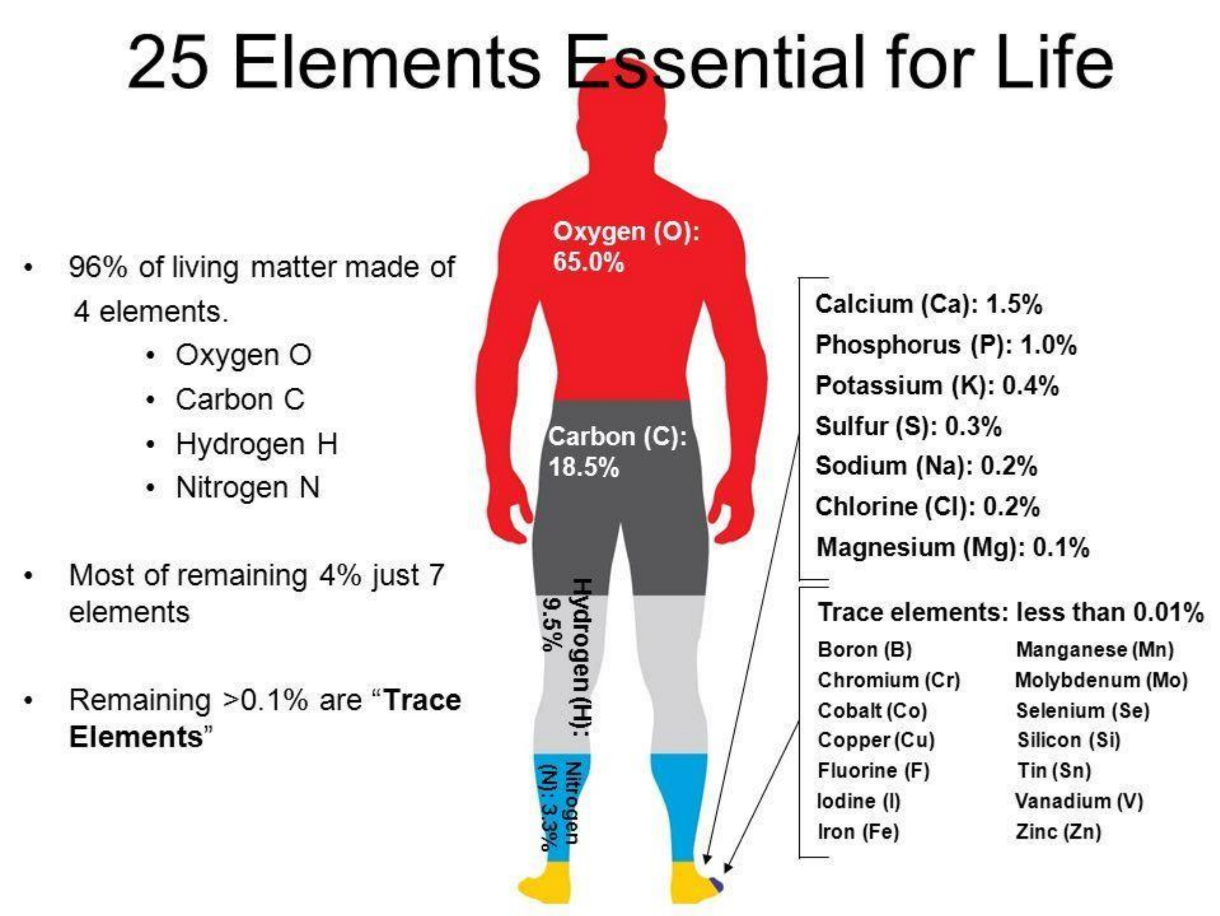


Table 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number (see p. 33)	Percentage of Human Body Weight
Elements making up about 96% of human body weight			
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Elements making up about 4% of human body weight			
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1
Elements making up less than 0.01% of human body weight (trace elements)			
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), zinc (Zn)			

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

Each element consists of a certain type of **atom** that is different from the atoms of any other element. An atom is the smallest unit of matter that still retains the properties of an element. Atoms are so small that it would take about a million of them to stretch across the period printed at the end of this sentence. We symbolize atoms with the same abbreviation used for the element that is made up of those atoms. For example, the symbol C stands for both the element carbon and a single carbon atom. **three kinds of particles are relevant here: neutrons, protons, and electrons.** Protons and electrons are electrically charged. Each proton has one unit of positive charge, and each electron has one unit of negative charge. These interactions usually result in atoms staying close together, held by

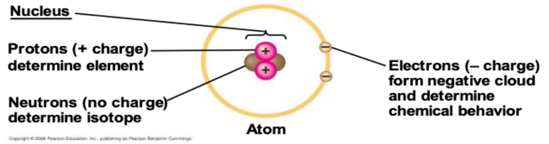
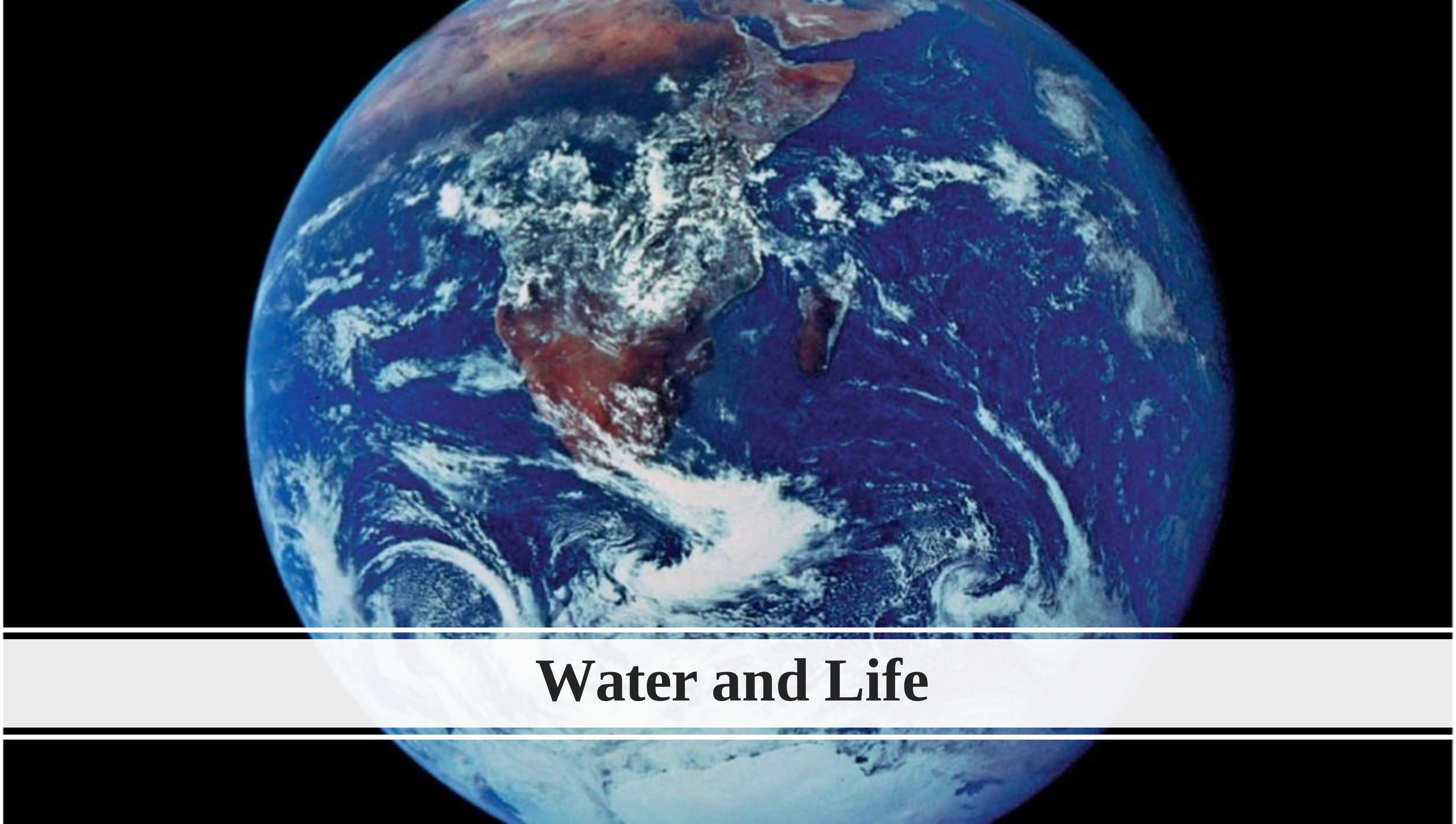


Figure 4 : Simplified models of a helium (He) atom

(a) Nitrogen deficiency **(b) Iodine deficiency**

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

Figure :demonstrate the deficiency of some trace elements could rise a serious health problem for example iodine deficiency



Water and Life

Water is the substance that makes possible life as we know it here on Earth. All organisms familiar to us are made mostly of water and live in an environment dominated by water. Water is the biological medium here on Earth, and possibly on other planets as well. Three-quarters of Earth's surface is covered by water. Although most of this water is in liquid form, water is also present on Earth as a solid (ice) and a gas (water vapor). Studied on its own, the water molecule is deceptively simple. It is shaped like a wide V, with its two hydrogen atoms joined to the oxygen atom by single covalent bonds(fig.5).

The water that supports all of life

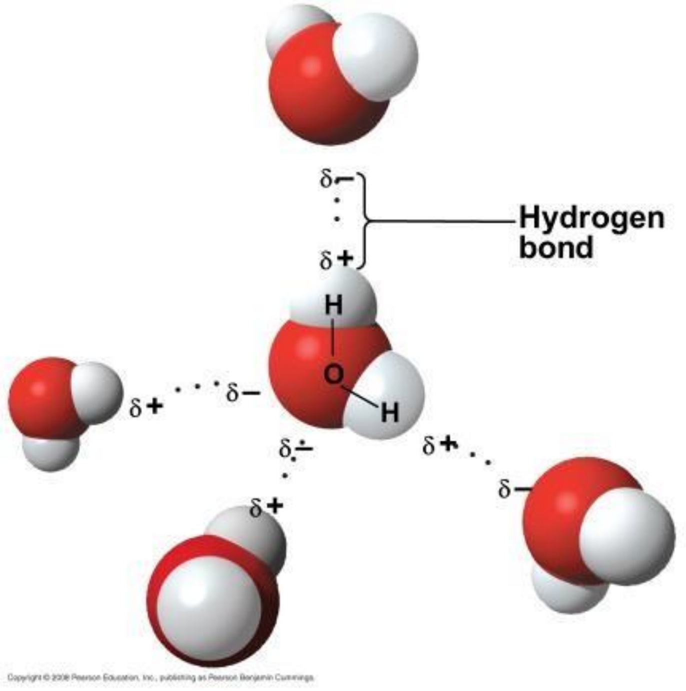
- Water is the biological medium on Earth
- All living organisms require water more than any other substance
- Most cells are surrounded by water, and cells themselves are about 70–95% water
- The abundance of water is the main reason the Earth is habitable

The Structure of Water

Watch this video and answer the flowing

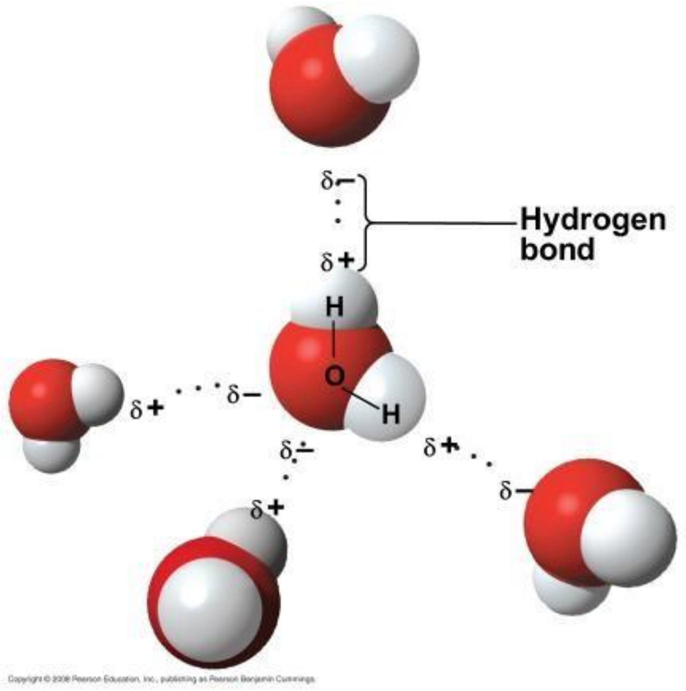
- 1- what is the water made of (list the elements ?
- 2-does the water consider a polar molecules or nonpoler ?
- 3- what type of bond that form between water molecules?
- 4- list Water’s Life-supporting Properties ?

https://www.youtube.com/watch?v=ASLUY2U1M-8



The Structure of Water

- The water molecule is a **polar molecule**: The opposite ends have opposite charges
- Polarity allows water molecules to form hydrogen bonds with each other
- The **structure of water molecules** explains most of <u>**water's life-supporting**</u> properties.



Water’s Life-supporting Properties

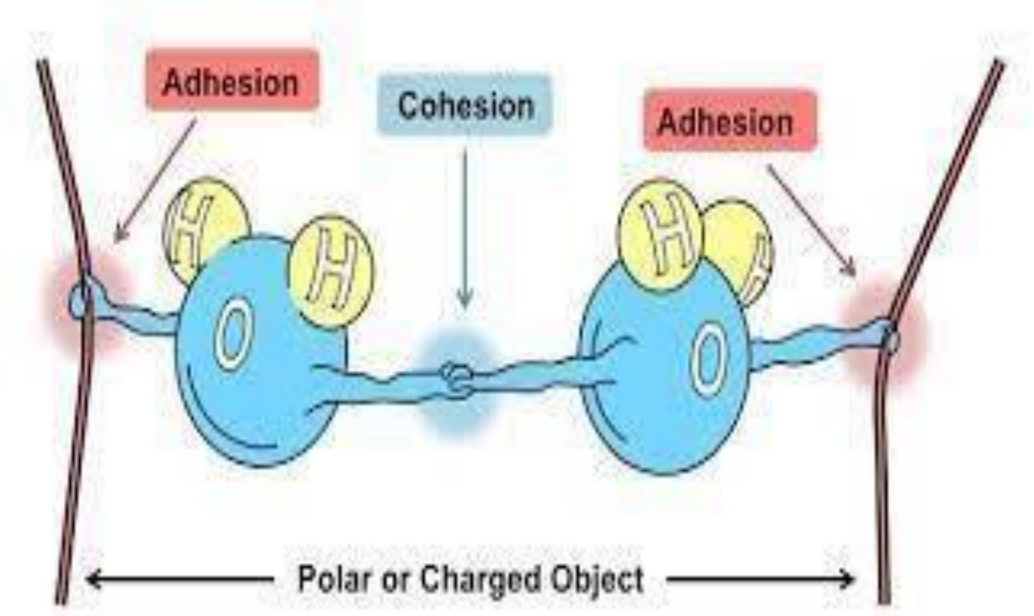
COHESION BEHAVIOR

ABILITY TO MODERATE TEMPERATURE

EXPANSION UPON FREEZING

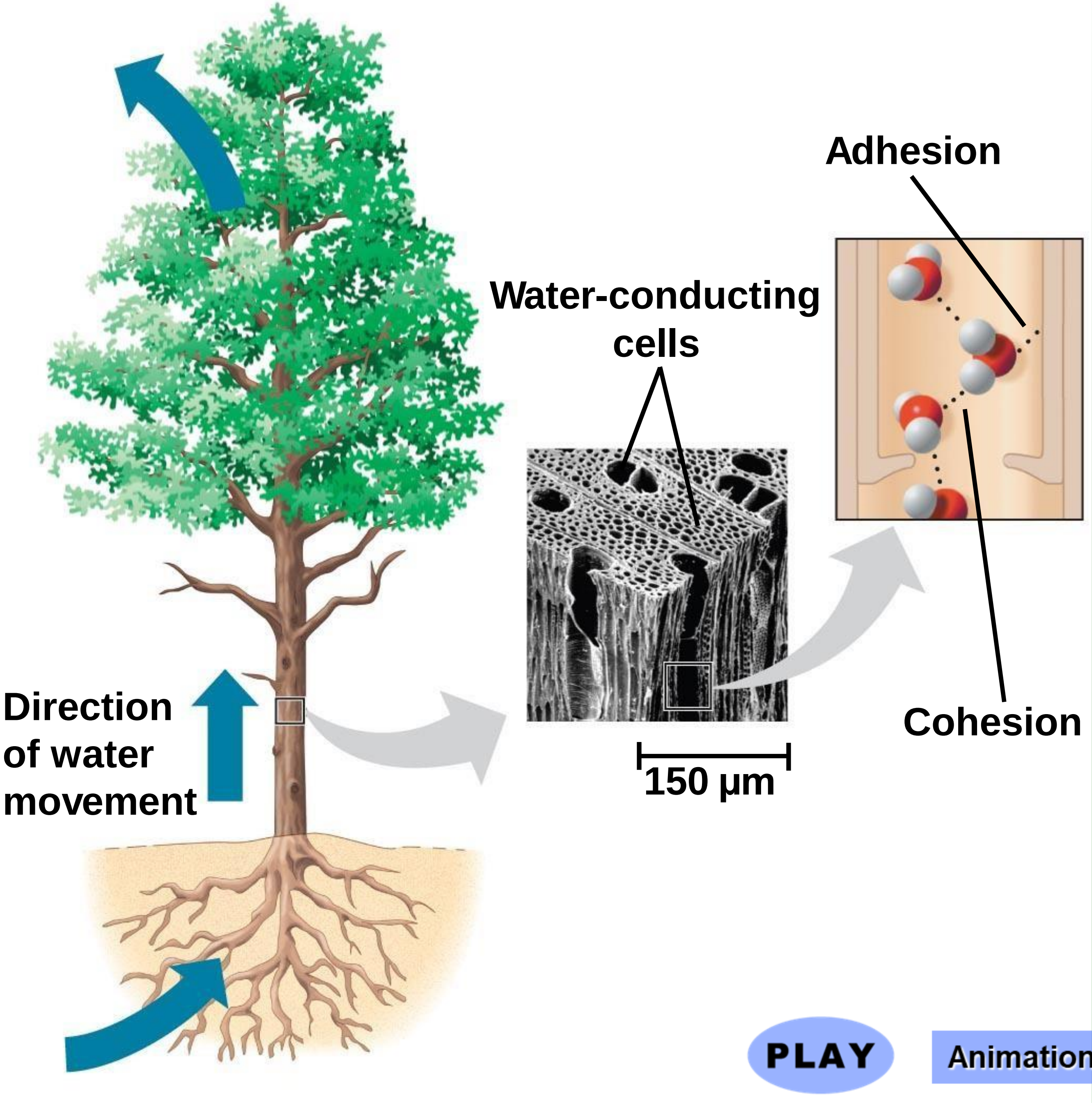
VERSATILITY AS A SOLVENT

The Cohesion of water



- Collectively, hydrogen bonds hold water molecules together, a phenomenon called **cohesion**
- **Cohesion** is the attraction between molecules of the same kind
- **Adhesion** is an attraction between different substances, for exampl[e] between water and plant cell walls

Fig. 3-3



Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

- **Trees depend on cohesion to help transport water from their roots to their leaves.**

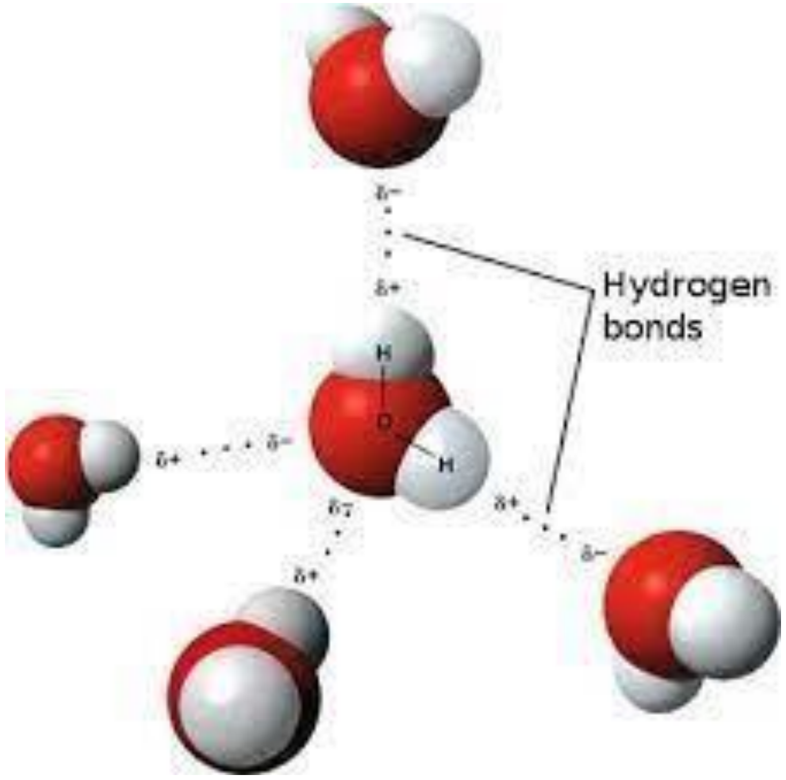
PLAY

Animation: Water Transport

- Hydrogen bonds give water high surface tension and make water behave as though it were coated with an invisible film.

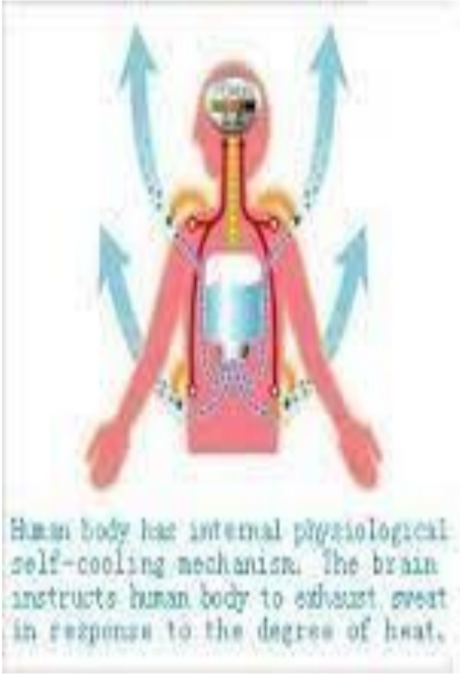
- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion

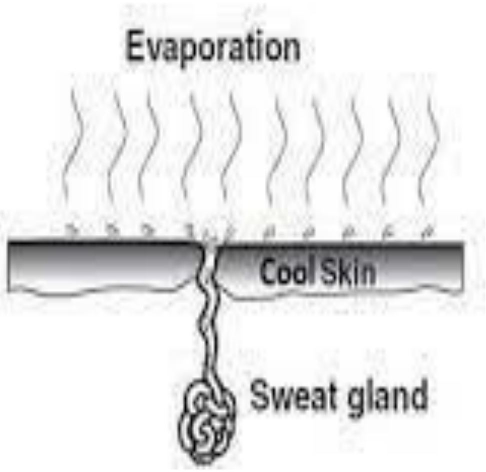
Moderation of Temperature



- Water has a stronger **resistance to temperature change than most other substances**.
- When <u>water is heated</u>, the heat is first used to **break hydrogen bonds** rather than raise the temperature.
- When <u>water cools</u>, **hydrogen bonds form**, releasing a considerable amount of heat.

Moderation of Temperature

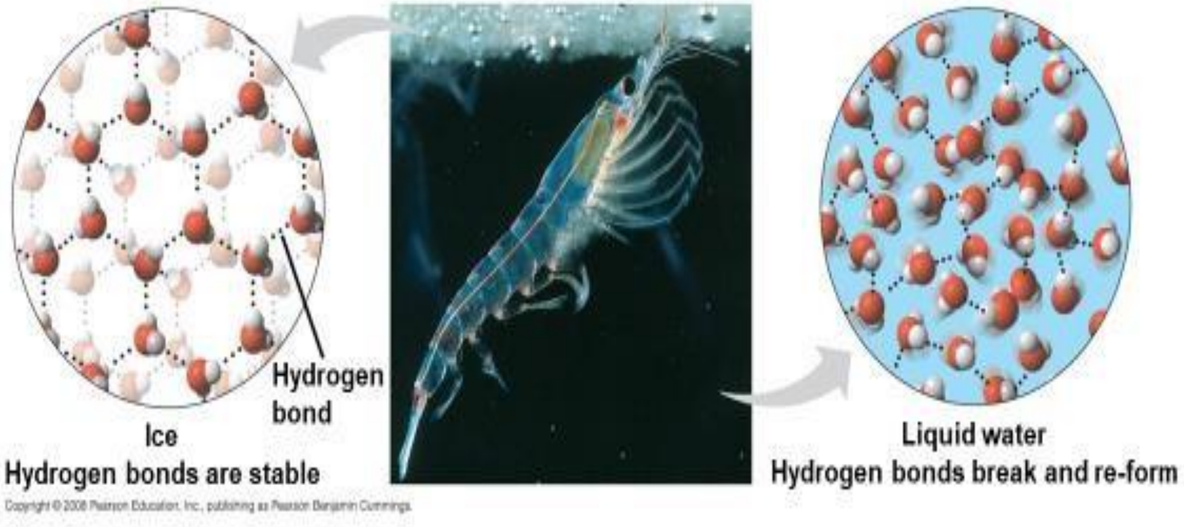




- Water is effective as a heat bank because it can absorb or release a relatively large amount of heat with only a slight change in its own temperature.
- Evaporative cooling of water helps stabilize temperatures.
- EX: Sweating helps dissipate our excess body heat

Floating of Ice on Liquid Water

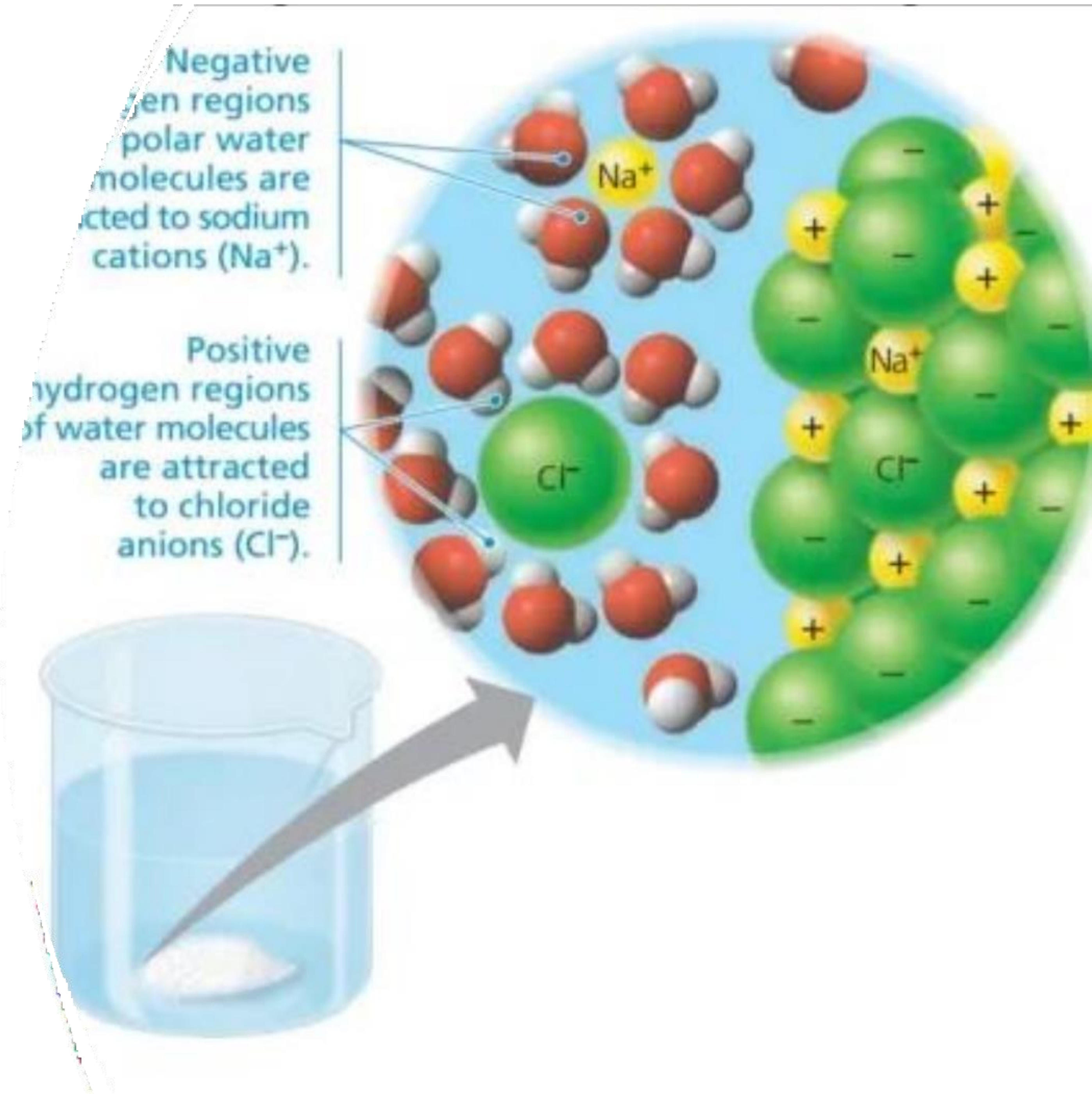
- Ice floats in liquid water because hydrogen bonds in ice are more “ordered,” making ice less dense
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth

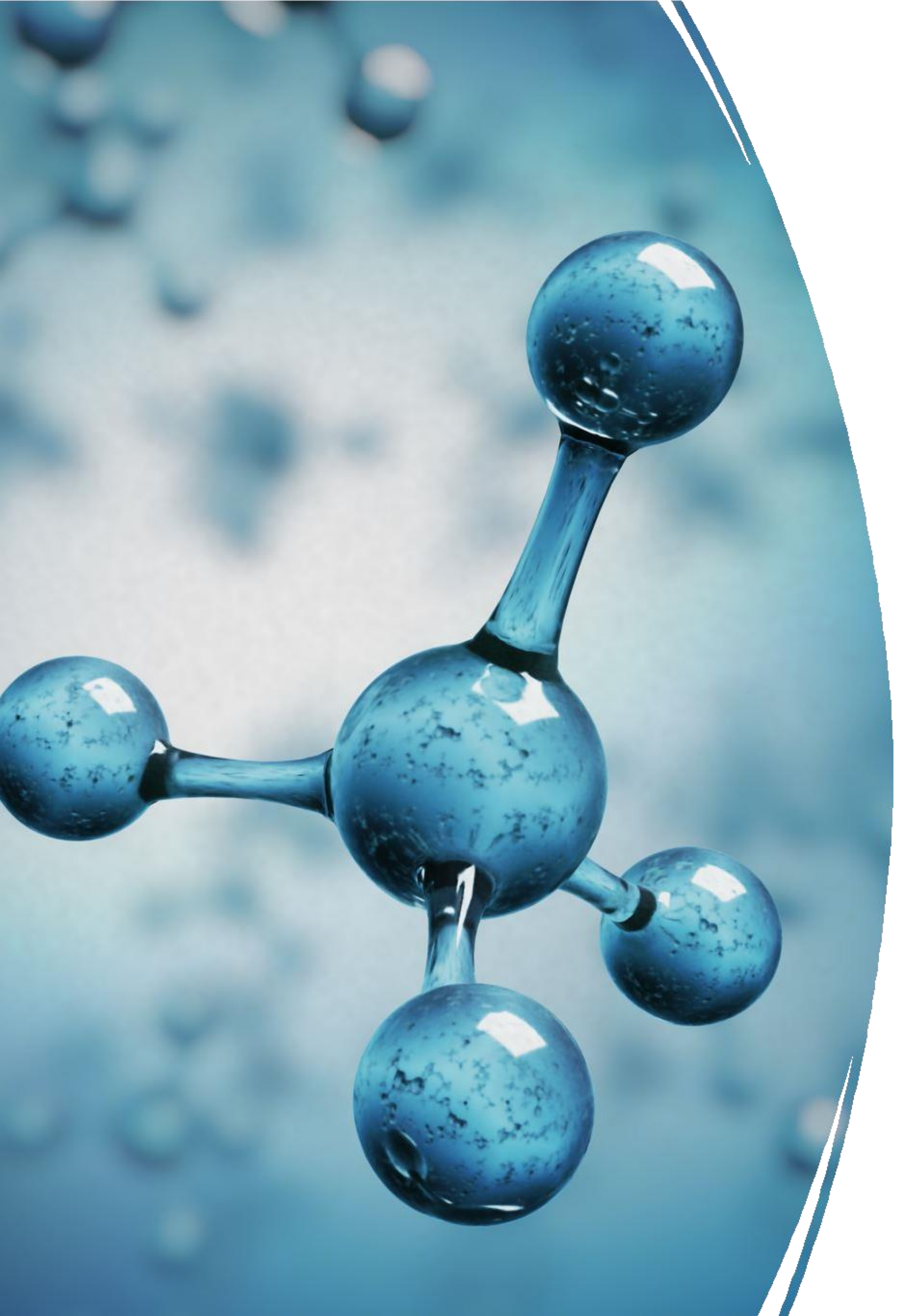


Floating ice acts as an insulating “blanket” over the liquid water, allowing life to persist under the frozen surface.

The Solvent of Life

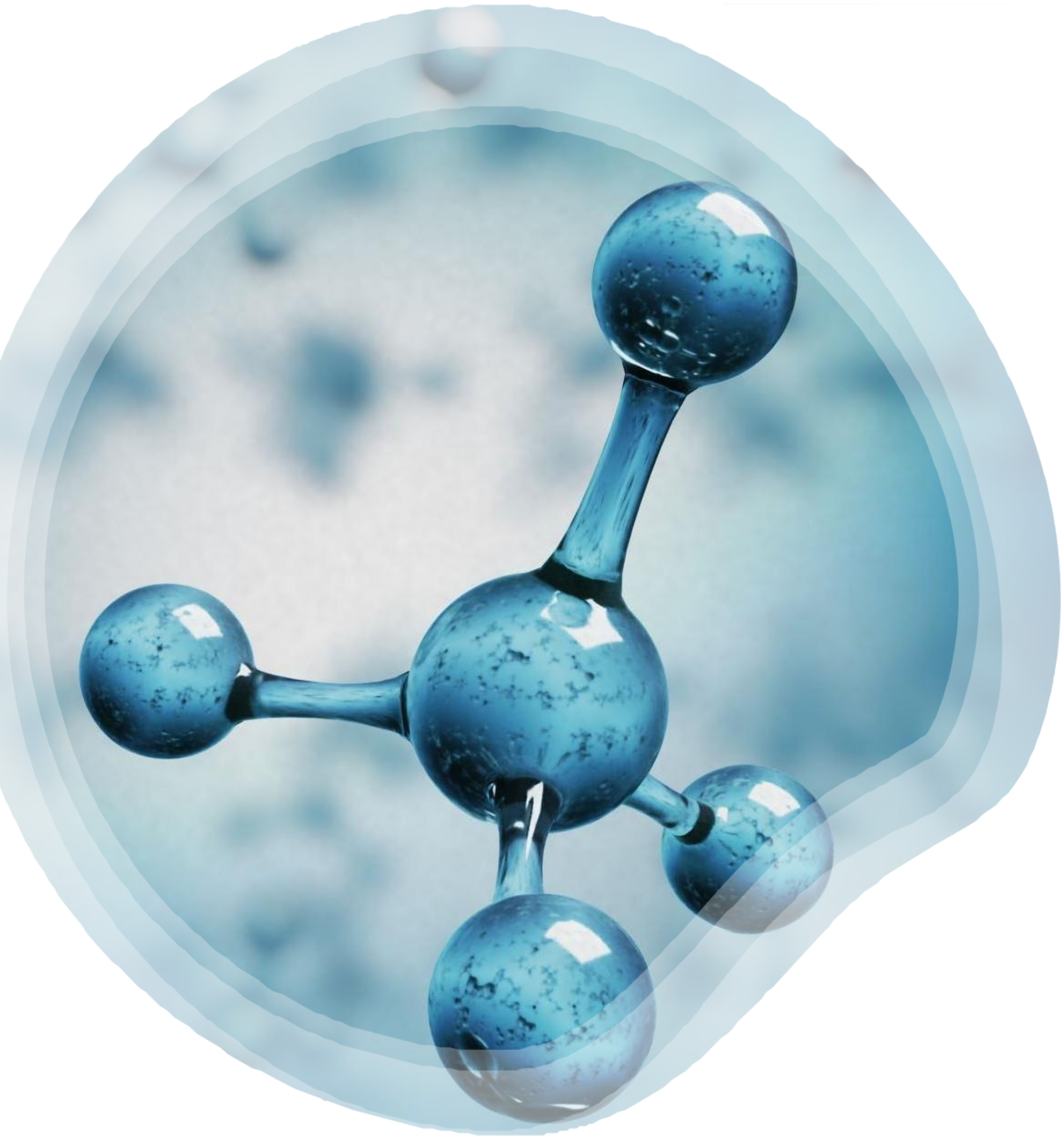
- A **solution** is a liquid that is a homogeneous mixture of substances
- A **solvent** is the dissolving agent of a solution
- The **solute** is the substance that is dissolved
- An **aqueous solution** is one in which water is the solvent





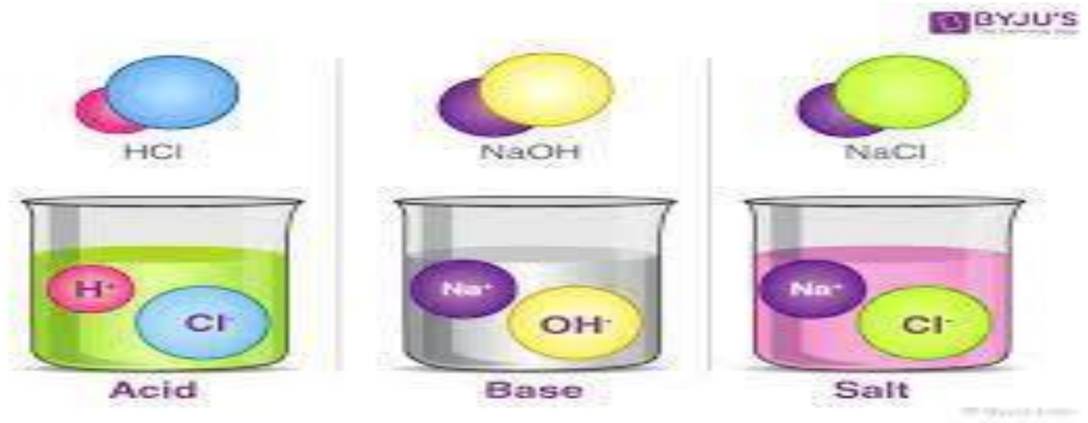
Effects of Changes in pH

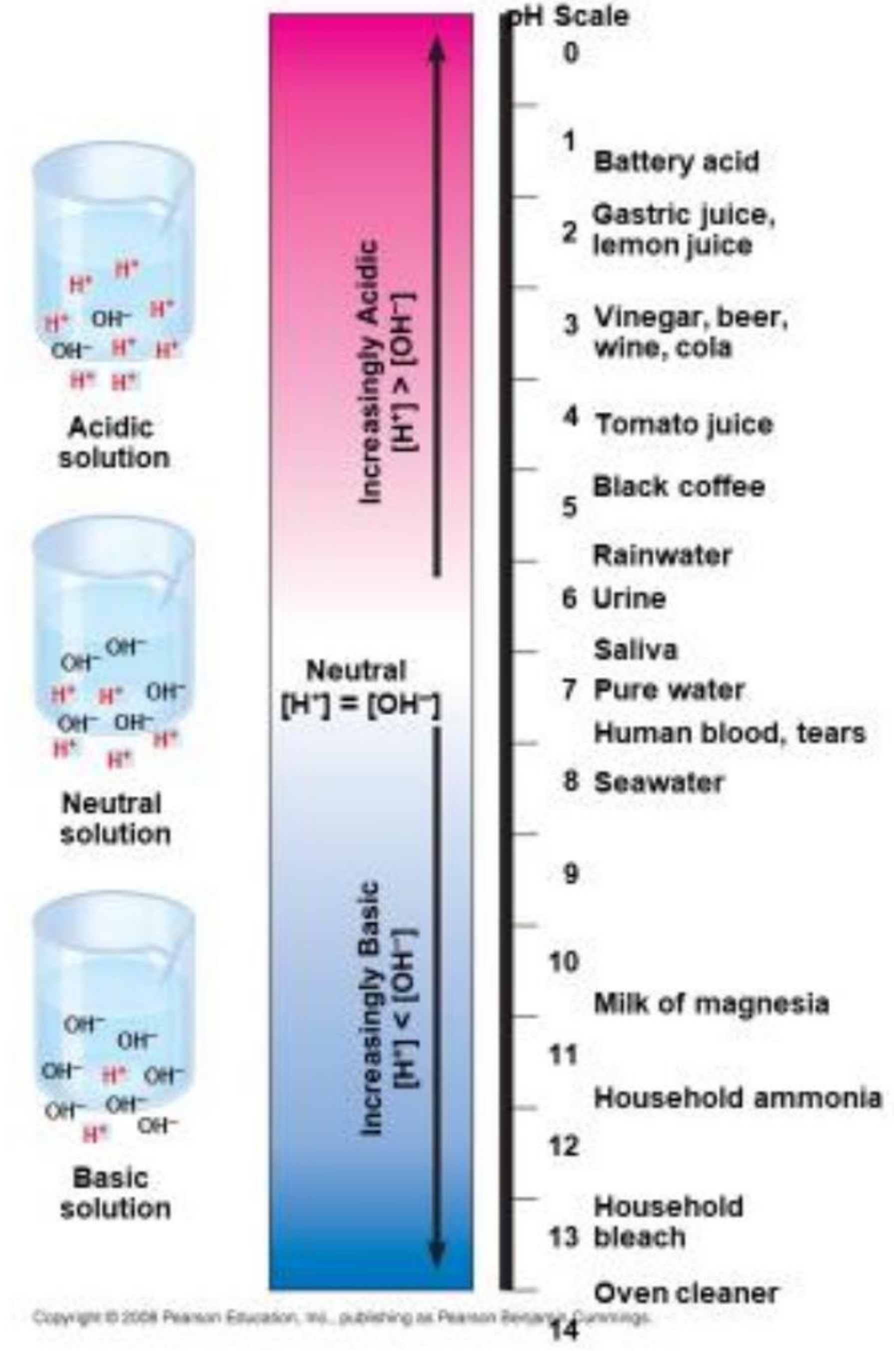
- In aqueous solution, most of water molecules are intact. However, some of the water molecules break apart into hydrogen ions (H+) and hydroxide ions (OH-)
- Adding certain solutes, called acids and bases, modifies the concentrations of H^+ and OH^-
- Biologists use something called the pH scale to describe whether a solution is acidic or basic (the opposite of acidic)



Acids and Bases

- **An acid** is any substance that increases the H+ concentration of a solution
- A base is any substance that reduces the H+ concentration of a solution



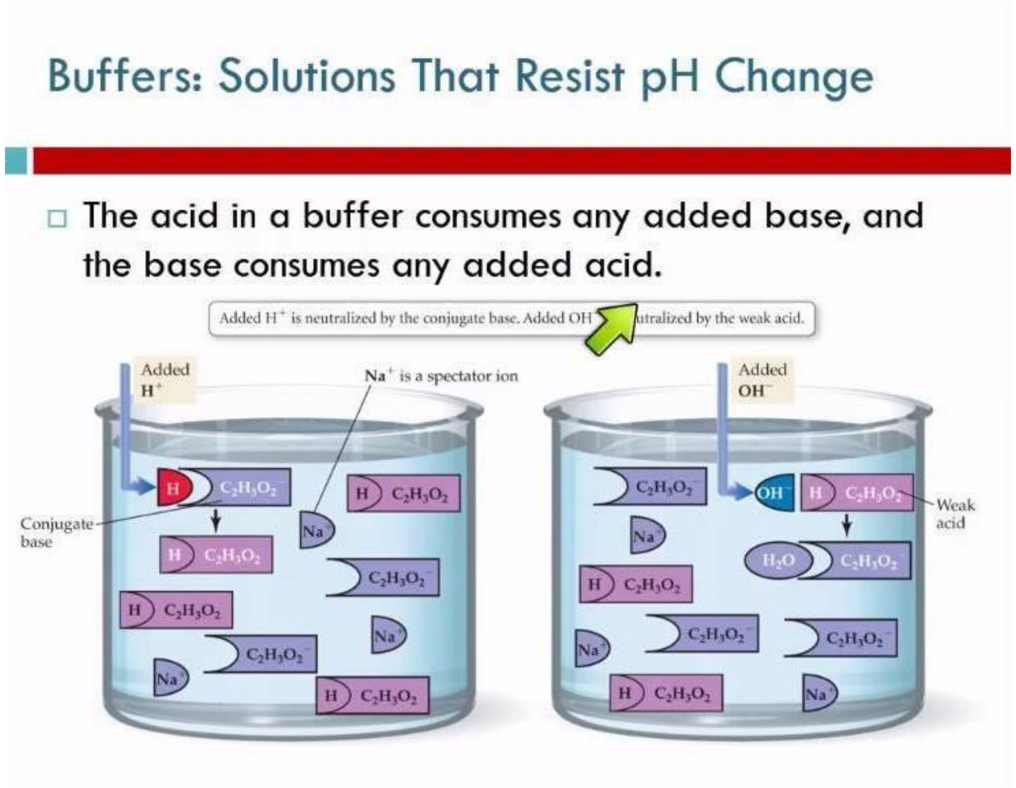


- The pH scale - a measure of the <u>hydrogen ion (H+) concentration</u> in a solution.
- Acidic solutions have pH values less than 7
- Basic solutions have pH values greater than 7
- Most biological fluids have pH values in the range of 6 to 8

The chemistry of life is sensitive to acidic and basic conditions

- Even a slight change in pH can be harmful to an organism because the molecules in cells are extremely sensitive to H+ and OH concentration.

- Biological fluids contain **buffers,** substances that minimize changes in pH by
- • accepting H+ when it is in excess.
- • donating H+ when it is depleted.



WATER'S LIFE-SUPPORTING PROPERTIES:

We will examine **four emergent properties of water** that contribute to Earth's suitability as an environment for life:

1-Cohesion of Water:

Water molecules stay close to each other because of hydrogen bonding. Although the arrangement of molecules in a sample of liquid water is constantly changing, at any given moment many of the molecules are linked by multiple hydrogen bonds. These linkages make water more structured than most other liquids. Collectively, the hydrogen bonds hold the substance together, a phenomenon called cohesion. **Cohesion** is the attraction between molecules of the same kind. Cohesion due to hydrogen bonding contributes to the transport of water and dissolved nutrients against gravity in plants (fig.6). Water from the roots reaches the leaves through a network of water-conducting cells. Adhesion, the clinging of one substance to another. **Adhesion** is an attraction between different substances, for example, between water and plant cell walls. Related to cohesion is **surface tension,** a measure of how difficult it is to stretch or break the surface of a liquid. At the interface between water and air is an ordered arrangement of water molecules, hydrogen-bonded to one another and to the water below. This gives water an unusually high surface tension, making it behave as though it were coated with an invisible film.

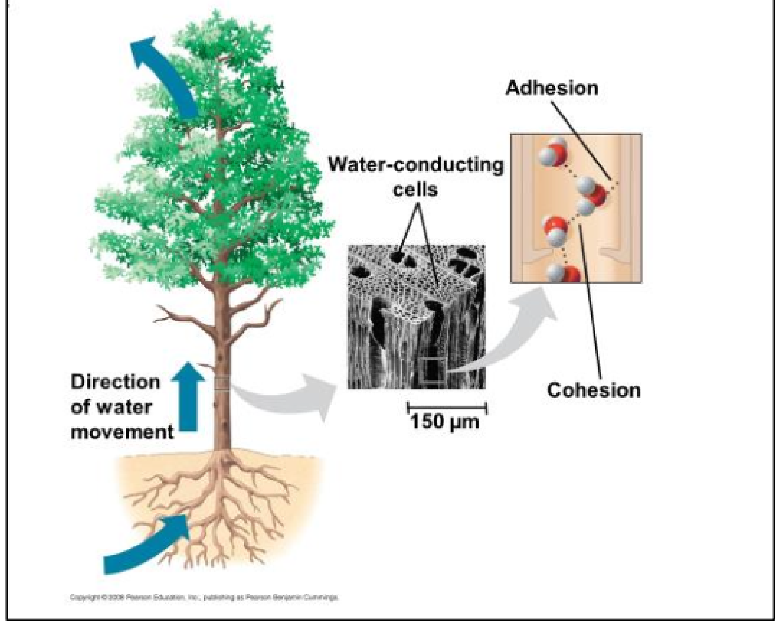


Figure 6: Water transport in plants.

2-Moderation of Temperature by Water :

Water moderates air temperature by absorbing heat from air that is warmer and releasing the stored heat to air that is cooler. Water is effective as a heat bank because it can absorb or release a relatively large amount of heat with only a slight change in its own temperature. Water has a stronger resistance to temperature change than most other substances. When water is heated, the heat is first used to break hydrogen bonds rather than raise the temperature. When water cools, hydrogen bonds form, releasing a considerable amount of heat. Evaporative cooling of water helps stabilize temperatures. For example sweating helps dissipate our excess body heat.

3-Floating of Ice on Liquid Water :

Water is one of the few substances that are less dense as a solid than as a liquid. In other words, ice floats on liquid water. The ability of ice to float due to its lower density is an important factor in the suitability of the environment for life (fig 8). If ice sank, then eventually all ponds, lakes, and even oceans would freeze solid, making life as we know it impossible on Earth.

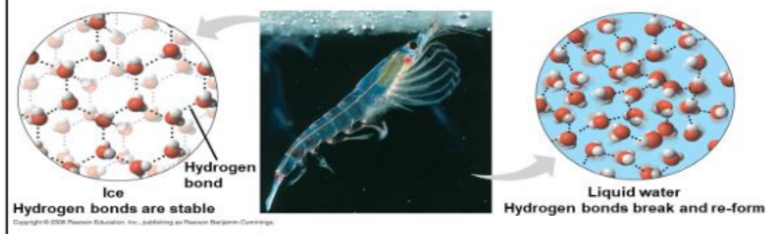


Figure 8: ice: crystalline structure and floating barrier

4-The Solvent of Life:

A sugar cube placed in a glass of water will dissolve with a little stirring. The glass will then contain a uniform mixture of sugar and water; the concentration of dissolved sugar will be the same everywhere in the mixture. **A liquid** that is a completely homogeneous mixture of two or more substances is called a solution. The dissolving agent of a solution is the **solvent**, and the substance that is dissolved is the **solute**. In this case, water is the solvent and sugar is the solute. **An aqueous solution** is one in which the solute is dissolved in water; water is the solvent. Water can dissolve an enormous variety of solutes necessary for life, providing a medium for chemical reactions.

ACIDS AND BASES

What would cause an aqueous solution to have an imbalance in H+ and OH- concentrations? When acids dissolve in water, they donate additional H+ to the solution. ***An acid*** is a substance that increases the hydrogen ion concentration of a solution. For example, hydrochloric acid (HCl). ***Bases is*** A substance that reduces the hydrogen ion concentration of a solution is called a bas. The pH scale is a measure of the hydrogen ion (H+) concentration in a solution. Each pH unit represents a 10-fold change in the concentration of H+.

The chemistry of life is sensitive to acidic and basic conditions Even a slight change in pH can be harmful to an organism because the molecules in cells are extremely sensitive to H+ and OH^- concentration. Biological fluids contain buffers, substances that minimize changes in pH by: accepting H+ when it is in excess OR donating H+ when it is depleted.