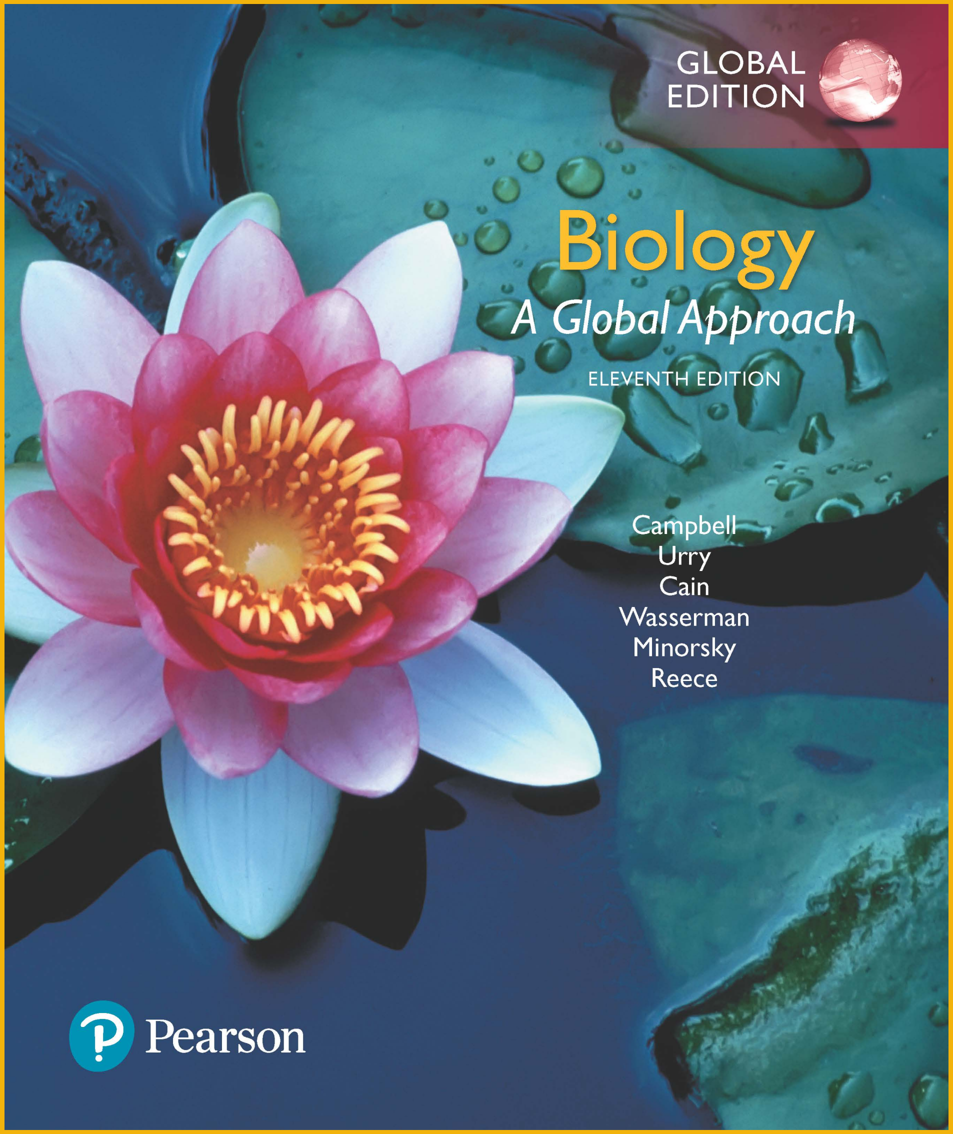


Chapter 3

The Chemistry of Water

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

he Molecule That Supports All of Life

- Water makes life possible on Earth
- Water is the only common substance to exist in the natural environment in all three physical states of matter
- Water's unique emergent properties help make Earth suitable for life
- The structure of the water molecule allows it to interact with other molecules

4 properties (to be studied)

Black guillemots, threatened by climate change

oncept 3.1: Polar covalent bonds in water molecules result in hydrogen bonding

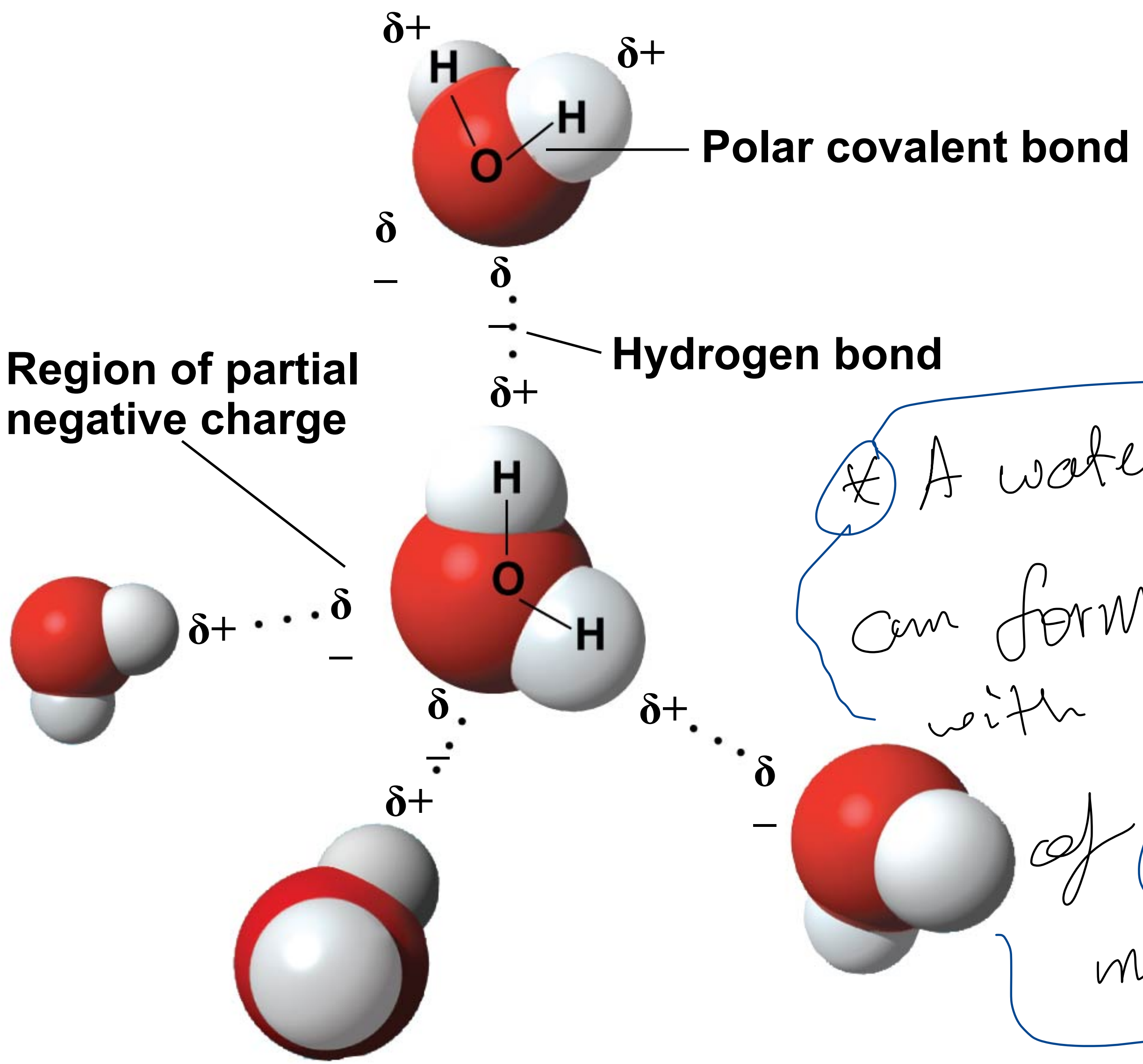
- In the water molecule, the electrons of the **polar covalent bonds** spend more time near the oxygen than the hydrogen due to its electronegativity
- The water molecule is thus a **polar molecule**: The overall charge is unevenly distributed
- Polarity allows water molecules to form hydrogen bonds with each other

H-Bonds are 1/20 as strong as covalent bonds.

(**) when water is liquid

and they last a few trillionths of a second.

Figure 3.2



* A water molecule can form bonds with a max. of (4) other molecules.

oncept 3.2: Four emergent properties of water contribute to Earth's suitability for life

- Four of water's properties that facilitate an environment for life are ⊛ what is Special about water?
  - I Cohesive behavior
  - II Ability to moderate temperature
  - III Expansion upon freezing
  - IV Versatility as a solvent

ohesion of Water Molecules

(I)

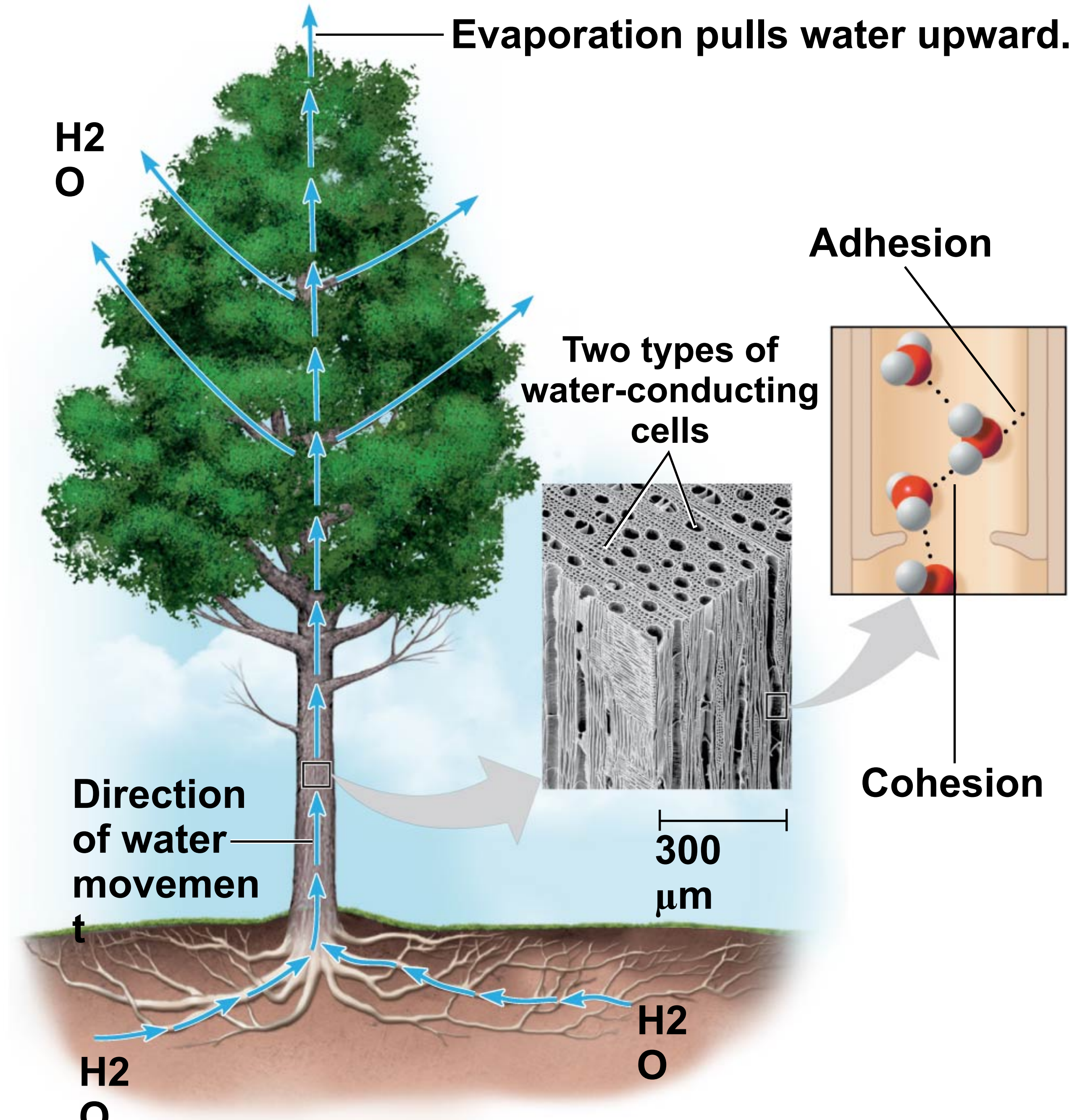
- Collectively, hydrogen bonds hold water molecules together, a phenomenon called **cohesion**
- Cohesion helps the transport of water against gravity in plants (1)
- **Adhesion** is an attraction between different substances, for example, between water and plant cell walls

→ cellulose

(*) Adhesion helps "get around" the problem of gravity when trans-porting water upwards in plants.

(*) Cohesion helps hold the column of water within the water conducting cells.

Figure 3.3


Evaporation pulls water upward.
H2
O
Adhesion
Two types of
water-conducting
cells
Cohesion
Direction
of water
movemen
t
300
µm
H2
O
H2
O

stretch or break

- **Surface tension** is a measure of how difficult it is to break the surface of a liquid
- Water has an unusually high surface tension due to hydrogen bonding between the molecules at the air-water interface and to the water below, but not to the air above.

(1) (2)

Asymmetry ⟹ unusually high surface tension.

⊗ H-Bonds make water more-structured than many other Liquids.

Figure 3.4

Moderation of Temperature by Water

- 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

That is why it is said to be a good moderator.

Temperature and Heat

Thermal Energy → reflects total KE
Volume dependent

Temperature → reflects avg. KE
Volume independent.

- **Kinetic energy** is the energy of motion
- The kinetic energy associated with random motion of atoms or molecules is called **thermal energy**
- **Temperature** represents the average kinetic energy of the molecules in a body of matter
- Thermal energy in transfer from one body of matter to another is defined as **heat**

Thermal Energy is the overall sum of the Kinetic Energy in a system.

- A **calorie** (**cal**) is the amount of heat required to raise the temperature of 1 g of water by 1ºC
- It is also the amount of heat released when 1 g of water cools by 1ºC
- The "Calories" on food packages are actually **kilocalories** (**kcal**); 1 kcal = 1,000 cal
- The **joule** (**J**) is another unit of energy; 1 J = 0.239 cal, or 1 cal = 4.184 J

1 cal > 1 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) → considerably High
- Water resists changing its temperature because of its high specific heat

$$\text{Specific Heat}_{(H_2O)} = \frac{1 \text{ cal}}{g \cdot {}^\circ C} = \frac{4184 \text{ J}}{kg \cdot {}^\circ C}$$

$$\text{Specific Heat}_{(\text{ethyl-Alcohol})} = 0.6 \text{ cal}/(g \cdot {}^\circ C).$$

- Water's high specific heat can be traced to hydrogen bonding

is due to

  - 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

support

* When a considerable amount of heat is absorbed, Temperature of water is slightly raised.
* When the Temperature of water is slightly decreased, a considerable amount of heat is released.

Evaporative Cooling

evaporating "departing" molecules are those with enough K.E.

- Evaporation (or vaporization) is transformation of a substance from liquid to gas

for H_2O, @ 25°C → 580 cal/g. nearly 2× that of alcohol or ammonia.

- **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

(*) Evaporation can occur at any temperature.

the speediest molecules

loating of Ice on Liquid Water

- Ice floats in liquid water because hydrogen bonds in ice are more "ordered," making ice less dense than water
- Water reaches its greatest density at 4ºC
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth

⊛ ordered bonds cause rigid structure and firm distances

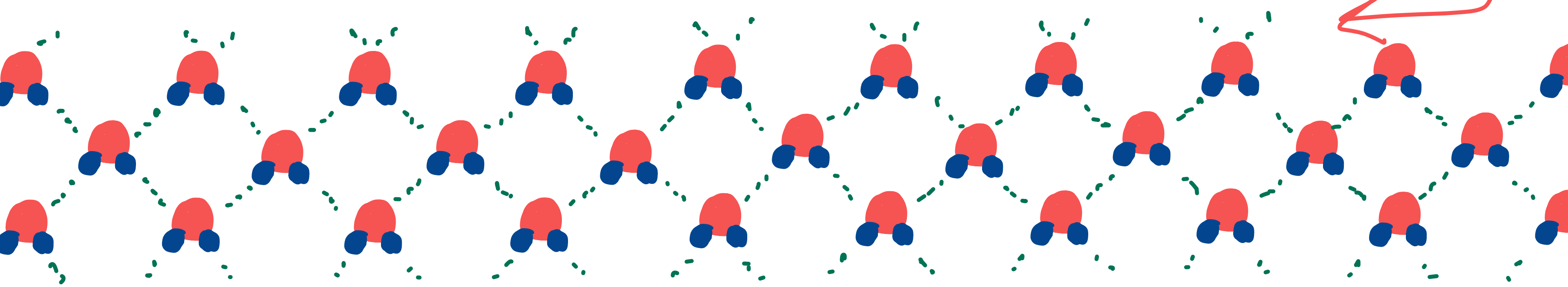
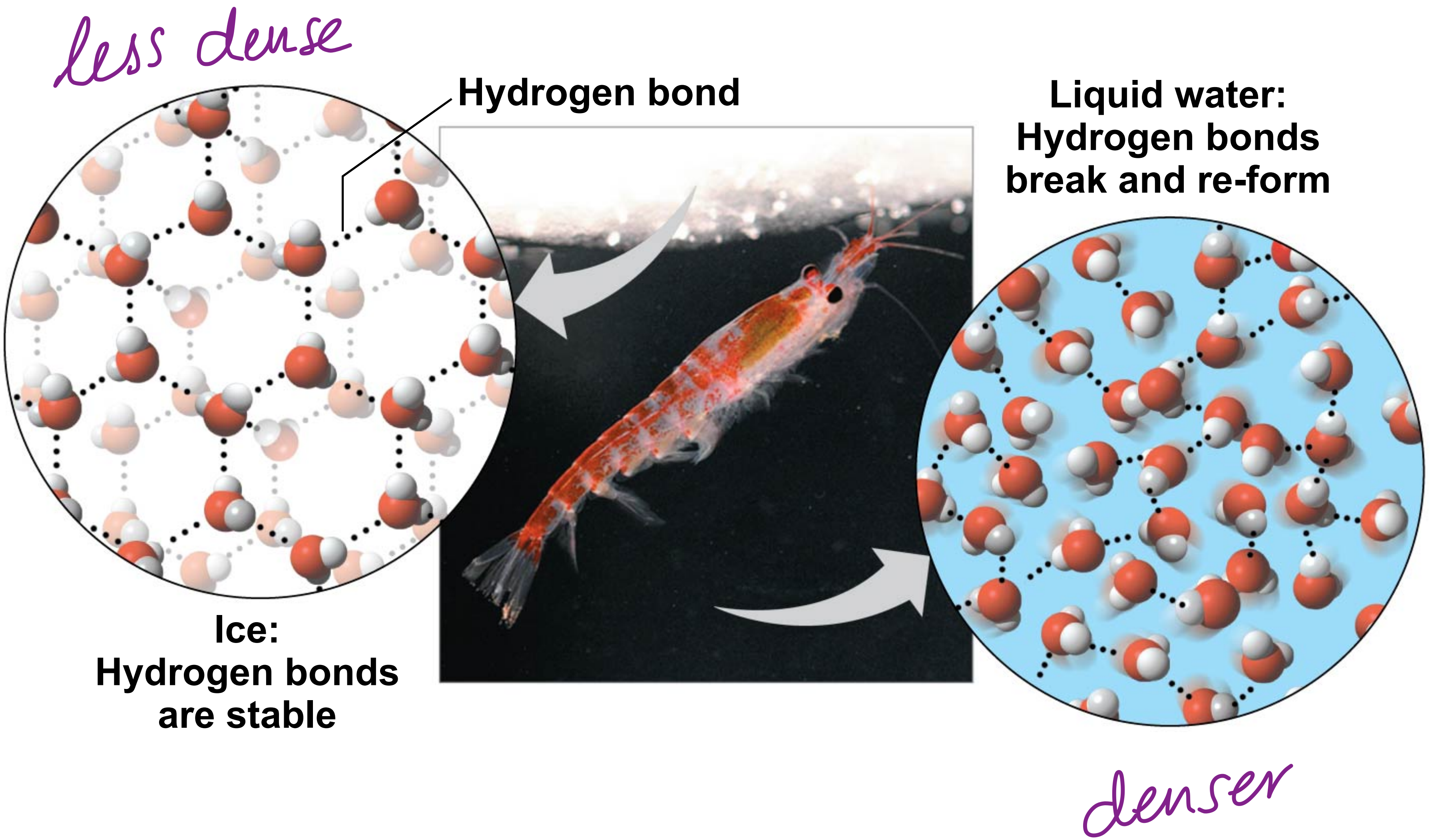


Figure 3.6



less dense
Hydrogen bond
Liquid water:
Hydrogen bonds
break and re-form
Ice:
Hydrogen bonds
are stable
denser

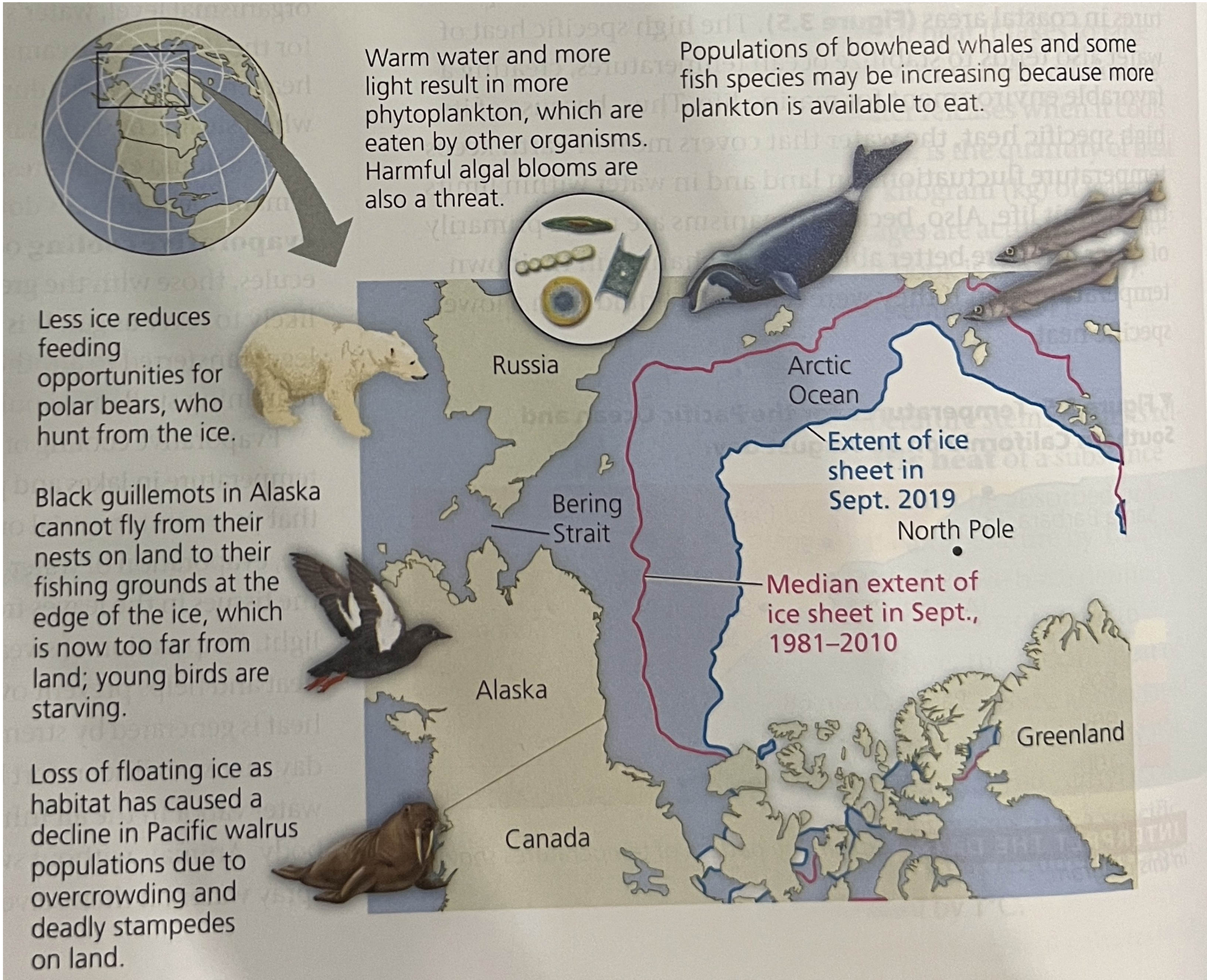
Read and Understand

- Many scientists are worried that global warming is having a profound effect on icy environments around the globe

+2.2°C since 1961.

- The rate at which glaciers and Arctic sea ice are disappearing poses an extreme challenge to animals that depend on ice for their survival

Figure 3.7

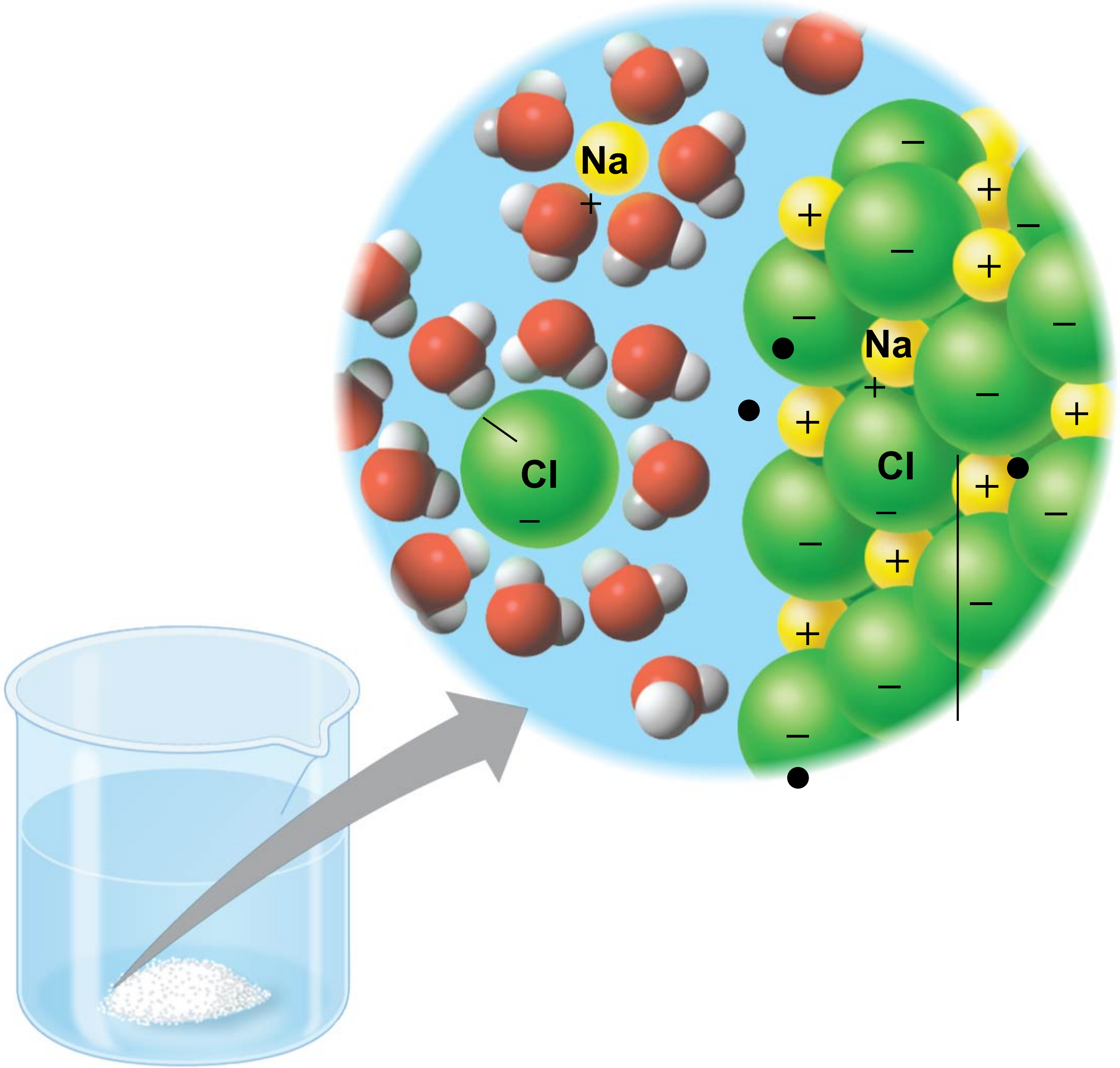


Warm water and more light result in more phytoplankton, which are eaten by other organisms. Harmful algal blooms are also a threat.
Populations of bowhead whales and some fish species may be increasing because more plankton is available to eat.
Less ice reduces feeding opportunities for polar bears, who hunt from the ice.
Black guillemots in Alaska cannot fly from their nests on land to their fishing grounds at the edge of the ice, which is now too far from land; young birds are starving.
Loss of floating ice as habitat has caused a decline in Pacific walrus populations due to overcrowding and deadly stampedes on land.
Russia
Arctic Ocean
Bering Strait
Extent of ice sheet in Sept. 2019
North Pole
Median extent of ice sheet in Sept., 1981–2010
Alaska
Canada
Greenland

/ater: The Solvent of Life

- A **solution** is a liquid that is a completely homogeneous mixture of substances
- The **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

Figure 3.8



- Water is a versatile solvent due to its polarity
- When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**

homogeneous mixture

in water

NaCl solution is an aqueous solution composed of two solutes

(1) sodium cations (Na^+)

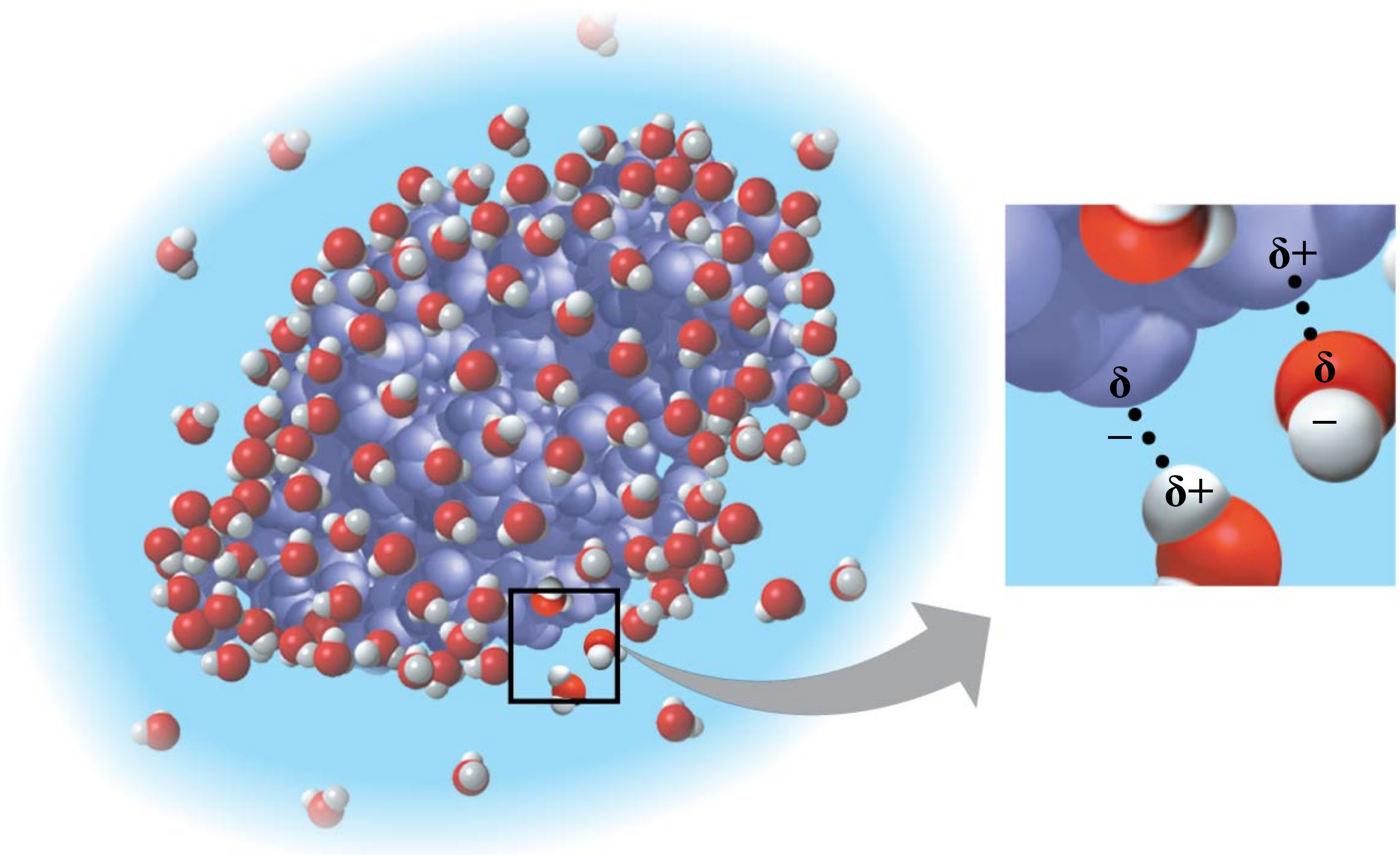
(2) Chloride anions (Cl^-).

- 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

Famous biological fluids (solutions):

Blood, Sap of Plants, cells' liquid (cytosol).

Figure 3.9



Hydrophilic and Hydrophobic Substances

cotton (although hydrophilic) is not soluble in water.
due to its large size.

- 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
- Hydrophobic molecules related to oils are the major ingredients of cell membranes

A C—H bond is almost nonpolar.
similar electronegativity.

olute Concentration in Aqueous Solutions

- Most chemical reactions in organisms involve solutes dissolved in water
- When carrying out experiments, we use mass to calculate the number of solute molecules in an aqueous solution

Extensive Calculations are not the core of the topic.

1 dalton ≡ 1 amu

1 g ≡ N_A daltons

Molarity (M) ⟹ the most used unit of concentration in aqueous solutions.

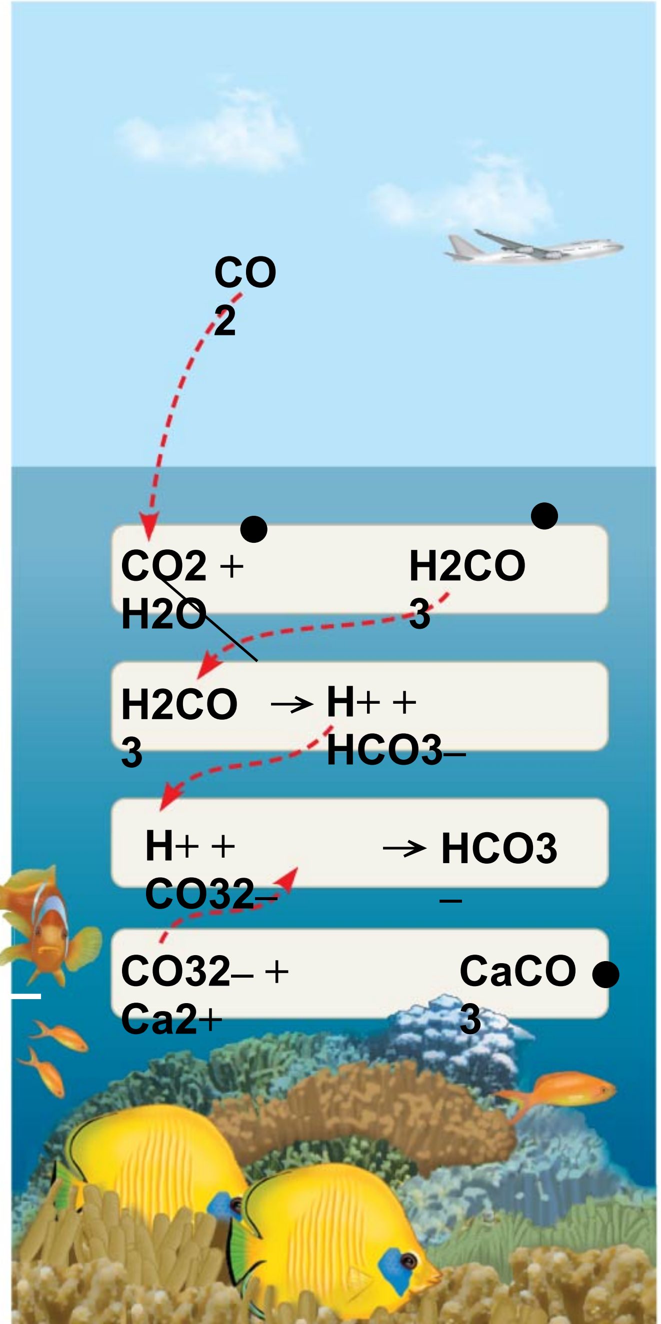
cidification: A Threat to Our Oceans

- Human activities such as burning fossil fuels threaten water quality
- CO_2 is the main product of fossil fuel combustion
- About 25% of human-generated CO_2 is absorbed by the oceans
- CO_2 dissolved in seawater forms carbonic acid; this process is called **ocean acidification**

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

Carbonic acid.

Figure 3.12



⊛ pH (ocean) is 0.1 less than any time 420,000 years ago. and expected to lower by 0.3—0.5 by the end of the century.

$[CO_3^{2-}]$ is expected to decrease by 40% by 2100

$$H^+ + CO_3^{2-} \longrightarrow HCO_3^-$$

- As seawater acidifies, H+ ions combine with carbonate ions to produce bicarbonate
- Carbonate is required for calcification (production of calcium carbonate) by many marine organisms, including reef-building corals

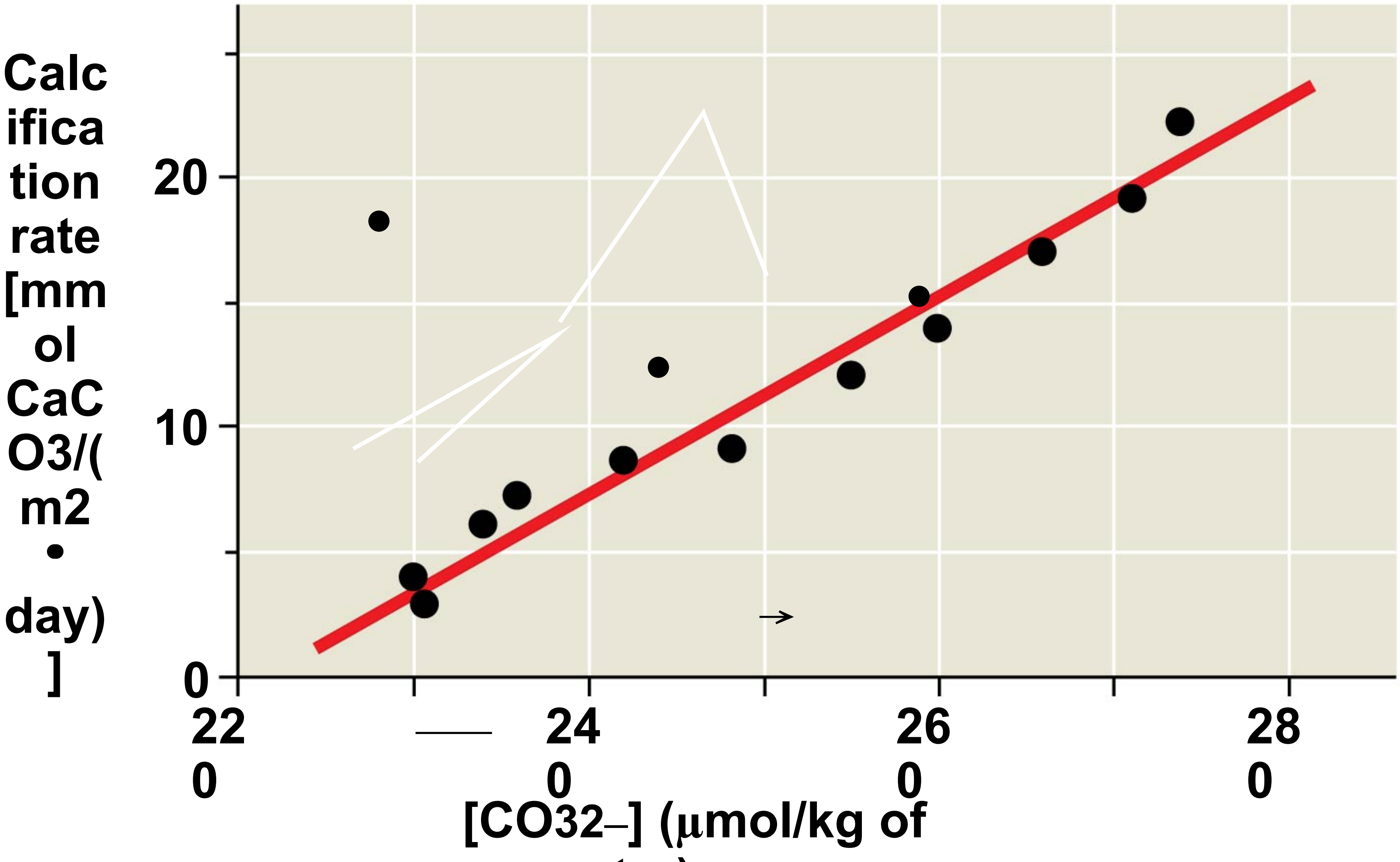
$$CO_3^{2-} + Ca \longrightarrow CaCO_3$$

calcium carbonate

- We have made progress in learning about the delicate chemical balances in oceans, lakes, and rivers

Figure 3.UN02a

Calcification ∝ amount of CO_3^{2-}



Data from C. Langdon et al., Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef, *Global Biogeochemical Cycles* 14:639–654 (2000).