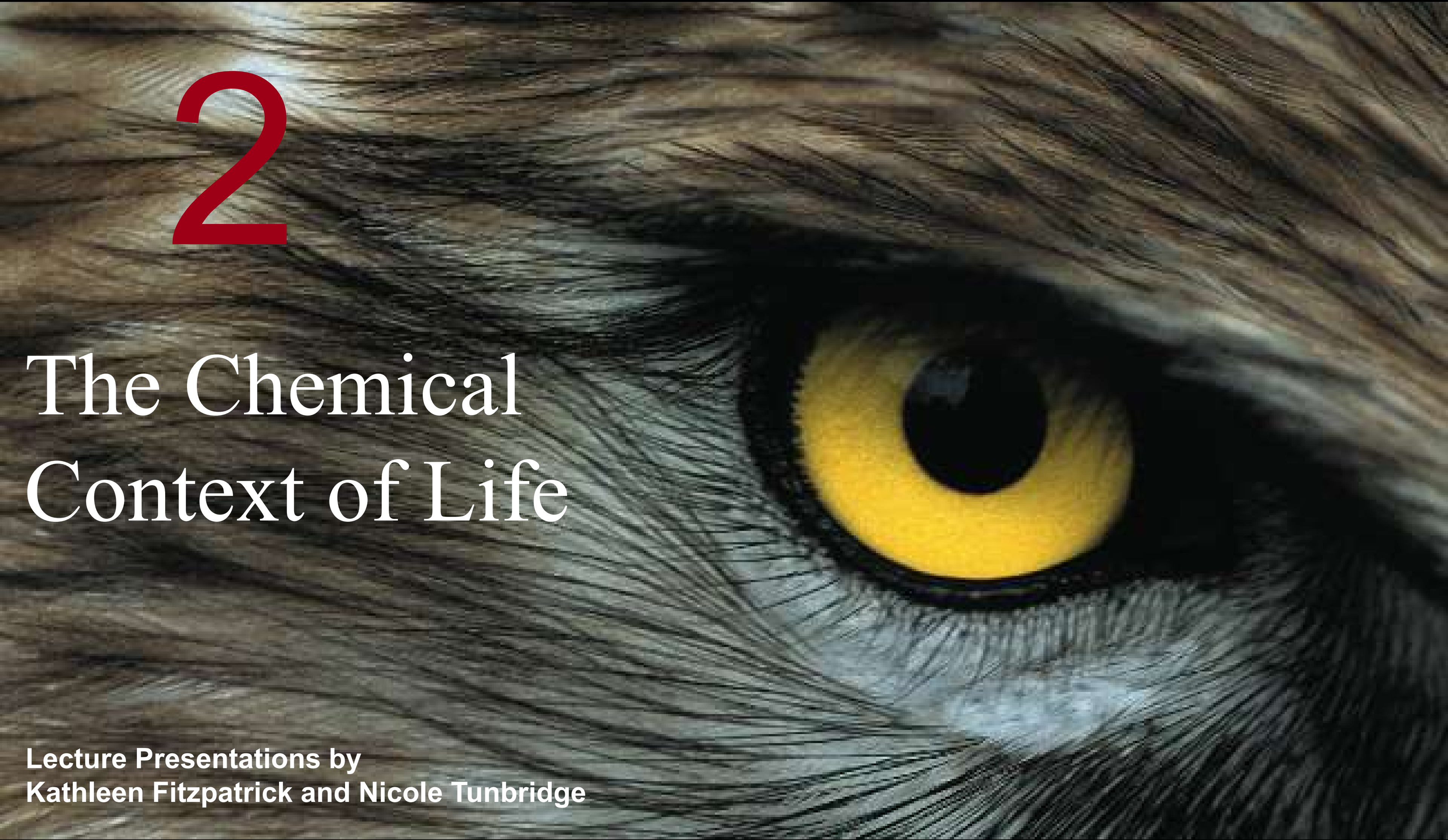
CAMPBELL BIOLOGY IN FOCUS

Urry • Cain • Wasserman • Minorsky • Jackson • Reece



2

The Chemical Context of Life

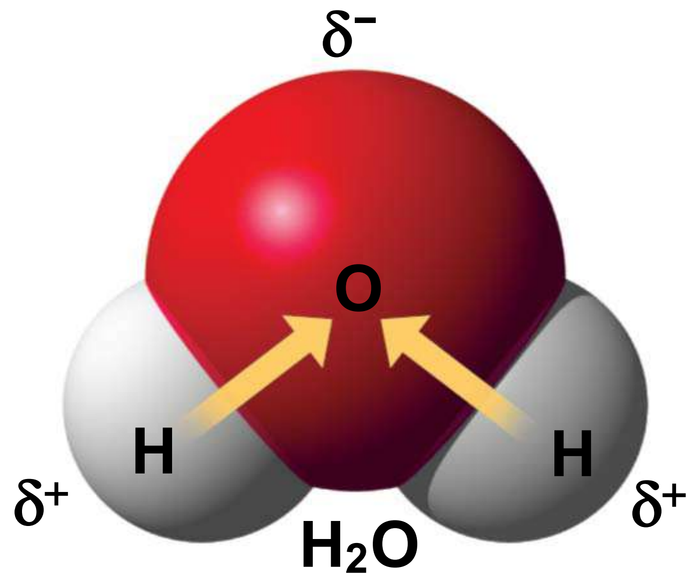
Lecture Presentations by
Kathleen Fitzpatrick and Nicole Tunbridge

Overview: A Chemical Connection to Biology

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

Figure 2.9

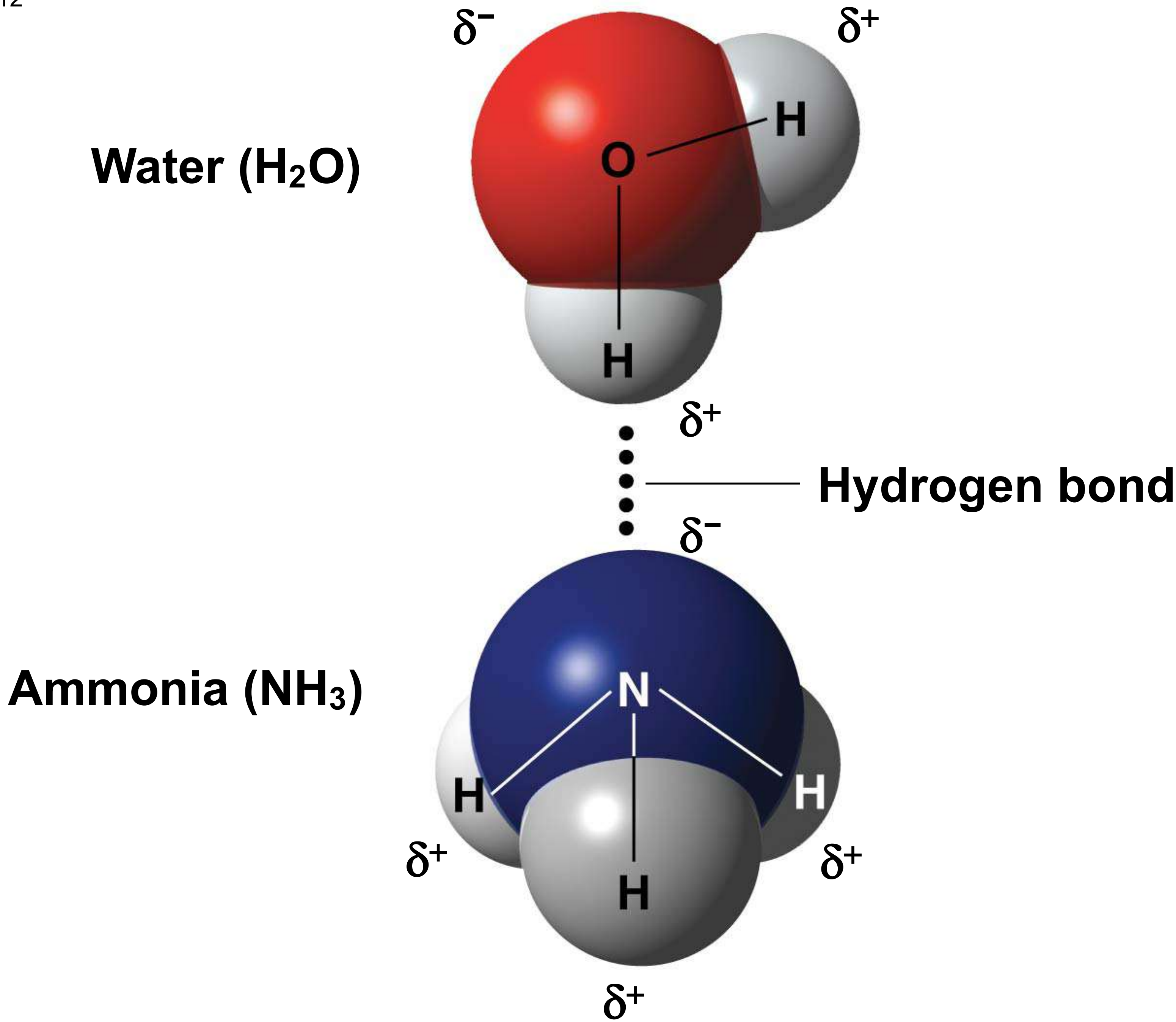
Water molecule



Hydrogen Bonds

- A **hydrogen bond** forms when a hydrogen atom covalently bonded to one electronegative atom is also attracted to another electronegative atom
- In living cells, the electronegative partners are usually oxygen or nitrogen atoms

Figure 2.12



Van der Waals Interactions

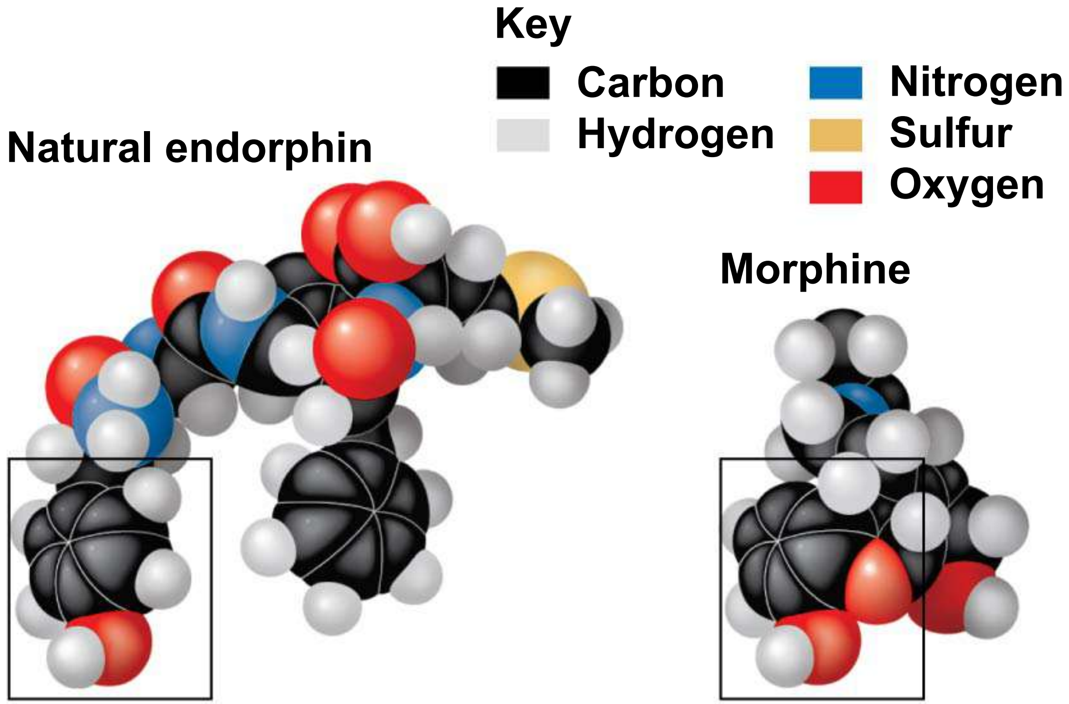
- If electrons are distributed asymmetrically in molecules or atoms, they can result in “hot spots” of positive or negative charge
- **Van der Waals interactions** are attractions between molecules that are close together as a result of these charges

- Van der Waals interactions are individually weak and occur only when atoms and molecules are very close together
- Collectively, such interactions can be strong, as between molecules of a gecko’s toe hairs and a wall surface

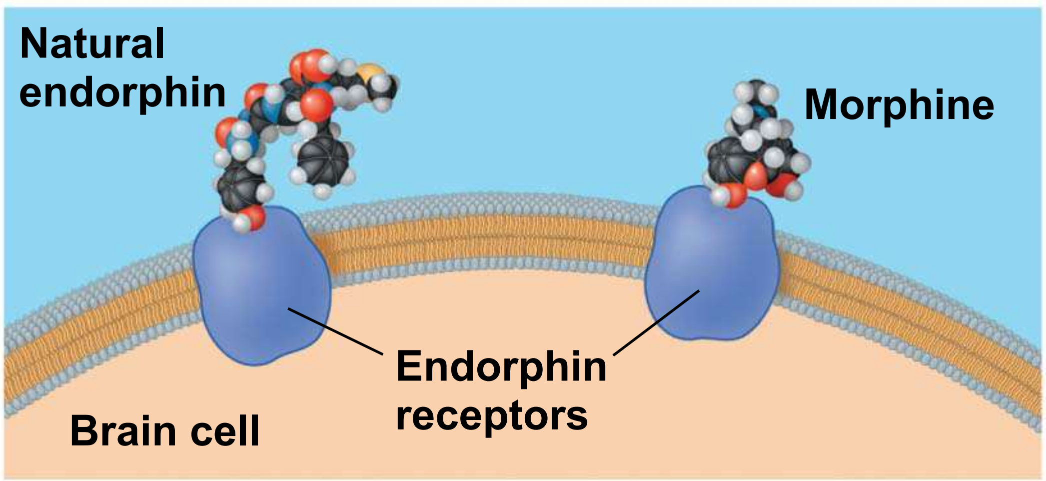
Molecular Shape and Function

- A molecule's shape is usually very important to its function
- Molecular shape determines how biological molecules recognize and respond to one another

Figure 2.14

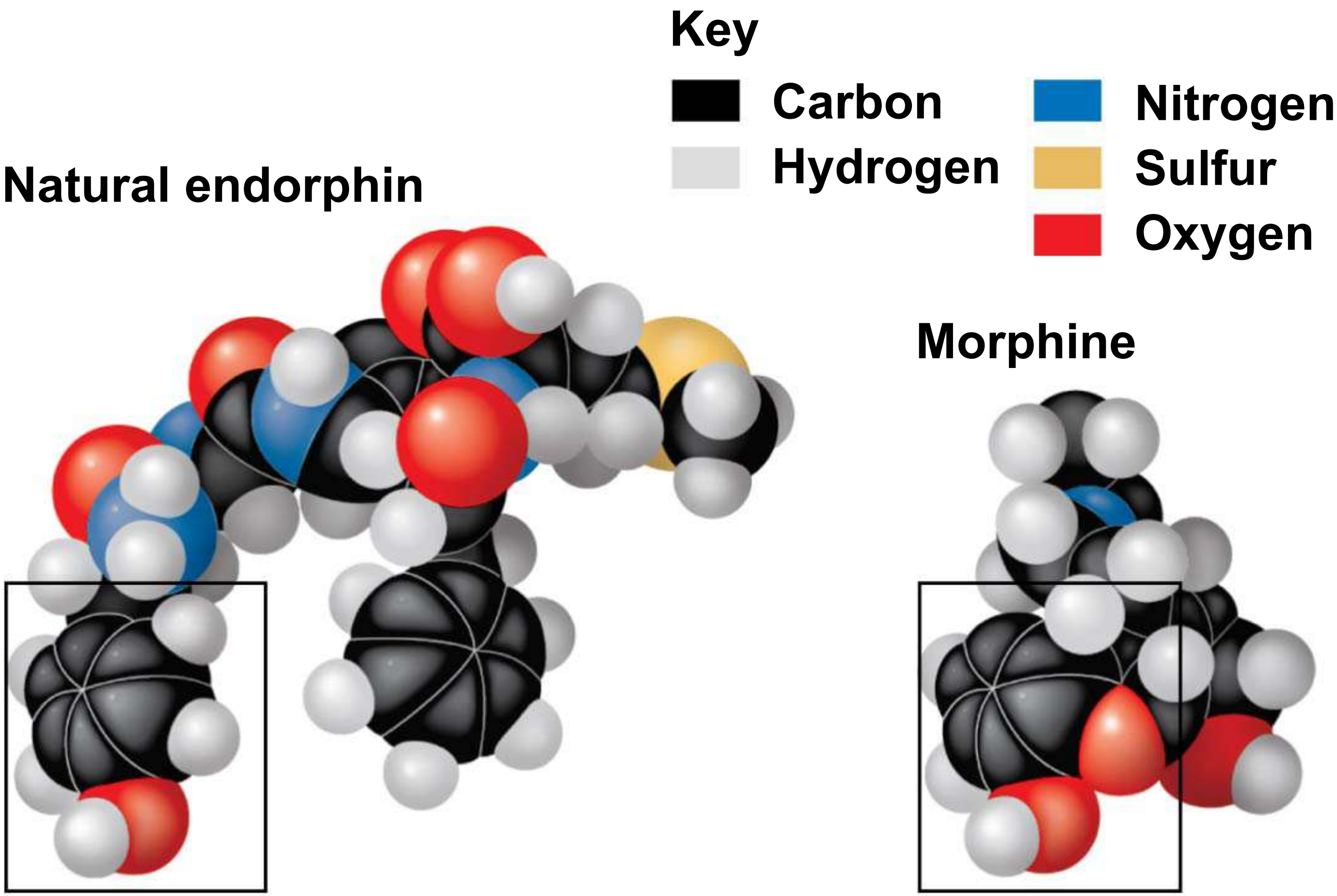


(a) Structures of endorphin and morphine



(b) Binding to endorphin receptors

Figure 2.14a

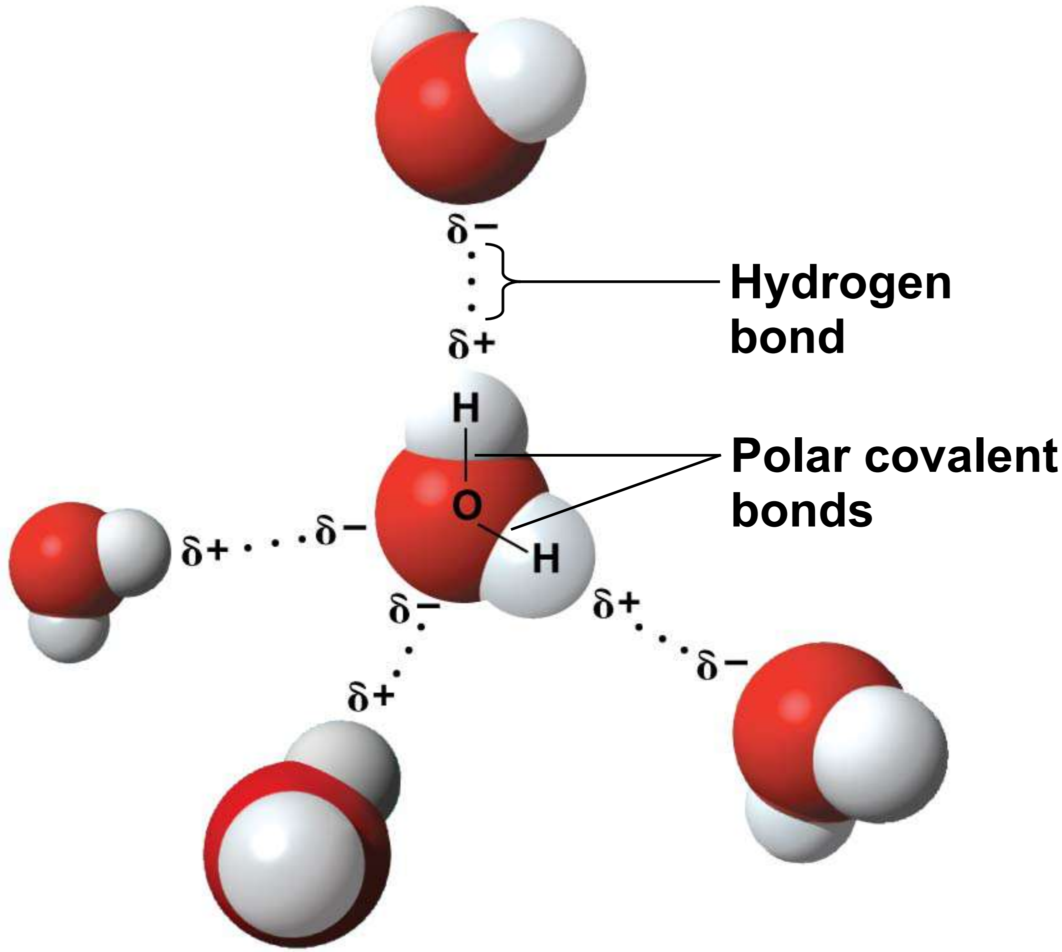


(a) Structures of endorphin and morphine

Concept 2.5: Hydrogen bonding gives water properties that help make life possible on Earth

- All organisms are made mostly of water and live in an environment dominated by water
- Water molecules are polar, with the oxygen region having a partial negative charge ($\delta-$) and the hydrogen region a slight positive charge ($\delta+$)
- Two water molecules are held together by a hydrogen bond

Figure 2.16

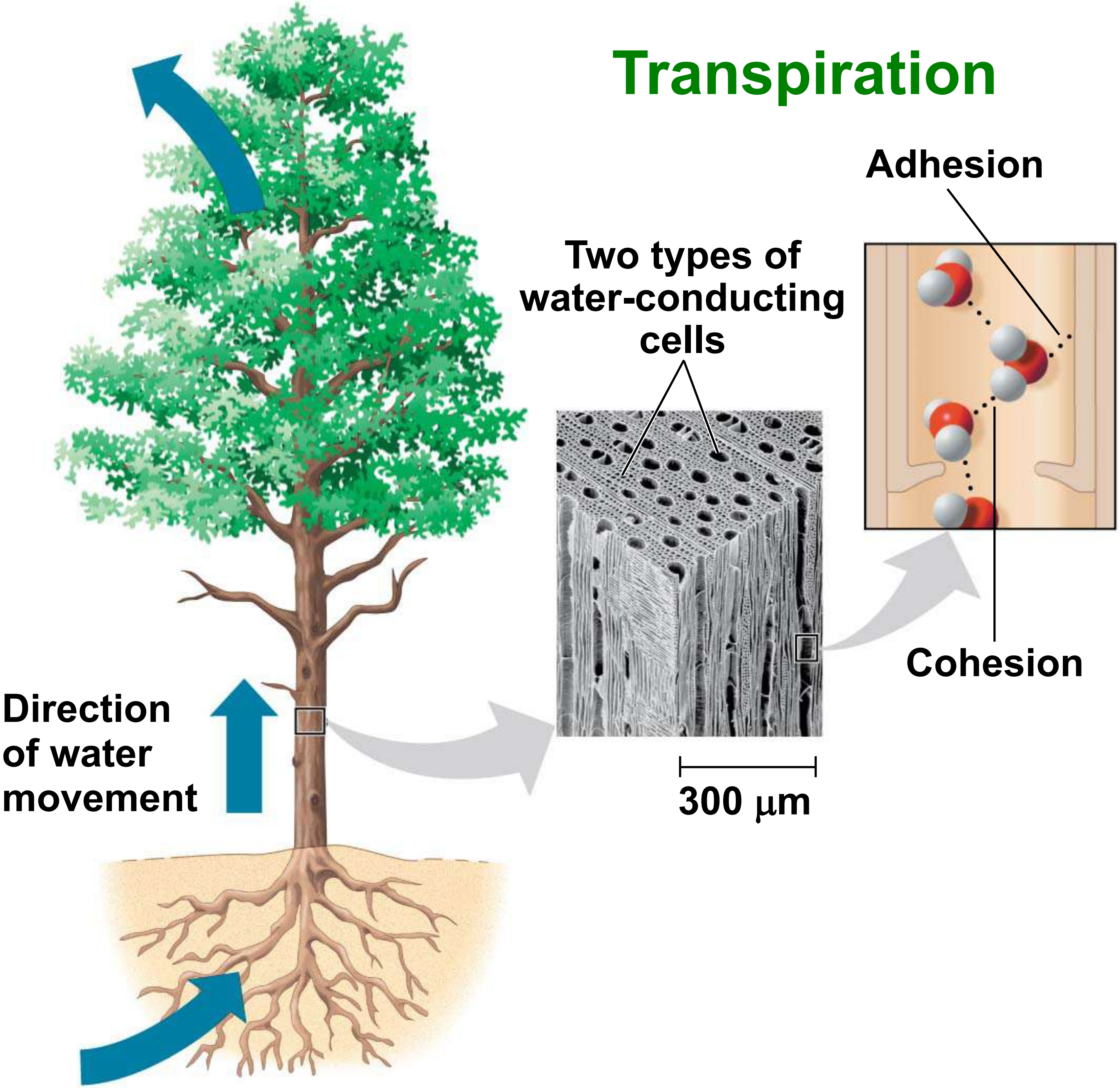


- Four emergent properties of water contribute to Earth’s suitability for life:
  - Cohesive behavior
  - Ability to moderate temperature
  - Expansion upon freezing
  - Versatility as a solvent

Cohesion of Water Molecules

- Water molecules are linked by multiple hydrogen bonds
- The molecules stay close together because of this; it is called **cohesion**
- **Surface tension** is a measure of how hard it is to break the surface of a liquid
- Surface tension is related to cohesion
- **Adhesion**, the clinging of one substance to another, also plays a role

Figure 2.17



Transpiration
Adhesion
Two types of water-conducting cells
Cohesion
Direction of water movement
300 μm

Figure 2.18

What are the four emergent properties of water that are important for life?

A. cohesion, expansion upon freezing, high heat of evaporation, capillarity
B. cohesion, moderation of temperature, expansion upon freezing, solvent properties
C. moderation of temperature, solvent properties, high surface tension, capillarity
D. heat of vaporization, high specific heat, high surface tension, capillarity
E. polarity, hydrogen bonding, high specific heat, high surface tension

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E. polarity, hydrogen bonding, high specific heat, high surface tension

Moderation of Temperature by Water

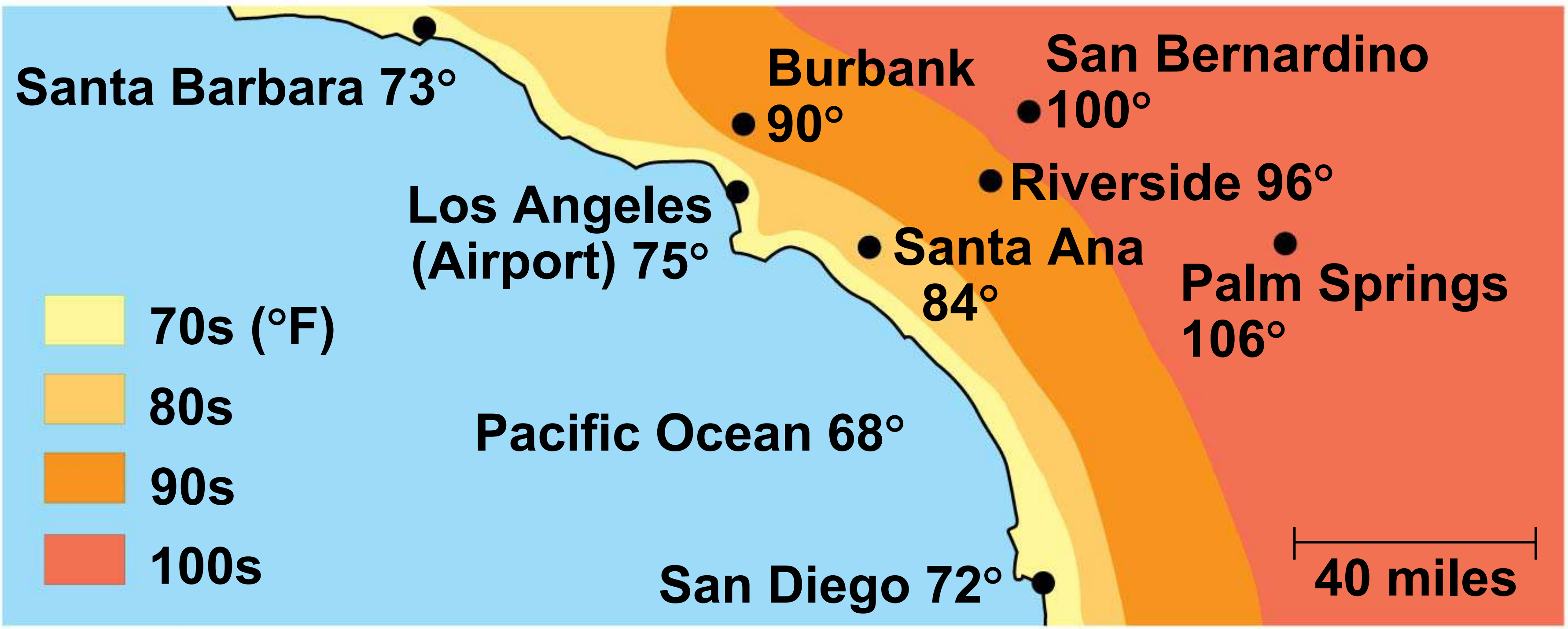
- Water absorbs heat from warmer air and releases stored heat to cooler air
- Water can absorb or release a large amount of heat with only a slight change in its own temperature
- Water resists changing its temperature because of its high specific heat
- The **specific heat** of a substance is the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1°C
- The specific heat of water is 1 cal/g/°C

Moderation of Temperature by Water

- 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 keeps temperature fluctuations within limits that permit life

Figure 2.19

Moderation of Land Temperature by Water



Water has an unusually high specific heat. This is directly related to which one of the following?

A. At its boiling point, water changes from liquid to vapor.
B. More heat is required to raise the temperature of water.
C. Ice floats in liquid water.
D. Salt water freezes at a lower temperature than pure water.
E. Floating ice can insulate bodies of water.

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Which of the following observations would distinguish between the alternative hypotheses that geckos walk on vertical surfaces via either hydrogen bonding or van der Waals interactions?

A. Geckos can walk up dry surfaces.
B. Geckos can walk up smooth glass surfaces—silicon dioxide is a polar, hydrophilic compound.
C. Geckos can walk up smooth plastic surfaces—plastics are hydrophobic.

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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, it uses the heat from the surroundings which cools down, a process called **evaporative cooling**
- Evaporative cooling of water helps stabilize temperatures in organisms and bodies of water
- 1g of water needs 580 cal at 25^0C to evaporate

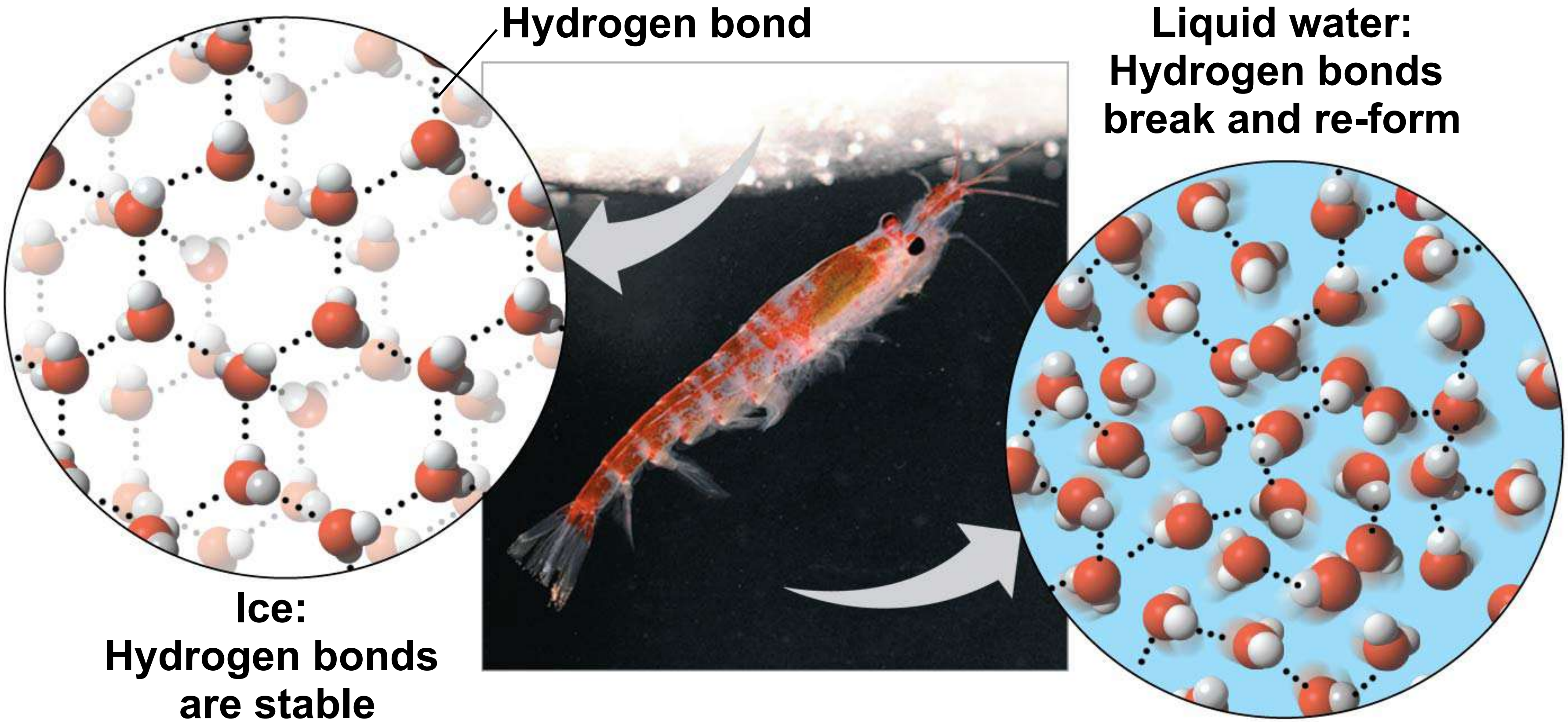
Evaporative Cooling

- Prevents temp fluctuations in lakes/ponds/seas/oceans
- Prevents overheating of all living things
- Specifically – sweating in humans, panting by dogs

Floating of Ice on Liquid Water

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

Figure 2.20


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

Water shows high cohesion and surface tension and can absorb large amounts of heat because of large numbers of which of the following bonds between water molecules? Solutions of other molecules have much less bonding between molecules.

A. strong ionic bonds

B. nonpolar covalent bonds

C. polar covalent bonds

D. hydrogen bonds

E. weak ionic bonds

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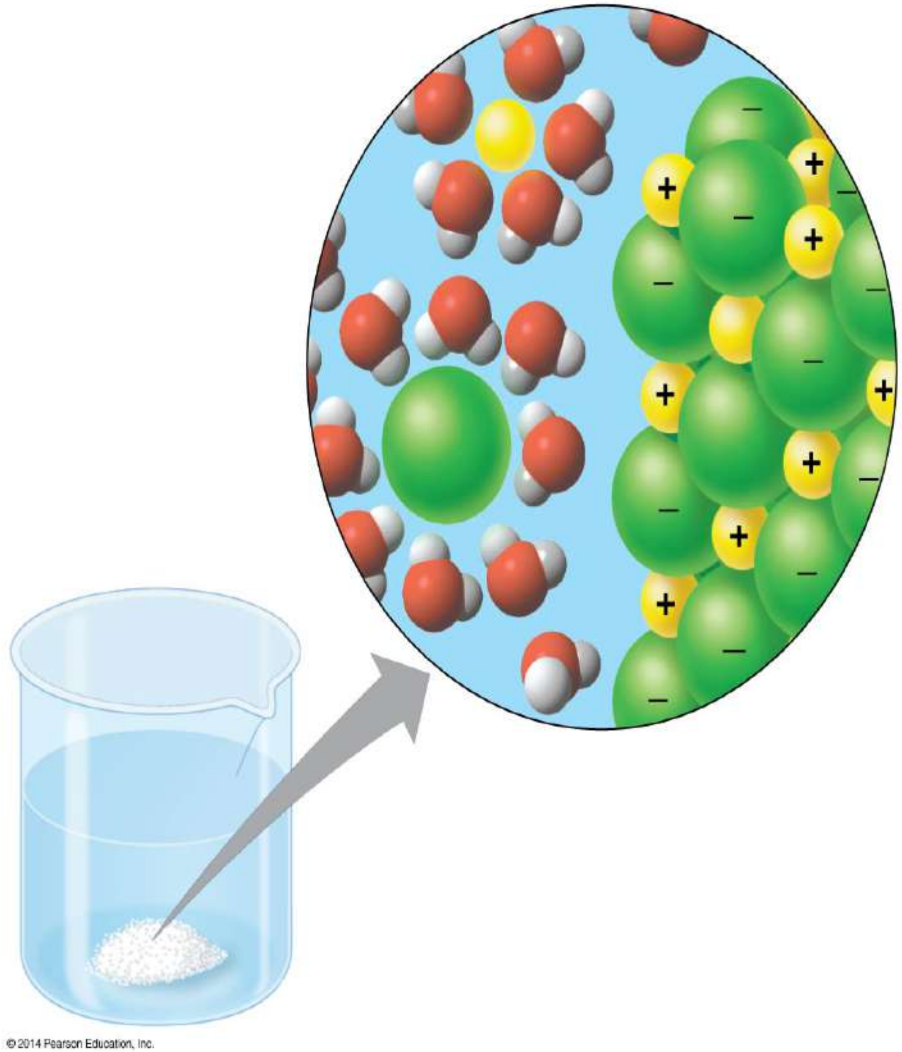
C. polar covalent bonds

D. hydrogen bonds

E. weak ionic bonds

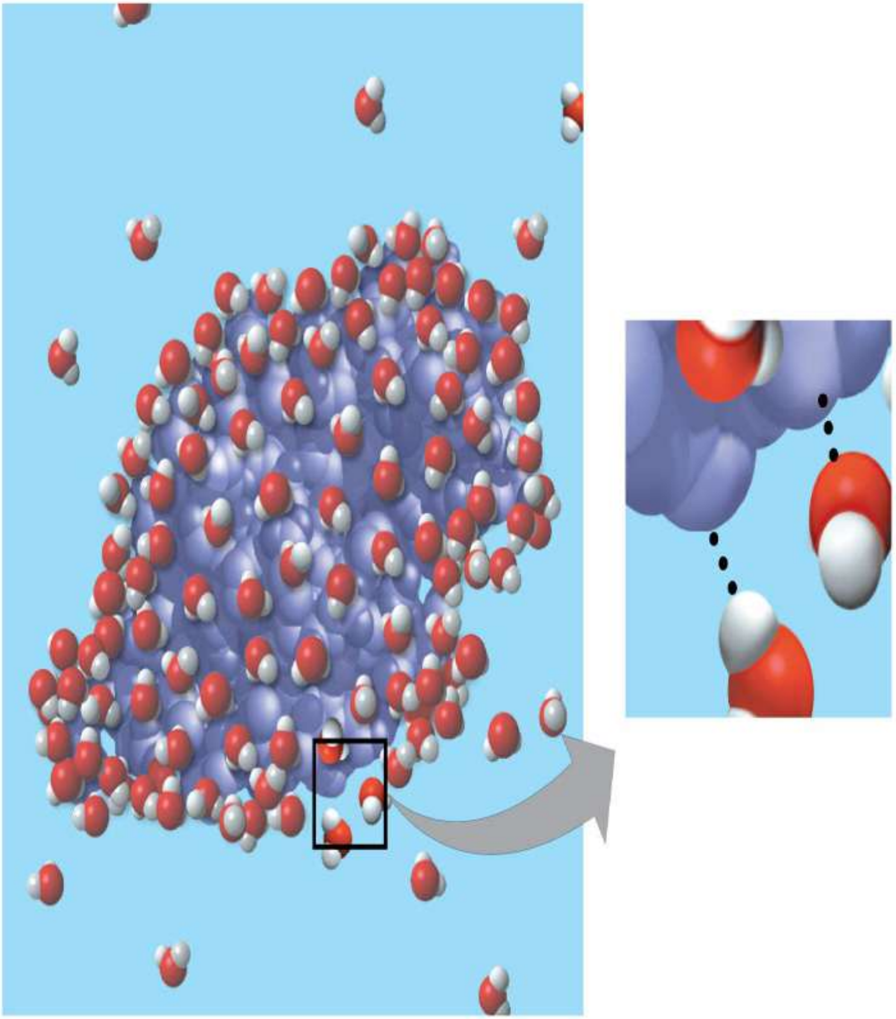
Water is an Universal solvent

- 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**



Water is an Universal solvent

- 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 stable suspension of fine particles in a liquid

Water is an Universal solvent

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

Surfactants reduce surface tension of a liquid. Which of the following would result if water was treated with surfactants?

A. Surfactant-treated water droplets will form a thin film instead of beading on a waxed surface.
B. Surfactant-treated water will form smaller droplets when dripping from a sink.
C. Water striders will sink.
D. All of the above will occur.
E. Only A and C will occur.

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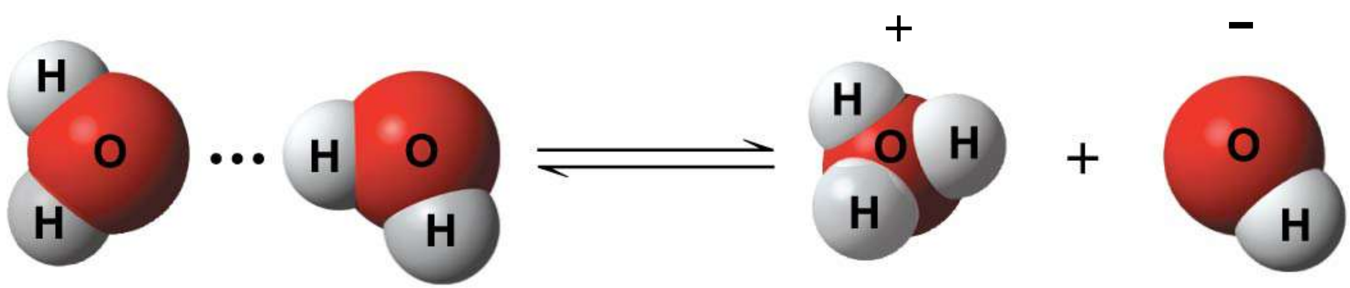
Acids and Bases

- Sometimes a **hydrogen ion** (H^+) is transferred from one water molecule to another, leaving behind a **hydroxide ion** (OH^-)
- The proton (H^+) binds to the other water molecule, forming **a hydronium ion** (H_3O^+)
- By convention, H^+ is used to represent the hydronium ion

Figure 2.UN03

Acids and Bases



$2\ H_2O$

Hydronium ion (H_3O^+)

Hydroxide ion (OH^-)

The pH Scale

- In any aqueous solution at 25°C, the product of H^+ and OH^- is constant and can be written as

$$[H^+][OH^-] = 10^{-14}$$

- The **pH** of a solution is defined by the negative logarithm of H^+ concentration, written as

$$pH = -\log [H^+]$$

- For a neutral aqueous solution, $[H^+]$ is 10^{-7}, so

$$-\log [H^+] = -(-7) = 7$$

Acids and Bases

- Though water dissociation is rare and reversible, it is important in the chemistry of life
- H^+ and OH^- are very reactive
- Solutes called acids and bases disrupt the balance between H^+ and OH^- in pure water
- **Acids** increase the H^+ concentration in water, while **bases** reduce the concentration of H^+

- A strong acid like hydrochloric acid, HCl, dissociates completely into H^+ and Cl^- in water:

$$HCl \rightarrow H^+ + Cl^-$$

- Sodium hydroxide, NaOH, acts as a strong base indirectly by dissociating completely to form hydroxide ions

- These combine with H^+ ions to form water:

$$NaOH \rightarrow Na^+ + OH^-$$

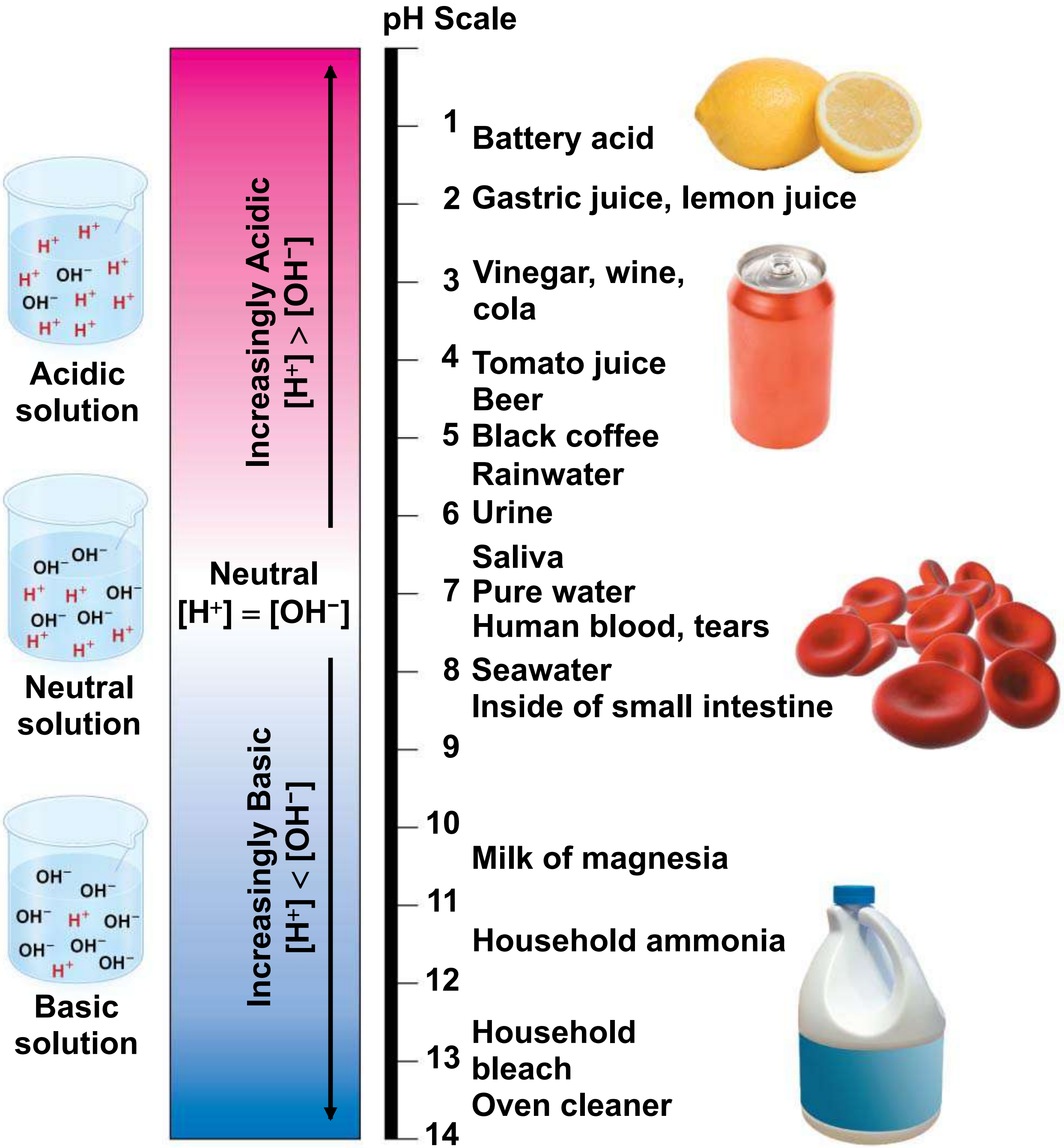
- Ammonia, NH_3, acts as a relatively weak base when it attracts an H^+ ion from the solution and forms ammonium, NH_4^+
- This is a reversible reaction, as shown by the double arrows:

$$NH_3 + H^+ \rightleftharpoons NH_4^+$$

- Carbonic acid, H_2CO_3, acts as a weak acid, which can reversibly release and accept back H^+ ions:

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

Figure 2.23



pH Scale
H^+ H^+ H^+ OH^- H^+ OH^- H^+ H^+ H^+ H^+
Acidic solution
OH^- OH^- H^+ H^+ OH^- OH^- OH^- H^+ H^+ H^+
Neutral solution
OH^- OH^- OH^- H^+ OH^- OH^- OH^- OH^- H^+
Basic solution
Increasingly Acidic
$[H^+] > [OH^-]$
Neutral
$[H^+] = [OH^-]$
Increasingly Basic
$[H^+] < [OH^-]$
1 Battery acid
2 Gastric juice, lemon juice
3 Vinegar, wine, cola
4 Tomato juice
Beer
5 Black coffee
Rainwater
6 Urine
Saliva
7 Pure water
Human blood, tears
8 Seawater
Inside of small intestine
9
10
Milk of magnesia
11
Household ammonia
12
Household bleach
13
Oven cleaner
14

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
- Most buffers consist of an acid-base pair that reversibly combines with H^+

- Carbonic acid is a buffer that contributes to pH stability in human blood:

Response to a rise in pH

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

H_2CO_3		HCO_3^-	+	H^+
H^+ donor (acid)	Response to a drop in pH	H^+ acceptor (base)		Hydrogen ion

Buffers will bind to one of the following shown in the reaction below. How will that change this reversible reaction?

$$H_2CO_3 \leftrightharpoons HCO_3^- + H^+$$

A. The reaction will proceed to the left.

B. HCO_3^- concentration will decrease.

C. H_2CO_3 concentration will increase.

D. H_2CO_3 concentration will not change.

E. HCO_3^- concentration will increase.

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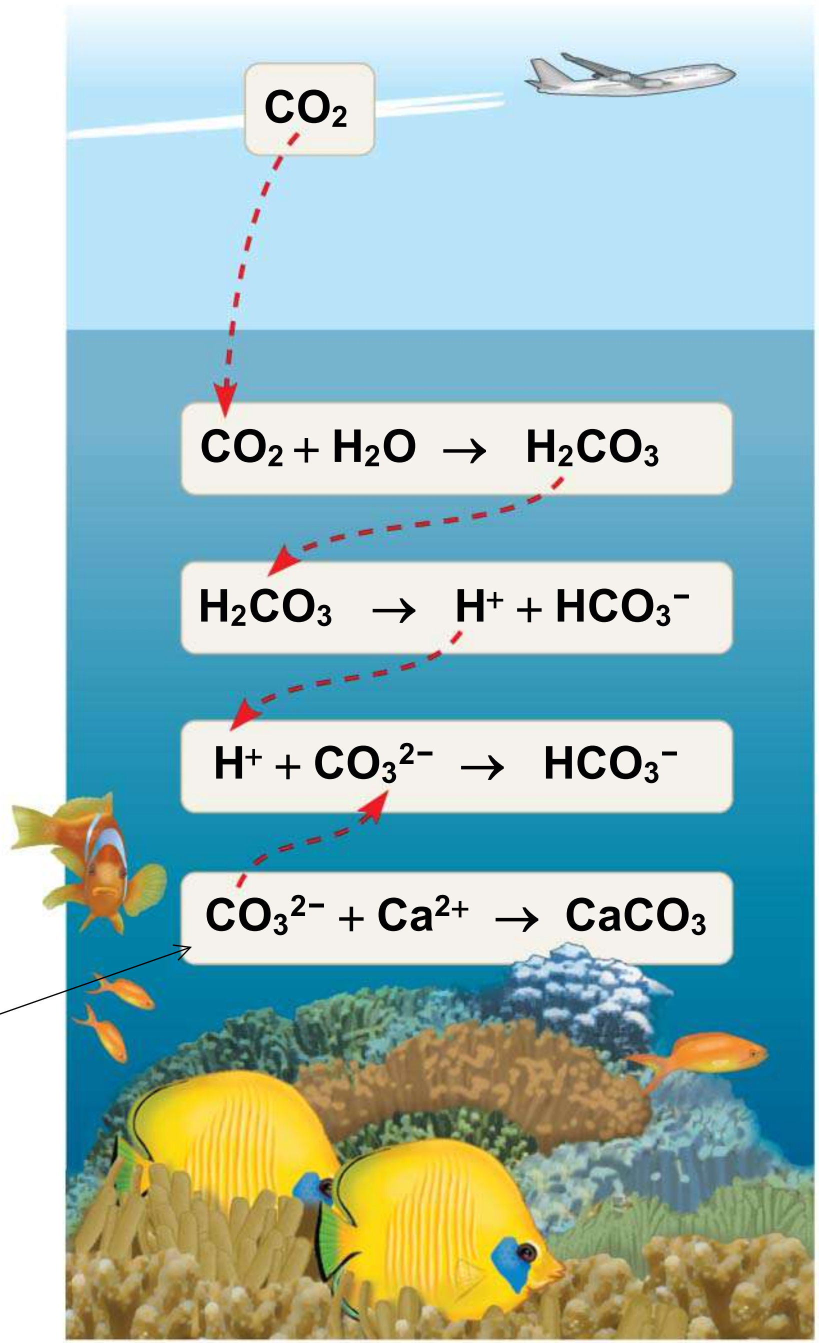
Acidification: A Threat to Our Oceans

- 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 causes ocean acidification

- As seawater acidifies, H^+ ions combine with CO_3^{2-} ions to form bicarbonate ions (HCO_3^-)
- This is a concern because organisms that build coral reefs or shells require carbonate ions
- It is predicted that carbonate ion concentrations will decline by 40% by the year 2100

Figure 2.24



Less CO_3^{2-} available for calcification by corals etc.

Figure 2.UN04