

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

Why does the abundance of water allow life to exist on the planet Earth?

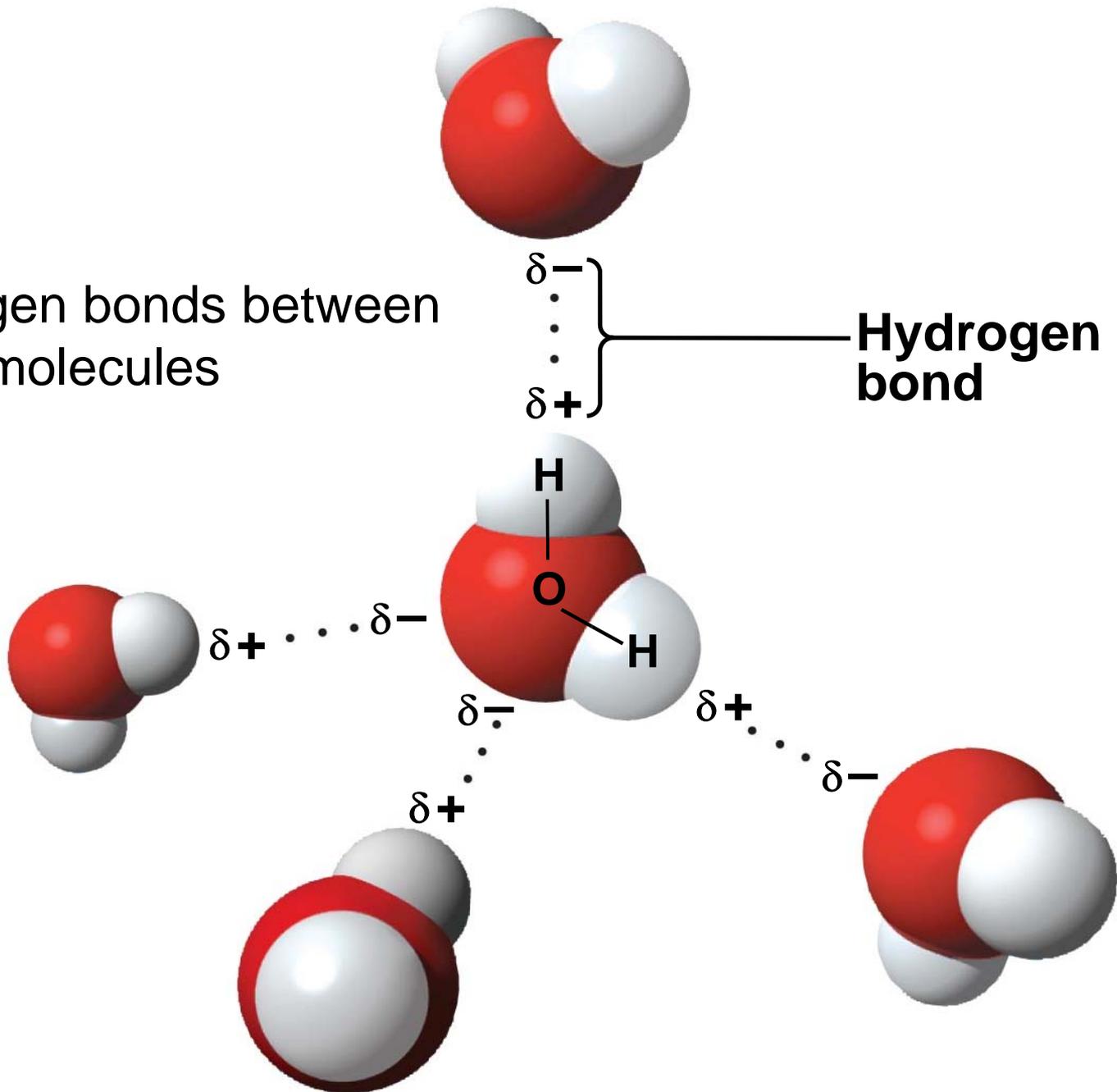


Concept 3.1: The polarity of water molecules results in hydrogen bonding

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

Fig. 3-2

Hydrogen bonds between
water molecules



Concept 3.2: Four emergent properties of water contribute to Earth's fitness for life

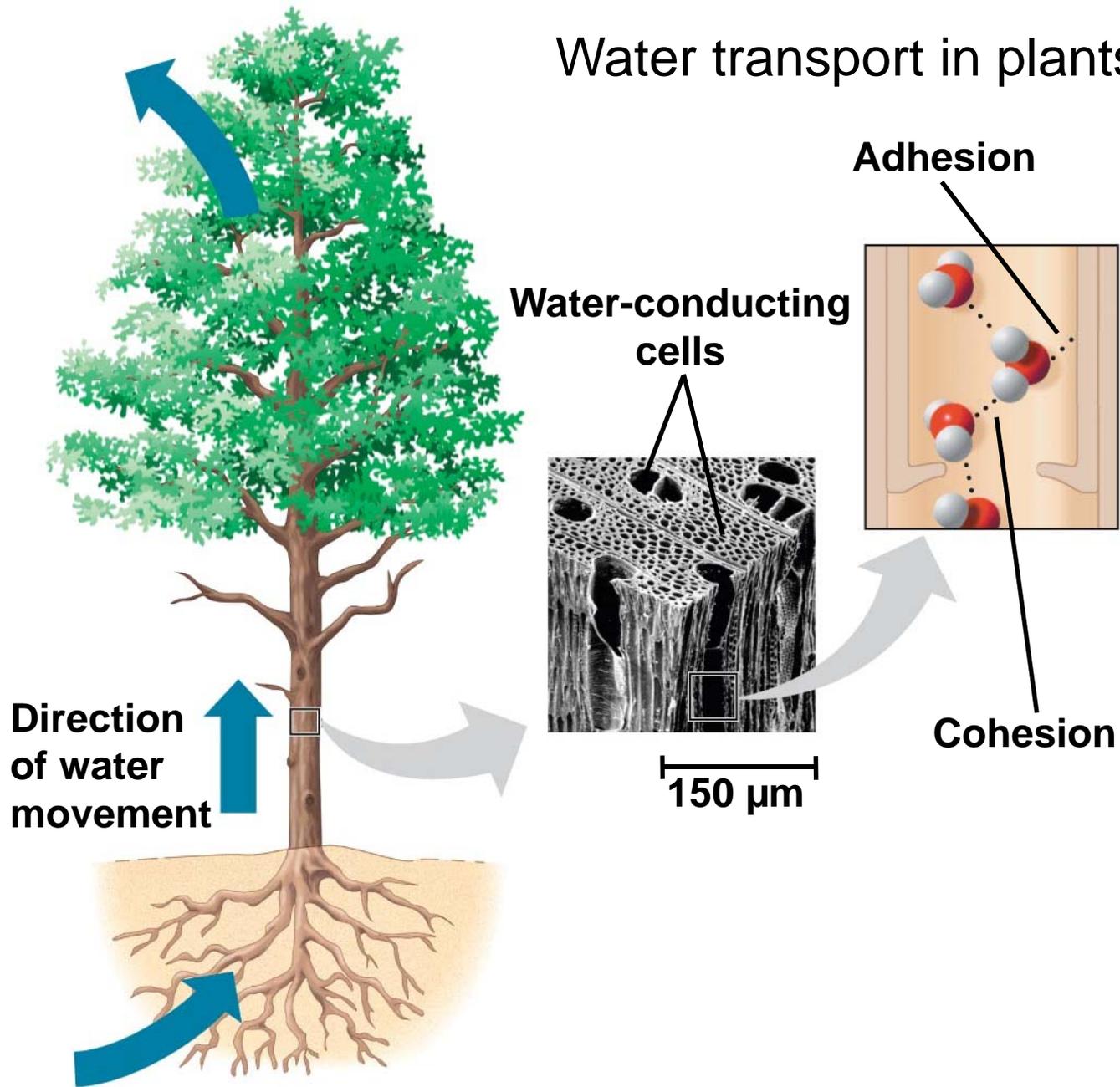
- Four of water's properties that facilitate an environment for life are:
 - Cohesive behavior
 - Ability to moderate temperature
 - Expansion upon freezing
 - Versatility as a solvent

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

Fig. 3-3

Water transport in plants



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

Fig. 3-4

Walking on water



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

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

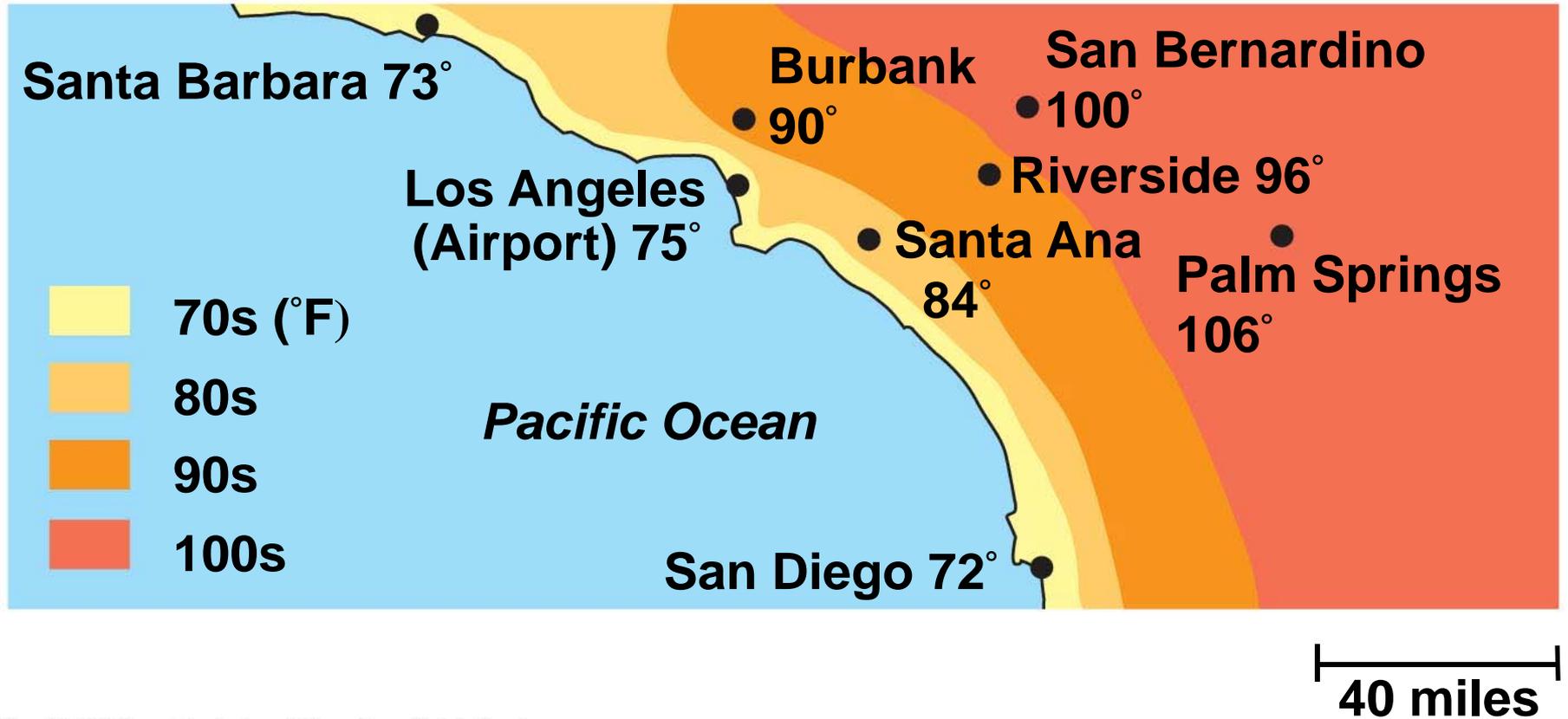
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- The **Celsius scale** is a measure of temperature using Celsius degrees ($^{\circ}\text{C}$)
 - A **calorie (cal)** is the amount of heat required to raise the temperature of 1 g of water by 1°C
 - The “calories” on food packages are actually **kilocalories (kcal)**, where $1 \text{ kcal} = 1,000 \text{ cal}$
 - The **joule (J)** is another unit of energy where $1 \text{ J} = 0.239 \text{ cal}$, or $1 \text{ cal} = 4.184 \text{ J}$

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 1°C
- The specific heat of water is $1 \text{ cal/g/}^{\circ}\text{C}$
- Water resists changing its temperature because of its high specific heat

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- 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



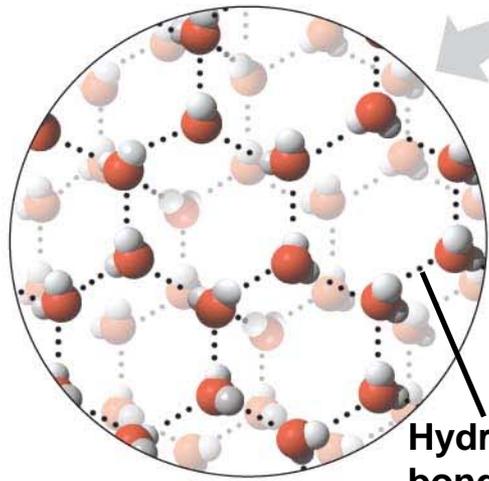
Evaporative Cooling

- *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

Insulation of Bodies of Water by Floating Ice

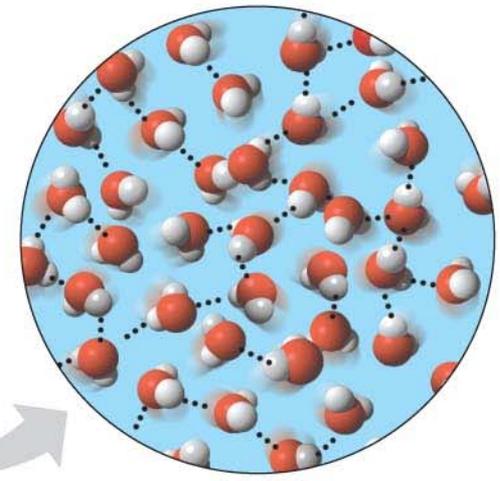
- Ice floats in liquid water because hydrogen bonds in ice are more “ordered,” making ice less dense
- Water reaches its greatest density at 4°C
- If ice sank, all bodies of water would eventually freeze solid, making life impossible on Earth

Ice: crystalline structure and floating barrier



Ice

Hydrogen bonds are stable



Liquid water

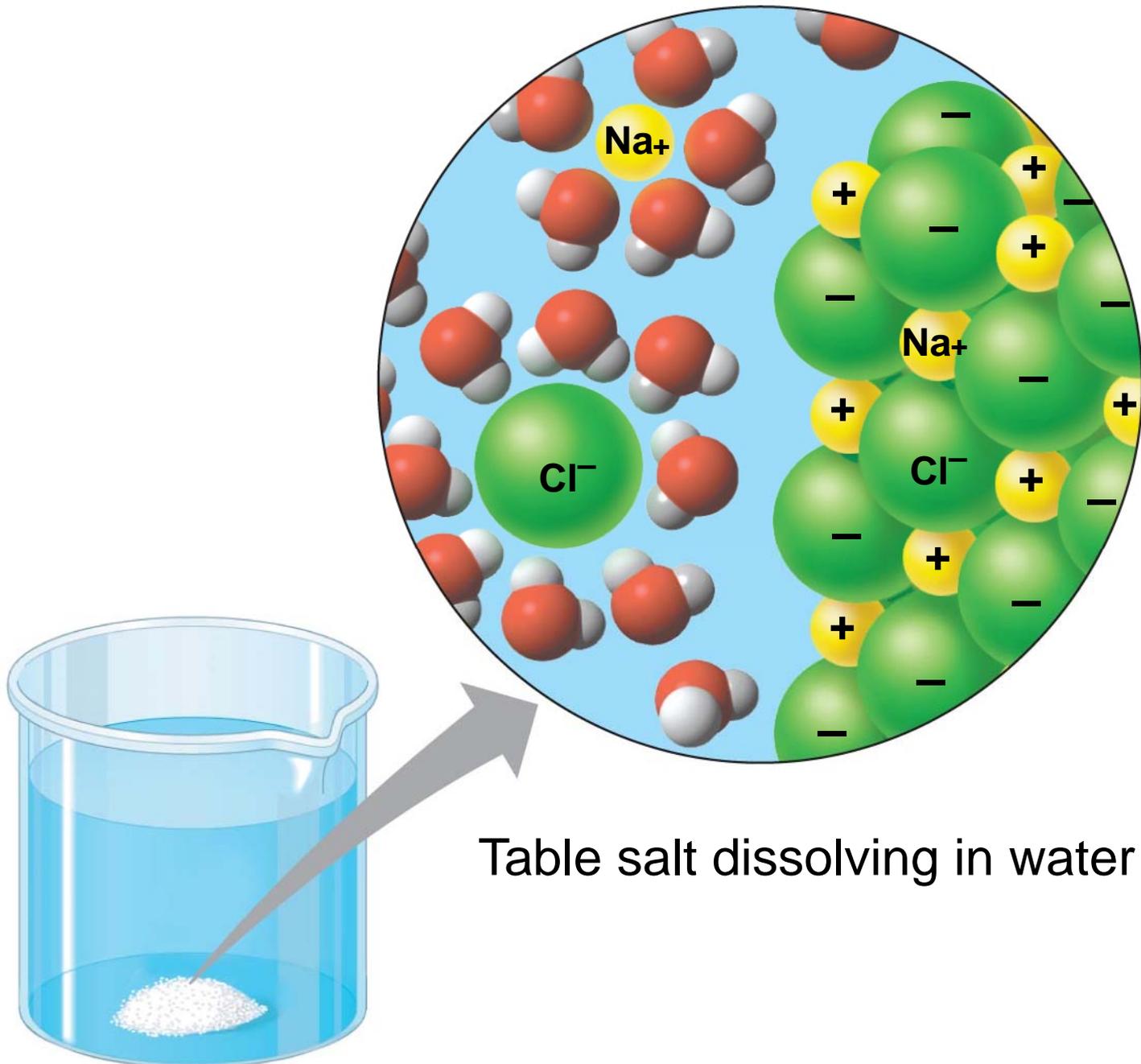
Hydrogen bonds break and re-form

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

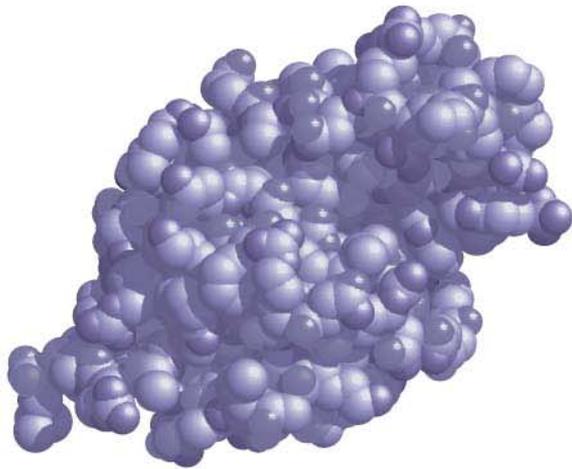
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- Water is a versatile solvent due to its polarity, which allows it to form hydrogen bonds easily
 - When an ionic compound is dissolved in water, each ion is surrounded by a sphere of water molecules called a **hydration shell**

Fig. 3-7

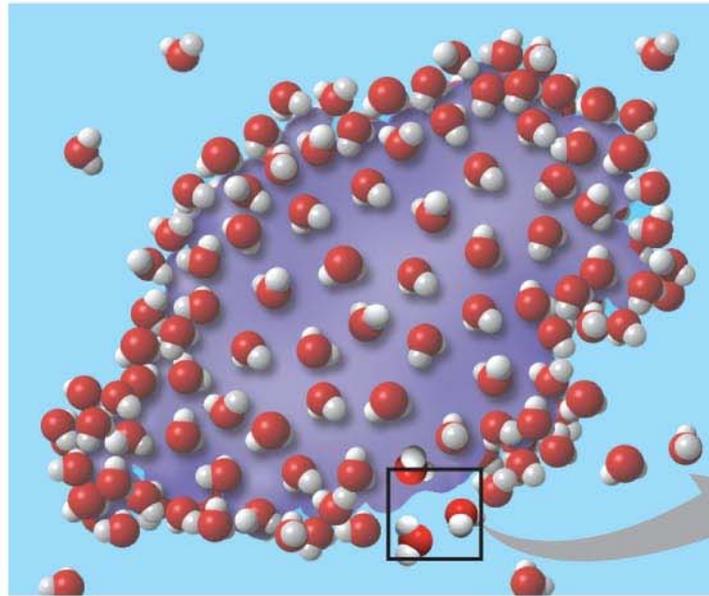


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- Water can also dissolve compounds made of nonionic polar molecules
 - Even large polar molecules such as proteins can dissolve in water if they have ionic and polar regions

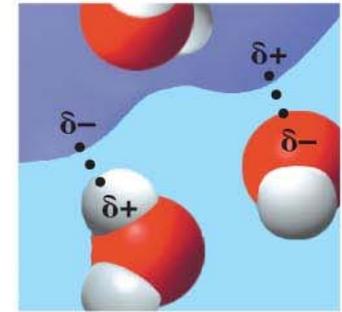
A water-soluble protein



(a) Lysozyme molecule in a nonaqueous environment



(b) Lysozyme molecule (purple) in an aqueous environment



(c) Ionic and polar regions on the protein's surface attract water molecules.

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

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

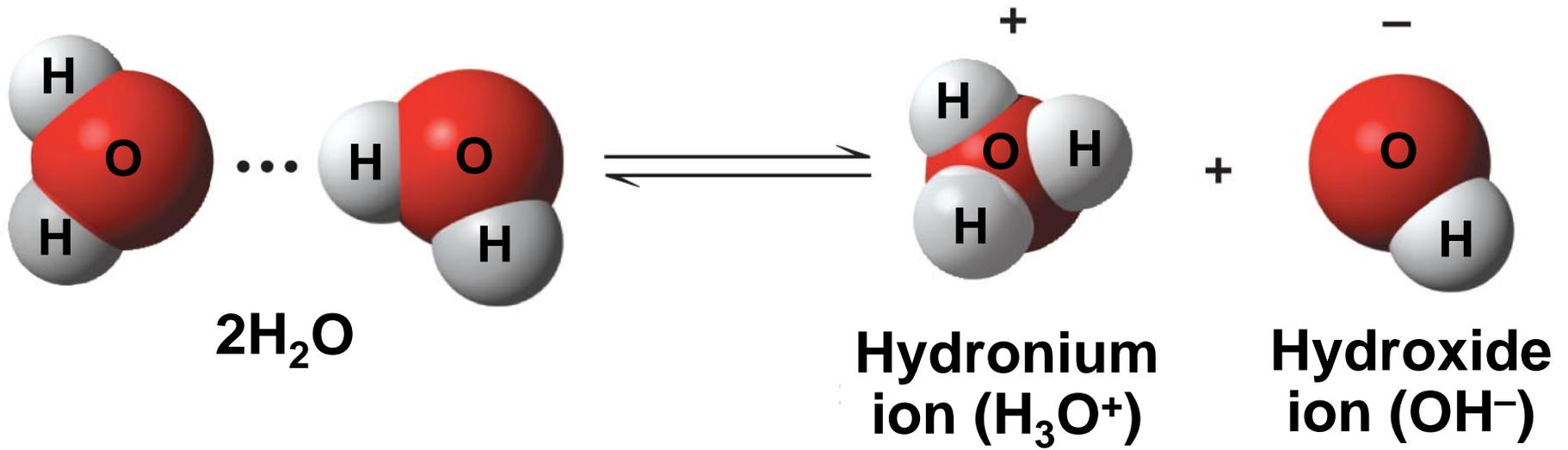
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- **Molecular mass** is the sum of all masses of all atoms in a molecule
 - Numbers of molecules are usually measured in moles, where 1 **mole (mol)** = 6.02×10^{23} molecules
 - Avogadro's number and the unit *dalton* were defined such that 6.02×10^{23} daltons = 1 g
 - **Molarity (*M*)** is the number of moles of solute per liter of 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 with the extra proton is now a **hydronium ion** (H_3O^+), though it is often represented as H^+
 - The molecule that lost the proton is now a **hydroxide ion** (OH^-)

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- Water is in a state of dynamic equilibrium in which water molecules dissociate at the same rate at which they are being reformed

Fig. 3-UN2



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- Though statistically rare, the dissociation of water molecules has a great effect on organisms
 - Changes in concentrations of H^+ and OH^- can drastically affect the chemistry of a cell

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^-
- 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

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

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

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

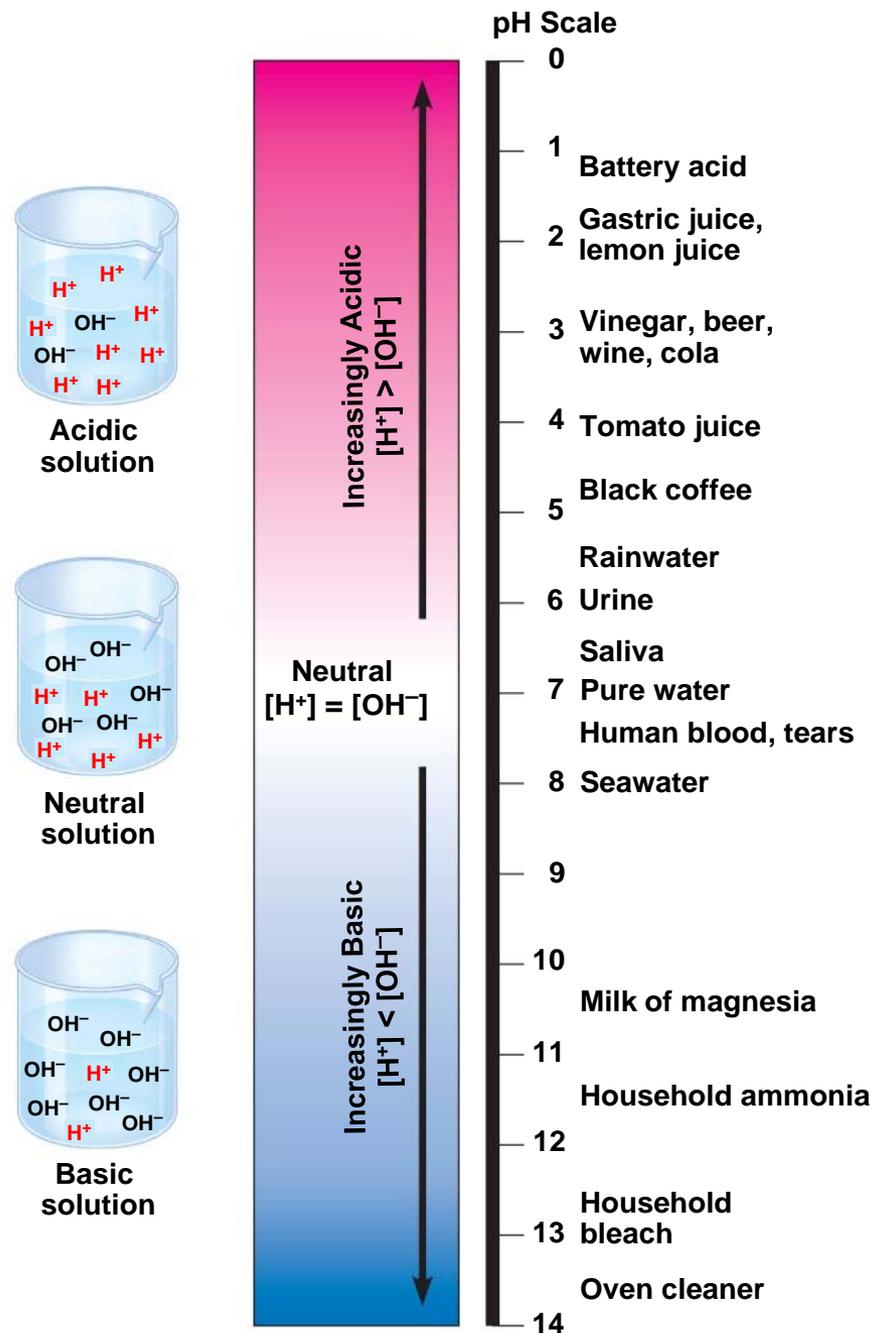
$$\text{pH} = -\log [\text{H}^+]$$

- For a neutral aqueous solution

$$[\text{H}^+] \text{ is } 10^{-7} = -(-7) = 7$$

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- 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

Fig. 3-9



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^+

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 with water in the air and can fall at some distance from the source of pollutants
- Acid precipitation can damage life in lakes and streams
- Effects of acid precipitation on soil chemistry are contributing to the decline of some forests

Acid precipitation and its effects on a forest



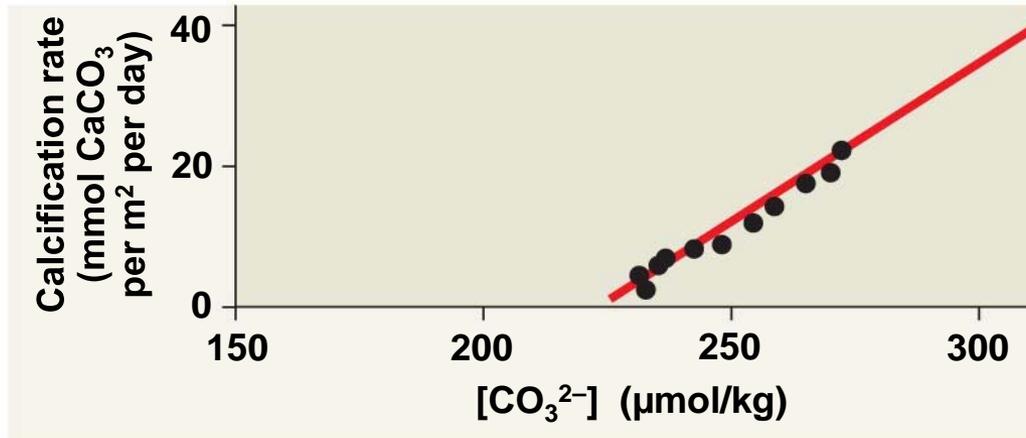
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- Human activities such as burning fossil fuels threaten water quality
 - CO₂ is released by fossil fuel combustion and contributes to:
 - A warming of earth called the “greenhouse” effect
 - Acidification of the oceans; this leads to a decrease in the ability of corals to form calcified reefs

Fig. 3-11



What is the effect of carbonate ion concentration on coral reef calcification?

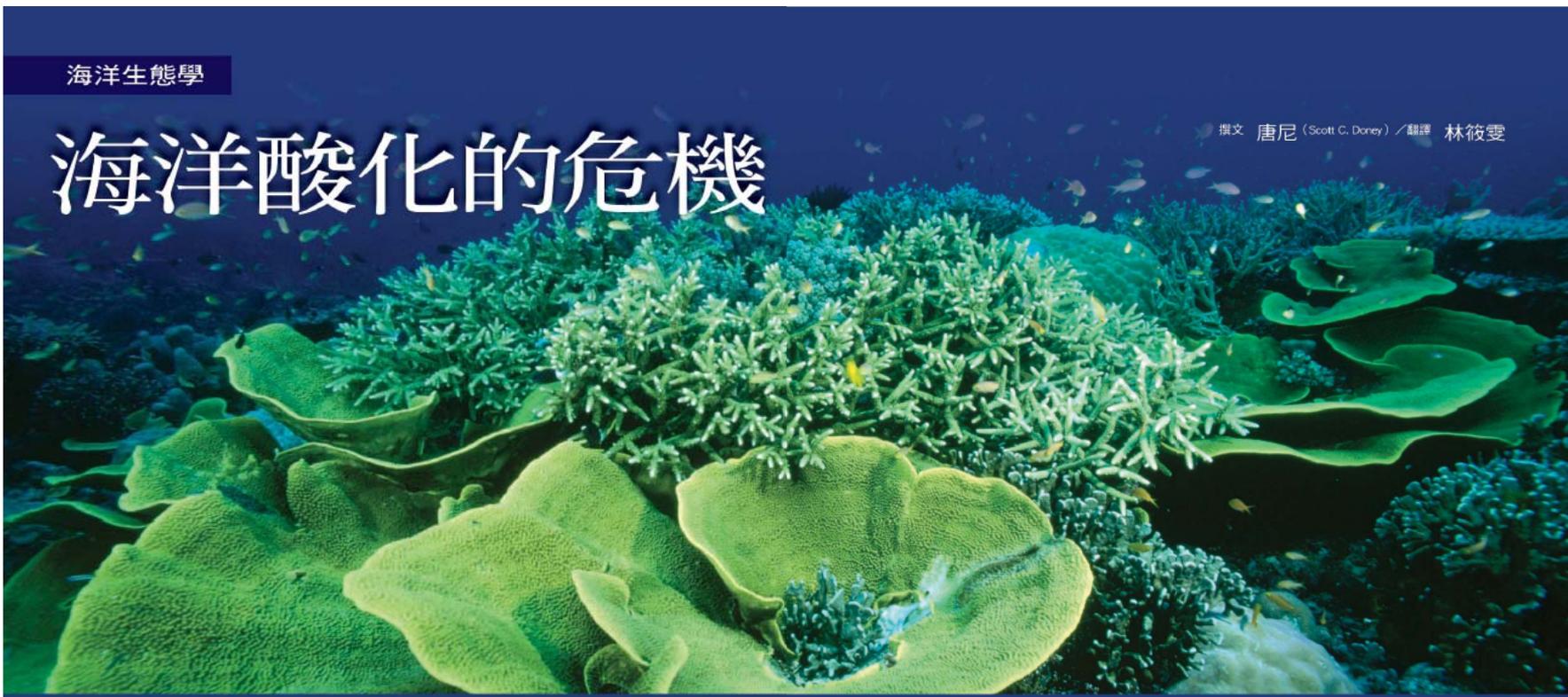
RESULTS



海洋生態學

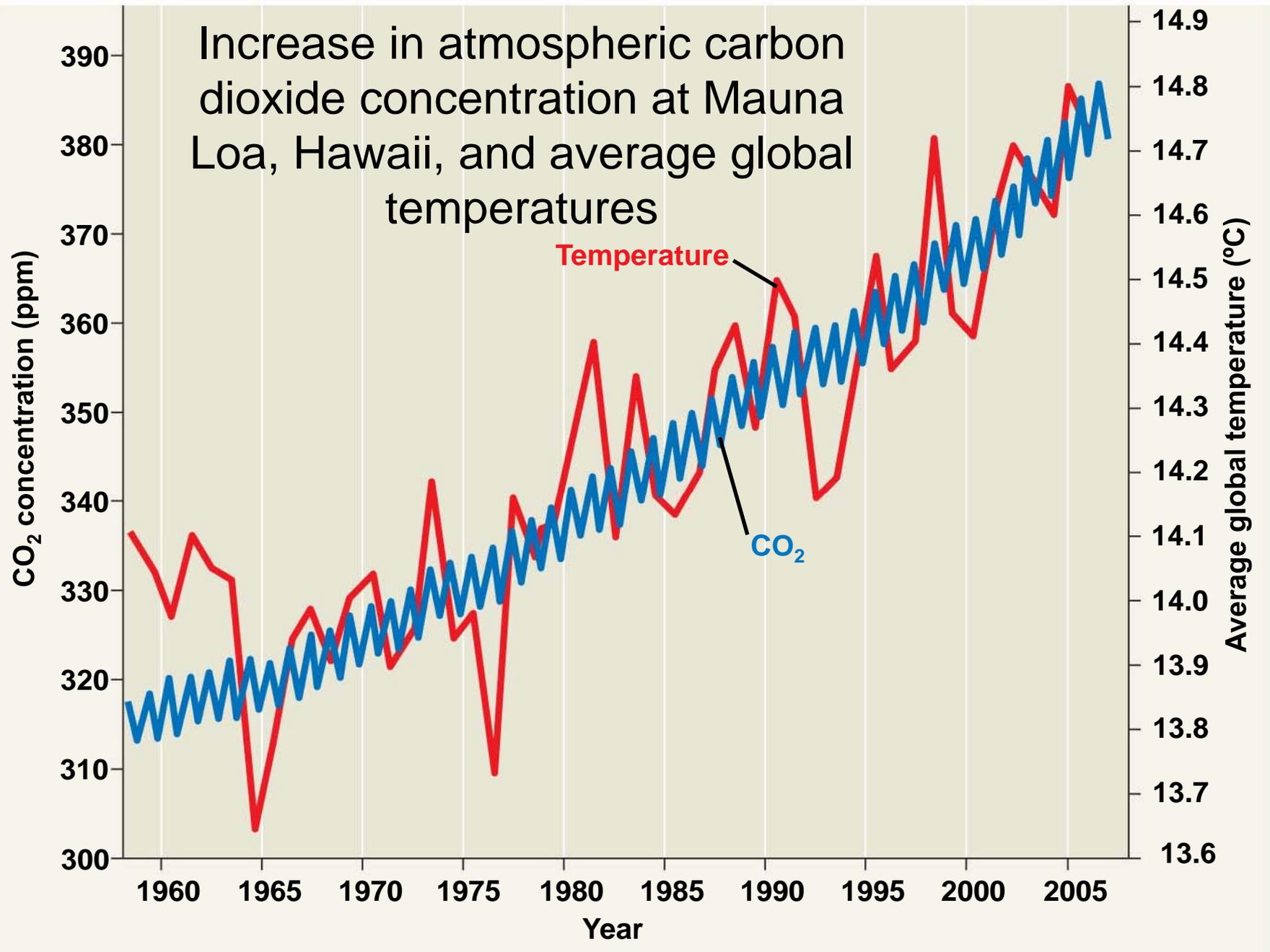
海洋酸化的危機

撰文 唐尼 (Scott C. Doney) / 翻譯 林筱雯



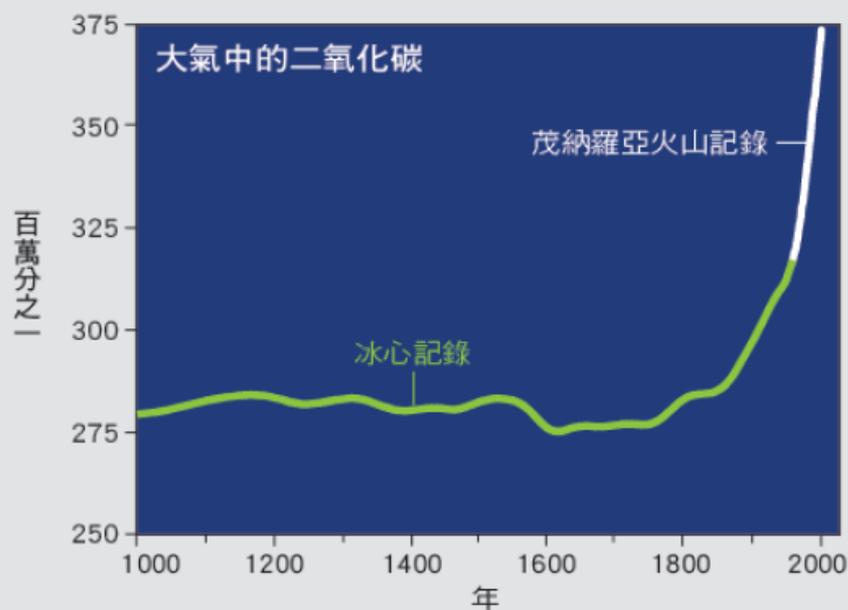
燃燒化石燃料產生的二氧化碳，大多由海洋吸收。它們改變了海水的酸平衡，對海洋生物影響重大。

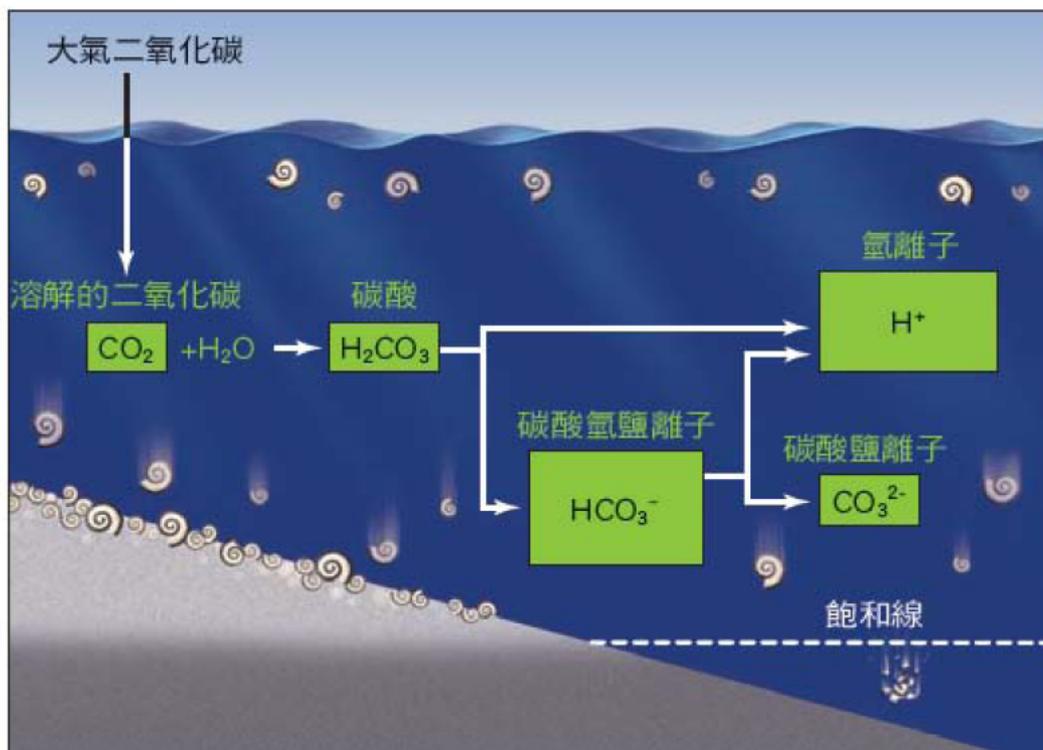
Fig. 55-21



過去一世紀左右，大氣中的二氧化碳濃度巨幅增加。科學家使用兩種觀測技術，記錄下這個驚人的趨勢（如右圖）。第一種是測量冰河的冰心內部殘留的氣泡（綠線，每一點都是前後75年的平均），另一種是直接測量大氣（白線，是夏威夷大島上茂納羅亞火山頂氣象站記錄的年平均）。

大氣二氧化碳的濃度已經很高，而且還在快速增加。但是，如果海洋沒有吸收其中的一大部份，二氧化碳濃度的成長速率會更加驚人。最近的海洋普查已經記錄到這個現象。下方的剖面圖顯示，目前，化石燃料的排放產物有一半在全球海洋上層。



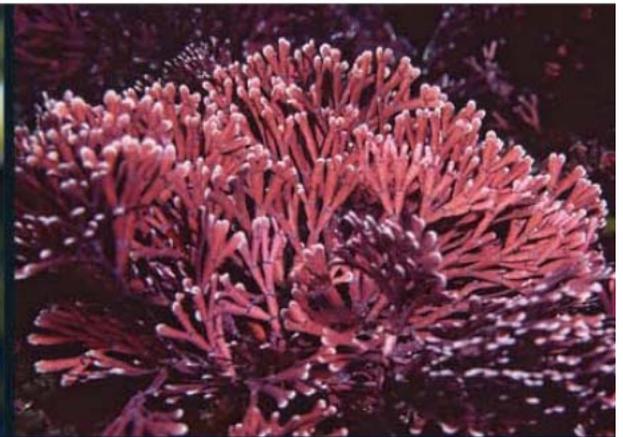


海洋吸收大氣裡的二氧化碳，跟水分子結合，形成碳酸。有少量碳酸保持原狀，但大多還是解離成氫離子跟碳酸氫鹽離子，讓海洋變酸。有些碳酸氫鹽離子會繼續解離，形成碳酸鹽離子與更多氫離子。這些化學變化導致方解石和霏石的「飽和線」向上移動。飽和線以下，海洋生物用這兩種碳酸鈣結晶製造的硬殼，會完全溶解。

受海洋酸化威脅的海洋生物包括珊瑚、珊瑚藻，在珊瑚礁聚落附近經常可以發現牠們；還有常見的有孔蟲和鈣板藻，這些生物在大部份淺水區的數量非常多。在極地冷水區，受到威脅的是一種小海螺，稱為翼足類。



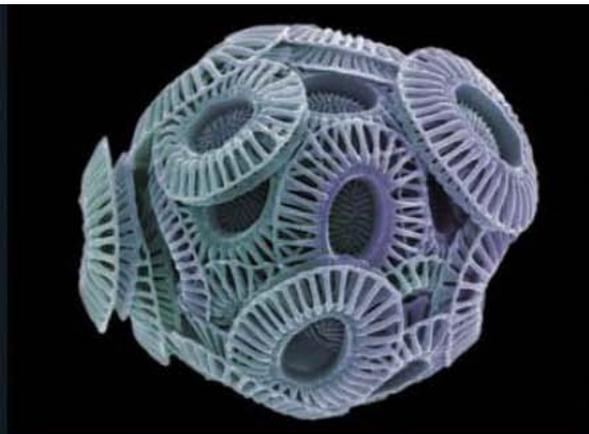
珊瑚 (*Millepora tenella*)



珊瑚藻 (*Amphiroa anceps*)



有孔蟲 (*Globigerina bulloides*)



鈣板藻 (*Emiliania huxleyi*)



翼足類 (*Limacina helicina*)

You should now be able to:

1. List and explain the four properties of water that emerge as a result of its ability to form hydrogen bonds
2. Distinguish between the following sets of terms: hydrophobic and hydrophilic substances; a solute, a solvent, and a solution
3. Define acid, base, and pH
4. Explain how buffers work