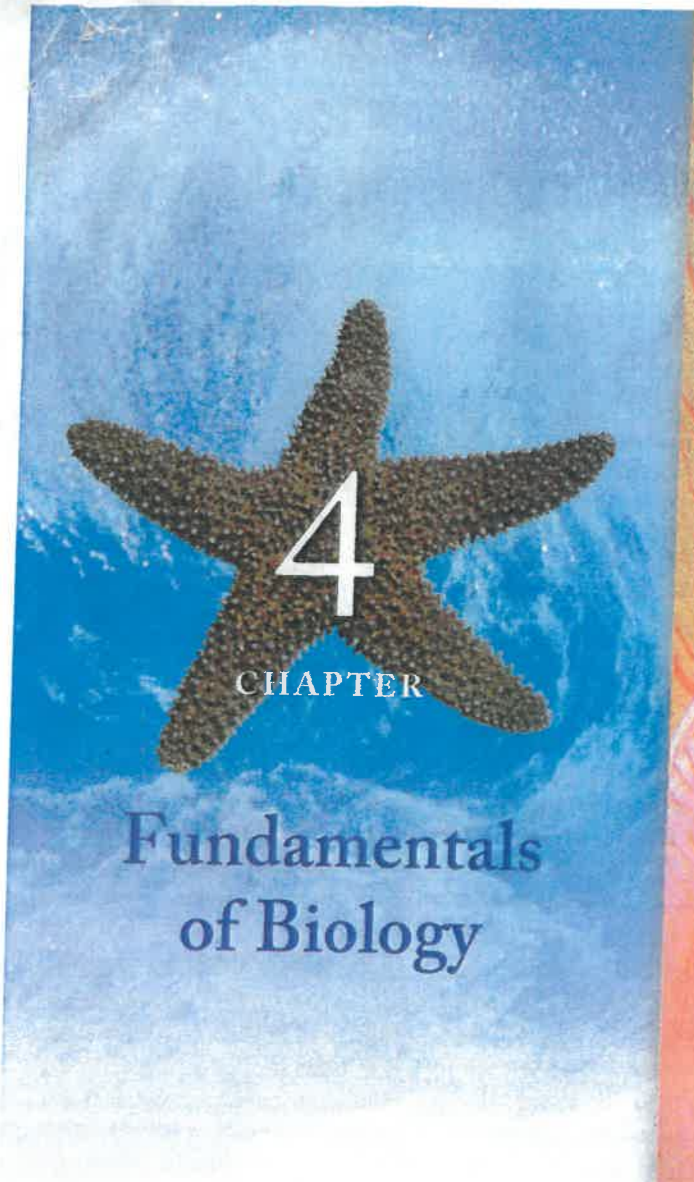
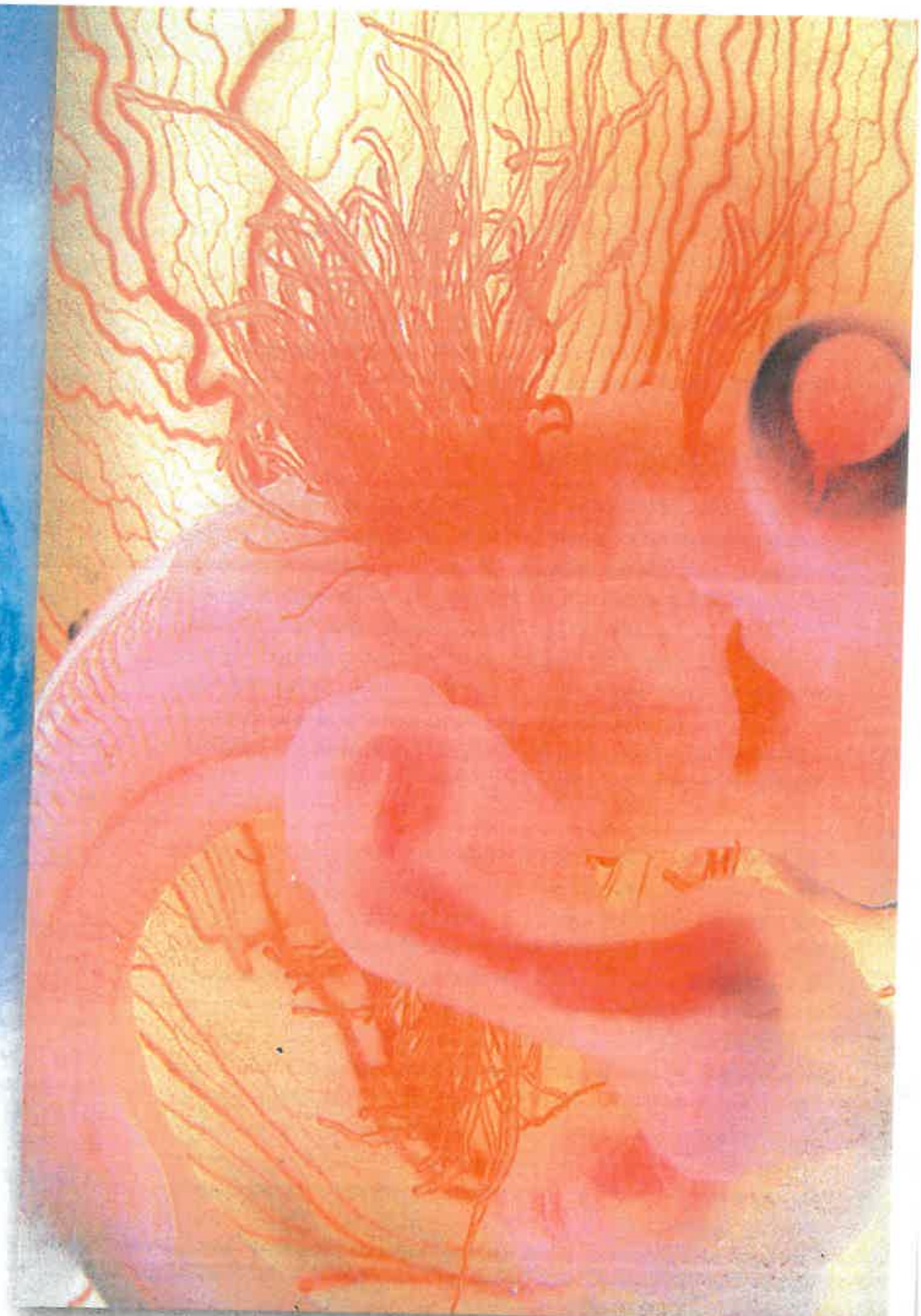


Chapter 4

Fundamentals of Biology



A shark (*Squalus acanthias*) embryo begins a new turn of the cycle of life.

Now that we have discussed some of the major features of the marine environment, we can turn our attention to life in the sea. Perhaps the most basic question of all is, What *is* life? Most people have a pretty good feel for what the word *living* means, but biologists have never been able to agree on a precise definition. The best we can do is describe the common properties of living things.

Organisms are not random collections of material, but have a precise chemical and physical **organization.** They all use **energy,** the ability to do work, to maintain themselves and grow. They do this through a vast number of chemical reactions that are collectively called **metabolism.** Living things also use energy to maintain stable internal conditions different from their surroundings, which is known as **homeostasis.** They can sense and react to their external environment. Finally, all life forms reproduce to perpetuate their kind, and use **nucleic acids** to record their individual characteristics and pass them on to their offspring (see "Nucleic Acids," p. 65).

All living things are physically and chemically organized, grow, metabolize, regulate their internal environment, react to the external environment, reproduce, and use nucleic acids to store genetic information.

The basic features of living things are shared by all organisms, not just those that live in the sea. Here, however, we will pay particular attention to marine organisms.

THE INGREDIENTS OF LIFE

Life requires an intricate series of interactions among an immense variety of chemicals. The most important of these is one of the simplest: **water.** As the universal solvent, water provides the medium in which all the other **molecules** dissolve and interact. Water is the base of a complex "chemical soup" inside all organisms where the chemical reactions of metabolism take place.

The Building Blocks

Besides water, most of the chemicals that make life possible are **organic compounds,** molecules that contain atoms of **carbon, hydrogen,** and usually **oxygen.** Organic compounds are high-energy molecules; that is, it takes energy to make them (Fig. 4.1). The ability to use energy to make, or **synthesize,** organic compounds is an important characteristic of living things. Organic compounds break down when left to themselves. When this happens they release the energy that went into their construction. Organisms have developed the ability to control this breakdown, often in order to harness the energy that is released.

Carbohydrates Most organic molecules belong to one of four main groups. **Carbohydrates** are composed mainly of only the basic elements of other organic molecules: carbon, hydrogen, and oxygen. The simplest carbohydrates are **glucose** and a few other **simple sugars.** More complex carbohydrates are formed by the combination of simple sugars into chains. Ordinary table sugar, for example, consists of two simple sugar molecules joined together. **Starches** and other complex carbohydrates consist of much longer chains, which may contain components other than simple sugars.

Organisms use carbohydrates in many ways. Simple sugars play a vital role in the most basic metabolic processes, as we will see. Organisms often use complex carbohydrates like starches to store energy reserves.

Some carbohydrates are **structural molecules,** which provide support and protection. For example, some animals use **chitin,** a modified carbohydrate, as a skeletal material. Plants and many algae produce a structural carbohydrate called **cellulose,** the main ingredient of wood and plant fibers (see Table 6.1, p. 113). Other carbohydrates have roles in reproduction, metabolism, and interactions among cells—in fact, in nearly every biological function—that scientists are only beginning to understand.

Proteins **Proteins** are another major group of organic molecules. Like complex carbohydrates, proteins are composed of chains of smaller subunits. In proteins the subunits are **amino acids,** which contain **nitrogen** as well as the carbon, hydrogen, and oxygen typical of all organic compounds.

Proteins have an extraordinary variety of functions. Muscles are made largely of protein. **Enzymes** are proteins that speed up, or **catalyze,** specific chemical reactions. Without enzymes, most metabolic reactions would proceed very slowly or not at all. There are also many structural proteins, including those in the skin, hair, and skeletons of some marine animals. Some **hormones,** chemicals that act as messengers to help different parts of the body work together, are proteins. Other proteins carry oxygen in the blood and muscles. Proteins also act as poisons, send chemical signals, produce light, act as antifreeze in the blood of some Antarctic fishes, and have countless other functions.

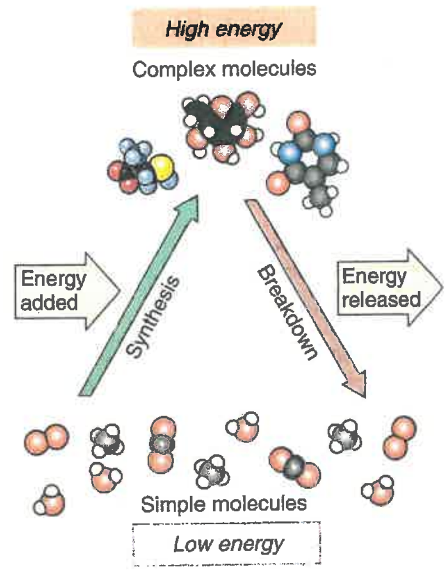


FIGURE 4.1 Chemical reactions can be divided into those that require energy and those that release it. Organisms need energy to make complex molecules from simple ones, much as energy is required to push a rock uphill. The breakdown of energy-rich complex molecules is a "downhill" process that releases energy.

Lipids Fats, oils, and waxes are examples of **lipids,** another group of organic chemicals. Lipids are often used for energy storage (Fig. 4.2). Another useful property of lipids is that they repel water: Many marine mammals and birds use a coating of oil to keep their fur or feathers dry. Some marine organisms that are exposed to the air at low tide have a coating of wax that helps keep them from drying out. Lipids also provide buoyancy because they float, and insulation from the cold. Some hormones are lipids rather than proteins.

Nucleic Acids **Nucleic acids** store and transmit the basic genetic information of life. Nucleic acid molecules are chains of subunits called **nucleotides,** which consist of a simple sugar joined to molecules, called **nitrogen bases,** that contain phosphorus and nitrogen. One type of nucleic acid is **DNA (deoxyribonucleic acid).** In most organisms, DNA molecules specify the organism's "recipe"—all the instructions for its construction and maintenance. An organism's complete genetic information is called its **genome.** The organism inherits this genetic information, in the form of DNA, from its parents and passes it on to its offspring. The DNA chains are often tens or hundreds of millions of nucleotides long, but the nucleotides contain only four different types of nitrogen bases: adenine, cytosine, thymine, and guanine.

Water is called the **universal solvent** because it can dissolve more different substances than any other liquid.

• Chapter 3, p. 43

Molecules Combinations of two or more *atoms;* most substances are composed of molecules rather than individual atoms.

• Chapter 3, p. 41

FIGURE 4.2 The thick layers of blubber on this whale are composed almost entirely of lipid. Whales can go without eating for long periods by using the energy stored in the blubber. The whale's blubber also helps protect it from the cold and gives it buoyancy. People once used the energy contained in blubber by burning oil made from it for light and heat. Most industrial whaling has ceased but so-called traditional whaling, such as that undertaken by these Alaskan Inuit, continues legally in some places.

The **sequence** of the different nucleotides on the chain forms a code, like a four-letter alphabet, that contains the genetic information. Four letters doesn't sound like much, but Morse code can record messages using only two: dots and dashes. DNA's "words" are **genes,** sequences of DNA that specify the order of amino acids in a single protein.

Another group of nucleic acids is **RNA (ribonucleic acid).** Like DNA, RNA consists of chains of only four types of nucleotides. Three are the same as in DNA, but the fourth nucleotide in RNA is uracil instead of thymine. Some RNA molecules act as intermediaries in converting the information stored in DNA into proteins, and in some microbes RNA stores the information itself. For decades these were thought to be the only roles for RNA, but we now know that RNA influences many if not most biochemical processes. Small RNAs regulate the expression of genes stored in DNA into proteins, trigger immune responses and defend against viral infections, regulate embryonic development, and catalyze reactions much as enzymes do. Discovery of the critical and widespread roles of RNA ranks among the most exciting discoveries in biology in decades, and has triggered a wave of new research, including many possible applications in medicine.

FIGURE 4.3 Giant kelp (*Macrocystis*), a seaweed from the temperate Pacific Ocean, captures the sunlight streaming down through the water to perform photosynthesis. The kelp uses the light energy to grow. Other organisms eat the kelp, making use of the energy that originally came from the sun.

Because organisms' nucleic acids define so much about them, determining their nucleotide sequences has become one of the hottest fields of biological research. Complete genome sequences are known for only a small but increasing number of organisms, most notably humans. Partial nucleic acid sequences are available for many more organisms and contain a wealth of information. These sequences can be used as genetic "bar codes" to identify species, including ones that have never been collected, and shed light on details of their metabolism and lifestyle (see "Tiny Cells, Big Surprises," p. 92).

Organic compounds are chemicals that contain carbon, hydrogen, and usually oxygen. The main types of organic compounds are carbohydrates, proteins, lipids, and nucleic acids.

The Fuel of Life

The molecules that make up living things interact in many complex chemical systems. The most basic of these have to do with the capture, storage, and use of energy or, more simply put, with the production and use of food. These systems store and transfer energy using **ATP (adenosine triphosphate)** as a common "energy currency." ATP is a high-energy molecule based on adenosine, one of the nucleotides in nucleic acids. Energy is stored as chemical energy by converting a related but lower-energy molecule, **ADP (adenosine diphosphate),** into ATP. When the ATP is broken back down into ADP the energy is transferred to other molecules to be used in metabolism. In an average day a person cycles through 57 kg (125 lb) of ATP. Whales must use tons!

Organisms transfer energy between different molecules using ATP (adenosine triphosphate), the energy currency of life.

Microorganisms use a variety of metabolic pathways to process energy (see Table 5.1, p. 87). Most other organisms, however, largely rely on only two: photosynthesis and respiration.

Photosynthesis: Making the Fuel

Most organisms ultimately get their energy from the sun (Fig. 4.3). In **photosynthesis,** algae, plants, and some other organisms capture the sun's energy and use it to make glucose, a simple sugar, some of which is converted into other organic compounds. Most other organisms use these organic molecules as a source of energy. Organic material

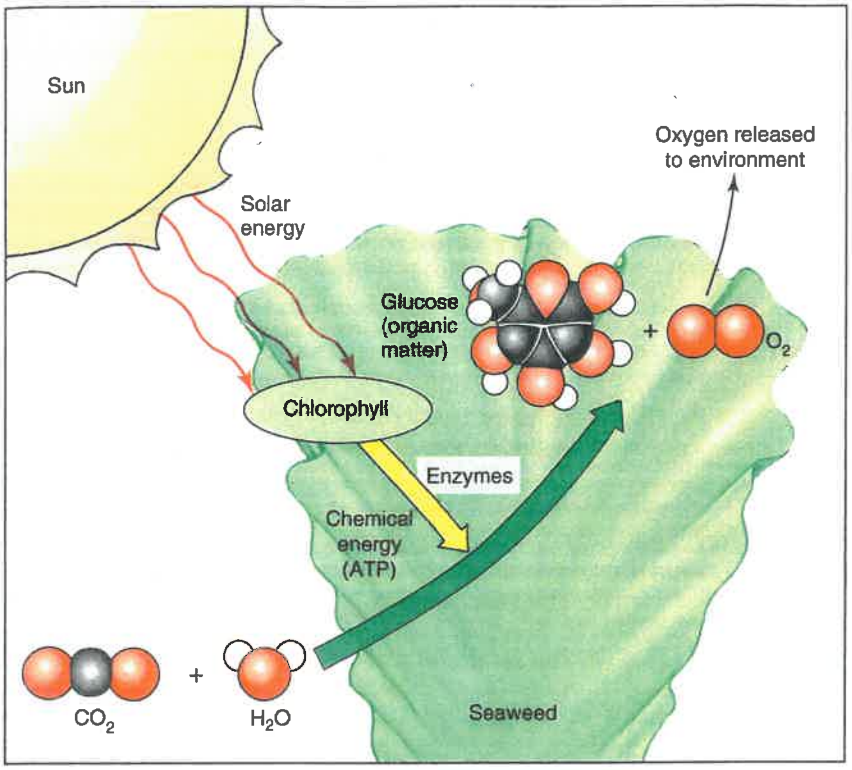


FIGURE 4.4 In photosynthesis, carbon dioxide and water are used to make glucose. The energy for this process comes from sunlight. Oxygen is given off as a by-product.

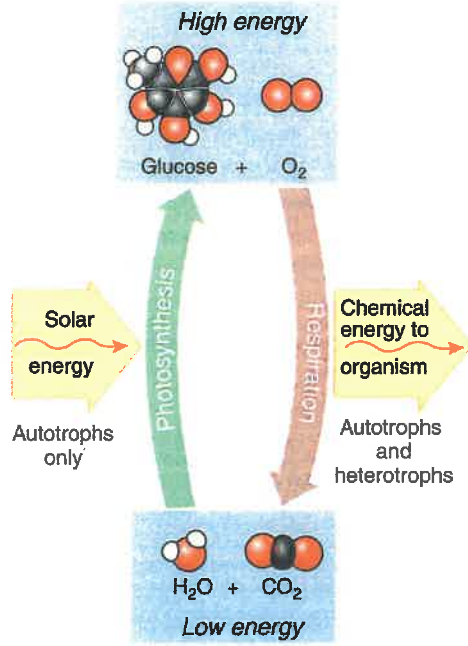


FIGURE 4.5 Respiration is basically the opposite of photosynthesis. Respiration breaks down glucose, using oxygen, and produces carbon dioxide and water. The energy that originally came from the sun is then made available to the organism.

contains a tremendous amount of energy. As food it fuels our bodies and those of most other creatures. In such forms as oil, gas, and coal, it heats our homes, runs our factories, and powers our cars.

Photosynthesis (Fig. 4.4) begins when an organism absorbs solar energy, sunlight, with chemicals called **photosynthetic pigments.** The most common photosynthetic pigment is **chlorophyll,** which gives plants their characteristic green color. Most algae have additional pigments that often mask the green chlorophyll (see Table 6.1, p. 113). Because of these pigments, algae may be brown, red, or even black instead of green.

In a long series of enzyme-controlled reactions, solar energy captured by chlorophyll and other pigments is converted into chemical energy, in the form of ATP, and then used to make glucose, with **carbon dioxide** (CO_2) and water (H_2O) as the raw materials. Carbon dioxide is one of very few carbon-containing molecules not considered to be an organic compound. Photosynthesis, then, converts carbon from an inorganic to an organic form. This is called **fixing** the carbon, or **carbon fixation.** The solar energy absorbed by chlorophyll is stored as chemical energy in the form of glucose. The glucose is then used to make other organic compounds (see "Primary Production," p. 68). ATP may be the "energy currency" of the cell, but fixed carbon—organic matter—is the "currency" in which energy flows through food webs and ecosystems.

Photosynthesis produces **oxygen gas** (O_2), as a by-product. All the oxygen gas on Earth, in the atmosphere we breathe and in the ocean, was produced by photosynthetic organisms, which constantly replenish Earth's oxygen supply. We rely on photosynthesis not only for food, but for the air we breathe.

Photosynthesis captures light energy from the sun to produce glucose. Carbon dioxide and water are used to make the glucose, and oxygen gas is liberated as a by-product:

$$H_2O + CO_2 \xrightarrow{\text{sun energy}} \underset{\text{(glucose)}}{\text{organic matter}} + O_2$$

Organisms that are capable of photosynthesis can obtain all the energy they need from sunlight and don't need to eat. They are called **autotrophs** ("self-feeders"). Plants are the most familiar autotrophs on land. In the ocean, however, bacteria and algae are the most important autotrophs.

Many organisms cannot produce their own food and must obtain energy from organic matter produced by autotrophs. These organisms, including all animals, are called **heterotrophs.**

Respiration: Burning the Fuel Both autotrophs and heterotrophs perform **respiration** to use the solar energy stored in organic chemicals by photosynthesis. The chemical reactions are different, but the net result of oxygen-dependent, or **aerobic,** respiration is essentially the reverse of photosynthesis (Fig. 4.5). Sugars are broken down using oxygen, and carbon dioxide and water are given off. This process is sometimes called cellular respiration to distinguish it from the physical act of breathing. Since breathing acts to provide oxygen for cellular respiration, the two are related.

Respiration, which occurs in nearly all organisms, breaks down glucose, releasing the energy it contains. Respiration consumes oxygen and produces carbon dioxide and water:

$$\underset{\text{(glucose)}}{\text{organic matter}} + O_2 \longrightarrow CO_2 + H_2O \quad \text{(chemical energy)}$$

Cellular respiration is similar to burning wood or oil in that organic material is broken down, oxygen is consumed, and energy is released. That's why dieters talk about "burning calories." In respiration, however, the energy in organic material is not released in flames. Instead, it is stored in ATP.

If oxygen isn't available, many organisms can use a different form of respiration called **anaerobic** respiration. Anaerobic respiration does not require oxygen, but it isn't as efficient as aerobic respiration and provides less energy to the organism. Many animals temporarily switch to anaerobic respiration, however, when extreme exertion depletes the oxygen in their muscles and blood. Some organisms that live in oxygen-depleted environments, like muddy sediments or the guts of fishes, use anaerobic respiration all the time. Aerobic respiration is much more widespread than anaerobic respiration, however, and in this text the general term "respiration" refers to aerobic, or oxygen-dependent, respiration.

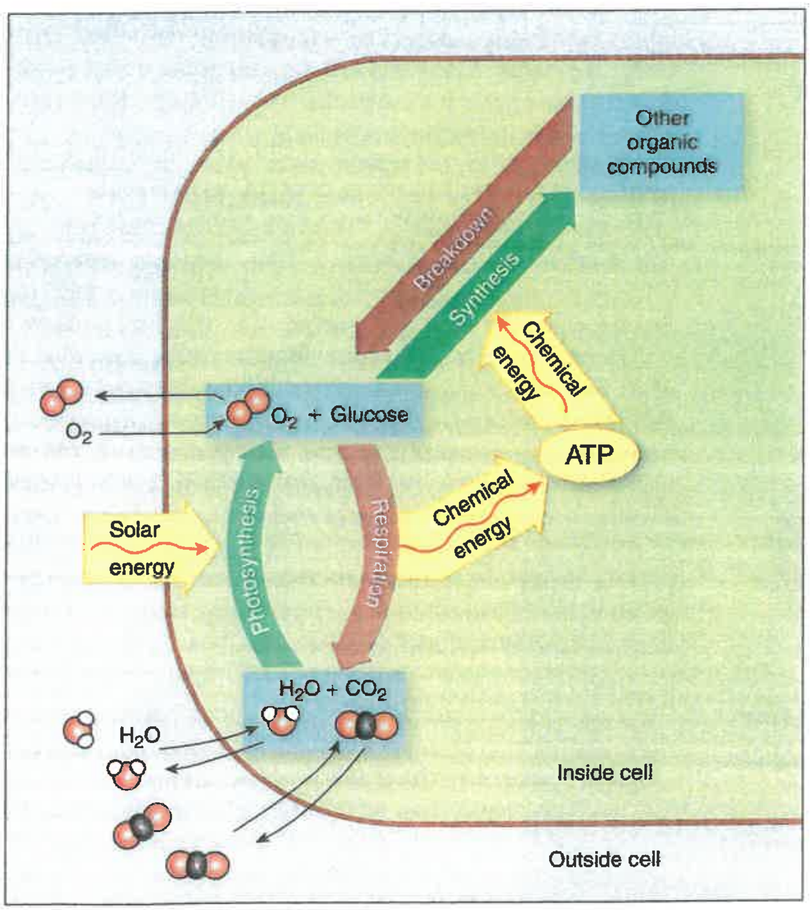


FIGURE 4.6 In photosynthesis, autotrophs capture energy from the sun and store it as chemical energy in simple sugars like glucose. Some of the sugars are broken down in respiration, and the energy is stored in ATP. This makes the energy available to the rest of the organism's metabolism—for example, to make other organic matter from the remaining glucose. If there is no light, autotrophs can perform only respiration, like animals and other heterotrophs. The thin black arrows represent molecules moving in and out of the cell.

Primary Production The sugars produced by photosynthesis supply both raw material and energy, via respiration, for the manufacture of other organic compounds. Through elaborate chemical processes, some of the glucose formed during photosynthesis is converted into other types of organic molecules—carbohydrates, proteins, lipids, and nucleic acids (Fig. 4.6). The energy for these conversions, in the form of ATP, comes from metabolizing much of the rest of the glucose. Thus, most of the glucose produced by photosynthesis is either converted to other organic compounds or respired to fuel this conversion.

When autotrophs produce more organic matter than they use in respiration, there is a net increase in organic matter. This is called **primary production.** Autotrophs use the extra organic material to grow and reproduce. In other words, the extra organic matter forms more living material, which means more food for animals and other heterotrophs. Organisms that perform this primary production of food are called **primary producers,** or sometimes just **producers.**

Primary production is the net gain in organic matter that occurs when autotrophs make more organic matter than they respire, usually by photosynthesis.

The Importance of Nutrients Only carbon dioxide, water, and sunlight are needed to make glucose by photosynthesis, but additional materials are needed to convert the glucose into other compounds. These raw materials, called **nutrients,** include minerals, vitamins, and other substances. Primary producers use large amounts of nitrogen, which is needed to make proteins, nucleic acids, and other compounds. **Nitrate (NO_3^{-1})** is the most important form of nitrogen in the ocean (see "Cycles of Essential Nutrients," p. 226). Phosphorus, needed to make ATP and nucleic acids among other compounds, is another important nutrient. Its main source is **phosphate (PO_4^{-2}). Diatoms, radiolarians,** and **silicoflagellates** require large amounts of **silica (SiO_2)** to make their shells. Another important nutrient is **iron** in various forms. Although needed in much smaller amounts than nitrogen, phosphorus, or silica, iron is in critically short supply in large parts of the ocean (see "Nutrients," p. 350).

Primary production by photosynthesis requires nutrients as well as light. Nitrogen, phosphorus, silica, and iron are the most important nutrients in the ocean.

LIVING MACHINERY

The chemical reactions of metabolism make life possible, but chemical reactions are not living things and organisms are not just bags of chemical soup. If you ran a fish through a blender, you would have all the same molecules but the fish would definitely not be alive. The molecules in living things are *organized* into structural and functional units that work in a coordinated way. It is this living machinery that is responsible for many of the properties of living things.

Cells and Organelles

The basic structural unit of life is the **cell.** All organisms are made of one or more cells. Cells contain all the molecules needed for life packaged in a living wrapper called the **cell membrane,** or **plasma membrane.** This membrane isolates the gelatinous contents of the cell, or **cytoplasm,** from the outside world. The cell membrane allows some substances to pass in or out but prevents others from doing so.

There are a number of structures within the cytoplasm. Among the most important are membranes similar to the outer cell membrane. These interior membranes act as sites for such chemical processes as photosynthesis and respiration. Membranes may also divide the cell into compartments that enclose still more complex structures specialized for particular tasks. These membrane-bound structures are known as **organelles.**

Cells also have a complex internal framework made of protein fibers. This framework, called the **cytoskeleton,** supports the cell, allows it to move and change shape, and helps it divide.

Structurally Simple Cells: Prokaryotes **Prokaryotic cells** are primitive in the sense that they are the most ancient of the two major types of cells. They are also the structurally simplest and smallest cells. Prokaryotic cells are distinguished by the absence of most kinds of organelles (Fig. 4.7), though some prokaryotes do have certain organelles or organelle-like structures and recent research has revealed a more complex cytoskeleton than was previously known. Organisms with prokaryotic cells are called **prokaryotes. Bacteria** are the best known group of prokaryotes. **Archaea** are the second prokaryotic group. Most prokaryotes are microscopic, and most are tiny even by the standards of microscopic organisms, but there a few giant bacteria that can be seen with the naked eye.

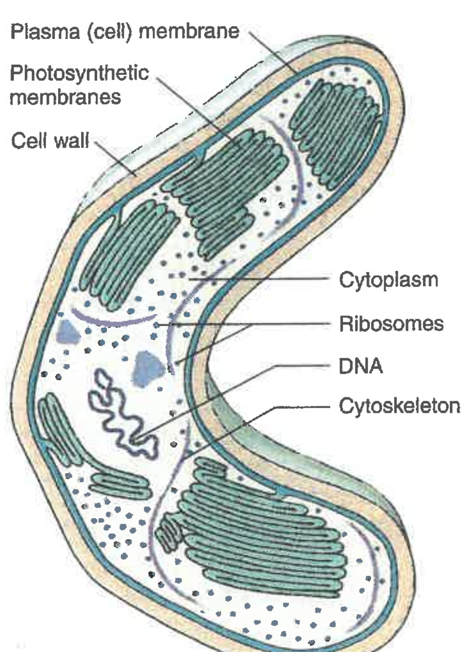


FIGURE 4.7
Prokaryotic cells have a plasma membrane lying inside a cell wall. The plasma membrane is where respiration occurs and may fold into the cell's interior. Membrane folding is particularly pronounced in photosynthetic bacteria like this one. The folds contain chlorophyll and are the site of photosynthesis. Prokaryotic cells also contain scattered ribosomes and a ring-like molecule of DNA. Otherwise there is relatively little structure inside the cell.

Outside the cell membrane of prokaryotes lies a supportive **cell wall.** Inside, the cell has a single, ring-like molecule of DNA. Attached to the cell membrane and scattered through the cytoplasm are small structures made of protein and RNA called **ribosomes** that make the cell's proteins. In photosynthetic prokaryotes, folds of the plasma membrane contain photosynthetic pigments. Some prokaryotes have one or more protein filaments known as **flagella** (singular, **flagellum**) that extend outside the cell membrane. These cells move by rotating their flagella like tiny propellers.

The structurally simplest cells are prokaryotic. They have relatively little internal structure and lack most kinds of membrane-bound organelles.

Structurally Complex Cells: Eukaryotes **Eukaryotic cells,** the second major cell type, are more organized and complex than prokaryotic cells (Fig. 4.8). Various membrane-bound organelles found only in **eukaryotes** do specialized jobs within the cell. The **nucleus** contains **chromosomes** that carry most of the cell's DNA. The nucleus thus holds the cell's genetic information and directs most of its activities. The nucleus can be thought of as the cell's headquarters.

The "factories" of eukaryotic cells are two structures, mostly folded membranes, called the **endoplasmic reticulum** and the **Golgi apparatus.** These organelles make, package, and transport many of the organic molecules that the cell needs. Ribosomes sit in some of the endoplasmic reticulum.

Respiration in eukaryotes takes place in **mitochondria.** Mitochondria are the cell's power plants, breaking down organic molecules to provide energy. Plant and algal cells have two important structures that animals don't. First, they have **chloroplasts,** chlorophyll-containing organelles where photosynthesis takes place. Second, except for some single-celled algae, they have a cell wall.

Eukaryotic cells often have flagella, which are called **cilia** when they are short and numerous. Eukaryotic flagella and cilia differ from prokaryotic flagella in being enclosed in a membrane, having a more complex structure, and beating back and forth instead of rotating. Some eukaryotes use their flagella or cilia to swim, as prokaryotes do, but many eukaryotes use flagella and cilia to push water and particles through or over their bodies instead of pushing their bodies through the water. Many marine animals, for example, use cilia to push food particles to the mouth. Cilia in your lungs carry away dust and other irritants.

The cells of eukaryotes are more structured than those of prokaryotes. They have membrane-bound organelles, including a nucleus in which the DNA is carried in chromosomes.

Diatoms Single-celled algae with a shell, or test, made of silica.
• Chapter 5, p. 94, Figure 5.6

Radiolarians Single-celled protozoans with a test made of silica.
• Chapter 5, p. 98, Figure 5.12

Silicoflagellates Single-celled algae with a skeleton made of silica.
• Chapter 5, p. 96, Figure 5.9

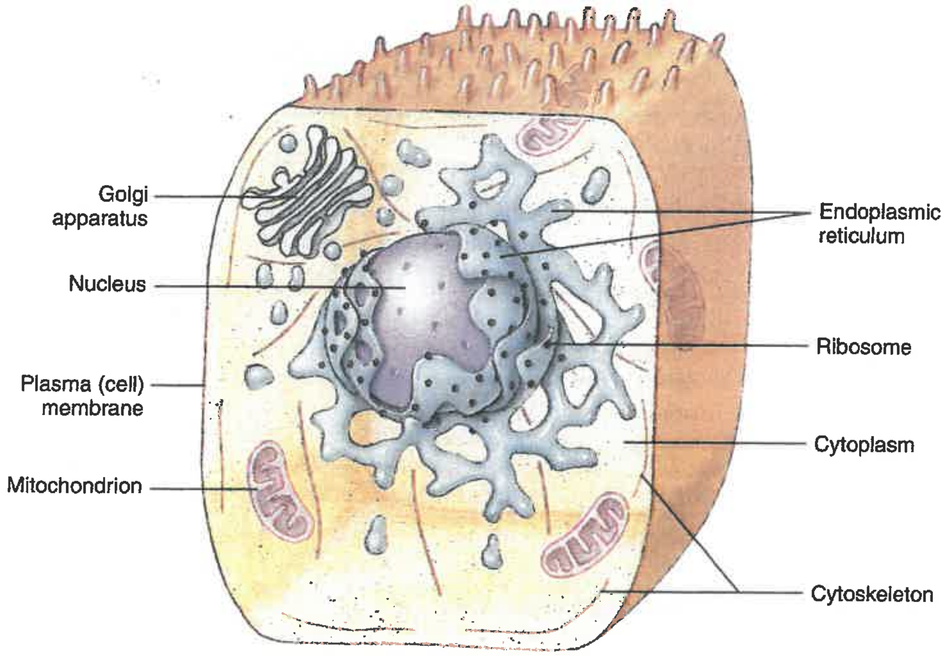


FIGURE 4.9 Sponges are the only multicellular animals that are at the cellular level of organization (see "Sponges," p. 116). Even sponges have specialized cells, though they don't form tissues.

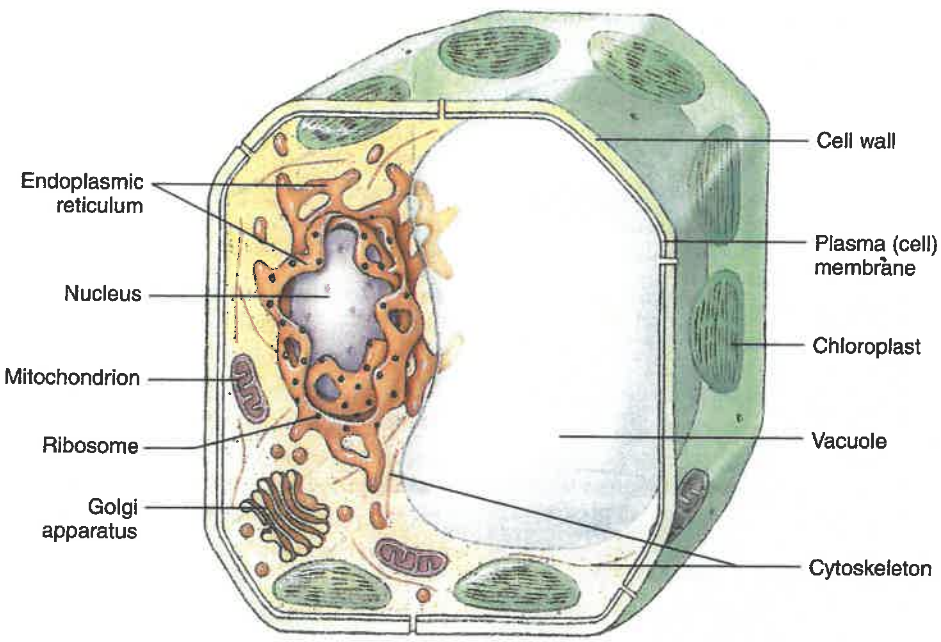


FIGURE 4.8 Typical cells of (*a*) animals and (*b*) algae and plants, and some of the structures they contain.

Levels of Organization

A cell is a self-contained unit that can carry out all the functions necessary for life. Indeed, many organisms get by just fine with only a single cell. One-celled organisms are called **unicellular. Multicellular** organisms have more than one cell. The human body, for instance, contains something like 100 trillion cells. In multicellular organisms the cells interact and communicate, and cells become specialized for particular jobs. Nearly all prokaryotes are unicellular, but some bacteria group together, interact, and specialize for specific functions in ways that border on multicellularity. Many eukaryotes are unicellular, but the majority are multicellular.

In multicellular organisms, specialized cells that perform the same task may be organized into more complex structures. The extent of specialization and organization is referred to as the **level of organization** (Table 4.1).

At the **cellular** level of organization, each cell is essentially an independent, self-sufficient unit. It can perform all the functions needed to sustain itself and reproduce, and there is little or no cooperation among cells.

Only a few multicellular organisms remain at the cellular level (Fig. 4.9). In most, groups of cells act together to do a particular job. These specialized, coordinated groups of cells are called **tissues.** Cells that are specialized to contract and do work, for example, are bound together to form muscle tissue. Nervous tissue, specialized to collect, process, and transmit information, is another example.

In most animals, organization doesn't stop at the tissue level. Their tissues are further organized into **organs** that carry out specific functions. The heart is an example of an organ. There are several different tissues that make up the heart. Muscle tissue, for example, allows the heart to contract and pump blood, and nervous tissue controls the muscle.

Different organs act together in **organ systems.** The digestive system, for instance, includes many organs: mouth, stomach, intestine, and so on. Animals usually have a number of organ systems, including nervous, digestive, circulatory, and reproductive systems.

Table 4.1 Levels of Organization of Biological Systems

(Increasing complexity ↑)

Level	Description	Examples	
Ecosystem	A community or communities in a large area, together with their physical environment	Nearshore ecosystem	One or more organisms
Community	All the populations in a particular habitat	Rocky shore community	
Population	A group of organisms of the same species that occur together	All the mussels on a stretch of rocky shore	
Individual	A single organism	One mussel	
Organ system	A group of organs that work in cooperation	Digestive system	Within individual organisms
Organ	Tissues organized into structures	Stomach	
Tissue	Groups of cells bound together and specialized for the same function	Muscle tissue	
Cell	Independent cells, the fundamental unit of living things	Muscle cell, single-celled organisms	
Organelle	A complex structure within cells, bound by a membrane	Nucleus, mitochondrion	Within cells
Molecule	Combinations of atoms that are bound together	Water, proteins	
Atom	The fundamental unit of all matter	Carbon, phosphorus	

Complex organization also exists at levels above the individual organism. A **population** is a group of organisms of the same kind, or **species,** that lives in one place. Mussels on a stretch of rocky shore, for example, form a population (Fig. 4.10).

Populations of different species that occur in the same place form **communities.** A community is more than just a collection of organisms that happen to use the same habitat. The characteristics of communities are determined by the way the organisms *interact*—which organisms eat each other, which compete, and which depend on each other (see "Ways That Species Interact," p. 213). Rocky shores, for example, are home to many organisms in addition to mussels: seaweeds, crabs, barnacles, snails, and sea stars, to name a few (Fig. 4.11). It is the interactions among all these organisms that give the rocky shore community its own unique structure.

FIGURE 4.10 These blue mussels (*Mytilus edulis*) growing on a rocky shore in New Zealand are part of a population.

A community, or often several communities, together with the physical, or non-living, environment, make up an **ecosystem.** The rocky shore community, for instance, along with other nearby communities, is part of a larger ecosystem that includes the tides, currents, nutrients dissolved in the water, and other physical and chemical aspects of the area.

CHALLENGES OF LIFE IN THE SEA

Every **habitat** has its own unique set of characteristics and presents special challenges to the organisms that live there. Marine organisms must cope with problems unlike those of land dwellers. Even within the marine environment there are different habitats, each of which poses special difficulties. **Planktonic** organisms—those that drift in the water—face very different conditions than **benthic** organisms—those that live on the bottom—or **nekton**—organisms that are strong swimmers (see Fig. 10.11). Organisms have evolved innumerable ways to adapt to the conditions of their habitats.

Many adaptations of marine organisms have to do with maintaining homeostasis. The living machinery inside most organisms is sensitive and can operate properly only within a narrow range of conditions. Living things have therefore evolved ways to keep their internal environments within this range regardless of the external conditions.

Habitat The natural environment where an organism lives.
• Chapter 2, p. 18

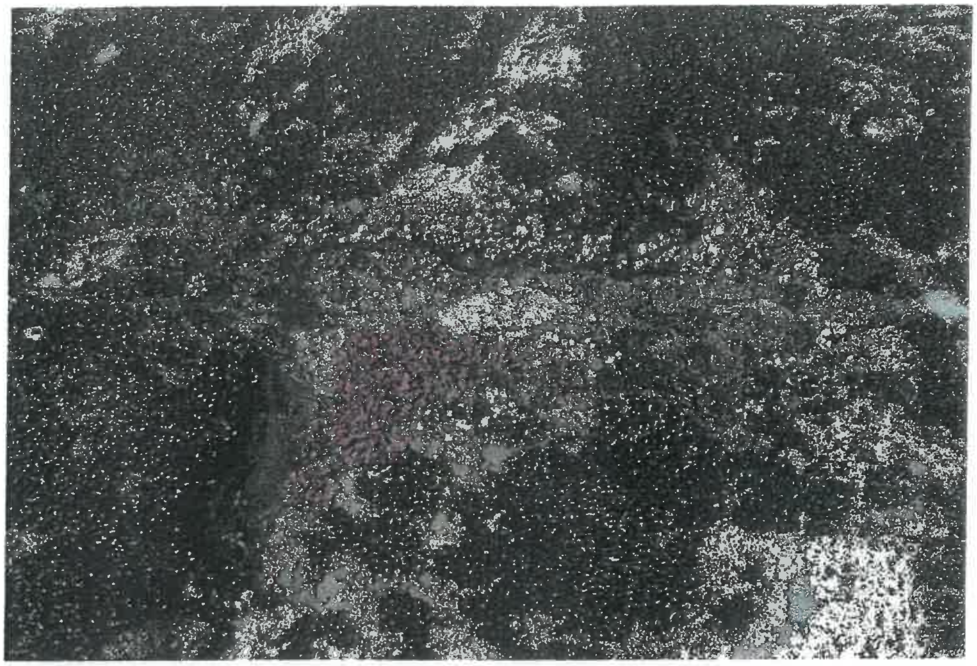


FIGURE 4.11 The community that lives on this rocky shore is made up of populations of blue mussels, barnacles, seaweeds, and many other species.

Whenever the internal composition of a cell differs from that on the outside, substances tend to move in or out of the cell by diffusion. If the surrounding seawater contains more sodium, say, than the cell's cytoplasm, sodium tends to diffuse into the cell. This is not good if the organism is sensitive to sodium. Similarly, substances that are concentrated inside cells tend to diffuse out. Many of the cell's precious molecules—like ATP, amino acids, and nutrients—are much more concentrated in the cell than in seawater. Therefore, they tend to leak out of the cell.

One answer to this problem is to have a barrier that stops molecules from diffusing in and out. The cell membrane is just such a barrier. It blocks the passage of the common ions in seawater as well as many organic molecules. The membrane cannot be a complete barrier, however, because the cell needs to exchange many materials—like oxygen and carbon dioxide—with its surroundings. The cell membrane is **selectively permeable;** that is, it allows some substances to enter and leave the cell but blocks others. Water and other small molecules pass readily through the cell membrane, for example, whereas ATP and many proteins do not.

The selective permeability of the cell membrane solves the problem of diffusion of ions and organic molecules, but it creates a new problem. Like any other molecule, water diffuses from areas where it is concentrated to areas of lower concentration. If the total concentration of ***solutes*** inside the cell is higher than that outside, the concentration of *water* will be lower. Because water molecules are free to cross the cell membrane, they will stream into the cell, causing it to swell (Fig. 4.13). On the other hand, the cell will tend to lose water and shrivel if the total salt concentration outside the cell is higher than inside. The diffusion of water across the cell membrane is known as **osmosis.**

Salinity

Many enzymes and other organic molecules are sensitive to **ion** concentrations. Marine organisms are thus immersed in a medium—seawater—with the potential to profoundly alter their metabolism. To fully understand the problems posed by **salinity,** we must know something about how dissolved ions and molecules behave.

Diffusion and Osmosis In solution, ions and molecules move around just like water molecules do. If the molecules are concentrated in one part of the solution, this random movement spreads them out until they are evenly distributed (Fig. 4.12). The overall result is that the molecules move from areas of high concentration to areas of low concentration. This process is called **diffusion.**

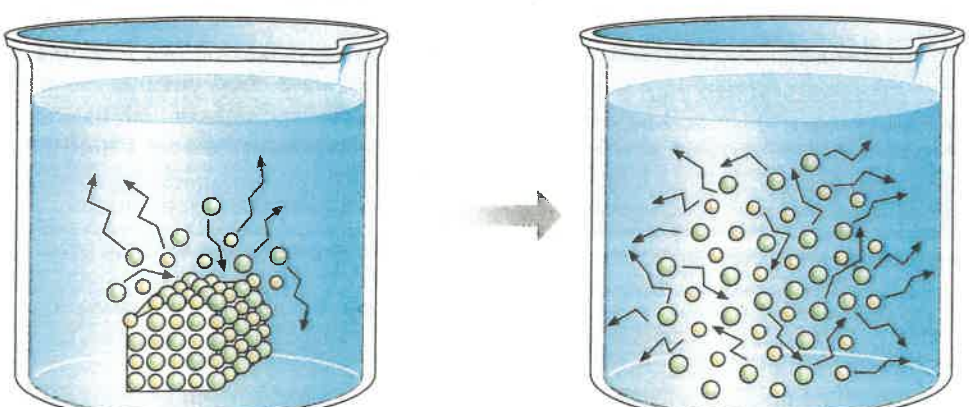


FIGURE 4.12 Ions and molecules dissolved in water tend to move around randomly just like water molecules do. When a crystal of salt dissolves in water, the ions start out concentrated in one part of the solution but eventually spread out because of their random movement. This process, called diffusion, results in the flow of ions from areas of high concentration to areas of low concentration.

Diffusion and osmosis always move materials from high concentration to low. The selective permeability of the cell membrane can control this movement, but not reverse it, and cells often need to move materials in the opposite direction. They may, for example, need to rid themselves of excess sodium even though the seawater outside is more concentrated than the inside of the cell, or to take up sugars and amino acids from the surrounding water even though they are already more concentrated inside the cell. In **active transport,** proteins in the cell membrane pump materials in the opposite direction to which they would move by diffusion. This process requires energy, in the form of ATP. Active transport is so

EVOLUTIONARY PERSPECTIVE

From Snack to Servant: How Complex Cells Arose

Prokaryotes were the first life on Earth. There are fossil bacteria thought to be 3.8 *billion* years old, nearly as old as the oceans themselves. It was another billion years or more before eukaryotic cells appeared. Strangely enough, this advance in cell design, shared by all multicellular life, may have started with a simple "meal."

Biologists believe that mitochondria, the "powerhouses" of the cell (see Fig. 4.8), were once free-living bacteria. They are 1 to 3 microns (μm) long, about the same size as many bacteria. Respiration in both bacteria and mitochondria takes place in their membranes, and mitochondria have folded internal membranes similar to those found in many bacteria. Although most of a eukaryotic cell's DNA is contained in the nucleus, mitochondria have a small amount of their own DNA. This DNA is even in the form of a single, circular molecule like the chromosome of bacteria. When a cell needs new mitochondria, it does not make them from scratch. Instead, the mitochondria within the cell divide, much as bacteria reproduce by cell division. Mitochondria resemble bacteria in several other respects.

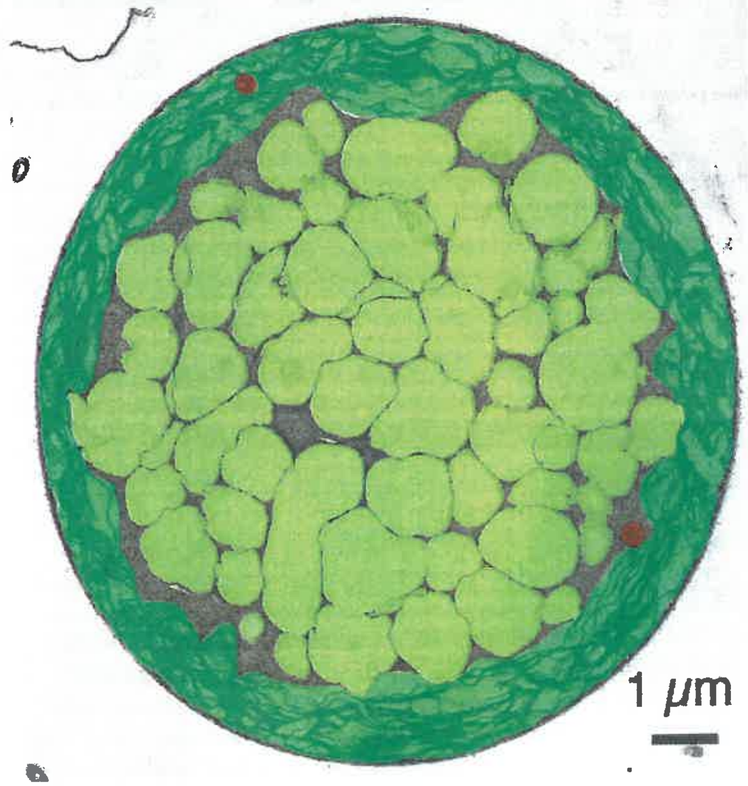
Because of these similarities, biologists believe that mitochondria were originally bacteria that came to live inside other cells. A relatively large cell that had already evolved some chemical features of today's eukaryotes may have engulfed a smaller one but been unable to digest it, or a disease-causing bacterium may have invaded the larger cell but not killed it. Both phenomena have been observed in the laboratory in living cells. Either way, the small cells eventually took up permanent residence in the larger cells, using them as hosts. The living together of different kinds of organisms like this is called **symbiosis** (see "Symbiosis," p. 218).

According to this theory, the host cells could not use oxygen in respiration. The smaller, symbiotic, bacteria did use oxygen and provided this ability to their hosts, giving them an advantage over cells without the symbionts.

Over time the host cells transferred most of the symbiotic bacteria's genes into their own nuclei, and thus came to control the symbionts. The symbionts and host cells became more and more dependent on each other. Eventually the symbionts became mitochondria.

Chloroplasts, the organelles that perform photosynthesis, are also thought to have arisen from symbiotic bacteria. Like mitochondria, they are about the right size, have a circular DNA molecule, and can reproduce themselves. Chloroplasts also contain folded membranes very similar to those of photosynthetic bacteria (see Fig. 4.7). Chloroplasts probably arose when a eukaryotic cell containing mitochondria engulfed a photosynthetic bacterium that wasn't digested and became symbiotic. The exact nature of this symbiont is hotly debated, but it probably looked something like a symbiotic bacterium called *Prochloron* that lives in some sea squirts and other invertebrates. The eukaryotic host cells gained the symbiont's photosynthetic ability and were the first algae. The algae eventually evolved different types of chloroplasts, which were later exchanged when one kind of alga engulfed another.

The hypothesis that mitochondria and chloroplasts arose from bacteria, once highly controversial, is now almost universally accepted by biologists. Some biologists even classify mitochondria and chloroplasts as symbiotic bacteria rather than organelles. All multicellular organisms, including humans, carry in their very cells the legacy of these bacterial partnerships, perhaps the result of an ancient snack.



Prochloron. This bacterium was once thought to be closely related to the symbiotic, photosynthetic bacterium that gave rise to chloroplasts, but genetic studies indicate that a slightly different group of bacteria was involved.

important that it represents over one-third of cells' total energy expenditure.

Diffusion is the movement of ions and molecules from areas of high concentration to areas of low concentration. Osmosis is the diffusion of water across a selectively permeable membrane. In active transport the cell uses energy to move materials in the opposite direction to diffusion.

Ions *Atoms* or groups of atoms that have a positive or negative charge. The most common ions in seawater are chloride and sodium.

• Chapter 3, p. 43

Solute Ions, organic molecules, or anything else that is dissolved in a solution.

Salinity The total amount of *salts* dissolved in water. Salts are combinations of ions.

• Chapter 3, p. 44

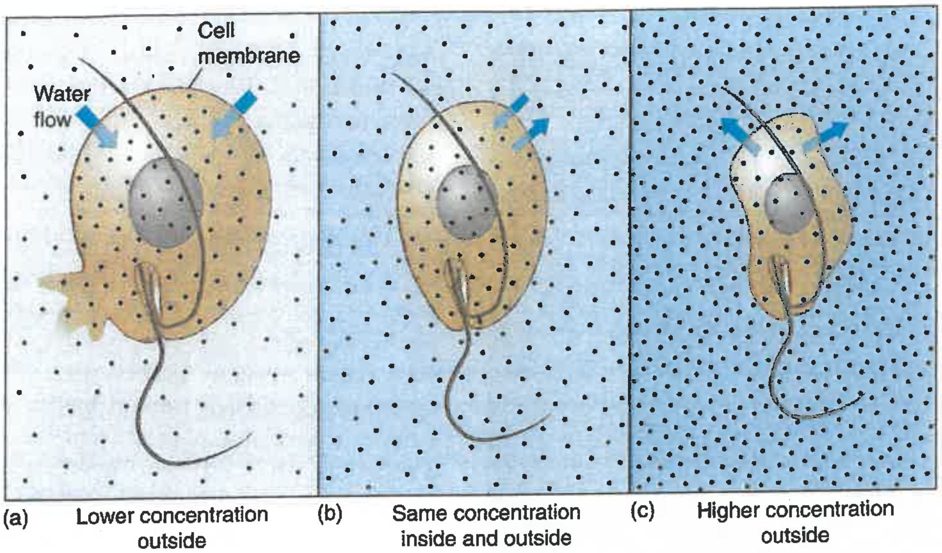


FIGURE 4.13 Osmosis. (*a*) If there is more dissolved material, and therefore less water, inside a cell then outside water will move into the cell by osmosis (a special case of diffusion). The cell will swell until it bursts. (*b*) If the internal and external concentrations are the same water moves in and out of the cell equally, and the cell stays in balance. (*c*) When the outside water is *more* concentrated, the cell loses water by osmosis and shrivels.

Regulation of Salt and Water Balance Marine organisms have adapted to the problems of maintaining the proper balance of water and salts in various ways. Some don't actively maintain salt and water balance at all; their internal concentrations change as the salinity of the water changes (see Fig. 12.6). Such organisms are called **osmoconformers.** Many osmoconformers can only live in a narrow salinity range. Others tolerate relatively large changes in the salinity of the surrounding seawater (and therefore their tissues), but even they experience osmotic problems outside their tolerance range. In areas like the open ocean, where salinity doesn't fluctuate much, osmoconformers have few difficulties.

Other marine organisms **osmoregulate,** or control their internal concentrations to avoid osmotic problems. Osmoregulators still have limits, but are generally able to tolerate salinity changes better than osmoconformers. One way osmoregulators adapt to different salinities is by adjusting the concentration of solutes in their body fluids so that the overall concentration of their fluids matches that of the water outside. It doesn't matter if there are the same dissolved chemicals inside and out as long as the total *amount* of dissolved material is the same. Some organisms osmoregulate by changing the amount of just one particular chemical to match changes in the salinity outside. Sharks, for example, increase or decrease the amount of a chemical called **urea** in their blood (see Fig. 8.18). A single-celled marine alga called *Dunaliella* uses a different chemical, glycerol, to do the same thing. *Dunaliella* may be the champion osmoregulator. It can maintain its water balance in water ranging from nearly fresh to more than nine times saltier than normal seawater.

By contrast, many osmoregulators maintain blood concentrations that are different from that of the surrounding seawater. Most marine fishes have body fluids considerably more dilute than seawater (Fig. 4.14*a*) and tend to lose water by osmosis. They replace the lost water by drinking seawater. They also conserve water by producing only a very small amount of urine. Some of the excess salts that are taken in with the seawater they drink are never absorbed and pass right through the gut. Marine fishes do absorb some of the salts they drink and must actively rid themselves of, or **excrete,** these excess salts. Some salts are excreted in the urine, but because so little urine is produced this is not enough. Most of the excess salts are excreted through the gills (see "Regulation of the Internal Environment," p. 164).

Freshwater fishes have the reverse problem: Their blood has a higher concentration of salt than the surrounding water, and they take in water by osmosis. Their adaptations are opposite those of marine fishes (Fig. 4.14*b*).

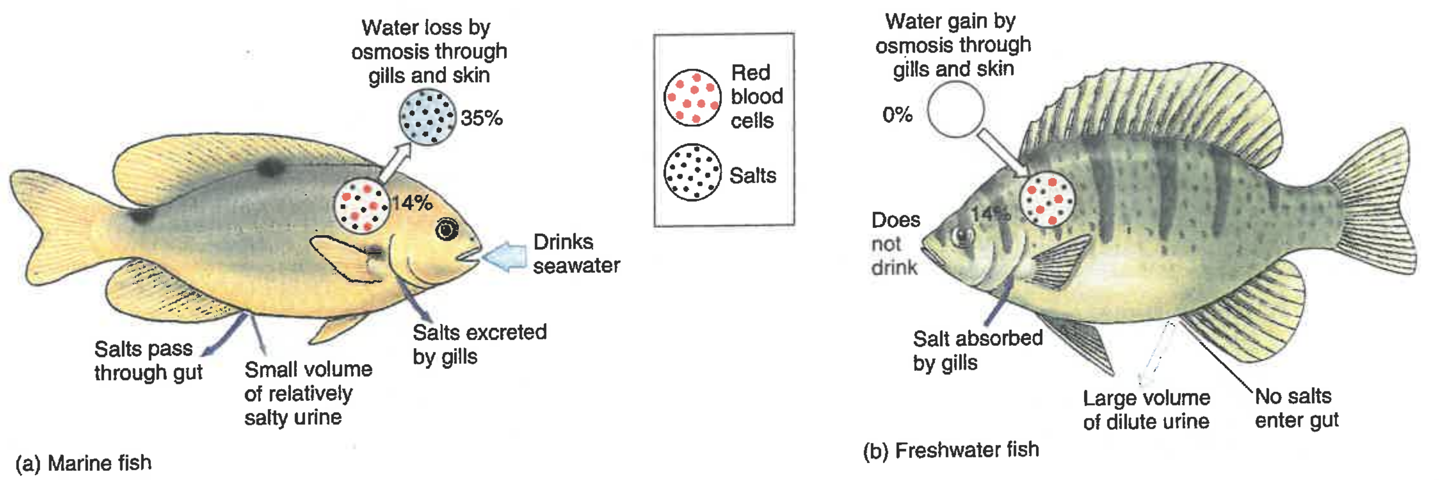


FIGURE 4.14 Regulation of salt and water balance. (*a*) In most marine fishes, water flows by osmosis from the relatively dilute body fluids to the more concentrated seawater. To compensate and avoid dehydration, the fish drinks seawater. It excretes as little urine as possible to conserve water. Some salts pass through the gut without being absorbed. Salts that are absorbed are excreted, mostly through the gills but also in the urine. (*b*) Freshwater fishes are in the reverse situation: The outside water has a very low salinity, so they tend to gain water by osmosis. To avoid swelling up, they refrain from drinking and produce large amounts of dilute urine. Salts are absorbed by the gills to replace those lost in the urine.

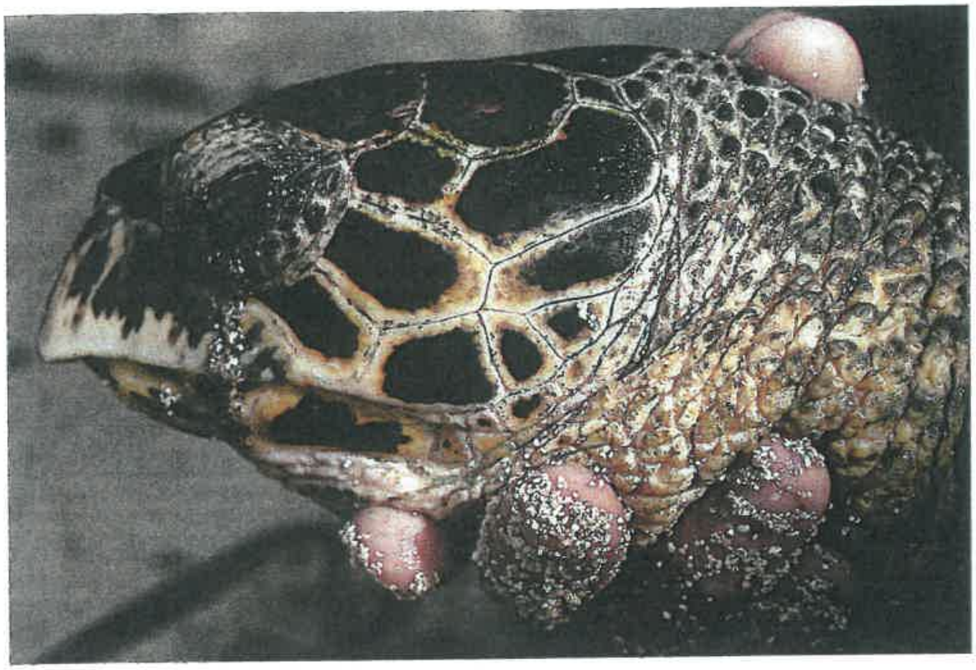


FIGURE 4.15 Sea turtles have glands near the eyes that excrete excess ions, producing salty "tears." This is a hawksbill turtle (*Eretmochelys imbricata*).

Marine birds and reptiles, and some marine plants, also have special cells or glands to rid themselves of excess salt (Fig. 4.15). Marine plants and most algae have the added advantage of a fairly rigid cell wall that helps them resist the swelling caused by osmotic water gain.

Temperature

Organisms are greatly affected by temperature. Metabolic reactions proceed faster at high temperatures and slow down dramatically as it gets colder. A general rule of thumb is that most reactions occur about twice as fast with a 10 °C (18 °F) rise in temperature. At extreme temperatures, however, most enzymes cease to function properly.

Most marine organisms are adapted to live in particular temperature ranges. Many polar species, for instance, have enzymes that work best at low temperatures, and they cannot tolerate warm water. The reverse is true of many tropical species. As a result, temperature plays a major role in determining where different organisms are found in the ocean (Fig. 4.16).

Organisms are often categorized according to how their metabolism affects their body temperature. All organisms generate metabolic heat, but in most organisms this heat is quickly lost to the environment and does not raise body temperature. These organisms are known as **ectotherms** and are commonly called "cold-blooded." In **endotherms,** on the other hand, metabolic heat is retained and raises the body temperature above that of the surroundings. Endotherms are often called "warm-blooded." Endotherms include mammals, birds, and some large fishes, including some tunas and sharks (see "Swimming: The Need for Speed," p. 345).

Another way to categorize organisms is by whether they can keep their body temperature more or less constant regardless of the temperature of the environment. The body temperature of **poikilotherms** changes along with the temperature of the surroundings. All ectotherms are also poikilotherms. As

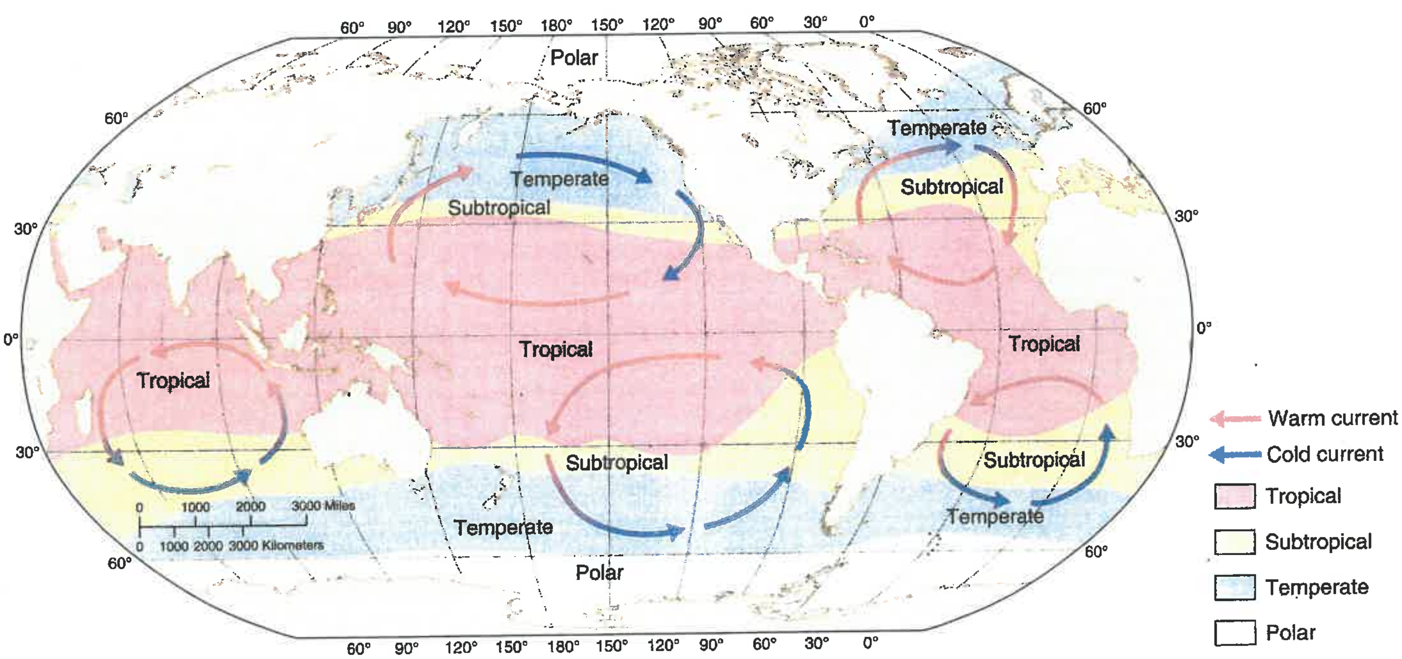


FIGURE 4.16 Marine organisms are often restricted to specific regions that correspond to average water temperatures. The major divisions are the polar, temperate, subtropical (or warm temperate), and tropical regions. The boundaries of these regions are not absolute and change slightly with the seasons and shifts in current patterns. This map refers only to surface waters; deep water is uniformly cold.

Table 4.2 Classification of Animals by Their Response to Changes in External Temperature

	Poikilotherms: Temperature varies with external temperature	**Homeotherms:** Regulate body temperature so it doesn't vary as much as external temperature
Ectotherms: Most metabolic heat is rapidly lost to the environment; body temperature matches external temperature	Invertebrates, most fishes, marine reptiles	None
Endotherms: Retain significant metabolic heat; internal temperature stays warmer than external temperature	Some large sharks, tunas, and billfishes	Mammals and birds

the temperature of the water rises and falls so does their body temperature, and consequently their metabolic rate. This can make ectothermic animals sluggish if the water is colder than they are used to. Warm-blooded, or endothermic, tunas and sharks are also poikilotherms. Although they retain metabolic heat generated by their large muscles and are warmer than the surrounding water, their internal temperature still goes up and down as water temperature changes.

Mammals and, to a lesser extent, birds are able to regulate their internal temperature so that it stays much the same even when the external temperature varies. They are called **homeotherms.** Being endotherms, they retain heat, but they also control their metabolism, producing more heat as needed by burning up fats and other energy-rich molecules. This allows them to remain highly active regardless of water temperature, but it also requires a lot of energy, so homeotherms need to eat more often than poikilotherms. To reduce the "heat bill"—the energy cost of maintaining their body temperature—mammals and birds are insulated with feathers, hair, or blubber. The classification of organisms according to how they respond to changes in the temperature of their environment is summarized in Table 4.2.

Surface-to-Volume Ratio

Adaptations to salinity and temperature are needed because salts and heat can flow in and out of organisms—if organisms were not affected by their environment, they would not have to adapt. Organisms also exchange nutrients, waste products, and gases with the environment. Such materials often move in and out across the surface of marine organisms, so the amount of surface area is very important. More precisely, it is the amount of surface area relative to the total volume of an organism—in other words, the **surface-to-volume ratio,** or **S/V ratio**—that determines how rapidly heat and materials flow in and out.

Volume	Surface area	S/V ratio	
1 cm^3	6 cm^2	6:1	
8 cm^3	48 cm^2	6:1	
8 cm^3	24 cm^2	3:1	

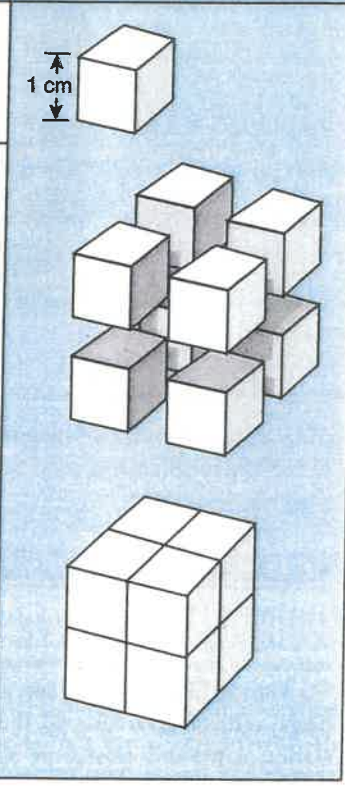


FIGURE 4.17 A cube that is 1 cm on a side (top) has a volume of 1 cm^3 and, because it has six sides, a surface area of 6 cm^2. Eight such cubes (middle) will, of course, have both eight times the volume and eight times the surface area, so the ratio of the surface area to the volume of the cubes, or surface-to-volume (S/V) ratio, will stay the same: 6:1. If the eight cubes are combined into a single large one (bottom), half the surfaces are hidden in the interior. The S/V ratio, like the surface area, is reduced by half, to 3:1. A large cube, therefore, has a lower S/V ratio than a small one.

One thing that determines the S/V ratio is the size of the organism. As organisms grow larger, their volume increases faster than their surface area. Small organisms have a larger S/V ratio than big ones (Fig. 4.17). Small organisms, especially single-celled ones, can therefore rely on simple diffusion across their surfaces for the exchange of materials. Larger organisms must develop supplementary mechanisms, like respiratory and excretory systems.

PERPETUATING LIFE

One of the most basic characteristics of living things is the ability to reproduce—to generate offspring similar to themselves. Any life form that failed to replace itself with new individuals of its own kind would soon vanish from the planet. It is only by reproducing that a species ensures its own survival.

Organisms must do two things when they reproduce. First, they must produce new individuals to perpetuate the species. Second, they must pass on to this new generation the characteristics of the species in the form of genetic information. The transfer of genetic information from one generation to the next is called **heredity.**

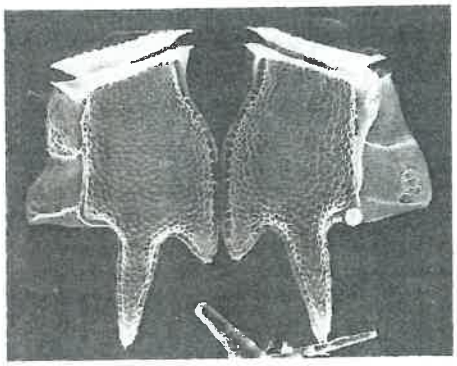


FIGURE 4.18 Two cells of a microscopic organism called a dinoflagellate *(Dinophysis tripos)*. These cells were formed by the division of a single cell. The two cells, joined here, will soon separate.

Organisms achieve the first objective, the production of offspring, in many different ways. But there are relatively few ways through which they pass on genetic information. This similarity of hereditary mechanisms is evidence that all living things are fundamentally related.

Modes of Reproduction

Individual cells reproduce mainly by dividing to form new **daughter cells** (Fig. 4.18). In prokaryotes, where the DNA that carries the genetic information is not enclosed in a nucleus, the cell divides into two new ones by a simple process called **cell fission.** Before dividing, the cell copies, or **replicates,** its DNA. Each daughter cell gets one of the copies, as well as the rest of the cellular machinery it needs to survive.

In eukaryotes the DNA lies on several different chromosomes. Before a cell divides, each chromosome is replicated. The most common form of eukaryotic cell division, **mitosis,** is a complex process that takes place in the nucleus. Mitosis ensures that each daughter cell gets a copy of every chromosome. As in bacterial cell division, the end result is two daughter cells that are exact duplicates of the original, with the same genetic information.

Asexual Reproduction Cell division is the primary way that single-celled organisms reproduce. Because a single individual can reproduce itself without the involvement of a partner, this form of reproduction is called **asexual reproduction.** All forms of asexual reproduction are similar in that the offspring inherit all the genetic characteristics of the parent. They are, in fact, exact copies, or **clones.**

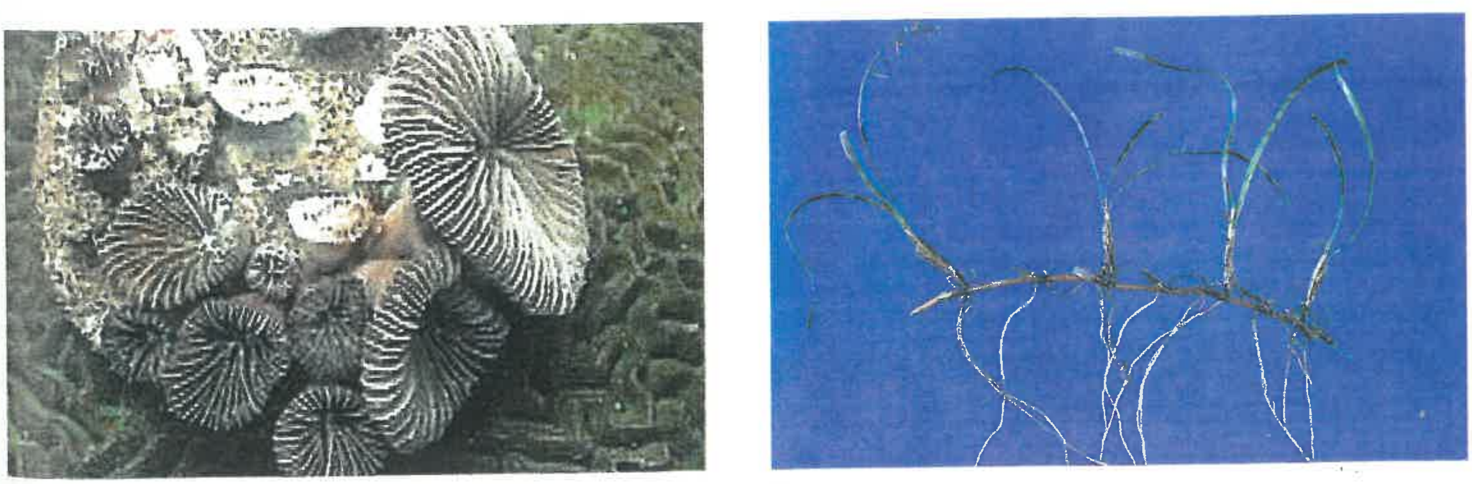
Many multicellular organisms also reproduce asexually. Some sea anemones, for example, split in half to create two smaller anemones. This process is known as **fission.** Another common form of asexual reproduction is **budding.** Instead of dividing into two new individuals, the parent develops small growths, or buds, that break away and become separate individuals (Fig. 4.19*a*). Many plants reproduce asexually by sending out various kinds of runners that take root and then sever their connection to the parent (Fig. 4.19*b*). Because it is so common in plants, asexual reproduction is sometimes called **vegetative reproduction,** even when it occurs in animals.

Asexual, or vegetative, reproduction can be performed by single individuals and produces offspring that are genetically identical to the parent.

Sexual Reproduction Most multicellular and some unicellular organisms reproduce part or all of the time by **sexual reproduction,** in which new offspring arise from the union of two separate cells called **gametes.** Usually each of the gametes comes from a different parent.

Organisms that reproduce sexually have a special kind of tissue called **germ tissue.** Whereas all the other cells in the body divide only by mitosis, germ cells are capable of a second type of cell division, **meiosis.**

In most cells of eukaryotic organisms the chromosomes occur in pairs, with each chromosome of a pair storing similar genetic information. Such cells are **diploid,** designated **2*n*.** Meiosis produces daughter cells that have copies of only half the parents' chromosomes—one of each pair. Cells with half the normal number of chromosomes are **haploid,** designated ***n*** or **1*n*.** The haploid daughter cells produced in meiosis are the gametes. In some seaweeds and microscopic organisms, all the gametes are the same.



(a) (b)

FIGURE 4.19 (*a*) Budding is a common form of reproduction in marine animals, including this mushroom coral (*Fungia fungites*). The parent coral is nearly dead, but the many buds on its surface will soon break off and become free-living adults (see Fig. 14.3*a*). (*b*) This seagrass (*Halodule pinifolia*) reproduces asexually by sending out rhizomes, or "runners," that take root and form new plants.

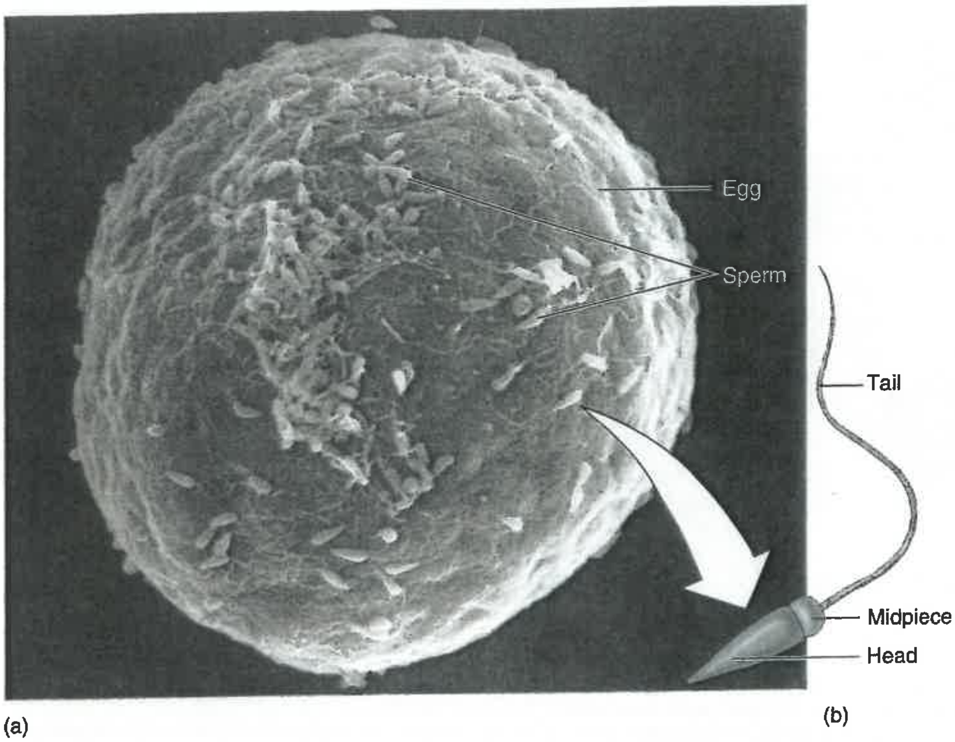


FIGURE 4.20 (*a*) The egg of the variegated sea urchin (*Lytechinus variegatus*) is many times larger than sperm from the same species. Though many sperm surround the egg, only one will fertilize it. The egg contains a large amount of cytoplasm and the organelles characteristic of other cells. It also contains yolk to nourish the developing embryo. (*b*) The head of a sperm cell is made up almost entirely of the cell nucleus and contains the genetic material. The midpiece contains mitochondria that power the tail, or flagellum, with which the sperm swims.

Most organisms, however, have two types of gametes: female gametes called **eggs** and male gametes called **sperm** (Fig. 4.20). In animals the germ tissue is usually contained in **gonads,** the organs that produce the gametes. **Ovaries** are the female gonads, which produce eggs. In animals the male gonads, or **testes,** produce sperm. Seaweeds also have gonads that produce sperm, while in flowering plants sperm develop within pollen, which is produced by organs in the flower called anthers.

Eggs are large cells, usually an organism's largest. They contain all the cellular machinery—organelles and cytoplasm—characteristic of regular cells. The eggs of many species also contain large amounts of energy-rich yolk. Sperm, by contrast, are usually an organism's smallest cells, with almost no cytoplasm and few of the typical organelles. Sperm are little more than tiny packages of chromosomes equipped with mitochondria-powered flagella that enable the sperm to swim.

Mitosis, the most common form of cell division, produces two daughter cells that are identical to the original cell. Meiosis, on the other hand, produces daughter cells that have half the normal number of chromosomes—that is, they are haploid. These daughter cells are called gametes. Eggs and sperm are the female and male gametes, respectively.

Sperm are attracted to eggs from the same species. When egg and sperm come into contact, they fuse; in other words, **fertilization** occurs. The genetic material contained in the two gametes combines. Since both haploid gametes had $1n$ chromosomes—or half the normal number—the fertilized egg, called a **zygote,** is back to the normal diploid, or $2n$, number of chromosomes. It has DNA from *both* parents, however, and is therefore different from either. This **recombination** of genetic information to produce offspring that differ slightly from their parents is the most important feature of sexual reproduction.

In sexual reproduction two gametes, usually eggs and sperm, fuse to create a genetically distinct individual.

The fertilized egg begins to divide by ordinary mitosis. Now called an **embryo,** it is nourished by the yolk. Through an extraordinarily complex process called embryological development, the embryo eventually becomes a new adult of the species. Along the way, most marine organisms pass through immature, or **larval,** stages that often look completely different from the adults (see Figs. 7.39 and 15.11).

Reproductive Strategies

The goal of reproduction for any organism is to pass its hereditary characteristics on to a new generation. There is a nearly endless variety of ways to achieve this (Fig. 4.21). Some species release millions of eggs and sperm into the water, where fertilization occurs, and have no further interaction with their offspring. This is called **broadcast spawning.** Others issue only a few offspring and invest a lot of time and energy in caring for them. Some species have many different larval stages, whereas others develop directly from egg to adult. Some reproduce asexually, some reproduce sexually, and some do both. In sexually reproducing species, males and females may always be separate individuals, or there may be **hermaphrodites,** individuals that have both male and female reproductive organs either at the same time or at different times of life.

The particular combination of methods used by a given species is called its **reproductive strategy.** The strategy used by a species depends on its size, on where and how it lives, on what kind of organism it is—in fact, on just about everything about it and its environment.

THE DIVERSITY OF LIFE IN THE SEA

There are so many different living things in the sea that it almost boggles the mind. From microscopic bacteria to gigantic whales, marine organisms come in all shapes, sizes, and colors. The ways in which they live are just as varied. Making sense of all this **diversity** might seem a hopeless task. Fortunately, there is a unifying concept that helps make the bewildering diversity of life comprehensible. This concept is the **theory of evolution.** Remember

(a) (b) (c) (d)

FIGURE 4.21 Marine organisms have many different reproductive strategies, a few of which are shown here. (*a*) Like many marine organisms, giant clams (*Tridacna gigas*) simply spawn into the water, a strategy known as broadcast spawning. Successful fertilization requires that other members of their species are spawning nearby and that currents will mix their eggs and sperm together. (*b*) Male yellowhead jawfish (*Opistognathus aurifrons*) aerating and incubating eggs, Caribbean. (*c*) Marine mammals like this New Zealand fur seal (*Arctocephalus forsteri*) take care of their young for much longer than most marine animals. (*d*) Marine plants like seagrasses flower (arrow) to reproduce. Most seagrasses have even more inconspicuous flowers than this one (*Enhalus acaroides*).

that scientists do not use the term "theory" lightly. Evolution, the gradual alteration of a species' genetic makeup, is supported by a vast body of evidence. The *ways* in which evolution occurs, on the other hand, never cease to fascinate biologists.

Natural Selection and Adaptation

Evolution occurs because individual organisms have genetic differences in their ability to find food and avoid being eaten, in their success at producing offspring, in their metabolism, and in countless other attributes. The best-adapted individuals, those most successful at meeting the challenges of the environment, produce more offspring on average than those that are not so well adapted. This process was called **natural selection** by Charles Darwin, the nineteenth-century English naturalist who, along with another Englishman, Alfred Wallace, first proposed the modern theory of evolution.

The best-adapted individuals not only produce more offspring, they also pass their favorable characteristics on to those offspring. The favorable traits therefore become more common, and over generations the population as a whole gradually becomes more similar to the best-adapted individuals. Thus, the result of natural selection is that the population continually adapts to its environment—that is, it evolves.

Natural selection occurs when some members of a population survive and reproduce more successfully than others. Evolution is the genetic change in the population that results because these more successful individuals pass their favorable characteristics on to their young.

Every population is constantly adapting to its environment. The world is an ever-changing place, however, and organisms are always being faced with new challenges. Populations either adapt to the changes in the environment or become extinct, making way for others. As a result, evolution is an endless process.

Classifying Living Things

The adaptation of various populations to different environments has produced a fantastic variety of life forms. It is difficult to study and discuss the millions of life forms on Earth unless we first classify them, or sort them into groups. One of the goals of biological classification is to give a universally accepted name to different types of organisms so that scientists from all over the world can call a species by the same name.

The Biological Species Concept We have loosely defined a species as a "type" of organism, but what exactly does that mean? After all, fishes are all the same general type of animal, but a sailfish is obviously not the same species as a tuna (see Figs. 1.17 and 1.18). No definition is perfect, but here we will define species as populations of organisms that have common characteristics and can successfully breed with each other. This definition is often referred to as the **biological species concept.**

Scientific Theory A *hypothesis* that is accepted as "true" because it has passed test after test and is supported by a large body of evidence.
• Chapter 1, p. 14

EYE ON SCIENCE

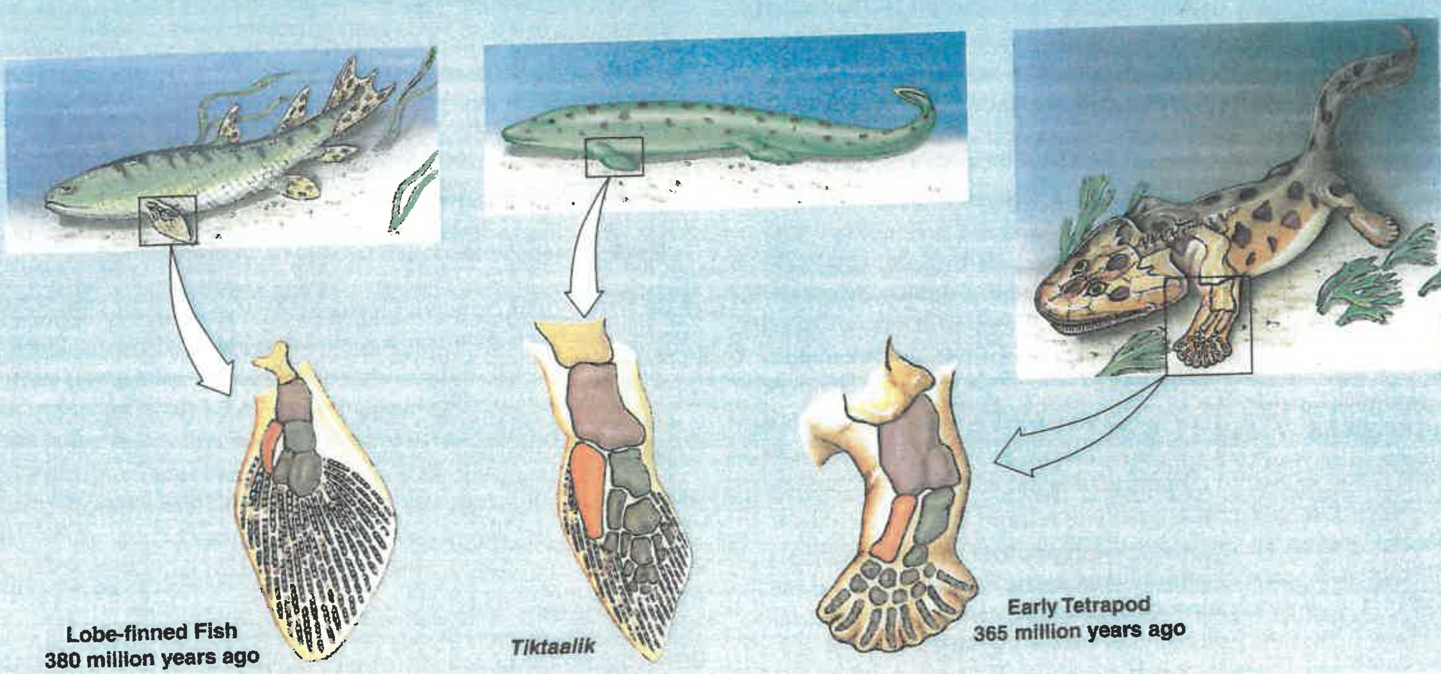
When Fishes Stepped on Land

Organisms evolve in tiny steps, with each change only incrementally different from before, so a key challenge in evolutionary biology is to understand how complex and radically different new structures could have evolved. Fins are great for swimming, and legs are great for walking, but how did animals get from one to the other while still being able to catch food, avoid predators, and find mates every step of the way? Recent breakthroughs have helped us understand how fishes moved onto land to become tetrapods (animals with two pairs of limbs).

Paleontologists recently discovered fossils of a fish *(Tiktaalik roseae)* that appears very close to the so-called missing link between fishes and the first land vertebrates. *Tiktaalik* lived about 375 million years ago, 10–15 million years before the earliest known fossil tetrapods. The arrangement of bones in *Tiktaalik*'s fins is almost perfectly intermediate between the limbs of early tetrapods and the fins of lobe-finned fishes, the ancestors of tetrapods. In particular, *Tiktaalik*'s fin bones foreshadow the elbow, wrist, and fingers of tetrapods. *Tiktaalik* was probably unable to walk, but it could at least use its fins to do push-ups. *Tiktaalik*, had other features that would be refined in tetrapods, such as the beginnings of the first neck. Like its fins, *Tiktaalik's* skull and associated vertebrae have features in between those of fishes and tetrapods. Scientists doubt that *Tiktaalik* is the direct ancestor of tetrapods, but it is probably a very close cousin. Every summer *Tiktaalik's* discoverers return to the Canadian Arctic where they found its fossils in hope of new discoveries about the emergence of tetrapods, which 300 million years later would return to the sea as whales (see "The Whales That Walked to Sea," p. 191).

Meanwhile, biologists are learning the genetic basis for these changes. The key is that evolution does not have to completely reinvent the wheel—or the limb. The genome is flexible enough that the same basic system, with only minor tweaks, can control the development of a range of different structures. The earliest fishes did not have paired fins on the side, only median fins, single fins along the midline like the dorsal fin of sharks (see "Cartilaginous Fishes," p. 153). In today's sharks the dorsal fin and paired fins develop from different cells in different parts of the embryo, but biologists recently showed that the same genetic programs control the embryonic development of both. These genes are also involved in the development of median fins in lampreys, primitive fishes that branched off before paired fins emerged (see "Jawless Fishes," p. 153), and the development of wings in chick embryos. Thus, the same genetic mechanism controls the development of median fins, paired fins, limbs, and wings. Paired fins and limbs did not evolve from scratch, but emerged through the application of the molecular system that was already producing median fins. The researchers are testing this hypothesis by studying lancelets, the nearest invertebrate relatives of vertebrates (see "Chordates Without a Backbone," p. 145).

For more information, explore the links provided on the Marine Biology *Online Learning Center.*



Successful breeding means that the offspring produced are fertile and can themselves propagate the species. Dogs, to use a familiar example, are all the same species because all breeds of dog—no matter how different they may look—can interbreed to produce fertile offspring. Organisms that cannot breed with each other are not members of the same species no matter how similar they look. When two populations are unable to interbreed successfully, they are said to be **reproductively isolated.**

A species is a population of organisms that share common characteristics, can breed with each other, and are reproductively isolated from other populations.

FIGURE 4.22 *Panulirus interruptus*, the Pacific spiny lobster, is sometimes called a rock lobster or a crayfish.

Biological Nomenclature Organisms are identified biologically by two names, the name of their **genus** and a species name or, more correctly, **species epithet.** A genus is a group of very similar species. Dogs, for example, have the scientific name *Canis familiaris*. They are closely related to other species in the genus *Canis*, like wolves, *Canis lupus*, and coyotes, *Canis latrans*. Similarly, the genus *Balaenoptera* contains several related species of whales, including the blue whale, *Balaenoptera musculus;* the fin whale, *Balaenoptera physalus;* and the minke whale, *Balaenoptera acutorostrata*. This two-name system is called **binomial nomenclature.** It was first introduced in the eighteenth century by the Swedish biologist Carolus Linnaeus. At that time Latin was the language of scholars, and Latin is still used for scientific names, along with Greek. By convention, binomial names are always underlined or italicized. The first letter of the generic name, but not the species epithet, is capitalized. When the name of the genus has been previously mentioned it may be abbreviated. Thus, the blue whale could be identified as *B. musculus*. The species epithet is never used by itself, but only in conjunction with the genus name or initial.

Students often ask why biologists have to use complicated, hard-to-pronounce Latin or Greek names rather than ordinary common names. The trouble with common names is that they are not very precise. The same common name may be applied to different species, and the same species may have different common names. The name "spiny lobster" (Fig. 4.22), for example, is applied to many different species that are not even all in the same genus. Australians call spiny lobsters "crayfish." Americans reserve the name "crayfish" for freshwater relatives of lobsters. Things get even more confusing when people speak different languages. In Spanish, spiny lobsters are called *langostas*, which can also refer to grasshoppers. Another example is the name "dolphin," which is applied not only to the lovable relatives of whales but also to a delicious game fish. Dolphin fish are called *dorado* in Latin America and *mahimahi* in Hawai'i. At the local crab shack this confusion is only a minor annoyance. To biologists, however, it is essential to precisely identify whatever species they are discussing. The use of scientific names that are accepted worldwide avoids confusion.

Confusion over common names can have practical implications as well. After a dive on a coral reef near Australia, one of the authors mentioned to his dive buddy that he had seen a gray reef shark. Gray reef sharks, although not so dangerous as to force you out of the water, can be aggressive and merit some attention and respect. The diving partner, who was familiar with the area, replied that the shark was not a gray reef, but a "graceful whaler." "Looks just like a gray reef shark to me," said the author but, reassured, he continued diving, blissfully ignoring the "graceful whalers" that swam by. Only later did he discover that "graceful whaler" was just a local name for the gray reef shark, *Carcharhinus amblyrhynchos* (see Fig. 8.6*a*)!

Phylogenetics: Reconstructing Evolution The goals of biological classification include not only assigning agreed-upon names to organisms but also grouping them according to their relatedness. Most people instinctively understand that a seal is related to a sea lion, for example, or that oysters and clams are related. They might be hard-pressed, though, to explain exactly what they mean by "related." To a biologist, saying that two groups of organisms are "related" means that they share a common evolutionary history, or **phylogeny.** In particular, it means that both groups evolved from a common ancestral species. Closely related groups evolved from common ancestors relatively recently, while the common ancestors of distantly related groups occurred further in the past. The study of such evolutionary relationships is called **phylogenetics.**

It is almost always difficult to determine the phylogenetic relationships among organisms. Very few groups have a good record

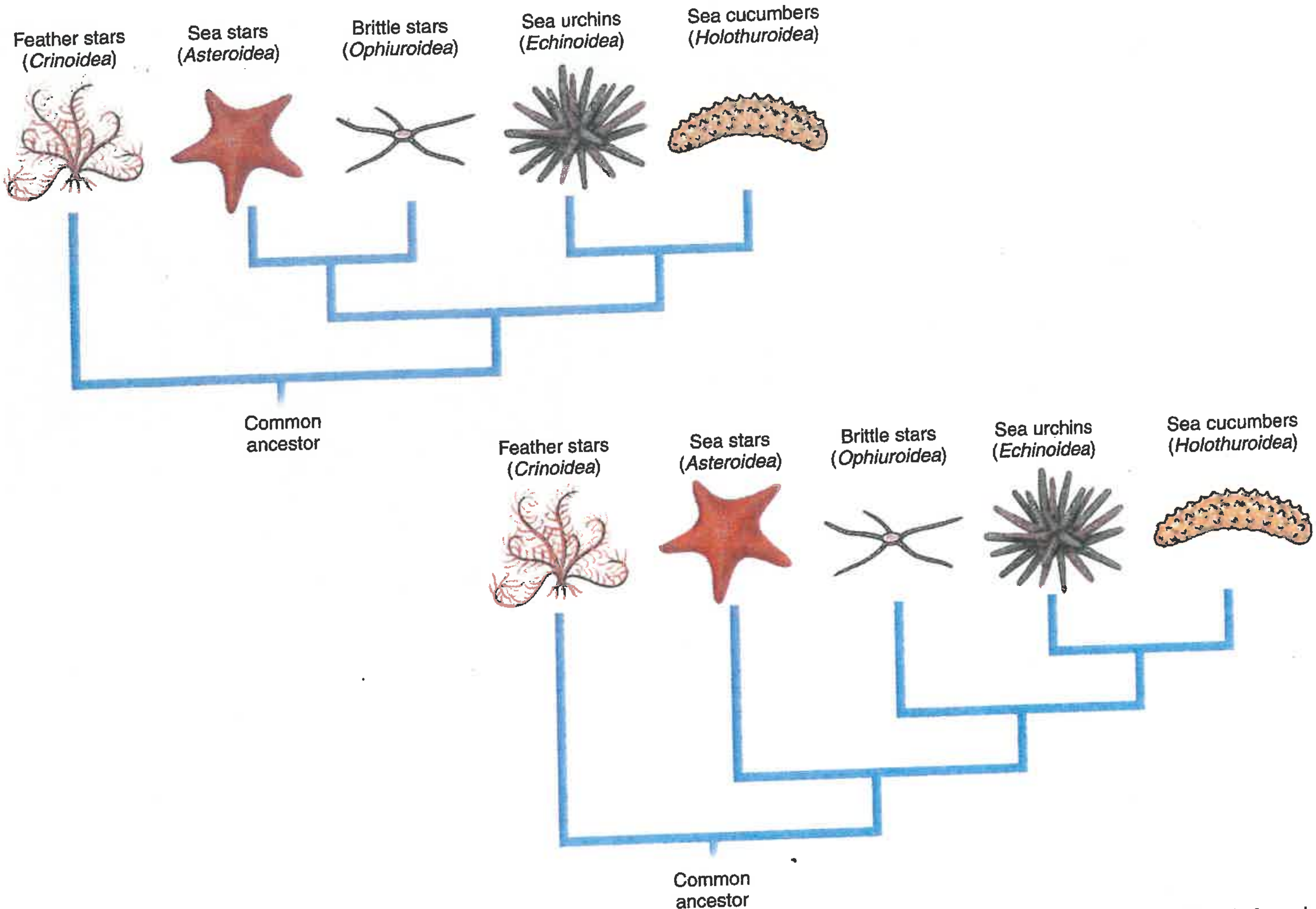


FIGURE 4.23 Alternative proposals for the phylogeny of the major groups of echinoderms. Both schemes accept that feather stars diverged early from the common ancestor of all echinoderms and that urchins and sea cucumbers are more closely related to each other than to other echinoderms. The proposals differ, however, with regard to the phylogeny of sea stars and brittle stars. Conflicting hypotheses like these are common in phylogenetics.

of fossils that trace their evolutionary history. Usually the fossil record is incomplete or nonexistent. Biologists have to try to piece together an organism's evolutionary history from other evidence. Body structure, reproduction, embryological and larval development, and behavior all provide clues. Biologists rely increasingly on molecular studies and, in particular, on DNA and RNA sequences. Because evolution is genetic change by definition, the study of the nucleic acids that store organisms' genetic information reveals a great deal about evolution. Unfortunately, different methods of studying phylogeny frequently yield different results, and experts in a particular group often disagree about its phylogeny (Fig. 4.23). Classification schemes change and new arguments arise as fresh information becomes available.

As noted previously, biological classification seeks to group organisms according to their relatedness. Species that are very closely related, for example, are grouped into the same genus. Genera with similar phylogenies can be grouped together into a larger group, called a family. This process can be continued to sort organisms into progressively larger groups. All the members of a group, or **taxon** (plural, **taxa**), have certain common characteristics and are thought to share a common ancestry. Taxa are systematically arranged in a hierarchy that extends from the most general classification, the domain, down to the species (Table 4.3).

The Tree of Life In centuries past, all known organisms were classified as either plants (kingdom **Plantae**) or animals (kingdom **Animalia**). As biologists learned more about the living world, however, they discovered many organisms that didn't fit, and the classification scheme was changed to recognize additional kingdoms. A system of five kingdoms became widely accepted. In addition to the Animalia and Plantae, this traditional system included fungi (kingdom **Fungi**), bacteria (kingdom **Monera**), and protists (kingdom **Protista**). Fungi are multicellular, heterotrophic organisms that are neither plants nor animals. Protists are an extremely varied group of organisms, some plant-like and some animal-like, that includes both unicellular eukaryotes and multicellular seaweeds. Biologists now recognize that protists are a collection of taxa with different evolutionary histories rather than a true kingdom, although for convenience they are still often grouped together under the name "protists."

In recent years, studies of the RNA and cellular chemistry of prokaryotes have led biologists to conclude that there are two main

Table 4.3 Biological Classification of Humans (*Homo sapiens*) and the Bottlenose Dolphin (*Tursiops truncatus*)

	Taxonomic Level	Example
Human		
	Domain	Eukarya
	Kingdom	Animalia
	Phylum	Chordata
	Class	Mammalia
	Order	Primates
	Family	Hominidae
	Genus	*Homo*
	Species	*Homo sapiens*
Dolphin		
	Domain	Eukarya
	Kingdom	Animalia
	Phylum	Chordata
	Class	Mammalia
	Order	Cetacea
	Family	Delphinidae
	Genus	*Tursiops*
	Species	*Tursiops truncatus*

Tursiops truncatus, the bottlenose dolphin.

Note: The term "division" is used in place of "phylum" in the classification of plants.

groups of prokaryotes that are as different from each other as they are from all eukaryotic organisms (see "Prokaryotes," p. 86). To recognize this, some classification systems place these two groups of prokaryotes into two new kingdoms, the **Bacteria** and the **Archaea.** Other systems recognize a new taxon, the domain, that is even more general than the kingdom; in this system the Bacteria and Archaea are separate domains and each includes a number of different kingdoms. In this text we use the three-domain system of classification (Fig. 4.24), but not all biologists agree with this system.

Viruses are not included in this system because biologists are not in agreement that they are alive or where to fit them in the tree of life (see "Viruses," p. 86). Viruses consist of little more than a handful of genes, encoded in either RNA or DNA, enclosed in a capsule of protein. Viruses are best known for causing disease in humans. Viruses also infect marine organisms, from prokaryotes to marine mammals, and even other viruses, and in doing so have been a driving force in evolution and play a major role in marine food webs.

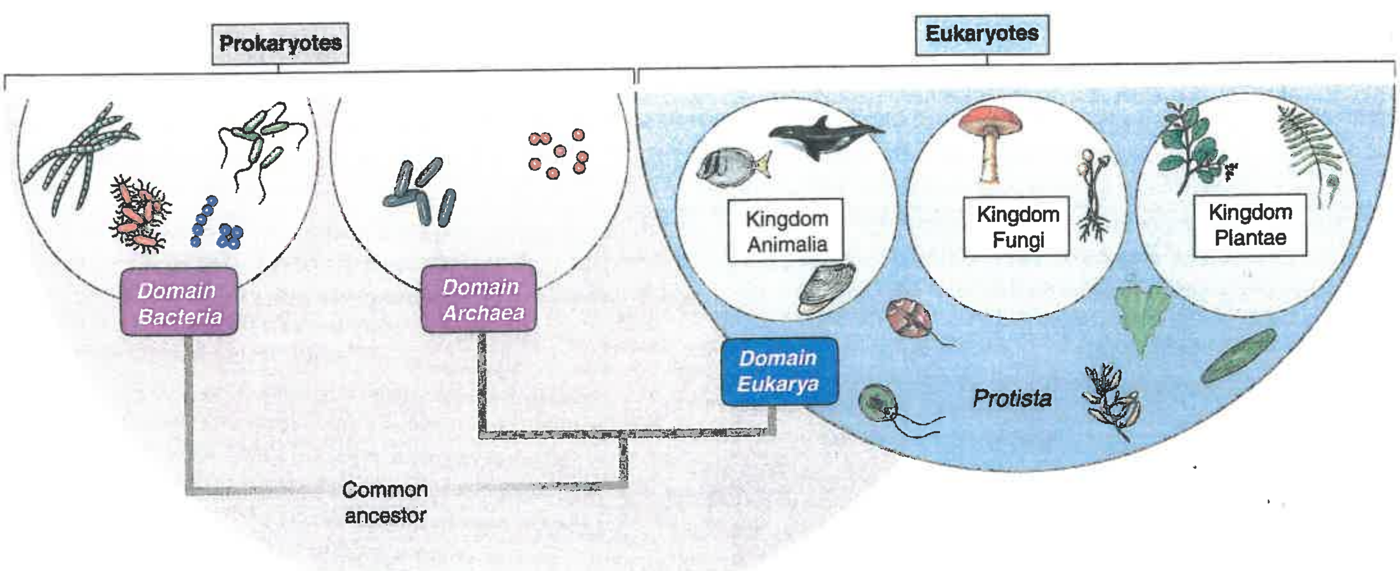


FIGURE 4.24 The major groups of living things.

Interactive Exploration

The *Marine Biology* Online Learning Center is a great place to check your understanding of chapter material. Visit **www.mhhe.com/castrohuber9e** for access to interactive chapter summaries, chapter quizzing, and more! Further enhance your knowledge with videoclips and weblinks to chapter-related material.

Critical Thinking

1. During the day, algae carry out both photosynthesis and respiration, but at night, when there is no light, they can only perform respiration. Small, isolated tide pools on rocky shores are often inhabited by thick growths of seaweeds, which are algae. Would you expect the amount of oxygen in the water to differ between night and day? How?
2. The cells of some marine organisms are known to have high concentrations of ions found in minute amounts in seawater. Could these organisms accumulate the ions by diffusion? Formulate a hypothesis to explain how this accumulation is accomplished. How might this hypothesis be tested?

For Further Reading

Some of the recommended reading may be available online. Look for live links on the *Marine Biology* Online Learning Center.

General Interest

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