CHAPTER 15

MICROBES

In This Chapter

- Classifying prokaryotes
- Bacteria and Archaea
- Beneficial and harmful prokaryotes
- Viral reproduction and evolution
- Naked pathogens: viroids and prions

Microbes have ruled the earth for about three billion of the roughly four billion years life has existed. They were the first life forms to evolve, and today they number in the nonillions. That's 10 with 29 zeroes after it. If that doesn't convince you of their significance in biology, perhaps the fact that you yourself are home to entire communities of the little critters will get your attention. We use the term "microbes" to describe pretty much anything we can't see with the naked eye, but this chapter focuses on the prokaryotic and viral forms, with a few naked nucleic acid and protein examples tossed into the mix.

THREATENING PROKARYOTES, USEFUL HELPMATES

When we hear about food-borne bacterial outbreaks or flesh-eating bacteria, we can really start to get the wrong idea about microbes in general. Bacteria are everywhere, existing by the billions and trillions in and on us. You have entire specialized communities of bacteria occupying the crook of your elbow, while a whole different kind of community hangs out in your gut.

Our fear of bacteria has led to an unfortunate overproliferation of antibacterial products and antibiotic abuse, which has had the effect opposite that intended: we've ended up producing lots of bacteria that completely resist these chemicals. Check out the next bottle of antibacterial stuff you buy. It probably says that it kills 99-point-something percent of bacteria. Guess what happens to that other 0.point-something percent? It survives and makes a lot of completely resistant bugs.

> ***Bio Bits***
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> The first person to lay eyes on a bacterium was Antony van Leeuwenhoek, a Dutch scientist obsessed with microscopes, having made at least 500 of them. In the seventeenth century, he built microscopes that could magnify objects over 200 times, enough to view bacteria. He called these organisms "animacules." In a rather disgusting side note, he was also the first person to observe animacules in tooth plaque—his own, his family's, and that of two old men who had never cleaned their teeth their entire lives.

Never fear. The less of that kind of thing we use, the more the nonresistant forms will make a comeback. And even as we attack the prokaryotes we can reach, the world is literally crust to mountaintop, pole to pole packed with nonillions of the little microbes we can't spray away. Some of them are really quite interesting, so read on.

DIVERSITY

We can classify prokaryotes roughly based on their shape. Some are spheres, and we name them with terms that end in *–coccus,* which means spherical. Examples include the pathogenic strains such as *Streptococcus* and *Staphylococcus.* Other bacteria are shaped more like rods, and their names include the suffix *–bacillus.* Examples of these include the "friendly" bacteria in yogurt, the *lactobacilli.* The cell wall and the cytoskeleton determine the shape, and the shape in turn determines how a bacterium moves, eats, fights, and sticks to things.

We talk about bacteria as single-celled organisms. As with many things in biology, the line is not so clear cut. Prokaryotes can group together in colonies that take on specific forms, such as pairs or even long strings of cells encompassed by a shared sheath.

When they stick to a surface in layers, they form biofilms, which can be more than a foot deep in some cases. The line between multicellular and colonial can get muddied in these enormous groupings of bacteria as different areas of the film, microcolonies, serve different purposes for the film as a whole.

Bio Basics
The myxobacteria completely smudge the line between uni- and multicellular. They can aggregate under dire environmental circumstances and allocate different jobs to different cells in the group, depending on location, the very beginnings of multicellular existence.

Because even these classifications of bacteria—shape, behavior—yield groups that are too broad, we have historically divided them more specifically based on their metabolic activity. More recent classifications (and reclassifications, in many cases) rely on sequencing of a specific ribosomal subunit, *16S rRNA*, which can distinguish relationships among the species.

Even though the rapid growth of information about bacterial nucleic acid sequences sometimes does not support the established relationships based on metabolism, we still use basic metabolic criteria to group them: Where they get their carbon and where they get their energy help us classify what type of prokaryote they are.

One grouping is into lithotrophs, phototrophs, and organotrophs, all designated based on their initial source of energy. For example, lithotrophs (literally, "rock eaters") may turn to minerals from rocks, while the energy source for phototrophs is sunlight, and organotrophs must use organic molecules. The trophic requirements for any of these trophs, regardless of their prefix, include carbon for building organic molecules and energy for doing the building. As with harvesting of energy in cellular respiration or photosynthesis, much of this energy for building comes from falling electrons.

Bio Basics
When you see the word trophic or suffix *–troph* or *–trophic* in a term in biology, think energy intake.

Having only three groupings seems pretty straightforward until you dig into the minutiae of each one. Bacteria have a couple of choices for scrounging up carbon. They can be like plants and fix it from carbon dioxide or *inorganic carbon*, or they can be like us and obtain it from organic molecules. Which method they use also serves as a way to classify them, as does the kind of compounds they use as their electron source

> ***Definition***
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> The meaning of **inorganic carbon** has changed over the years. Today, carbon-containing compounds lacking hydrogen, such as carbon dioxide, are considered inorganic.

The lithotrophs alone are so diverse in terms of these other two parameters—carbon sources and electron sources—that a discussion of their subcategories could make up a chapter in itself. Here, we're sticking with a basic breakdown and a few examples.

Bacterial Energy Sources

Type	**Energy source**	**Special features**
Lithotrophs ("rock eaters")	Inorganic compounds (e.g., H_2, iron, ammonia)	Found in Bacteria and Archaea (methanogens, "methane producers"); usually autotrophs
Organotrophs	Organic compounds	Usually heterotrophs
Phototrophs	Sunlight	Bacteria (purple, green, cyanobacteria) and some Archaea (halobacteria); autotrophs

The Rock Eaters

A lithotroph uses inorganic molecules as an energy and electron source, such as hydrogen gas or minerals. You may recall from Chapter 7 of *The Complete Idiot's Guide to College Biology* that in cellular respiration, electrons stripped from the organic molecule glucose fell down the electron transport chain, the free energy of their fall harvested to build ATP. Lithotrophs do the same thing with their electrons; they simply use a different—and inorganic—source for them.

Bio Bits

Lithotrophic bacteria can turn up in strange places, including in a mutually beneficial relationship with the worms that live in boiling-hot deep-sea vents. Some plants have lithotrophic properties, as well.

Some lithotrophic bacteria fall into a broader group of organisms known as chemotrophs. A chemotroph obtains energy by oxidizing, or stripping electrons from, a molecule, usually a reduced compound (one that has some extra electrons hanging around). And every lithotroph requires a carbon source, which can help define them, too. Like plants, lithoautotrophs use CO_2, while lithoheterotrophs are like animals and rely on organic molecules. Lithotrophs known as mixotrophs can use either.

Lithotrophs can also be quite flexible about their starting material for energy capture, with some capable of capturing energy from organic compounds, as well as inorganic compounds. Not all lithotrophs have this flexibility, but the ones that do are called *facultative* lithotrophs. Those that must use inorganic compounds only are *obligate* lithotrophs.

Definition

Facultative means that an organism can live with it or live without it. A bacterium that can thrive with or without oxygen is a facultative aerobe. An **obligate** aerobe must have oxygen to survive.

Finally, a few lithotrophs are photolithotrophs, able to capture energy from the Sun. They also use inorganic molecules as electron donors and can use these molecules as energy sources when no sunlight is available.

As with all creatures on our island Earth, lithotrophs play their specific roles in the grand scheme of life. One of their key activities is the breakdown of rock into soil. If you think about it, dirt has to come from somewhere, and most of the plants that feed everything else on Earth require soil to grow.

In addition, their various activities with important members of the SPHONC required elements of life (Chapter 3, *The Complete Idiot's Guide to College Biology*), including nitrogen and sulfur, keep nutrients cycling through the food chain for the rest of us to use. The bottom line is that without lithotrophs busily creating a bottom line, none of us would be here.

Phototrophs

We encountered our first bacterial phototrophs in Chapter 8 of *The Complete Idiot's Guide to College Biology*, which highlighted the high-profile cyanobacteria. These blue-green bacteria (also erroneously called blue-green algae) make a critical contribution to life on Earth through their photosynthetic activity. Cyanobacteria perform photosynthesis in much the same way that plants do, but their phototrophic cousins, the purple and green bacteria, do it differently. Even stranger in their light-capturing processes are the *halophile* (salt-loving) Archaea.

Cyanobacteria use chlorophyll *a*, as plants do, as the major light-harvesting pigment. Green and purple bacteria use bacterial chlorophyll, which is different in structure from chlorophyll *a* and absorbs at different wavelengths. An additional and critical pigment in cyanobacteria is phycobiliprotein, which exist in phycobilisomes in the prokaryotes.

Comparison of Photosynthetic Processes

Feature	**Plant-like Photosynthesis**	**Bacterial Photosynthesis**
Organism	Plants, cyanobacteria	Purple bacteria, green bacteria
Pigment	Chlorophyll a, phycobiliprotein (cyanobacteria)	Bacterial chlorophyll
Photosystem(s)	I and II	I
Electron source	Water	Sulfur compounds, hydrogen gas, organic molecules

For the light reactions, all photosynthetic bacteria use Photosystem I (see Chapter 8 of *The Complete Idiot's Guide to College Biology*) in some form, in which NADPH can be the final electron acceptor. The more complex phototrophs, like cyanobacteria, also use Photosystem II, as plants do. But the electron source for phototrophic bacteria represents a divergence from plants. Plants, as we learned in Chapter 8 of *The Complete Idiot's Guide to College Biology*, split water. Phototrophic bacteria use all manner of electron sources, from hydrogen sulfide to hydrogen gas to organic molecules.

Because phototrophs are almost universally also autotrophs, they obtain their carbon by fixing carbon dioxide in the dark reactions.

Organotrophs (and Other Trophs)

Organotrophs are the metabolic opposites of lithotrophs. Where lithotrophs use inorganic molecules for energy, organotrophs, as their name implies, use organic sources. In addition, while many lithotrophs are also autotrophic, organotrophs are usually heterotrophs.

In general, if the carbon source is an organic molecule, the organism is likely a heterotroph; if carbon is obtained through fixation, as plants do in the dark reactions of photosynthesis, then the organism is likely an autotroph.

BENEFITS AND DRAWBACKS

Although the modern world is awash in antibacterial wipes, soaps, hand washes, and sprays, the fact is that most bacteria and their friends in prokaryoticity, the Archaea, do not harm or kill us. In fact, many of them help us, either directly in or on our bodies or indirectly through their contributions to the great chain of being or drug development. And let's not forget what we owe to them for their role in making great cheeses.

Plants

The best-known example of a good relationship between plants and bacteria is the one involving nitrogen-fixing bacteria. Soybeans, alfalfa, and other legumes have nodules on their roots. In these nodules reside bacteria specialized for grabbing nitrogen from the environment and rearranging it into molecules the plant can use for growth. This relationship is mutually beneficial and necessary to both plant and bacteria.

Animals

You may not realize it, but about 90 percent of the cells you're carrying around are actually bacteria residing in and on you. But don't freak out—they're almost all helping you, just as you are helping them.

Our intestinal microbes are a good example. The bacteria in our gut serve a variety of purposes, from helping to make vitamin K and a kind of vitamin B to helping us break down some of the carbs we take in. They also appear to play an important and beneficial role in the maturation of our gut lining and in keeping down the microbes that would do us harm. It's a battle royale down there in your intestines, with the good bacteria swarming and conquering invaders and yeast, keeping things in a healthy balance.

Making Antibiotics

Your gut is not the only microbial battlefront. Microbial wars rage all around us, in the soil, on surfaces, and in the water. Part of the weaponry in these battles are chemicals that will disable or kill the enemy. In some cases, we have commandeered these chemicals, known as antibiotics, to use in our own battles against bacterial invaders.

Bio Bits

Fungi and bacteria are generally sworn enemies, and many of us owe our lives to this enmity. Alexander Fleming discovered penicillin in 1929 thanks to the weaponry of the mold *Penicillium notatum*. This mold (a fungus) produces a toxin to battle *Staphylococcus aureus* bacteria, something Fleming discovered when he accidently let the mold invade his bacterial culture dishes. This discovery led to the purification of this toxin as the antibiotic penicillin.

What are the microbes fighting about? What anything in nature fights for: resources like food, water, and habitat.

Causing Disease

In spite of their many helpful contributions, it is true that lots of bacterial strains can make us feel awful or even kill us. Before Louis Pasteur discovered in the nineteenth century that heat killed bacteria, people suffered frequently from food-borne bacterial illnesses or hospital-transmitted infections. Even today, we have outbreaks of salmonella poisoning thanks to contaminated foods.

Bio Bits

Louis Pasteur is probably most famous for his discovery that heating food products to a specific temperature will kill bacteria contaminating it, a finding that led to the process of pasteurization we still use today.

We can ward off some bacterial diseases thanks to vaccinations. These diseases include pertussis (whooping cough) and some kinds of bacterial meningitis. Other bacterial diseases, including strep throat and some pneumonia-causing bacteria, remain responsive to antibiotics.

But with our use and misuse of antibiotics, we have also engaged in directional selection for bacteria that resist these chemicals. The most high-profile of these are the resistant tuberculosis strains, some of which now remain unresponsive to our most powerful antibiotics.

ARCHAEA: WEIRDOS OF THE PROKARYOTIC WORLD

To find Archaea, look where you think nothing can live. In the boiling hot ocean vents, you'll find the thermophiles. In waters with extreme pH values, you'll find acidophiles. In the gut of a cow (no place for most organisms), you'll find methanogens, diligently producing that characteristically cow-related gas, methane. In highly salty environments, you'll find the halophiles. Archaea are even enjoying the high life in petroleum deposits that never see the light of day and deep in marshy muds.

VIRUSES: DEATH-DEALING PARASITES?

Viruses have plagued (really, really plagued) the human species since its beginnings. They don't have anything against us, but they can literally be mindless killing machines. In addition, they may do nothing to us directly but can disable species on which we rely to survive. They're not only threaten us, they threaten our pets, our plants, and our personal pleasures.

Biohazard!

Want to avoid picking up a viral illness? Your best bet is frequent handwashing or use of alcohol-based disinfectants. Handwashing should be thorough and soapy.

Around our house, when it's time for a major holiday and some good, relaxing family fun, a virus will inevitably appear and have us all hurling within days of each other. How do they do it? The answer lies in their reproduction: fast, furious, and ultimately destructive.

Bio Basics

Viruses don't confine themselves only to animals. Plants can also contract viruses. One of the best-known plant viruses is the tobacco mosaic virus, which leaves a characteristic mottled, or mosaic, appearance on the plant leaves.

Reproduction: A Deadly Cycle

The rapid reproductive rates of viruses is one reason for their usefulness in evolution and genetics studies. Take the bacteria-infecting bacteriophages we met in Chapter 13 of *The Complete Idiot's Guide to College Biology*. These viruses can be fairly harmless or acutely deadly to a bacterium. If the viral reproductive cycle is a low-key version, the viral DNA simply incorporates into the bacterial genome and sits there as the bacteria divide. The lying-low version of the virus is known as a prophage, and as long as it just hangs out in the host DNA, replicating along with the host, everything is fine. This lysogenic cycle can continue for several bacterial divisions.

But once the copied viral DNA leaves the host genome and contributes to making new viruses, everything changes. The bacteriophage enters its lytic cycle. The virus uses the host's machinery to make a lot of new viruses that then repay the host's services by breaking up the cell membrane and escaping. The cell dies as a result of the destruction. Viruses can have much the same effect in us.

Evolution: A Constant Threat

That rapid turnover of new viruses can translate into rapid accumulation of mutations, which can make viruses useful for studying mutation rates in the context of evolution. Considering that a basic norovirus (famous for afflicting cruise ship passengers) can build up a critical and disease-causing viral load within 24 hours of infection, there are literally trillions of opportunities for new changes to arise.

We can vaccinate against some of the more stable varieties, such as the virus that causes polio. But viruses with high mutation rates, such as the influenza viruses, keep us on our toes. Every flu season requires the development of a new flu vaccine. And every flu vaccine is really the health authorities' best guess for which viruses may be coming down the pipeline that year.

The biggest concerns involved with the capacity of some viruses to mutate rapidly are the possibility of increased *virulence* and the development of drug resistance.

> ***Definition***
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> **Virulence** refers to how infectious a pathogen is and how dire the consequences of infection may be. A **pandemic** occurs when an illness outbreak affects two or more geographic areas around the globe, such as occurring on two continents.

And then there are the ongoing fears that a new flu strain will arise and cause a global and deadly *pandemic*. The tendency of influenza viruses to mutate rapidly feeds these fears. No one can predict whether this process of change will maintain a virus's current state or produce a virus with greater or lesser virulence. That's one of the problems with these viruses: they're so unpredictable.

> *Bio Basics*
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> Many influenza viruses arise from animals we live near, like ducks and pigs. Pigs pose a specific threat. They can pick up infections from humans and birds, serving as a mixing vat of different viruses. Infectious disease specialists fear that these porcine pathogen vats will produce a deadly mixture of bird, swine, and human virus that transmits easily from pig to human and from human to human. The 2009 H1N1 viral pandemic seemed to confirm those fears.

PATHOGENIC PARTICLES: VIROIDS AND PRIONS

Sometimes, microbes that can kill are even simpler than viruses. Plants are specifically susceptible to plain old naked, single-stranded RNA pathogens called viroids. These RNA sequences may catalyze their own reproduction, but they don't encode proteins. Instead, they may cause symptoms in plants by blocking the messenger RNA in the plants themselves. No access to the mRNA means no proteins, leading to plant disease.

Another naked pathogen is the prion, which affects animals. Prions, rogue proteins that go around turning other proteins "bad," were first identified in the 1980s. They're responsible for several degenerative brain diseases, including the infamous "mad cow" disease. In these disorders, the rogue proteins tap normal proteins to go rogue as well, leading to clumping of brain proteins. This clumping manifests literally as holes in the infected brain tissue.

The Least You Need to Know

- Prokaryotes can be classified as lithotrophs, phototrophs, or organotrophs based on their energy sources, with more classification based on carbon sources.
- Autotrophs build organic molecules using fixed carbon, while heterotrophs acquire their carbon from organic molecules.
- Not all bacteria are disease causing, and some are in fact beneficial to ecosystems and individual organisms.
- Archaea are spectacularly capable of living in some of the most inhospitable places on Earth.
- Viruses cause disease by hijacking the host cell's machinery to make more viruses that destroy the host while exiting.
- Other pathogens include viroids and prions, naked particles that infect plants and animals, respectively.