MICROBES

The Good, the Bad, the Ugly

Table of Contents

The Story Behind the Scenes

Conrad Storad
The Story Behind the Scenes

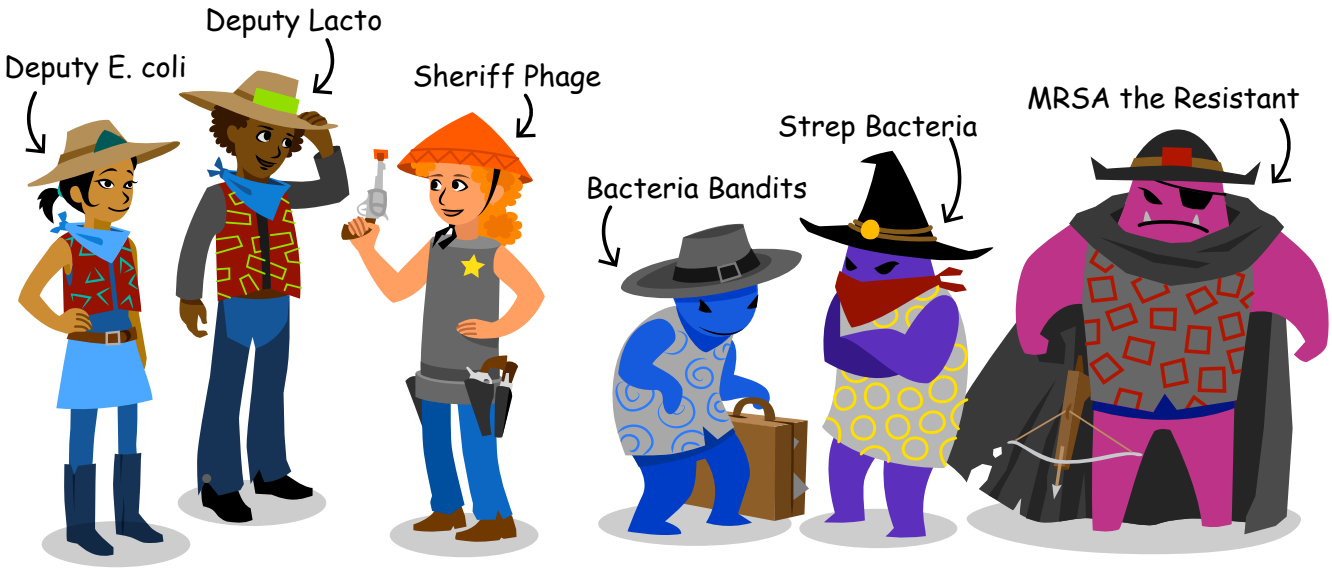
Karla Moeller
Editor

Sabine Deviche
Illustration, Design and Original Script

Gustavo Castaneda
Additional Illustration for Story Behind the Scenes

Web Version
askabiologist.asu.edu/microbes

Microbes is printed on FSC certified paper



Prologue

You may already know that some bacteria can make you sick. Unlike the bacteria that cause diseases and infections, most of the bacteria inside you right now are harmless and live peacefully side by side with the cells of your body. These bacteria work together with your cells to keep other unwanted invaders away and to help keep your body running smoothly.

Cast

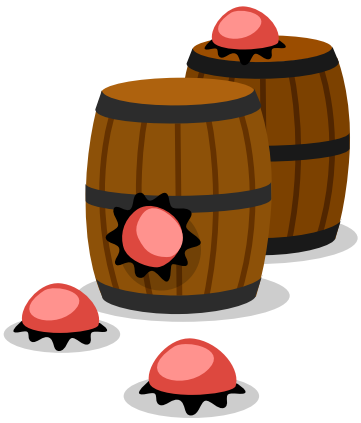
In this story, you will see how good bacteria, antibiotics, and new technologies help keep the bad guys from taking over the body. Many bacteria appear throughout this story. They come in many different colors, shapes, and sizes.

Learn More

This icon lets you know that there is more you can learn about this topic in the Behind the Scenes story.

Words to Know

If you find an **orange** word in the Story Behind the Scenes that you don't know, you can find out what it means by looking in the Words to Know on page 28.



Our story takes place in the tiny hidden world inside your body...

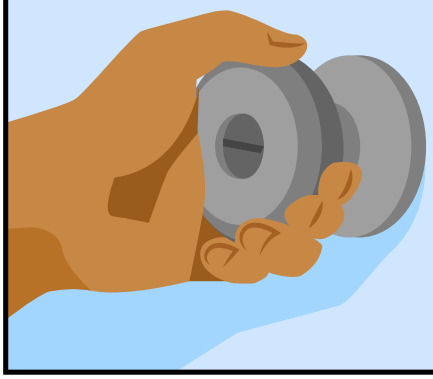
You might not realize it, but you are home to **trillions** of bacteria, tiny life forms too small to see without the help of a microscope.

Bacteria come here from many different places.

Some float through the air in tiny particles of water.

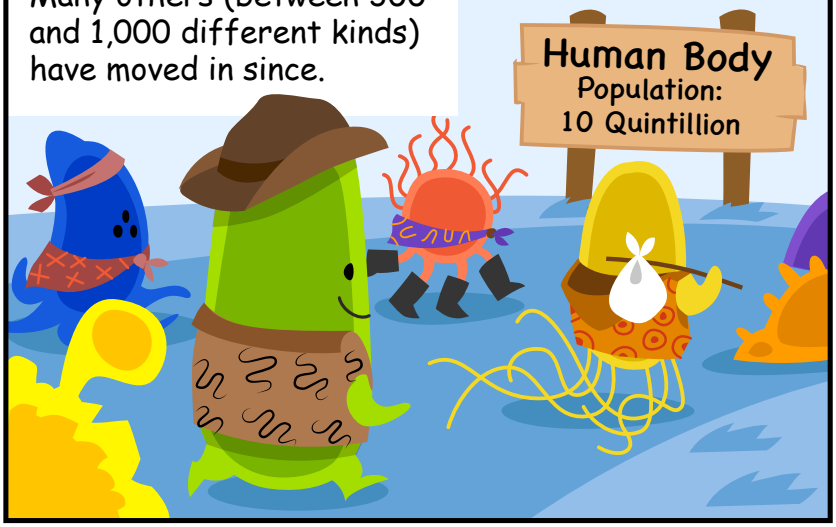
Others hitch a ride down the digestive system with the food you eat.

Some hop from person to person through the objects we touch, like money or door knobs.

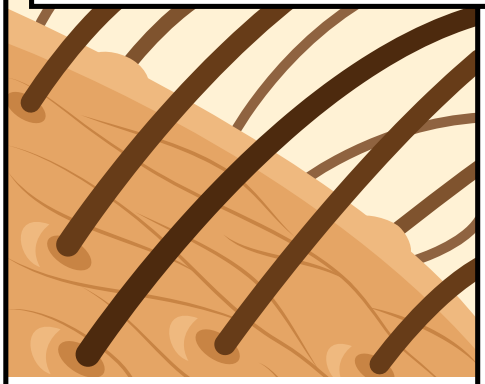


Some kinds have lived here since the very beginning, when your body was just a couple days old.

Many others (between 300 and 1,000 different kinds) have moved in since.

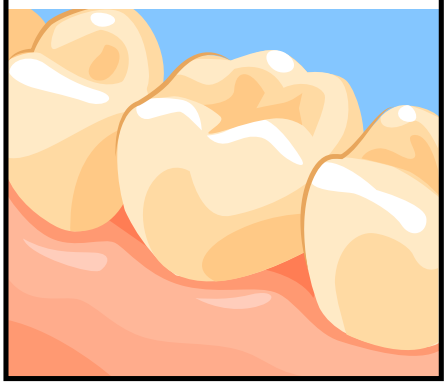


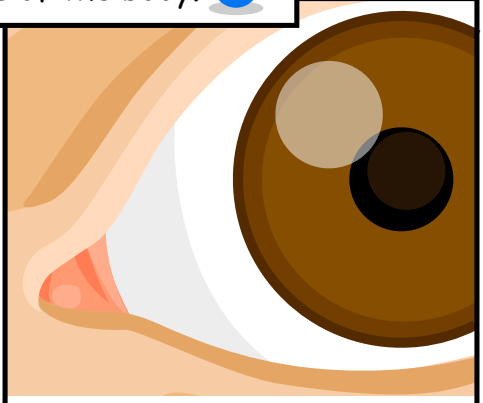
Thriving bacterial communities exist in many different parts of the body.



Some live on the surface of your skin and on the hairs of your scalp.

Others make themselves at home in the plaque inside your mouth.

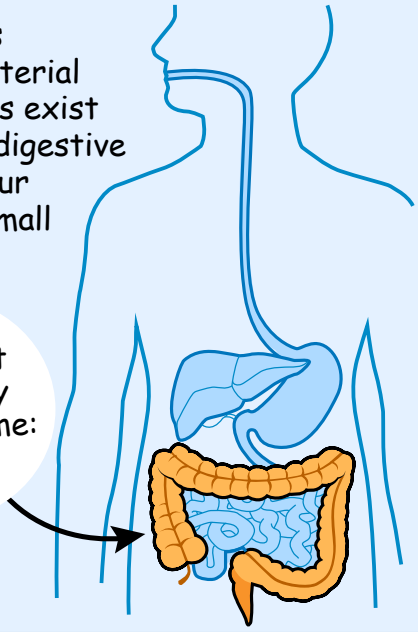




Little colonies even exist under your eyelids, on the surface of your eyes.

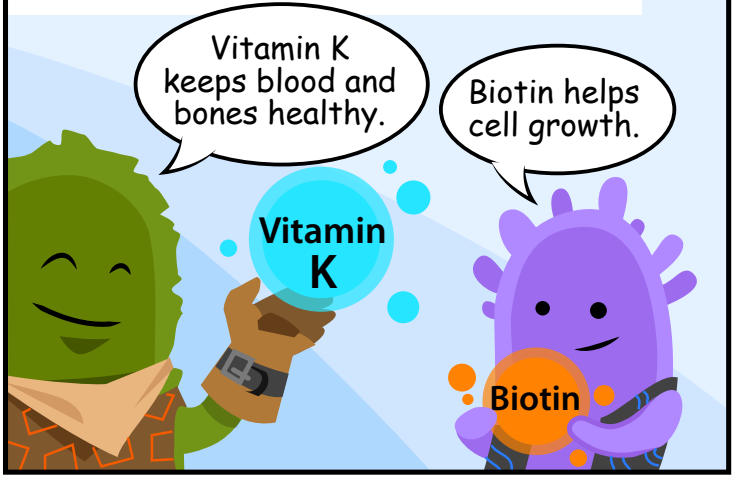
Your body's largest bacterial communities exist along your digestive tract, in your large and small intestines.

You might know it by another name: **your gut**.



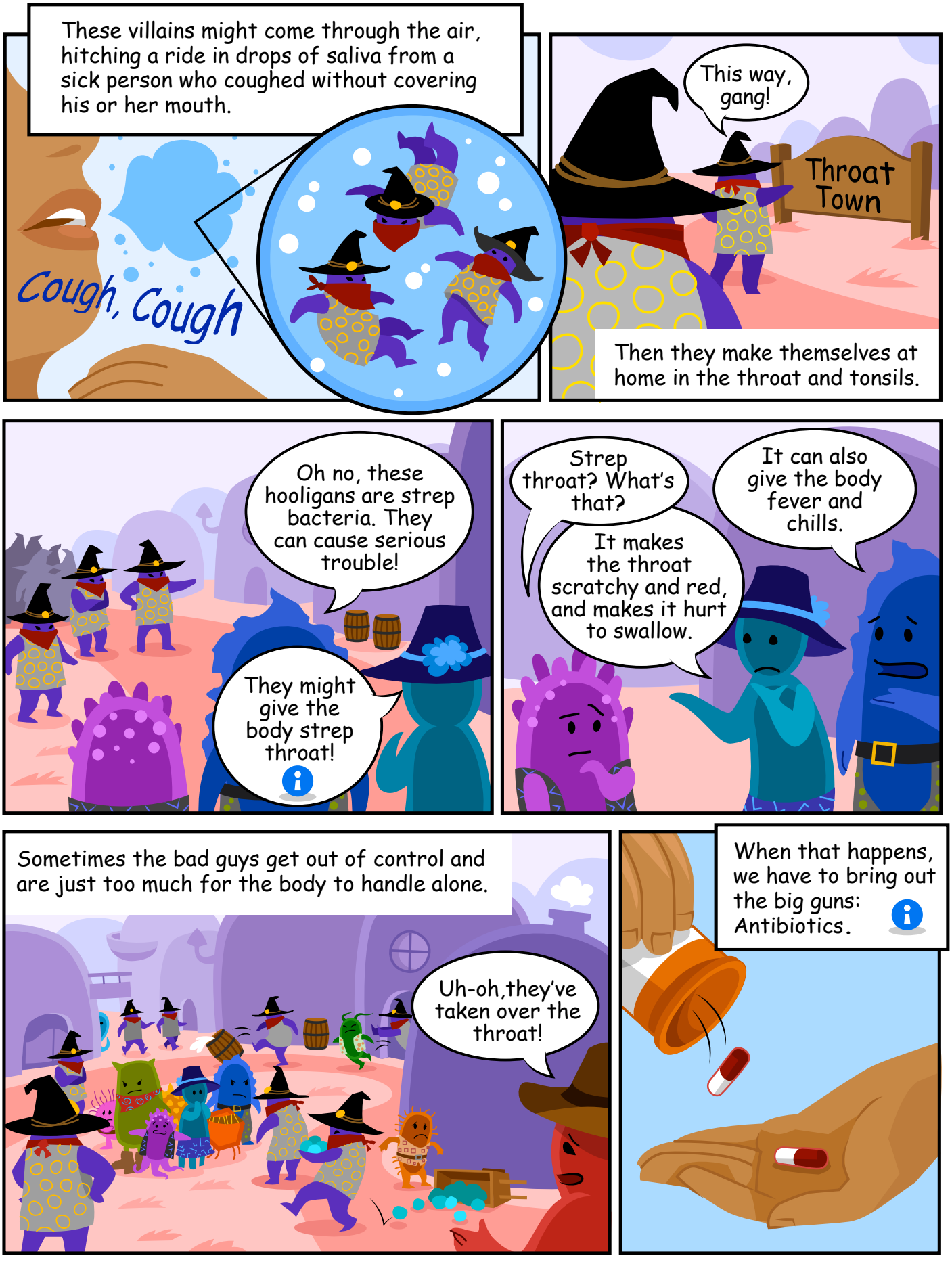
Most folks in this town are good, helpful, law-abiding bacteria.

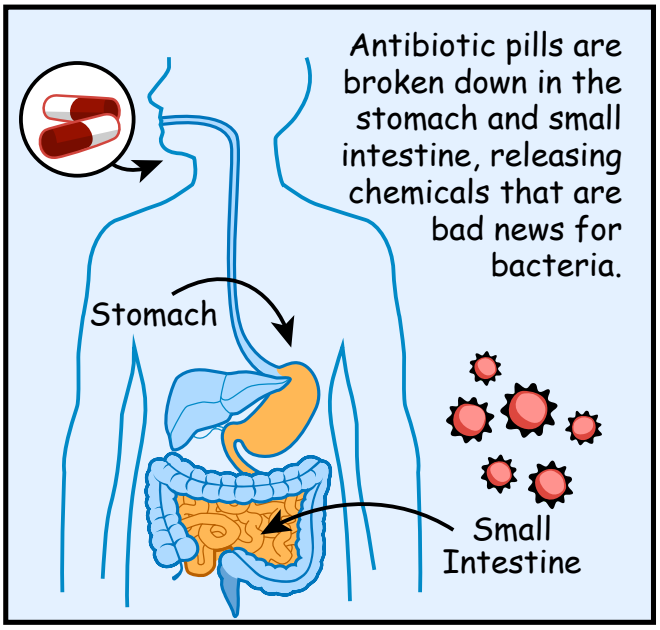
They help with digestion and make important vitamins the body needs.

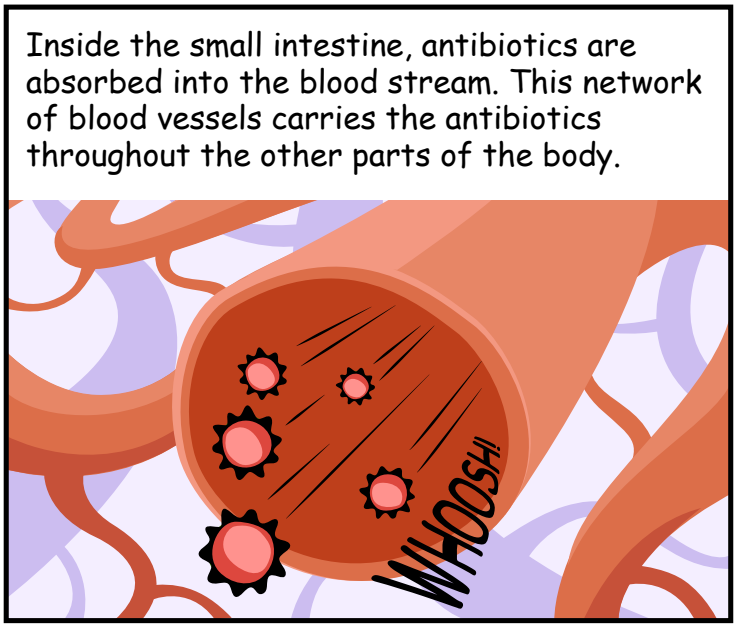


Once in a while, some pretty unsavory characters come to visit...

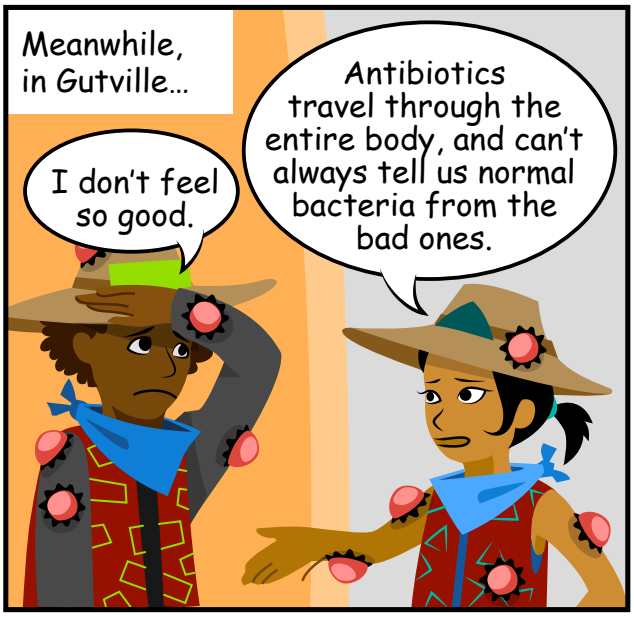

Let's meet the heroes of our town. When bad bacteria come to visit, it's up to these deputies to keep bad guys from making themselves at home.
How about that one?
Looks like we found our new home!
Howdy, I'm deputy Lacto.
Meet my partner, deputy E. coli.
So, what brings you to Gutville?
Woah, you don't belong here.
We're looking for a place to stay.
There's no room here for you folks.
Move along now!
EXIT
Usually, the body's defenses can keep the bad bacteria from sticking around.
Good job, partner!
Other unwelcomed visitors aren't quite so easy to get rid of...

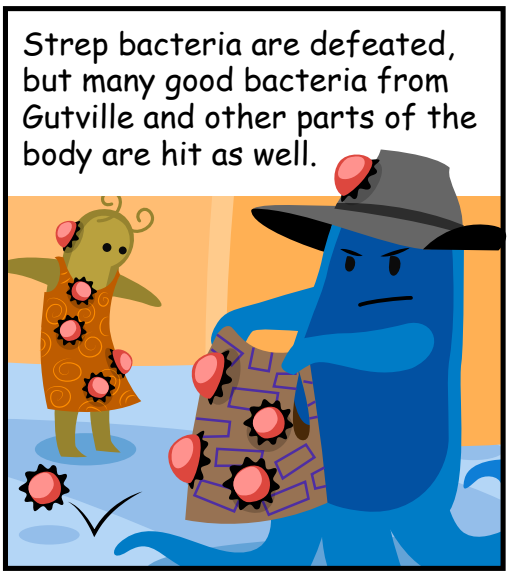

These villains might come through the air, hitching a ride in drops of saliva from a sick person who coughed without covering his or her mouth.
Cough, Cough
This way, gang!
Throat Town
Then they make themselves at home in the throat and tonsils.
Oh no, these hooligans are strep bacteria. They can cause serious trouble!
They might give the body strep throat!
Strep throat? What's that?
It makes the throat scratchy and red, and makes it hurt to swallow.
It can also give the body fever and chills.
Sometimes the bad guys get out of control and are just too much for the body to handle alone.
Uh-oh,they've taken over the throat!
When that happens, we have to bring out the big guns: Antibiotics.


Antibiotic pills are broken down in the stomach and small intestine, releasing chemicals that are bad news for bacteria.
Stomach
Small Intestine


Inside the small intestine, antibiotics are absorbed into the blood stream. This network of blood vessels carries the antibiotics throughout the other parts of the body.
WHOOSH!!


Back in Throat Town, the antibiotics are working!
Let's get out of here, quick!


Meanwhile, in Gutville...
I don't feel so good.
Antibiotics travel through the entire body, and can't always tell us normal bacteria from the bad ones.


Strep bacteria are defeated, but many good bacteria from Gutville and other parts of the body are hit as well.


The once-thriving bacterial communities throughout the Human Body are now ghost towns.

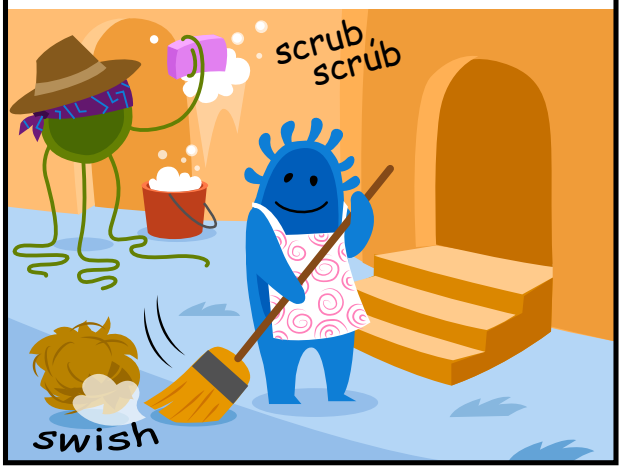
It takes about 3 days for antibiotics to leave the body after the last pill is taken.

To help normal bacteria return, a doctor might recommend eating yogurt.

Why yogurt?

It's full of good bacteria called cultures, or probiotics.

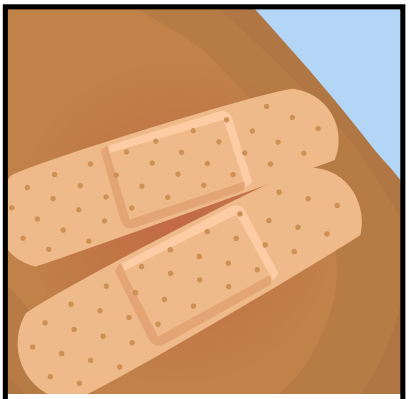
Bit by bit, good bacteria return. New bacteria move in to fill the empty spaces left behind.



Large families of bacteria move in with the yogurt and other foods.

It doesn't happen overnight but after a while, the towns are back to normal and running smoothly again.

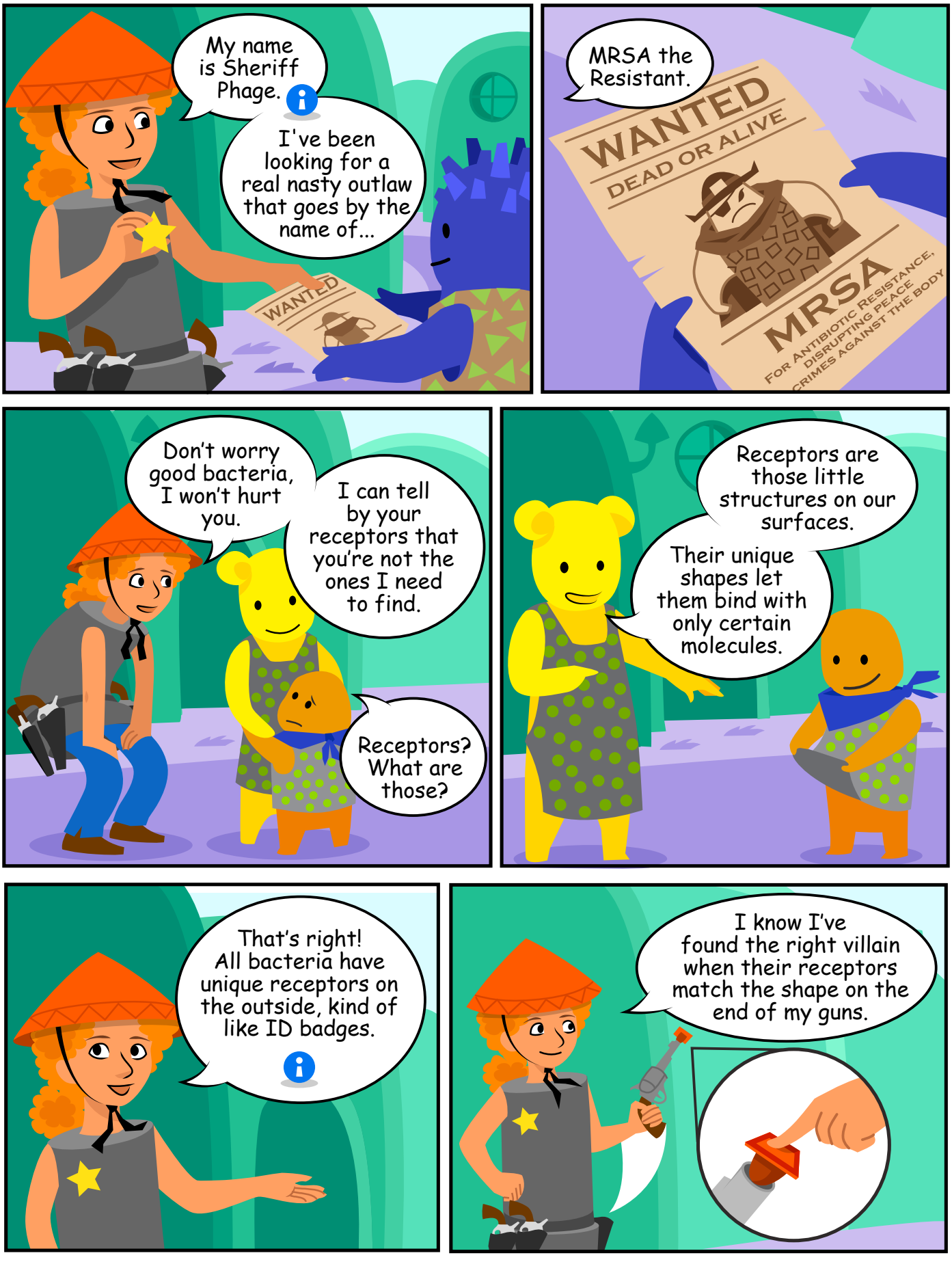
But peace and quiet might not last. One day a new band of strangers appear.



A few came in through a cut in the skin that wasn't properly washed, and they multiplied fast.

They were soon on the move, using the blood stream to travel to other parts of the body.


MRSA sets up camp in many places such as the lungs, bone, blood, and skin.
Let me introduce myself: I'm MRSA the Resistant.
My gang and I are taking over the entire body!
Better move along MRSA, you're not welcome here!
We know just what to do with your type...
More antibiotics were taken to try to get rid of MRSA. This time, however, something unexpected happened...
Hahaha, you can't hurt me!
Oh no, the antibiotics aren't working!
Taking more antibiotics will only end up hurting us good bacteria.
We're in serious trouble!
This is where cutting edge nanotechnology comes to the rescue!
Who's that??
Howdy, folks!
Nanotechnology deals with making new materials and medicines out of tiny building blocks such as atoms and molecules.


My name is Sheriff Phage.
I've been looking for a real nasty outlaw that goes by the name of...
WANTED
MRSA the Resistant.
WANTED
DEAD OR ALIVE
MRSA
For Antibiotic Resistance, Disrupting Peace, Crimes Against The Body
Don't worry good bacteria, I won't hurt you.
I can tell by your receptors that you're not the ones I need to find.
Receptors? What are those?
Receptors are those little structures on our surfaces.
Their unique shapes let them bind with only certain molecules.
That's right! All bacteria have unique receptors on the outside, kind of like ID badges.
I know I've found the right villain when their receptors match the shape on the end of my guns.


I get it now!
My receptors don't match so you know I'm not MRSA.
Yes, exactly!
Phage Virus... we meet again!
MRSA the Resistant.
This body isn't big enough for the both of us.
rustle... rustle...
GASP!
whoosh!
click-click
BANG!

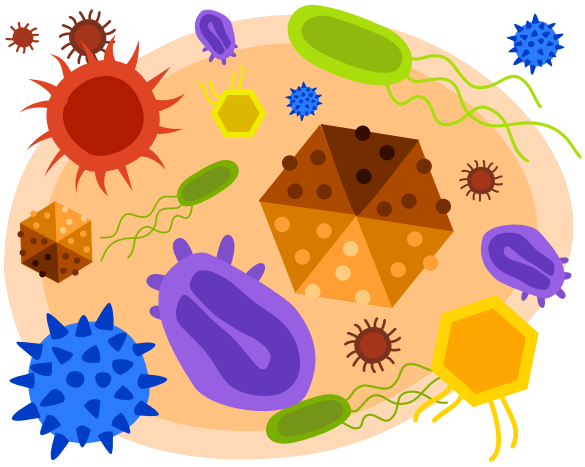

Gahhh!
Thunk!
Zap!
Urg...
whoosh
Phage Virus just defeated the boss!
Ok, who's next?
We better get out of here quick!
Thank you so much!
You spared us good townsfolk from MRSA's gang when antibiotics weren't enough.
No problem! My work is not finished yet.
My posse of phage viruses will keep looking for MRSA's gang.
We won't rest until all of those villains have been defeated.
THE END
Good luck!
Bye!
The body can rest soundly again, knowing it's safe thanks to our heroes watching over it.


The Story
Behind the Scenes
Microbes
DATE
SCENE
TAKE

Bacteria Overview

The world is alive with tiny things too small for the human eye to see. In fact, these living things are so small that we call them **microorganisms**. Many microorganisms (also called **microbes**) are made of a single cell, like **bacteria**.

Bacteria were among the very first life forms to appear on Earth. Thousands of types of bacteria are known. Many more kinds have not yet been described or even discovered. Scientists who study bacteria are called or bacteriologists.



A very small world

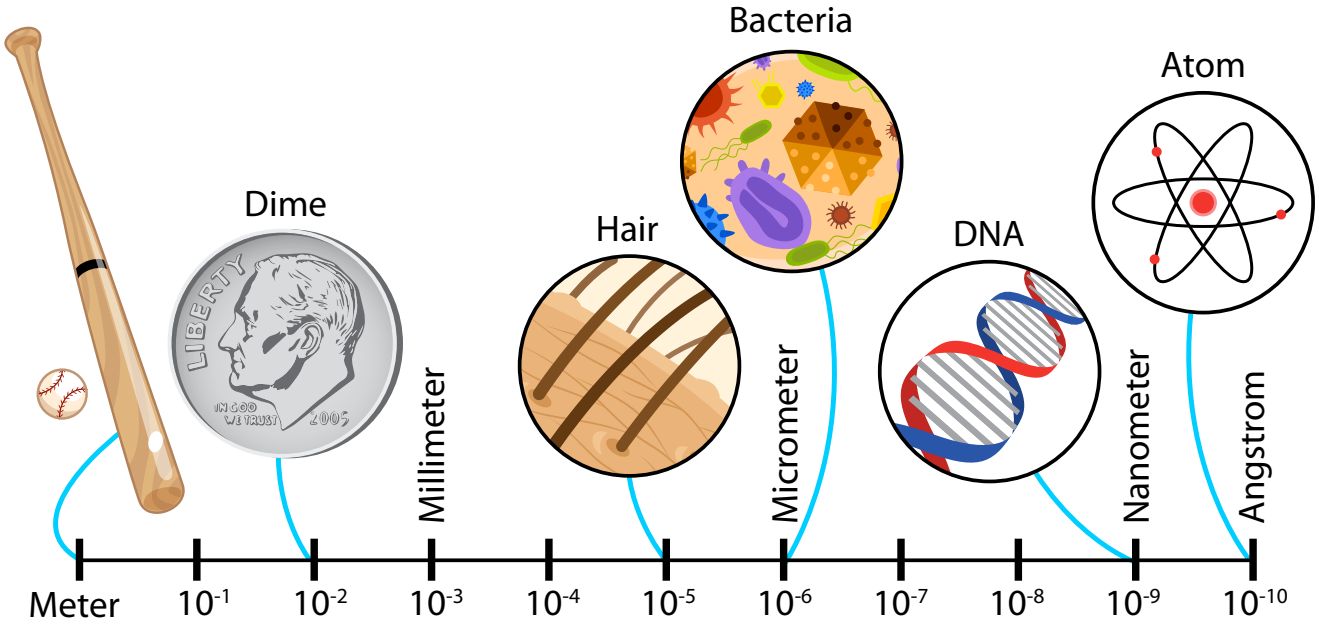
Size does matter and bigger does not always mean better. Bacteria are small. According to experts at the Centers for Disease Control in Atlanta, Georgia, the average human being on Earth today is a little more than 5 feet 9 inches tall. The average microbe is a million times smaller.

Measuring things as small as bacteria can be very difficult. Feet and inches just do not work well at all. To make it easier, scientists use the metric system.

The metric system

A meter is a standard metric unit of length. One meter is equal to 100 centimeters or 1,000 millimeters. It is equal to about 39 inches. That is just a bit longer than a yard stick.

But meters are still way too big for measuring bacteria. So are centimeters and even millimeters. Scientists use the terms microns or micrometers to measure microbes. One micrometer is the same as one micron. One micron is equal to one millionth of a meter. Most bacteria are from 1 to 10 micrometers long.



For every step down in scientific notation (10^{0} to 10^{-1}), an item gets 10 times smaller. 10^{-5} is 1,000 times (10 x 10 x 10) smaller than 10^{-2}.

A matter of scale

Just how many bacteria live on and inside our body at any one time? The number is big. Very big. The number is so huge it can be hard to understand. Having a sense of scale can help. That means being able to compare one number with another.

For example, think about it this way. Scientists estimate that there are about 5 million (5×10^6) hairs on the average human body. There are about 7 billion (7×10^9) capillaries to transport blood rich in oxygen from the arteries to all the cells in the body. The average body has 25 trillion (2.5×10^{13}) red blood cells. And the body itself is made up of 60 trillion (60×10^{12}) cells.

Those are big numbers. But they are small when compared to the numbers of bacteria living on and inside the average human body. *Escherichia coli* is one of the most common types of bacteria found in the body. It lives in our digestive systems.

E. coli, one of the most common types of bacteria found in the human body. Image from Mattosaurus.

Consider this

What if one single *E. coli* bacterium was allowed to reproduce under perfect conditions? After just one day there would be 10×10^{28} *E. coli* bacteria.

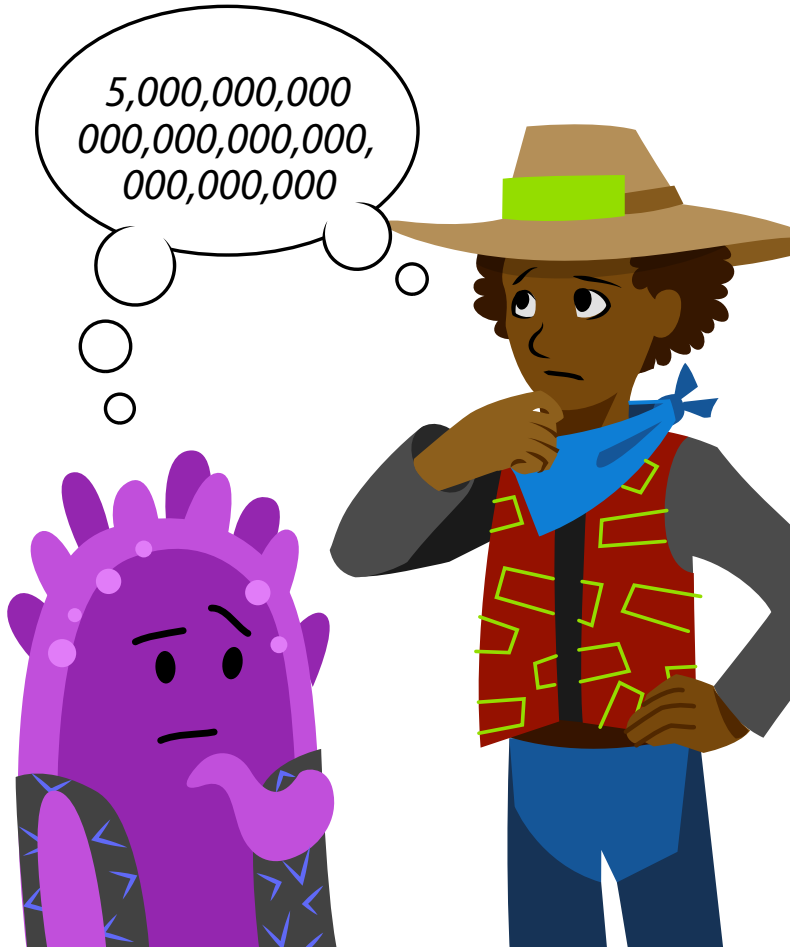
That is 100,000,000,000,000,000,000,000,000,000 bacteria! Luckily, the human body keeps bacteria from growing out of control most of the time.

Where do bacteria live?

Bacteria live everywhere. There are trillions upon trillions upon trillions of bacteria. Scientists estimate that 5×10^{30} bacteria live on our planet at any one time. What does that mean? Written out, that would be 5,000,000,000,000,000,000,000,000,000,000 bacteria. That's a LOT of bacteria!

Many bacteria live on, in, or under the soil. One gram of soil, which is about how much you might pinch between two fingers, may contain as many as 40 million bacterial cells. Some bacteria live in water, with over a million bacteria in just a few drops. Bacteria live on the outside and inside of plants and animals.

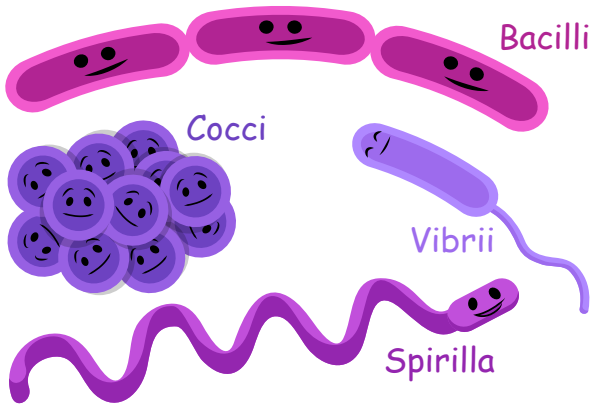
Clumped together, all of those bacteria would weigh much more than every animal and plant living on Earth, combined.

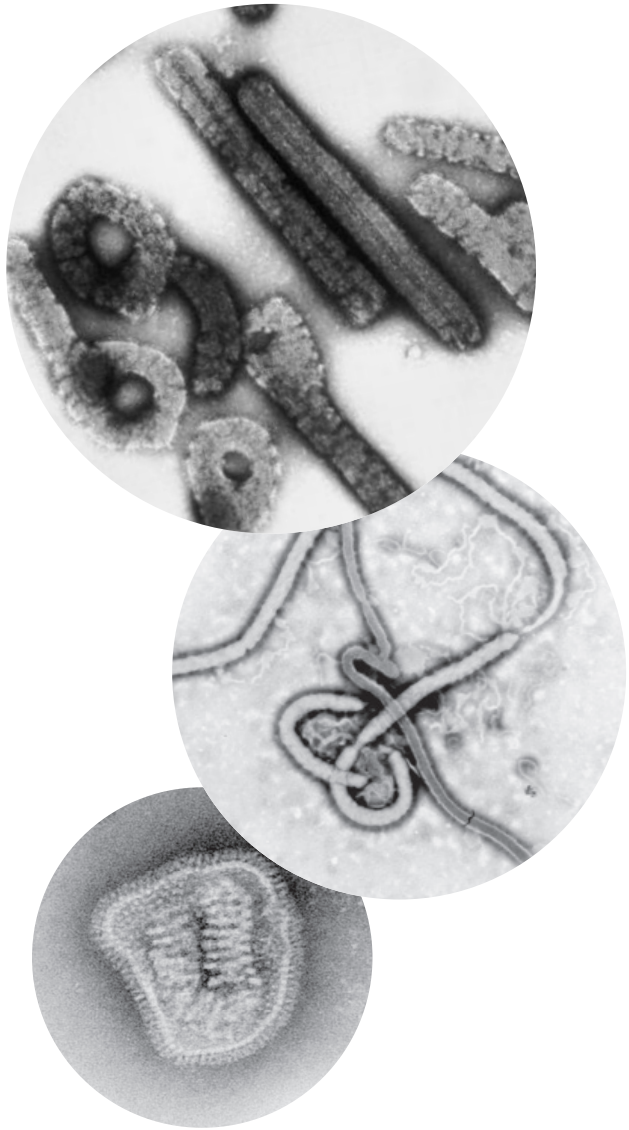


Rods, spheres, and spirals

Bacteria come in many common shapes and sizes. Some look like spheres. These bacteria are known as cocci. Some bacteria are shaped like rods. These are bacilli. Some bacilli are long, skinny rods. Others are short, fat rods (coccobacilli). Other bacteria look like spirals or little corkscrews. They are called spirilla. Still other bacteria are shaped like commas. They are known as vibrii.

But not all kinds of bacteria fit these four common shapes. There are rare types that actually look like stars or squares and some bacteria have no regular shape at all.





Top: Marburg virions from CDC, E. Palmer, R. Regnery.
Middle: Ebola Virus from CDC, F. Murphy.
Bottom: Influenza virus from CDC, E. Palmer, R. Regnery.

Viewing the microworld

Any living thing can be called an organism. Whales, redwood trees, horses, and people are large organisms. Microscopic organisms include protozoa, bacteria, and fungus.

You might be wondering about viruses. Viruses are the smallest germ that we know, but they aren't really considered organisms. They require the living body of another organism to make more viruses. Although they aren't microorganisms, they are definitely very tiny.

They exist in what scientists call the submicroscopic world. Let's compare size. Most common bacteria are about 1 to 2 microns in diameter and 5 to 10 microns long. A micron is one millionth of a meter, or 1/100,000th of a centimeter.

The human eye is amazing. Still, unaided, the smallest objects our eyes can see are about 100 microns long. That is 1/10th of a millimeter. Under perfect conditions, without using magnification, you might be able to see a large microbe such as an amoeba or a paramecium. Using a magnifying glass would help, but only a bit.

Scientists use light microscopes to study bacteria and other larger microbes. These instruments use a system of lenses to magnify an image. It is possible to see structures inside a cell. You can see the nucleus, mitochondria, chloroplasts, and other structures as well.

The human eye can see particles as small as 0.2 to 1 micron in diameter but only with the help of the very best light microscope. Viruses are much smaller. Scientists need powerful electron microscopes just to see their outlines.

Viruses range in size from 20 to 200 millimicrons in diameter. One inch contains about 25 million millimicrons. The most powerful light microscopes can bring bacteria into view, but not viruses.

Seeing "little animalcules"

The first real microscopes were built in the early 1600s. They were not very powerful. Scientists used these devices to magnify things only about 20 to 30 times their normal size. In the 1660s, a Dutch craftsman named Antonie van Leeuwenhoek devised ways to make better microscopes. His simple devices were much more powerful than those used by anyone else in the world at that time.

Van Leeuwenhoek made microscopes that could magnify things to more than 200 times their normal size. He was the first person to see bacteria and write about them. Because of his detailed work, van Leeuwenhoek is called the "Father of Microbiology."

Van Leeuwenhoek wasn't like most scientists living in the 1600s. He didn't come from a rich family. He didn't have a university diploma or any special education in science. But he was a skilled lens maker. And he was very curious about the world around him. Van Leeuwenhoek used his skills to build the best microscopes of his time. He used them to examine samples of all kinds.

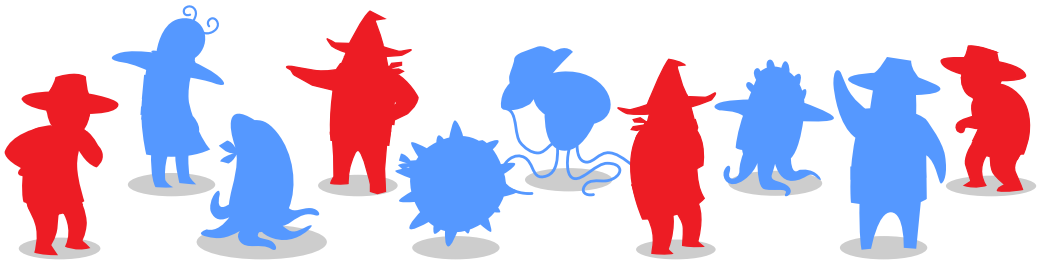
The Dutch scientist saw things that no one had ever seen before. Almost every sample he examined was full of little life forms too small to see with the unaided eye. Van Leeuwenhoek called these tiny organisms "little animalcules."

Like a true scientist, van Leeuwenhoek spent a lot of time recording what he saw in great detail. He was very patient setting up samples and lighting to get the best possible view. He was the first to observe and describe bacteria. He also saw muscle fibers and blood cells flowing in the tiny vessels we know as capillaries.

Top: Antonie van Leeuwenhoek, 1680.
Image from Jan Arkesteijn.

Left: Reproduction of Leeuwenhoek's microscope.
Image from Science Museum, London.

Identifying Bad Bacteria



Figuring out the "bad guys"

Many important discoveries in microbiology happened during the 1800s. Two major questions needed answers. First, did microbes just suddenly (**spontaneously**) appear in rotting material? Many scientists back then thought that microbes could grow in dead material without being produced by other microbes. If the microbes didn't appear spontaneously, they would have to come from some other process.

The great French scientist Louis Pasteur found the answer. He showed that boiled water or any type of material in which all microbes were killed or removed (called **sterilized**) would remain clear of bacterial growth. This meant microbes did not spontaneously grow. However, sterilized fluid would only stay free of bacteria as long as bacteria carried in the air did not "infect" that fluid.

The second question seems silly today. Scientists wanted to know whether microbes cause specific diseases. If they did, how could one be sure which microbe was responsible? Which bacteria were good and which were bad?

Robert Koch was one of many who took on the task of answering this question. The German scientist developed a set of rules, or **postulates**. Koch's rules help us tell the difference between actual disease-causing microbes and those that are harmless.

Today, scientists still use Koch's postulates. For a microbe to be considered a disease-causing agent, Koch's rules state the following:

1. The microbe must be regularly found in the diseased tissue (like in the wounds caused by certain diseases).
2. The microbe must be able to be grown alone (called **cultured**), without other bacteria. (Keeping unwanted microbes out is important to this process.)
3. If you introduce the microbe culture into an organism that could carry the disease, it should cause the disease.
4. The same microbe should be found once again in the diseased tissue of the new host.

Koch used his own postulates to learn about **anthrax**, a life-threatening disease. He showed that anthrax in cattle was caused by a bacterium. Scientists began classifying all kinds of bacteria and the diseases they caused by using Koch's ideas.

The Human Microbiome

Trillions of bacteria and other microbes live all over the outside and inside the human body. Altogether, these microbes are called the human **microbiome**. Many types of bacteria have a bad reputation. They cause all sorts of illness and disease. But other kinds of bacteria do many helpful things in the body.

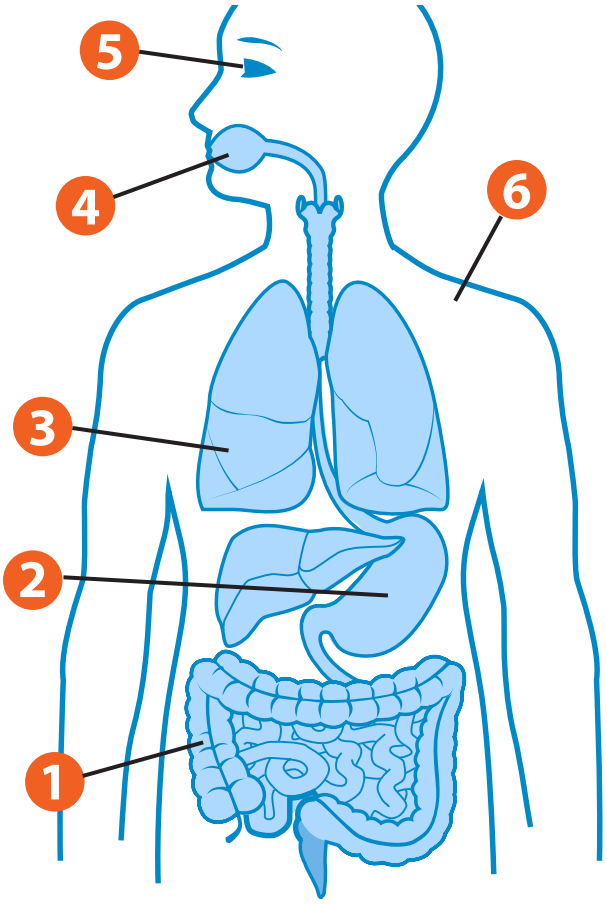
Scientists estimate that each of us carry 10 times more bacterial cells than all the cells that make up our body. Many kinds of bacteria live on our skin. Bacteria live all over our bodies— there are lots in our mouths, too. They live in our saliva. And some bacteria even live under our eyelids on the surface of our eyes. However, the largest number of bacteria live in our guts.

1. Bacteria in our guts

Our guts are important. The gut includes the stomach, small intestine, and large intestine. Together, these pieces make up a large part of the digestive system. Scientists know that the gut has a huge impact on each and every human body system. Some experts say that as much as 70 percent of the **immune system** actually lives in the gut.

The human gut is home to more than 100 trillion microorganisms. This massive crowd includes more than 400 kinds of bacteria. Some are good. Some are not so good. And some are downright ugly and nasty.

Good bacteria in the gut are important. They play key roles in keeping the body working smoothly and efficiently. Nasty bacteria can make you sick. They can cause diseases and infections. Luckily, most bacteria inside you right now are harmless. They live peacefully side by side with the cells of your body.



2. Bacteria in our stomachs

Our stomachs are filled with powerful acid. The acid helps to digest all of the food that we eat. Most living things cannot survive in acid. That includes most microbes.

Still, some types of bacteria can survive in the **hostile** environment of the stomach. *Heliobacter pylori* are bacteria shaped like tight spirals. Scientists know that this microbe can attach to the stomach's cell lining. It can cause peptic ulcer disease and might be a cause of stomach cancer. Scientists are still exploring what roles this bacteria may play in our digestive process.

3. Bacteria in our lungs

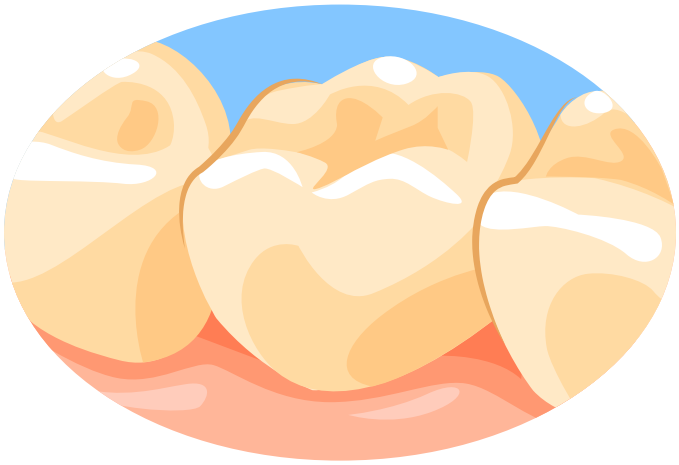
The lungs are a major part of our respiratory system. We must breathe air to get oxygen into our blood. But air is always filled with microbes. Our lungs have built-in ways to remove bacteria and other harmful microbes. Special cells produce mucous, which is the thick, sticky substance that traps bacteria.

Other special cells are always moving the mucous out of the lungs. When you cough or sneeze, you might spew millions of droplets of mucous into the air. That mucous is filled with bacteria. That is why it is always important to cover your mouth when you cough or sneeze.

4. Bacteria in our mouths

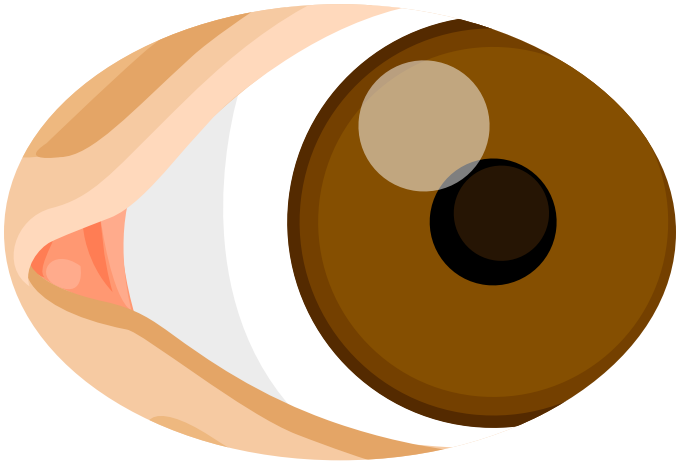
The number and type of bacteria on any given part of the body varies from person to person. Plenty of bacteria live in our mouths. They live on our tongues and on our teeth. Bacteria are part of a sticky substance called plaque. You brush your teeth to get rid of the plaque.

When you don't brush well, the plaque hardens into a substance called tartar. Dentists call it calculus. These same bacteria secrete acid that can dissolve tooth **enamel**. This can cause cavities and tooth decay. These bacteria are always in your mouth, but it is important to go see the dentist so that you can clean out old build up.



5. Bacteria in our eyes

Some bacteria even live on the cells that form the inside of our eyelids and the surface of our eyes. That cell lining is called the conjunctiva. **Glands** in our eyes make fluid constantly. That fluid keeps the conjunctiva moist. When we blink, the eyelids wash away bacteria, dust, and other harmful substances from the surface of our eyeballs. Our tears also contain chemicals that keep bacteria from growing out of control.

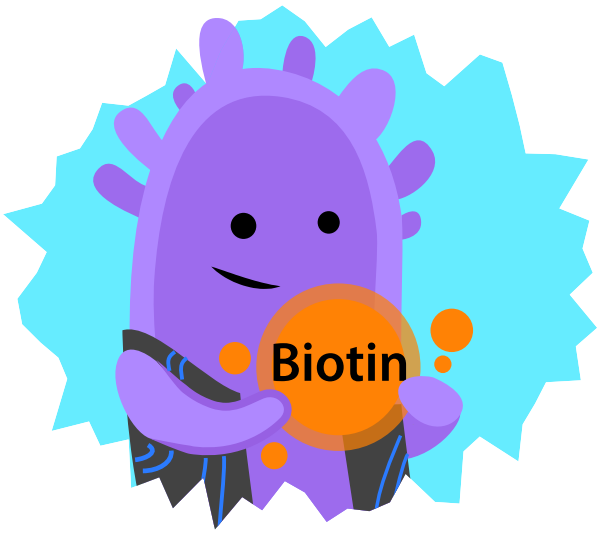


6. Bacteria on our skin

Our skin acts as a barrier. It keeps nasty, disease-causing microbes from getting inside our bodies. However, plenty of bacteria live in our hair, on our scalps, and all over every square inch of our skin. Some live on the skin's surface. Some live deep among the many layers of our skin.

Lots of bacteria are found near the tiny glands that produce oil and sweat. These glands provide the bacteria with water and nutrients to grow and reproduce. By itself, human sweat has no smell. The bacteria living near sweat glands play a role in producing body odor. It's true, bacteria can make you stink.

Important Vitamins



Biotin

Biotin is also known as Vitamin H and Vitamin B7. It helps with cell growth and helps convert sugars to chemical energy your body can use. It also plays a role in keeping blood sugar levels steady, which is especially important for people with **diabetes**. Biotin helps keep skin, the digestive tract, and nerves healthy. Your body does not store extra biotin. Instead, it uses what it needs at the moment and gets rid of the extra as waste.

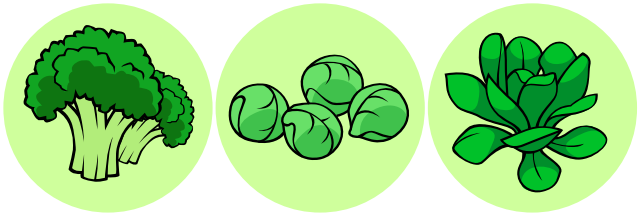
Bacteria in your gut make most of the biotin in your body. Fortunately, they're very good at this. These hard-working bacteria make way more biotin than your body will ever need. Thanks to these little guys, it's extremely rare for your body not to have enough biotin.

Vitamin K

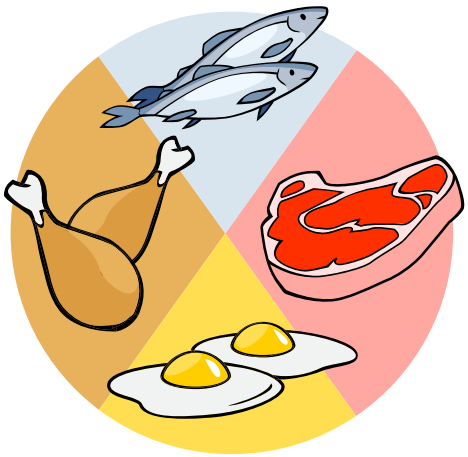
Ever scraped a knee, or had a paper cut? You might not realize it but your body is actually very busy keeping you healthy and strong. As soon as you get a cut or a scratch, your body springs into action to repair it. The first step is to stop the bleeding. The blood vessels around the area tighten so less blood flows there. Small discs called platelets rush to the scene and stick together in clumps inside the broken blood vessels.

Clotting **proteins** in the blood help hold the platelets in place. The process of blood forming clots is called coagulation. Your body needs **Vitamin** K to make clotting proteins. Vitamin K is also important for strong bones. It helps with the storing of minerals in your bones, which makes them denser and less likely to break.

Fortunately, it's very easy for your body to get enough Vitamin K. Some of your Vitamin K comes from the food you eat. It's found in leafy green plants like broccoli, spinach, and Brussels sprouts. That's one more good reason to listen to your parents when they tell you it's important to eat your vegetables! Vitamin K is also made inside your body by the bacteria in your gut.



Lacto & *E. coli*



Escherichia coli (E. coli)

We already know that microbes live everywhere. We know that the human body contains more bacterial cells than human cells. And scientists estimate that there are more bacteria in your mouth alone than there are people living on Earth. But not all bacteria are bad. In fact, most are good. We could not survive without bacteria. Most bacteria in our bodies actually work to keep us healthy. They fight bad bacteria.

Normally, *E. coli* is a good kind of bacteria. It is mostly harmless. *E. coli* lives in our intestines and on our skin. It helps to break down food and keeps our digestive systems running smoothly. But a few types, or strains, of *E. coli* can give us cramps and cause diarrhea. Infections from bad strains of *E. coli* are rare.

Most people get infected from contaminated food or water. Undercooked meat and raw, unwashed vegetables can carry the bad microbes. *E. coli* bacteria can pass easily from person to person, especially when infected people don't wash their hands properly. That is why it is important to always wash your hands after you use the bathroom and before you eat or serve food.

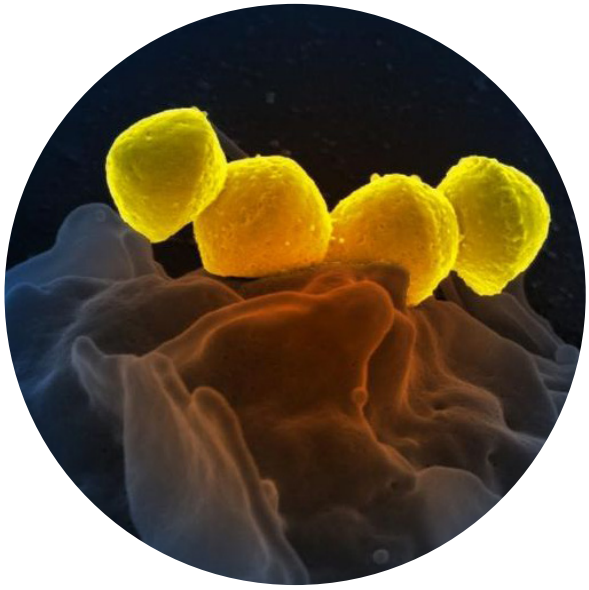
Lactobacillus

Lactobacillus is one of many families of "good bacteria." These microbes live in our mouths and intestines. They help to prevent the overgrowth of harmful bacteria.

A common form is called *Lactobacillus acidophilus*. It helps our body to maintain a normal balance of good bacteria. *L. acidophilus* works by breaking down lactose and other sugars. It helps to promote healthy digestion.

Strep Throat

Each of us has suffered with a sore throat at one time or another. You feel icky. Your voice is scratchy. It just plain hurts. Lots of things can cause a sore throat. Viruses and bacteria cause them. So does pollen and cigarette smoke or other irritants in the air we breathe. Most sore throats will heal without treatment. But some can turn dangerous.



Scanning electron micrograph of streptococcus bacteria (yellow). Image from National Institutes of Health (NIH).

Did you ever have a sore throat that hurt a lot? I mean hurt really bad? If so, it may have been an infection called **strep throat**. The culprits were some particularly bad bacteria called group A *Streptococcus*. We know that many types of bacteria do very helpful things for the human body. But others are outlaws and bandits. Some *Streptococcus* are just plain nasty dudes.

The group A strep bacteria can live in your nose and throat. The tonsils are a favorite spot to infect. These nasty bacteria are easy to spread. We spew lots of tiny droplets of fluid into the air when we cough or sneeze. Those millions of wet droplets are filled with strep bacteria.

A simple test can help a doctor know quickly if the strep bacteria are the problem. Just looking at your red, swollen throat and tonsils is not enough. **Antibiotics** can wipe out the bad guys in a few days. They also help to keep a sick person from spreading the infection to friends and family members.

The best way to keep from getting strep throat is to wash your hands often. Don't share your spoon and fork or drink cup with others. And always, ALWAYS cover your mouth and nose when you cough or sneeze.

Yogurt & Probiotics

Has a doctor ever suggested that you "Eat some yogurt!" when you're sick and taking antibiotics? It's a smart thing to do. Yogurt is chock-full of protein, vitamins, and calcium. It's also a superb source of good, helpful bacteria. Another word for these good bacteria is **probiotics**.

The good bacteria found in yogurt are known as live cultures. That means they are still alive when you eat them. Yogurt usually contains a few different kinds of microbes. It's made under controlled conditions to allow only the good bacteria to grow. Letting in bad bacteria might spoil the food and make it taste bad, or even make you sick. The reason to eat probiotics after being treated with antibiotics is simple. You recharge your digestive system with a new batch of good bacteria.

Antibiotics

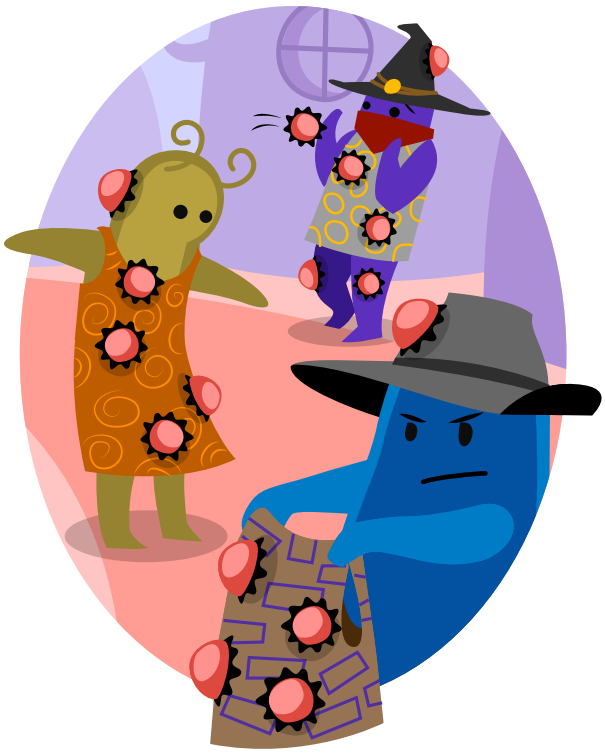
Compare a single bacterial cell to one of your body's many cells. The structure is different. They reproduce differently. They absorb nutrients from the environment in different ways. The way they convert and use energy is not the same.

Antibiotics are substances that kill bacteria without harming the cells of your body. They do this by interfering with the way bacteria live and grow. Normal body cells work differently, so they stay safe.

Antibiotics work in various ways. They can actually kill the bacteria or they can stop its ability to grow and reproduce. How? Some antibiotics break down a bacterium's cell wall. Others stop the bacterium's ability to absorb nutrients. Others stop its ability to convert nutrients into energy.

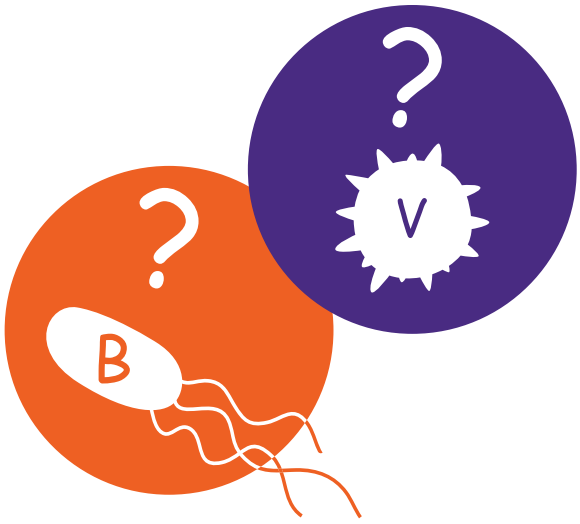
Your body's immune system is tough. It's usually able to fight off harmful bacteria without help. But sometimes it cannot do it quickly enough. Antibiotics are the reinforcements. They ride to the rescue. Antibiotics slow or stop fast-growing bacteria. They give your immune system time to get an infection under control.

Unfortunately, most antibiotics can't tell the difference between good and bad bacteria. Lots of good bacteria are killed as a result. It takes time for your body to replace all those good bacteria.



Viruses are other germs that can also make you sick, but antibiotics cannot kill or stop viruses from causing illness. Why not? Because viruses are very different from bacteria, both in structure and in how they function.

Viruses reproduce and grow only when inside living cells. They are much smaller and simpler than bacteria. Technically, they are not living things at all.



Viruses vs. bacteria

You feel lousy. Your throat is sore. Your head aches and you have a fever. What could be making you sick? The symptoms alone can't tell you if the culprit is a virus or bacterium. Viruses that cause the common cold produce these symptoms. So do streptococcus bacteria, the cause of strep throat. Antibiotics will kill the strep bacteria but they do nothing against viruses.

Doctors need to figure out what microbe is making you sick in order to help. If a doctor suspects strep bacteria are the cause, they will often collect a sample to test for the bacteria. Samples are taken by swabbing the back of the throat. If the strep bad guys are present, the doctor will give you antibiotics to help your body fight them off. If not, the doctor will probably instruct you to stay home, rest, and drink plenty of fluids.

How are antibiotics given?

Antibiotics come in different forms. The type of antibiotic you take depends on what kind of bacterial disease you're trying to treat.

Oral antibiotics are pills taken by mouth. Doctors often use these to treat strep throat and other bacterial infections.

Topical antibiotics include creams and lotions. They are applied directly to the problem area on the outside of the body. These are good for treating infected cuts or scrapes.

Antibiotics can also be given as injections. The more serious infections are usually treated this way. Injections get antibiotics into the bloodstream quickly. Injections are usually given by a doctor or nurse in a clinic or at the hospital.

The first antibiotic

We learned about bacteria long before we figured out antibiotics. Infection and disease have always been dangerous. But we've only been using antibiotics to kill bacteria and treat disease for less than 100 years. Before antibiotics, even cuts and minor scrapes could turn deadly.

Luck plays a role in many aspects of life. The same is true in science. Sir Alexander Fleming would probably agree. In 1928, the famous Scottish scientist discovered the first antibiotic entirely by accident.

By the early 1900s, scientists had discovered a lot about bacteria. Fleming was studying a common family of bacteria called Streptococcaceae, which are usually harmless. Many forms of staph bacteria live on our skin. Others live in the soil.

Fleming was a brilliant researcher, but he was not the tidiest person. He went away for most of a month to spend a summer holiday with his family. He left behind a very messy laboratory. Petri dishes filled with bacterial cultures were left stacked on a bench in a corner.

Fleming noticed something quite interesting when he returned to work. A fungus mold was growing in one of the sample dishes. Fleming did not toss it out and instead, he took a closer look. Groups of *Staphylococcus* grew in one part of the dish, but none grew near the mold.

The mold was from a group of fungi called *Penicillium*. Fleming had the idea that something in the mold was killing the bacteria. He was right. For a while, he called it "mould juice." In 1929, Fleming wrote a paper and named his bacteria-killing substance **penicillin**.

Science can be a long and tedious process. Fleming's discovery was just the beginning. There was plenty of work to be done. He did many experiments and published his results. However, Fleming was disappointed. It took a long time to grow the mold. It was also very difficult to collect enough penicillin to treat infections in humans. Fleming stopped his research.

Fortunately, good science is all about sharing information. Fleming had written and published his discoveries. Other teams of researchers became interested in penicillin. They continued Fleming's work.

Eventually, scientists found ways to grow and refine penicillin in large amounts. Penicillin and other antibiotics changed the world of modern medicine. Penicillin has saved the lives of millions of people. It is still saving lives today.

Image of Sir Alexander Fleming from Materialscientist.

MRSA

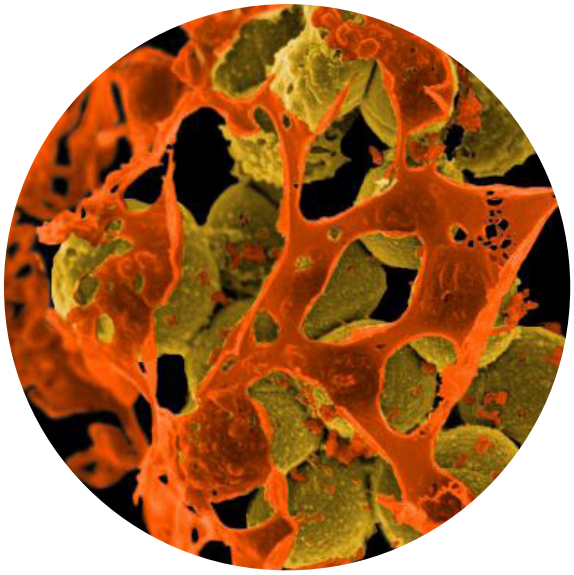
You learned earlier that many kinds of bacteria live on the surface of our skin. One common type is *Staphylococcus aureus*. Normally, these bacteria will work to keep other bacteria under control. They help to prevent skin rashes, sores, and infections.

Everything is fine as long as the staphylococcus bacteria stay on the outside of our bodies. Trouble starts when they enter the body through a puncture wound, cut, or deep scrape.

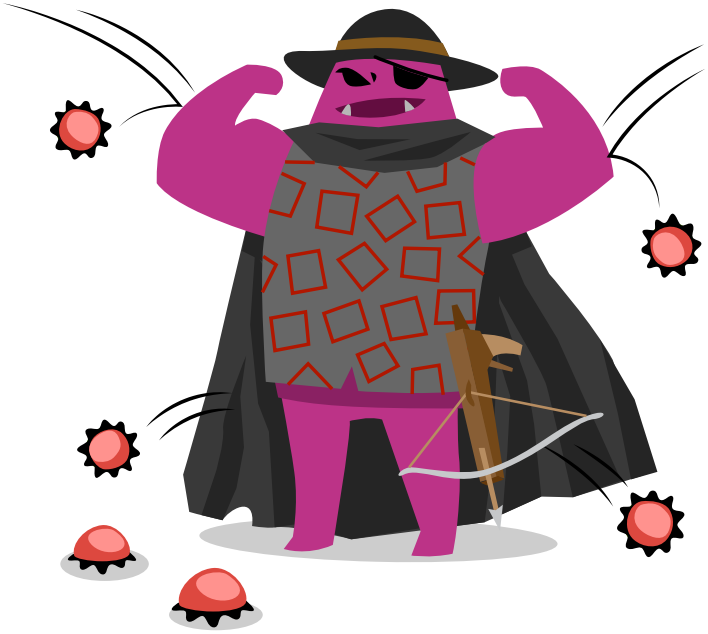
Even worse, many of the staphylococcus bacteria are now resistant to certain kinds of antibiotics. They are known as **MRSA**, short for Methicillin-resistant *Staphylococcus aureus*.

MRSA causes very serious, even deadly, infections. Most are skin infections. A person's life could be in danger when MRSA gets into the bloodstream. MRSA can even infect a site where doctors have cut during surgery.

Scientists have learned a lot about MRSA. As many as two out of every 100 people carry the MRSA bacteria on their bodies. Lots of people have staph bacteria in their noses. Most never get sick.



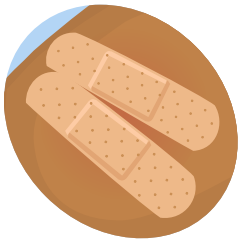
Scanning electron micrograph of MRSA (yellow). Image from ArturoJuárezFlores.



Protect yourself!

You can protect yourself from MRSA infections with good personal hygiene. Follow these tips to help stop germs from invading your body.

Wash your hands often. Keep your body clean, especially after exercise.



Keep cuts, scrapes, and wounds clean and covered until healed.

Don't share personal items such as towels or wash rags.

Don't wait. See a doctor if you think you might have an infection.

Phage Virus

Viruses of many kinds exist on our planet. Some viruses infect humans. Some viral infections are minor and annoying, like the common cold. Others are severe and deadly, like **AIDS**.

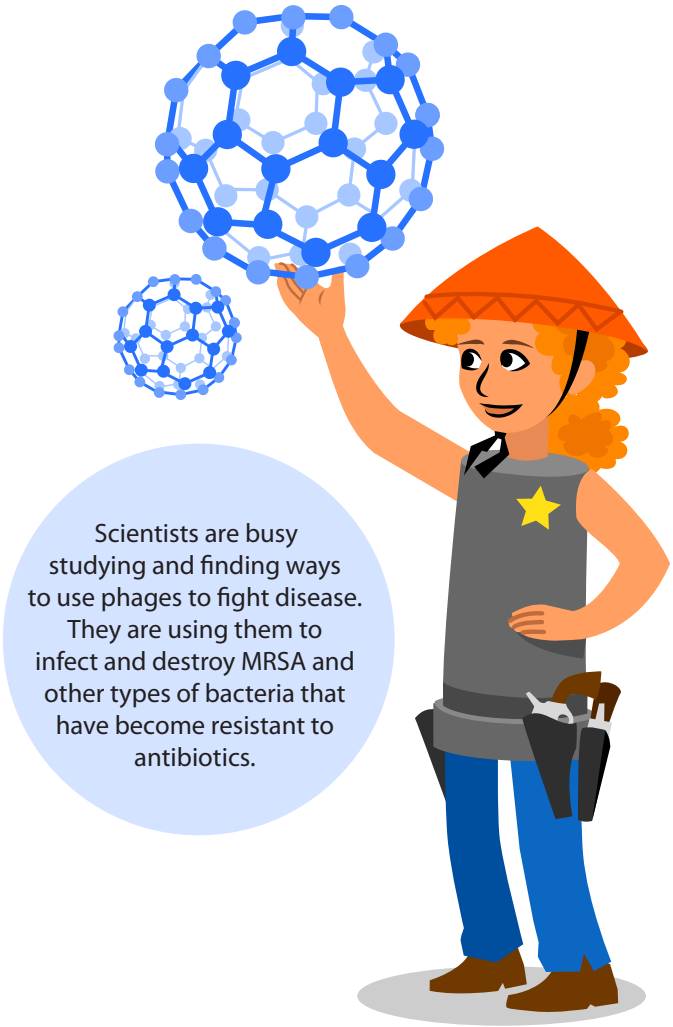
Did you know that there are viruses that only infect bacteria? They are helpful and important. Scientists call them **bacteriophages**, which means "bacteria eaters." We can call them phages for short.

Phages have the ability to make copies of themselves. To do this, they need a host cell. The phage attaches itself to a **receptor** on the surface of a bacterium's cell wall. It is almost like a key searching for the lock that it fits.

Once firmly attached, the phage then injects its genetic material into the host cell. Phages are like pirates. They take over the internal machinery bacteria use to reproduce. Once infected with a phage, a bacterium is reprogrammed to make copies of that phage.

Phage viruses attack a bacterial cell.
Image from Webridge.

Certain types of phages only infect certain kinds of bacteria, so they are named after the type of bacteria they infect. For example, the phages that infect *E. coli* bacteria are called coliphages.



Scientists are busy studying and finding ways to use phages to fight disease. They are using them to infect and destroy MRSA and other types of bacteria that have become resistant to antibiotics.

Nanotechnology

It's time to think small. I mean really, really, really small. A **nanometer** is one-billionth of a meter. Structures of that size are much too small to see, even with a powerful laboratory microscope. But what if doctors had ultra-tiny tools they could use to repair parts of broken cells? Or what if they could insert pumps the size of **molecules** into sick people to deliver medicine only in the spots it was most needed?

These ideas are not science fiction. Welcome to the world of **nanotechnology** and **nanomedicine**. In this world, scientists are creating and using materials and devices the size of atoms and molecules. Engineers are already working to create miniature computers made out of DNA, the material that codes all life on Earth. Others are creating tiny semiconductor chips made out of strings of individual molecules.

Scientists want to better understand how the body's own molecular machines work when we are healthy. Once that understanding is strong enough, doctors will put nanomedical tools and techniques to work to help repair damaged cells and cure sick cells in our body when we are ill. The work continues to advance. Scientists are learning more each day.

Receptors & Cell Surface Markers

Internal alarm system

The human body has the ability to recognize millions of different enemies. Our built-in "defense force" is called the immune system. Different parts of the system can produce cells and powerful chemicals called **cytokines**.

These cells and cytokines match up with and destroy bacteria and other invaders. Millions and millions of immune system cells are organized into sets and subsets. These groups of cells pass information back and forth.

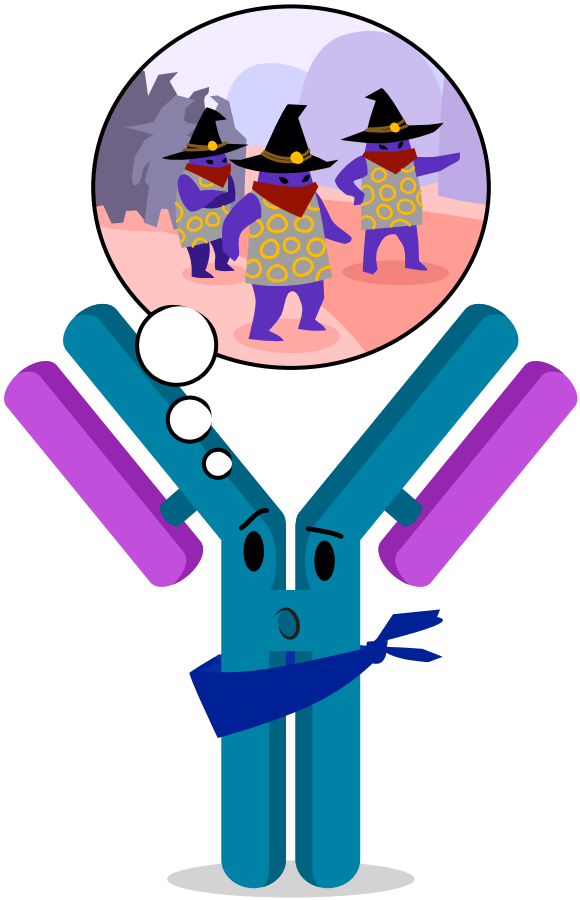
The chemical substances produced by these cells function as an internal alarm system. Their message is simple: "Germs are here. Kill the germs."

Friend or foe?

The immune system does much more than simply protect us from infection. It can tell the difference between the body's own cells and those belonging to invaders. Immune system cells can tell the difference between "self" and "non-self."

Each and every cell in our body carries special marker molecules. These markers are also called **antigens**. They advertise "self." Think of a typical cell as being an orange covered with knobby toothpicks and colorful little marker flags.

On a real cell, these toothpicks and flags are bits of protein and other special molecules. One or more of these bits of protein tell the immune system's hunter and killer cells that everything is fine. The alarm sounds when immune defenders come across a cell or microbe that has no "self" marker. The system swings into action to meet the threat of disease.



Long-term memory

Immune system cells can remember past fights with disease-causing viruses and bacteria. The system keeps a chemical record of how it recognized each invader. These special protein molecules are called **antibodies**.

Antibodies are Y-shaped molecules. They fit a specific antigen much like a key fits into a lock. Any cell or organism that triggers the immune system into action is called an antigen (and is usually a non-self antigen). Antigens can be germs such as a virus or bacterium. Or they can be bits and pieces of those germs.

Antibodies lock onto an antigen. They serve as the flag that marks the invader for destruction. Later, when a similar microbe invades again, the body recognizes it as an invader. The immune system cranks into action. The goal is to destroy the invading antigen or microbe before it can develop into a new infection.

This is why most people get chicken pox or other childhood diseases only once. The immune system fought the fight once against these invading germs. Vaccines work the same way. They expose your body to pieces or weakened versions of the germs, and your body learns to fight them off. Vaccines for measles and mumps help children avoid getting the disease at all. Your body keeps a chemical record and protects you from contracting those illnesses.

Words to Know

AIDS (aids): a disease that causes the immune system not to function as well as it normally would.

Anthrax (**an**-thracks): a disease caused by bacteria that can infect animals, including humans. Anthrax can be life-threatening.

Antibiotic (anti-by-**ah**-tic): a substance that weakens or destroys harmful bacteria inside the bodies of animals.

Antibiotic resistant (anti-by-**ah**-tic re-***zis***-tuh-nt): when a group of bacteria can no longer be harmed or killed by a certain antibiotic.

Antibody (**ant**-i-body): a molecule made by B-cells to trap foreign particles and microbes.

Antigen (anti-**jen**): a molecule that can be recognized by the immune system.

Bacteria (back-teer-ee-**uh**): one-celled, microscopic organisms that grow and multiply everywhere on Earth. They can be either useful or harmful to animals.

Bacteriophage (back-teer-ee-**uh**-feyj): a virus that can infect bacterial cells.

Culture (**kuhl**-chur): a growing "soup" of microscopic organisms and the nutrients they need to survive.

Cytokine (**sight**-oh-kine): a chemical released by cells in the immune system that helps coordinate an immune response by sending messages to specific cells.

Diabetes (die-uh-**bee**-tees): diseases that affect blood sugar levels and often urine production.

Enamel (ee-nam-**uh**-l): a hard, white substance that works as a protective covering. The outsides of human teeth are enamel.

Gland (gland): an organ that releases materials for use in certain places in the body or on the outside of the body.

Hostile (**hoss**-tile): unfriendly.

Immune system (im-**mewn sis**-stem): all the cells, tissues, and organs involved in fighting diseases in the body.

Microbe (**my**-krohb): a living thing so tiny that you would need a microscope to see it.

Microbiologist (my-kroh-by-**all**-oh-jist): someone who studies living things too small to see without the help of a microscope.

Microbiome (my-kroh-**by**-ohm): the community of microorganisms that live inside and/or on your body.

Microorganism (my-kroh-**org**-an-ism): a living thing that is so small you need a microscope to see it. There are microorganisms from all the kingdoms of life.

Molecule (**mol**-e-cue-l): a chemical structure that has two or more atoms held together by a chemical bond.

MRSA (**mer**-suh): short for Methicillin-resistant *Staphylococcus aureus*. A bacterium that is resistant to certain kinds of antibiotic and can cause infections that are difficult to treat.

Nanomedicine (**nan**-oh-med-uh-sin): medical use of tools built out of atoms and molecules to diagnose and treat diseases and injuries.

Nanometer (**nan**-oh-meet-er): one-billionth of a meter.

Nanotechnology (**nan**-oh-tech-nol-uh-jee): technology that works on a very small scale, with atoms and molecules.

Penicillin (pen-**uh**-sill-in): one of the first antibiotics, medicine that kills bacteria.

Postulate (**pos**-chew-lit): a set of rules used to argue that something is true.

Probiotic (pro-by-**ah**-tic): food or another substance that helps to replenish microorganisms in specific parts of the body.

Prologue (**pro**-log): a section before a story or movie that introduces characters and important information.

Protein (**pro**-teen): molecules found in the cells of living things, made up of special building blocks called amino acids.

Receptor (re-**sep**-ter): a molecule on the surface of a cell that receives signals from specific molecules.

Spontaneous (spon-**tane**-ee-uhs): to appear suddenly without an obvious cause.

Sterilize (**ster**-uh-lies): to remove or kill all bacteria.

Strep throat (strep **throw**-t): an illness that causes fever and sore throat, and is sometimes treated with antibiotics.

Vitamin (**vie**-tuh-min): molecules found in the cells of living things that are needed for growth. They come from the food you eat, and cannot be made in the body.

Credits

Funding Support

SEPA SCIENCE EDUCATION PARTNERSHIP AWARD
Supported by the National Institutes of Health

Collaborative Support

ARIZONA SCIENCE CENTER

ASU SCHOOL OF Life Sciences
ARIZONA STATE UNIVERSITY

Acknowledgements

Microbes was developed with the help of Arizona Science Center's Pathways Design Team. Graphic and website development provided by Arizona State University School of Life Sciences Visualization Laboratory. Additional photos from wikimedia.com.

Plan your next visit to Arizona Science Center and play the part of your favorite microbe in the live demonstration, Microbes: The Good, The Bad, and The Ugly.

BODY DEPOT

Arizona Science Center and Ask A Biologist have joined forces in building Body Depot, a place where you can learn about your amazing body. Visit Body Depot online at **askabiologist.asu.edu/body-depot**

MONSTER MANUAL

Read a real monster tale about the tiny instruction manual that you carry around in each of your cells. Then try out Monster Builder, a fun game where you decode and build your own monsters. You can find it at **askabiologist.asu.edu/monster-manual**