Bacteria

The word **bacteria** is the plural of bacterium. Grammatically the headline should just say "What are bacteria?" The incorrect usage has been included in the headline to remind readers that it is wrong - and hopefully help correct an increasingly common mistake in the English language. Bacteria are tiny living beings (microorganisms) - they are neither plants nor animals - they belong to a group all by themselves. Bacteria are tiny single-cell microorganisms, usually a few micrometers in length that normally exist together in millions.

A gram of soil typically contains about 40 million bacterial cells. A milliliter of fresh water usually holds about one million bacterial cells.

Planet Earth is estimated to hold at least 5 nonillion bacteria. Scientists say that much of Earth's biomass is made up of bacteria.
5 nonillion = 5,000,000,000,000,000,000,000,000,000,000 (or 5×10^{30})
(Nonillion = 30 zeros in USA English. In British English it equals 54 zeros. This text uses the American meaning)

Bacteria come in three main shapes:

- **Spherical (like a ball)**

  These are usually the simplest ones. Bacteria shaped like this are called *cocci* (singular *coccus*).

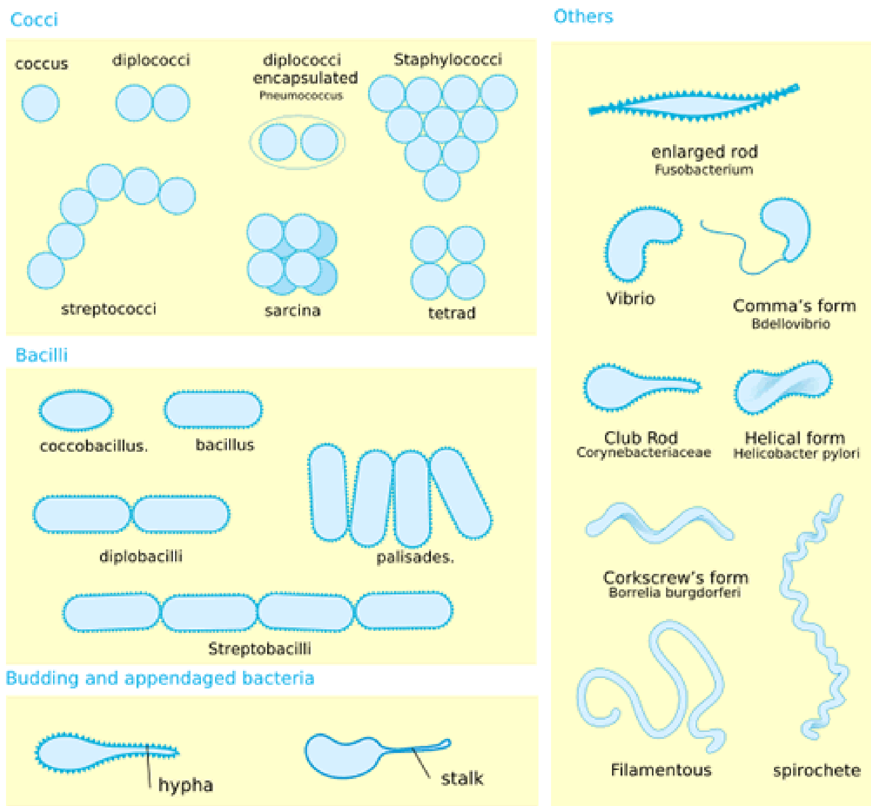
- **Rod shaped**

  These are known as *bacilli* (singular *bacillus*).
  Some of the rod-shaped bacteria are curved; these are known as *vibrio*.

- **Spiral**

  These known are as *spirilla* (singular *spirillus*).
  If their coil is very tight they are known as *spirochetes*.

There are many variations within each shape group.



Bacteria are found everywhere

Bacteria can be found in:

- Soil
- Radioactive waste
- Water
- Plants
- Animals
- Deep in the earth's crust

- Organic material
- Arctic ice
- Glaciers
- Hot springs
- The stratosphere (between 6 to 30 miles up in the atmosphere)
- Ocean depths - they have been found deep in ocean canyons and trenches over 32,800 feet (10,000 meters) deep. They live in total darkness by thermal vents at incredible pressure. They make their own food by oxidizing sulfur that oozes from deep inside the earth.

Scientists who specialize in bacteria - bacteriologists - say bacteria are found absolutely everywhere except for places that humans have sterilized. Even the most unlikely places where temperatures may be extreme, or where there may be a high concentration of toxic chemicals have bacteria - these are known as extremophiles (an extremophile is any organism adapted to living in conditions of extreme temperature, pressure, or/and chemical concentrations) - these bacteria can survive where no other organism can.

The cells of bacteria

A bacterial cell differs somewhat from the cell of a plant or animal. Bacterial cells have no nucleus and other organelles (sub-units within a cell with a specific function) bound by a membrane, except for ribosomes. Bacteria have pili, flagella, and a cell capsule (most of them), unlike animal or plant cells. An organism without a nucleus is called a *prokaryote*.

A bacterial cell includes:

- **Basal body** - this anchors the base of the flagellum, allowing it to rotate.

- **Capsule** - a layer on the outside of the cell wall. Some bacteria don't have a capsule.

- **Cell wall** - a thin layer (membrane) outside the plasma membrane, and within the capsule.

- **DNA (Deoxyribonucleic acid)** - contains all the genetic instructions used in the development and functioning of the bacterium. It is inside the cytoplasm.

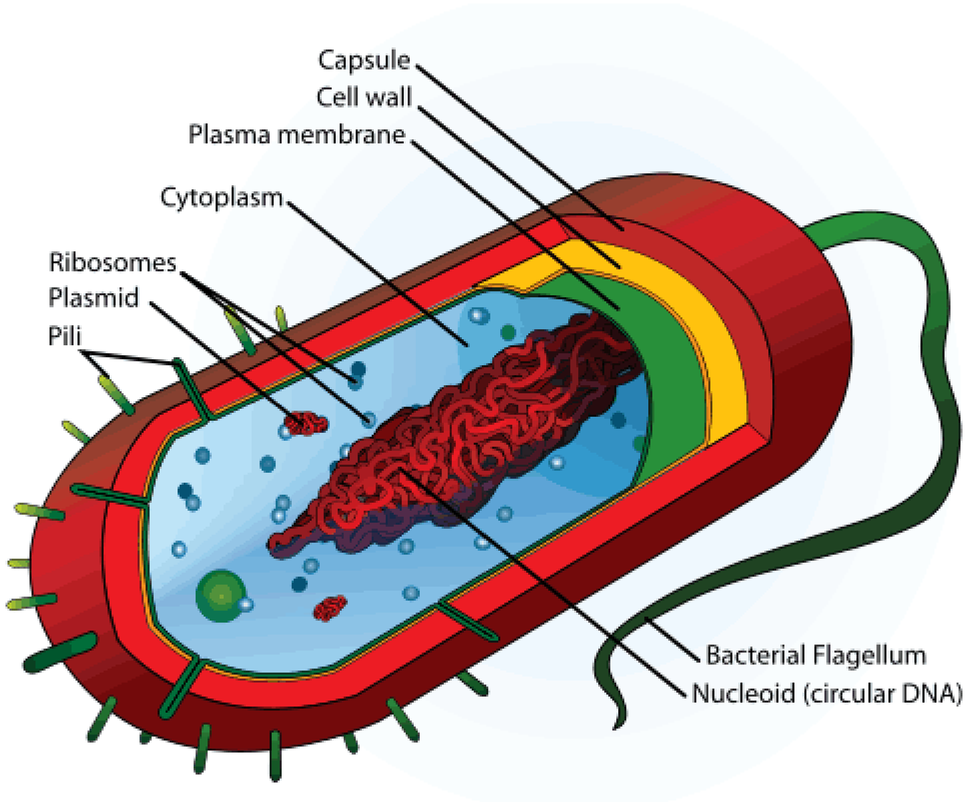
- **Cytoplasm** - a gelatinous substance inside the plasma membrane. Genetic material and ribosomes lie inside.

- **Flagellum** - this is used for movement; to propel the cell. Some bacterial cells have more than one.

- **Pili (singular: pilus)** - these spikes allow the cell to stick to surfaces and transfer genetic material to other cells. A study revealed that pili are involved in causing traveler's diarrhea.

- **Plasma membrane** - it generates energy and transports chemicals. Substances can pass through the membrane (permeable). It is located within the cell wall.

- **Ribosomes** - this is where protein is made (synthesized). Ribosomes are small organelles made up of RNA-rich granules.



The origins and evolution of bacteria

Modern bacteria's ancestors - single-celled microorganisms - appeared on earth about 4 billion years ago. Scientists say they were the first life forms on Earth. For the following 3 billion years all life forms on Earth were microscopic in size, and included two dominant ones: 1. Bacteria, and 2. Archaea (classified as bacteria, but genetically and metabolically different from all other known bacteria).

There are fossils of bacteria. However, because their form and structure (morphology) are not distinctive it is virtually impossible to date them, making it extremely hard to study the process of bacterial evolution with any degree of accuracy. However, with the help of gene sequences, it is now possible to know that bacteria diverged from their original archaeal/eukaryotic ancestry (Eukaryotic = pertaining to an eukaryotice; a single-celled or multicellular organism whose cells contain a distinct membrane-bound nucleus).

Archaea is bacteria's most recent common ancestor - it was most likely hyperthermophile, an organism that thrived in extremely hot environments, approximately 2.5 - 3.2 billion years ago. Bacteria were also involved in the divergence of archaea and eukaryotes. Eukaryotes came from a very early bacteria which had an endosymbiotic association (when an organism lives within the body or cells of another organism) with the predecessors of eukaryotes cells, which were probably related to the Archaea. Biologists say that some algae probably originated from later endosymbiotic relationships.

Put simply - bacteria were the first organisms to appear on earth, about 4 billion years ago. Our oldest known fossils are of bacteria-like organisms.

A short history of bacteriology

Some people had suggested thousands of years ago that something too small for the naked eye to see may be the cause of disease. Over the hundreds of years that followed various theories were given. It was not until 1676 that bacteria were properly identified as microorganisms. Below is a short synopsis of some of the most famous scientists/microbiologists in history:

- **Marcus Terentius Varro** (Roman - 116 BC-27 BC) - a prolific author. He suggested that disease may be caused by miniscule animals that floated in the air. He is admired by many scientists today for his anticipation of microbiology (the study of microorganisms and their effects on other living organisms) and epidemiology (the study of the causes, distribution, and control of disease in populations). He believed marshy places should be avoided during building work because they might contain insects too small for the eye to see that entered the body through the mouth and nostrils and cause diseases.

- **Hippocrates** (c 460-377 BC) - a physician, considered one of the most outstanding figures in the history of medicine. He was the first physician to separate medicine from superstition. He said disease was not a punishment meted out by gods, but rather a result of lifestyle, diet and environmental factors. However, Hippocrates' theories on diseases being an imbalance of the four humors present in the human body, caused by miasmas - vapors from rotting vegetables or bodies, polluted rivers and marshy places - were slightly wider of the mark than we know about today.

- **Jacobo Forli and Alexandro Benedetti** (Italian c. 14th/15th century) - they said it was not possible to get ill just by breathing in the air. They said particles that floated in the air may cause disease if they were breathed in.

Nevertheless, the Miasma Theory persevered for a long time, right from the first century through to about 1500, when the *Germ Theory* started to develop:

- **Antonie van Leeuwenhoek** (Dutch 1632-1723) - he handcrafted single-lens microscopes himself, with which he saw what he called *animalcules* in 1676 (to be called bacteria 162 years later). In a series of letters to the Royal Society (England) he published his findings. He is commonly known as the *father of microbiology* and considered to be the first microbiologist.

- **Christian Gottfried Ehrenberg** (German 1795-1876) - one of the most famous and prolific scientists during the nineteenth century, introduced the term *bacterium* in 1838.

- **Louis Pasteur** (French - 1822 - 1895) - a remarkable chemist who became famous for many breakthroughs in the causes and preventions of disease. He created the first vaccine for rabies. Pasteur demonstrated in 1859 that the fermentation process is caused by the growth of microorganisms, and not spontaneous generation. He and Robert Kich, said that diseases were caused by germs (The Germ Theory).

- **Robert Koch** (German - 1843-1910) - a brilliant physician/researcher who was awarded the Nobel Prize in 1905 after he proved The Germ Theory.

- **Paul Ehrlich** (German - 1854-1915) - a scientist who became a world authority in immunology. He invented the term *chemotherapy*. He developed the first antibiotic(Salvarsan) and used it to cure syphilis. He was awarded the Nobel Prize in 1908 for his research on immunology. He pioneered the use of stains to detect bacteria.

- **Carl Woese** (American - 1928-) - currently professor of microbiology at the University of Illinois at Urbana-Champaign. His work recognized that archaea evolved along a separate line from bacteria.

Metabolism - How do bacteria feed themselves?

Bacteria feed themselves in a variety of ways.

- **Heterotrophic bacteria (or just heterotrophs)** - these eat other organisms.

  Most of them are *saprobes*, they absorb dead organic material, such as decomposing flesh. Some of these parasitic bacteria kill their host, while others help them.

- **Autototrophic bacteria (or just autotrophs)** - these make their own food.
  - **This could be done by photosynthesis** - they use sunlight, $C0_2$, and water to make their food. Bacteria that use sunlight to synthesize their food are called*photoautotrophs*. These include the cyanobacteria which probably played a vital role in creating the Earth's oxygen atmosphere. Other photoautotraphs do not produce oxygen, such as heliobacteria, purple non-sulfur bacteria, purple sulfur bacteria, and green sulfur bacteria.

- **Others do it by chemosynthesis** - they use $C0_2$, water, and such chemicals as ammonia to synthesize their food. We call them *nitrogen fixers*. They are commonly in legume roots and ocean vents. Examples of legumes are alfalfa, clover, peas, beans, lentils, and peanuts. These bacteria are known as *chemoautotrophs*. Other chemicals used for nutrition are nitrogen, sulfur, phosphorous, vitamins, and such metallic elements as sodium, potassium, calcium, magnesium, manganese, iron, zinc, and cobalt.

What kinds of environments do bacteria inhabit?

- **Aerobes (aerobic bacteria)** - these can grow only in the presence of oxygen. Some types may cause serious problems to people's infrastructure as they can cause corrosion, fouling, problems with water clarity, and bad smells.

- **Anaerobes (anaerobic bacteria)** - these can only grow if there is no oxygen present. In humans, they are most commonly found in the gastrointestinal tract. They also cause gasgangrene, tetanus, and botulism. Most dental infections are caused by this type of bacterium.

- **Facultative anaerobes (facultative anaerobic bacteria)** - these thrive in environments with or without oxygen. However, when given both options, they prefer to use oxygen for respiration. Most commonly found in soil, water, vegetation and some normal flora of humans and animals. An example of a facultative anaerobic bacterium is*salmonella*.

- **Mesophile (mesophilic bacteria)** - these thrive in moderate temperatures. Examples include *Listeria monocytogenes, Pesudomonas maltophilia, Thiobacillus novellus, Staphylococcus aureus, Streptococcus pyrogenes, Streptococcus pneumoniae, Escherichia coli*, and *Clostridium kluyveri*.

Human bacterial infections are mainly caused by mesophilic bacteria - this is because the body of a human is moderate (37 Celsius). The human intestinal flora contains many beneficial mesophilic bacteria, such as dietary*Lactobacillus acidophilus*.

- **Extremophiles (extremophilic bacteria)** - these thrive in conditions considered too extreme for most life forms, including mankind. There are several different types of extremophilic bacteria, depending on what kind of extremes they can tolerate:

  - **Thermophiles (thermophilic bacteria)** - these thrive in temperatures above 55 Celsius, and can tolerate up to 75-80 Celsius. They take longer to destroy in boiling water than other bacteria. The bacteria *Pyrolobus fumarii* can tolerate temperatures up to 113 Celsius - it is classed as a hyperthermophile.

  - **Halophiles (halophilic bacteria)** - these only thrive in a salty environment, such as saltine lakes. An example is *Halobacteriacea*.

  - **Acidophiles (acidophilic bacteria)** - these only thrive in acidic environments.*Cyanidium caldarium*, and *Ferroplasma sp* can tolerate an environment with an acidity of pH 0.

  - **Alkaliphiles (alkiliphilic bacteria)** - these only thrive in alkaline environments.*Natronobacterium, Bacillus firmus OF4*, and *Spirulina spp* can all tolerate up to pH 10.5.

- **Psychrophiles (psychrophilic bacteria)** - these thrive at very low temperatures, such as in glaciers. An example is *Psychrobacter*.

How do bacteria reproduce?

Binary fission

This is known as an asexual form of reproduction; it does not involve a male and female. The cell continues growing and growing, eventually a new cell wall grows through the center forming two *daughter* cells, which eventually separate. Each daughter cell has the same genetic material as the parent cell.

Bacterial recombination

The problem with binary fission is that every daughter cell is identical to the cell it came from, as well as all its sisters. This makes it harder for bacteria to prevail, especially if we attack them with antibiotics. To get around this, bacteria use a process called *recombination*. Bacterial recombination is achieved through:

- **Conjugation** - this simply means passing pieces of genes from one bacterial cell to another one when they come in contact. A bacterium connects itself to another through a tube structure called pilus (there are lots of them, spiky things, plural: pilli), you can see them in the second illustration in this article (scroll up). Genes from one bacterial cell go through this tube into the other cell.

- **Transformation** - some bacterial cells can grab DNA form the environment around them - often DNA from dead bacterial cells. The bacterial cell binds the DNA and carries it across the bacterial cell membrane. Put simply, it pulls the DNA in from outside through its cell wall.

- **Transduction** - bacteria get infected by viruses called bacteriophages. The bacteriophage inserts its genome into the bacterium when it attaches itself to the bacterial cell. The genome of this virus, enzymes and components of the virus are replicated and assembled inside the host bacterium. The newly formed bacteriophages then cause the rupture or disintegration of the bacterial cell wall, resulting in the release of the replicated viruses. Sometimes, however, some of the bacterium's DNA can become encased in the viral capsid (protein shell that surrounds a virus particle) instead of the viral genome during the assembly process. When this bacteriophage goes and infects another bacterium it injects DNA fragments from its previous host (the first bacterium), which then becomes inserted into the DNA of the new bacterium. We call this *generalized transduction*.

  Put simply - transduction is when a virus gets into the bacterium, picks up some of its DNA, and then places it in the next bacterium it gets into.

  Researchers at Texas A&M University's Artie McFerrin Department of Chemical Engineering suggest that genetic material isn't really captured as much as it is simply utilized after it's injected into the bacteria by an invading virus.

  Another form of transduction is *specialized transduction*. Fragments of the first bacterium's DNA become incorporated into the viral genome of the new bacteriophage. These DNA fragments are then transferred to the next bacterium the bacteriophage infects.

Resting stage - spores

This is more a form of hibernation than reproduction. When bacteria do not have enough resources they can reproduce by forming spores, which hold the organism's DNA material.

These spores are alive but not active. When conditions are appropriate the spores become new bacteria. Spores can remain dormant for centuries before becoming new bacteria. The main function of these spores is to survive through periods of environmental stress. They are resistant to ultraviolet and gamma radiation, desiccation, starvation, chemicals and extremes of temperature. Some bacteria produce endospores (internal spores) while others produce exospores (released outside) or cysts. The spore contains enzymes which are involved in germination.

An example of an endospore-forming bacterium is *Clostridium*, which consists of about 100 species that include common free-living bacteria as well as important human disease causing bacteria, such as botulism *(C. botulinim)* and pseudomembranous colitis *(C. difficile)*.

A study found that bacterial spores "listen in" find out what their neighbors and doing.

The effects of bacteria

Most people tend to imagine negative things when asked about bacteria. It is important to remember that bacteria are so ubiquitous, and have been around so long - since the beginning of life on earth, in fact - that we would not have existed without them. The air we breathe - specifically the oxygen in the air we breathe - was most probably created millions of years ago by the activity of bacteria.

Nitrogen fixation

Bacteria assimilate atmospheric nitrogen and then release it for plant use when they die. Plants cannot extract nitrogen from the air and place it in the soil - but plants need nitrogen in soil to live - without the bacteria doing this would not be able to carry out a vital part of their metabolism. The relationship between plant and bacteria has become so close in this sense that many plant seeds have a small container of bacteria that will be used when the plant sprouts.

Humans need bacteria to survive

The human body contains huge amounts of *friendly bacteria* that are either neutral or help us somehow. Bacteria in the digestive system are crucial for the breakdown of certain types of nutrients, such as complex sugars, into forms the body can use. Friendly bacteria also protect us from dangerous ones by occupying places in the body the pathogenic (disease causing) bacteria want attach to. Some friendly bacteria actually come to the rescue and attack the pathogens.

Bacteria and the obesity epidemic

According to a study released by the International & American Association for Dental Research,bacteria may be a contributory factor in today's obesity explosion.

Effect of bacteria as pathogens to humans (causes of diseases)

Some of the most deadly diseases and devastating epidemics in human history have been caused by bacteria.

Smallpox and malaria - not caused by bacteria - have killed more humans than bacterial diseases. However, the following bacterial diseases have destroyed hundreds of millions of human lives:

- Cholera
- Diphtheria
- Dysentery
- Plague
- Pneumonia
- Tuberculosis
- Typhoid
- Typhus

In the year 1900 pneumonia, tuberculosis and diarrhea were the three biggest killers in the USA. As water purification improved, vaccines and immunization programs evolved, and antibiotic treatment became more advanced - the human death toll in the USA from bacterial diseases has dropped significantly (as well as in the rest of the developed world). In developing countries, success rates have depended on several factors, such as the strategies implemented by local health authorities, and whether countries enjoyed periods of peacetime (no wars). Countries such as Mexico, Argentina, and Uruguay, to mention but a few, have also seen significant falls in bacterial related deaths over the last 100 years.

Significance of bacteria in food technology

Lactic acid bacteria, such as *Lactobacillus* and *Lactococcus* together with yeast and molds (fungi) have been used for the preparation of such foods as cheese, soy sauce, vinegar, yoghurt and pickles. Humans have been using these bacteria for preparing fermented foods for thousands of years.

Significance of bacteria in other technologies

Bacteria can break down organic compounds at remarkable speed and help us in our waste processing and bioremediation activities. Bacteria are frequently used for cleaning up oil spills. They are useful in clearing up toxic waste.

The pharmaceutical and chemical industries use bacteria in the production of certain chemicals. They are used in the molecular biology, biochemistry and genetic research because they can grow quickly and are relative easy to manipulate. Scientists can use bacteria to study the functions of genes and enzymes, as well as bacterial metabolic pathways, and then test out their results on more complex organisms.

Such bacteria as *Bacillus thuringiensis (BT)* can be used in agriculture instead of pesticides, without the undesirable environmental consequences that pesticide use may cause.