**How Cells Work**

by [Marshall Brain](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/about-author.htm#brain)

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**The human body is composed of about 10 trillion cells. Everything from reproduction to infections to repairing a broken bone happens down at the cellular level. Find out all about cells. See more**[**brain pictures**](http://health.howstuffworks.com/human-body/systems/nervous-system/brain-pictures.htm)**.**

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**Introduction to How Cells Work**

At a microscopic level, we are all composed of cells. Look at yourself in a mirror -- what you see is about 10 trillion cells divided into about 200 differen­t types. Our muscles are made of muscle cells, our livers of liver cells, and there are even very specialized types of cells that make the enamel for our teeth or the clear lenses in our eyes!

If you want to ­understand how your body works, you need to understand cells. Everything from [reproduction](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/human-reproduction.htm) to infections to repairing a broken bone happens down at the cellular level. If you want to understand new frontiers like [biotechnology](http://news.discovery.com/biotechnology/) and genetic engineering, you need to understand cells as well.

Anyone who reads the paper or any of the scientific magazines (Scientific American, Discover, Popular Science) is aware that genes are BIG news these days. Here are some of the terms you commonly see:

* Biotechnology
* Gene splicing
* Human genome
* Genetic engineering
* Recombinant DNA
* Genetic diseases
* Gene therapy
* DNA mutations
* DNA fingerprinting or DNA profiling

Gene science and genetics are rapidly changing the face of medicine, agriculture and even the legal system!

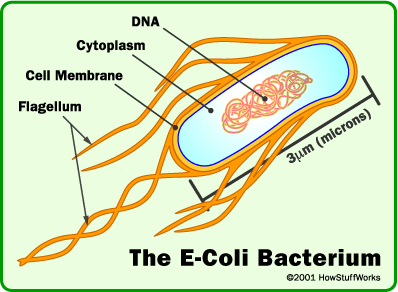
In this article, we'll delve down to the molecular level to completely understand how cells work. We'll look at the simplest cells possible: **bacteria cells**. By understanding how bacteria work, you can understand the basic mechanisms of all of the cells in your body. This is a fascinating topic both because of its very personal nature and the fact that it makes these news stories so much clearer and easier to understand. Also, once you understand how cells work, you will be able to answer other related questions like these:

* What is a virus and how does it work at the molecular level?
* What is an antibiotic and how do antibiotics work? Why don't antibiotics kill normal cells?
* What is a vitamin, and why do we need to take them every day?
* How do poisons work?
* What does it mean to be alive, at least at the cellular level?

All of these questions have obvious answers once you understand how cells work -- so let's get started!

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**Cell Parts**

Your body is made of about **10 trillion cells**. The largest human cells are about the diameter of a human hair, but most human cells are smaller -- perhaps one-tenth of the diameter of a human hair.

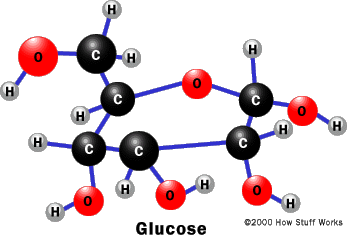
Run your fingers through your hair now and look at a single strand. It is not very thick -- maybe 100 microns in diameter (a micron is a millionth of a meter, so 100 microns is a tenth of a millimeter). A typical human cell might be one-tenth of the diameter of your hair (10 microns). Look down at your little toe -- it might represent 2 or 3 billion cells or so, depending on how big you are. Imagine a whole house filled with baby peas. If the house is your little toe, the peas are the cells. That's a lot of cells!

Bacteria are about the simplest cells that exist today. A bacteria is a single, self-contained, living cell. An ***Escherichia coli*** bacteria (or **E. coli** bacteria) is typical -- it is about one-hundredth the size of a human cell (maybe a micron long and one-tenth of a micron wide), so it is invisible without a [microscope](http://science.howstuffworks.com/light-microscope.htm). When you get an infection, the bacteria are swimming around your big cells like little rowboats next to a large ship.

Bacteria are a lot simpler than human cells. A bacterium consists of an outer wrapper called the **cell membrane**, and inside the membrane is a watery fluid called the **cytoplasm**. Cytoplasm might be 70-percent water. The other 30 percent is filled with proteins called**enzymes** that the cell has manufactured, along with smaller molecules like amino acids, glucose molecules and ATP. At the center of the cell is a ball of DNA (similar to a wadded-up ball of string). If you were to stretch out this DNA into a single long strand, it would be incredibly long compared to the bacteria -- about 1000 times longer!

An E. coli bacterium has a distinctive, capsule shape. The outer portion of the cell is the cell membrane, shown here in orange. In E. coli, there are actually two closely-spaced membranes protecting the cell. Inside the membrane is the cytoplasm, made up of millions of enzymes, sugars, ATP and other molecules floating freely in water. At the center of the cell is its DNA. The DNA is like a wadded-up ball of string. There is no protection for the DNA in a bacterium -- the wadded-up ball floats in the cytoplasm roughly in the center of the cell. Attached to the outside of the cell are long strands called **flagella**, which propel the cell. Not all bacterium have flagella, and no human cells have them besides sperm cells.

Human cells are much more complex than bacteria. They contain a special nuclear membrane to protect the DNA, additional membranes and structures like mitochondria and Golgi bodies, and a variety of other advanced features. However, the fundamental processes are the same in bacteria and human cells, so we will start with bacteria.



**The chemical structure of glucose**

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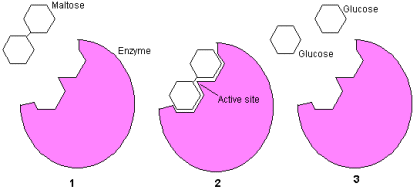
**Enzymes**

At any given moment, all of the work being done inside any cell is being done by **enzymes**. If you understand enzymes, you understand cells. A bacterium like E. coli has about 1,000 different types of enzymes floating around in the cytoplasm at any given time.

Enzymes have extremely interesting properties that make them little chemical-reaction machines. The purpose of an enzyme in a cell is to allow the cell to carry out chemical reactions very quickly. These reactions allow the cell to build things or take things apart as needed. This is how a cell grows and reproduces. At the most basic level, a cell is really a little bag full of chemical reactions that are made possible by enzymes!

Enzymes are made from **amino acids**, and they are proteins. When an enzyme is formed, it is made by stringing together between 100 and 1,000 amino acids in a very specific and unique order. The chain of amino acids then folds into a unique shape. That shape allows the enzyme to carry out specific chemical reactions -- an enzyme acts as a very efficient catalyst for a specific chemical reaction. The enzyme speeds that reaction up tremendously.

For example, the sugar maltose is made from two glucose molecules bonded together. The enzyme **maltase** is shaped in such a way that it can break the bond and free the two glucose pieces. The only thing maltase can do is break maltose molecules, but it can do that very rapidly and efficiently. Other types of enzymes can put atoms and molecules together. Breaking molecules apart and putting molecules together is what enzymes do, and there is a specific enzyme for each chemical reaction needed to make the cell work properly.

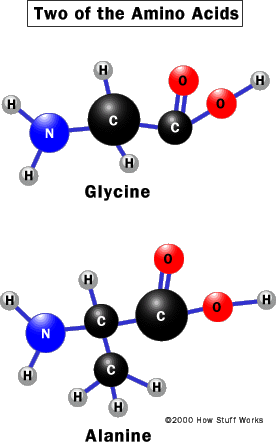


**Maltose is made of two glucose molecules bonded together (1). The maltase enzyme is a protein that is perfectly shaped to accept a maltose molecule and break the bond (2). The two glucose molecules are released (3). A single maltase enzyme can break in excess of 1,000 maltose bonds per second, and will only accept maltose molecules.**

You can see in the diagram above the basic action of an enzyme. A maltose molecule floats near and is captured at a specific site on the maltase enzyme. The **active site** on the enzyme breaks the bond, and then the two glucose molecules float away.

You may have heard of people who are **lactose intolerant**, or you may suffer from this problem yourself. The problem arises because the sugar in milk -- lactose -- does not get broken into its glucose components. Therefore, it cannot be digested. The intestinal cells of lactose-intolerant people do not produce **lactase**, the enzyme needed to break down lactose. This problem shows how the lack of just one enzyme in the human body can lead to problems. A person who is lactose intolerant can swallow a drop of lactase prior to drinking milk and the problem is solved. Many enzyme deficiencies are not nearly so easy to fix.

Inside a bacterium there are about 1,000 types of enzymes (lactase being one of them). All of the enzymes float freely in the cytoplasm waiting for the chemical they recognize to float by. There are hundreds or millions of copies of each different type of enzyme, depending on how important a reaction is to a cell and how often the reaction is needed. These enzymes do everything from breaking glucose down for energy to building cell walls, constructing new enzymes and allowing the cell to reproduce. Enzymes do all of the work inside cells.



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**Proteins**

A protein is any chain of amino acids. An amino acid is a small molecule that acts as the building block of any protein. If you ignore the fat, your body is about 20-percent protein by weight. It is about 60-percent water. Most of the rest of your body is composed of minerals (for example, calcium in your bones).

Amino acids are called "amino acids" because they contain an amino group (NH2) and a carboxyl group (COOH) that is acidic. In the figure above, you can see the chemical structure of two of the amino acids. You can see that the top part of each one is the same. That is true of all amino acids -- the little chain at the bottom (the H or the CH3 in these two amino acids) is the only thing varying from one amino acid to the next. In some amino acids, the variable part can be quite large. The human body is constructed of 20 different amino acids (there are perhaps 100 different amino acids available in nature).

As far as your body is concerned there are two different types of amino acids: essential and non-essential. Non-essential amino acids are amino acids that your body can create out of other chemicals found in your body. Essential amino acids cannot be created, and therefore the only way to get them is through food. Here are the different amino acids:

**Non-essential:**

* Alanine (synthesized from pyruvic acid)
* Arginine (synthesized from glutamic acid)
* Asparagine (synthesized from aspartic acid)
* Aspartic acid (synthesized from oxaloacetic acid)
* Cysteine (synthesized from homocysteine, which comes from methionine)
* Glutamic acid (synthesized from oxoglutaric acid)
* Glutamine (synthesized from glutamic acid)
* Glycine (synthesized from serine and threonine)
* Proline (synthesized from glutamic acid)
* Serine (synthesized from glucose)
* Tryosine (synthesized from phenylalanine)

**Essential:**

* Histidine
* Isoleucine
* Leucine
* Lysine
* Methionine
* Phenylalanine
* Threonine
* Tryptophan
* Valine

Protein in our diets comes from both animal and vegetable sources. Most animal sources (meat, milk, eggs) provide what's called "complete protein", meaning that they contain all of the essential amino acids. Vegetable sources usually are low on or missing certain essential amino acids. For example, rice is low in isoleucine and lysine. However, different vegetable sources are deficient in different amino acids, and so by combining different foods you can get all of the essential amino acids throughout the course of the day. Some vegetable sources contain quite a bit of protein. Nuts, beans and soybeans are all high in protein. By combining them, you can get complete coverage of all essential amino acids.

The digestive system breaks all proteins down into their amino acids so that they can enter the [bloodstream](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/blood.htm). Cells then use the amino acids as building blocks to build enzymes and structural proteins.

See [How Food Works](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/food.htm) for additional information.

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**Enzymes at Work**

There are all sorts of enzymes at work inside of bacteria and human cells, and many of them are incredibly interesting! Cells use enzymes internally to grow, reproduce and create energy, and they often excrete enzymes outside their cell walls as well. For example, E. coli bacteria excrete enzymes to help break down food molecules so they can pass through the cell wall into the cell. Some of the enzymes you may have heard of include:

* **Proteases** and **peptidases** - A protease is any enzyme that can break down a long protein into smaller chains called peptides (a peptide is simply a short amino acid chain). Peptidases break peptides down into individual amino acids. Proteases and peptidases are often found in laundry detergents -- they help remove things like blood stains from cloth by breaking down the proteins. Some proteases are extremely specialized, while others break down just about any chain of amino acids. (You may have heard of **protease inhibitors** used in drugs that fight the AIDS virus. The AIDS virus uses very specialized proteases during part of its reproductive cycle, and protease inhibitors try to block them to shut down the reproduction of the virus.)
* **Amylases** - Amylases break down starch chains into smaller sugar molecules. Your saliva contains amylase and so does your small intestine. Maltase, lactase, sucrase (described in the previous section) finish breaking the simple sugars down into individual glucose molecules.
* **Lipases** - Lipases break down [fats](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/fat.htm).
* **Cellulases** - Cellulases break cellulose molecules down into simpler sugars. Bacteria in the guts of cows and termites excrete cellulases, and this is how cows and termites are able to eat things like grass and wood.

Bacteria excrete these enzymes outside their cell walls. Molecules in the environment are broken down into pieces (proteins into amino acids, starches into simple sugars, etc.) so they are small enough to pass through the cell's wall into the cytoplasm. This is how an E. coli eats!

Inside a cell, hundreds of highly specialized enzymes carry out extremely specific tasks that the cell needs to live its life. Some of the more amazing enzymes found inside cells include:

* **Energy enzymes** - A set of 10 enzymes allows a cell to perform **glycolysis**. Another eight enzymes control the **citric-acid cycle** (also known as the Krebs cycle). These two processes together allow a cell to turn glucose and oxygen into adenosine triphosphate, or ATP. In an oxygen-consuming cell like E. coli or a human cell, one glucose molecule forms 36 ATP molecules (in something like a yeast cell, which lives its life without oxygen, only glycosis occurs and it produces only two ATP molecules per glucose molecule). ATP is a fuel molecule that is able to power enzymes by performing "uphill" chemical reactions.
* **Restriction enzymes** - Many bacteria are able to produce restriction enzymes, which recognize very specific patterns in DNA chains and break the DNA at those patterns. When a virus injects its DNA into a bacterium, the restriction enzyme recognizes the viral DNA and cuts it, effectively destroying the virus before it can reproduce.
* **DNA-manipulation enzymes** - There are specialized enzymes that move along DNA strands and repair them. There are other enzymes that can untwist DNA strands to reproduce them (DNA polymerase). Still others can find small patterns on DNA and attach to them, blocking access to that section of DNA (DNA-binding proteins).
* **Enzyme-production enzymes** - All of these enzymes have to come from somewhere, so there are enzymes that produce the cell's enzymes! Ribonucleic acid (RNA), in three different forms (messenger RNA, transfer RNA and ribosomal RNA), is a big part of the process.

A cell really is nothing but a set of chemical reactions, and enzymes make those reactions happen properly.

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**Making Enzymes**

As long as a cell's membrane is intact and it is making all of the enzymes it needs to function properly, the cell is **alive**. The enzymes it needs to function properly allow the cell to create energy from glucose, construct the pieces that make up its cell wall, reproduce and, of course, produce new enzymes.

So where do all of these enzymes come from? And how does the cell produce them when it needs them? If a cell is just a collection of enzymes causing chemical reactions that make the cell do what it does, then how can a set of chemical reactions create the enzymes it needs, and how can the cell reproduce? Where does the miracle of life come from?

The answer to these questions lies in the **DNA**, or deoxyribonucleic acid. You have certainly heard of DNA, **chromosomes** and **genes**. DNA guides the cell in its production of new enzymes.

The DNA in a cell is really just a pattern made up of four different parts, called **nucleotides** or **bases**. Imagine a set of blocks that has only four different shapes, or an alphabet that has only four different letters. DNA is a long string of blocks or letters. In an E. coli cell, the DNA pattern is about 4 million blocks long. If you were to stretch out this single stand of DNA, it would be 1.36 mm long -- pretty long considering the bacteria itself is 1,000 times smaller. In bacteria, the DNA strand is like a wadded-up ball of string. Imagine taking 1,000 feet (300 meters) of incredibly thin thread and wadding it up -- you could easily hold it in your hand. [A human's DNA is about 3 billion blocks long, or almost 1,000 times longer than an E. coli's. Human DNA is so long that the wadded-up approach does not work. Instead, human DNA is tightly wrapped into 23 structures called **chromosomes** to pack it more tightly and fit it inside a cell.]

The amazing thing about DNA is this: DNA is nothing more than a pattern that tells the cell how to make its proteins! That is all that DNA does. The 4 million bases in an E. coli cell's DNA tell the cell how to make the 1,000 or so enzymes that an E. coli cell needs to live its life. A **gene** is simply a section of DNA that acts as a template to form an enzyme.

Let's look at the entire process of how DNA is turned into an enzyme so you can understand how it works.

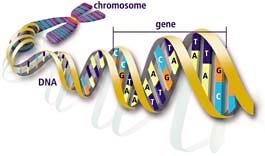


Image courtesy [U.S. Department of Energy Human Genome Program](http://www.ornl.gov/hgmis)

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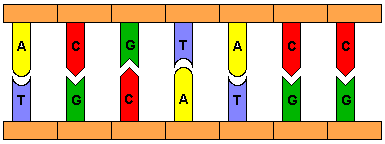
**DNA**

You have probably heard of the DNA molecule referred to as the "double-helix." DNA is like two strings twisted together in a long spiral.

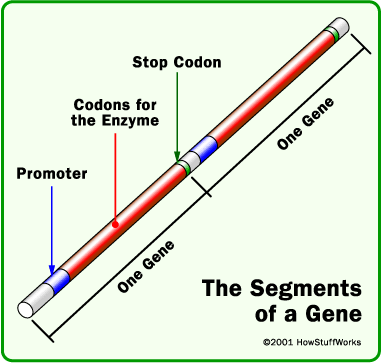
DNA is found in all cells as **base pairs** made of four different **nucleotides**. Each base pair is formed from two complementary nucleotides bonded together. The four bases in DNA's alphabet are:

* **Adenine**
* **Cytosine**
* **Guanine**
* **Thymine**

Adenine and thymine always bond together as a pair, and cytosine and guanine bond together as a pair. The pairs link together like rungs in a ladder:



**Base pairs in DNA bond together to form a ladder-like structure. Because bonding occurs at angles between the bases, the whole structure twists into a helix.**

In an E. coli bacterium, this ladder is about 4 million base pairs long. The two ends link together to form a ring, and then the ring gets wadded up to fit inside the cell. The entire ring is known as the **genome**, and scientists have completely decoded it. That is, scientists know all 4 million of the base pairs needed to form an E. coli bacterium's DNA exactly. The **human genome project** is in the process of finding all 3 billion or so of the base pairs in a typical human's DNA.

**A gene consists of a promoter, the codons for an enzyme and a stop codon. Two genes are shown above. The long strand of DNA in an E. coli bacterium encodes about 4,000 genes, and at any time those genes specify about 1,000 enzymes in the cytoplasm of an E. coli cell. Many of the genes are duplicates.**

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**The Big Question**

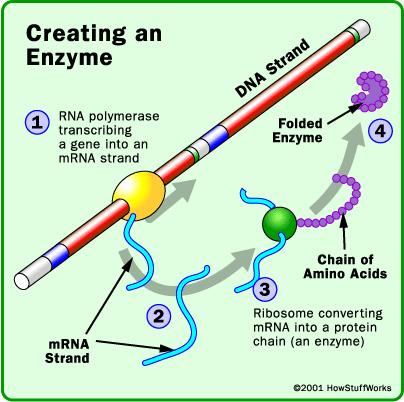
You may remember from a previous section that enzymes are formed from 20 different amino acids strung together in a specific order. Therefore the question is this: How do you get from DNA, made up of only four nucleotides, to an enzyme containing 20 different amino acids? There are two answers to this question:

1. An extremely complex and amazing enzyme called a **ribosome** reads messenger RNA, produced from the DNA, and converts it into amino-acid chains.
2. To pick the right amino acids, a ribosome takes the nucleotides in sets of three to encode for the 20 amino acids.

What this means is that every three base pairs in the DNA chain encodes for one amino acid in an enzyme. Three nucleotides in a row on a DNA strand is therefore referred to as a **codon**. Because DNA consists of four different bases, and because there are three bases in a codon, and because 4 \* 4 \* 4 = 64, there are 64 possible patterns for a codon. Since there are only 20 possible amino acids, this means that there is some redundancy -- several different codons can encode for the same amino acid. In addition, there is a **stop codon** that marks the end of a gene. So in a DNA strand, there is a set of 100 to 1,000 codons (300 to 3,000 bases) that specify the amino acids to form a specific enzyme, and then a stop codon to mark the end of the chain. At the beginning of the chain is a section of bases that is called a **promoter**. A gene, therefore, consists of a promoter, a set of codons for the amino acids in a specific enzyme, and a stop codon. That is all that a gene is.

To create an enzyme, the cell must first **transcribe** the gene in the DNA into **messenger RNA**. The transcription is performed by an enzyme called **RNA polymerase**. RNA polymerase binds to the DNA strand at the promoter, unlinks the two strands of DNA and then makes a complementary copy of one of the DNA strands into an RNA strand. RNA, or **ribonucleic acid**, is very similar to DNA except that it is happy to live in a single-stranded state (as opposed to DNA's desire to form complementary double-stranded helixes). So the job of RNA polymerase is to make a copy of the gene in DNA into a single strand of messenger RNA (mRNA).

The strand of messenger RNA then floats over to a **ribosome**, possibly the most amazing enzyme in nature. A ribosome looks at the first codon in a messenger RNA strand, finds the right amino acid for that codon, holds it, then looks at the next codon, finds its correct amino acid, stitches it to the first amino acid, then finds the third codon, and so on. The ribosome, in other words, reads the codons, converts them to amino acids and stitches the amino acids together to form a long chain. When it gets to the last codon -- the stop codon -- the ribosome releases the chain. The long chain of amino acids is, of course, an enzyme. It folds into its characteristic shape, floats free and begins performing whatever reaction that enzyme performs.



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**No Simple Task**

Obviously, the process described on the previous page is not a simple one. A ribosome is an extremely complex structure of enzymes and ribosomal RNA (rRNA) bonded together into a large molecular machine. A ribosome is helped by ATP, which powers it as it walks along the messenger RNA and as it stitches the amino acids together. It is also helped by**transfer RNA** (tRNA), a collection of 20 special molecules that act as carriers for the 20 different individual amino acids. As the ribosome moves down to the next codon, the correct tRNA molecule, complete with the correct amino acid, moves into place. The ribosome breaks the amino acid off the tRNA and stitches it to the growing chain of the enzyme. The ribosome then ejects the "empty" tRNA molecule so it can go get another amino acid of the correct type.

As you can see, inside every cell there are a variety of processes keeping the cell alive:

* There is an extremely long and very precise DNA molecule that defines all of the enzymes the cell needs.
* There are RNA polymerase enzymes attaching to the DNA strand at the starting points of different genes and copying the DNA for the gene into an mRNA molecule.
* The mRNA molecule floats over to a ribosome, which reads the molecule and stitches together the string of amino acids that it encodes.
* The string of amino acids floats away from the ribosome and folds into its characteristic shape so it can start catalyzing its specific reaction.

The cytoplasm of any cell is swimming with ribosomes, RNA polymerases, tRNA and mRNA molecules and enzymes, all carrying out their reactions independently of each other.

As long as the enzymes in a cell are active and all of the necessary enzymes are available, the cell is alive. An interesting side note: If you take a bunch of yeast cells and mistreat them (for example, place them in a blender) to release the enzymes, the resulting soup will still do the sorts of things that living yeast cells do (for example, produce carbon dioxide and alcohol from sugar) for some period of time. However, since the cells are no longer intact and therefore are not alive, no new enzymes are produced. Eventually, as the existing enzymes wear out, the soup stops reacting. At this point, the cells and the soup have "died."

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**Reproduction**

The hallmark of all living things is the ability to [reproduce](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/human-reproduction.htm). A bacterium reproduction is simply another enzymatic behavior. An enzyme called **DNA polymerase**, along with several other enzymes that work alongside it, walks down the DNA strand and replicates it. In other words, DNA polymerase splits the double helix and creates a new double helix along each of the two strands. Once it reaches the end of the DNA loop, there are two separate copies of the loop floating in the E. coli cell. The cell then pinches its cell wall in the middle, divides the two DNA loops between the two sides and splits itself in half.

Under the proper conditions, an E. coli cell can split like this every 20 or 30 minutes! The enzymatic process of growing the cell, replicating the DNA loop and splitting happens very rapidly.

For more information, see [How Human Reproduction Works](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/human-reproduction.htm).

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**Poisons and Antibiotics**

You can now see that the life of a cell is dependent on a rich soup of enzymes that float in the cell's cytoplasm. Many different poisons work by disrupting the balance of the soup in one way or another.

For example, diphtheria toxin works by gumming up the action of a cell's ribosomes, making it impossible for the ribosome to walk along the mRNA strand. The toxin in a death-cap mushroom, on the other hand, gums up the action of RNA polymerase and halts the transcription of DNA. In both cases, the production of new enzymes shuts down and the cells affected by the toxin can no longer grow or reproduce.

An **antibiotic** is a poison that works to destroy bacterial cells while leaving human cells unharmed. All antibiotics take advantage of the fact that there are many differences between the enzymes inside a human cell and the enzymes inside a bacterium. If a toxin is found, for example, that affects an E. coli ribosome but leaves human ribosomes unharmed, then it may be an effective antibiotic. Streptomycin is an example of an antibiotic that works in this way.

Penicillin was one of the first antibiotics. It gums up a bacterium's ability to build cell walls. Since bacterial cell walls and human cell walls are very different, penicillin has a big effect on certain species of bacteria but no effect on human cells. The sulfa drugs work by disabling an enzyme that manages the creation of nucleotides in bacteria but not in humans. Without nucleotides, the bacteria cannot reproduce.

You can see that the search for new antibiotics occurs down at the enzyme level, hunting for differences between the enzymes in human and bacterial cells that can be exploited to kill bacteria without affecting human cells.

The unfortunate problem with any antibiotic is that it becomes ineffective over time. Bacteria reproduce so quickly that the probability for mutations is high. In your body, there may be millions of bacteria that the antibiotic kills. But if just one of them has a mutation that makes it immune to the antibiotic, that one cell can reproduce quickly and then spread to other people. Most bacterial diseases have become immune to some or all of the antibiotics used against them through this process.

UP NEXT

* [How DNA Works](http://science.howstuffworks.com/life/cellular-microscopic/dna.htm)
* [How Viruses Work](http://science.howstuffworks.com/life/cellular-microscopic/virus-human.htm)
* [Curiosity Project: What causes apoptosis?](http://curiosity.discovery.com/question/what-causes-apoptosis)

**Viruses**

Viruses are absolutely amazing. Although they are not themselves alive, a virus can reproduce by hijacking the machinery of a living cell. The article [How Viruses Work](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/virus-human.htm) describes viruses in detail -- below is a summary.

A virus particle consists of a viral jacket wrapped around a strand of DNA or RNA. The jacket and its short strand of DNA can be extremely small -- a thousand times smaller than a bacterium. The jacket normally is studded with chemical "feelers" that can bond to the outside of a cell. Once docked, the viral DNA (or RNA, depending on the virus) is injected into the cell, leaving the jacket on the outside of the cell.

In the simplest virus, the DNA or RNA strand is now floating freely inside a cell. RNA polymerase transcribes the DNA strand, and ribosomes create the enzymes that the viral DNA specifies. The enzymes that the viral DNA creates are able to create new viral jackets and other components of the virus. In simple viruses, the jackets then self-assemble around replicated DNA strands. Eventually the cell is so full of new viral particles that the cell bursts, freeing the particles to attack new cells. Using this system, the speed at which a virus can reproduce and infect other cells is amazing.

In most cases, the [immune system](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/immune-system.htm) produces antibodies, which are proteins that bind to the viral particles and prevent them from attaching to new cells. The immune system can also detect infected cells by discovering cells decorated with viral jackets, and can kill infected cells.

Antibiotics have no effect on a virus because a virus is not alive. There is nothing to kill! Immunizations work by pre-infecting the body so it knows how to produce the right antibodies as soon as the virus starts reproducing.

See [How the Immune System Works](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/immune-system.htm) for further details.

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**Genetic Diseases**

Many genetic diseases occur because a person is missing the gene for a single enzyme. Here are some of the more common problems caused by missing genes:

* **Lactose intolerance** - The inability to digest lactose (the sugar in milk) is caused by a missing lactase gene. Without this gene, no lactase is produced by intestinal cells.
* **Albinism** - In albinos, the gene for the enzyme tyrosinase is missing. This enzyme is necessary for the production of melanin, the pigment that leads to [sun tans](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/sunscreen.htm), hair color and eye color. Without tyrosinase, there is no melanin.
* **Cystic fibrosis** - In cystic fibrosis, the gene that manufactures the protein called cystic fibrosis transmembrane conductance regulator is damaged. According to**Encyclopedia Britannica**: The defect (or mutation) found in the gene on chromosome 7 of persons with cystic fibrosis causes the production of a protein that lacks the amino acid phenylalanine. This flawed protein somehow distorts the movement of salt and water across the membranes that line the lungs and gut, resulting in dehydration of the mucus that normally coats these surfaces. The thick, sticky mucus accumulates in the lungs, plugging the bronchi and making breathing difficult. This results in chronic respiratory infections, often with Staphylococcus aureus or Pseudomonas aeruginosa. Chronic cough, recurrent pneumonia, and the progressive loss of lung function are the major manifestations of lung disease, which is the most common cause of death of persons with cystic fibrosis.

Other genetic diseases include Tay-Sachs disease (damage to the gene for the enzyme hexosaminidase A leads to an accumulation of a chemical in the brain that destroys it), sickle cell anemia (improper coding of the gene that produces hemoglobin), hemophilia (lack of a gene for a blood-clotting factor) and muscular dystrophy (caused by a defective gene on the X chromosome). There are something like 60,000 genes in the human genome, and over 5,000 of them, if damaged or missing, are known to lead to genetic diseases. It is amazing that damage to just one enzyme can lead, in many cases, to life-threatening or disfiguring problems.

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**Biotechnology**

So what is **biotechnology** and **genetic engineering**? There are three major developments that act as the signature of biotech, with many more surprises coming down the road:

* Bacterial production of substances like human interferon, human insulin and human growth hormone. That is, simple bacteria like E. coli are manipulated to produce these chemicals so that they are easily harvested in vast quantities for use in medicine. Bacteria have also been modified to produce all sorts of other chemicals and enzymes.
* Modification of plants to change their response to the environment, disease or pesticides. For example, tomatoes can gain fungal resistance by adding chitinases to their genome. A chitinase breaks down chitin, which forms the cell wall of a fungus cell. The pesticide Roundup kills all plants, but crop plants can be modified by adding genes that leave the plants immune to Roundup.
* [Identification of people by their DNA](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/dna-evidence.htm). An individual's DNA is unique, and various, fairly simple tests let DNA samples found at the scene of a crime be matched with the person who left it. This process has been greatly aided by the invention of the **polymerase chain reaction** (PCR) technique for taking a small sample of DNA and magnifying it millions of times over in a very short period of time.

To understand some of the techniques used in biotechnology, lets look at how bacteria have been modified to produce human insulin.

Insulin is a simple protein normally produced by the pancreas. In people with [diabetes](http://science.howstuffworks.com/life/cellular-microscopic/cell.htm/diabetes.htm), the pancreas is damaged and cannot produce insulin. Since insulin is vital to the body's processing of glucose, this is a serious problem. Many diabetics, therefore, must inject insulin into their bodies daily. Prior to the 1980s, insulin for diabetics came from pigs and was very expensive.

To create insulin inexpensively, the gene that produces human insulin was added to the genes in a normal E. coli bacteria. Once the gene was in place, the normal cellular machinery produced it just like any other enzyme. By culturing large quantities of the modified bacteria and then killing and opening them, the insulin could be extracted, purified and used very inexpensively.

The trick, then, is in getting the new gene into the bacteria. The easiest way is to splice the gene into a **plasmid** -- a small ring of DNA that bacteria often pass to one another in a primitive form of sex. Scientists have developed very precise tools for cutting standard plasmids and splicing new genes into them. A sample of bacteria is then "infected" with the plasmid, and some of them take up the plasmid and incorporate the new gene into their DNA. To separate the infected from the uninfected, the plasmid also contains a gene giving the bacteria immunity to a certain antibiotic. By treating the sample with the antibiotic, all of the cells that did not take up the plasmid are killed. Now a new strain of insulin-producing E. coli bacteria can be cultured in bulk to create insulin.

For more information on cells, bacteria, enzymes and related topics, check out the links on the next page.