BIOLOGY

WHAT YOU NEED TO KNOW

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Last updated: October 25, 2023.

HOW TO STUDY BIOLOGY

Biology studies all living things, or even those things whose living status is questionable, like viruses.

You should learn about biology through observation and by looking at pictures and videos, but most of the details will come through reading. If you are just reading a fiction book you can often guess the meaning of words from the context, but that won't work so well for biology and other sciences. You need to understand the exact meaning of every sentence that deals with complex topics. So, if you see an unfamiliar word that is not specifically explained in the text, look it up! Some people respond better to audio and can benefit from a screen reader even if they are not visually impaired – try some free readers.

People of many religions believe that an entity created the universe and is responsible for the fact that life exists on this planet. Any argument over the existence of a Creator is beyond the scope of biology, and the scope of science in general. However, the issue of evolution versus creation is a persistent and emotionally charged controversy that affects how people study biology.

If you don't want to hear anything about creation, you can read this online textbook: CK-12 Biology | CK-12 Foundation (ck12.org)

If you don't want to hear anything about evolution, you can read the modified version of the same book: Guest Hollow's High School Biology Online Textbook - Guest Hollow. Note that this book omits the anatomy section found in the unmodified version, which is fine if you plan to study anatomy as a separate course. If not, you can always look at the original text.

This e-book is a study guide, designed to highlight and explain important facts in these and other biology textbooks.

1. Read a chapter in this guide.
2. Explore online through pictures, videos and textbooks.
3. Read the guide again to review and see what you should remember.

THE CHEMISTRY OF LIFE

Atoms

Atoms are the building blocks of matter. The simplest atom is the hydrogen atom, referred to by the letter **H** in chemistry. The hydrogen atom has a **nucleus** consisting of a single positively charged particle called a **proton**. This positive charge is balanced out by the negative charge of its single **electron**. Diagrams of atoms usually show electrons as little balls orbiting the nucleus, somewhat like planets orbit the sun. Although that isn't what things look like in reality, this representation does help us to understand what happens with electrons.

The next simplest atom is the helium atom, He. It has two protons in its nucleus, as well as some **neutrons** to help hold them together. There are two electrons around the nucleus to balance out the electrical charges. After that comes lithium, Li, with 3 protons and 3 electrons, and so on. Some of these atoms exist singly, while others combine with more of the same kind of atoms. Any substance made up of only one kind of atom is called an **element**. Since there is a limit to how many protons can be packed together in a nucleus, there are a limited number of elements. They are all shown in the **Periodic Table**.

Atoms can combine with other atoms of the same kind, or different kinds, to form many different substances. They do so by sharing electrons, or by giving one or more of their electrons to another atom. If an atom loses electrons, it loses negative charge so that it ends up being positively charged. An atom that gains extra electrons becomes negatively charged. These charged atoms are called **ions**. If the hydrogen atom, H, loses its single electron it becomes a hydrogen ion, **H^+**.

Water and Air

Let's look at water, which makes up about 60% of the human body. You're so used to water that you probably take it for granted, but it is a very unique liquid. It has special properties that help sustain life.

Like other liquids water is made up of molecules, and there are many trillions of these molecules in even a tiny drop. Each water molecule consists of one oxygen atom and two hydrogen atoms that are bound together by their shared electrons. These molecules can be split apart into oxygen and hydrogen, but energy is required to do so. That energy can be recovered, as we will see when we look at how plants use energy from sunlight.

Water molecules are **polar** – one end of the molecule is somewhat negatively charged while the other end is slightly positive. This makes water good at dissolving many substances. A large proportion of your blood is water, and it carries dissolved nutrients that your body needs, as well as waste substances to be eliminated.

When water freezes, the polar water molecules form a crystal structure that is less dense than liquid water. Ice floats, allowing life to continue in ponds and lakes even when the surface freezes.

Water also has a high specific heat, which means that it takes longer to heat an amount of water than it does to heat the same amount of many other substances. When the temperature of the surroundings drops, the heat in a body of water is released and warms the surrounding environment. Large bodies of water moderate the climate, making it easier for **terrestrial** (land-dwelling) organisms to survive.

Water sticks to itself, forming drops, but it also sticks to its surroundings. If you put a thin straw in a glass of water, a little bit of water stays behind when you lift the straw. Look closely at where the water touches the glass: it is pulled up very slightly on the edges. The surface of the water, the **meniscus**, looks like a double line when viewed from the outside of the glass. Whenever you measure water in a cup, use the lower line to determine the amount. If you had a really thin tube, you would see water rising in it spontaneously. Look for a video on **capillary action**. Plants can use very thin channels to pull water up from their roots, and as it evaporates from the leaves more water is pulled up through these channels. This is an amazing passive process – no pump required!

This is a good time to experiment. Use three liquids: water, rubbing alcohol, and any kind of vegetable oil. Only small quantities are needed.

Try freezing equal amounts of these liquids in small identical containers like bottle caps. Which of these liquids freeze?

Afterwards, expose the same containers to some warmth like bright sunlight, or just leave them alone at room temperature for a few days. How easily do they evaporate?

Next, try dissolving a tiny bit of salt in your liquids. Polar liquids are best at dissolving salt, but to see which liquid is the best solvent you need to carefully measure the amounts of both the liquid and the solid. Also try a tiny bit of room-temperature butter. Which liquid is the best solvent for this substance?

There are 3 different ways to mix two of these liquids together. Which ones mix?

Air is another important part of the chemistry of life. Air is composed of about 78% nitrogen (N_2), 21% oxygen (O_2), and 0.04% carbon dioxide (CO_2). All of these substances are important to living organisms. Carbon dioxide made up about 0.03% of the atmosphere in the 1950's, but it has increased steadily since then.

Organic Compounds

The element **carbon** (**C**) forms the basis of life on Earth. Its ability to create four bonds with other atoms allows it to form long complex chains. **Organic compounds** are substances containing carbon and hydrogen. They are called "organic" because for a long time it was thought that they could only be created by living organisms. Now we know that these compounds are common in our universe. There are four important kinds of organic compounds you need to know about:

1. **Carbohydrates** are organic substances like sugar, starch and cellulose. Some carbohydrates are digestible by humans, and others are not.

2. **Proteins** are made up of **amino acids**, which contain the element nitrogen (N). Humans and other animals need to eat protein, which may be obtained from animal or vegetable sources. **Enzymes** are special proteins that help reactions proceed faster.

3. **Lipids** are fats. Phospholipids are important in biology because they make up cell membranes. **Saturated fats** are straight carbon chains saturated with hydrogen. They are usually solid at room temperature, and can potentially clog your arteries. **Unsaturated fats** chains are bent where there is less hydrogen, so they don't form solids as easily.

4. **DNA** and **RNA** are nucleic acids. They carry and transmit genetic information. DNA (deoxyribonucleic acid) is a long molecule that can carry genetic information in the form of a code. The building blocks of DNA each contain one of 4 different bases: Adenine, Guanine, Cytosine, or Thymine. Different combinations of these bases allow for encoding of information. DNA is composed of two strands, which allows for replication. You should look at pictures that show the structure of DNA. RNA is very similar to DNA, but it is usually a single strand. It contains Uracil instead of Thymine.

You should read about these different kinds of molecules and look at their structure. Notice that all of them have quite complex structures, unlike simple molecules such as water or oxygen. It is not necessary to memorize the details, but you should be familiar with the main ideas outlined above. Also check the nutrition labels on your food for some of the substances mentioned above.

Once people learned to create chemical compounds, they did so enthusiastically and with little thought about potential consequences. Chemicals are also simply released as a byproduct of human activities. There are a lot of people on this planet, and the amount of chemicals involved is staggering. Even the drugs we take end up being flushed down the toilet as they leave our bodies, and so enter the environment. The chemistry of life on Earth is changing as organisms encounter new chemical compounds or increased amounts of chemicals they were already used to.

CELLS

The discovery that animals and plants are made up of cells was a major breakthrough in science. Microscopes also allowed scientists to see that our world is teeming with a multitude of single-celled organisms. Cells are incredibly complex tiny living machines. After centuries of study there is still much that we don't know about how they work. This section provides a brief overview.

Both plant and animal cells have a **nucleus** that contains the genetic material (DNA) of the cell, and they are similar in many other ways. Many single-celled organisms look like individual animal cells. Others, usually very much smaller, don't have a separate nucleus to contain their genetic material. Biologists call plants and animals **eukaryotes**. The word eukaryote means "true nucleus". Single-celled organisms with a nucleus are eukaryotes, and those without a nucleus are called **prokaryotes** ("before nuclei"). Bacteria are prokaryotes. The prokaryotic cell is not only smaller, but also simpler in structure than the eukaryotic cell.

Although there are prokaryotes that have multiple cells, most multicellular organisms are eukaryotes. In a multicellular organism the cells usually carry the same genetic information, but they may look very different from each other because they specialize to perform different tasks. Some cells may even lose their nucleus as they specialize, but that does not mean they have turned into prokaryotic cells! The difference between prokaryotes and eukaryotes is a very fundamental difference between two types of organisms. People often think of prokaryotes as ancient and primitive, but each prokaryote that exists today is uniquely adapted to survive in its environment.

Some prokaryotes are dangerous bacteria that cause diseases in humans, other animals, and even plants. We fight these bacteria with **antibiotics**, which exploit the differences between prokaryotic and eukaryotic cells. For example, penicillin kills bacteria by interfering with the formation of their cell walls as they try to grow and divide. Our cell boundaries are very different, so we are not affected.

Cell Structure

Eukaryotic cells have a nucleus that contains their DNA (deoxyribonucleic acid). DNA stores all of the information needed by the cell as well as the information required for the development, function and reproduction of a multicellular organism. Thanks to its double helix structure, DNA can be replicated efficiently. The two strands split and new complementary strands are synthesized. DNA strands are incredibly long compared to the size of cells, but they can fit into the nucleus because they are tightly wound around proteins called **histones**.

Cells are filled with **cytoplasm** that contains many specialized **organelles** besides the nucleus. **Mitochondria** make **ATP**, which provides energy for the cell. **Ribosomes** are made inside a small, more darkly staining, area of the nucleus called the **nucleolus.** Ribosomes produce proteins. Ribosomes may be found loose in the cytoplasm, or attached to the **rough endoplasmic reticulum**. The **smooth endoplasmic reticulum** does not have attached ribosomes, and functions in the processing of lipids rather than proteins. The **Golgi apparatus** modifies and packages proteins and lipids for distribution inside and outside the cell. **Lysosomes** are small vesicles that contain enzymes which break down unwanted substances. All cells have a **cell membrane**, which keeps the contents in but allows some things in and out.

Plant cells look a bit different from animal cells, mostly because they have a rigid **cell wall** and contain green **chloroplasts** that are able to make food using only water, air and sunlight. There is usually a large central **vacuole** that stores water and other molecules. Other than that, plant cells have the same organelles as animal cells, including mitochondria and their own version of lysosomes.

Plant cells are self-sufficient and can make their own amino acids, lipids, carbohydrates, RNA, and replacement DNA. Animal cells are partly reliant on nutrients from the environment, but they can also make or modify many organic molecules to meet their needs.

Chloroplasts, found only in plant cells, are able to use the carbon in carbon dioxide to produce **glucose**, as well as many other organic molecules. Glucose is a high-energy compound, and chloroplasts use energy from sunlight in order to make it. Chloroplasts contain their own DNA and reproduce as needed.

Mitochondria provide both plant and animal cells with the energy that they need to function. They use oxygen to help extract energy from nutrient molecules like glucose, and then store that energy in ATP molecules that act like tiny batteries. Mitochondria also have their own DNA, and reproduce as needed.

Osmosis is a physical phenomenon that is very important to cells. Water always moves through a semipermeable membrane (a barrier that lets some substances through but not others) into an area with a higher concentration of dissolved substances. Because cell membranes are semi-permeable, cells could either lose water to their environment, or take in so much water that they would explode. Cells have to be adapted to the osmotic pressure in their environment. Take a close look at diagrams showing the structure of cell membranes, and read about the phospholipid bilayer. If you did the liquid experiments in the last chapter, you can easily see why those bilayers stick together and hold the cell’s contents inside.

What to Study

Study diagrams of prokaryotic cells, animal cells, and plant cells. Pay attention to the similarities and the differences. Look up the meaning of any unfamiliar words.

- Prokaryotic vs. Eukaryotic Cells
- Prokaryotic cells have ribosomes but lack nuclei, mitochondria, and chloroplasts
- Prokaryotes are often able to move with flagella, pili or in other ways
- Eukaryotic cells have a nucleus, and membrane-bound organelles
- Plant cells have a cell wall, chloroplasts, and a central vacuole
- Know the function of each organelle
- Study the structure of DNA
- Osmosis: water moves through a semipermeable membrane into an area with higher solute concentration

PROTEIN SYNTHESIS

DNA contains four different bases: Adenine, Guanine, Cytosine and Thymine. Together these bases provide a surprisingly efficient code. A group of 3 bases is called a **codon**. There are 64 different ways to create a group of three bases, which is more than enough to code for the different amino acids used by cells. Twenty different amino acids are coded for by DNA, with most represented by more than one codon.

For the code to be read, the tightly wound DNA must be partially unwound, and the double helix must be "unzipped" so that one strand can be translated. The enzyme **RNA polymerase** copies the information into messenger RNA (**mRNA**). RNA also contains four different bases, but it has **Uracil** instead of Thymine.

The mRNA is exported from the nucleus into the cytoplasm, where it attaches to a ribosome. Each ribosome has two parts: a small subunit and a large subunit. The small subunit reads the mRNA, and the large subunit assembles individual amino acids into a protein, in the order specified by the mRNA. The different amino acids are brought to the ribosome by transfer RNA (**tRNA**). The proteins that are produced may be antibodies, hormones, enzymes that allow the cell to carry out chemical reactions, structural proteins like components of muscle fibers, proteins that transport substances, etc.

The message in the mRNA can be read more than once, and multiple ribosomes can be attached to a single strand of mRNA. Once the cell is finished using the mRNA it is broken down, which can be after several minutes or up to a few days.

CELL DIVISION: MITOSIS

Simple cell division in eukaryotic cells is called **mitosis**. Multicellular organisms grow through cell division, and they also use division to replace worn-out cells. The purpose of mitosis is to produce two new cells that are identical to the original cell, and contain the same genetic information.

Interphase: Cells normally spend most of their time in this phase. The cell duplicates its DNA at the end of this phase to prepare for mitosis.

Prophase: The first phase of mitosis. Chromosomes become visible and the mitotic spindle begins to form. Due to the duplication that happened at the end of interphase, each chromosome is now composed of two identical sister chromatids.

Prometaphase: The nuclear membrane breaks down, and the microtubules of the spindle can attach to the chromosomes.

Metaphase: The chromosomes line up in the center of the completed spindle.

Anaphase: The sister chromatids separate.

Telophase: The cell splits into two new cells. The nucleus reassembles in each cell.

Chromosomes normally exist in the nucleus as long coiled threads which are not really visible with a regular microscope. They only assume the shape you see in pictures when division is about to take place. Each chromosome has two identical sister **chromatids** that are held together at the **centromere** region. The spindle's **microtubules** attach to each of the two kinetochores located in the centromere region, and pull the chromatids apart.

Mitosis in plant cells is similar to what happens in animal cells.

Prokaryotic cells divide through a process called **binary fission**, which turns one single-celled organism into two.

There are some amazing videos about mitosis online. Look at animations and pictures first, then search for mitosis in live cells.

CELL DIVISION: MEIOSIS

Some species of multicellular plants and animals can reproduce asexually, but sexual reproduction requires a special type of cell division called **meiosis**. That makes sense if you think about it, because just combining one cell from each parent would result in the offspring ending up with twice the amount of genetic material. Although there are plants that can pull that off once, the problem would rapidly get worse with each generation. Sexual reproduction relies on alternating **diploid** and **haploid** forms. Diploid organisms (like people) have two sets of chromosomes. To accomplish sexual reproduction, the chromosomes are divided up to produce new cells with only a single set of chromosomes (haploid). Now a cell from one parent can combine with a cell from another parent without excessive duplication. The process of meiosis consists of two division cycles and results in four haploid **gametes** (reproductive cells).

Like mitosis, meiosis starts with duplication of the genetic material so that each chromosome has two strands (two sister chromatids). Next, each chromosome has to line up with its matching chromosome. During prophase I of meiosis, DNA segments are exchanged between matching pairs of chromosomes. This provides more mixing of genetic material, resulting in more diverse offspring. Once that is finished, the chromosome pairs are pulled apart so that each new cell contains only one set of chromosomes.

Humans have 23 pairs of chromosomes, for a total of 46. After the first division of meiosis, the resulting cells each contain 23 chromosomes – one of each pair. Humans, like many other organisms, have sex chromosomes. Females have two X chromosomes and males have an X and a Y chromosome. When meiosis starts in males, the X chromosome pairs with the Y chromosome, and then these two chromosomes are pulled apart. The resulting cells will have either an X or a Y chromosome.

With the first division finished, the new cells divide again to separate the two sister chromatids of each chromosome. There are now 4 gametes, carrying genetic information from each chromosome of the parent organism.   For humans, each of these gametes will contain 23 chromosomes. Once two gametes – one from each parent – combine, there will once again be 23 pairs of chromosomes. That may include two X-chromosomes so the baby will be female, or and X and a Y to create a male baby.

In males, meiosis produces 4 sperm cells. In females, the haploid egg needs to carry nutrients to sustain the developing embryo. The first division of meiosis gives most of the cytoplasm to one cell, while the other one turns into a small **polar body**. The polar body may or may not go through the second division of meiosis. The cell that is destined to become the egg will complete the second division that is again unequal, resulting in one egg and another polar body.

Sexual reproduction through meiosis results in more genetic variation than asexual reproduction through mitosis, but potential errors are a disadvantage. If a pair of matching chromosomes fails to separate properly during the critical first division one cell ends up with two copies of the chromosome, while the other gets none. Such errors can be fatal or have serious consequences for the offspring. At this point you will want to read up on **Down's syndrome**, which results from a person carrying 3 copies of chromosome 21.

Parthenogenesis

Once a haploid egg is formed through meiosis, we would expect it to develop into an embryo after fertilization by a sperm cell. However some organisms, like bees, are able to survive as haploid adults so they can develop from an unfertilized egg. In other organisms the female may be able to reproduce without a male present. This process, called **parthenogenesis**, or "virgin birth", can happen if the haploid egg fuses with a polar body. Due to the exchange of genetic material between chromosomes in meiosis I the offspring will not be exactly like the mother.

Parthenogenesis is more common in invertebrates, but has been observed in sharks, reptiles, and rarely in birds.

PHOTOSYNTHESIS: ENERGY FROM SUNLIGHT

To start studying this subject, find a large tree. You can imagine that this tree is very heavy. Roughly half of that weight is water, but the rest of it is other stuff. And where did that other stuff all come from? You might think that the roots of the tree absorbed it from the soil, but notice that there isn't the sort of depression around the tree that you would expect if it built itself out of dirt. In fact, almost all of the bulk of this tree appeared out of just air and water!

The extremely complex process that creates trees and other plants starts with photosynthesis. These are the basics:

$6\ CO_2 + 6\ H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$

Carbon dioxide (CO_2) from the air is combined with water to form glucose ($C_6H_{12}O_6$) and oxygen (O_2). Oxygen is the waste byproduct. To make something complex like glucose out of simpler building blocks takes energy. The first step in photosynthesis is the splitting of water molecules, and of course it isn't easy to pull a molecule apart. Plants use the energy of the sun to accomplish this feat.

We don't have the tricks that plants use, but we can split water by using energy from a battery. Use a 9V battery and 2 pencil leads, preferable 0.7mm as they are less likely to break. You can take the pencil leads out of a mechanical pencil, as they can be dried and reused after the experiment. Tape one end of each pencil lead to each terminal of the battery, using electrical tape if available. The leads will stick out from the battery at a 90 degree angle. Because I am usually working by myself I prefer to place the leads onto the tape first, and then attach the battery. Do not touch both terminals of the battery with a single lead because that will short out the battery. Work gently to avoid breaking the leads. Once you have everything in place, fill a glass or bowl with tap water and insert the free ends of the leads into the water. Do not immerse the battery – keep it dry. If your experiment is working, you should see bubbles forming at the ends of the leads that are in the water.

The + side of the battery pulls away the electrons that hold the water molecule together. After the water molecules split, two oxygen atoms come together to form oxygen gas (O_2). Hydrogen, which doesn't hold electrons as strongly as oxygen, is now left without any electrons. The hydrogen ions, H^+, drift towards the pencil lead attached to the negative side of the battery where they gain new electrons, so they can combine form hydrogen gas (H_2). The bubbles you see are oxygen gas and hydrogen gas.

The energy that splits the water molecules is not lost. If you could gather enough hydrogen, and add a little spark, there would be an explosion as the hydrogen combines with oxygen in the air to form water again. Hydrogen is a high-energy compound, but plants don't want something potentially explosive. Instead of letting the energy get stored in hydrogen gas, they use it to make **ATP** and NADPH. ATP molecules, adenosine triphosphate, are like tiny rechargeable batteries that can power the chemical reactions inside cells. The discharged form is **ADP**, adenosine diphosphate. The hydrogen from NADPH ends up in glucose, the final product of photosynthesis.

Study the steps of photosynthesis, but don't get lost in the details.

Photosynthesis occurs in chloroplasts, which are specialized for this purpose. Chlorophyll is the main compound that allows chloroplasts to absorb and use light. This compound absorbs mainly blue and red light, while green and yellow are reflected back causing plants to look green.

Once the plant has glucose from photosynthesis, it can produce many other organic compounds that it needs. Other compounds require nitrogen and minerals that can be absorbed from the soil. These substances are often added as fertilizer by people who are wanting to grow plants faster. They also occur naturally in the soil, added by decomposing matter and animal droppings. Nitrogen in the air can't be taken up directly by plants, but thunderstorms and soil bacteria can convert atmospheric nitrogen into soil nitrates that the plant can use.

CELLULAR RESPIRATION

Animals cannot use energy from the sun because their cells don't have chloroplasts. They must survive by eating plants or other animals. In doing that, they take in many different organic compounds, which are broken down during digestion before they enter cells. The main reaction that happens inside both animal and plant cells to produce energy is called cellular respiration.

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + energy

If you look carefully, you will see that this is the exact reverse of photosynthesis. It is essential for animal cells, but plants are not busy making glucose to help animals! They use glucose for themselves to break down for energy whenever they need it, especially when there is no sunlight. Plants also use glucose to produce the materials needed for growth, and they can convert it to starch to store for later use.

GENETICS

Patterns of Inheritance

Our first real understanding of genetics was provided by Gregor Mendel, a monk who studied the characteristics of pea plants. His work explained how offspring inherit certain traits from their parents. For example, Mendel noticed that some of his plants produced yellow peas instead of green ones. When he crossed the yellow-pea plants with the green-pea plants, all of the offspring produced yellow peas. But the green pea color wasn't lost! Using these **hybrid** plants to produce more offspring, he found that one in every 4 resulting plants made green peas again. Pea color is determined by a single gene, and offspring get one copy of this gene from each parent. Different copies of the same gene are called **alleles**. The **dominant allele** (yellow peas) will determine the color, but the **recessive allele** (green peas) is still present and shows its effects when the offspring happens to receive two copies of it. Look at some images of **Punnett squares** to see how this works.

The **phenotype**, which is the outward appearance, of a pea plant may be to have yellow seeds, but its **genotype** – the actual genes it carries – affect what its offspring will look like. It works the same for humans: two parents with brown eyes (dominant) may have one or more children with blue eyes if they both carry the recessive gene for blue eyes. An organism is **heterozygous** for a trait if it carries both alleles. If both parents are **homozygous** dominant for eye color their children will have brown eyes. Homozygous recessive parents will have blue eyes, and so will their offspring.

Once scientists understood that DNA in the cell's nucleus contained the genes that control inherited characteristics, it seemed like they would soon be able to know everything about a plant or animal by identifying its genes. Unfortunately things are not as simple as they seemed at first. Some traits show **incomplete dominance**, so what you see looks like a mix of both parents. For example, crossing a plant with red flowers with a plant that has white flowers may produce pink-flowered offspring. The red allele is partially expressed. In **codominance** both traits are fully expressed, which may result in spotted or striped offspring. Even all of that is one gene controlling one trait, but things get far more complicated when multiple genes are involved in determining a particular trait. Unfortunately this **polygenic inheritance** is common, which makes it difficult for us to figure out how things work. More surprises occur when we find a single gene that has many different effects.

Sex Determination

Many species have one pair of chromosomes that determines whether an individual will have a male or female genotype. For humans and other mammals these are the X and Y chromosomes, named for their shapes. During meiosis, the XY male produces sperm that has either an X or a Y chromosome. The eggs produced in the ovary by the XX female all carry a single X chromosome. Fertilization results in either XX or XY offspring.

One of the two sex chromosomes is typically smaller with fewer genes, so that the organism can end up with only a single copy of a particular gene. Human males normally have one X chromosome and a smaller Y chromosome that carries few genes. If the X chromosome happens to have a defective gene there usually is no extra copy to compensate. The male, who has the XY genotype, is more likely to show symptoms of an inherited disease carried on the X chromosome than the female (XX), who would need to have two defective copies to be affected. The common example of such **sex-linked inheritance** is hemophilia.

Although sex determination seems simple at first glance, with XY being male and XX female, there are many possible complications. Errors in the separation of chromosomes can occur in during meiosis and/or mitosis. Females may be XO (missing one X chromosome), XXX, XXXX, or even XXXXX. Males can be XXY, XXXY, XXXXY, XYY or XXYY. There are also several other **intersex** conditions. An intersex person or animal may have ambiguous **external genitalia**, or appear to be male or female while carrying the genes for the opposite sex. Doctors used to rush to correct perceived abnormalities of intersex babies shortly after birth, but today we understand that such conditions are an inevitable part of our biology. Many states now allow M, F, or I on birth certificates so that intersex people can be legally recognized.

Even when an individual is a regular XY male or XX female, there is considerable overlap in genetically influenced behavior. There is no gene on the Y chromosome that codes for an aversion to wearing nail polish, and having two X chromosomes does not guarantee the ability to produce three dozen cookies for the bake sale. Hmm, come to think of it, the Women's League never contacted me again…. The experience of being female or male is subject to wide variation. Please enjoy yours, while being considerate of those around you.

Epigenetics

Most cells in your body carry all of your genetic information (your **genome**), but they don't actually need all of it when they are specialized, like muscle cells or skin cells. Somehow cells know which part of the genetic code applies to them, and they read only those genes. A fair bit of information contained in the DNA of organisms is never used at all. For example, chickens have genes with information for growing teeth, and snakes have genes for developing legs. Something keeps these traits from showing up. **Epigenetics** refers to changes in the activity of genes that are already present in the DNA. Some of these changes are hereditary and persist in subsequent generations. Scientists are already learning how to turn genes off or on in plants to create hereditary changes. They hope to create better crops using these epigenetically modified plants.

Mutation

In the spring after I moved into my new home, I was pleasantly surprised to see the pretty purple flowers that the previous owners had put in the front planters. As summer went on, I was less pleased to see that these purple flowers had seeded out all over the front and back yards. By the next year there were purple flowers everywhere. As I was removing them, I found one plant that looked just like the others but had white flowers instead of purple. I had discovered a **mutation**! Mutations are not uncommon, because when DNA is copied enough times eventually something will go wrong. Many mutations are useless or harmful, and since I didn't want white flowers everywhere either I just discarded the mutated plant. Sometimes though, the new trait may give the organism an advantage. Had the flowers been a more striking color like red or bright blue, I might have left the mutated plant while removing the others. That would have caused the new color to become more common in my yard as the plant reproduced.

Genetic Diversity

Sexual reproduction results in greater genetic variability, but even asexual reproduction doesn't produce a population of genetically identical clones, because of mutations and division errors. A large gene pool is like an insurance policy: if the environment changes, or a deadly disease comes along, most of the population may die but some individuals will survive. Humans often fail to appreciate this genetic variability in their own population, as it comes with a large amount of phenotypic and behavioral variation. People may prefer to associate with others who look more like them, and children tend to make fun of those who are different. As a result, it is not uncommon for individual humans to feel like they don't "belong", or that they are worthless. And yet, because humans are a social species, genetic variability has more than just survival value. Here is an example, based on a true story:

Someone, let's call him person C, is hired by a large company to work as a research scientist. Person C is "different" in how he thinks and acts, which soon gets him into trouble with other employees. Complaints are made to management, and person C is in danger of losing his job. He becomes discouraged and considers quitting. However, one of his colleagues, person B, has a disabled autistic brother. He notices similarities between his brother and person C. Person B sticks up for person C, successfully defending him to management. He also begins to encourage person C using the same tactics he has used with his brother. Person C decides against quitting, and because he thinks differently he soon makes an important discovery that turns out to be very profitable for the company.

We can commend person C for his persistence, and praise person B for his empathy, but note the contribution of person A. Person A did absolutely nothing except to carry his genes, but the profitable discovery would not have been made without him. It is impossible to know which gene or combination of genes will be important in some way. You carry your own unique DNA, and even if nature made a backup copy in the form of a twin your epigenetic profile will still be different. So, take good care of your genetic code – we may need it!

EVOLUTION

Evolution is simply the hereditary change in populations of organisms over time. This is something that we can observe even in a short time frame. These hereditary changes allow us to grow better crops and breed animals with specific inherited characteristics, because we can push evolution in the direction we desire by selectively breeding certain organisms. The theory of evolution attempts to explain how and why evolution happens spontaneously, and how this could have resulted in the diversity of life we see on Earth today.

When people argue about evolution, they seem to agree that there are in fact hereditary changes in populations over time. After all, everyone can see that we have created different breeds of dogs, and those changes are inherited. The disagreement is over whether evolutionary changes over time can result in new “kinds” of animals. Two different species of snakes are both snakes, so they can be considered the same kind of animal.

A **species** is usually defined as a group of interbreeding individuals, but that definition becomes fuzzy as you look closely at the details. It is possible for a lion and a tiger to breed, but the offspring is not fertile. The chromosomes from the two parents are different, and they don’t line up during meiosis in the hybrid animal. The hybrid fails to reproduce. We commonly exclude this situation and consider the lion and the tiger to be two different species. All dogs, and dogs and wolves, can interbreed to produce fertile offspring, so we haven’t really created a new species by breeding dogs. For two isolated populations of a single species to develop into two separate species, the genetic material of one or both has to change substantially. That would usually be expected to take a lot longer than a few human lifetimes.

The best chance of observing speciation is to focus on organisms with short generation times, such as insects or smaller plants. In one case, two different populations of the same species of fruit flies were shown to produce only infertile male offspring when mated, while female hybrids were fertile. A partial genetic incompatibility developed between the two populations. A new species appeared recently when two different species of Salsify plants were able to produce hybrid offspring that could reproduce only with its own kind, but not with the original parent species. Normally these hybrids are sterile, but some ended up with two sets of chromosomes, doubling the original amount. Thanks to this occurrence of **polyploidy**, each chromosome has a partner during meiosis, and reproduction can occur. This mechanism of speciation is not common, since we would otherwise see large numbers of polyploid organisms.

According to the theory of evolution, very simple organisms appeared first, and more complex animals and plants evolved later. An emphasis on this theory tends to make people think of some groups of organisms as more “advanced” than others, but when you look closely you will see that every living thing on this Earth is amazingly complex. All organisms that exist today are uniquely adapted to the environment in which they live. A frog is not busy “evolving” to become a reptile or a human, but we may see genetic changes in a population of frogs if their environment changes.

GROUPS OF ORGANISMS

There are so many different living organisms on Earth that you couldn't possibly study them all in your lifetime. To make things easier we divide them into groups. A good way to learn about each group is to pick one representative organism and study it closely. Although it is common to start with "simpler" organisms and work up to humans, you may run out of time and miss out on information that is more relevant to your life. Jellyfish may be very interesting, but you need to know enough about your own body that you can take care of your health and understand what your doctor tells you. This guide starts with humans.

It is not necessary to dissect a frog to learn about the structure of animals. Putting things together is not as easy as taking them apart, and anatomical model kits actually provide a better learning experience. If you really want to dissect something **after** you have carefully studied anatomy, you can order an injected fetal pig. These specimens are a byproduct of the meat industry, and the internal organs are very similar to those of humans.

The most relevant groups of organisms are mentioned here. It is not a complete list.

MAMMALS

Humans are classified as mammals. All organisms in this group feed their young with milk that they produce in their mammary glands. Mammals are **endothermic** (warm-blooded), which means that they keep a steady body temperature independent of their surroundings.

Skeleton

Bones are amazing structures. They are hard, but they grow as the organism develops, and they can still heal and remodel in a mature organism. Long bones have growth plates, also called **epiphyseal plates**. Strong but flexible tissue called **cartilage** forms here, and then gets replaced by bone so that the bone gets longer. On x-rays, an open epiphyseal plate appears as a dark line near the end of a bone. These growth plates close when the person or animal is mature. Look for x-ray pictures of open and closed growth plates. An injury to an open growth plate can cause a bone to grow crooked.

You should look carefully at images of a human skeleton, and compare it with those of other mammals. You don't have to know the names of every bone, but memorize the major ones: **humerus**, **radius**, **ulna**, **femur**, **tibia**, and **fibula**. Also look at the bones that allow you to move your head – the atlas and the axis. Other interesting bones are those of the inner ear.

The **vertebral column** (spine) protects the **spinal cord**, allows spinal nerves to pass through, and lets you bend and twist. **Intervertebral disks** are cartilage disks between the vertebrae. If you lift something heavy by bending your back instead of using your legs you can damage these disks, which may lead to long-lasting back pain and/or leg pain due to pressure on the sciatic nerve.

Articular cartilage coats the surfaces of joints, allowing for smooth movement. If you have a cooked chicken, you can detach the leg carefully at the hip joint to see the cartilage.

Many bones contain **bone marrow**. Blood cells are produced here.

Circulatory System

Blood looks red because it contains red blood cells. Red blood cells are filled with hemoglobin, which is a protein that can carry oxygen. Iron atoms are an essential component of hemoglobin, which is why we need adequate amounts of iron in our diet. Red blood cells wear out after about 3 to 4 months and need to be constantly replaced. Insufficient numbers of red blood cells or not enough hemoglobin results in **anemia.** A person with anemia may feel tired and look pale.

Mammals have two separate blood flow circuits. The right side of the heart sends blood through the **pulmonary artery** to the lungs to pick up oxygen. From there, blood is directed to the stronger left side of the heart which pumps it into the **aorta** for distribution all through the body. You should carefully study the anatomy of the heart. Look for the **bicuspid valve** that separates the right atrium from the right ventricle, and the **tricuspid valve** that separates the left **atrium** from the left **ventricle**. These valves keep blood from flowing backwards. When these valves close they produce the first sound in the "lub -dub" of the heartbeat. The second sound is made by the valves that keep blood in the pulmonary artery and the aorta from flowing back into the heart. Real hearts don't look much like the diagrams you see. Beef hearts are sold for specialized recipes or for pet food. You may be able to obtain one for dissection, or watch someone do that online.

Respiratory System

All of the oxygen intake and expulsion of carbon dioxide is done through the lungs in mammals. Movement of the rib cage and the **diaphragm** allows the lungs to expand and contract. The actual exchange of gasses between the air and the blood occurs in the thin delicate tissues of the **alveoli**. The airways consist of the **trachea**, the main **bronchi**, and the smaller **bronchioles**. The cells that line the airways have tiny hair-like structures called **cilia** with which they move mucus and contaminating particles up to the throat to be coughed out or swallowed.

Bronchitis is inflammation of the airways caused by viruses, bacteria, or smoking. **Pneumonia** is an infection of the lungs themselves, which can be very serious.

Digestive System

Among mammals, **herbivores** (animals that eat only plants) have a more complex digestive system than **carnivores** (animals that eat meat) and **omnivores** (animals that eat both plants and meat). Plants, and especially grass, are more difficult to digest. In humans the esophagus leads into the stomach, where food is mixed with stomach acid. This acid is strong, and can cause gastric ulcers if something interferes with the protective mucous barrier. The lower **esophageal sphincter** prevents food from going back up into the esophagus. Then the food passes through the **pyloric sphincter** into the small intestine.

When food arrives in the small intestine the **pancreas** adds digestive enzymes to it. The pancreas also has a second function, which is the production of **insulin** to regulate the amount of glucose (sugar) in the blood. All vertebrates (animals with a backbone like birds, reptiles, amphibians and fish) have a pancreas.

The **liver** adds **bile** which is stored in the **gallbladder**. Bile helps to digest fats. Digestion proceeds in the small intestine, aided by intestinal bacteria. Nutrients are absorbed here and passed to the liver for processing and/or storage. The liver works hard to remove any poisonous substances that enter your body. However, repeated large quantities of alcohol can damage and scar the liver.

The **large intestine** removes water, and leftover material is eliminated as feces through the **anus**.

If you look at the digestive system of a cow, you can see that its food takes more effort to digest. Bacteria and other microorganisms that live in the **rumen** can break down tough plant material into compounds that the cow can use.

Kidneys

The building blocks of protein are amino acids. If you look carefully at the structure of amino acids, you will see that they all contain an **amino group**: a nitrogen (N) atom with two hydrogens (H). When the protein you eat is broken down for energy, that amino group turns into **ammonia**, NH_3, which is a toxic waste product. To remove ammonia safely, mammals convert it to **urea**, which is excreted in the urine by the kidneys. The kidneys also filter other substances from the blood, and make sure that the electrolytes sodium and potassium stay balanced in the body. Glucose (sugar) is normally reabsorbed after the kidneys filter blood, but if there is excess sugar, as in diabetes, the kidneys can't reabsorb all of it. Glucose appears in the urine, and because it attracts water by osmosis there is more urine than normal.

Urine travels from the kidneys through the **ureters** into the bladder, where it is stored until it can be expelled through the **urethra**.

Skin

Many mammals, including humans, are able to synthesize vitamin D if their skin is exposed to sunlight. However, due to lack of fur humans have had to balance their need for vitamin D against the damaging effect of the sun's ultraviolet rays. The pigment **melanin** protects us against skin cancer, and the amount of melanin in our skin increases with sun exposure. People who live near the equator benefit from darker skin, but near the poles where there the sunlight is not as strong people with pale skin are less likely to become deficient in vitamin D. Vitamin D is also available through food and as supplements.

Mammals and other vertebrates with **albinism** have little or no melanin pigment.

Reproduction

Most mammals bear live young. Only the platypus and echidna lay eggs.

In most mammals eggs are released by the **ovaries** and travel through the **fallopian tubes** into the uterus. Fertilized eggs implant in the uterus. The **placenta** allows nutrients to pass from the mother to the fetus through the **umbilical cord**.

The release of eggs from the ovaries is called **ovulation**. Ovulation may occur in regular cycles or, in some species, as a result of mating. Human females ovulate in regular cycles approximately 28 days apart. The lining of the uterus builds up each time in preparation for a potential pregnancy. If no fertilized egg implants the lining is shed along with varying amounts of blood. This shedding is referred to as a **period**. Periods are often painful as the uterus contracts to expel the unneeded tissue.

Larger mammals like humans often give birth to a single offspring. **Identical twins** are the result of a split in a single fertilized egg. Identical twins are always the same sex. **Fraternal twins** occur when two eggs are released and fertilized. Fraternal twins may be of opposite sex.

Nature puts a high priority on reproduction, and pregnancy may occur before the female is fully mature. This is less than optimal, except in the known case of guinea pigs who need to give birth early before their pelvic bones fuse. Pregnancy in humans can occur before the first period, shortly after the first egg is released.

Male mammals begin to produce sperm when they reach puberty. Sperm is produced in large numbers in the **testes** (testicles). Mammals carry their testes outside the abdomen because their sperm production requires a lower temperature. Sperm travels through the **ductus deferens** and out through the urethra. The **prostate gland** which surrounds the urethra produces a fluid that helps the sperm survive.

The close contact required for reproduction also allows for the spread of sexually transmitted diseases (STDs). Important human STDs include HIV, which is the cause of AIDS, herpes, syphilis, gonorrhea, and many others.

BIRDS

Birds that fly need to have bones that are lightweight. Many of their bones are hollow and filled with air. Some of the bones are fused together to make the light skeleton stronger. When you look at images of bird skeletons you should notice the large keel where the flight muscles attach.

Birds have a high metabolism so they need a lot of oxygen. Their respiratory system is very efficient. Miners used to take canaries with them to monitor the air for toxic gases, as the bird would show symptoms very quickly. Birds don't have a diaphragm, but use their muscles to expand and contract multiple **air sacs** in their bodies. Air is pushed in only one direction through the lungs, which don't expand like the lungs of mammals.

Bird hearts have four chambers like those of mammals. The heart usually beats very fast.

Many birds have a **crop** near the throat, which allows them to store food before it reaches the stomach. Some digestion takes place in the crop. The stomach is usually composed of two parts. The glandular stomach secretes acid and the muscular stomach, or **gizzard**, helps to mix and break down the food. Because birds don't have teeth they may swallow small bits of gravel that end up in the gizzard and aid in breaking food into smaller pieces. The digestive tract ends in the **cloaca**.

Birds deal with ammonia waste from protein by converting it to uric acid. Unlike urea, uric acid doesn't take much water to eliminate, so the bird doesn't have to carry the weight of a full bladder while flying. The uric acid is eliminated through the cloaca as a white paste.

All birds lay eggs. Most female birds have only a single developed ovary. Male birds have two testes which are carried inside the body. Female birds can lay eggs without mating. Parthenogenesis may occur in birds: an unfertilized egg starts to develop. This does not commonly result in live offspring, and those that do survive may be sterile. Some birds produce milk in their crops to help feed the young, while others only regurgitate the partially digested crop contents for their offspring.

REPTILES

Reptiles can be recognized by their smooth scaly skin. They are not slimy. Reptiles include lizards, snakes, turtles, alligators and crocodiles. All reptiles are **exothermic** (cold-blooded). This means that if you have a pet reptile you must provide an environment with sufficient heat to allow for digestion, and both cool and warm areas so the animal can select the proper temperature. Heat lamps are typically placed on one side of the enclosure. Heat rocks are available but must be closely monitored to prevent burns.

Popular pet reptiles that relate well to humans are bearded dragons, green anoles (shown on the cover of this guide), and leopard geckos. Most people don't like snakes, and the feeling is generally mutual as escapes are common. Never buy a reptile without knowing how big it will grow. Larger reptiles should be kept only by very dedicated enthusiasts.

Reptiles have a three-chambered heart with a partially divided ventricle. They produce uric acid which is eliminated through the cloaca. Reptiles usually lay eggs, but some retain the eggs inside the body until they hatch. Parthenogenesis can occur in reptiles.

All reptiles have lungs and need to breathe air, even aquatic turtles.

AMPHIBIANS

Frogs, toads, and salamanders are amphibians. The name amphibians comes from the ancient Greek amphi bios, which means both lives. Most amphibians spend the early part of their lives in water, and then undergo **metamorphosis** to achieve their land form. The axolotl, a type of salamander, is unusual in that it doesn't undergo metamorphosis and lives all of its life in water. Pet axolotls may be crossbred and can possibly change to an adult form, in which case they need to get out of their aquarium and into a carefully adjusted moist terrestrial environment.

Amphibians have a three-chambered heart with two atria and one ventricle. The immature forms have gills to obtain oxygen from the water. Most mature amphibians have lungs, but much of the oxygen and carbon dioxide exchange occurs in the mouth cavity. Throat muscles produce air movement for breathing. Oxygen can also be taken in through the moist skin.

Tadpoles excrete ammonia, but the kidneys of adult frogs excrete urea. This means that frogs produce urine, and they can and will pee on you.

Frog eggs are laid in water and hatch into tadpoles, which undergo metamorphosis into adults.

BONY FISH

Sharks and rays are cartilaginous fish, and lampreys and hagfish are classified as jawless fish. When you think of the word "fish" you most likely imagine a bony fish, which is the group described in this section.

The fish heart has a single atrium and a single ventricle. Blood is pumped through the gills which allow fish to get oxygen from the water and get rid of carbon dioxide. When blood leaves the gills it flows to the rest of the body, and then back to the heart.

A **swim bladder** keeps fish from sinking or floating too much.

Lungfish have one or two lungs that they can use to breathe air. This allows them to survive on land when necessary.

Fish kidneys regulate water balance, which allows some fish species to live in both fresh and salt water. Nitrogen wastes are excreted as ammonia through the gills.

MOLLUSKS

Mollusks are **invertebrates** (animals without a backbone). Examples of mollusks are octopuses, clams, oysters, snails and slugs.

Mollusks have an open circulatory system – there are no blood vessels. A two-chambered heart pumps blood through the body, and there may be additional hearts.

The mollusk you are most likely to encounter is the snail. All land snails and many water snails have a lung. Land snails have a kidney that excretes nitrogen waste as urea. Most land snails are **hermaphrodites** – they have both male and female reproductive organs.

People have noticed that many mollusks seem intelligent and learn quickly.

ARTHROPODS

Arthropods are a highly varied group. It includes spiders, lobsters, crabs, shrimp, centipedes, millipedes, insects, and other creatures.

Arthropods have a strong **exoskeleton** made of chitin. They have an open circulatory system with multiple heart chambers that pump blood to the head. Aquatic arthropods have gills, while those living on land have openings in the exoskeleton called **spiracles** that allow air to diffuse into the body.

A significant number of arthropod species, including bees and ants, have haploid males. This means that males develop from unfertilized eggs that have only one set of chromosomes. Females of the same species hatch from fertilized eggs so they get two copies of each chromosome (diploid). Males with severely defective genes don't survive because they don't have an extra copy to compensate. This removes such lethal genes from the gene pool quickly.

Some species have a complex social structure. Individuals cooperate to promote survival of the colony.

CNIDARIA

This group of aquatic animals is characterized by stinging cells used to poison and capture prey. It includes jellyfish, corals, anemones and others.

Unlike the head-and-tail body plan of other animals, cnidarians have **radial** (round) **symmetry**.

They have a network of nerves but no brain, and there is no heart or circulatory system. The digestive cavity has a single opening that serves as a mouth and anus

There are two possible life cycle stages: the **polyp** and the **medusa**, with some species spending their entire lives in only one of these stages. The polyp is attached to a surface and stays there, while the medusa stage swims around. The jellyfish you see are the medusa form.

Adult jellyfish release eggs and sperm into the water. A fertilized jellyfish egg develops into a larva called a planula. The planula finds somewhere to attach itself and develops into a polyp. Through budding, the polyp produces multiple free-swimming medusae. Then the cycle repeats.

BACTERIA

Bacteria are everywhere! They are all around us, on our skin, in our mouths and noses, and in our intestines. Almost all bacteria are microscopic. Many people think of bacteria as nasty germs, but actually relatively few species are harmful. Intestinal bacteria help people and animals digest their food, and they even produce vitamins. Soil bacteria can change nitrogen from the air into a form that plants can use to make proteins (**nitrogen fixation**).

Bacteria are single-celled prokaryotes – there is no nucleus. They usually have one large circular strand of DNA, which is their only chromosome. Smaller circular pieces of DNA called plasmids are often present. Bacteria can pass copies of their plasmids to other bacteria, even unrelated ones, through a process called **conjugation**.

You should be aware of some important bacteria that can be harmful to humans. Yersinia pestis is the bacterium responsible for the **Plague** (the black death). Treponema pallidum causes **syphilis**, a sexually transmitted disease. Group A Streptococcus can cause **strep throat** and **flesh-eating disease**. **E. coli** can give you food poisoning when you eat lettuce, undercooked hamburgers, or raw spinach. **Salmonella** bacteria may lurk in raw poultry and eggs, and they can easily survive on kitchen surfaces and utensils.

In 1928 Alexander Fleming discovered penicillin when he noticed that bacteria kept in a petri dish were not able to grow near a penicillium mold. Penicillin can only kill some species of bacteria, but we now have many different antibiotics available. Unfortunately bacteria can become resistant to antibiotics. A bacterium with a plasmid that codes for antibiotic resistance can easily pass copies to many other bacteria. Overuse of antibiotics encourages the spread of resistance. When animals are raised for food, antibiotics are often used to compensate for overcrowding and poor sanitation. People tend to pressure their doctors to prescribe antibiotics for viral illnesses, but **viruses are not affected at all by antibiotics**. When you take an antibiotic, it will kill good bacteria along with the bad ones. You may get diarrhea as your helpful intestinal bacteria die off and nasty resistant ones take over. If you have a few Clostridium difficile bacteria in your colon, they can multiply quickly and cause bloody diarrhea that can be life-threatening.

Severe antibiotic-resistant infections are sometimes treated using **bacteriophages** – viruses that infect bacteria.

VIRUSES

Viruses are small pieces of DNA or RNA surrounded by a protein coat.

Bacteria are tiny, but most viruses are much smaller. The real pictures of viruses you see online are taken with **electron microscopes**. Viruses do not meet all of the defining characteristics of living things. They do not move or grow, take in food or produce waste, and cannot reproduce on their own. Viruses rely on living cells to make and assemble their components. After that, the cell usually dies and the fully formed viruses are released, ready to infect another cell.

Only some viruses are a danger to humans, with many others preferring other hosts including plants or bacteria. Important viral diseases include **smallpox**, COVID-19, **rabies**, Ebola, **polio**, influenza and many others. Viruses that are not fatal may persist in your body forever. For example, people who had **chickenpox** as a child may get a painful and potentially serious condition called **shingles** when they get older.

Vaccines

Antibiotics do not affect viruses. While some antiviral medications are available, we mostly rely on vaccines to prevent viral infections.

The first form of vaccination was practiced many centuries ago by exposing children to material from scabs of people with smallpox. Obviously this was quite risky, but smallpox was both common and highly fatal. Edward Jenner noticed that milkmaids infected with cowpox seemed to be immune to smallpox, so he began to immunize people by exposing them to cowpox. Better smallpox vaccines were developed later, and eventually this resulted in the elimination of smallpox. Only a few samples of the virus remain in specialized laboratories.

Today, children no longer have to die or become paralyzed from polio, and shingles will become a disease of the past thanks to chicken pox vaccines. Rabies is almost 100% fatal, but you can receive a rabies vaccine as part of treatment to prevent the virus from getting to your brain and killing you.

Vaccines work by tricking your body into responding as though you had a disease. Your specialized immune cells proliferate and produce **antibodies.** The immune system stores information about the disease-causing agent and responds quickly when the real threat comes along. Immunity to illness generated by vaccines can last from months to years, and it may be more or less effective at preventing symptoms. Viruses may be able to get around vaccine protection by mutating, but not all viruses mutate readily.

So, vaccines seem great, but what is the downside? Well, a foreign substance like a vaccine, an antibiotic, or any type of medication can cause a serious or even fatal reaction in some people. You don’t expect to die when you take an antibiotic, and the chance of that is extremely small, but you also know that you are sick and need the medication. With a vaccine, the risk of side effects must be carefully weighed against the risk of getting the associated disease and becoming disabled or dying from it. These calculations are informed by reports from the public and from doctors that are collected in large databases like VAERS (Vaccine Adverse Event Reporting System).

Inactivated or subunit vaccines use killed virus or part of a virus so they cannot possibly cause disease, but people can still have serious allergic reactions to either the viral proteins or other components of the vaccine. Such reactions usually happen quickly, which is why you may be asked to wait at the location after receiving a vaccine. As the immune system gears up there can be also be collateral damage that shows up several days later.

Modified live virus vaccines use a weakened form of a virus that could potentially reactivate if a person is **immunocompromised**. This re-activated virus could spread to others.

DNA vaccines contain a part of the DNA of the target virus. This is synthetic DNA that can be created quickly in large quantities without the need to grow the virus. Inside the cells of a vaccinated person or animal the DNA is transcribed onto mRNA, which is then used to make a viral protein that induces an immune response. Some scientists worry that this DNA could potentially become inserted into the DNA of some of those cells, which would be a problem if it happened to disrupt a critical gene.

mRNA vaccines bypass the first step of DNA vaccines, as the synthetic mRNA is immediately used to make viral protein. After several uses the cell breaks down the mRNA, so it doesn't persist in the body. Like DNA vaccines, mRNA vaccines can be created rapidly and are easily adjusted for viral mutations. However, mRNA is fragile and the vaccine must be kept frozen at very low temperatures.

In 1998 Andrew Wakefield published a study claiming that childhood vaccines cause autism. It was later discovered that he had been paid a large amount of money by lawyers suing the vaccine company, and that he had manipulated his data. Many subsequent studies showed that his conclusions were invalid. Nevertheless, many parents became afraid to have their children vaccinated. At the same time, childhood diseases had become much less common thanks to vaccination programs. My mother told me how I nearly died of mumps as an infant, and I had a friend who survived polio after being in an iron lung, a machine that helped people breathe before there were ventilators. Such collective memories are fading now, and people have less trust in their governments and vaccine companies.

The risk-benefit analysis of vaccines is always changing. There will be new viruses, affecting children and adults alike. We may fight them with better antiviral drugs and improve at making **synthetic antibodies** that can be administered after infection, but vaccines will remain important because they can act before the damage is done. New cancer vaccines are used to help the body's immune system fight cancer after it occurs, and their side effects have to be weighed against those of conventional treatments.

PLANTS

Plants feed the world, produce the oxygen we breathe, provide us with medicines, and produce many of the raw materials we use. Even so, the average person today knows little about plants. Here we will only highlight some of the most important facts.

Plants are characterized by their ability to carry out photosynthesis, which produces glucose. This process happens in the chloroplasts, with the most important light-absorbing pigment being chlorophyll. Since chlorophyll doesn't absorb green light plants usually look green. **Deciduous** trees and shrubs lose their leaves in the fall. When chlorophyll production stops natural breakdown causes the green pigment to disappear and other pigments become visible.

Like animals, plants also carry out cellular respiration, which breaks down glucose for energy.

Gases for photosynthesis are exchanged at the surface of the leaf through openings called **stomata**. When the stomata are open, water is also lost.

Nonvascular plants are very low-growing and live in moist areas. Plants that have **vascular tissues** to conduct water and nutrients are able to grow tall. Water is lost from the leaves at the top of the plant, which creates suction that pulls more water up from the roots. The water flows upwards through small channels in the **xylem**, aided by **capillary action**. The **phloem** transports nutrients both ways.

When animals produce haploid gametes for sexual reproduction, they usually do so through specialized organs. Plants are a bit different. Plants produce **spores** that develop into gametophytes. The gametophytes may be part of a flower, attached to a pine cone, or even be completely independent plants. Gametophytes may produce both male and female gametes, or be specialized for only one kind.

A **seed** contains a plant embryo and a supply of food for the new plant.

Plants are adapted to specific conditions. **Plant Hardiness Zone** maps can tell you if you have a chance of successfully growing a particular plant outdoors, but you also have to meet sunlight, moisture and soil type requirements.

Many plants (and mushrooms) are poisonous, and toxic plants can look very similar to non-toxic plants. Never eat anything you find in nature unless you are absolutely sure it is safe. Even if you see birds eating berries that doesn't mean they are safe for humans. Depending on where you live, you should be familiar with the appearance of plants like poison ivy, poison oak, poison sumac, giant hogweed and stinging nettles to avoid unpleasant consequences of touching random plants.

ANGIOSPERMS

Angiosperms are flowering plants. Most of the plants in people's yards are angiosperms, including grass. If you haven't seen grass flower, you need to look more closely as many angiosperms have tiny inconspicuous flowers.

The sporophyte (diploid plant that produces spores) phase is dominant, and the tiny gametophytes are part of the flower.

Dicot angiosperms have two embryonic leaves inside the seed. These first leaves are called **cotyledons**, and they will look different from the other leaves. You should plant some seeds so you can observe this, and almost any seed that you can find will show these two leaves when it germinates. Dicot angiosperms have flowers with 4, 5 or many petals. Even when they are not flowering you can recognize them by the branching veins in their leaves. Examples of dicots are oak trees, roses, lettuce, dandelions, and many others. After you look at diagrams of flower structure, take a close look at some real flowers to see if you can identify the parts.

Monocot angiosperms have a single embryonic leaf, parallel leaf veins, and flowers with 3 or 6 parts. Look around outside to see if you can find any monocot angiosperm plants.

GYMNOSPERMS

Gymnosperms ("naked seed" plants) do not flower. Examples are pines, ginkgo trees and sago palms.

The diploid sporophyte phase is dominant, and it is the tree or plant that you see. It produces haploid spores that develop into gametophytes. Female gametophytes are small and grow in female cones on the tree or plant. Male gametophytes are pollen grains, which grow in male cones.

Fertilization results in diploid seeds that grow into new sporophytes.

SEEDLESS VASCULAR PLANTS

Ferns and horsetails are vascular plants that don't produce any seeds. The plant you see is the diploid sporophyte. Ferns produce spores on the underside of their fronds ("leaves"). The spores drop to the ground and develop into gametophytes. The gametophytes are tiny but completely independent plants. Some produce male gametes and others produce female gametes. When water is available, the male gametes can swim to the female gametes. Look for spores on houseplant or wild ferns, and try growing them in moist soil. Instructions for this can be found online.

Both the sporophyte and the gametophyte may reproduce asexually as well.

NONVASCULAR PLANTS

This group is composed of mosses, liverworts and hornworts. A nonvascular plant can't grow tall and must live in moist areas.

The haploid gametophyte phase is dominant, and it is most of the plant you see. There are male and female gametophytes. Sexual reproduction needs water: male gametes swim to female gametophyte. The diploid sporophyte develops on the female gametophyte. The sporophyte produces haploid spores through meiosis, and the spores produce new plants.

FUNGI

Fungi are not plants, and they do not photosynthesize.

Mushrooms are fungi, but the part you see is the just the reproductive structure that produces spores. The main part of the organism is the underground **mycelium**, composed of filaments called **hyphae**. Molds and yeasts are also classified as fungi.

Since fungi have no mouths to take in food, they have to produce enzymes that can break down organic matter into small molecules that they can absorb easily. They usually prefer decaying plant and animal matter, although some attack living organisms. Fungi can live in water, or on land in moist areas. They range from single cells (like yeast) to enormous.

Multicellular fungi have hyphae that absorb nutrients. Hyphae are not divided into completely separate cells, and may be multinuclear with no divisions, The cell walls contain chitin, which is the same substance that forms the exoskeleton of insects.

Fungi are usually haploid. They can reproduce asexually through spores that can disperse easily through the environment. Mold spores can cause allergic reactions in people, or even disease if the person has a compromised immune system. You can wear an N95 mask to avoid inhaling spores when cleaning up mold. Extensive mold growth in a home should be taken care of by professionals.

MISCELLANEOUS ORGANISMS

Algae are eukaryotic photosynthetic organisms. They usually live in water, but some algae can live on land in very moist areas. This very diverse group has been subdivided into green, brown and red algae. Green algae are most closely related to plants. Brown algae are multicellular brown or greenish brown aquatic organisms like kelp and seaweed..

Lichens consist of two organisms living together in a very close relationship. The algae part provides food through photosynthesis, while the fungus holds on to the surface and provides protection. This kind of relationship is called **symbiosis**, and it gives both organisms a survival advantage.

You may also want to read up on amoebas and slime molds, which are interesting moving organisms.