What is life?

Learn about the basic properties of life as well as ongoing debates about the definition of life.

Introduction

We define biology as the branch of science concerned with the study of living things, or organisms. That definition is pretty straightforward. However, it opens the door to more difficult—and more interesting—questions: What is life? What does it mean to be alive?

You are alive, and so am I. The dog I can hear barking is alive, and so is the tree outside my window. However, snow falling from the clouds is not alive. The computer you're using to read this article is not alive, and neither is a chair or table. The parts of a chair that are made of wood were once alive, but they aren't any longer. If you were to burn the wood in a fire, the fire would not be alive either.

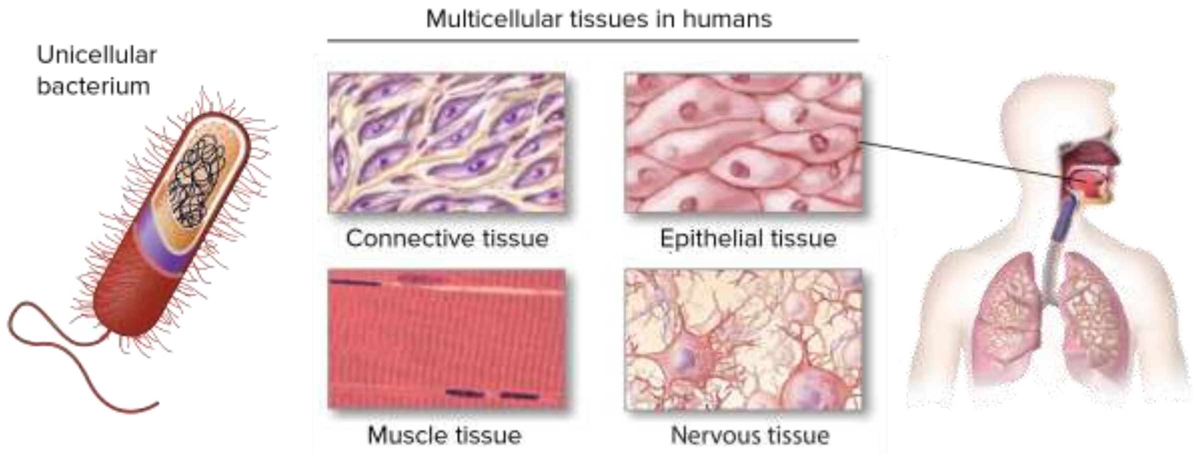
What is it that defines life? How can we tell that one thing is alive and another is not? Most people have an intuitive understanding of what it means for something to be alive. However, it's surprisingly hard to come up with a precise definition of life. Because of this, many definitions of life are operational definitions—they allow us to separate living things from nonliving ones, but they don't actually pin down what life is. To make this separation, we must come up with a list of properties that are, as a group, uniquely characteristic of living organisms.

Properties of life

Biologists have identified various traits common to all the living organisms we know of. Although nonliving things may show some of these characteristic traits, only living things show *all* of them.

1. *Organization*

Living things are highly organized, and all living organisms are made up of one or more **cells**, which are considered the fundamental units of life. Individual cells perform complex biochemical processes needed to maintain their structure and function, and each cell is highly organized. **Unicellular** organisms consist of only a single cell, while **multicellular** organisms—such as humans—are made up of many cells. The cells in multicellular organisms may be specialized to do different jobs and are organized into **tissues**, such as connective tissue, epithelial tissue, muscle, and nervous tissue. Tissues make up **organs**, such as the heart or lungs, which carry out specific functions needed by the organism as a whole.



Left: unicellular bacterium, with the exterior of the cell cut away to show the multiple layers of the cell and the DNA in its interior. Center: multicellular tissues in humans. Small drawings of connective tissue, epithelial tissue, muscle tissue, and nervous tissue. Right: diagram of a human upper body, showing one location where epithelial tissue like that shown in the center panel could be found—the lining of the mouth.

Image credit: left, modified from "Prokaryote cell by Ali Zifan (CC BY-SA 4.0), modified image is licensed under a CC BY-SA 4.0 license; center, modified from "Four types of tissue" by the National Institutes of Health (public domain); rIght, modified from "PseudostratifiedCiliatedColumnar" by Blausen staff (CC BY 3.0)

2. *Metabolism*

Life depends on an enormous number of interlocking chemical reactions. These reactions make it possible for organisms to do work—such as moving around or catching prey—as well as growing, reproducing, and maintaining the structure of their bodies. Living things must use energy and consume nutrients to carry out the chemical reactions that sustain life. The sum total of the biochemical reactions occurring in an organism is called its **metabolism**.

Metabolism can be subdivided into anabolism and catabolism. In **anabolism**, organisms make complex molecules from simpler ones, while in **catabolism**, they do the reverse. Anabolic processes typically consume energy, whereas catabolic processes can make stored energy available.

3. *Homeostasis*

Living organisms regulate their internal environment to maintain the relatively narrow range of conditions needed for cell function. For instance, your body temperature needs to be kept relatively close to 98.6°F (37°C). This maintenance of a stable internal environment, even in the face of a changing external environment, is known as **homeostasis**.

How do organisms maintain homeostasis? There are a huge number of different strategies, but one easy-to-see example is shown in the photo below. A jackrabbit can release heat through the surface of its large, thin ears, and will actually increase blood flow to the many blood vessels in the ears to cool down when it's hot.

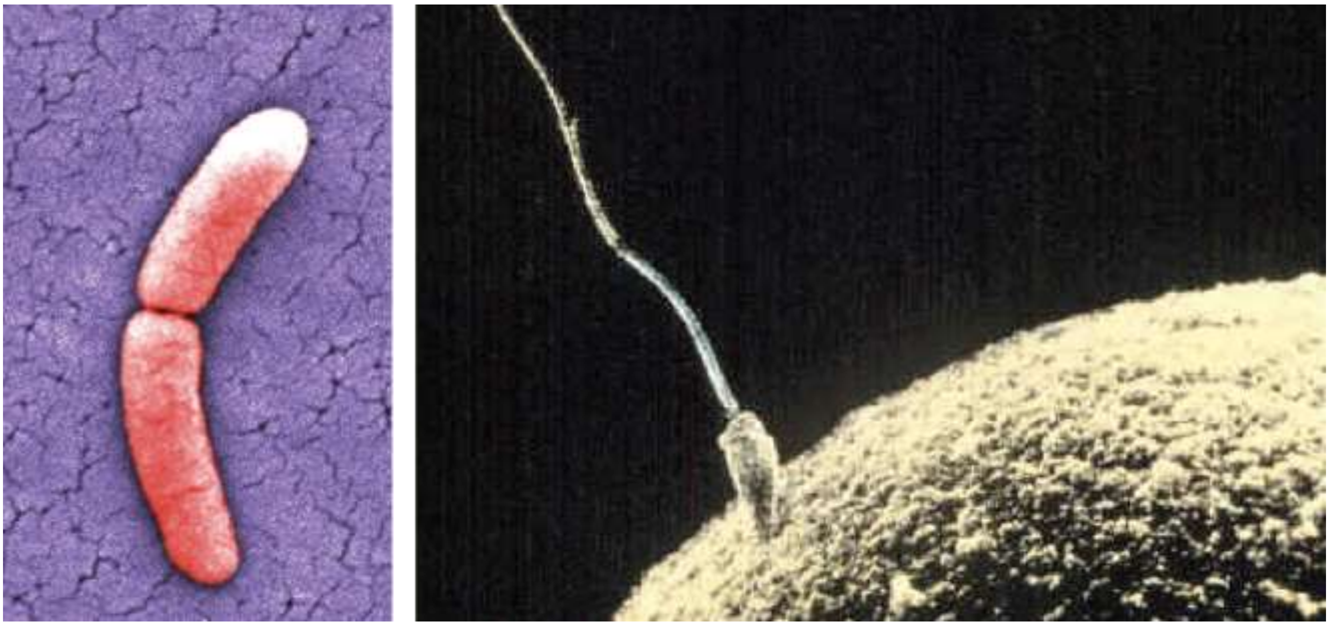
Image of a jackrabbit in the desert, showing the rabbit's very thin—almost see-through—heavily veined ears, which are used for heat dissipation.
Image credit: "Black-tailed jackrabbit" by Jerry Oldenettel (CC BY-NC-SA 2.0)

4. Growth

Living organisms undergo regulated growth. Individual cells become larger in size, and multicellular organisms accumulate many cells through cell division. You yourself started out as a single cell and now have tens of trillions of cells in your body! Growth depends on anabolic pathways that build large, complex molecules such as proteins and DNA, the genetic material.

5. Reproduction

Living organisms can reproduce themselves to create new organisms. Reproduction can be either **asexual**, involving a single parent organism, or **sexual**, requiring two parents. Single-celled organisms, like the dividing bacterium shown in the left panel of the image at right, can reproduce themselves simply by splitting in two!



Left: image of a Salmonella bacterium dividing into two bacteria. Right: image of a sperm and egg meeting in fertilization.
Image credit: left, "Salmonella typhimurium" by Janice Carr (public domain); right, "Sperm-egg," (public domain)

In sexual reproduction, two parent organisms produce sperm and egg cells containing half of their genetic information, and these cells fuse to form a new individual with a full genetic set. This process, called fertilization, is illustrated in the image at far right.

6. Response

Living organisms show “irritability,” meaning that they respond to stimuli or changes in their environment. For instance, people pull their hand away—fast!—from a flame; many plants turn toward the sun; and unicellular organisms may migrate toward a source of nutrients or away from a noxious chemical.

This short video of the plant *Mimosa pudica* demonstrates that plants, like animals, are capable of rapid response to a stimulus. If a *Mimosa* plant is touched, it will respond by folding its leaves inward, as shown below. Most plants do not show as dramatic a response to stimuli as *Mimosa*. However, all plants are capable of sensing their environment and responding. Their response may just be biochemical—such as the production of defense toxins—or developmental—such as the production of a new branch—rather than a rapid, visible response like that of *Mimosa*.

Short movie (GIF) of a *Mimosa pudica* plant responding to touch. When the tip of a branch is touched, the leaves on that branch rapidly fold inwards in series, starting with those closest to the touched point.

Image credit: "Mimosa pudica" by Hrushikesh (public domain)

7. Evolution

Populations of living organisms can undergo **evolution**, meaning that the genetic makeup of a population may change over time. In some cases, evolution involves **natural selection**, in which a heritable trait, such as darker fur color or narrower beak shape, lets organisms survive and reproduce better in a particular environment. Over generations, a heritable trait that provides a fitness advantage may become more and more common in a population, making the population better suited to its environment. This process is called **adaptation**.

Is this the definitive list?

Living organisms have many different properties related to being alive, and it can be hard to decide on the exact set that best defines life. Thus, different thinkers have developed different lists of the properties of life. For instance, some lists might include movement as a defining characteristic, while others might specify that living things carry their genetic information in the form of DNA. Still others might emphasize that life is carbon-based.

Image of a mule on a farm. The mule looks similar to a donkey and is clearly a living animal, despite the fact that it cannot reproduce.

Image credit: "Mule head" by Skeeze (public domain).

It's also true that the list above is not foolproof. For instance, a mule, the offspring of a female horse and a male donkey, is unable to reproduce. However, most biologists (along with everyone else) would consider a mule, pictured at right, to be alive. A similar point is illustrated in this amusing story: a group of scientists had, after much debate, decided that ability to reproduce was the key property of life. To their disappointment, someone pointed out that a lone rabbit did not meet this bar.

Nonetheless, the list above provides a reasonable set of properties to help us distinguish between things that are alive and those that are not.

Separating living and non-living things

How well do the properties above allow us to determine whether or not something is alive? Let's revisit the living and nonliving things we saw in the introduction as a test.

The living things we saw in the introduction—humans, dogs, and trees—easily fulfill all seven criteria of life. We, along with our canine friends and the plants in our yards, are made of cells, metabolize, maintain homeostasis, grow, and respond. Humans, dogs, and trees are also capable of reproducing, and their populations undergo biological evolution.

Nonliving things may show some, but not all, properties of life. For instance, crystals of snow are organized—though they don't have cells—and can grow but don't meet the other criteria of life. Similarly, a fire can grow, reproduce by creating new fires, and respond to stimuli and can arguably even be said to “metabolize.” However, fire is not organized, does not maintain homeostasis, and lacks the genetic information required for evolution.

Living things may keep some properties of life when they become nonliving, but lose others. For instance, if you looked at the wood in a chair under a microscope, you might see traces of the cells that used to make up the living tree. However, the wood is no longer alive, and, having been made into a chair, can no longer grow, metabolize, maintain homeostasis, respond, or reproduce.

Let’s test out our list of properties on a trickier case. Imagine a very sophisticated robot, such as R2D2 or C3PO from the Star Wars movies. Such a robot would show organization—without cells—respond to stimuli, and even have a metabolism of sorts, using energy to power the circuitry of its “nervous system”. It might even maintain homeostasis, with an internal fan or heater that turned on if the temperature changed.

A typical robot would not grow, reproduce, or be part of an evolving population, and thus wouldn’t be considered alive. However, what if a robot were programmed to add pieces onto itself? To build more robots? To build more robots with variations in the “DNA” of their programs? As these ideas show, a sophisticated enough computer or robot—far beyond what we have today!—could start to bend the definition of life.

What counts as life is still being defined.

The question of what it means to be alive remains unresolved. For instance, viruses—tiny protein and nucleic acid structures that can only reproduce inside host cells—have many of the properties of life. However, they do not have a cellular structure, nor can they reproduce without a host. Similarly, it’s not clear that they maintain homeostasis, and they don’t carry out their own metabolism.

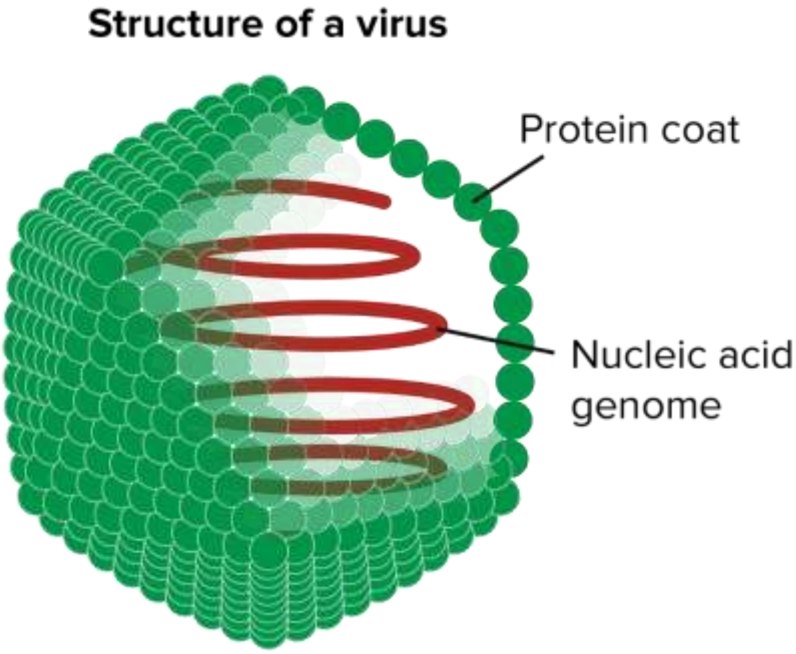


Diagram of a virus. The virus consists of a nucleic acid genome inside an external protein coat. Image credit: Image modified from "Enveloped icosahedral virus," by Anderson Brito (CC BY-SA 3.0; the modified image is licensed under a CC BY-SA 3.0 license

For these reasons, viruses are not generally considered to be alive. However, not everyone agrees with this conclusion, and whether they count as life remains a topic of debate. Some even simpler molecules, such as self-replicating proteins—like the “prions” that cause mad cow disease—and self-replicating RNA enzymes, also have some, but not all, of the properties of life.

Moreover, all of the properties of life we have discussed are characteristic of life on earth. If extraterrestrial life exists, it may or may not share the same characteristics. Indeed, NASA's working definition that "life is a self-sustaining system capable of Darwinian evolution" opens the door to many more possibilities than the criteria defined above. However, this definition also makes it hard to quickly decide whether something is alive!

As more types of biological entities are discovered, on Earth or beyond, they may demand that we re-think what it means for something to be alive. Future discoveries may call for revisions and extensions of the definition of life.