

Prefix	Abbreviation	Mathematical Equivalent	Level of Biological Organization	Example Application
kilo	k	$10^3$	biosphere	circumference of earth, $\sim 10^4$ km
centi	c	$10^{-2}$	organism	average human height, $\sim 180$ cm
			organ	width of human heart, $\sim 10$ cm
milli	m	$10^{-3}$	tissue	width of largest human vein, $\sim 24$ mm
micro	$\mu$	$10^{-6}$	cell	cell, $\sim 5\text{--}120$ $\mu\text{m}$
nano	n	$10^{-9}$	biomolecule	biomolecule, $\sim 10\text{--}1000$ nm
angstrom	$\text{\AA}$	$10^{-10}$	molecule	average length of a chemical bond, $\sim 1$ $\text{\AA}$
pico	p	$10^{-12}$	atom	typical atomic width, $\sim 100$ pm

Table 1.1. Metric prefixes commonly used in biology.

## 1.2 What is Life?

### 1.2.1 Life vs. Non-life

Now that we have discussed what science is, how science works, and some of the important tools and measurements that biologists use, it is time to explore the nature of life.

“Is it alive?” is a question that even the youngest of children ponder. My 5-year-old daughter recently asked me, “Are earthquakes alive?” It was a good question, and not only because we live in Southern California where earthquakes are common. Earthquakes move, can cause massive damage, and act without apparent cause.<sup>2</sup> Nonetheless, earthquakes are not alive.

So then, what is it that makes something alive? Just like an earthquake, you move, cause damage (hopefully not very often!), and act according to your own will. Unlike an earthquake, however, you are composed of cells, undergo metabolism, grow, have the potential to reproduce, respond to stimuli, and adapt to the changing environment. All in all, the characteristics that distinguish life from non-life are summed up in one word—*purpose*.

Let's take a minute to unpack what the word purpose means and how purpose is distinct from the design evident in the physical (non-living) world.

In the Physical Science text that is sister to this text, the author states that the universe is comprised of three basic things—matter, energy, and intelligence.<sup>3</sup> Matter is anything that has mass and takes up space; energy is what holds everything together and enables any process to happen; and intelligence is the wisdom of God or his creatures that causes everything to work together in an orderly and beautiful way. Since God created all that exists, his wisdom is evident everywhere, including in the laws of nature that govern how everything in the universe works.

In the study of life, we distinguish between non-living and living matter. Like everything else in the universe, living things are made of matter, use energy, and obey the laws of nature. However, non-living things do not act according to a guiding purpose as living things do. The

<sup>2</sup> Of course, you learned in Earth Science that earthquakes are caused by the shifting of tectonic plates due to the buildup of stress. However, this cause was not apparent to my young daughter.

<sup>3</sup> The most rigorously scientific way of describing this trio would be matter, energy, and order, where the order in nature is due to the laws of nature. The truth behind the order observed in nature is that this order is a manifestation of the intelligence of the Creator.

word purpose implies an end or goal (or, in Aristotle's language, a *telos*), such that everything a living organism does is aimed toward a singular, meaningful endpoint. Non-living matter does not behave in a purposeful fashion; it simply responds to physical processes.

Consider a common inanimate (non-living) object, such as a rock. The rock is made of atoms and molecules (matter). Its existence is the result of the God-given laws of nature (being formed by chemical reactions and weathering). It does not, however, act according to an innate purpose. If the rock moves, it is because an outside force acts on it. A living thing, on the other hand, has a guiding purpose that directs all its more specific characteristics. The simplest purpose a living thing can have is to survive and reproduce. Beyond this, organisms display more complex purposes such as supporting other life in an ecosystem. Finally, human beings have many purposes, including the most noble "chief end" of all: "to glorify God and to enjoy Him forever."<sup>4</sup>

Beyond the general characteristic of exhibiting purpose, all living things possess six specific characteristics, listed in Table 1.2. You can also think of these six characteristics as six requirements that must be met in order for a thing to be regarded as alive. Note that all six move an organism toward the fulfillment of its purpose. In the remaining subsections of this section, we examine these six characteristics in more detail.

To illustrate, my children were recently subjected to a dramatic experience that highlights the dividing line between life and non-life. At a school picnic, they excitedly participated in a number of games, winning three live goldfish in little plastic baggies. Not wanting to dampen their enthusiasm for their new pets, I invested in a small aquarium, colorful gravel, plastic plant-like decor, and a small pink castle, not to mention the required chemical additives to make tap water safe. We carefully transferred the fish to their new home, making sure that their baggies had time to adjust temperature so as not to shock the fish. At first, everything went along swimmingly (pun intended). Our three goldfish beautifully displayed to us that they were alive, displaying the characteristics listed in Table 1.2. Were they composed of cells? Check. Did they metabolize? Yes. They utilized matter and energy. We fed them diligently twice a day, and it was evident that they were producing excrement. They energetically swam back and forth, using the energy that the food gave them. Did they grow, develop, and reproduce? Though we didn't get to see it ourselves, as living things, these fish most certainly grew from small eggs. And my children most earnestly hoped that there might be both a male and female goldfish among them so that they might have babies. Did they use and transmit genetic information? Yes. They had genes that specified where exactly their fins should be placed, the bright orange color of their scales, and how they would breathe the oxygen dissolved in their tank water. Any of their offspring would have displayed similar traits. Did they respond? Yes, indeed! If they swam too close to a spiky plastic plant, they turned around and swam in another direction. If they swam underneath the "waterfall" produced by the filter water being returned to the tank, they swam more vigorously in order to stay on their intended path. Did they adapt to their environment? Here is where we ran into trouble.

After a few days, our goldfish friends began to behave strangely. One, whose name was Buddy, decided he preferred to hang out in one spot near the gravel. We could see his gills and mouth moving back and forth, though, so we knew he was alive. Another one, whose name was Buddy Jr., floated to and fro, but didn't exert the same energy that he once did. It was almost as though he became paralyzed, subject to the forces of the filter water alone. However, his gills and mouth continued to move, indicating that he was still alive. I looked for information as to why they might be behaving this way. Based on the best available "goldfish care theory," I came up with the hypothesis that their water had too much ammonia and needed to be partially changed. I set out to complete this change, making sure to place the correct number of drops of water

4 The "chief end of man," as described by the Westminster Catechism.

1. Living things are composed of cells and operate on many levels of organization.	Living things are made of matter, and are arranged according to highly organized, complex, purposeful designs. The most fundamental level of organization that displays all the characteristics of life is the cell.	Section 1.2.2
2. Living things metabolize.	Living things use materials from the environment and excrete waste, a process called metabolism. Waste products are broken down and used again. Energy is continually supplied from the sun, converted, and used by organisms, which produce waste heat in the process.	Section 1.2.3
3. Living things grow, develop, and reproduce.	Organisms proceed through various life stages, typically of increasing complexity, until maturity is reached and the organism is able to reproduce.	Section 1.2.4
4. Living things use and transmit genetic information.	Living things share a common genetic code, or instruction manual for life. These instructions dictate how an organism functions and are passed on to offspring.	Section 1.2.5
5. Living things respond.	Living things have some sort of sensory system by which they respond to light, sound, motion, or other stimuli. They process the information received and respond accordingly.	Section 1.2.6
6. Living things adapt to their environments.	Populations of organisms adapt to a changing environment, as each generation favors survival of organisms with the most suitable traits.	Section 1.2.7

Table 1.2. Six characteristics of life.

conditioner, and to equalize the temperature before adding the new water. Just minutes after the fish had their new water, I heard a distressed shriek coming from upstairs. One of my children saw that the goldfish were no longer breathing. Their gills and mouths were now completely still. Our pets had ceased living.

What happened? Most likely, the stress of being a carnival prize, being driven home in a baggie, and “lovingly” handled by a six-year-old child, followed by the shock of entering a new aquarium environment was too much for these sweet goldfish to handle. They could not adapt to the stressful environment, and then, one by one, lost all the other attributes of life.<sup>5</sup>

The living goldfish had purpose. They lived to survive and reproduce (and to bring delight to my children). The bodies of the deceased goldfish became non-living matter. They moved because of outside forces (like the filter waterfall), not of their own accord. Now laid to rest in backyard graves, their cells are decomposing into smaller building blocks. They no longer possess any of the attributes of life.

In the following subsections, we take a closer look at these six characteristics of life. In later chapters, we address aspects of these characteristics in much greater detail.

### 1.2.2 Cellular Structure and Levels of Organization

So far as we know, all living things are made of *cells*. Just as atoms are the fundamental building blocks of matter, cells are the fundamental building blocks of life. A cell is a self-contained living factory, surrounded by a barrier called a *membrane*, containing genetic material

<sup>5</sup> If I had maintained a large population of goldfish in a much larger tank, perhaps a few fortunate ones might have survived the unfavorable water conditions. After several generations, all the resulting fish would have been much more resistant to the ammonia in the water.