The Languorous Lathe of Life

 We're humans. We tend to measure time in units of minutes, hours, days, and years. Our history books refer to events from thousands of years ago, and we can speak of the beginnings of civilization using tens of thousands of years. Alas, this tends to give us a skewed perspective. The universe we live in embraces amounts of time so small that we can't perceive them, like the interactions and reactions between atoms and molecules, or so large we can't believe them, like the lifetimes of planets, stars and galaxies.

 Our planet was born about four billion and five hundred million years ago. That means our planet is roughly forty five million times older than our oldest humans. It is three hundred and seventy-five million times older than you, if you're around 12 years old. If you were to try to count to three hundred and seventy-five million, at a rate of one number per second, it would take you almost 12 years of your life.

 All this is to say, Earth is very, very old when compared to you. Unimaginably old. We can write about it and talk about it, but it is unlikely that any of us can truly understand how much time has passed on our planet. It is simply too old, and it is completely outside of the sorts of timeframes we have to deal with as humans.

 So, 4.5 billion years ago (BYA) Earth is born. It is hot, red hot. It will take another one thousand million years for the planet to cool off enough that liquid water becomes common, and oceans start forming. Even then, it was a vicious environment. Volcanoes were everywhere, belching liquid rock, toxic gasses and various vapors into the atmosphere. The giant clouds of ash and water probably caused incredible lightning storms. If you could be transported to back then, you would be astounded by the violent beauty of the barren landscape before you dropped dead after simultaneously inhaling various poisons, being struck by lightning, and roasting to death in the high temperatures. This is known as the Hadean Eon, so called because it was a hellish place, and Hades is the name for the Greek underworld.

 At some point, life begins, marking the beginning of the Archaean Eon. Actually, some scientists argue that it could have begun several times, over and over, because they believe there is good reason to assume conditions were excellent for random reactions between molecules to assemble a new molecule that was capable of making copies of itself. We don’t know much about the first organism on our planet, but based on indirect evidence, we can make certain assumptions. It was probably made of a molecule like RNA, which could both store genetic information and act like an enzyme to cause chemical reactions, and it probably had a simple cell membrane. In theory, this very basic cell was the beginning of life. Sadly, this could not be observed, since humans wouldn't exist for quite some time yet, and no fossils or other evidence of this event could possibly form. A common question (and it is a good and reasonable question indeed) is to ask how it would be possible for a solution of naturally occurring molecules to randomly join together to form a molecule that could make copies of itself? While there is no definitive answer to this (and there may never be,) part of the response may be found in the vast amounts of time available and the vast number of molecules and atoms available to interact.

Still, if we are assuming that life formed from non-living molecules that were lucky enough to react together in just the right way, then we must assume that the basic building blocks of living molecules must have been present. How can we even assume that? Well, many experiments that have attempted to recreate the early conditions of primitive Earth have demonstrated that many biologically important molecules would be created naturally in such a warm, electrically charged environment, even though life was not present yet. At some point, then, a group of those non-living molecules joined together into a larger and more complex one that: life was created by non-life. This is sometimes called a-(non)bio-(life)genesis-(creation,) or abiogenesis. (This concept is one that is frequently challenged, especially by groups that propose that this event was so unlikely that it likely could not have occurred without some sort of intelligent or divine intervention. While these arguments are tremendously interesting, they are outside of the scope of this chapter. For now, we must only accept that the generally accepted model for the emergence of life on Earth by the majority of scientists relies on abiogenesis.)

 After abiogenesis occurred, life was free to start expanding and changing. What likely began as a community of prokaryotic microorganisms living near some deep sea volcano would soon expand into new environments and diversify. The descendants of that ancestor population would eventually spread across the globe, giving rise to bacteria, funguses, plants, animals, and protists.

 The process of groups of organisms changing over time to adapt to their environments and to create new species is known as evolution. Now, evolution has a long and sometimes troubled academic history, but the basic ideas underlying evolutionary theory are largely undisputed.

 The first important idea that leads to evolution is that of variation. If we look at any population of organisms, it is pretty clear that they are not all identical. Even communities of organisms that seem very similar can still have pretty significant differences, like colonies of bacteria. They may look the same, but they each have small differences in their cell surface proteins, or ability to digest certain molecules. The key to variation is that is means that not all organisms are equal. Let's imagine one of those original deep sea populations of microorganisms. We can look at a simple trait like heat tolerance. This is just a way of measuring how much these microorganisms can withstand high or low temperatures. Because of variation, there will be some organisms that can stand higher temperatures close to the undersea volcano, and some that are better suited to the cooler zones further from the volcano.

 The second important idea is the idea of selection. Depending on their traits, some organisms will survive an environment better than others. In a way, the environment is responsible for picking or selecting what organisms survive. For example, if the volcano near our imagined microorganisms erupts and warms the environment, then only organisms that can survive the resulting increased temperatures will survive. In that case, heat-resistant organisms will have been selected for. On the other hand, if the volcano stops erupting, then the cells who can best survive cooler temperatures will be the most likely to survive.

 The final important idea is that of inheritance, or heritability. This just means that organisms are likely to pass on a version of their traits to their offspring. This means that the cells that survive the cooler environment without the volcano can pass that ability on to their offspring. This wouldn't mean much, except in combination with the other major ideas. The total result is that because of variation, some organisms are best suited to survive in an environment. Because of selection, only some will survive, because they have the best traits for that environment. Because of heritability, they can pass the traits that let them survive onto their offspring, so their offspring are also more likely to survive.

 Altogether, this leads to the idea of evolution: populations of organisms are likely to change to adjust to the demands of their environments, and then pass their traits on. As groups of organisms move into new environments, or as their environments change around them, then selection of various traits will cause the characteristics of the population to change to match their environment.

 Let's examine our imaginary volcano, and the microorganisms that live near it. The volcano has been erupting for over a hundred years, and it has a stable population of microorganisms nearby. The ones best able to survive the heat live closest to the volcano, and others live further away. This is because variation in heat tolerance is present in the community.

 Suddenly, the volcano erupts, growing larger in a matter of minutes. The organisms closest to the volcano are overwhelmed immediately, but groups nearby experience selection. The organisms with the traits most tolerant of heat survive and reproduce, causing the overall population to become more heat tolerant. Voila! Evolution has occurred. Still, the kind of evolution that has occurred is a kind of piddling little thing. A population of organisms changed their average heat tolerance. Hardly exciting, and it isn't like anything truly new was created.

 So, this sort of evolution seems pretty obvious and simplistic. The real question is this: how did we get from populations of single cell prokaryotes living on a fairly unpleasant planet 3.5 BYA to the modern day, where the Earth is a remarkably pleasant environment, populated by a huge variety of organisms, many of which are multicellular and eukaryotic?

 The fundamental problem with the idea of evolution is fairly simple. We need to understand where variations come from, and we need to appreciate the incredible depth of time necessary for evolution to really work to create new specific life forms. Let's start with the origins of variation.

 The first source of variation is genetic mutations. Since the function of a protein depends on its shape, and its shape depends on the DNA found in that particular gene, changes in the DNA can cause changes in protein shape, which can cause changes in what that protein can *do*. These changes are mutations. They can occur because during replication, DNA isn't copied correctly, or because chemical contaminants (chemicals that aren’t normally found in a cells environment, and that can mess up how a cell functions) can react with the DNA to change it. Mutations can even occur because radiation causes an unusual chemical reaction to occur in the cell, changing the DNA. In each of these cases, since the DNA has mutated, the resulting protein will be different, which means that the organism's traits will be different.

 There are other varieties of mutation, but most of them work in more or less the same way: they take an existing gene and change it, so the trait that gene controls changes also. This leaves a basic problem, though. Where do new genes and traits come from? How can an organism pass a mutation on, if the mutation changes a gene that is needed for survival? Wouldn't the resulting offspring die without the needed protein?

 The answer is that sometimes an entire gene or group of genes can be accidentally duplicated. When this happens, the original genes still exist to create the proteins an organism needs to survive. The new, extra set of genes is then free to mutate and change and create new traits, because the original set of genes is still working at creating the necessary traits. This is a fairly slow process, with useful mutations occurring very rarely, but if we consider that the early populations of microorganisms likely reproduced every few hours, and there is evidence that the first organisms on Earth appeared 3.5 billion years ago, then there is ample time for enough mutations to have created plenty of variety for environmental selection to pick through during the process of evolution.

 [Let's suppose that useful mutations are rare, occurring once out of every billion mutations. Just suppose that out of the entire population of every microorganism on early Earth (of which there were almost certainly trillions), only one useful mutation would then occur per generation. This means that, if the population reproduced once per hour, then there would be 24 "good" mutations per day. Over the course of a billion years, this means that there would be roughly 8.7 trillion "good" mutations in the first billion years of life on Earth.]

 So, somehow life begins. Over the next billion years, those early cells inch forwards through the painful process of mutation causing variation, selection preferring some variations, and inheritance passing those successful variations onto the next generation. After over a billion years, sexual reproduction finally evolves, and suddenly everything changes...

Use the text to create your own definitions for the following terms, on a separate sheet of paper to be handed in and graded formatively. Use the definitions rubric, and avoid reusing descriptive words that do not add to the explanation.

1. Abiogenesis
2. Chemical Contaminants
3. Gene Duplication
4. Evolution
5. Genetic Mutation
6. Hadean Eon
7. Archaeon Eon
8. Heritability
9. Inheritance
10. Radiation
11. Replication
12. Selection
13. Variation