This chapter is an excerpt from *Principles of Planetary Biology*, by Tom E. Morris.

Chapter 6

The Origin of Earth and Life

6.1 Introduction

If life is ever to achieve planet-changing stature, it must first *start* on the planet. It happened on Earth. But exactly *how* it happened remains a frustrating mystery. We cannot go back in time to witness the origins of life on our world. So scientists must approach this problem as a detective would. What are the reasonable possibilities? Where does one start to look for clues?

All active pursuits in this field have traced the origin of life back to some kind of chemical moment. The origin of life's chemistry marks the origin of life. So investigators wonder about modern biochemistry's origins. How did molecules 'learn' to self-organize? How did they 'learn' to copy their stores of information to new molecules?

Life is matter that is animated in very purposeful ways. The self-assembly and replication phenomena represent the ascent of matter from *slave* of the physical world to the level of purposeful entity that *exploits* the physical world. Overall, there is no built-in OFF button. Once molecules begin to self-assemble, they will continue to do so as long as their surrounding physical environment permits it. The more gracious their environment, the more living molecules will do their thing – becoming more abundant as a result. And as living matter becomes more abundant, its impact on the planet will increase.

Let's consider the theories. It turns out that newer understandings of the primordial Earth have cast doubt on some old favorites. For example, the famous Oparin-Haldane primordial soup idea captivated several generations of scientists in the twentieth century. This idea is very dependent upon a particular mix of gases in the Earth's early atmosphere. New findings about the early atmosphere mean this once most popular view, is highly unlikely. Other creative ideas dependent upon a certain kind of early atmosphere also have fallen victim. So, right from the very beginning, we must think of life in the context of the whole planet. In spite of these setbacks, science continues its search.

Also, you will quickly discover that science is far away from an answer to this most interesting question. But that is not the point. What is most interesting is how persistent human minds are unwilling to give up despite formidable odds. Trying to solve a mystery that happened over 3.8 billion years ago is not easy, and may be altogether impossible. Yet scientists never stop wondering about new possibilities, searching for new clues, and scouring their data for some overlooked detail. The human mind directs this quest, but it is consistent with the notions about life in general. Life is an activity that prepares innovative experiments, some of which lead to successful solutions in the struggle for survival. In this sense, creative innovation literally is a way of life. Why should the human mind act otherwise?

6.2 Physicists theorize that the Universe began with a bang

Cosmologists believe the Universe began about 15 billion years ago in what is popularly known as the *Big Bang*. The Big Bang theory proposes that the first elements in the Universe consisted of hydrogen (fig. 6.1) and maybe helium. These simple molecules are not much good for making up life. Not just yet. Still, the original hydrogen atoms perhaps played a very crucial role in the development of the Universe. Visualize the Universe, say, a billion years after the big bang.

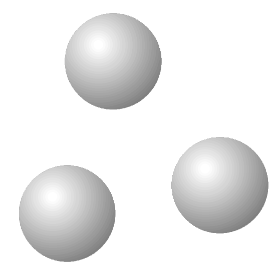


Figure 6.1. After the Big Bang, matter in the universe consisted mainly of hydrogen (nuclei shown here) and helium atoms.

According to this model, it was nothing more than a dark cloud of hydrogen gas rapidly expanding. The Universe is hard to imagine at this stage because it was dark, absolutely. What is missing? Stars.

The stars in the night sky, and the huge one in our daytime sky are thought to have been formed from the hydrogens interrupted by gravity from their race across space. Our understanding is that the first stars could have formed following the development of eddies in the flow of the universal wind. These eddies could have established opportunities for density differences in the cloud. That is, the cloud could become thicker in some parts and thinner in others. In the thicker parts, gravitational pull between all of the congregating hydrogens would have started to grow stronger, pulling the hydrogen atoms toward the centers of these eddies. As more hydrogens were pulled closer, the gravitational pull would increase, pulling still more hydrogens in at faster and faster speeds. So, little disruptions in the cloud (like eddies) could have served as focal points for the concentration of hydrogen gas in a still very dark place. But a dense hydrogen pocket does not a star make.

In the process of star-making, two main ingredients are required:

- trillions and trillions of tons of hydrogen gas
- gravitation that pulls these hydrogen atoms tighter and tighter together

The gravitation exerted by all of the hydrogen atoms on each other eventually could have caused the cloud to collapse in all directions, forming a discrete sphere, the precursor of a star (protostar). As this ball collapsed still more, temperatures in the millions of degrees could be generated, stripping hydrogen atoms of their electrons. The continuing build up of pressure by the collapsing ball eventually can force the bare hydrogen atoms (protons) to fuse to each other. This fusing action produced the first flickers of light in the foggy dungeon of the big bang.

When hydrogen protons stick together, this is what is known as a nuclear fusion reaction. It is the same kind of reaction humans used to create the hydrogen bomb. In this reaction, hydrogen protons fuse together to make the nucleus of a new element, helium. In the process of fusing, tremendous amounts of energy are released in the form of electromagnetic radiation (part of its spectrum includes a range of frequencies we interpret as 'light'), heat and explosive force. When the first rays of light begin to emerge from a collapsing protostar, the collapse halts, balanced by the outward push of billions of nuclear fusion reactions. So, a star actually exist in a steady balance. On the one hand it wants to collapse under the crush of its own weight, but is buoyed out on all sides by the force of internal nuclear explosions. On the other hand, it wants to explode outward into space, but is held tight at all quarters by its own immense gravity.

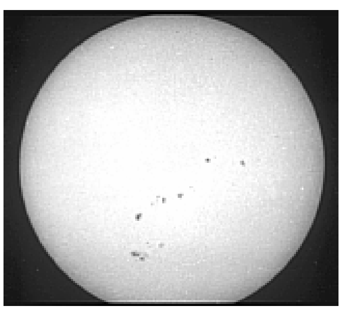


Figure 6.2. The first stars formed out of hydrogen atoms compressed by immense gravity.

For stars, a standoff is reached between two competing forces, gravity and nuclear explosions. But gravity will win in the end. Still, this struggle can last for one million to 10 billion years or more, depending upon the size of the star. In the meantime, these warriors of physics shower nearby space with light and heat. And when stars appeared, the universe for the first time was illuminated with exciting possibilities (fig. 6.2).

But living things and even rocks are made up not only of hydrogen, but of carbon and nitrogen, oxygen and more. Today, there are over 100 elements. But in the early universe, these elements did not exist — only hydrogen and helium. Then, there was no possibility of planets, nothing to make dirt out of. So, the familiar soil upon which we walk wasn't made at the time of the big bang. It came much later — after the death of stars.

6.3 Planets formed from the debris spewed into space from exploding stars

Even for stars, as with so many things, all good things must end. Some time between 1 million years (for really big stars) and hundreds of billions of years (for very small stars – if the Universe lasts that long), the hydrogen fuel is used up. No longer inflated by nuclear reactions, the star will begin to collapse under it own immense gravity. As the star contracts, the helium core can heat up to 100 million °C and hotter. In addition, greater pressures are generated at the star's core by the contracting mass. The combination of higher temperatures and pressures can be sufficient to renew nuclear reactions for awhile. But this time the products are not just helium. Instead, helium nuclei are forced together to make new elements like carbon, oxygen, nitrogen and others. This is followed by a series of more stellar contraction events yielding higher temperatures, pressures and even heavier elements like lead and gold. The sequence of contraction and element synthesis can involve many cycles, each time producing heavier and heavier elements. The result is that the dying star's core becomes layered like the inside of an onion. The layers contain progressively heavier and heavier elements, the heaviest of which are found at the center. Weighty with a diversity of elements, the aged star now is poised to bear forth the cosmic seeds of planets.

If the star is about 1-1/2 times the size of our sun, it could experience one final mighty collapse and then a cosmic explosion – a supernova (fig. 6.3). This explosion ejects much of the star's core materials into space, sometimes leaving behind a small core

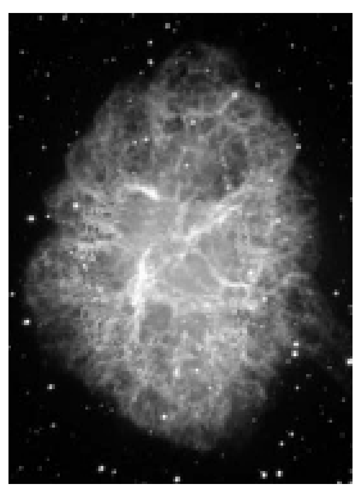


Figure 6.3. The Crab Nebula is the aftermath of an exploding star. Coutesy NASA.

remnant – a neutron star. The materials spewed from the star form a large, colorful cloud much larger than our solar system, called a nebula (fig. 6.3).

Cosmologists propose that our sun and the planets in our solar system could have formed from the nebular remains of an exploding star. Evidence that this can happen has been seen with the Hubble Space telescope. The Hubble telescope has observed disks of dust surrounding at least half the stars in the nearby Orion nebula. According to this theory of planet formation, the nebular gases began to collect once again into a protostar which was to become our sun. But this time the surrounding gases were composed of not only of hydrogen and helium. Instead, they were filled with a treasure of planet-building elements. As portions of the ancestral star's element-rich nebular cloud swirled around our newly-created proto-sun, eddies of gravitation were once again developed (fig. 6.4). The gravitational turbulence around the sun perhaps

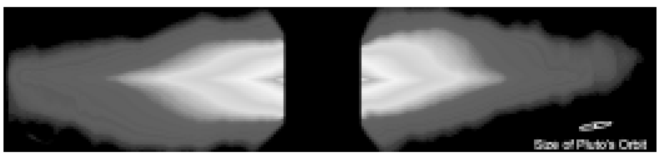


Figure 6.4. Side-on scan of the planet-forming disk of star, Beta Pictoris. Courtesy NASA.

caused the cloud particles to collect into spherical objects swirling around the sun. In the first stages, there could have been dozens of heavenly bodies competing for orbital territory. Sometimes merging, sometimes exploding under the battle of cosmic collisions. The final nine planets of our solar system (fig 6.5) are the victors of the orbit war, the end of which has been followed by a lasting peace (occasionally interrupted by persistent debris like asteroids and comets). Such a calm and generally stable environment was necessary for construction of the complex living systems that soon followed.

6.4 Earth's early atmosphere and overall environment influenced the way life could have started

Biologists think that life started on Earth as early as 3.8 billion years ago. The question is, what was the Earth's atmosphere like back then? In the first half of the 20th century, scientists believed that the earliest atmosphere contained mostly carbon dioxide (in the air you breathe out), methane (what we call natural gas), ammonia (a good cleaner), and hydrogen gas (used in the old blimps). This view of the atmospheric composition was necessary to support certain popular life origin ideas (namely the Oparin-Haldane idea, discussed below).

However, in the 1950s, the understanding of the primordial atmosphere began to change, and it had to do with where the gases came from in the first place. There was a growing understanding among geologists that the gases in the atmosphere came from within the Earth itself — from volcanoes. Geochemists, Claude Allegre' and colleagues, have determined that nearly all of the atmosphere was made by the time the Earth was a mere one million years old (Earth is believed to be about 4500 million years old). Its composition was very much different from what was previously thought. According to this view, it was mostly carbon dioxide and nitrogen (fig. 6.6). There might have been very small amounts of methane, ammonia, and almost no free hydrogen gas was present. Let's see how the kinds of gases in the atmosphere can influence the origin of life.

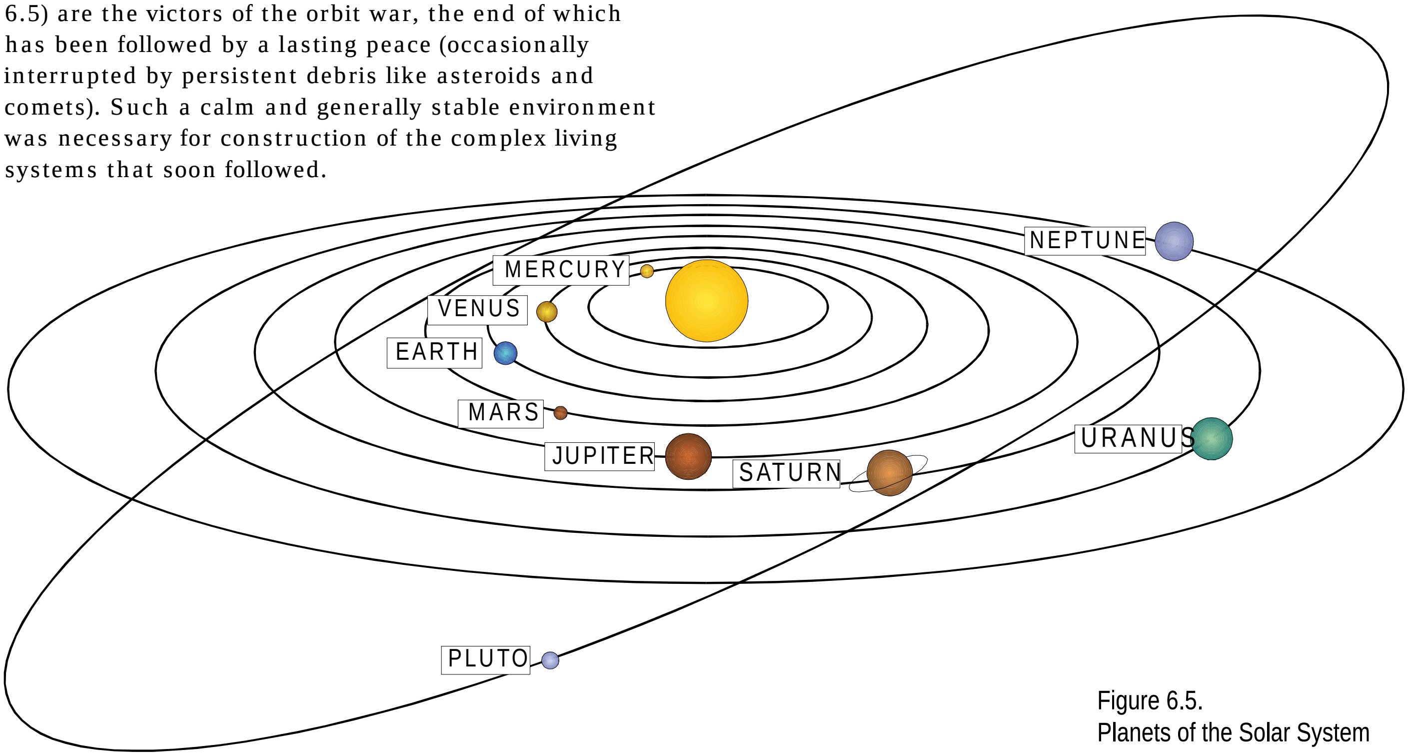


Figure 6.5.
Planets of the Solar System

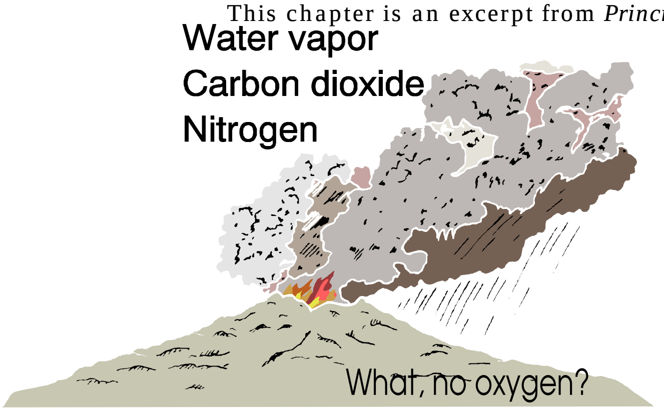


Figure 6.6. Volcanic eruption. Earth scientists now believe that the Earth's atmosphere was the product of volcanoes. Along with huge amounts of dust particles, volcanoes spew out gases -- mainly water vapor, carbon dioxode, and molecular nitrogen (N_2). The carbon dioxide may have acted like a thermal blanket to help keep the planet warm because the sun was much cooler when life began.

6.5 The mix of gases in an atmosphere can powerfully influence the chemistry of life

Biologists who study the origin of life are very interested in the chemical composition of the original atmosphere. This is because nearly all origin ideas start at the level of chemical reactions. The chemistry of the atmosphere can powerfully influence the chemistry of life. For example, I hope you noticed that the earliest atmosphere had no molecular oxygen (a molecule in which two atoms of oxygen are stuck together). Molecular oxygen is what we seek when we inhale.

The absence of molecular oxygen was very important for the early chemistry of life because ironically, molecular oxygen is very destructive to other molecules. Molecular oxygen is very reactive and tends to break other molecules apart. It does this by reacting with them to make something else. This is bad news for defenseless molecules in the open environment. No doubt you have seen the effects of oxygen gas on your car’s paint. Oxidized paint has been destroyed by reactions with oxygen gas. If oxygen can damage something as rugged as car paint, think what it can do to delicate little molecules floating in water. It pulverizes them. In a high oxygen atmosphere, it is very unlikely that the molecules of life could undergo the kinds of building processes necessary to lead to a living thing. Oxygen would destroy them each step of the way, and no progress would be made.

So, it was probably a very good thing that the early atmosphere had no free oxygen gas. The earliest molecules could accumulate and react with one another in a safe environment without being “harassed” by oxygen. Why doesn’t molecular oxygen harm living things now? It can, but living things have a defense system. It is called aerobic cellular respiration. In later chapters we will learn the astonishing story about how aerobic cellular respiration helped the spread of life by harnessing and benefiting from the destructive power of oxygen.

There is much more to learn about the atmosphere’s exciting connection with the development of life and the planet. I will cover more on this topic in later chapters.

6.6 Scientists are uncertain how life began on Earth.

We do not know how life actually got started on Earth. You may find this hard to believe, but biologists are still very far away from understanding how life began on this planet. There are some popular ideas, but they are very incomplete and untested. That stuff you have heard about the old primordial soup? Maybe it’s right. Probably it’s not. I think it is important for you to understand that, in spite of all its technological bluster, modern scientific work still is unable to answer many very fundamental questions. The origin of life is one of these unanswered questions. That is not to say scientists are not trying. Some scientists have spent much of their careers seeking the answer to this most inviting mystery. But we are not sure if their productive work has led to progress. There are so many paths that could lead back to life’s origins. Which is the one true path we may never know. For now, let’s focus on the different ideas science has on the origin of life on Earth.

6.7 The Oparin-Haldane hypothesis depends upon an unlikely atmosphere

In the 1920s, Soviet scientist Alexander Oparin and English scientist J. B. S. Haldane independently proposed an hypothesis on the origin of life. It was later to be popularly known for its “primordial soup” idea. The Oparin-Haldane hypothesis was the first truly modern idea on the origin of life, and it has been widely adopted by biologists (but is probably dead wrong). Their hypothesis was modified through the years, and in the early 1950s it was endorsed by Nobel Prize chemist Harold Urey. The hypothesis can be summarized as follows:

1. When life began, Earth had an atmosphere that was composed of the mostly methane (like the natural gas you use in your stove), ammonia (like the stuff you use to clean your floors with), hydrogen (like the gas that kept the early blimps afloat, including the ill-fated Hindenberg that exploded), and water (fig. 6.7). There was no free molecular oxygen (O_2) in the atmosphere.
2. Lightning, ultraviolet radiation from the sun, and volcanic heat energized reactions involving the gases in the atmosphere. This led to the formation of carbon molecules. Living things are made from carbon molecules.

3. As Haldane put it, these new molecules “must have accumulated until the primitive oceans reached the consistency of a hot dilute soup.”
4. Later changes amongst the molecules in the soup led to the formation of life.

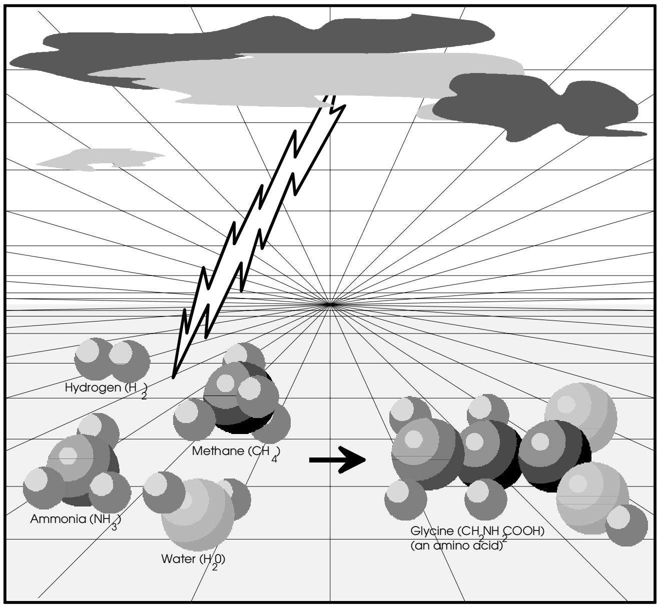


Figure 6.7. A drawing depicting the reactions of the Oparin-Haldane primordial soup. The main product is a simple amino acid. Amino acids are building block molecules used by life to make proteins. The big problem with this idea right now is that the atmosphere upon which it is based is considered highly unlikely.

This idea enjoyed widespread popularity in the 20th century. However, we now know it has problems that are probably fatal. For example, the conventional wisdom amongst geologists today is that the Earth’s early atmosphere was much different than the one proposed by Oparin-Haldane. That is, it was high in water vapor, carbon dioxide and nitrogen. There is little support for the presence of methane, ammonia, of hydrogen which was proposed in the Oparin-Haldane hypothesis. There are additional questions regarding the longevity of the so-called prebiotic soup. For example, geologist Lars Gunnar Sillen predicts that even if there *was* an Oparin-Haldane atmosphere, any molecules in solution would not last long. They would quickly re-convert back to the original atmospheric gases. Why is this a problem? If they didn’t re-convert back, chemist Arie Nissenbaum suggests that instead of floating free, the molecules would be deposited on the ocean floor in gooey tars or tied up in reactions with minerals. Such fates would virtually eliminate the possibility of chemical reactions leading to life.

Given these shortcomings, the Oparin-Haldane idea rightly has lost much support in the scientific community. But there is another idea that dovetails into the Oparin-Haldane hypothesis. It is called the Miller-Urey experiment.

6.8 The Miller-Urey experiment also assumes an unlikely atmosphere

Stanley Miller was a graduate student at the University of Chicago in 1952. Under the guidance of his research advisor, Professor Harold Urey, Miller performed an experiment whose outcome would capture the imagination of the biological world. Stanley Miller wondered if a mixture of Oparin-Haldane gases could lead to the formation of the molecules of life. This was an idea that invited Miller to experiment. So, he set about to design an apparatus to help him test this seductive idea. His apparatus can best be described as a large hollow tube of glass that was bent into a circle and connected at both ends. This established a totally enclosed environment inside the tube. Miller then added water and a mixture of the Oparin-Haldane gases, methane, ammonia, and hydrogen. He attached electrodes that made sparks inside the tube. This was to simulate lightning on early Earth. He let his experiment run for a week. After this period of time, he noticed a tarry substance coating the inside of the tube. When he analyzed it for its contents, he found small amounts of two simple amino acids, alanine and glycine. Amino acids are the building block molecules for larger molecules called proteins (proteins are very important in living things). When Miller announced his findings, the scientific community flocked to declare its

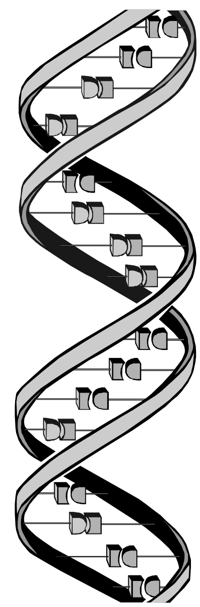


Figure 6.8. A drawing of a section of DNA. DNA is the molecule that carries the genetic code in living things. Two properties make this the most powerful of all biological molecules. They are: 1) it can make copies of itself; and 2) its sequence of building blocks can be rearranged like the letters in an alphabet, enabling it to be a carrier of coded information.

support. For here was an experiment that, in their minds, demonstrated that forming the molecules of life was possible on early Earth. But let's be scientists for a minute here.

If we study the Miller-Urey as skeptical scientists, we will find that it is not all that remarkable. We will also learn that making a few amino acids in a test tube falls far short of synthesizing complex molecules of life, like DNA (fig. 6.8). The main problems with this experiment are summarized below:

1. The initial gas mixture was based on the Oparin-Haldane atmosphere. This gas mixture in the early atmosphere now is thought to be highly improbable by geologists.
2. The first design of the experimental apparatus produced no amino acids. After he modified the organization of different parts of the apparatus, Miller achieved the desired outcome. Other attempts to "improve" the design also failed to produce amino acids. Small variations produced no amino acids. The problem with this is that the sensitive eccentricities of the experimental apparatus are not widely communicated. What does this tell you about the "inevitability" of the process on early Earth? As a result, the Miller experiment has seriously misled many students and prominent scientists alike.
3. The presence of simple amino acids is not really relevant to the *origin* of life. This is because in order for life to work, molecules must be able to make copies of themselves. Nucleic acids, like DNA can do this. There is no evidence that amino acids or their protein constructs have any ability to self-replicate. If we cannot find copying abilities in amino acids, linking the Miller-Urey experiment to the origin of life issue, is scientifically risky.

6.9 Leslie Orgel suggests that the first replicators may have been RNA, but then again...

Leslie Orgel advocates the idea that RNA molecules (or similar variants) may have been the first replicators. The term, RNA, stands for "ribonucleic acid". RNA (fig. 6.9) is a cousin to DNA, the master replicator. For now, let's think of RNA as a very large molecule like a kind of chain of smaller units or "links". Orgel's vision is that RNA could have spontaneously assembled in the prebiotic world. This could have been done as each of the links, already present, came together to form a long thread of RNA. What makes RNA so interesting is not so much that it is a chain of smaller molecules, but that each of the links has an attraction for an "opposite" link - like the teeth of a zipper. This is a property that makes it possible for RNA to duplicate itself. So, if a single strand of RNA is present, then each of its links attracts a complimentary link which comes out of the prebiotic soup. It would be like building a zipper by starting with only one side of the zipper, then placing it in a pan of free zipper teeth. The free zipper teeth then encounter and stick to the zipper half, forming a new strand of zipper. The result is two complete zipper strands. There is a problem here though. The second half of the zipper isn't a duplicate, it's a mirror image. So the process would have to be repeated, this time using the newly formed zipper half as the template to make yet another new zipper half. Orgel has successfully completed the first step of this copying process without the benefit of helping molecules called enzymes (kinds of proteins). But enzymes are needed in order to complete the second round of copying. The need for enzymes was to lead to another problem that I will discuss a little later below.

The point is that RNA has the potential for being the first self-replicating molecule. But that's not the only reason Orgel is interested in RNA. RNA also can carry coded information. Remember that RNA is made up of little "link" molecules. These make up the chain of RNA. There are four different kinds of "link" molecules, like there are different kinds of letters in the alphabet. RNA has an alphabet of four letters. If you think of the link molecules like the letters in the alphabet can you see RNA's potential for carrying information? Coded information contained in molecules like RNA (in particular, DNA) is used as a basis for making other chain-type molecules called proteins. Proteins are powerful molecules that have important functions in living things. So, if Orgel is correct, RNA was the first replicating and information-containing molecule — possessing the two essential properties of life. But there are some roadblocks to this idea.

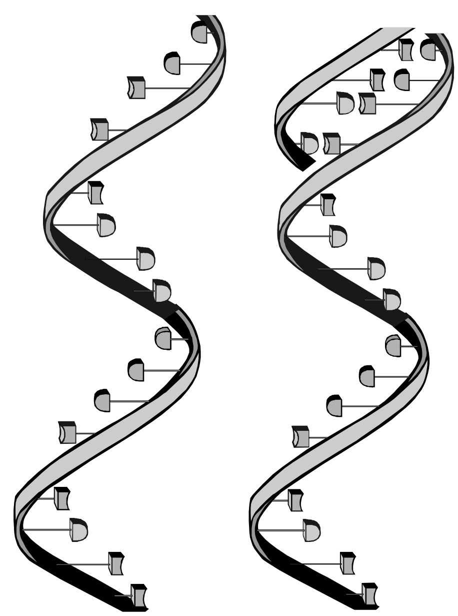


Figure 6.9. A drawing of RNA (left). Unlike DNA, which is a double-stranded molecule, RNA is a single strand. The first step in replicating RNA is to make a mirror image of the original strand, shown on the right.

The RNA idea assumes an Oparin-Haldane atmosphere. As we saw above, it is increasingly doubtful that such an atmosphere ever existed on Earth. Another problem has to do with the sequence of the appearance of RNA and proteins. The synthesis and replication of RNA today happens with the help of proteins (enzymes). But proteins are synthesized using the coded information in the RNA (or DNA). This situation represent a chicken-or-egg problem that may be impossible to overcome.

Orgel and others continue to pursue variations of the RNA theme, drawn by its self-replicating and information-carrying properties. However, whether they are on the right trail or a wild goose chase probably won't be known for many years to come.

6.10 Sydney Fox proposed that cells made out of proteins came first.

The question on the origin of DNA (or RNA) has puzzled scientists for decades. It would make the field so much simpler if DNA (or RNA) actually was the first living molecule. It has all the characteristics that are needed to make a molecule "alive". It has the interesting power to make copies of itself (with the help of proteins). But there is a problem with assuming that DNA was the first self-replicating molecule. This is because DNA, in addition to being absolutely huge, is also an immensely complicated molecule. So, it seems unlikely that the march of life on Earth was dependent upon the random synthesis of the first DNA molecule. The chances of this happening are extremely low. Professor Sydney Fox of the University of Miami believes he has the answer to DNA (or RNA) - protein paradox. He thinks proteins came first (see fig. 6.10 for a drawing of a protein).

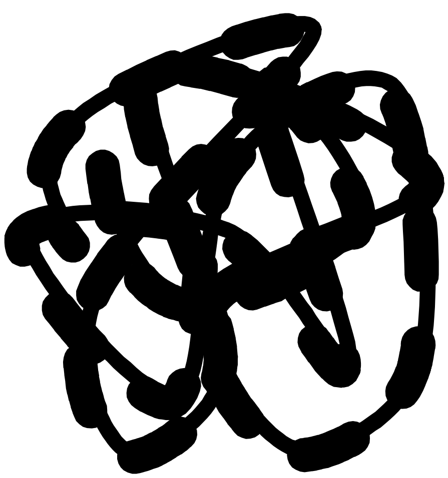


Figure 6.10. A stylized drawing of a protein. Proteins are made from chains of amino acids. The sequence of amino acids in proteins is determined by the sequence of building blocks that make up DNA (the genetic code). Proteins can be very large molecules and take an infinite number of shapes. Their function largely is determined by their shape.

In his world, Fox imagined lagoons filled with tiny bubble-like structures he called microspheres. Each microsphere was composed of a substance called proteinoids. These were molecules that were somewhat similar to proteins but not quite the same. In his model, the proteinoids catalyze chemical reactions and form outer surfaces that act like cell membranes. The chains of amino acids could self-replicate and, therefore, could evolve. In the process, they were able to produce nucleic acids like DNA and RNA. The DNA (or RNA) then began to evolve on its own.

There are many problems with Fox's proposal, and most have to do with the natural chemical properties of amino acids. Attempts to synthesize the proteinoids according to his hypothesis have produced unusual combinations of amino acids that do not resemble conventional protein chains. Attempts to synthesize microspheres proved marginally successful, as they tended to be extremely fragile to subtle changes in their environment. Still, the microspheres did display a form of reproduction, a sort of crystalline budding property. Other interesting lifelike properties were displayed, including the fusing of microspheres and the exchanging of material. Fox claims that this property demonstrates the origin of "protosexuality". Fox called these microspheres "protocells", and proclaimed them to be *the* precursor to DNA-based organisms. Is it? Despite Fox's exhaustive attempts to demonstrate the validity of his hypothesis, many biologists still find it incomplete.

6.11 Graham Cairns-Smith proposed a simpler idea less dependent on the atmosphere

Scottish chemist Graham Cairns-Smith suggested that perhaps the first living things on Earth were not based on carbon, as they are today. Instead, he proposed in the early 1980s that first life might have been a sort of clay crystal formed in the mud (fig. 6.11). That is, a being made out of silicon dioxide crystals. You are familiar with silicon dioxide crystals. Quartz rock is a kind of silicon dioxide crystal. Mica is a mineral of silicon dioxide that is made in volcanic lavas. Mica forms in thin, transparent layers that can be peeled away like flimsy sheets of glass.

Crystals are interesting because they are the result of atoms naturally organizing themselves in very deliberate patterns. For example, common table salt is a crystalline form of sodium chloride. In salt, sodium and chlorine atoms attach to each other in an alternating pattern that leads to a three-dimensional lattice shaped like a cube. Look at an individual salt crystal with a magnifying glass and you will see what I mean.

We know that mineral crystals have the ability to grow by simply adding on to an existing crystal. If a growing crystal breaks apart, the fragments of that crystal can continue to grow on their own. In a sense, this is self-replication, and it is a process that is essential for life.

Certain kinds of clays called kaolinite have the interesting property of growing in thin layers. Cairns-Smith argues that the clay crystals began growing by adding layers to themselves, like adding pages to a book. The growing crystals competed with each other for resources as they grew. Some crystals would break apart, wash downstream and settle in a new area where they would continue their growth and later fragmentation.

In the early Earth proposed by this idea, the world would be populated by communities of competing clay "beings". Eventually, these clay creations would begin to incorporate carbon-based molecules into their living apparatus. One way to do this would be the synthesis of DNA or RNA to augment clay-based genes. In time there would be a transition period where carbon based genetic material (DNA or RNA) would become a suitable alternative to clay-based genes. Then, the move to carbon-based life would be complete. DNA would have been created, and the march of organic life could begin.

I have left out many details to this idea because it is not the purpose of this book to exhaustively treat competing notions on the origin of life. Still, there are elements in the Cairns-Smith model that are manageable by science and should provoke continued investigation. First, it makes no assumptions about the composition of Earth's early atmosphere. This is a major problem with other earth-based life hypotheses. It also is founded on the simplest of crystal properties, that they have the ability to grow and "reproduce", by fragmentation. This property is a true nature of crystals, and can be easily demonstrated. Reproduction is an essential property of life. Many of the basic ideas of this proposal are testable in the laboratory or in the field. However, Cairns-Smith argues that the clay idea provides a preparatory path for the ultimate synthesis of DNA or RNA. But he does not present a complete idea on how DNA came from clay.

The Smith-Cairns idea has not received widespread acceptance in the scientific community. Maybe because it is so offbeat. Accepted or not, it is an interesting piece of work because of its initial simplicity and testability.

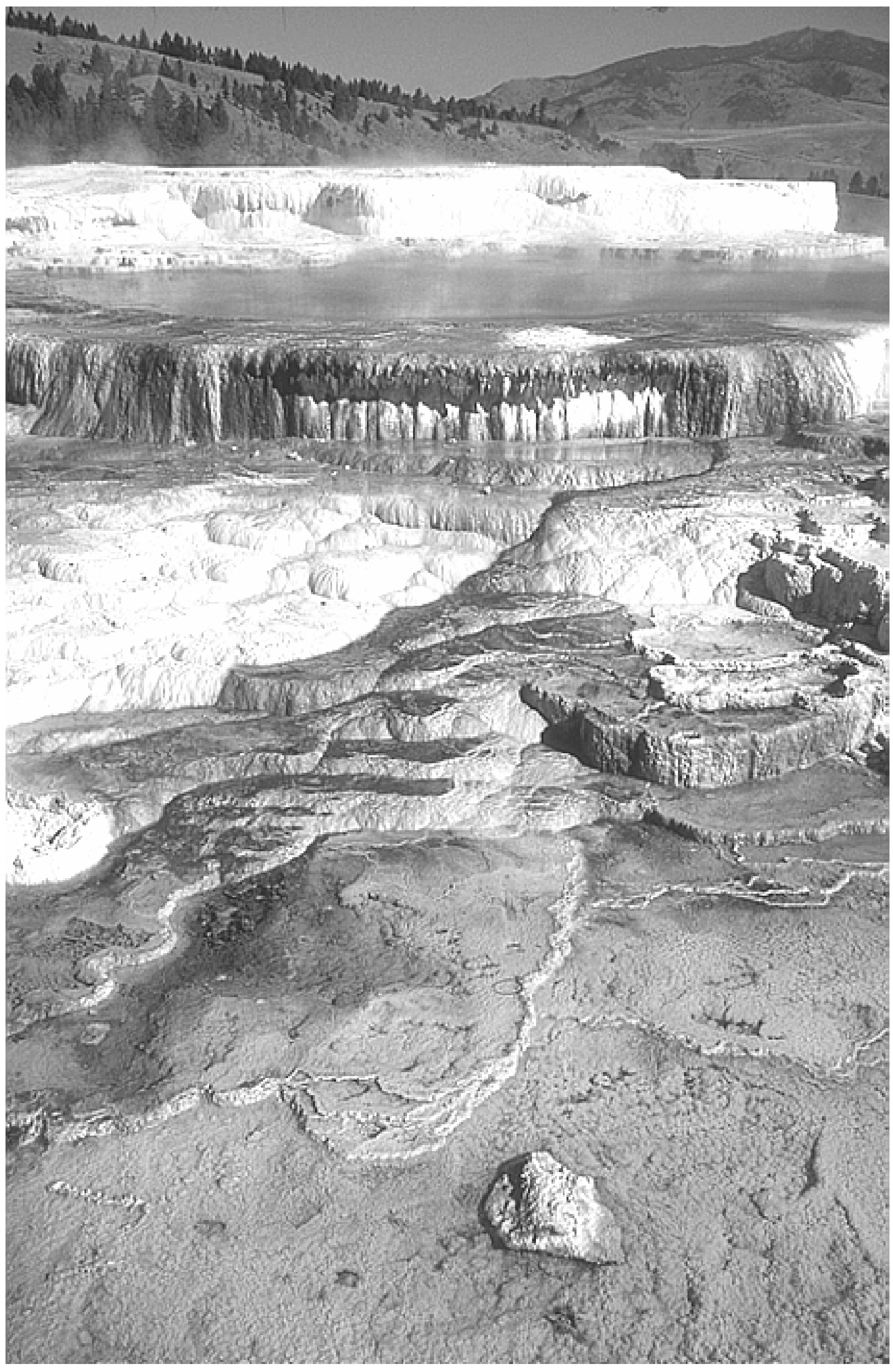
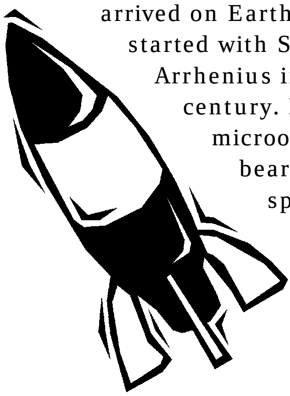


Figure 6.11. Hot springs like this could have given rise to the first self-replicating molecules -- of silicon dioxide.

6.12 Svante Arrhenius suggested that microorganisms were ejected from other life-bearing planets



With the apparent flight of support from the Oparin-Haldane hypothesis, and Miller-Urey experiment, there has been renewed interest in the idea that life arrived on Earth from some distant planet. It started with Swedish chemist Svante Arrhenius in the early part of the 20th century. He proposed that microorganisms were ejected from life-bearing planets and drifted through space. One of them encountered Earth quite by accident and started life here. This idea fails for two main reasons. The odds of a single microorganism happening upon Earth are astronomically low. Also, there is the matter of surviving the journey. Radiation, vaccum and intense cold definitely would present major challenges to biological molecules traveling in space. If unprotected, large biological molecules would be destroyed. But if embedded deep inside a large rock, dormant microorganisms might have a chance. Of course, then there's the problem of surviving the fiery entry through the Earth's atmosphere.

6.13 Crick and Orgel proposed a dramatic idea called "Directed Panspermia"

A variation of the cosmic seed idea was presented by respected biologist Francis Crick and his colleague Leslie Orgel. Crick is the co-discoverer of the structure of DNA. In their idea called "Directed Panspermia", Crick and Orgel proposed that life actually originated first on another planet outside our solar system a long time ago. On this planet, a vast intelligent civilization was confronted with the realization that their sun soon would expand into a Red Giant and reduce their world to a burned out cinder. They failed in attempts to fly to other suitable worlds. The distances were too great and travel time in the thousands of years. So, instead of sending "people" (whatever they were), they decided to distribute the seeds of life itself, namely primitive bacteria. About 3.2 billion years ago, one of the ships from this ancient civilization reached earth and discharged its load of bacteria (fig 6.11). The rest is history.

WOW! Now, *that's* a story! Reminds me of the planet Krypton. Ironically, even Crick himself believes his proposal is farfetched. He states that his purpose in presenting it was not to cultivate believers in this science fiction like drama. Instead, he wanted to recruit greater interest on the problem of life's origins. Why is this idea not a valid hypothesis?

6.14 Hoyle and Wickramasinghe suggested that life originated elsewhere and colonized the comets of the solar system

Sir Fred Hoyle and Chandra Wickramasinghe have postulated a most complex cosmic connection. In the late 1970s, they proposed that life also originated elsewhere and it traveled to our part of the galaxy just as our solar system was forming. The Earth and the rest of the inner solar system was too hot then. So, microorganisms in the form of bacteria, viruses, and bits of genetic material survived in the cooler outer solar system. There, the bits of life became incorporated into comets (fig. 6.13) whose orbits kept them on the outer fringes of the solar system. From time to time a comet would break free and start its descent toward the sun. On its journey, the comet would strike Earth and deposit its long-held load of living material, establishing life on the planet. Then, throughout Earth's history, later comets would deposit different kinds of living material, perhaps changing the course of the evolution of life.

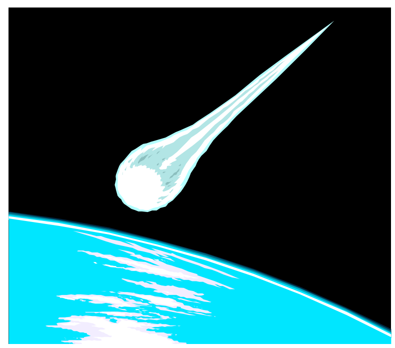


Figure 6.13. A comet striking the Earth at 50,000 miles per hour.

Assessing this story is extremely difficult since it relies on speculative assumptions regarding the presence of organic substances in comets.

Despite their ingenious story lines, all of these cosmic proposals fail to address the ultimate question. How did life begin in the first place? Instead, they avoid the question by assuming that life began elsewhere and was imported to Earth. As a scientist, I think these proposals ar interesting but hard to work with because they are difficult to test.

6.15 We are far away from a solution

It is important to note, as does Robert Shapiro in his book, *Origins, a Skeptics Guide to the Creation of Life on Earth*, that simply possessing some of the pieces to the puzzle does not necessarily lead to life. That is, not all parts of a living thing are created equally. Some parts may be easily fabricated in a thousand different ways. Others may need extremely specialized conditions. I am reminded of a wonderful Gary Larson cartoon where two cows are constructing what looks like a rocket ship out of discarded lumber. What makes this a joke is that we humans know that rockets are enormously more complex than a bunch of boards nailed together. But the cows don't know this, and will be disappointed when, although their construct looks like a rocket to them, it won't fly.

For example, it may be possible to synthesize amino acids in a hundred different ways. Stanley Miller just happened to discover one of the ways. Which particular amino acid fabrication technique led to life may not be important. Stumbling on one of many fabrication techniques for such simple compounds does not necessarily lead down the path of life's origin. Instead, it may lead to a dull dead end. The same is true for clay replicators and protocells. These may be almost unavoidable results that might be obtained in a thousand different ways. Does the formation of a proteinoid sphere automatically point to life? It doesn't have to. Maybe it does. Maybe not.

Some ideas claim they lead toward the development of the master replicator, DNA, almost as an inevitable outcome of simple beginnings. We have to be careful here. Asking conservative scientific thinkers to make the leap from simple amino acid to complex life armed only with incomplete mechanisms and speculations is risky. Nonetheless, scientist and lay person alike *do* make this leap, in spite of the enormous gaps in origin ideas. Maybe this is to be expected. Like all humans, we seek order in our universe, and not knowing about the origin of life and ourselves is unsettling. Many find solace by adopting one of the numerous explanations offered by religious philosophies. For science, there remains healthy doubt regarding ideas on the origin of life.

So, where does all this leave us? We have a long, long way to go. I believe that none of the ideas on the development of life on Earth is much more than a potential starting point. And there may be hundreds of potential starting points. It is possible that all of these could ultimately lead to life. Or, only one of them will. How can we ever know? The only way to feel really confident in such an idea is to actually demonstrate the synthesis of DNA starting from the humble beginnings of early Earth. But even if this is done, there is no way to tell if this was same way that DNA was originally made on Earth. There may be a multitude of routes for reaching DNA. A very frustrating field of inquiry.

6.16 Still, humans are incurably curious

One final note on this issue. The continuing uncertainty enveloping the question of life's origin is a natural consequence of the scientific mind seeking answers to difficult questions. Despite the overwhelming magnitude of this problem, scientists seem willing to work at it. In the words of physicist, Richard Feynman, "Confusion is a terrible thing." Science provides an opportunity for skeptical people to eliminate confusion in their lives. If we discover the one true origin theory, it will undoubtedly be one of the greatest accomplishments of humankind. But even if we don't find it, the search will be nothing less than a celebration of the human mind's unending desire for understanding. And this alone is reason enough to continue.

17.17 Life and biosynthesis

Anyways, life did get started on Earth a long time ago. And it has become very sophisticated in the way it chemically exploits the planet. Today, the chemistry of life powerfully churns the planet and leaves its remarkable impression on the planetary surface environment. But what is the nature of life's planet-changing chemistry? What kinds of materials is life moving back and forth? And to what end? I address these questions in the next chapter.

Panel 6.1 The route of the problem

Trying to determine how life began on Earth is like trying to explain how a football stadium came to be filled with people.

Suppose you investigate the crowd and determine that one of the football fans came to the game from City A. Does this mean that all the fans came from City A? The problem is that there are dozens of cities near the stadium. The fans in the stadium could have trickled in from all of them. There is no logical way to determine from which city each person came.

But the problem gets even more complicated. Suppose you identify all the fans who came from City A. What route did they take? There could be dozens of routes. One person could have taken the most direct route. Another could have gotten there in a roundabout way. For example, she could have stopped off to pick up a friend. Then they could have stopped to get some gas and beef jerky. Then they might have taken a less direct route in order to avoid traffic.

Like the fans filling up a football stadium, life could have started from many different potential starting points. And there are dozens of different routes that life could have taken from each potential origin point.