

# A Curious Mission: An Analysis of Martian Molecules

by

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## Part I – Biochemical Analysis of Atmospheric Sample

April 27, 2032

Johnson Space Center  
Houston, TX

5:53am

In the parking lot at Johnson Space Center, the morning dew is just beginning to evaporate into a misty haze that envelops you as you step out of your car. The campus is quiet, except for the baying of the longhorn cows in the pasture nearby.

You make your way to Building C, say hello to the security guards who are nearing the end of their shift, and walk through the double glass doors into the research wing. Once through the doors, the quiet disappears. The hallways are abuzz with energy and chatter about what the day will hold. In a few minutes, a very special delivery will be made and the most important work of your life will begin. This is the day you have been waiting for since elementary school.

You head into the clean room entry area, put on your sterile white suit, shoe covers, and gloves, and step through the revolving door into the clean room. Sheila and Marcus are already inside, getting the gas chromatograph ready and speculating about what they will find. You double-check that all of the equipment you will need is set out and ready for use, then pull your laboratory notebook from the shelf. Turning to a new page, you write a title across the top of the blank sheet: *Sample Analysis—Materials Returned to Earth by Mars Curiosity Mission 5.*

6:21am

The revolving door spins open and Alexa bursts into the room holding a clear glass cylinder. “It’s here!” she exclaims. “Are you guys ready?” The cylinder appears to be empty, but in fact it holds a precious sample of the Martian atmosphere, collected by the Mars Curiosity 5 rover from an area within the Gale Crater. You and your team have been given the task of analyzing the molecular makeup of the air inside the cylinder using GC-MS (gas chromatography-mass spectrometry). Gas chromatography will allow you to separate the compounds in the sample, and mass spectrometry will detect the molecular weight of each individual molecule. You inject some of the gas sample into the GC-MS instrument and wait anxiously for the results.



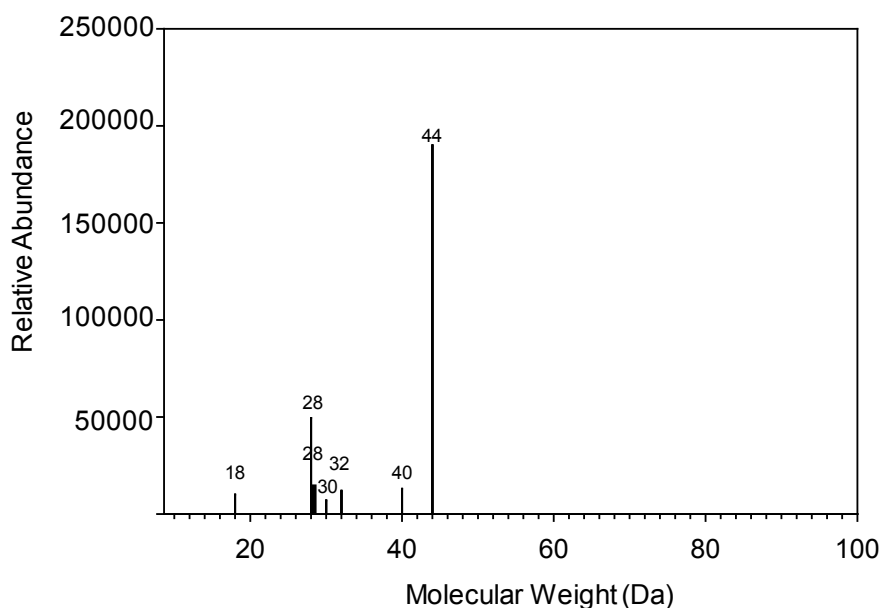


Figure 1: Results from the gas chromatography-mass spectrometry analysis of the Gale Crater atmospheric sample. (Note that there are two peaks at 28 Da. How do you interpret those seemingly redundant data?)

### Data Analysis of Atmospheric Sample

*Assignment 1:* Refer to the background reading you have been given about the conditions of Mars. Use that information to identify the atoms or molecules that correspond to the seven peaks identified in Figure 1. List each of the molecules and give their chemical formula and molecular weight.

Atom/Molecule	Chemical Formula	Molecular Weight

*Assignment 2:* Draw the molecular structure of each of the molecules you identified in the sample of Martian atmosphere. To do this, you will need to determine the number of valence electrons for each atom to decide if the bonds between atoms will be single, double, or triple bonds. In your drawings, you must also show any lone pair electrons not participating in the bonds. Use your knowledge of electronegativity to determine whether the bonds that will be formed between the atoms of each molecule are polar or nonpolar, and write the polarity beneath each molecule. Indicate any partial charges as appropriate.

Atom/Molecule	Drawing of Molecular Structure

Atom/Molecule	Drawing of Molecular Structure

### *Making Predictions about the Atmospheric Sample*

*Assignment 3:* Based on the atomic content of the molecules you identified in the Mars atmospheric sample, predict whether the following molecules that exist on Earth could be produced. List the molecules in the Martian atmosphere that contain the necessary atoms to build them, or if you predict that they could not be constructed, list the atoms that are missing from what you found in the atmospheric molecules.

a. *DNA:*

b. *Glucose:*

c. *Valine (amino acid):*

d. *Cysteine (amino acid):*

e. *Fatty acid:*

f. *Phospholipid:*

*Assignment 4:* Look at the list of molecules that are present in the Martian atmosphere. Compare this list with the predicted components that were present in the atmosphere of ancient Earth.

*Martian atmosphere:*

*Ancient Earth atmosphere:*

*Assignment 5:* Based on your predictions about which of the molecules that exist on Earth could be produced from the atmospheric contents of Mars, do you think that life on Mars could exist? If so, which of the Mars atmospheric molecules or conditions would be important for creating the necessary molecules for life? If not, what additional molecules or conditions would be required to make life possible? Explain your reasoning.

## Part II – Geological Analysis of the Gale Crater

April 27, 2032  
Johnson Space Center  
Houston, TX

1:03pm

After lunch, you suit up and head back into the clean room to find a new package awaiting you on the lab bench. You open the wooden crate to find a glass box filled with soil and rocks collected from within the Gale Crater. Using atomic absorption spectroscopy, you will be able to identify the major elements within the sample.

3:17pm

Marcus emerges from the analysis room and shouts, “The results from the chemical analysis are in!” Examining the data sheet, you can see that the geological sample contains several new elements that were not present in the atmospheric sample:

Element	Atomic Mass (Da)	Percent Abundance
Si	28.085	20.9
Fe	55.845	12.7
S	32.06	3.1
P	30.974	<0.25

### Experimental Design – Could Life Exist on Mars?

*Assignment 6:* Now you have a complete list of the atoms and molecules present on Mars, both in the atmosphere and in the soil. Use your knowledge of the conditions of ancient Earth and the atomic components of the essential molecules of life on Earth to predict whether life could exist on Mars. Explain your reasoning thoroughly.

*Assignment 7:* In your groups, write an outline that describes an experiment to determine if life could exist on Mars. Refer to Miller’s Spark-Discharge experiment as well as the discussion of the RNA world in your textbook for ideas. During the next class session, we will discuss your ideas as a group.



*Image Credits:* The title block image, “Daybreak at Gale Crater,” is a computer-generated view of part of Mars that includes Gale Crater beginning to catch morning light. NASA/JPL-Caltech, from [http://www.nasa.gov/mission\\_pages/msl/multimedia/gallery/pia14293.html](http://www.nasa.gov/mission_pages/msl/multimedia/gallery/pia14293.html). Photo of Microsystems Fabrication Laboratory at NASA Glenn (on page 1) by Marvin Smith (WYLE), from [http://www.nasa.gov/centers/glenn/multimedia/imagegallery/if035\\_clean\\_room2.html#.UtX2DbRLkmY](http://www.nasa.gov/centers/glenn/multimedia/imagegallery/if035_clean_room2.html#.UtX2DbRLkmY).

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# CASE TEACHING NOTES

for

## “A Curious Mission: An Analysis of Martian Molecules”

by

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### INTRODUCTION / BACKGROUND

In this case study, students play the role of a NASA scientist who has been given the task of analyzing samples of atmosphere and soil collected on Mars as part of the Mars Curiosity Mission. The case study takes place in the future when samples of the Martian atmosphere and surface have been returned to Earth as part of the fictional Curiosity Mission 5. This setting provides an opportunity for a discussion of many facets of this possible future, ranging from the current need for STEM researchers to support NASA's aspiration to send humans to Mars and return them safely in approximately the next 25 years, to the demands (e.g., physiological, psychological, etc.) of such a mission. The goal for students is to identify which elements and molecules are present in the samples and to use this information to determine which macromolecules could be created. Finally, students make a prediction about whether life (as we know it or otherwise) could exist on Mars, and discuss possible experimental designs to test their ideas.

This case was developed for an introductory level general biology course. It could also be appropriate as an early review activity in a biochemistry course. The case was delivered during the first three weeks of the course, within the units on the scientific method, defining life, chemical bonding, and macromolecules. Students need to have background knowledge on the scientific method, conditions on early Earth and on Mars, atomic bonding, basic molecular structure, principles of chemical reactivity, and components of macromolecules. In our implementation of the case, we had already devoted considerable time and effort to helping the students understand atomic structure (e.g., mass number) and the concept of electronegativity. Therefore, our students were well-prepared for the tasks that we asked them to perform in Assignments 1 and 2. We recommend that those topics be taught or reviewed prior to beginning this

case study. Some of this information was provided as part of the regular course content. Specific information on the soils and atmospheres of Mars and Earth is included in a handout (included at the very end of these Teaching Notes), which is distributed during the first week of the semester. Students are asked to read this handout prior to the beginning of the case study.

### Objectives

Upon completion of this case, students should be able to:

- Calculate the molecular weight of an atom.
- Construct molecular diagrams using structural formulas.
- Determine the type of bond formed between two atoms based on their valence and relative electronegativities.
- Recall the atomic content of the major macromolecule types.
- Design an experiment.
- Analyze and extract data from a scientific figure.

### CLASSROOM MANAGEMENT

In advance of the case, students were given a handout with background information about conditions on Mars and early Earth. This handout is included at the very end of these teaching notes. Students were instructed to read the handout before coming to class and also to bring it with them to use as a reference source during the case. Following the units on atomic bonding, molecular structure, electronegativity and bond polarity, which were taught during the first two weeks, students were given Part I of the case study as a handout in class to work on together in small groups in order to complete Assignments 1 and 2. This part of the case required approximately 20 minutes. We then spent another two weeks discussing the major macromolecule types, after which we gave students an entire class period to complete Assignments 3 through 6, again in small groups.

Assignment 7 was not implemented in our course but is included here in this version of the case study as

a possible follow-up exercise. This assignment requires that students write an outline describing an experiment that they propose to explore the possibility of life on Mars. Assignment 7 thus provides an excellent capstone to the case study, as it incorporates all of the concepts that are covered in the case study and asks that students integrate them to form conceptual models of what it means to be alive and what data would be necessary in order to define that a particular specimen is alive or may have been alive in the past. In our experience, at this point in the case study, students are sufficiently knowledgeable and enthusiastic to engage one another in discussion and critique of their respective ideas.

## BLOCKS OF ANALYSIS

### *Biochemistry*

The major concepts that are required to perform the assignments of this case study span many fundamental topics in biochemistry. In Part I, students need to be able to calculate the molecular weight of a molecule, determine the valence of an atom in order to predict bond structures, diagram simple molecules using their structural formulas (a.k.a. bond-line structures), understand how electronegativity results in partial charges on atoms and influences the polarity or non-polarity of covalent bonds, and recall the chemical makeup of the four major types of macromolecules (proteins, carbohydrates, lipids, and nucleic acids) to compare the atomic content of different molecules.

The biggest challenge that students face in Part I is to apply their understanding of electronegativity to predict what type of bond will form between two atoms. Electrons shared between two identical atoms or between two atoms with very similar electronegativities form a nonpolar covalent bond. In contrast, atoms shared between two atoms with very different electronegativities form a polar covalent bond. Students also need to determine the bond order (whether a single, double, or triple bond will be formed), based on the number of electrons in the valence shell of each atom, and whether any lone pair electrons will be present in the molecule. To achieve this, students must be able to determine the valence of each atom in a molecule and apply the rules of electron configuration.

### *Conditions on Early and Modern Earth*

For this case study, students will need to have information about the atmospheric content of Mars and Earth. This information is contained, as explained above, in a

handout that is given to the students before beginning the case study (see the very end of these teaching notes for this handout). The information is also summarized below:

The early Earth was hot. That history is evident in the core and deep mantle of modern Earth, which are still very hot today. Ancient Earth eventually cooled as heat dissipated into space, and water formed on the surface. It is thought that the ancient atmosphere had very little oxygen and was dominated by gases found in volcanic emissions today. Specifically, the ancient Earth atmosphere is thought to have been rich in carbon dioxide ( $\text{CO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ), carbon monoxide ( $\text{CO}$ ), hydrogen sulfide ( $\text{H}_2\text{S}$ ), hydrochloric acid ( $\text{HCl}$ ), nitrogen ( $\text{N}_2$ ), ammonia ( $\text{NH}_3$ ), methane ( $\text{CH}_4$ ), and water vapor ( $\text{H}_2\text{O}$ ). The absence of oxygen in that list provides an excellent teaching opportunity as the presence of oxygen in our modern atmosphere is common knowledge, and its absence typically piques students' curiosity. That opportunity can be used to introduce the idea of anaerobic life, meaning that it flourishes in the absence of oxygen, and to emphasize that the abundance of anaerobic life on ancient Earth (approximately 2,700–2,400 million years ago, abbreviated MYA) was quite different than what we have today. In contrast to those conditions, the atmosphere of modern Earth is mostly nitrogen and oxygen. This is detailed in the following list assembled from data collected by probes that began with the Viking probes as they passed by Mars in the 1970's and as of September 2013 have now passed out of our solar system.

#### *Atmospheric contents of modern Earth:*

Nitrogen	78.1%
Oxygen	20.9%
Argon	0.93%
Carbon dioxide	0.04%
Neon, Helium, Methane, Krypton, Hydrogen, $\text{N}_2\text{O}$ , $\text{CO}$ , Xenon, Ozone, $\text{NO}_2$ , Iodine, Ammonia each	< 0.01%

Water vapor typically 1–4% at sea level

Several factors contribute to the comfortable conditions of our "Spaceship Earth." First, Earth has a relatively smooth surface, making for an abundance of area that is useful and easily traversed to build structures, farm land, etc. There are some high mountains and some deep ocean basins, but the surface is still very smooth on



average. Second, the temperature on Earth is especially conducive to life: the average global temperature (approximately 49° F averaging over summer and winter) is one at which water is in its liquid form. Therefore, there is an abundance of water available on Earth, and liquid water and its properties are of fundamental importance in the biochemical processes that support life as we know it.

## CONDITIONS ON MARS

In contrast to our relatively luxurious accommodations here on Earth, Mars would be a much harsher environment. The surface is very dry, and liquid water is essentially absent, although ice has been found at the poles and just below the surface. In addition, temperatures are very cold (spacecraft that have landed have measured highs of 1° F and lows of -161° F), and there is large daily variation in temperature at some sites away from the poles (as much as 200° F). Many of the gases in the Martian atmosphere are the same as those on Earth, but their relative abundance is very different on Mars:

### *Atmospheric contents of modern Mars:*

Carbon dioxide	95.3%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon monoxide	0.07%
Nitric oxide	0.01%
Water vapor typically	0.03%

The differences between the atmosphere of modern Earth and modern Mars provide an opportunity to engage students in a conversation about whether life could exist on Mars. Initially, students tend to answer no, but instructors can ask students to consider that life can withstand incredibly harsh conditions, such as spores that can survive the conditions of outer space. The discussion can be extended even further to reconsider the atmospheric content of Ancient Earth and to introduce concepts that will be essential in later portions of the course, such as evolution and adaptation.

## ANSWER KEY

Answers to the questions posed in the case study are provided in a separate answer key to the case. Those answers are password-protected. To access the answers for this case, go to **the key**. You will be prompted for a

username and password. If you have not yet registered with us, you can see whether you are eligible for an account by reviewing our **password policy and then apply online** or write to **answerkey@sciencecases.org**.

## POSTSCRIPT: MARS CURIOSITY MISSION

Though not required to understand the case study, students may be interested to learn about the Mars Science Laboratory and the Mars Curiosity Mission. To learn about past, present and future missions to explore the possibility of life on Mars and elsewhere and to find up-to-date photos and an abundance of information regarding the Mars Science Laboratory and the Mars Curiosity Mission, we direct the students to the following page on the NASA website: [http://www.nasa.gov/mision\\_pages/msl/index.html](http://www.nasa.gov/mision_pages/msl/index.html).

## REFERENCES

*Note:* In addition to the following references, we also instruct the students to consult us, our class textbook, and additional other textbooks.

- Clarke, J.T., et al. (2011) Establishing a time-scale for plant evolution. *New Phytologist* 192 (1): 266–301
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# COMPARING ANCIENT EARTH TO MODERN MARS

## Introduction

This handout is intended to provide you with information that will assist you in developing and critiquing hypotheses about how life may have developed on Earth. We will accomplish that goal through a case study designed to lead you through an investigation of the possibility of life on Mars. By exploring our understanding of what it means to be alive, a necessary step to being able to try to recognize life on Mars, we will develop an understanding of the basic properties of life on Earth.

## What Are the Properties of Modern Earth?

Earth is a very comfortable place to live. Sometimes called “Spaceship Earth” because it provides us a home as we hurtle through space, the properties of Earth are very well-suited to support life as we know it. Other planets would be too cold, others would be too hot, but the temperature of Earth is conducive to water being in its liquid state. For reasons that we will discuss in class, water is thought to be fundamental to the processes of life.

When we say that Earth is well-suited for life, we could just as easily say that life is well-suited for the properties of Earth, as life has evolved to flourish in a huge variety of ecosystems all over our planet. In that light, let’s look at the properties of planet Earth. Specifically, let’s look at the composition of our atmosphere and the properties of the surface.

### Atmospheric contents of modern Earth

Our atmosphere contains many components:

Nitrogen	78.1%
Oxygen	20.9%
Argon	0.93%
CO <sub>2</sub>	0.04%

Neon, Helium, Methane, Krypton, Hydrogen, N<sub>2</sub>O, CO, Xenon, Ozone, NO<sub>2</sub>, Iodine, Ammonia each < 0.01%

Water vapor typically 1–4% at sea level

Density of air is approx. 1.2 g/L at sea level

Atmospheric pressure is approximately 101.3 kiloPascals (kPa) = 14.7 pounds per square inch (psi) = 760 torr = 29.92 inches of mercury (Hg) at sea level.

As you can see, the atmosphere of Earth is mostly nitrogen and oxygen. That content is preserved as we ascend to higher altitudes, such as living at 7,220 feet in Laramie, Wyoming, for example, but the pressure gets progressively lower as we get progressively higher. That change in pressure occurs because there is less atmosphere pressing down from above when we are at higher altitudes.

### Earth’s surface

The surface of the Earth is also relatively comfortable. It is a relatively smooth surface, making for an abundance of useful living surfaces (e.g., building structures, farming land, etc.) and easy mobility. There are some high mountains and some deep ocean depths, but the surface is still very smooth on average. To get an idea of how smooth it is, let’s consider Earth on the scale of a billiard ball. The Earth is more than 12,000 km in diameter. The top of Mt. Everest is less than 10 km above sea level, and the deepest ocean trenches are approximately 11 km below sea level. Therefore, the extremes of Earth’s highs and lows are on the order of 1 part in 1000, and such extremes are very rare. On a billiard ball (2.25 inch diameter), the equivalent of Everest would be 2/1000th of an inch. When considered at that scale, it is somewhat astonishing that most parts of Earth are a lot smoother than a billiard ball!



Figure 1. Earth as seen from space. NASA/Visible Earth (<http://visibleearth.nasa.gov/view.php?id=57723>).

### *Temperature conditions on Earth*

The temperature on Earth is especially conducive to life, as the average global temperature (approximately 49°F averaging over summer and winter, Figure 2) is one at which water is in its liquid form (that is, not ice or water vapor). Therefore, there is an abundance of water available on Earth, and as we will discuss in class, liquid water and its properties are of fundamental importance in the biochemical processes that support life.

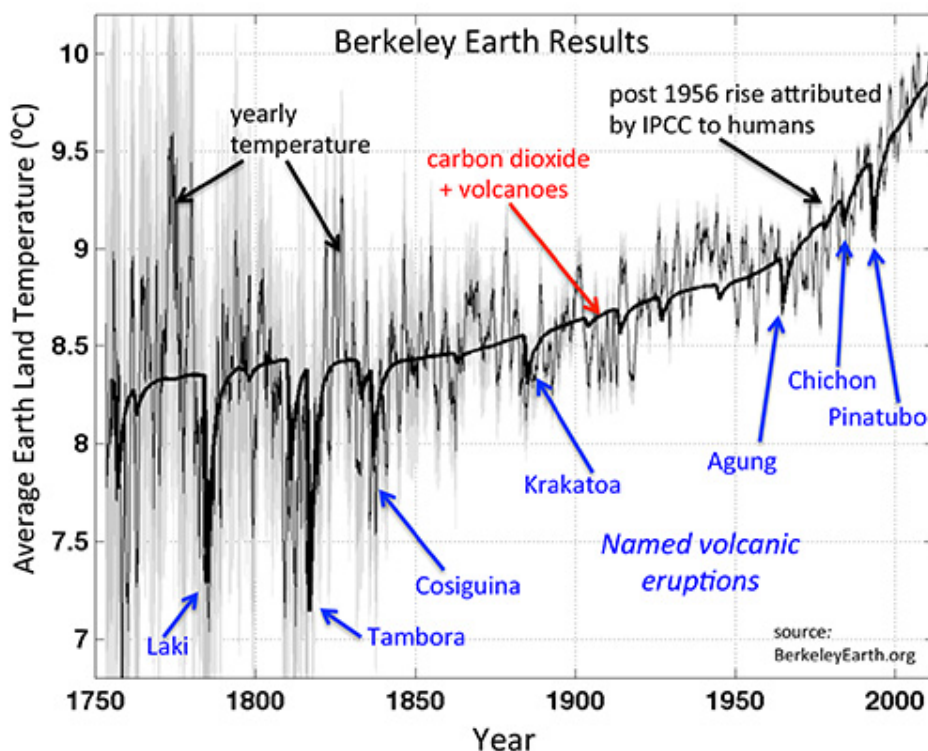


Figure 2. Average temperature on Earth collected from approximately 36,000 temperature monitoring sites worldwide. Image courtesy of NASA data summarized by BerkeleyEarth.org (<http://berkeleyearth.org/volcanoes>).

From our everyday experience, we are certain that life can flourish with that composition of atmospheric gases and that ambient temperature. The atmospheric conditions of modern Earth are easy to measure—we can collect data simply by walking outside. In this portion of our class, however, we are seeking to understand the environment in which life developed. What was Earth like when life is thought to have developed? Investigating ancient climate conditions can be challenging. To answer the question of what Earth was like long ago, we will have to investigate things that were also here long ago. To measure the properties of ancient materials, we must first find those materials, and for that we turn to the field of geology.

### *When Do Geologists Think Earth Formed?*

The prevailing model of the history and future of the universe is the “Big Bang” model in which the universe is thought to have begun rapidly expanding from an extremely high-density of energy. The following dates describe astronomers’ and geologists’ best estimates of the time since important events in Earth’s history.

#### ***Ancient history of Earth:***

- |            |   |
|------------|---|
| 13,700 MYA | Estimated time of the Big Bang (MYA = millions of years ago).   |
| 4,500 MYA  | Coalescence of materials that formed Earth. This estimate has been developed from radioactive dating, a processes commonly used to estimate the age of ancient materials. The details of that |

process and others used to estimate the age of certain items are beyond the goals of this class, but an abundance of reference materials are available if you would like to learn more.

- 3,800 MYA Surface of Earth had cooled. Water was present on the surface, as evident in the formation of the oldest water-related sediments.
- 3,500 MYA The earliest forms of life are thought to have emerged. Although there is debate about this date, there is general agreement that life had emerged by 2,700 MYA. “Life” is defined as the ability to take materials from the environment to meet the needs required to grow and reproduce. One idea is that simple cells may have emerged approximately 3,500 MYA, and photosynthetic organisms (stromatolites) may have emerged approximately 3,400–2,700 MYA.
- No one knows where or how life first emerged, but speculations focus primarily on warm watery environments, such as warm ponds or deep-sea hydrothermal vents. Scientists are currently studying simple structures called stromatolites and single-celled organisms called Archaea in hopes that they may provide insight into early forms of life on Earth.
- The fact that this is thought to have occurred in ponds or oceans underscores the importance of water in the processes of life. That is also the rationale for why NASA chose the Gale Crater as the landing spot for the Curiosity Rover: it is thought to be the site of sedimentary deposits from an ancient river flowing into a larger body of water. When searching for evidence of life, NASA follows the simple philosophy of “follow the water.”

***Relative newcomers to the party – Plants:***

- 450–650 MYA First land plants emerged.
- 150 MYA Flowering plants emerged.
- 55–60 MYA Grasses emerged. Interestingly, the extinction event that killed off the dinosaurs occurred 65 MYA. Therefore dinosaurs were extinct prior to the earliest records of grasses. So dinosaurs did not eat grass!

***Relative newcomers to the party – Animals:***

- 570 MYA Arthropods (invertebrates) emerged.
- 500 MYA Fish emerged.
- 400 MYA Insects emerged.
- 360 MYA Amphibians emerged.
- 300 MYA Reptiles emerged.
- 200 MYA Mammals emerged.
- 150 MYA Birds emerged.
- 2.5 MYA The genus *Homo* emerges.
- 0.25 MYA Earliest records of *Homo sapiens*. Our species has been around for only about 0.005% of the age of the Earth.

Although we as a species developed extremely recently in the life history of Earth, life is thought to have been present on Earth for approximately 3.5 billion years.

Next we’ll investigate what Earth’s atmosphere was like at the time that life is thought to have developed.

## What Were the Properties of Earth's Atmosphere When Life is Thought to Have Developed?

The early Earth was hot. That history is evident in the core and deep mantle of modern Earth, which are still very hot today (Figure 3). Ancient Earth eventually cooled as heat dissipated into space, and water formed on the surface. At that time, the atmosphere is thought to have been rather different than it is today. Specifically, it is thought that the ancient atmosphere had very little oxygen and was dominated by gases found in volcanic emissions today. Specifically, the ancient Earth atmosphere is thought to have been rich in carbon dioxide ( $\text{CO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ), carbon monoxide ( $\text{CO}$ ), hydrogen sulfide ( $\text{H}_2\text{S}$ ), hydrochloric acid ( $\text{HCl}$ ), nitrogen ( $\text{N}_2$ ), ammonia ( $\text{NH}_3$ ), methane ( $\text{CH}_4$ ), and water vapor ( $\text{H}_2\text{O}$ ). Note the absence of oxygen ( $\text{O}$ ) in that list.

The conditions on Earth changed dramatically with the emergence of photosynthetic organisms. As we will study in detail later in the class, photosynthesis is a process through which energy in sunlight is harnessed to produce carbohydrates. In addition to making sugars, another important result of that process is the release of oxygen. Because the development of the ability to use abundantly-available sunlight to make energy provided such a huge advantage to photosynthetic organisms (thought to have been bacteria and Archaea), those organisms rapidly became very common. That resulted in one of the most profound environmental changes in the history of our planet. Suddenly (at least on the time scales we are discussing), the atmosphere became rich in oxygen. More information can be found by researching the “Great Oxidation Event,” which is thought to have occurred approximately 2,400 MYA.

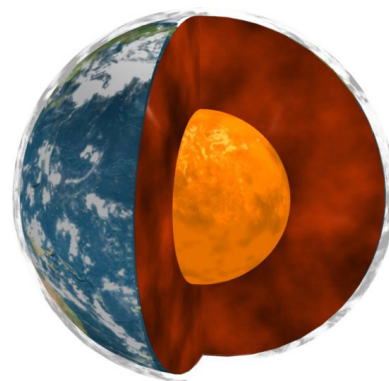
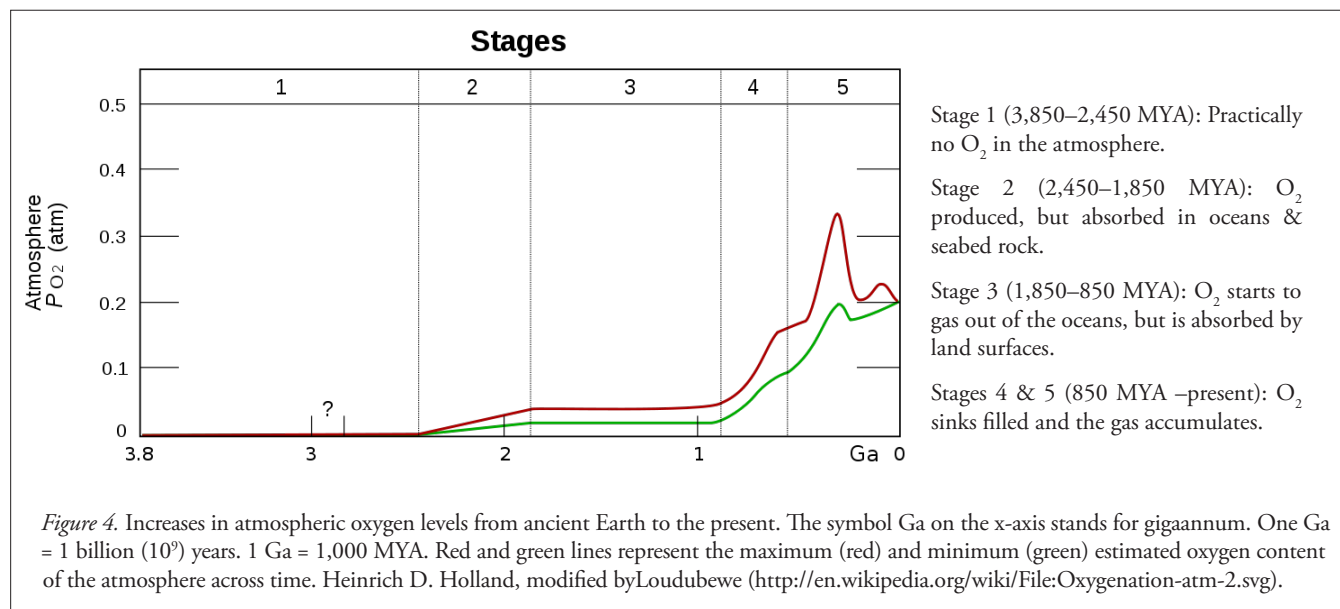


Figure 3. Earth's deep structure (core and mantle). NASA (<http://www.nasa.gov/topics/earth/features/earth20110309.html>).



On ancient Earth (approximately 2,700–2,400 MYA), much of the life was anaerobic, meaning that it flourished in the absence of oxygen. With the development of photosynthesis, oxygen became common. In the presence of oxygen, anaerobic organisms can have negative reactions and can easily die. Therefore, the emergence of photosynthesis, which is so important in so many forms of life on modern Earth, led to what is thought to be the largest extinction event in Earth's history. Not all anaerobic organisms perished, as some are still present on modern Earth (e.g., anaerobic bacteria in the soil, water, and bodies of humans and other animals), but the emergence of abundant oxygen changed the planet, and oxygen has been abundant in the atmosphere ever since.



### *Can We Test the Idea that the Conditions of Ancient Earth Were Conducive to the Emergence of Life?*

It remains a mystery how life emerged, but experiments have been able to show that early-Earth conditions are conducive to the formation of the complex molecules that are the building blocks of life. In 1953, two graduate students named Stanley Miller and Harold Urey filled a beaker with methane, ammonia, hydrogen, and water, and then they sealed the beaker to create a micro-environment (Figure 5). Do those gases sound familiar? At the time of the experiment, those gases were thought to be the contents of the ancient Earth atmosphere. The scientists were testing the idea that the conditions of ancient Earth favored chemical reactions that resulted in the formation of organic compounds (carbon-containing compounds, many of which are fundamental to life as we know it) from simpler components. To simulate the heat and energy of the early Earth, they added a heater outside the beaker to warm the system and a spark inside the beaker to simulate the lightning storms that are thought to have been common on the early Earth. After letting the sealed beaker persist in that state for some time, they examined the contents. With time and energy, some of the simple contents of the beaker had formed new bonds to become amino acids, organic compounds that are the building blocks of proteins!

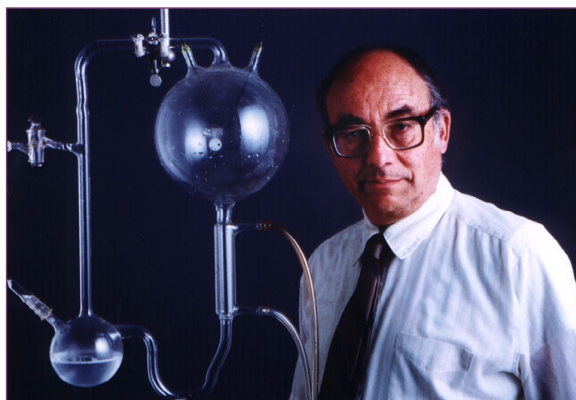


Figure 5. Stanley Miller and his experimental apparatus. NASA (<http://commons.wikimedia.org/wiki/File:SLMILLER.JPG>).

Although this experiment does not directly address the origins of life, it does reveal that the building blocks of life can emerge in an atmosphere like that of early Earth. Now that we know that those building blocks can emerge from the atmospheric conditions that existed on early Earth, let's turn our attention back to Mars. As we consider whether Mars may have been habitable at some point (or perhaps even is still home to living organisms), let's consider what we know about Martian atmospheric conditions.

### *What Are the Properties of Modern Mars?*

In contrast to our luxurious accommodations here on Earth, Mars would be a much harsher environment (Figure 6).

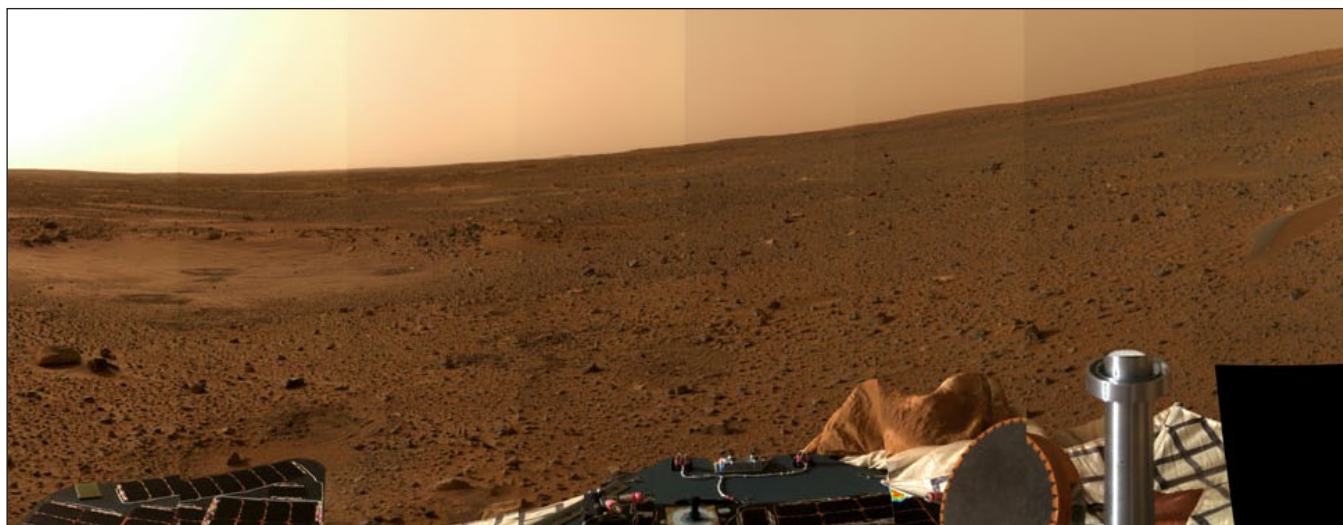


Figure 6. View of the surface of Mars as taken by the Spirit Rover. NASA/JPL/Cornell (<http://marsrover.nasa.gov/gallery/press/spirit/20040108a.html>).

Spacecraft that have flown by, orbited, or landed on Mars (e.g., the Viking probes beginning in the 1970s) have reported many measurements of its atmosphere and the harshness of its climate. Although some Martian features are reminiscent of those on Earth (e.g., mountain ranges, polar ice caps, winds, very wispy clouds, seasonal variation in temperature, dust storms, etc.), other features are very different than those of Earth. For example, many of the gases in the Martian atmosphere are the same as those on Earth, but their relative abundance is very different on Mars.

*Atmospheric contents, surface conditions, and temperature of modern Mars*

Carbon dioxide	95.3%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon monoxide	0.07%
Nitric oxide	0.01%

Water vapor on Mars is typically 0.03%. Therefore the surface is very dry, although ice has been found at the poles and just below the surface. In addition, temperatures are very cold (spacecraft that have landed have measured highs of 1°F and lows of −161°F), and there are giant daily changes in temperature at some sites away from the poles (as much as 200°F). Furthermore, the atmosphere is very thin and consequently there is very low atmospheric pressure on Mars, approximately 0.03% that of Earth (0.0044 psi on Mars vs. 14.69 psi on Earth). Finally, there are also giant Martian dust storms that can affect almost the entire planet at once (winds commonly approx. 40 mph with gusts to approx. 60 mph). In short, modern Mars is a harsh climate by our Earthly standards. However, just because the Martian climate is different than the climate on Earth, it does not mean that life cannot survive on Mars. Life has been shown to survive very harsh conditions, even those of outer space. Therefore, it remains an open question whether Mars is or ever was habitable.

*If We Found Life on Mars, How Would We Recognize It?*

One idea is that it might look something like the life we recognize here. For example, life on Mars could also be carbon-based. As we will explore in this class, carbon affords the most variable combinations of bonded atoms while also filling the least amount of space. Therefore, carbon is an ideal basis for assembling the complex organic (carbon-containing) compounds that are the building blocks of life on Earth (e.g., proteins). Given that the properties of individual elements are conserved throughout the universe as we have explored it thus far (i.e., carbon in Earth has the same properties as carbon on Mars), it may be the case that carbon will be fundamental to complex molecules—and therefore to life—in other forms of life elsewhere in the universe. In further support of that idea, evidence from space suggests that molecules that are the building blocks of life found here are also present elsewhere in the universe. Specifically, a meteorite fell to Earth over Murchison, Australia, on September 28, 1969. Over 200 pounds of the meteorite were recovered for study, and analysis of its components revealed dozens of amino acids, including many that are the building blocks of proteins found in living things on Earth.

Alternatively, life elsewhere could look somewhat or very different than what we find on Earth. Scientists have factored that into their thinking, remaining open-minded in their investigation of possible signs of extraterrestrial life. However, the conservation of physical and chemical properties of elements both here and on other planets leads us to suspect that the properties of life on Earth could provide a way to recognize the properties of life on other planets if we find it. A fundamental goal of this case will be to explore the properties of those elements, the bonds that link them into molecules, and the structures and functions of special molecules that are essential building blocks to life on Earth.

*Based on What We Know about Life on Earth, Was Mars Ever Habitable (Or Is It Possibly Inhabited Now)?*

This is a fascinating question. In a simple sense, the answer can only be either yes or no. The rationale for why you might answer one way or the other, however, is far from simple. Presenting your ideas about whether life could exist on Mars will require understanding of what we know about the properties of living things on Earth, and explaining those ideas will require careful thinking and clear communication. That is the goal of this case study regarding our



analysis of hypothetical specimens returned from Mars. This case study provides a framework in which to apply what we know and to develop our skills in critical thinking and effective communication. Presently, NASA is working very hard to answer that question for us. In the meantime, we can enjoy thinking about what we know thus far and work together to develop and present our rationale for hypotheses about whether life could exist on Mars.

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