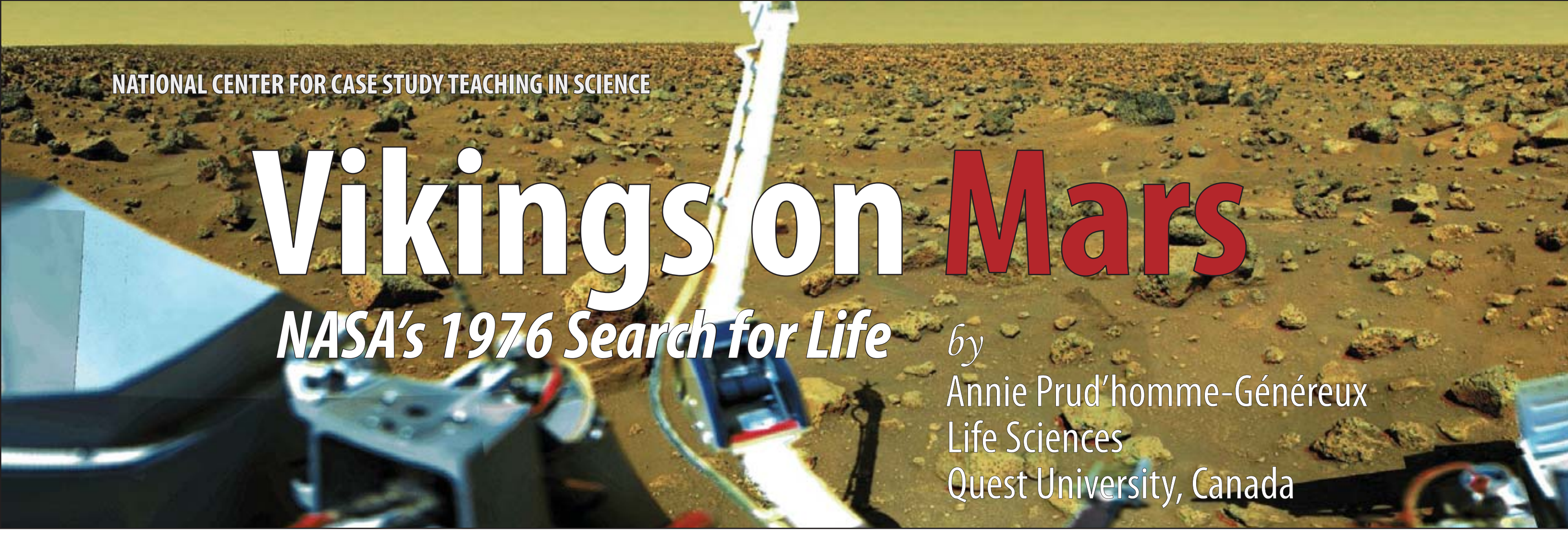

NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

Vikings on Mars

NASA's 1976 Search for Life

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Part I – NASA Needs You!

I really shouldn't be here, you think while taking your seat in a lecture hall for your first biology class as a graduate student. You sit in the back row in order to be less conspicuous in case you decide to leave early.

It's the fall of 1969 and this summer you watched Neil Armstrong walk on the moon. The moon! While the decision to pursue biology seemed reasonable last spring, a lot's happened since then. You want to join NASA's exploration of space, not sit behind a microscope counting bacteria.

Your teacher takes the podium; class is about to begin.

"I expect that the landing on the moon this summer galvanized the interest of many people in this room. NASA is very excited about its achievement and has set its sight on a more distant target for its next mission: Mars. NASA is particularly interested in whether the Red Planet harbours living organisms and it has just put out a call for proposals in the scientific community. Researchers are asked to develop experiments that could be placed onboard an unmanned spacecraft that will land on Mars and test whether life exists there. Your first assignment in this class is to propose such an experiment. I will work with the students who propose the best experiments to submit a proposal to NASA. Your idea might just be the one that tells us if there is life on another world!"

I made the right decision by signing up for graduate school in biology, you think to yourself as your doubts about your career choices instantly evaporate.

Questions

1. What might you look for as a signature of life on the Red Planet? In other words, what distinguishes life from non-life? Brainstorm a list of all the possible characteristics that, if found in a sample, would convince you that it contains a living organism.
2. Are any of the criteria you listed in answer to Question 1 sufficient for life? (If they are *sufficient*, then a positive result for this criterion would be enough to confirm that there is life on Mars; otherwise, other criteria might also need to yield a positive result in order to confirm that there is life on Mars.) What are the consequences of your answer for designing experiments to search for life on Mars?
3. Design an experiment that would allow you to determine whether *one* of the signs of life you identified above is present on Mars. Be sure to describe your hypothesis, your control and experimental conditions, and the expected results if life is present or absent.
4. What assumptions did you make about life in your proposed experiment?

 Image credit: Viking 2 panorama of the Martian surface, NSSDCA Photo Gallery, http://nssdc.gsfc.nasa.gov/image/planetary/mars/vikinglander2-1.jpg.

5. Harold Klein (1992), a researcher at NASA, categorizes the search for life on Mars into three categories:
   a. experiments that make no (or extremely minimal) assumptions about the chemistry and physiology of Martian organisms;
   b. experiments that assume that life on Earth and on Mars evolved along similar lines and produced organisms with similar biochemical properties; and
   c. experiments that assume that Martian life is based on organic compounds (i.e., life is carbon-based) but whose biochemistry differs significantly from that of Earth life (for example, Martian life is not assumed to eat sugars and exhale carbon dioxide). This is an intermediate position between the ones outlined above.

   Revisit your experimental design. Which of the three categories of experiment does your proposed method fall under? What are the strengths and pitfalls of such an approach?

Part II – Viking's Life Detection Mission

Your instructor selected three proposals from the class for submission to NASA. Yours is one of them! You work feverishly with your instructor over the next few months. Unfortunately, your proposal is not selected by NASA's reviewers for inclusion in the unmanned Martian probe. However, the NASA team was impressed with the ideas and the rigour of your proposal and asks you and your two classmates to join them as interns on this project.

NASA has selected three proposals that will each be carried out on the two Viking landers that will touch down on Mars in 1976. The two landers are identical but will descend at different places on the Red Planet's surface. Viking 1 will land on the western slope of Chryse Planitia (the Plains of Gold), a smooth plain with many small impact craters at a latitude of 23 degrees (i.e., north of the equator; it would be comparable to the Florida Keys on Earth). Viking 2 will settle down at Utopia Planitia on the other side of the planet, a region where the area is rough and blanketed by dunes, located at a latitude of 48 degrees (i.e., a location closer to the north pole than Viking 1; it would be equivalent to the Upper Peninsula of Michigan on Earth).

Mars is generally colder than Earth; the average temperature hovers between −50°C and 0°C. Near the poles, the temperature can dip as low as −153°C. In the summer months at noon, the temperature around the equator can reach as high as 20°C, which is like a warm spring (it's not t-shirt weather, but you wouldn't need a jacket, either) and is sufficient to have liquid water (James and Leon, n.d.).

The Viking landers will launch separately from Cape Canaveral in Florida in 1975 and will spend nearly a year traveling to the Red Planet. Prior to lift-off, the spacecrafts will be disinfected to ensure that they do not inadvertently carry Earth microbes with them that might contaminate Mars.

The Viking landers will each be equipped with a camera, so if there are little green men walking around, or any sort of macroscopic (large) life, we should be able to capture them in a snapshot.

The Viking Biological Laboratory is an automated laboratory which will carry out three experiments that were selected from the pool of proposals.

- The Labeled Release (LR) experiment will look for signs of organic catabolism.
- The Pyrolytic Release (PR) experiment will look for signs of organic anabolism.
- The Gas Exchange (GEx) experiment will look for the production of gases known to be associated with metabolism.

NASA researchers have agreed ahead of time that a positive signal on any one of the experiments would constitute evidence for life on Mars.

Your internship at NASA is about to begin! Each intern will be assigned to one of the three experimental teams where you will become an expert in one life-detecting experiment carried on-board Viking. Team A will examine the design and data for the LR experiment; Team B will do the same for the PR experiment; and Team C will focus on the GEx experiment. At the end of these respective studies, members of the three teams will reconvene to share and compare results and come to a conclusion about life on Mars.

Questions

1. What are the pros and cons of NASA's decision to interpret a positive signal on any one of the three experiments as sufficient to claim the detection of life on Mars?
2. What is metabolism? Catabolism? Anabolism?
3. From the information you have received thus far, which of the three approaches proposed by Klein seems to be the one chosen by NASA (refer to Part I, Question 5)? Explain your reasoning.

Part III (Team A) – Design of the Labeled Release (LR) Experiment

Dr. Gilbert Levin proposed the Labeled Release (LR) experiment to which you have been assigned. Dr. Levin is very enthusiastic about the prospect of finding life on Mars. Prior to joining NASA, he was a sanitation engineer for the California State Health Department where he developed ways of detecting minute quantities of bacterial contamination in drinking and swimming water. His method, called radiorespirometry, serves as the basis for the LR experiment.

The LR experiment tries to detect the products of organic catabolic metabolism. "Catabolic metabolism" is the breakdown of complex molecules into simpler ones. This is what happens during digestion. The experiment consists of adding sugars, amino acids, and other organic molecules that serve as food for terrestrial organisms to a sample of Martian soil. The experiment then monitors the production of breakdown products of these carbon compounds. If there are organisms in the Martian soil, and these organisms feed on the broth of organic molecules, it is expected that simpler, lower-energy carbon compounds such as carbon monoxide (CO), carbon dioxide (CO_2), or methane (CH_4) will be "exhaled" or "excreted" by the organisms into the environment.

To track the input (the energy-rich organic compounds formate, lactate, glycolate, and the amino acids glycine and alanine) and output (expected to be CO, CO_2, CH_4), the carbon atoms in the organic molecules are radiolabeled. Specifically, the carbon atoms used to make the organic molecules are isotopes of carbon-14 instead of the more common carbon-12. The heavier isotopes are not expected to affect the ability of an organism to digest the organic molecules containing it. Above the test chamber is a Geiger counter that can detect the presence of carbon-14 in any gas that is generated by the sample (i.e., gases such as ^{14}CO, $^{14}CO_2$ and $^{14}CH_4$). This is the radiorespirometry innovation that Levin developed to detect bacteria in drinking water and which he adapted for the purposes of searching for life on other planets.

The experiment is quite simple. Scoop up a sample of Martian soil and put it in a test chamber. Then spray some radiolabeled nutrient broth onto the Martian soil. If ^{14}CO, $^{14}CO_2$, or $^{14}CH_4$ gases are produced, they will diffuse into the atmosphere of the chamber where their presence will be detected by the Geiger counter. A diagram of the test apparatus is shown in Figure 1.

The experiment is repeated three times, with soil samples that differ in the way in which they are treated. Here is a description of what was done to each soil sample before the addition of the nutrient broth:

- Soil receives no treatment.
- Soil is heated to 160°C, then cooled to ambient temperature.
- Soil is heated to 50°C, then cooled to ambient temperature.

In any given experiment, the nutrient broth is added to the soil sample in three discrete injections, separated in time by a few days. This experiment is carried out in the dark.

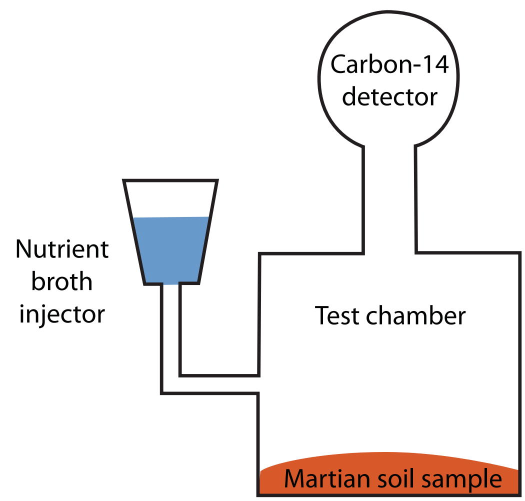


Figure 1. Set-up of LR experiment.

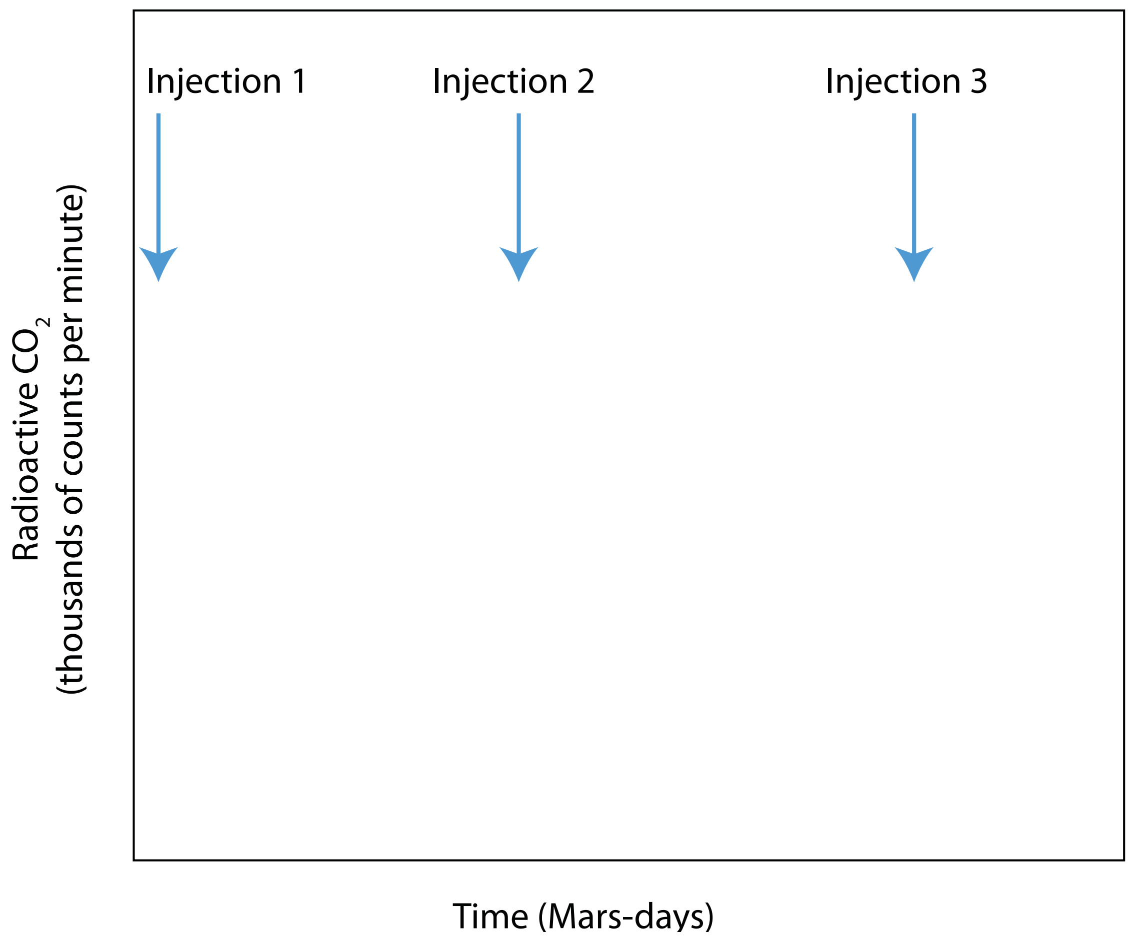
Questions

1. Analysis of Experiment Design
    a. What is the hypothesis tested in this experiment?
    b. What is the purpose of the experiments in which the soil samples were heated to 160°C or 50°C before the nutrient broth is added?
2. Assumptions
    a. What are some of the assumptions made in this experimental design?

   b. Where does this experiment fall in Klein's three proposed categories of assumption about life on another planet (see Part I, Question 5)?

3. Critique of the Design
   a. What are potential pitfalls of the experimental design?
   b. Propose ways to improve the design of this experiment.
4. On the graph below, draw the predicted curves for:
   a. a soil sample taken from Earth (with living microorganisms in it).
   b. a soil sample taken from Earth that has been sterilized.

   (Be mindful of what happens after each of the three injections of nutrient broth.)



Part IV (Team A) – Results of the Labeled Release (LR) Experiment

After years of working on this project, the Viking landers launched, traveled to Mars, and landed successfully. Within 20 seconds of landing, they sent back the first images taken from the surface of a foreign planet. Marvin the Martian, or any other little green men, were not in the snapshot. Rather, the images looked rocky and distinctly barren. However, this doesn't prevent the existence of microscopic life on the Red Planet, which is what the LR experiment was designed to investigate.

Here is a typical result (Figure 2). It only shows what happened after two injections, but the effects of Injection 3 were similar to those of Injection 2.

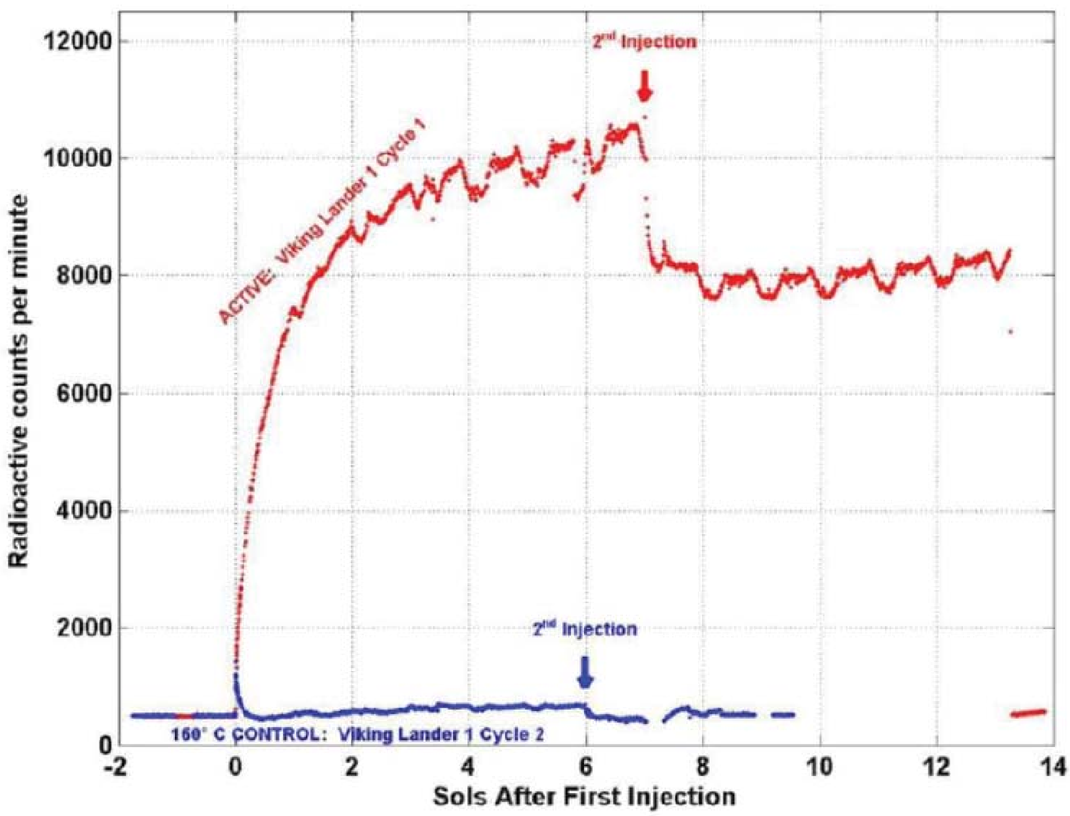


Figure 2. Typical LR Experiment Result. The x-axis shows time described as "sols." A sol is the duration of a day on Mars (which is slightly longer than an Earth day at 24 hours, 39 minutes, 35 seconds). The numbers indicate the number of sols since the injection of nutrient broth onto the Martian soil sample. The y-axis shows the recordings of the Geiger counter. As indicated on the graph, the blue line shows the results of the 160°C-treated control; the red line shows the data from the untreated soil sample. *Source:* Figure 1 of G.V. Levin (2013), Implications of Curiosity's findings for the Viking labeled-release experiment and life on Mars, *Proceedings of the SPIE* 8865, DOI: 10.1117/12.2023063. Used with permission of the publisher and author.

Questions

1. *Focusing only on what happened after the first injection,* how do you interpret this figure?
2. How do you interpret the data *after the second injection?*
3. How do you interpret the fact that the 50°C treated sample gave intermediate results between the 160°C-treated sample and the untreated sample?
4. Can you think of anything that might account for all this data that isn't life?
5. Based on this evidence, did Viking's LR experiment find evidence for life on Mars?

Part III (Team B) – Design of the Pyrolytic Release (PR) Experiment

Dr. Normand Horowitz proposed the Pyrolytic Release (PR) experiment. An academic geneticist by training, he joined NASA's Jet Propulsion Laboratory, becoming Chief of the Bioscience section. In his mind the exploration of space should be a rigorous scientific endeavour driven by curiosity, not to be confused with a lust for adventure. He does not hold out much hope for finding life on Mars.

The PR experiment is designed to detect organic anabolic metabolism. "Anabolic metabolism" is the creation of complex molecules from simpler ones. (As a trick to remember that anabolism means "building up," think of anabolic steroids, which are sometimes taken by body builders to bulk up.) One familiar form of anabolism is photosynthesis, where plants and some bacteria use the energy of sunlight to combine molecules of CO_2 and form larger non-volatile molecules of sugar containing many carbon atoms.

The basic design of the PR experiment involves incubating a sample of Martian soil with CO_2 and CO (at concentrations that mirror their presence in the Martian atmosphere) and detecting the incorporation of the carbon atom of these gases into larger organic molecules.

To track the creation of large carbon-containing compounds derived from CO and CO_2, the gases fed to the sample contained a radioisotope of carbon called carbon-14. It's expected that organisms can make use of molecules containing either the common carbon-12 or the rare carbon-14. Carbon-14 can be detected with a Geiger counter.

Figure 3 shows the experimental set-up. The procedure is as follows:

- Scoop up some Martian soil and place it in the apparatus.
- Add ^{14}C-containing CO and CO_2 to the test chamber.
- Shine a light on the sample for 120 hours (five days) to give time for anabolic metabolism to take place in the soil sample (if organisms are present).
- Purge the gases (this will get rid of any carbon radioisotope in the atmosphere of the test chamber).
- Seal the test chamber so that no further compounds are lost. Now we have to test whether any isotope remains in the soil sample.
- Heat up the soil sample to a high temperature (625°C) that will decompose large organic molecules. The organic matter will burn off into the gases CO_2 and CO, which can be detected in the atmosphere of the test chamber with a Geiger counter.

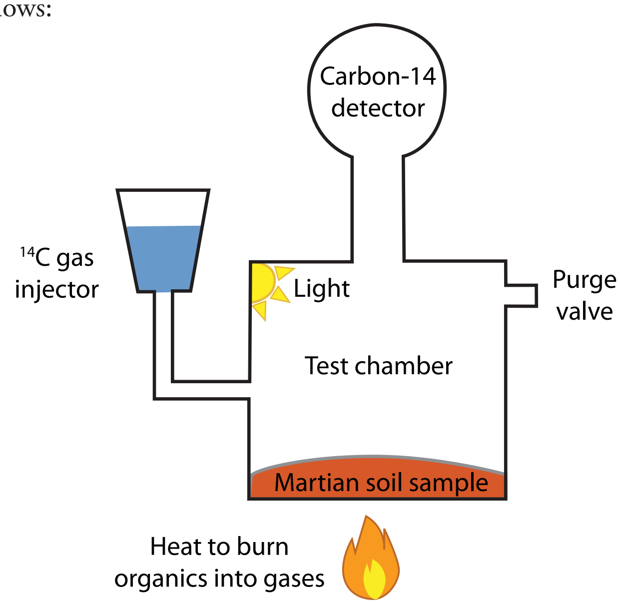


Figure 3. Set-up of PR experiment.

This experiment was performed in light and in darkness. One sample had water added to it (all others were performed using the soil sample as is). The temperature of the test chamber was maintained between 10–18°C.

Some experiments were performed using untreated soil samples. Others pre-treated the soil sample by heating it to 175°C for three hours and then letting it cool before performing the experiment.

The experiment was performed several times, altering some of the variables between experiments.

Questions

1. Analysis of Experimental Design
   a. What is the hypothesis tested in this experiment?

b. What is the purpose of the experiments in which the soil samples were heated to 175°C for three hours before the addition of ^{14}C-containing gases?

c. Why was the experiment performed in light and in dark?

2. Assumptions

   a. What are some of the assumptions made in this experimental design?

   b. Where does this experiment fall in Klein's three proposed categories of assumption about life on another planet (see Part I, Question 5)?

3. Critique of the Design

   a. What are potential pitfalls of the experimental design?

   b. Propose ways to improve the design of this experiment.

4. Predict the results expected. On the Y-axis, indicate the relative amount of ^{14}C that you expect to be "fixed" (used by the living organisms to make larger organic molecules) in the sample. On the bar graph, draw bars for each of the following conditions.

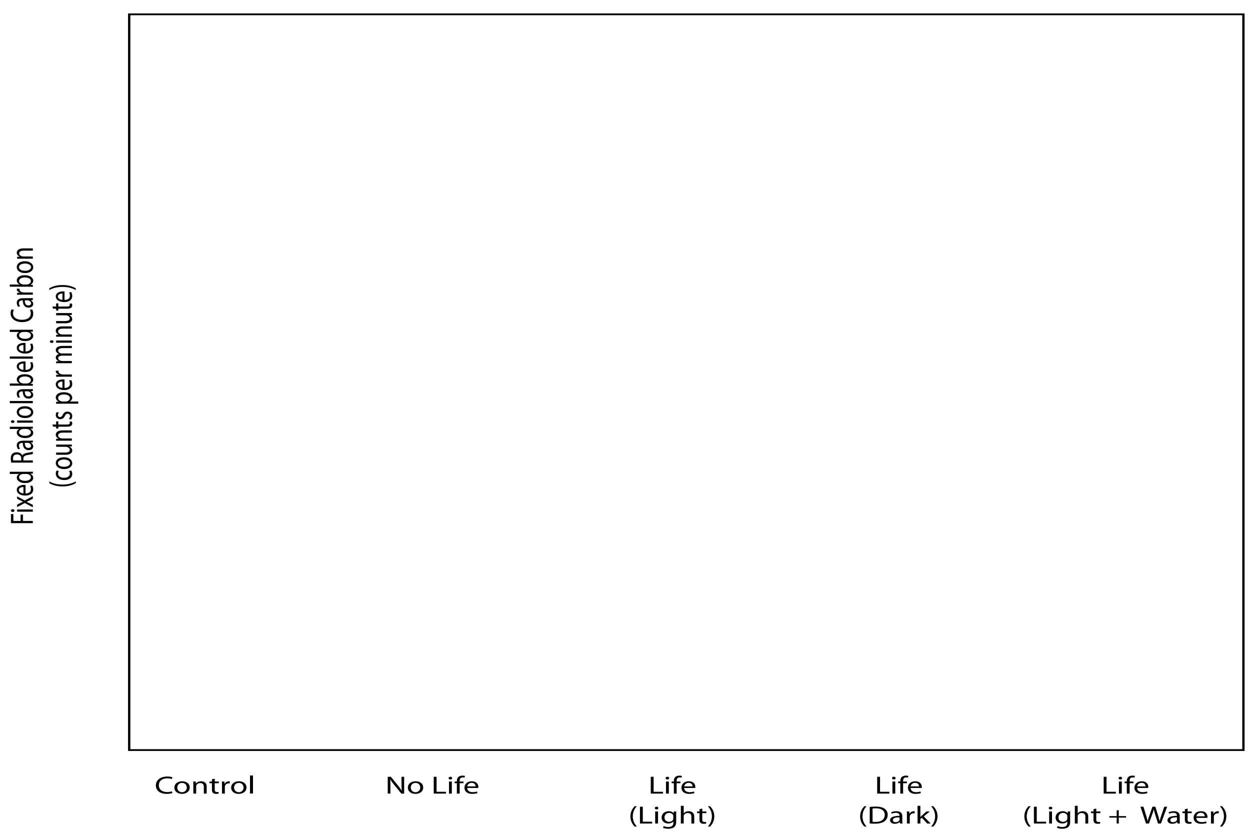
   a. Control

   b. No life present

   c. Life that is fixing carbon into larger organic compounds—in presence of light

   d. Life that is fixing carbon into larger organic compounds—in absence of light

   e. Life that is fixing carbon into larger organic compounds—in presence of light and water



Part IV (Team B) – Results of the Pyrolytic Release (PR) Experiment

After years of working on this project, the Viking landers launched, traveled to Mars, and landed successfully. Within 20 seconds of landing, they sent back the first images taken from the surface of a foreign planet. Marvin the Martian, or any other little green men, were not in sight. Rather, the images looked rocky and distinctly barren. However, this doesn't prevent the existence of microscopic life on the Red Planet, which is what the PR experiment was designed to investigate.

The results of 7 of the 9 repeats of this experiment, which were the ones initially reported in the publication of the data, are shown in Figure 4 below. Each experiment is named after the site where the soil sample was taken and the order in which the experiments were performed. The y-axis shows the amount of isotope released from the soil after it was baked at 625°C. The error bars indicate standard errors. There are a couple of things to note about each experiment.

- All Chryse samples were recorded after exposure to light for 120 hours (five days).
- Chryse 2 was measured after subjecting the soil sample to 175°C for three hours (i.e., it is the control).
- Chryse 3 was performed at a temperature of 26°C rather than the more typical 10–18°C at which the other experiments were performed due to a malfunction inside the coolers of the Viking lander.
- Chryse 4: NASA recorded data about each experiment in addition to the Geiger recordings. Some of this additional information suggests that something may have gone wrong with the Chryse 4 experiment. Either too little CO and CO_2 gas was added to the sample, or too little soil sample, or else there was a leak in the gas chamber that allowed gas to escape. Keep this in mind when you interpret the results..
- Utopia 1 was performed in darkness.
- Utopia 2 was performed in the presence of light and water.
- Utopia 3 was performed in darkness and used soil obtained fron under a rock.
- Another experiment (data not shown) was performed after heating the soil sample at 90°C for two hours. This treatment did not interfere with the production of organic molecules in the presence of light.

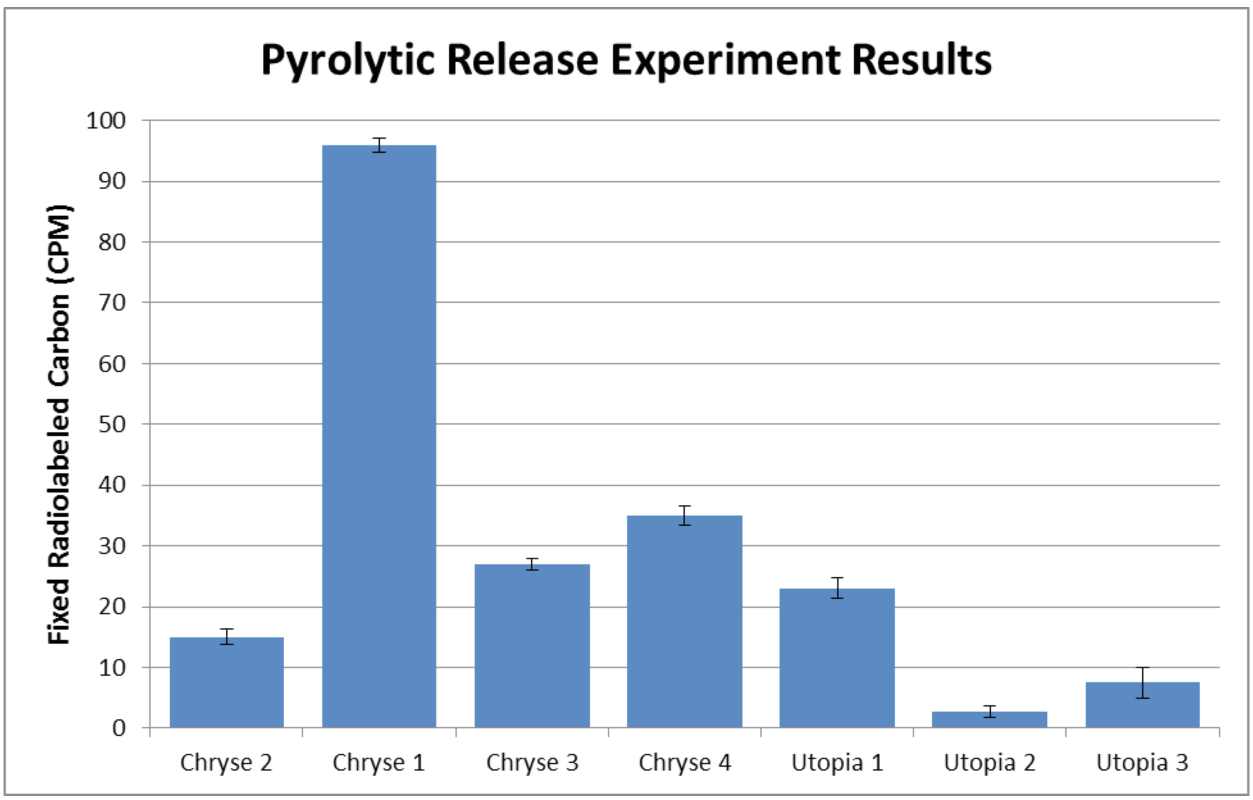


Figure 4. Results of the Pyrolytic Experiment. Created using data from Table 1 of Horowitz, N.H. and G.L. Hobby (1976), The Viking carbon assimilation experiment: Interim report, *Science* 194: 1321–1322.

Questions

1. Under each column, write the conditions of the experiment. This will help you analyze the data.
2. Which experiment(s) support and do not support the conclusion that there is life on Mars? (Remember that not all data is shown on this figure—one other result was summarized in the text above.)
3. How do you interpret the large amount of variability between experiments?
4. How do you interpret the results of experiments performed in darkness?
5. How do you interpret the results of the experiment performed in the presence of water?
6. Based on this evidence, did Viking's LR experiment find evidence for life on Mars?

Part III (Team C) – Design of the Gas Exchange (GEx) Experiment

The Gas Exchange (GEx) group is led by Dr. Vance Oyama, a biochemist who worked on life detection experiments on Apollo lunar samples. He is perhaps the most optimistic of all the researchers involved in this project of the prospect of finding life on Mars.

The goal of the GEx experiment is to look for the signature products of metabolism. On Earth, microorganisms produce and consume gases such as O_2, H_2, N_2, CO, NO, N_2O, H_2S, CH_4 and CO_2. Changes in the concentration of these gases might indicate the presence of metabolizing microorganisms on Mars.

The experiment consists in depositing a Martian soil sample into a test chamber. The soil sample is then humidified by the addition of water vapour. To ensure that the water does not freeze, the temperature inside the test chamber is maintained between 8–15°C. For ten days, the composition of the atmosphere above the sample is recorded. This is called the *humid mode.*

After this period, a nutrient broth consisting of 19 amino acids, vitamins, and other organic molecules and salts is sprayed onto the soil sample. The composition of the gases above the sample is monitored for up to seven months. This is called the *wet mode* of the experiment.

In the two phases (humid and wet) the composition of the atmosphere above the soil sample is determined using a gas chromatograph and a mass spectrometer (GC/MS). The gas chromatograph separates each of the chemicals in the atmosphere above the soil sample so that they can be studied in isolation. Each one is then identified by its precise mass using the mass spectrometer. Any atom can be studied using GC/MS, which is why the GEx is the only Viking experiment to examine chemicals other than carbon-based compounds (the methods used by the other two Viking experiments rely on methods that can only detect carbon compounds). Figure 5 shows this experimental set-up.

This experiment is repeated a few times. In some cases the Martian sample is heated to 145°C and then left to cool before the experiment is performed. In other cases untreated Martian soil is used.

The concentration of the noble gases neon (Ne), argon (Ar), and krypton (Kr) are monitored throughout the experiment.

All experiments are conducted in darkness.

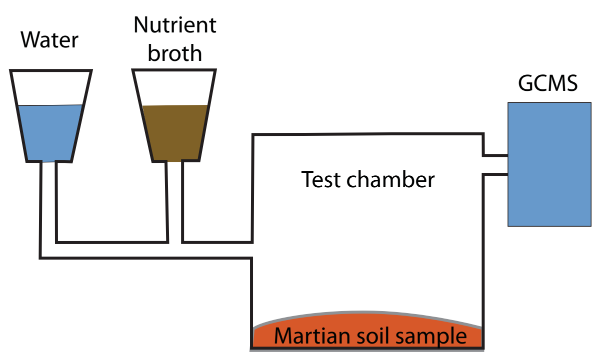


Figure 5. Set-up of GEx experiment.

Questions

1. Analysis of Experimental Design
   a. What is the hypothesis tested in this experiment?
   b. What is the purpose of the experiments in which the soil samples were heated to 145°C before performing the experiment?
   c. Why perform a humid mode and a wet mode?
   d. Why monitor the concentration of noble gases?
2. Assumptions
   a. Which type of metabolism is this experiment testing?
   b. What are some of the assumptions made in this experimental design?
   c. Where does this experiment fall in Klein's three proposed categories of assumption about life on another planet (see Part I, Question 5)?

3. Critique of the Design
    a. What are potential pitfalls of the experimental design?
    b. Propose ways to improve the design of this experiment.
4. Characterize the changes in gas levels you might expect if they are caused by living organisms:
    a. Do you expect rapid or slow changes?
    b. Do you expect continuous or intermittent changes?
    c. Do you expect differences between the humid and the wet mode?
    d. How might the results differ between the untreated and 145°C-treated samples?

Part IV (Team C) – Results of the Gas Exchange (GEx) Experiment

After years of working on this project, the Viking Landers launched, traveled to Mars, and landed successfully. Within 20 seconds of landing, they sent back the first images taken from the surface of a foreign planet. Marvin the Martian, or any other little green men, were not in sight. Rather, the images looked rocky and distinctly barren. However, this doesn't prevent the existence of microscopic life on the Red Planet, which is what the GEx experiment was designed to investigate.

The GEx experiment monitored several gases. Here are some results.

- The concentration of neon (Ne) and krypton (Kr) remained unchanged through both humid and wet mode.
- The concentration of argon (Ar) could not be resolved from the concentration of CO (in other words, the concentration of both is reported in one number). The values fluctuate a bit, but they are very small suggesting that there was little of either gas in the test chamber.
- No H_2, NO, or CH_4 was detected in the gas chamber at all.
- The levels of CO_2 increased soon after water vapour was added but then plateaued. The levels increased a bit again at the time of addition of nutrient broth, but soon tapered off.
- The levels of O_2 were nearly undetectable at the start of the experiment. Upon addition of water vapour, there was an immediate and large burst of O_2. The fluctuations of O_2 during this experiment are shown in Figure 6.
- The heat-treated soil sample released as much O_2 as the untreated sample (not shown in Figure 6).

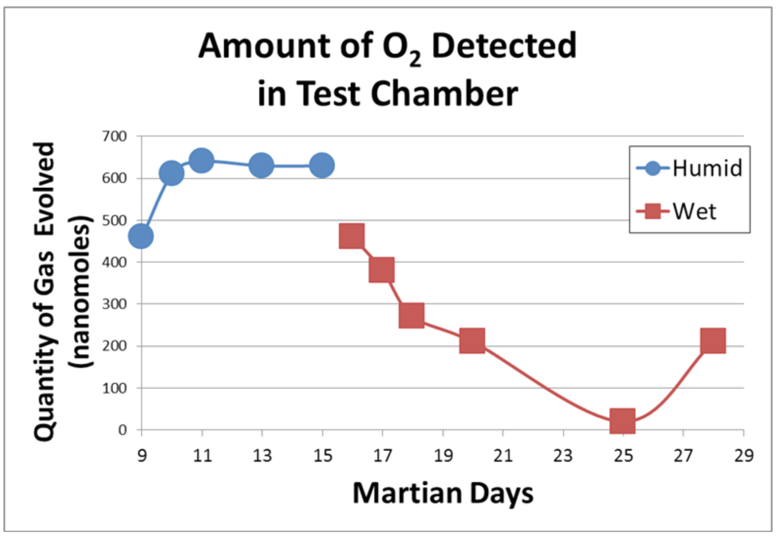


Figure 6. Levels of O_2 obtained during the GEx experiment. Figure adapted from Tables 4 and 5 of H.P. Klein et al. (1976), The Viking biological investigation: Preliminary results, *Science* 194(4260): 99–105. DOI: 10.1126/science.194.4260.99.

Questions

1. What evidence suggests that the changes in O_2 and CO_2 levels were caused by chemical reactions in the soil rather than living organisms?
2. How might the disappearance of oxygen from the atmosphere during the wet mode suggest the presence of living organisms?
3. One of the chemicals added in the nutrient broth is vitamin C (ascorbic acid). This chemical is an antioxidant, meaning it reacts with reactive oxygen species. How can this knowledge explain some of the data?
4. Did the GEx experiment find evidence for life on Mars?

Part V – NASA's Press Release

The world has been eagerly awaiting the results of these experiments. You and your classmates have been selected by NASA to compose a press release. Working with members of the other two research teams, you must decide what to tell the world about the three experiments and their conclusions about whether Mars harbors life. Prepare a five minute statement that you will read at a press conference. Be sure that your message is clear and is based on evidence. Do not aggrandise nor dismiss the results. The public foot the bill for this research endeavour and they have the right to know what has been learned.

You will have 15 minutes to share with the other interns what you learned by working in your LR, PR, or GEx team. Once you have shared what you have learned, craft a message for the public that encapsulates what the Viking missions taught us about life on Mars.

Part VI – What We Now Know

You may have been confused by the results of these three experiments. If so you are not alone. NASA took the official position that the Viking experiments found no evidence of life on Mars. Not all researchers agreed with this interpretation. However, the "there is no life" conclusion was reached after considering additional evidence, not examined thus far.

First, another experiment onboard Viking looked for organic compounds in the Martial soil and found none. In fact, the Martian soil was so devoid of organic compounds that the researchers turned up the gain on the equipment in the hopes of finding faint levels. The instruments were so sensitive that they detected traces of an organic solvent used to clean the Landers when they were still on Earth a year earlier.

The lack of organics on Martian soil is troubling, because organic chemicals are thought to abound in the solar system. They are easily created from inorganic gases (for example, O_2, CH_4, NH_3) and have been found in comets and meteorites. So why are none found on Mars?

One hypothesis is that when Martian soil is placed with CO_2 under extremely cold and dry conditions, and in the presence of UV light (all of which are prevalent on Mars), it produces superoxides (O_2–), a class of reactive oxygen-containing chemicals. These chemicals are known to degrade organic compounds, explaining why no organics were detected in the Martian soil.

Superoxides could explain some of the perplexing GEx and LR results. Superoxides are known to react with water to produce O_2, explaining the rapid burst of O_2 produced upon addition of water vapour in the GEx experiment (which was probably the most interesting finding of the GEx experiment).

Superoxides could also explain the LR experiment results. In the LR experiment, organic molecules were added to the soil. Superoxides are known to react with small organic molecules to produce CO_2. Thus superoxides in the soil would give a positive signal in the LR experiment. In addition, superoxides are known to be destroyed by excessive heat, which would explain why the heat-treated control did not yield any CO_2.

Another idea could explain the PR experiment results. In the time since the Viking mission, we have learned that if Earth soil is warmed, it takes up CO_2. The Viking experiments were performed at a temperature that is higher than the ambient temperature on Mars. Therefore, it is not inconceivable that by placing the soil samples in the warm Viking test chamber, the warmed soil was induced to take up CO_2. When the soil sample was heated to much higher temperatures (during the pyrolytic release), the CO_2 was liberated. This mimics the results expected in the PR experiment if bacteria were fixing CO_2 into more complex organic molecules.

Most researchers now believe that the surface of Mars is not conducive to life, with its extreme dryness, the presence of oxidizing chemicals, and strong UV light. However, this doesn't answer the question of whether there is life underground (protected from some of these harsh elements and where liquid water may exist) or whether there was life in a distant past (when the conditions on the surface were more favourable and there was liquid water on the surface). No probe sent to Mars since the Viking landers has investigated the presence of life directly (probes have looked for indicators like water, but never life itself).

Questions

1. Articulate some of the difficulties in determining whether there is life on Mars.
2. In 2015, the Mars rover Curiosity uncovered evidence of organic molecules on Mars (Rincon, 2015). One substance appeared to be a fatty acid and another may be an alcohol. Contamination cannot be ruled out. How might these findings affect our interpretation of the Viking results?
3. If NASA asks you to lead a new unmanned mission to Mars to investigate whether there is life on Mars, what experiment will you propose to do? Revisit your original proposal (Part I, Question 3) to give you some ideas. Your proposal should keep in mind the challenges of the Viking experiments. It might address a shortcoming

of these experiments or a question raised by them. Alternatively, you may choose to design an experiment to investigate whether there are remnants of past life on Mars. You will defend your proposal in front of NASA's budgetary panel.

4. Your colleague proposes a sample return mission where a sample of Martian soil is brought back to Earth for analysis. Assess the risks such a sample might pose for terrestrial life. Explain your reasoning.

References

James, D., and M. Leon. *n.d.* Mars facts. NASA Quest, an educational web site. Retrieved November 28, 2014 from http://quest.nasa.gov/aero/planetary/mars.html.

Horowitz, N.H. and G.L. Hobby. 1976. The Viking carbon assimilation experiment: Interim report. *Science* 194: 1321–1322.

Klein, H.P. 1992. The Viking biology experiments: Epilogue and prologue. *Origins of Life and Evolution of the Biosphere* 21: 255–261.

Klein, H.P., N.H. Horowitz, G.V. Levin, V.I. Oyama, A. Rich, J.S. Hubbard, G.I. Hobby, P.A. Straat, B.J. Berdahl, G.D. Carle, F.S. Brown, and R.D. Johnson. 1976. The Viking biological investigation: Preliminary results. *Science* 194(4260): 99–105. DOI: 10.1126/science.194.4260.99

Levin, G.V. 2013. Implications of Curiosity's findings for the Viking labeled-release experiment and life on Mars. *Proceedings of the SPIE* 8865, id. 886503 13 pp. DOI: 10.1117/12.2023063.

Rincon, P. 2015. Possible fatty acid detected on Mars. *BBC News* (20 March 2015). Retrieved 29 April 2015 from http://www.bbc.com/news/science-environment-31988540.