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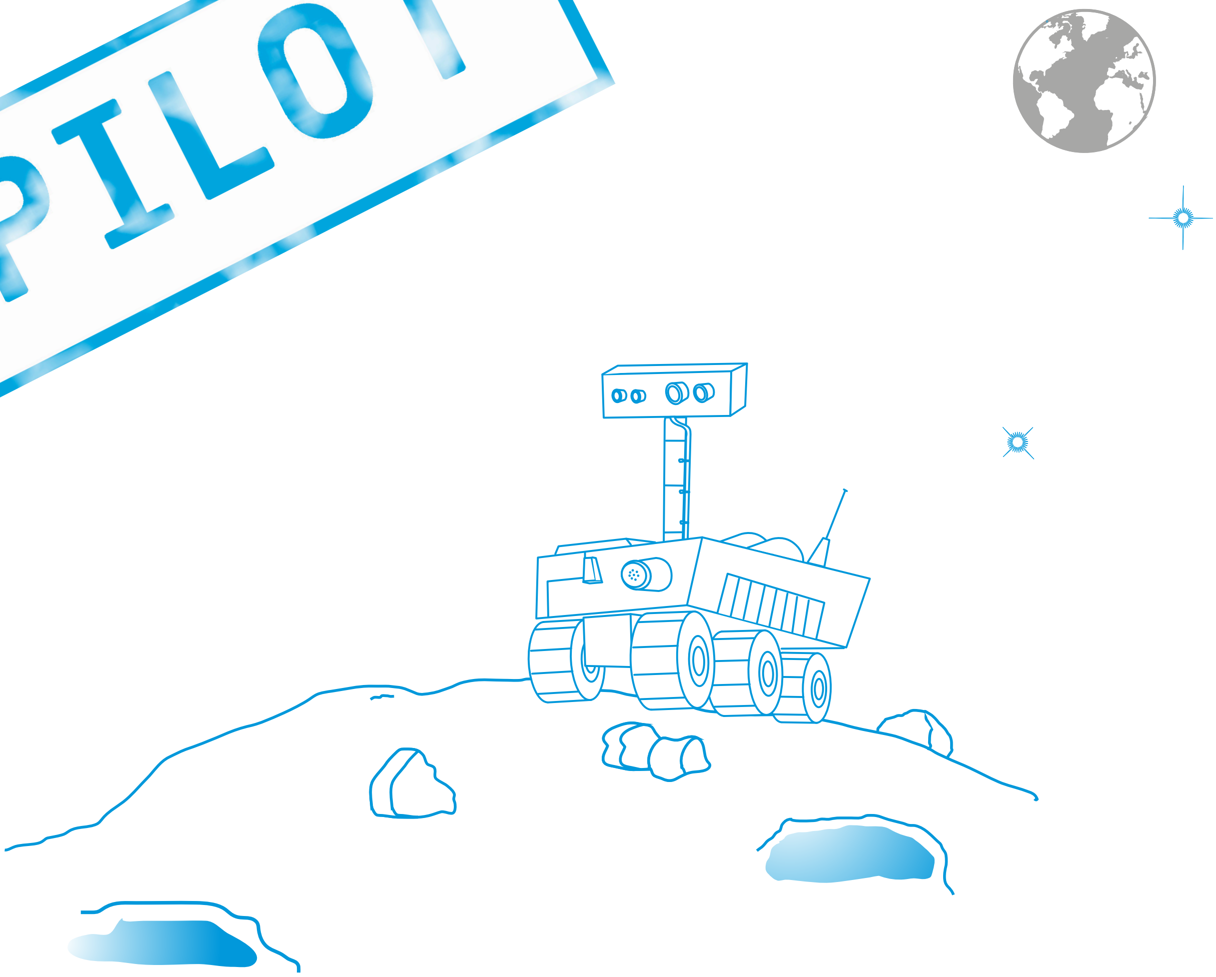
teach with space

→ LOOKING FOR LIFE ON MARS

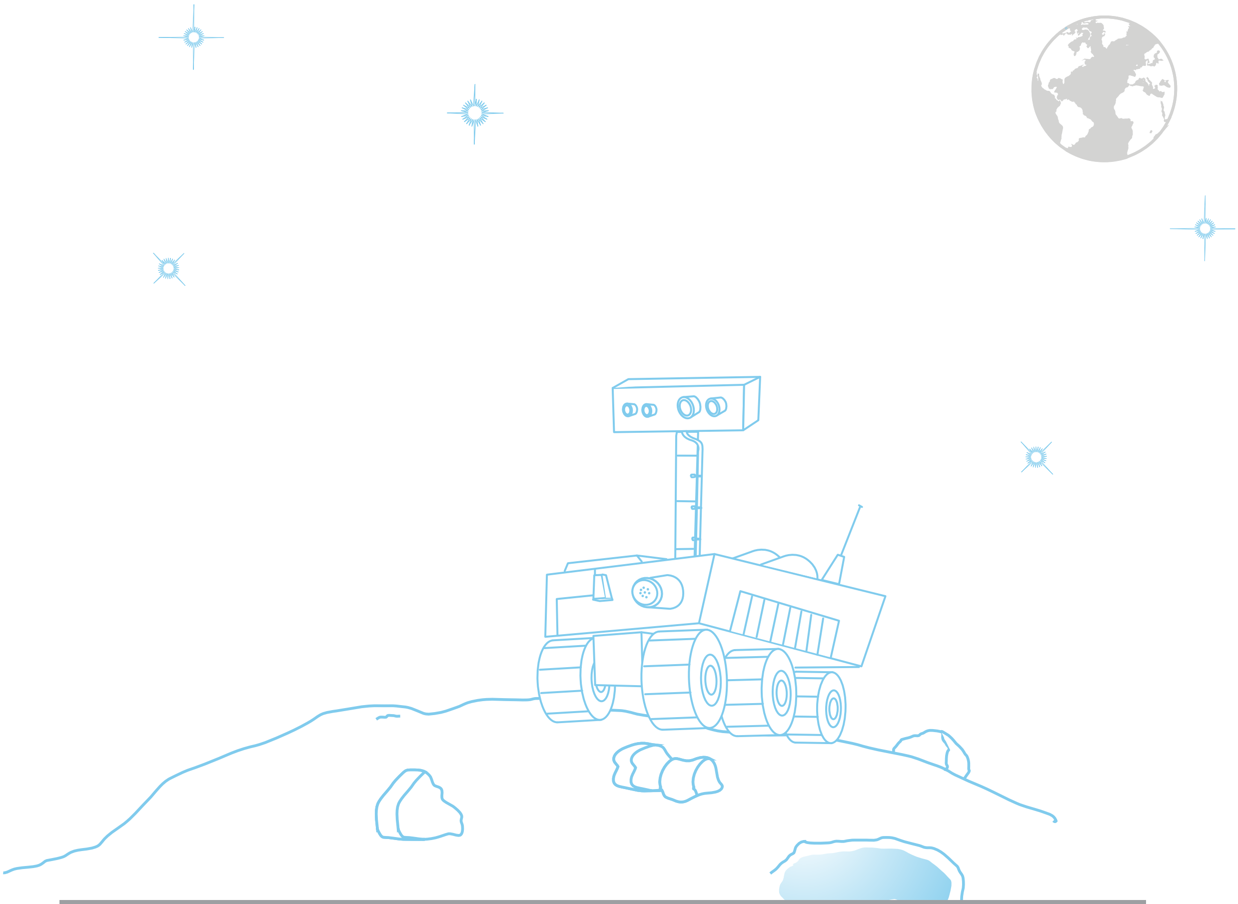
Sample analysis, looking for signs of life

PILOT



teacher guide & student worksheets

European Space Agency



Teacher guide

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→ LOOKING FOR LIFE ON MARS

Sample analysis, looking for signs of life

Fast facts

Subject: Biology, Chemistry, Science

Age range: 10 – 14 years old

Complexity: Easy

Lesson time required: 45 minutes

Cost: low (0-10 euros)

Location: School laboratory or classroom

Includes the use of: Yeast, sugar, alka-selzer, sand, warm water (approximately 45 – 50 °C)

Keywords: Biology, Chemistry, Science, Life, Mars, Sample analysis, Chemical reaction

Brief description

In these activities, students will look for evidence of life in three samples resembling Martian soil and discuss experiments from the point of view of different scientists. Students will perform simple experiments to compare the behaviour of the samples under specific conditions. They will observe that certain chemical reactions produce gases, such as carbon dioxide, and also learn that chemical reactions can be caused by living and non-living things.

Learning objectives

- Learn about chemical reactions.
- Learn about properties of life on Earth.
- Understand that some microorganisms can produce carbon dioxide in a process called anaerobic respiration.
- Compare some properties of planets Earth and Mars.
- Solve problems by working as a scientist.
- Draw conclusions based on observations and measurements.

→ Summary of activities

Summary of activities					
	Title	Description	Outcome	Requirements	Time
1	How to determine if life is present?	Students will play the role of a biologist, chemist, engineer or planetary scientist to discuss the best way to perform an experiment to indicate the presence of microorganisms in a soil sample.	Learn how scientists work individually as well as in a group to plan an experiment.	None	15 minutes
2	Analyse your samples	Perform a practical experiment to analyse three soil samples to look for evidence of life in them by comparing the chemical reactions occurring.	Learn about chemical and bio-chemical processes. Draw conclusions about the presence of life in the samples, based on the observations.	Completion of activity 1.	30 minutes

→ Introduction

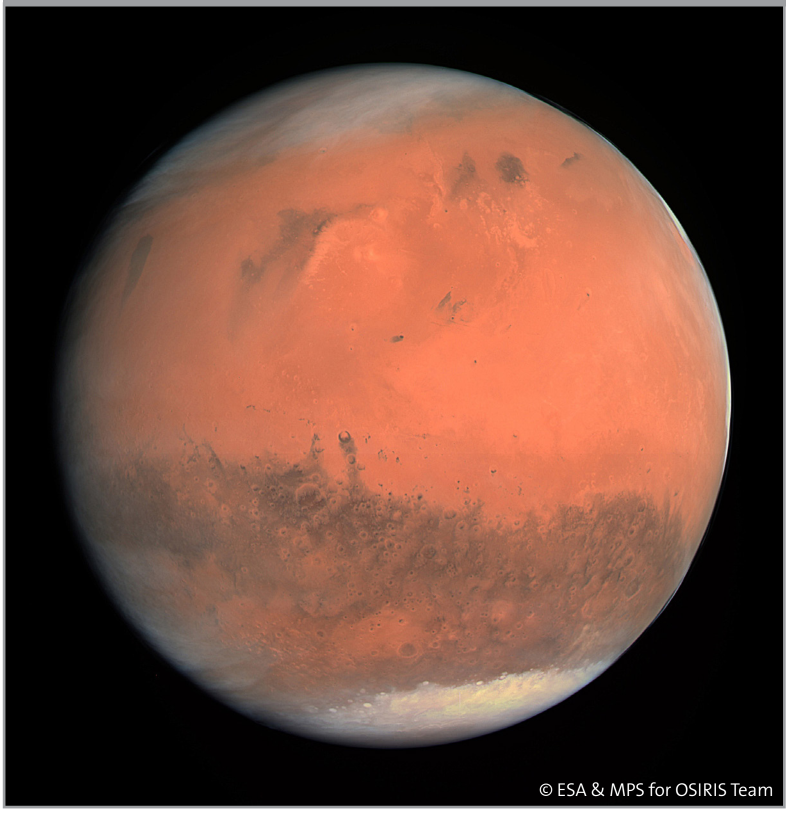
For thousands of years humans have gazed at the night sky and wondered about the presence of life elsewhere in the Universe. Are we alone? Where did life come from? So far, no proof has been found of past or present life anywhere except on Earth.

It is no easy task to detect life outside planet Earth. Scientists search for evidence of liquid water, which acts as a solvent and on Earth is a key ingredient for the existence life. Other signs that life may be present are biological markers, such as gases produced by the chemical process of respiration or fermentation.

Most living things on Earth need oxygen to survive, but some organisms have adapted to extreme conditions where oxygen is absent. The possibility of life on Mars, due to its proximity to Earth, is of particular interest. Sensitive techniques are used by scientists to detect minute quantities of gases that could indicate (but not prove) the presence of life on Mars. However, geological processes can also release gases and produce similar results. The characteristics of present or past life are very difficult to determine, especially when scientists are limited to the study of very small samples or fossilised material. Without in-situ observations it is extremely difficult to draw definitive conclusions.

In this activity, students will work as a group to analyse three "Martian" soil samples and look for evidence of life in them.

Figure 1



↑ Planet Mars

→ Activity 1: How to determine if life is present?

In this group activity, every student will take on a role of a different scientist (biologist, chemist, engineer, or planetary scientist) to plan an experiment together. In each group, the students should share the information they have according to their "expertise" and work together to plan the experiment.

Equipment

- Fact cards available in Annex 1 for each group.
- Printed student worksheet for each group.

Exercise

As an introduction provide an overview of tardigrades' properties and discuss which extreme Start by introducing the context of this activity to the students. On Earth, life thrives in very different conditions, including extreme environments. Ask the students if they think life can exist outside our planet, for example on different planets like Mars.

Explain to the students that they will plan an experiment to search for indicators of the presence of life (in this case microorganisms) in different soil samples from "Mars", imagining they were provided by the European Space Agency. They should subsequently record their observations to discuss them. In this group activity each student will have a role: biologist, chemist, engineer, or planetary scientist. Divide the students for this activity into groups of four members and assign them their new role, distributing the appropriate cards to each student. If some groups have a lower number of students, it is possible to combine the expertise of more than one role: for example, chemical-engineer.

Each student will then have to study the facts related to their new "profession". After reading the facts the students should operate in the new role and work as a team while discussing the best way to perform an experiment to determine the presence of life in soil samples.

Depending on the age group, introduce the concept of chemical reactions and their importance on the maintenance of life, or let students explore the fact cards on their own.

Discussion

Discuss with the students what kind of experiments they propose to perform to indicate the presence of microorganisms in their samples. Explore their ideas and the type of outcome they predict for their experiments.

Here is a list of examples of possible experiments:

- Add warm water to the sample to observe if CO_2 is produced.
- Add warm water to the sample and determine if alcohol is produced.
- Analyse the sample sediment when dissolved in water.
- Analyse the sample under the microscope.
- Do a petri-dish cultivation.

The students should be guided to realise that if life is present, adding warm water to each sample may result in the production of gas (carbon dioxide). However, the production of gas alone is not enough evidence to conclude that life is definitely present.

→ Activity 2: Analyse your samples

In this activity, students should perform the experiment they have described in Activity 1; alternatively they can follow the instructions provided below. Each group should record the evolution of their samples over time and discuss their conclusions based on their observations with the class.

Equipment per group

- Printed student worksheet
- Building sand
- Rock salt
- Table salt
- Fine grit
- Gravel
- Flour or talc
- Dried instant yeast
- Sugar
- Crushed Alka-Seltzer
- 3 transparent sealable bags
- Warm water (approximately 45-50 °C)
- Timer or stopwatch
- Measuring cup or beaker
- Magnifying glass or microscope
- Ruler

Preparation

In activity 2, students should analyse the three soil samples when water is added and compare the different chemical reactions occurring. Sample A is inert. Sample B contains the microorganism yeast and sugar; when mixed with warm water the yeast will use the sugar as a source of energy to produce carbon dioxide. Sample C contains Alka-Seltzer, which will react immediately with the water, releasing CO_2.

Prepare 3 soil samples for each group in transparent sealable bags, labelled A, B and C.

Sample A	Sample B	Sample C
2 tbs building sand	2 tbs building sand	2 tbs building sand
2 tbs rock salt	1 tbs gravel	1 tbs gravel
1 tbs table salt	1 tbs flour or talc	1 tbs flour or talc
1 tbs fine grit	packet of dried instant yeast	2 tbs rock salt
1 tbs gravel	2 tbs sugar	Crushed Alka-Seltzer
1 tbs flour or talc		

Exercise

In this activity, students should analyse the three soil samples and identify if life is present. They should start by outlining step-by-step the experiment proposed on Activity 1. As a tip, propose that the students replicate the Martian wet episodes by adding water to the samples, and compare the different chemical reactions occurring.

Proposed experiment:
- Observe the samples up close using a magnifying glass or a microscope. Take note of any visual differences between the samples.
- Take note of your initial predictions.
- Add approximately 30ml of warm water (45-50°C) to each sample.
- Quickly press the bag to remove excess air and seal.
- Mix the contents together by gently pressing the bag. Ensure that the bag is completely sealed to prevent the escape of gas.
- Record the gradual inflation of the samples using a table or a graphic (videos or photographs can also be taken to register the evolution of the samples).

The students should answer the student worksheet questions while completing the experiment and record the evolution of the samples.

Following the performance of the experiments instruct the students to discuss their results and conclusions about the indication of the presence of life in the given soil samples.

Results

In this activity, students should analyse the three soil samples and identify if life is present. They should start by out

- **Sample A:** Inert.
- **Sample B:** Adding warm water should start a bio-chemical reaction. The water should not be hotter than 50°C to avoid killing the yeast. Sample B contains the microorganism yeast and sugar. When mixed with water the yeast will use the sugar as a source of energy to produce carbon dioxide. The students should see the formation of bubbles of carbon dioxide over time. The bag should begin to swell after about 10 minutes; after 30 minutes the bag should be well-inflated. The students should be able to draw conclusions by observing the samples for 15-20 minutes.
- **Sample C:** After adding warm water the students should observe an immediate reaction. Sample C contains Alka-Seltzer, which will react immediately with the water, releasing CO_2. This is visible through the immediate inflation of the sealable bag.

Discussion

Questions 6, 7 and 8 are meant to be answered after a discussion with the whole class. The students should share their observations with the rest of the class and compare their observations and conclusions.

Below are some examples of topics that can be discussed:
- Did the final results match their initial predictions?
- Did the groups all have similar results?
- Were there any unexpected results? Did they identify any anomalies? For example, contamination or human error.
- Can they explain what happened?

Discuss with the students the differences between the chemical reactions observed. The effect seen on sample C is typical of a chemical reaction; it happens quickly when the reagents are put in contact, but it is short-lived. The production of gas in sample B took longer to occur, but sustained longer over time, a key feature of biochemical reactions and therefore life.

Explain to the students that scientists take great care when they draw conclusions from tests such as these, because in real samples these differences are very difficult to distinguish.

Students can also be encouraged to list the key characteristics that an organism should have to be considered alive. On Earth we consider living organisms to have all of the following properties:
- they are composed of cells which can have a different level of organisation: unicellular or multicellular;
- they depend on their own metabolism which performs a number of interlocking chemical reactions to maintain homeostasis;
- they respond to their environmental conditions;
- they are able to grow, reproduce, and evolve.

Even on Earth this definition can be unclear for certain organisms, such as viruses.

Discuss with the students if they would expect these properties to be the same for a living organism in a foreign world. If life characteristics can be different elsewhere, how can astrobiologists identify life signals when searching for them?

As an extension to the activity, students could be encouraged to perform further investigations to discover how different conditions may affect the growth of microorganisms. They may wish to try investigating the effect of light, temperature or different nutrients upon the growth of the yeast.

→ LOOKING FOR LIFE ON MARS

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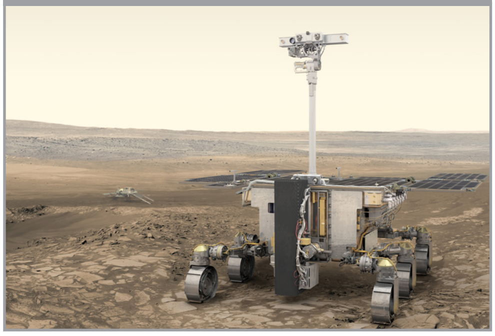
→ Activity 1: How to determine if life is present?

Imagine that you are joining a team of space experts to which the European Space Agency has provided three samples of soil from Mars.

Get your scientific team to examine the samples. Each team should have a biologist, a planetary scientist, a chemist, and an engineer. Each team member will have access to cards with information about their scientific role.

1. Read the fact cards about your "expertise".
2. Discuss ideas of experiments you can do to determine if there is life in any of the samples.
3. Write a short description of how your team would test for life in the different samples:

Figure A1



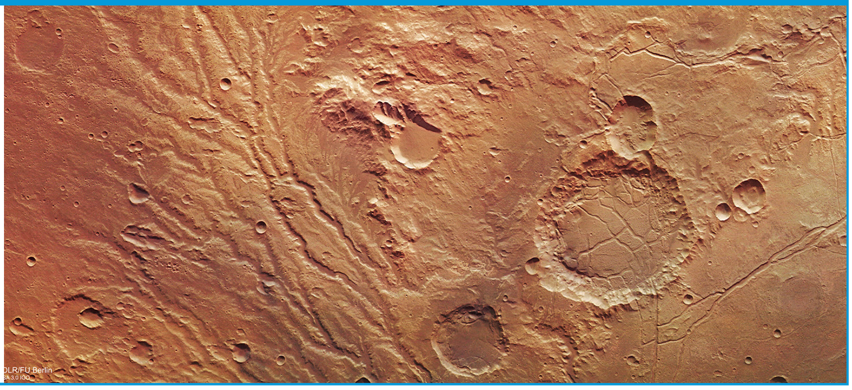
↑ The ExoMars rover.

→ Activity 2: Analyse your samples

Before proceeding with your experiment you will have to prompt the tun state in the tardigrades. In this activity you will transfer your tardigrades to small containers and induce anhydrobiosis by leaving them to desiccate.

Did you know?

The most prominent evidence of water erosion on Mars is the large dry valleys that are thought to have been formed by large floods. Many of these valleys start from the chaotic terrain in the Margaritifer Sinus region, south of the Chryse basin, and extend northward for hundreds of kilometres.



Scientists believe that a very long time ago there were brief wet episodes on Mars. There is evidence of erosion by **glaciers**, **wind** and **running water** in many places, including some indication that there may have been large lakes or oceans, small river systems, and large floods early in the history of the planet.

We know that liquid water is a key ingredient for life on Earth. It is important because it acts as a solvent, meaning it can dissolve and transport nutrients across the surface of the planet.

Exercise

Try to replicate the Martian wet episodes when analysing your Martian samples.

1. Given the equipment available, outline step-by-step the experiment your group has planned.

2. Make notes of your initial predictions.

3. Perform your experiment. Record the evolution of the samples (for example, you can use a table or a graphic).

4. What can you conclude from your observations?

5. Could you identify, with certainty, which of the samples contained living organisms?

6. Compare your results with the other groups. Did you obtain the same results? Explain the differences.

7. With the other groups, discuss the key properties that an organism should have to be considered alive.

8. Do you expect these properties to be the same for a living organism on a different planet? If life characteristics can be different elsewhere, how can astrobiologists identify life signals when searching for them?

→ Links

ESA resources

Could life survive in extreme environments?
esa.int/Education/Teachers_Corner/Could_life_survive_in_alien_environments_-_Defining_environments_suitable_for_life_Teach_with_space_B09

ESA classroom resources
esa.int/Education/Classroom_resources

Space Bears
esa.int/Education/Teachers_Corner/Space_Bears_Lab-experience_with_Tardigrades_Teach_with_space_B10

ESA missions

Exomars Mission
http://exploration.esa.int/mars/48088-mission-overview

Robotic Exploration of Mars:
exploration.esa.int/mars

Life on Mars?
http://exploration.esa.int/mars/43608-life-on-mars

Extra information

Planetary facts
https://nssdc.gsfc.nasa.gov/planetary/factsheet

Is There Life in There?
https://www.stem.org.uk/resources/collection/3998/biology-activities

Is There Anyone Out There?
https://www.stem.org.uk/elibrary/resource/30199

Searching for signs of life on Mars
exploration.esa.int/mars/43608-life-on-mars

Ten things you did not know about Mars
esa.int/Our_Activities/Human_and_Robotic_Exploration/Exploration/ExoMars/Highlights/Ten_things_about_Mars

ESA Euronews: Mars on Earth
esa.int/spaceinvideos/Videos/2018/02/ESA_Euronews_Mars_on_Earth

Chemist	Biologist
Chemist	Planetary Scientist
Chemist	Planetary Scientist

Biology fact

Yeast is a single cell microorganism, classified as a fungus. Through the chemical process known as fermentation, yeast uses sugar ($C_6H_{12}O_6$) for energy and breaks it down into two products: alcohol (C_2H_5OH) and a gas called carbon dioxide (CO_2).

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

This process is usually used in the production of bread and also alcoholic and fizzy drinks.

Chemistry fact

Rusting requires both oxygen and water. Rust is an iron oxide, which forms in a reduction-oxidation chemical reaction between iron and oxygen in the presence of water:

$$4\ Fe\ (s) + 6\ H_2O\ (l) + 3\ O_2(g) \rightarrow 4\ Fe(OH)_3\ \ (s)$$

Iron hydroxide, ($Fe(OH)_3$), then dehydrates to produce $Fe_2O_3.nH_2O$ (s), most commonly known as rust.
The Martian surface has a large percentage of rust, giving Mars its familiar red colour.

Mars fact

Mars has an atmosphere composed almost entirely of carbon dioxide (CO_2) 95,32%, nitrogen (N_2) 2.7%, argon (Ar) 1.6%, oxygen (O_2) 0,13% and carbon monoxide (CO) 0.08%.

Despite CO_2 making up only 0.04% of Earth's atmosphere, there is more CO_2 in Earth's atmosphere than in Mars's atmosphere.

Chemistry fact

What is a chemical reaction?

In a chemical reaction one or more substances come into contact to produce a new substance. When a chemical reaction occurs it can produce: a colour change, gas production, a precipitate, and/or a temperature change.

Earth fact

On Earth the major components of the atmosphere are nitrogen (N_2) 78,08%, oxygen (O2) 20,95%, argon (Ar) 0.09%, and carbon dioxide (CO_2) 0.04%. Water vapour typically makes up about 1% of the atmosphere. This mixture is vastly different from the atmospheres of Mars and Venus.

The high concentration of oxygen in Earth's atmosphere is mainly due to photosynthesis: a process which converts carbon dioxide and sunlight into sugars that plants and other organisms can use for energy.

Chemistry fact

Chemical reactions between non-living things can produce gases such as carbon dioxide (CO_2).

For example, when you mix baking soda (sodium bicarbonate, $NaHCO_3$) with vinegar (acetic acid, $HC_2H_3O_2$) it produces sodium acetate ($NaC_2H_3O_2$), water (H_2O) and carbon dioxide (CO_2)

$$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

Biologist	Planetary Scientist
Engineer	Biologist
Engineer	Planetary Scientist

Mars facts

Mostly due to its smaller size and its farther distance from the Sun, Mars's environmental conditions are very different from conditions on Earth.
Average temperature: –63°C

Wind speed: up to 30 m/s during dust storms

Surface pressure: up to 9 mb (1% of Earth's surface pressure)

Surface gravity: 3.71 m/s^2 (2.6 times smaller than Earth's surface gravity)

Biology fact

Most living things need oxygen to survive but not all microorganisms do. Microorganisms can live in very extreme places on Earth. These type of microorganisms are called extremophiles.

Could these type of organisms have lived on Mars?

Biology fact

Life, as we know it on Earth, has been traced to a single organism called the last universal common ancestor (LUCA). LUCA genes were identified by comparing the genome of living organisms today and looking for the presence of common genes amongst them. This does not mean that LUCA was the first living organism on Earth. It is estimated that LUCA lived on Earth 3.5 to 3.8 billion years ago.

Exploration fact

Since the late 1960s, several space missions have explored Mars. Exploration on the surface has been possible thanks to robots, while the study of its atmosphere and landscape is performed mainly by spacecraft that orbit the planet.

In 1976, Viking 1 & 2 were the first Mars landers that carried out experiments to look for biomarkers on the Martian surface. Their results, and the results of following missions, were inconclusive.

Mars fact

Early in its history, Mars was much more like Earth. Most of its carbon dioxide was used to form carbonate rocks, but because it cannot recycle any of this back into the atmosphere, it is much colder than the Earth would be at that same distance from the Sun. Its average temperature is around –60°C but surface temperatures range widely, from as low as –133°C at the winter pole to almost 27°C on the day side during summer.

Exploration fact

ESA's ExoMars 2020 mission programme will deliver a rover to the surface of Mars. The rover will be the first mission to combine the capability to move across the surface and to drill deep under the rocky Martian surface. It will collect samples using a drill that can reach a depth of 2 m and perform analysis. Underground samples are more likely to include biomarkers, since the tenuous Martian atmosphere offers little protection from radiation and photochemistry at the surface.