

**April/May 2017 Teacher's Guide**

**Background Information**

**for**

***Growing Green on the Red Planet***

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# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.

# Background Information

**(teacher information)**

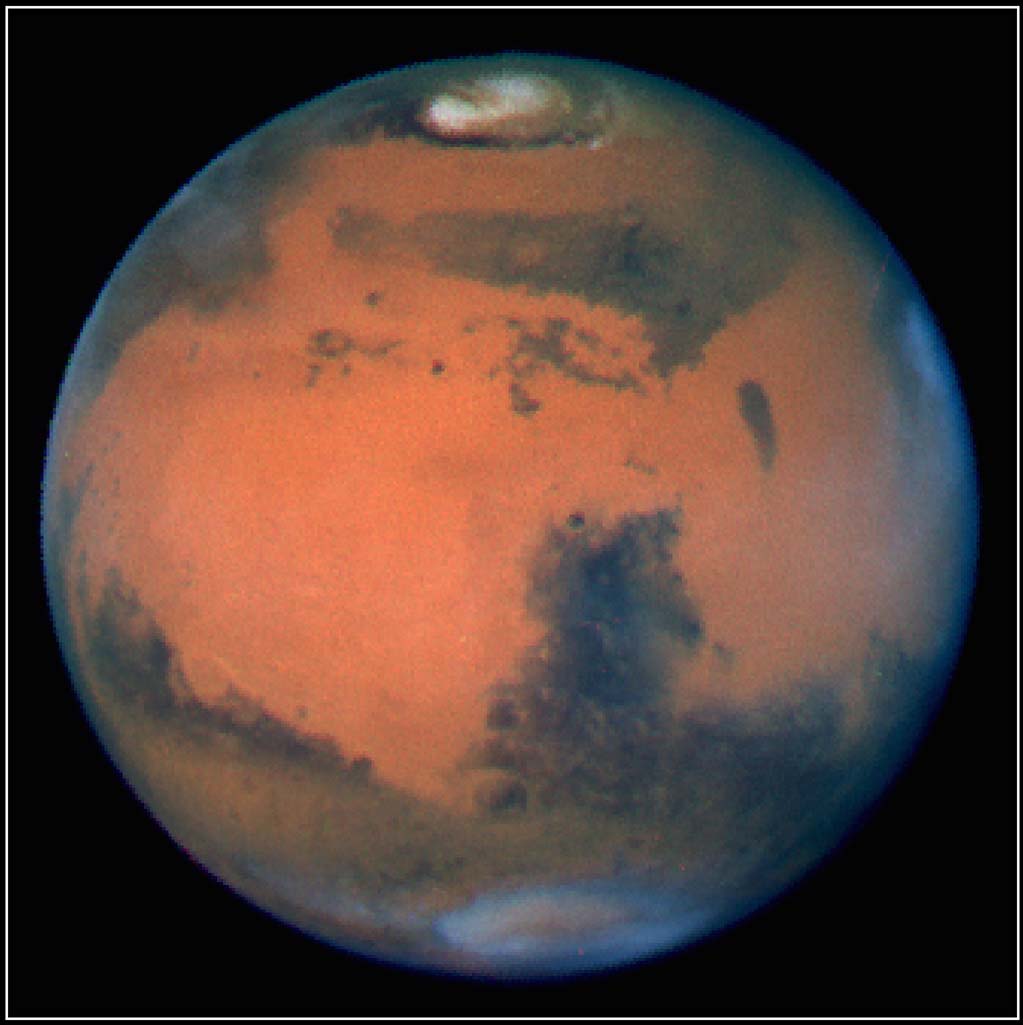
**Mars—the planet**

**History**

Mars is the fourth planet in our solar system. It was named by the Romans after their god of war, because of its red, blood-like color. The Egyptians named it “Her Desher” meaning “the red one.” Mars is the most studied planet after Earth.

*Mars, 4th planet from the sun*

*(*[*http://nssdc.gsfc.nasa.gov/image/planetary/mars/hst\_mars\_opp\_9709a.jpg*](http://nssdc.gsfc.nasa.gov/image/planetary/mars/hst_mars_opp_9709a.jpg)*)*



The first recorded reference of Mars was made in 1534 BCE by Egyptian astronomers who described it as a wandering object in the night sky. They described that the planet appeared as a star but moved differently than other stars. It would slow down and even reverse its course, and then return to the original course. Astronomers of the Neo-Babylonian Empire (626 BCE–539 BCE) regularly recorded the positions of the planets. They detailed Mars’s orbital period and its passage through the zodiac. By the 5th–4th century BCE, the Greeks made additional observations on Mars’s behavior, which helped them better understand its position in the solar system.

The first to observe Mars with a telescope was Galileo Galilei in 1610. His goal was to determine if Mars exhibited phases as the Moon does. Galileo did note that Mars’s angular size did seem to decrease. Mars’s phases were observed by a Polish astronomer, Johannes Hevelius, in 1645. In 1659, the first map of Mars that displayed terrain features was produced by Christiaan Huygens, a Dutch astronomer. He also determined that the rotation period of the planet was about 24 hours. Domenico Cassini, an Italian astronomer, improved on Huygens’s measurement and determined that the rotation was closer to 24 hours and 40 minutes. Cassini also observed a fuzzy white cap at Mars’s north pole in 1672, which for the next 300 years people assumed was either snow or ice. We now refer to them as the polar ice caps.

By the 20th century, improvements in the resolution of telescopes made it possible to see surface features on Mars. One of the features researchers saw a network of long, straight canals. This led to the hypothesis that the canals were an indication of a civilization that used them to move water from the poles to the dry center of the planet. Other researchers argued that there could not be canals with water because the surface temperatures on Mars were too cold. The controversy concerning the canals was not settled until spacecraft arrived near Mars and revealed that Mars was a barren world with no signs of life or civilization.

The following information gathered from various NASA documents provides an overview of the history of some of the spacecraft studying Mars.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| |  |  |  | | --- | --- | --- | | **DATE** | **SPACECRAFT** | **RESULTS** | | 1964 | Mariner 4 (orbiter) | Sent images of Moon-like, cratered terrain. Measured atmospheric pressure and daytime temperatures. | | 1969 | Mariner 6 and 7 (orbiters) | Sent images of equator and south pole which showed the surface to be very different from that of the moon. | | 1971 | Mariner 9 (orbiter) | Mapped 80% of Mars, discovering volcanoes and canyons. | | 1976 | Viking 1 and 2 (orbiter and lander) | First successful landing on Mars. Took close-up pictures and carried out biological experiments to look for possible signs of life. | | 1996 | Mars Pathfinder (lander and small robotic wheeled rover) | Rover was named Sojourner. Took and returned more than 17,000 images. Performed chemical analyses of rocks and soils. Collected extensive data on wind and weather factors. | | 1997 | Mars Global Surveyor (orbiter) | Studied entire Martian surface, atmosphere and interior over period of several years. | | 2001 | Mars Odyssey (orbiter) | Discovered vast amounts of water ice buried below the surface in the polar regions. | | 2003 | Spirit and Opportunity (rovers) | The Mars Exploration Rover Mission launched and landed the two rovers on opposite sides of Mars. Both found evidence that water once flowed on the planet. | | 2006 | Mars Reconnaissance Orbiter (orbiter) | The goal for this orbiter was to search for evidence that water persisted on the surface of Mars for a long period of time. It has confirmed that liquid water flows on today’s Mars. This orbiter continues today (2017) to send back pictures and data. | | 2008 | Phoenix (lander) | It landed near the northern pole. Scientists designed it to study the history of water and search for complex organic molecules in the soil. It confirmed water ice, observed falling snow, found perchlorate in rocks. | | 2012 | Curiosity (rover) | The rover is part of the Mars Science Laboratory Mission. Its main scientific goals are to help determine whether Mars could have ever supported life, determine the role of water, and study the climate and geology of Mars. It is still operating today (2017). | | 2014 | MAVEN (Mars Atmosphere and Volatile Evolution Mission) (probe) | It was design to study the Martian atmosphere and determine how the planet’s water and atmosphere were lost over time. | |

**Composition and** **geology**

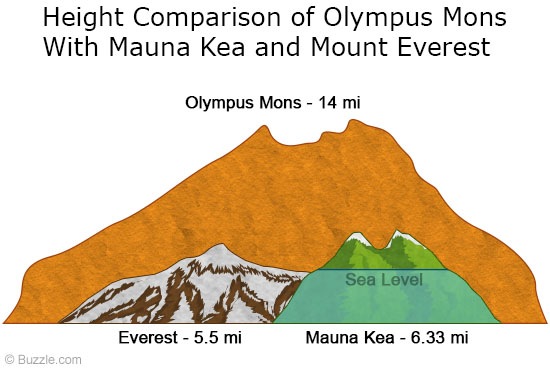
Mars is the second smallest planet, next to Mercury. It is a rocky body about one half the size of Earth. Although Mars is half the diameter of Earth, it has the same amount of dry land. The planet’s red color is due to iron-rich minerals. The iron minerals oxidize or rust, causing the soil to look red. Martian soil is rich in minerals containing silicon, oxygen, iron, magnesium, sodium, potassium and chlorine. The soil is slightly alkaline, with a pH of about 7.7. The crust is largely basalt, an igneous rock, which is also common in the crusts of Earth and the Moon. Basalt is rich in magnesium oxide, MgO, and calcium oxide, CaO, and low in silicon dioxide, SiO2. Some crustal rock may be a form of andesite, another igneous rock, which has more silicon dioxide than basalt.

There is no global magnetic field in Mars, yet Mars Global Surveyor orbiter found areas of the Martian crust in the southern hemisphere that are about ten times more strongly magnetized than anything measured on Earth. This provides an indication that an ancient magnetic field once existed on Mars.

Mars has the highest mountain and the deepest, longest valley in the solar system. Olympus Mons, once a volcano, is 16 miles (25 kilometers) high, which is about three times as tall as Mt. Everest.

*Olympus Mons compared to   
the state of Arizona*

*(*[*https://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html*](https://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html)*)*

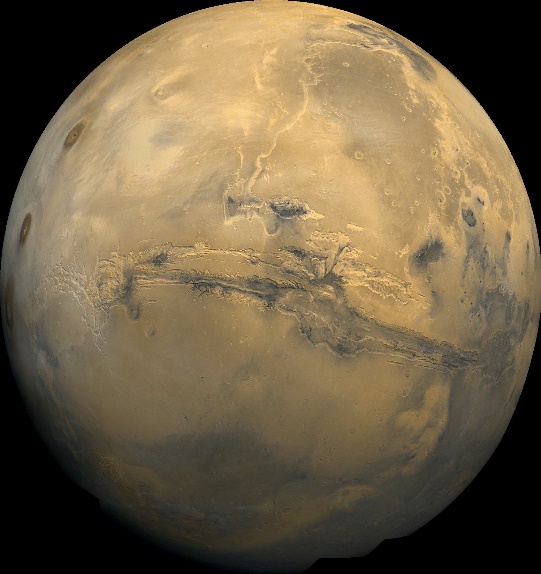


*(*[*http://www.buzzle.com/articles/facts-about-olympus-mons-a-large-shield-volcano-on-mars.html*](http://www.buzzle.com/articles/facts-about-olympus-mons-a-large-shield-volcano-on-mars.html)*)*

The Valles Marineris system of valleys is 6 miles (10 kilometers) deep in spots and runs east-west for roughly 2500 miles (4000 kilometers). These mountains that were once volcanoes are believed to have been active 2–3 billion years ago. Channels, valleys, and gullies exist all over the Mars surface. They suggest that liquid water might have flowed across the planet’s surface at one time. Scientists believe that Mars experienced a giant flood over 3.5 billion years ago; however, they do not know where the flood water came from, how long it lasted, or where it went.

*Valles Marineris*

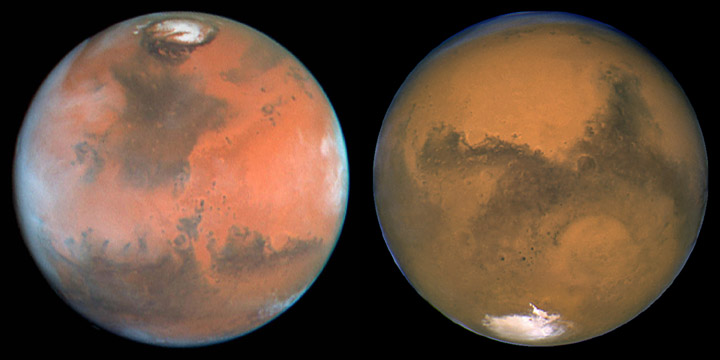
*(*[*https://www.nasa.gov/multimedia/imagegallery/image\_feature\_83.html*](https://www.nasa.gov/multimedia/imagegallery/image_feature_83.html)*)*



At the poles of Mars are vast deposits of finely layered stacks of (water) ice and solid carbon dioxide (dry ice), which extend from the pole to about 80 degrees latitude. There is a polar ice cap all year long, which grows in the winter and shrinks in the summer. The permanent northern polar ice cap is mostly water, while the one in the south is predominantly carbon dioxide ice, with some water ice. At times the northern permanent cap is 10 times larger than the southern cap. Scientists have no explanation for the differences at this time.

*Polar ice caps on Mars*

*(*[*http://www.windows2universe.org/mars/places/mars\_poles\_image\_gallery.html*](http://www.windows2universe.org/mars/places/mars_poles_image_gallery.html)*)*



Mars has two moons, Phobos and Deimos. They are named after the sons of the Greek god of war. Phobos means “fear” and Deimos means “rout”. These moons are composed of carbon-rich rock, mixed with ice covered in dust and loose rocks. They are small compared to the Earth’s moon. They are potato shaped because they have too little mass for gravity to make them spherical. Although it is uncertain how these moons were “born”, it is strongly believed that they may have been asteroids captured by Mars’s gravitational pull. Phobos is gradually getting closer to Mars each century and will eventually either crash into Mars or break up to form a ring of debris around the planet.

*Moons of Mars—Phobos and Deimos*

*(*[*http://www.universetoday.com/14701/mars/*](http://www.universetoday.com/14701/mars/)*)*



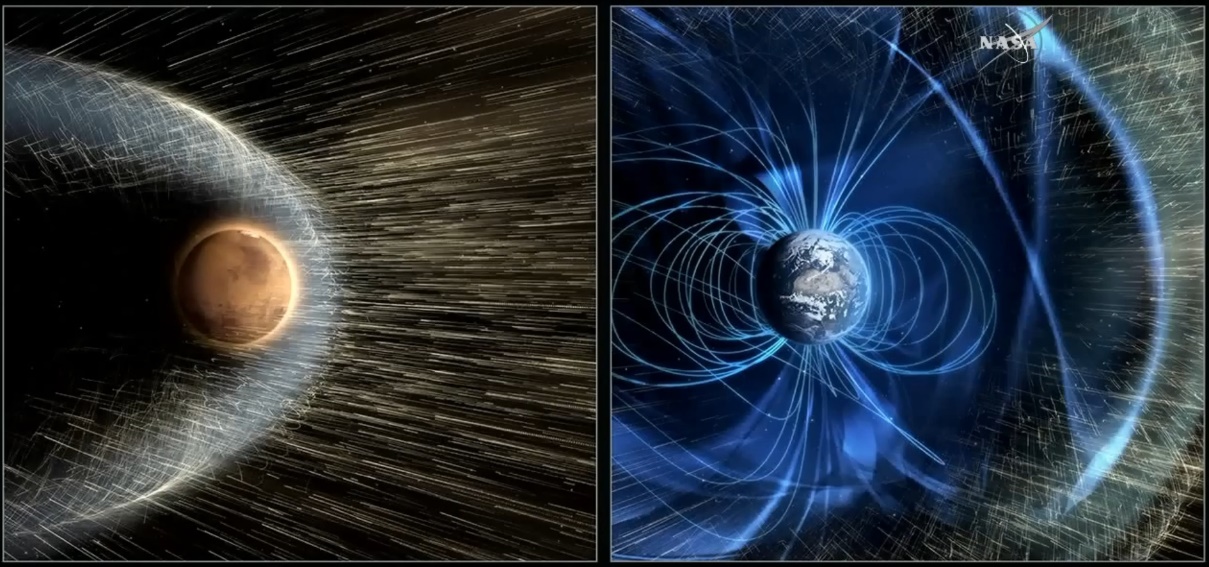
**Atmosphere and Climate of Mars**

Mars has a very thin atmosphere. The atmospheric pressure varies between 0.4 and 0.87 kilopascals, which is equivalent to about 1% of Earth’s atmospheric pressure at sea level. The composition of the Mars atmosphere consists of 95% carbon dioxide, CO2; 2.7% nitrogen, N2; 1.6% argon, Ar; 0.13% oxygen, O2; and 0.08% carbon monoxide, CO. Because the atmosphere is predominantly carbon dioxide, the Martian atmospheric pressure changes with the season. During the summer, the CO2 sublimes from the polar ice caps enough to increase the pressure. The pressure falls in the winter when the CO2 refreezes as snow (dry ice). The atmosphere is dusty and contains particulates that measure about 1.5 micrometers in diameter. This gives the sky a brownish-red color from the surface of the Mars.

At one time Mars had a much thicker atmosphere. Scientists did not know if the atmosphere was lost to space or absorbed by the planet, until NASA’s MAVEN orbiter arrived. From the data it collected scientists determined that the atmosphere was lost to space over four billion years ago. The stripping of the atmosphere continues today at a much slower rate. The loss of the atmosphere is due to solar winds, composed of mainly protons and electrons from the sun, which produce an electric field that accelerates ions in the upper Martian atmosphere to an escape velocity. The strong magnetic field on Earth prevents this from happening here.

Mars once had a strong magnetic field--like Earth does now--produced by a dynamo effect from its interior heat. But as the smaller planet cooled, Mars lost its magnetic field sometime around 4.2 billion years ago, scientists say. During the next several hundred million years, the Sun’s powerful solar wind stripped particles away from the unprotected Martian atmosphere at a rate 100 to 1,000 times greater than that of today.

(<https://arstechnica.com/science/2015/11/how-mars-lost-its-atmosphere-and-became-a-cold-dry-world/>)



*Without a strong magnetic field like Earth, Mars is laid bare due to solar winds.*

*(*[*https://arstechnica.com/science/2015/11/how-mars-lost-its-atmosphere-and-became-a-cold-dry-world/*](https://arstechnica.com/science/2015/11/how-mars-lost-its-atmosphere-and-became-a-cold-dry-world/)*)*

Mars is much colder than Earth, due to its thin atmosphere and its greater distance from the sun. Mars does experience seasons, much like Earth, due to the tilt of its rotational axis. Because of its slightly elliptical orbit around the sun, the length of the seasons on Mars vary. The average temperature is about –80 oF (–60 oC); however, there is a wide range of temperatures on the planet. Near the poles during the winter, the temperature can drop to   
–195 oF (–125 oC). During the summer near the Martian equator, the temperature can reach   
95 oF (35 oC). These temperatures currently prevent liquid water existing on the Martian surface for any length of time.

Mars experiences dust storms that are the largest in the solar system; these can blanket the entire planet and last for months. During the warmer season, the sun heats up the atmosphere and causes small convection currents that lift dust into the atmosphere. The airborne dust particles absorb sunlight and heat up the atmosphere further, which causes more wind, lifting more dust into the air. This cycle continues and creates tornado-like dust storms.

The table below compares the characteristics of Mars to those of Earth.

|  |  |  |
| --- | --- | --- |
|  | **Mars** | **Earth** |
| **Atmosphere** (composition) | Carbon dioxide (95.32%)  Nitrogen (2.7%)  Argon (1.6%)  Water vapor (0.03%)  Nitric oxide (0.01%) | Nitrogen (77%)  Oxygen (21%)  Argon (1%)  Carbon dioxide (0.038%) |
| **Atmosphere** (pressure) | 7.5 millibars (average) | 1013 millibars (at sea level) |
| **Deepest canyon** | **Valles Marineris**  7 km (4.35 miles) deep  4000 km (2485 miles) wide | **Grand Canyon**  1.8 km (1.1 miles) deep  400 km (248.5 miles) long |
| **Distance from the sun** (average) | 227,936,637 kilometers (142,633,260 miles) | 149,597,891 kilometers  (92,955,820 miles) |
| **Equatorial radius** | 3,397 kilometers (2,111 miles) | 6,378 kilometers (3,963 miles) |
| **Gravity** | 0.375 that of Earth | 2.66 times that of Mars |
| **Largest volcano** | **Olympus Mons**  26 kilometers (16 miles) high  602 kilometers (374 miles) in diameter | **Mauna Loa (Hawaii)**  10.1 kilometers (6.3 miles) high  121 kilometers (75 miles) in diameter |
| **Length of day** (time required to make a full rotation onits axis) | 24 hours 37 minutes | Just slightly under 24 hours |
| **Length of year** (time required to make a complete orbit of the sun) | 687 Earth days | 365 days |
| **Polar caps** | Covered with a mixture of carbon dioxide ice and water ice | Permanently covered with water ice |
| **Surface temperature** (average) | –81 oF (–63 oC) | 57 oF (14 oC) |
| **Tilt of axis** | 25 degrees | 23.45 degrees |
| **# of satellites** | 2 (Phobos and Deimos) | 1 (Moon) |

(<http://phoenix.lpl.arizona.edu/mars111.php>)

**Plant growth and nutrients**

Many factors affect the growth of a plant, and each kind of plant has its own needs and requirements. All plants do require certain basic environmental factors in their environment. If any one factor is less than ideal, it will become a limiting factor in the plant’s growth. The basic environmental factors are: light, temperature, water, pH, and nutrients.

The energy source for plants is **sunlight**. There are three principle characteristics of light that affect plant growth. The quantity of light, which is the intensity or concentration of sunlight, is the first factor. The intensity varies with the season. During the summer it is at its maximum and it is at a minimum in winter. The more sunlight a plant receives, the more photosynthesis occurs and the more food the plant produces. The quality of light is another characteristic. This refers to the color or the wavelength reaching the plant surface. Red and blue light increase plant growth the most. Green light is mostly reflected, which is why plants look green, so it has little effect on plant growth. The third factor is the duration or photoperiod of the light. The photoperiod relates to the amount of time the plant is exposed to sunlight, and it triggers flowering. Actually, it is not the length of daylight, but the length of uninterrupted dark periods that is critical.

**Temperature** affects plant growth. Plants grow best within an optimum range of temperatures. For some species the optimum range maybe wide, while for others it is narrow. The temperature must allow the plant to carry on life-sustaining chemical reactions. Plants experience abnormal growth and reduced production when the temperatures are either too high or too low. Warm season vegetables and most flowers grow best when the temperatures are between 60 oF (15 oC) and 80 oF (27 oC). Cool season vegetables, like spinach and lettuce, grow best between 50 oF (10 oC) and 70 oF (21 oC).

**Water** is essential for plant growth, even though different plants have different needs. Some plants tolerate drought, some need winter rains, and others need a consistent supply of moisture to grow well. Water is a primary component in photosynthesis. It also plays a critical role as a solvent for minerals moving into a plant. Water maintains the firmness of tissue, referred to as turgor pressure. The turgor pressure regulates the opening and closing of the stomata, which regulates the plants respiration. Water pressure helps the roots move through the soil.

The **pH** of the soil and water affect the ability of plant roots to take up certain nutrients. Most plants grow best in soils that have a relatively neutral pH (pH = 7). Some plant such as azaleas and blueberries thrive in slightly acidic soil (pH=6). The solubility of trace elements is controlled by pH and only soluble nutrients can be used by the plant. For instance, iron is not soluble when the pH is high (basic) and iron deficiencies are often present in high pH soils even when the soil contains plenty of iron.

There are sixteen elements that are important to plant’s growth and survival. They can be divided into two categories; **non-mineral nutrients** and **mineral nutrients**. The non-mineral nutrients are carbon, hydrogen and oxygen and are obtained from the air and water. Carbon dioxide and water are converted to sugars by photosynthesis. Since these elements come from the air and water there is little that can be controlled by farmers and gardeners. The remaining 13 essential elements, which are the mineral nutrients, are taken up from the soil and can be grouped into three categories: primary macronutrients, secondary macronutrients and micronutrients.

The **primary macronutrients** are nitrogen, phosphorus and potassium. These nutrients are the ones used in the largest quantities by plants and, as a result, are frequently the first elements to be depleted in the soil. Fertilizers generally contain these three nutrients and the percentage of each is given as a three-number combination. A general balanced fertilizer would be labeled (10-10-10) which would be 10% nitrogen, 10% phosphorus expressed as P2O5 and 10% potassium expressed as K2O. Most lawns and grasses need nitrogen, so a (20-10-10) fertilizer would be a good choice.

*Example of an all-purpose fertilizer*

*(*[*https://www.yardcaregurus.com/what-do-fertilizer-numbers-mean/*](https://www.yardcaregurus.com/what-do-fertilizer-numbers-mean/)*)*



The **secondary macronutrients** are calcium, magnesium and sulfur. These elements are needed in smaller quantities than the primary macronutrients. Generally, soils have sufficient quantities of these elements. Dolomitic lime (a mixture of calcium carbonate and magnesium carbonate) is used when soils are too acidic, or deficient in calcium or magnesium. Sulfur usually comes from decaying organic matter.

**Micronutrients** are those elements needed in very small amounts by plants. The micronutrients are iron, manganese, zinc, copper, boron, molybdenum and chlorine. Although only needed in very small amounts, their importance is still great. If there is a shortage of them, it can limit the plant’s growth and crop yield. Without sufficient amounts, the plant can even die.

Below is a table giving some of the roles each of these essential elements play.

|  |  |
| --- | --- |
| **Element** | **Function** |
| **Primary Macronutrients** | |
| Nitrogen | · Necessary for formation of amino acids, the building blocks of protein  · Essential for plant cell division, vital for plant growth  · Directly involved in photosynthesis as an element in chlorophyll · Necessary component of vitamins  · Aids in production and use of carbohydrates  · Affects energy reactions in the plant |
| Phosphorus | · Involved in photosynthesis, respiration, energy storage and transfer, cell division, and enlargement  · Promotes early root formation and growth  · Improves quality of fruits, vegetables, and grains  · Vital to seed formation  · Helps plants survive harsh winter conditions  · Increases water-use efficiency  · Hastens maturity |
| Potassium | · Carbohydrate metabolism and the break down and translocation of starches  · Increases photosynthesis  · Increases water-use efficiency  · Essential to protein synthesis  · Important in fruit formation  · Activates enzymes and controls their reaction rates  · Improves quality of seeds and fruit  · Improves winter hardiness  · Increases disease resistance |
| **Secondary Macronutrients** | |
| Calcium | · Utilized for continuous cell division and formation  · Involved in nitrogen metabolism  · Reduces plant respiration  · Aids translocation of photosynthesis products from leaves to fruiting organs  · Increases fruit set  · Essential for nut development in peanuts  · Stimulates microbial activity |
| Magnesium | · Key element of chlorophyll  · Improves utilization and mobility of phosphorus  · Activator and component of many plant enzymes  · Increases iron utilization in plants  · Influences earliness and uniformity of maturity |
| Sulfur | · Integral part of amino acids  · Helps develop enzymes and vitamins  · Promotes nodule formation on legumes  · Aids in seed production  · Necessary in chlorophyll formation (though it isn’t one of the constituents) |
| **Micronutrients** | |
| Boron | · Essential of germination of pollen grains and growth of pollen tubes  · Essential for seed and cell wall formation  · Promotes maturity  · Necessary for sugar translocation  · Affects nitrogen and carbohydrate |
| Chlorine | · Not much information about its functions  · Interferes with P uptake  · Enhances maturity of small grains on some soils · Aids in plants metabolism |
| Copper | · Catalyzes several plant processes  · Major function in photosynthesis  · Major function in reproductive stages  · Indirect role in chlorophyll production  · Increases sugar content  · Intensifies color  · Improves flavor of fruits and vegetables |
| Iron | · Promotes formation of chlorophyll  · Acts as an oxygen carrier  · Reactions involving cell division and growth |
| Manganese | · Functions as a part of certain enzyme systems  · Aids in chlorophyll synthesis  · Increases the availability of P and Ca |
| Molybdenum | · Required to form the enzyme "nitrate reductase" which reduces nitrates to ammonium for protein synthesis · Aids in the formation of legume nodules  · Needed to convert inorganic phosphates to organic forms in the plant |
| Zinc | · Aids plant growth hormones and enzyme system  · Necessary for chlorophyll production  · Necessary for carbohydrate formation  · Necessary for starch formation  · Aids in seed formation |

(<http://eldoradochemical.com/fertiliz1.htm>)

**Fertilizers**

Soil used repeatedly to grow plants will eventually become deficient in the nutrients needed for healthy plant growth. Fertilizers are used to add nutrients to the soil so growing plants have an adequate supply. Fertilizers can either be organic or inorganic. Organic fertilizers are substances that are derived from natural organisms, such as plants and animals. Examples of organic fertilizers include manure (excreta from animals), bone meal, fish emulsion, and decomposed vegetation. Since these fertilizers are complex organic materials, they decompose slowly and the nutrients are released slowly. The nutrients in organic fertilizers are not water soluble. Soil microbes play an important role in converting nutrients into soluble ones that can be absorbed by the plant. These fertilizers contain a wide range of nutrients but at a low concentration. In addition, organic fertilizers tend to improve the soil structure and water-holding capacity.

Inorganic fertilizers are mineral in nature. Today most of these are synthetic and are the result of a chemical process. They are typically salts containing nitrogen, phosphorus, and potassium, as well as other macronutrients and micronutrients. Inorganic fertilizers may contain such salts as ammonium nitrate, NH4NO3, ammonium sulfate, (NH4)2SO4, diammonium phosphate, (NH4)2HPO4, potassium chloride, KCl, and potassium nitrate, KNO3. Inorganic fertilizers usually contain the three essential nutrients—nitrogen, phosphorus and potassium. They can be produced so that the nutrient content is suitable for the type of plants being grown. These fertilizers are water-soluble and can be taken up by the plant almost immediately. For that reason, it is necessary to be careful in applying inorganic fertilizers, for too much can damage the plant. The inorganic fertilizer can be formulated for immediate use or for the slow release of the nutrients. The inorganic fertilizer does little to improve the soil texture and some have a high acid content, which can affect the soils fertility.

One of the problems with inorganic fertilizers is that the nitrogen compounds are very water soluble and, frequently, much of it is washed away before plants can absorb it. This requires the use of more fertilizer, which is expensive and creates environmental problems with excess nitrogen in natural waters. Slow release fertilizers are available, but they are expensive. These are usually made by coating urea with water-insoluble sulfur or a polymer. The slow release fertilizers have not been very effective in increasing crop yield.

Gehan Amaratunga, an engineer from the University of Cambridge, is experimenting with a new approach using nanotechnology.

They [Amaratunga and his colleagues] attached urea molecules to nanoparticles of hydroxyapatite, a naturally occurring form of calcium phosphate found in bone meal. Hydroxyapatite is nontoxic and a good source of phosphorus, which plants also need. In water, the urea-hydroxyapatite combination released nitrogen for about a week, compared with a few minutes for urea by itself. In field trials on rice in Sri Lanka, crop yields increased by 10%, even though the nanofertilizer delivered only half the amount of urea compared with traditional fertilizer.

(<http://cen.acs.org/articles/95/web/2017/02/Slow-release-nitrogen-fertilizer-increase.html>)

The nanofertilizer is a little more expensive than traditional fertilizer but since less fertilizer is needed the cost is not a factor. The experimentation with the nanofertilizer continues but looks very promising.

**Photosynthesis**

Photosynthesis is the process by which plants, algae and certain bacteria capture light energy and convert it to chemical energy. In the process, sugars, such as glucose, are synthesized from carbon dioxide and water. Oxygen is release as a byproduct. The sugar molecules provide organisms with two important resources: energy and organic carbon.

There are two types of photosynthesis: oxygenic photosynthesis and anoxygenic photosynthesis. Oxygenic photosynthesis is the most common and is what occurs in plants, algae and cyanobacteria. During oxygenic photosynthesis electrons are transferred from water to carbon dioxide, driven by light energy. Carbohydrates and oxygen are produced in the process. The process is complex and a series of multistep reactions. The overall reaction is generally given as:

6 CO2 + 6 H2O + light energy 🡪 C6H12O6 + 6 O2

The anoxygenic photosynthesis uses electron donors other than water. This process usually occurs in bacteria, such as purple bacteria or green sulfur bacteria. Since water is not the electron donor, this process does not produce oxygen. The byproduct produced depends on the electron donor. An example of an electron donor is hydrogen sulfide, H2S, which is used by many bacteria. When hydrogen sulfide is used, solid sulfur is the byproduct. The overall general equation is given as:

n CO2 + 2n H2A + light energy 🡪 (CH2O)n + 2n A + n H2O

where H2A is the variable electron donor and A would be the by product.

The cellular components that play an essential role in photosynthesis are pigments, plastids, antenna, and reaction centers. Pigments are molecules that give plants, algae and bacteria their color. They are responsible for trapping sunlight. Different colored pigments absorb different wavelengths. There are three main groups of pigments. Chlorophylls are green pigments that absorb blue and red light. Carotenoids are pigments that are red, orange or yellow. They absorb bluish-green light. The third type of pigment is phycobilins; some of these are red and some are blue in color. They tend to absorb wavelengths of light that are not absorbed by the other two. They are seen primarily in cyanobacteria and red algae.

Plastids are organelles found in the cells of plants and algae and are the site of manufacture and storage of important chemical compounds used by the cell. Three plastids in plants include leucoplasts, chromoplasts and chloroplasts. Leucoplasts store fats and starch and do not involve synthetic activities. Chromoplasts contain many red, yellow and orange pigments commonly found in flowers and fruits. Chloroplasts contain chlorophylls; photosynthesis occurs in chloroplasts.

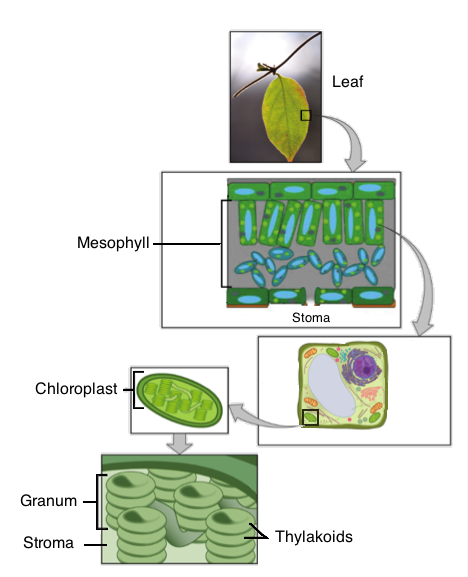
A large collection of pigment molecules (100–5000) create the components known as antennae. The pigment molecules are associated with proteins that allow them to be flexible so they can move toward the light. Antennae are complex light harvesting systems that capture the light energy from the sun and transfer it to the reaction centers.

The reaction center is a complex of pigments and proteins that converts light energy to chemical energy. This begins the process of electron transfer.

In plants, photosynthesis predominantly occurs in the leaves.

*Structure of   
photosynthesis components*

*(*[*https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis*](https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis)*)*



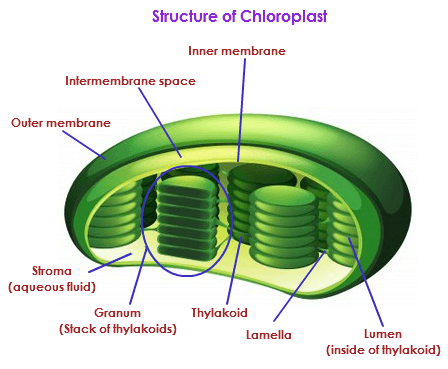
The cells in a middle layer of leaf tissue called the **mesophyll** are the primary site of photosynthesis. Small pores called **stomata**—singular, stoma—are found on the surface of leaves in most plants, and they let carbon dioxide diffuse into the mesophyll layer and oxygen diffuse out. Each mesophyll cell contains organelles called chloroplasts, which are specialized to carry out the reactions of photosynthesis. Within each chloroplast, disc-like structures called **thylakoids** are arranged in piles like stacks of pancakes that are known as **grana**—singular, granum. The membrane of each thylakoid contains green-colored pigments called **chlorophylls** that absorb light. The fluid-filled space around the grana is called the **stroma**, and the space inside the thylakoid discs is known as the **thylakoid space**. Different chemical reactions occur in the different parts of the chloroplast.

(<https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis>)

Photosynthesis is a complicated series of steps, but the process can be broken down into two stages: light-dependent reactions and light-independent reactions. The light-dependent reactions occur in the thylakoid membrane of the chloroplast, where chlorophyll pigment is located. When a photon of light hits the reaction center, it energizes an electron in chlorophyll. The chlorophyll releases an electron. The electron escapes by travelling through an electron transport chain in the thylakoid membrane.

*Structure of chloroplast*

*(*[*http://biology.tutorvista.com/animal-and-plant-cells/chloroplasts.html*](http://biology.tutorvista.com/animal-and-plant-cells/chloroplasts.html)*)*

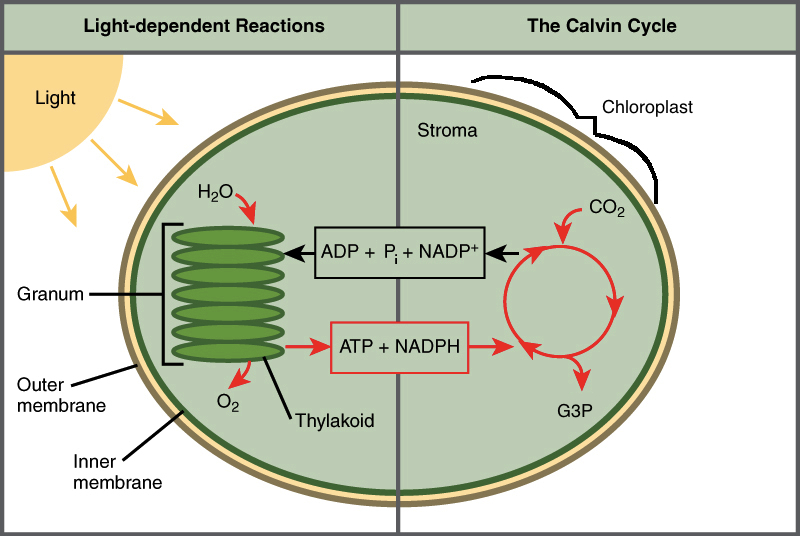


Every step in the electron transport chain brings each electron to a lower energy state. The energy is harnessed by producing ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate). ATP serves as a source of chemical energy for cells and NADPH is a reducing agent that supplies electrons and hydrogen ions, H+. Each chlorophyll molecule replaces its lost electron with an electron from a water molecule. Oxygen is released in the process.

In plants, carbon dioxide diffuses through the leaf’s stomata (pores in the leaf) and enters the chloroplast stroma. This is where the light-independent reactions, also called the Calvin Cycle (see diagram at right), take place. Light is not required for these reactions. The ATP and NADPH molecules provide the energy for the reactions that take the carbon from carbon dioxide (from the atmosphere) and produce a three-carbon sugar called glyceraldehyde-3-phosphate (G3P). Cells then use G3P to build a variety of sugars, including glucose, as well as other organic molecules.

*Photosynthesis processes*

*(*[*https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis*](https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis)*)*



**Oxygen generation in space**

Oxygen is necessary for life. On Earth, we have a plentiful supply of oxygen, and it is produced in photosynthesis. In space, there is an insufficient supply of oxygen to support life. On short space travels, the spaceship carries its own supply of oxygen in tanks. For extended stays in space, such as on the International Space Station, it is necessary to generate oxygen. On the International Space Station, the oxygen generators make oxygen by the electrolysis of water. This occurs by passing electric current through water. The reduction of water occurs at the cathode where electrons combine with water to produce hydrogen and hydroxide ions:

2 H2O (l) + 2e─ 🡪 H2 (g) + 2 OH─ (aq)

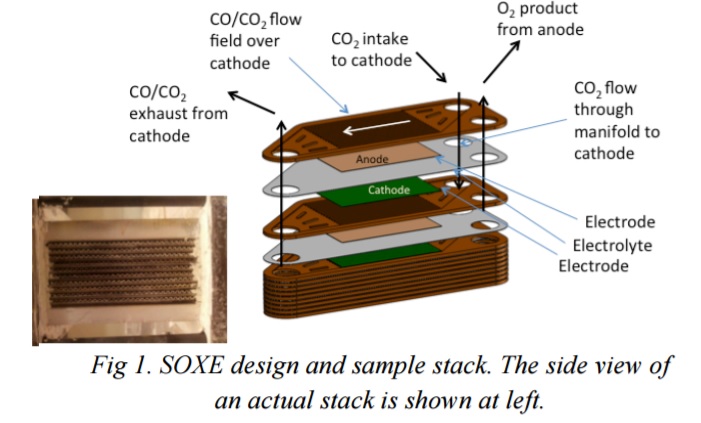
Oxidation occurs at the anode, where electrons from water flow into the anode and to the cathode. This produces oxygen and hydrogen ions.

2 H2O (l) 🡪 O2 (g) + 4 H+ (aq) + 4 e─

The water is delivered to the space station from Earth by re-supply ships. It is also condensed from the air in the space station and recycled from the astronauts’ urine. The space station’s solar panels generate the electricity.

As scientist look to send people to Mars, oxygen will need to be generated from whatever is available on Mars. As in the movie *The Martian*, NASA has announced that the Mars 2020 rover will carry an oxygen generator to the Mars surface. The Mars Oxygen In-situ Resource Utilization Experiment (MOXIE), developed by the Massachusetts Institute of Technology, will generate oxygen from carbon dioxide. The oxygen can be used for rocket fuel and, in the future, for human breathing. The Mars atmosphere is predominantly carbon dioxide, but the atmosphere is very thin. MOXIE will collect CO2 from the atmosphere, compress it to a pressure of one atmosphere, and store it. It will then be fed into the Solid Oxide Electrolyzer (SOXE) where the CO2 will be split electrochemically. The SOXE operates at temperatures between 800 oC and 850 oC, requiring sophisticated thermal insulation. An explanation of how the SOXE operates is given below.

MOXIE uses a solid oxide electrolysis (SOXE) stack developed by Ceramatec, Inc. for converting CO2 to O2. Its working elements are stacked scandia-stabilized zirconia (ScSZ) electrolyte-supported cells with thin screen-printed electrodes, coated with a catalytic cathode on one side and an anode on the other. These are separated by expansion-matched interconnects that direct the source, exhaust, and product gases to and from their respective manifolds, as illustrated in Fig. 1. The stacks operate in the 800–850°C range.



When CO2 flows over the catalyzed cathode surface under an applied electric potential, it is electrolyzed according to the reaction CO2 + 2e- ⇒ CO + O=. The CO is exhausted, while the oxygen ion is electrochemically driven through the solid oxide electrolyte to the anode, where it is oxidized (O= ⇒ O + 2e-). The O atoms combine to produce the gaseous O2.

(<http://ssed.gsfc.nasa.gov/IPM/PDF/1134.pdf>)

**Hydrazine**

Hydrazine, also known as diamine and nitrogen hydride, is a highly reactive inorganic compound with the formula N2H4. It is a colorless, flammable liquid that has a pungent smell similar to ammonia. It is a toxic irritant and sensitizer that can damage the central nervous system, producing symptoms such a tumors and seizures. Hydrazine is very useful because it is a strong reducing agent, as well as serving as a precursor for some organic syntheses.

More than 100,000 metric tons of hydrazine are produced annually. Today hydrazine is produced by many methods. One of the most common methods is called the Olin-Raschig process, developed by a German chemist named Fredrick Raschig in 1907. The process occurs in two steps. Initially sodium hypochlorite (NaOCl), the active ingredient in bleach, is mixed with ammonia (NH3) at 5 oC. This forms chloramine (NH2Cl) and sodium hydroxide (NaOH). This mixture is rapidly added to anhydrous ammonia under pressure and at 130 oC. In addition to hydrazine, water and sodium chloride are also produced, as waste products.

NaOCl + NH3  🡪 NH2Cl + NaOH

NH2Cl + NaOH + NH3 🡪 N2H4 + H2O + NaCl

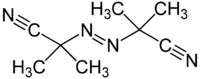
The most common use of hydrazine is to produce blowing agents.

These are gases which are blown through a liquid which causes it to foam, and then harden into a lightweight solid, an example being expanded polystyrene [Styrofoam®]. The two main blowing agents made from hydrazine are azodicarbonamide and azobisisobutyronitrile. Azodicarbonamide is used to produce foamed plastic, because when heated it decomposes into N2, CO, CO2 and NH3 which then get trapped as bubbles in the polymer. Azobisisbutyronitrile is also used as a foamer in plastics and rubber, but is also used as a radical initiator in polymerization reactions because it readily expels N2 gas leaving two CN-substituted cyclopropane radicals behind to begin the free-radical chain reaction.

(<http://www.chm.bris.ac.uk/motm/hydrazine/hydrazineh.htm>)

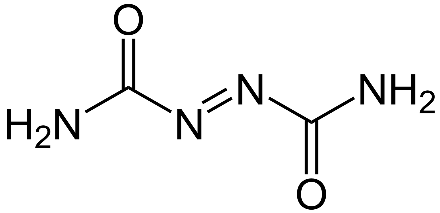
*Azobisisobutyronitrile*

*(*[*https://en.wikipedia.org/wiki/Azobisisobutyronitrile*](https://en.wikipedia.org/wiki/Azobisisobutyronitrile)*)*



*Azodicarbonamide*

*(*[*https://en.wikipedia.org/wiki/Azodicarbonamide*](https://en.wikipedia.org/wiki/Azodicarbonamide)*)*



Sodium azide (NaN3), which is used to activate automobile air bags, is produced by the reaction between hydrazine and sodium nitrite. Sodium azide decomposes rapidly when it is heated, creating a huge volume of gas filling the air bag to protect the person in the car.

NaNO3 + N2H4 🡪 NaN3 + H2O2

2 NaN3 (s) 🡪 2 Na(s) + 3 N2 (g)

Hydrazine is a strong reducing agent with by-products of only water and nitrogen gas. For that reason, it is commonly used as an oxygen scavenger and corrosion inhibitor in water cooling systems of power plants:

N2H4 + O2 🡪 H2O + N2

Hydrazine is used to reduce metal oxides back to metals. An example of this is the reduction of plutonium oxide in nuclear waste back to plutonium metal.

As in *The Martian*, hydrazine is also used as rocket fuel propellant. It is used mainly for the maneuvering thrusters of spacecraft. Hydrazine was used to power the Space Shuttle auxiliary power units. Hydrazine-fueled rocket engines are used in the terminal descent of spacecraft. These were used on the Viking program landers in the 1970s. They were also used on the Phoenix lander in 2008 as well as the Curiosity rover in 2012.

Hydrazine is used as a monopropellant, which is a chemical propulsion fuel that does not require a separate oxidizer for the reaction. In the monopropellant engine, the hydrazine passes over an iridium metal catalyst that causes it to decompose rapidly, producing ammonia, nitrogen and hydrogen. The decomposition reactions (reactions #1 and #2 below) are extremely exothermic, causing the reaction chamber to reach temperatures of 800 oC in milliseconds. The final reaction is endothermic which takes away some of the heat and produces even more nitrogen and hydrogen gas. These reactions produce a large volume of hot gases from a small volume of liquid, making hydrazine an efficient propellant. The hot gases are forced out of the rocket through a tight nozzle to create thrust.

1. 3 N2H4  → 4 NH3  + N2
2. N2H4  → N2  + 2 H2
3. 4 NH3  + N2H4  → 3 N2  + 8 H2

# References

**(non-Web-based information sources)**

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles   
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen).**

**Selected articles and the complete set of   
Teacher’s Guides for all issues from the past three   
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



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The article “Life on Mars” describes the purpose and the experiments performed by the Viking 1 and Viking 2 spacecraft that landed on Mars in 1976. One of the purposes of the landers was to determine if there was life on Mars. The experiments describe the theory behind them, what they detected and the analysis of the results. (Scott, D. Life on Mars. *ChemMatters*, 1994, *12* (4), pp 10–13)

The exploration of Mars by the Pathfinder spacecraft and its robotic rover, Sojourner, are described in this article. The soil of Mars was examined, and it was determined that it has many similarities to the soil on Earth. The article explains the methods used to analyze the Martian soil and rocks. (Stone, C. Clues from a Far Planet. *ChemMatters*, 1998, *16* (2), pp 7–9.)

This article describes the purpose of the Mars Science Laboratory that was sent to Mars in 2010. The purpose of this mission was to search for carbon. In the article, the various methods to detect carbon are explained. (Bleacher, L. Follow the Carbon. Follow the What? *ChemMatters*, 2008, *26* (1) pp 16–19.)

The importance of nitrogen in fertilizer is described in this article. It includes a good explanation of the nitrogen cycle. The use of manure and some advantages of organic farming are described. The hazards of excess nitrogen in the environment is also explored. (Nolte, B. Nitrogen From Fertilizers: Too Much of a Good Thing. *ChemMatters*, *28* (2), pp 5–7.)

The Teacher’s Guide for the April 2010 ChemMatters fertilizer article above provides more information on nitrogen, its compounds and its pollution. It also contains the sources for a nitrogen cycle activity as well as a simulation on the nitrogen cycle.

# Web Sites for Additional Information

**(Web-based information sources)**

**Mars**

This NASA site has a graphic comparison of Mars and Earth. (<http://mars.nasa.gov/allaboutmars/facts/#infographic>)

This is a short article produced by *National Geographic* and NASA about Mars, its water and its landscape. In addition, there are nice graphics of Mars, its moons and its relationship to our solar system. (<http://science.nationalgeographic.com/science/space/solar-system/mars-article/>)

At this site you will find a more detailed article about Mars. It includes information about the size, orbit, composition, moons, atmosphere and climate of Mars. There are also several imbedded videos in the article dealing with Mars. (<http://www.universetoday.com/14701/mars/>)

Another extensive article about Mars, it composition, atmosphere, and climate can be found at <http://www.space.com/47-mars-the-red-planet-fourth-planet-from-the-sun.html>.

**Plant growth and nutrients**

The basic needs of plants are briefly discussed at this site: <http://www.aces.uiuc.edu/vista/html_pubs/hydro/require.html>.

This is an extensive article about the nutrient requirements for plants. It provides information on the role each nutrient plays. (<http://www.ncagr.gov/agronomi/pdffiles/essnutr.pdf>)

More information about plant nutrients can be found at this site. The information at this site is a little more concise and given in a bulleted format. (<http://www.ncagr.gov/cyber/kidswrld/plant/nutrient.htm>)

This article provides a comparison between inorganic and organic fertilizer. It provides the comparison in a chart, as well as providing a discussion on the history, cost, and supply of nutrients. (<http://www.diffen.com/difference/Chemical_Fertilizer_vs_Organic_Fertilizer>)

At this site, a graphic comparison of organic and inorganic fertilizers can be found. (<http://www.majordifferences.com/2013/10/difference-between-organic-manures-and.html#.WK3oNzsrJPZ>)

**Photosynthesis**

A basic explanation of photosynthesis is given at this site. It includes a discussion of the cellular components essential for photosynthesis, as well as the photosynthetic process. (<http://www.livescience.com/51720-photosynthesis.html>)

This article on photosynthesis includes illustrations that help in the understanding of the process. (<http://www.nature.com/scitable/topicpage/photosynthetic-cells-14025371>)

A study guide on photosynthesis for students can be found at this site. It provides a review of the processes involved, study questions, and a photosynthesis quiz. (<http://chemistry.about.com/od/lecturenotesl3/a/photosynthesis.htm>)

The Khan tutorial on the introduction of photosynthesis can be found at this site. The explanation of photosynthesis includes graphics to aid in student understanding. More tutorials on the specific processes involved in photosynthesis can be accessed from this site as well. (<https://www.khanacademy.org/science/biology/photosynthesis-in-plants/introduction-to-stages-of-photosynthesis/a/intro-to-photosynthesis>)

**Oxygen generation in space**

This short NASA article discusses the Mars Oxygen ISRU Experiment (MOXIE), which will be on the Mars Rover in 2020 and will make oxygen from carbon dioxide. It includes a schematic of how it will work. (<http://mars.nasa.gov/mars2020/mission/instruments/moxie/for-scientists/>)

This article explains the scientific process that MOXIE will use to generate oxygen on Mars. (<http://ssed.gsfc.nasa.gov/IPM/PDF/1134.pdf>)

A technical paper on the production of oxygen using solid oxide electrolysis is found at this site. It explains the process as well as the experimentation that has occurred to test the process. (<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.194.6749&rep=rep1&type=pdf>)

At this site, the production of oxygen on the International Space Station is discussed and explained. (<http://science.howstuffworks.com/oxygen-made-aboard-spacecraft.htm>)

**Hydrazine**

At this site, information on hydrazine, as well as sources for the information, can be found: <https://pubchem.ncbi.nlm.nih.gov/compound/hydrazine#section=Synonyms>.

A discussion of the hydrazine and its uses can be found at <https://eic.rsc.org/magnificent-molecules/hydrazine/2000023.article>.

This article on hydrazine provides a little information on how it is produced and some of its uses. The uses described include: as a reducing agent, as a precursor for organic synthesis and blowing agents, and as a rocket thruster fuel. (<http://www.chm.bris.ac.uk/motm/hydrazine/hydrazineh.htm>)