Landmark Lesson Plan:

Mars Exploration with Infrared Spectrometers

Grades: 9-12
Subject Areas: Chemistry and History
Based on the National Historic Chemical Landmark on the Infrared Spectrometer and the Exploration of Mars
Principal author: Susan Cooper

The following inquiry-based student activities are designed for use in high school chemistry lesson planning, but they apply to all science subjects and also to the history of space exploration. Some middle school teachers may also find the lesson outline helpful. The lesson plan will help students understand the importance of instrumentation on space probes.

The content is designed as a ready-to-go lesson, easily implemented by a teacher or substitute, to supplement a unit of study. The chemistry activities relate to infrared (IR) spectrometry and how it works. The history activity covers the chronology of Mars exploration and asks students to think about the future of Mars exploration. Students also practice critical reading and writing skills in the lesson.

All resources are available online at www.acs.org/LandmarkLessonPlans.

While these activities are all thematically linked to Mars exploration by the Mariner 6 and 7 spacecraft, each is designed to stand alone as an accompaniment for the article provided on pages three to five. Teachers may choose activities based on curricular needs and time considerations.

- Take a few minutes to introduce the lesson with a few conversation starters. For example, ask students what they know about Mars or if they read *The Martian* or saw the movie.
- If you use the Anticipation Guide, do not distribute the reading on "Mars Exploration with Infrared Spectrometers" until students have indicated their initial opinions. Then distribute the article for students to check their answers and find the passage that supports or refutes their initial thoughts.
- For the remaining activities, distribute the exercise(s) selected for the class along with the reading on "Mars Exploration with Infrared Spectrometers." Make sure students understand the directions for each activity. While students are reading, they should complete the exercise(s).
- After all students have read the article and completed the exercise(s), use the Answer Key for student feedback and further discussion.

Student Activities with Objectives

Anticipation Guide and Reading on "Mars Exploration with Infrared Spectrometers" (5 minute introduction, followed by 15-20 minutes of reading)

- Students examine their ideas about the importance of IR spectrometers to the exploration of Mars.

History Exercise: Chronology of Mars Exploration (10-15 minutes)

- Students chronologically order events in the reading.
- Students predict the future of Mars exploration and create a timeline.

Graphic Organizer and Writing Exercise: Chemistry and Mars Exploration (20-25 minutes)

- Students describe the chemicals found on Mars by the IR spectrometers, as well as concepts related to the instrumentation.

Writing Exercise: Mars Exploration, IR Spectrometers, and You (15-20 minutes)

- Students consider how the exploration of Mars affects their lives, now and in the future.

Mars Exploration with Infrared Spectrometers

Today we know a great deal about the planets of the solar system, but a mere 50 years ago we knew almost nothing about them. Even observations of our closest planetary neighbors, Mars and Venus, through Earth-based telescopes had provided only the most rudimentary information on their physical characteristics and essentially no information on their chemical properties. That changed dramatically in mid-1969 when two identical National Aeronautics & Space Administration (NASA) spacecraft, Mariner 6 and 7, flew within a few thousand miles of Mars.

Each spacecraft carried four instruments, including a revolutionary type of infrared (IR) spectrometer designed and built by a team in the College of Chemistry and the Space Sciences Lab at the University of California, Berkeley. (The other instruments were television cameras, an infrared radiometer and an ultraviolet spectrometer.) The team was led by chemistry professor George Pimentel (1922-89), with Kenneth Herr (1937-2015), who had received his Ph.D. in chemistry in 1964 working in Pimentel's lab.

The instruments sent back new data about the chemistry of Mars. Among their revolutionary findings were that the thin Martian atmosphere is made up almost entirely of carbon dioxide (CO2) gas with trace amounts of water vapor, and that solid CO2 exists in the planet's upper atmosphere. The IR spectrometers also detected solid water and water-containing substances on the Martian surface as well as goethite, an iron oxide that is a major component of rust and that forms from iron-rich minerals during weathering in the presence of water. This was the first evidence that there was once liquid water on the Martian surface.

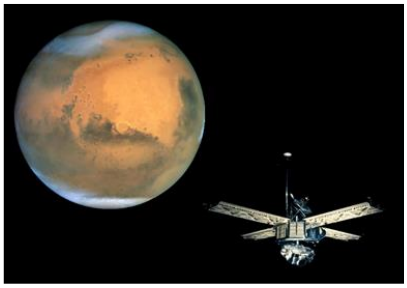
Gazing at the Heavens

Astronomers have been charting Mars' movements for more than 3,000 years. With the invention of the telescope, humans began to investigate the characteristics of the planets more deeply. In 1610 Galileo Galilei (1564-1642) became the first to observe Mars through a telescope. By the mid-19th century, the resolution of telescopes had become sufficient to decipher surface features on the planet.

Only a few years after the 1957 launch of Sputnik, the first artificial satellite to orbit Earth, space scientists in the U.S.S.R. and the U.S. began thinking of sending un-crewed spacecraft to Mars and Venus. These missions were intended to probe the features of these near neighbors more closely than any telescope could. After a number of failed Soviet and American attempts to reach Mars, in 1967, the U.S.'s Mariner 4 passed within 6,118 miles of the planet's surface and provided the first close-up images. Mariner 6 and 7 were designed to follow up on that mission.

Mariner 6 and 7

The infrared spectrometers that flew on Mariner 6 and 7 had their genesis in a conversation between UC Berkeley's Pimentel and Urner Liddel (1905-79), a long-time friend and mentor and a planetary science expert. Liddel was impressed with a rapid-scan IR spectrometer in Pimentel's lab. An IR spectrometer measures the absorption of infrared radiation by a sample. The resulting IR spectrum is characteristic of the



NASA/JPL-Caltech

The IR instruments on the Mars Mariner spacecraft scanned the atmospheric and surface chemistry of Mars. The spacecraft transmitted the IR spectral data back to Earth, along with photos and data from other scientific instruments aboard.

UC Berkeley

Kenneth Herr with a test model of the Mars Mariner infrared spectrometer at UC Berkeley's Space Sciences Lab, ca. 1967.

chemicals present in the sample and can therefore be used to identify its components.

Liddel said, "Look, if you can take an infrared spectrum in a millionth of a second, you ought to be able to tell us how to take an infrared spectrum of the atmosphere of Mars."

Within a few weeks, Pimentel figured out how to do it. The spectrometer he envisioned would use an interference filter as its dispersive element to generate the IR spectrum, rather than a prism or a grating. This approach simplified the spectrometer and made it feasible for such an instrument to be light enough to meet NASA's 25 lb weight maximum.

Pimentel and Herr won a grant from NASA in 1964 to develop a prototype, and in 1966 it was accepted for the Mars Mariner missions.

The UC Berkeley team designed and built the new IR spectrometer. Pimentel and Herr determined that the best wavelengths to be explored were in the 2 to 14-micron region, which would capture the reflected sunlight as well as the heat emissions from Mars. As chemists, they understood that several important molecules could absorb IR in these wavelengths, which would be helpful as the scientists identified what molecules were present and absent at the planet.

To utilize the most sensitive detectors—lead selenide and mercury-doped germanium (Hg-Ge) — in this region of the spectrum, an innovative and effective cooling system was required, because the Hg-Ge detector needed to be cooled to within 22 degrees of absolute zero. The investigators decided to use a novel refrigeration unit employing a high-pressure gas system that would operate only during the 30-minute flybys of Mars.

A Glitch on the Way

Mariner 6 and 7 were launched in February and March 1969 and reached Mars in late July and early August to examine different areas of the planet.

Only a few days before Mariner 6 arrived at Mars, NASA's contractor, Jet Propulsion Lab (JPL), lost contact with Mariner 7 and suspected that a rupture in the spectrometer's high-pressure cooling tank was to blame. JPL regained contact with Mariner 7, but Pimentel and Herr wouldn't know whether the spectrometer on Mariner 7 would function until the unit was turned on during the

Glossary

Absolute zero: The lowest temperature possible, at which molecular motion virtually stops, is -273 C or -460 F.

Dispersive element: A device that separates light into a spectrum of different wavelengths or frequencies.

Infrared (IR) radiation: Found at wavelengths of 700 nanometers (nm) to 1 millimeter (mm), this light is invisible to the human eye but it can be felt as heat and detected by instruments. An IR spectrometer measures the absorption of infrared radiation by a sample, which varies depending on the constituents. The resulting IR spectrum is characteristic of the chemicals present in the sample.

Interference filter: A device that filters out all wavelengths of light except for the one of interest. For the Mars missions, the interference filter selected the wavelengths that reached the IR spectrometers' detectors.

Micron: This unit of measurement is one millionth of a meter, or 0.001 mm, equivalent to about 0.00004 inches. A human hair is roughly 75 microns in diameter.

Further reading

Students can view these additional resources:

Mariner missions: https://tinyurl.com/ACS-missions

Mariner 6 and 7 video: https://tinyurl.com/ACS-video

Infographic about Mars infrared spectrometer: https://tinyurl.com/ACS-infog

flyby. Their anxiety is evident in video recordings made at JPL during the actual mission.

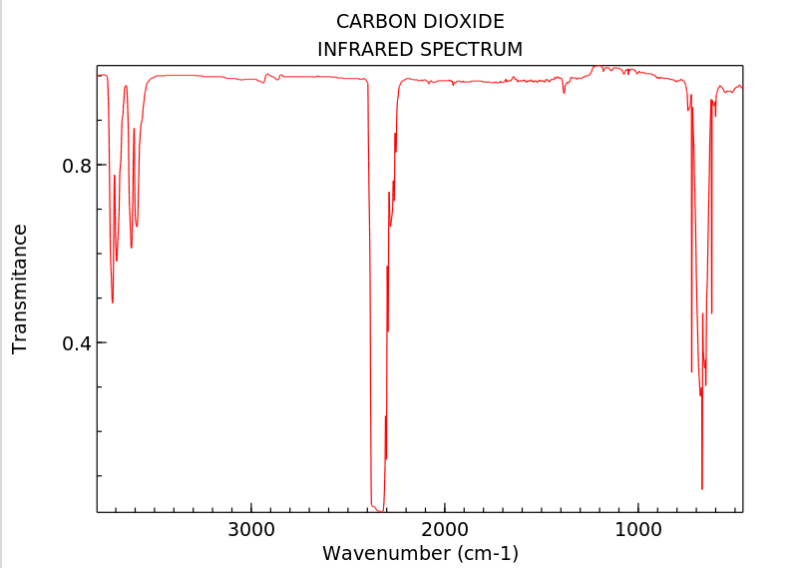
Ultimately, the instruments on both spacecraft successfully scanned the atmospheric and surface chemistry of Mars.

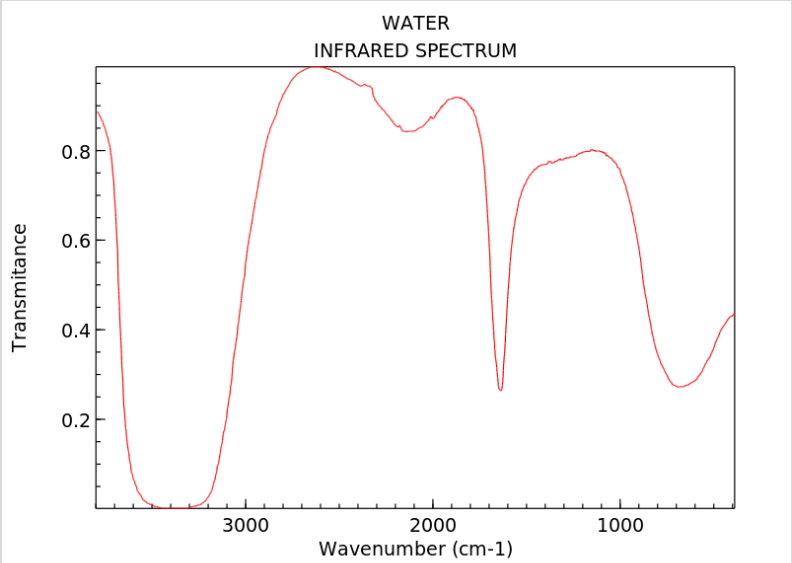
Scientific Results
The novel chemical measurements carried out by the IR spectrometers included:

- The determination of the composition of the Martian atmosphere.
- The first evidence for solid CO_2 in the Martian atmosphere.
- The determination of water vapor concentration in the Martian atmosphere.
- The detection of solid water and water hydrates on the Martian surface.
- The detection of goethite, which forms in aqueous weathering processes, the first evidence that there was once liquid water on the Martian surface.

Both spacecraft transmitted their IR spectral data back to Earth, along with photos and data from the other scientific instruments on board. Because the actual encounters with Mars were so brief, Pimentel designed equipment for conducting follow-up experiments back on Earth using the data in simulated space conditions, which verified and expanded the findings.

Ultimately, the design and performance of Pimentel's instruments set a new standard for spectroscopic studies of the solar system.





NIST Chemistry WebBook (https://webbook.nist.gov/chemistry)

NIST

Evidence for the presence of carbon dioxide and water on Mars was detected by the lightweight infrared (IR) spectrometers carried aboard the Mariner 6 and 7 spacecraft.

An IR spectrometer uses a detector to measure how much infrared radiation is absorbed or transmitted by a sample over a range of IR wavelengths (wavenumber = 1/wavelength). The resulting spectrum is characteristic of the chemicals present in the sample, such as carbon dioxide (top spectrum) or water (bottom).

As seen here, the shape, depth and location of the peaks differ for different compounds. That means a spectrum can be used to identify what's in a sample of unknown composition.

Student Name: _____ Date: _____ Period: _____

Anticipation Guide
Mars Exploration with Infrared Spectrometers

Anticipation guides engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students' responses to each statement ***before*** they read the article on "Mars Exploration with Infrared Spectrometers." Then, **while** they read the handout, students should look for evidence supporting or refuting their initial responses.

Directions: ***Before reading*** the article, in the first column, write "A" or "D" to indicate your agreement or disagreement with each statement. Then, ***while you read***, compare your opinions with information from the article, which you'll use to write "A" or "D" in the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Me	Text	Statement
		1. The physical and chemical properties of Mars and Venus have been well-established for more than 70 years.
		2. Mars has a thin atmosphere mostly made up of CO_2.
		3. Infrared (IR) spectrometers on Mariner 6 and 7 detected solid water on Mars in the late 1960s.
		4. The IR spectrometers used to explore Mars had a prism to generate the IR spectrum.
		5. Scientists chose a wide range of wavelengths to explore with the IR spectrometer.
		6. The detectors had to be cooled to within 22 degrees of absolute zero.
		7. The trip to Mars took Mariner 6 and 7 more than a year.
		8. Mariner 7 reached Mars, but was not able to send information back to Earth.

Student Name: _____ Date: _____ Period: _____

		9. The IR spectrometers used by the Mariner space probes could detect water vapor concentration in the Martian atmosphere.
		10. IR radiation can be felt as heat, but is invisible to human vision.

Optional Engagement Idea

Instead of using the Anticipation Guide, consider using these discussion questions to engage your students before they start reading. First, ask them the following questions and why they hold their opinions. Also tell them they will find the answers when they read the article.

1. When do you think the space probes first found evidence of water on Mars?
2. What kinds of instruments do you think were on the space probes? What do you think they were used to detect?

After this discussion, invite students to read the article on “Mars Exploration with Infrared Spectrometers” and record at least three of their ideas that were confirmed by the reading, and at least three pieces of information that surprised them and why.

Student Name: _____ Date: _____ Period: _____

History Exercise: Timeline of Martian Exploration

Preparation: Print enough copies of the events below for each student or student group. Cut the events apart and place them in an envelope for each student or student group.

Challenge students to put the following events in chronological order prior to reading.

As they read, students should re-order the events correctly.
Next, ask them to predict future events for the exploration of Mars.
Finally, ask students to create a timeline, drawn to scale, showing past and future events related to Mars exploration.

A. The Soviet spacecraft Sputnik was launched.

B. Humans began studying Mars' movements in the sky.

C. Galileo observed Mars through a telescope.

D. Mariner 6 flew within a few thousand miles of Mars.

E. Mariner 4 provided images of Mars.

Student Name: _____ Date: _____ Period: _____

Chemistry and Mars Exploration

Directions: Complete the table below to describe the form (gas, solid and/or liquid) and location of chemicals found on Mars by Mariner 6 and 7.

CHEMICALS

	Forms found on Mars	**Location where found on Mars**
Carbon dioxide (CO_2)		
Water		
Goethite		

IR SPECTROSCOPY

Directions: After reading the article and viewing the video (10 minutes) at http://bit.ly/ACS-spectrum, answer the following questions about infrared (IR) spectroscopy and its role onboard Mariner 6 and 7.

1. Define spectroscopy, and describe what information it can reveal about molecular compounds.

_____

_____

_____

_____

2. In IR spectroscopy, a compound is irradiated with IR light. What are the different ways the compound can interact with IR light?

_____

_____

Student Name: _____ Date: _____ Period: _____

_____

_____

3. What are the wavelengths of IR light? Can it be seen or felt?

_____

_____

4. Molecules absorb light at specific wavelengths associated with particular functional groups, producing an IR spectrum that is characteristic of that molecule. If the IR spectrum of a compound shows a peak corresponding to an "OH stretch," what does that tell you about the compound's molecular structure?

_____

_____

_____

_____

5. Why were IR spectrometers used on Mariner 6 and 7? How was the data they collected later confirmed?

_____

_____

_____

_____

Student Name: _____ Date: _____ Period: _____

Mars Exploration, IR Spectrometers and You

How does the exploration of Mars affect you now or in the future? Write a paragraph or two to explain, using information from the article.

Teacher notes:

- Instead of writing paragraphs, consider having students prepare a poster or infographic about the exploration of Mars. The infographic at https://tinyurl.com/ACS-infog will be helpful for this activity.

- There are additional excellent resources for this assignment in the Additional Resources at the end of the reading.
  - Mariner missions: https://tinyurl.com/ACS-missions (NASA Fact Sheet)
  - Mariner 6 and 7 video: https://tinyurl.com/ACS-video (21 min., with historic footage)

- This ACS "Reactions" video from 2016 has information about tiny satellites known as cubesats and their use in future space exploration: https://youtu.be/OGmiv53La0o

Anticipation Guide: Mars Exploration with Infrared Spectrometers

Me	Text	Statement
	D	1. The physical and chemical properties of Mars and Venus have been well-established for more than 70 years.
	A	2. Mars has a thin atmosphere mostly made up of CO_2.
	A	3. Infrared (IR) spectrometers on Mariner 6 and 7 detected solid water on Mars in the late 1960s.
	D	4. The IR spectrometers used to explore Mars had a prism to generate the IR spectrum.
	D	5. Scientists chose a wide range of wavelengths to explore with the IR spectrometer.
	A	6. The detectors had to be cooled to within 22 degrees of absolute zero.
	D	7. The trip to Mars took Mariner 6 and 7 more than a year.
	D	8. Mariner 7 reached Mars, but was not able to send information back to Earth.
	A	9. The IR spectrometers used by the Mariner space probes could detect water vapor concentration in the Martian atmosphere.
	A	10. IR radiation can be felt as heat, but is invisible to human vision.

History Exercise: Timeline of Martian Exploration

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As they read, students should re-order the events correctly.
Next, ask them to predict future events for the exploration of Mars.
Finally, ask students to create a timeline, drawn to scale, showing past and future events related to Mars exploration.

A. The Soviet spacecraft Sputnik was launched. 3 (took place in 1957)

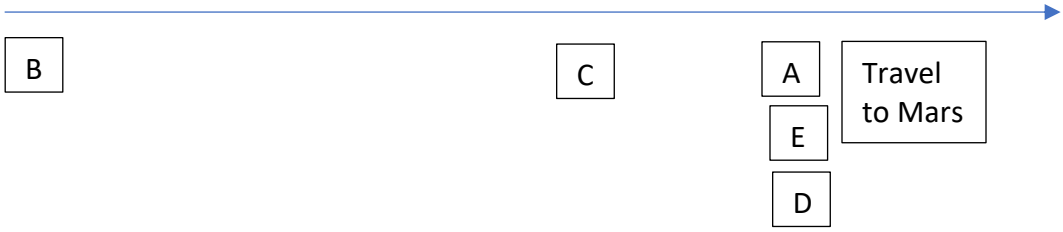
B. Humans began studying Mars' movements in the sky. 1 (took place 3,000 years ago)

C. Galileo observed Mars through a telescope. 2 (took place in 1610)

D. Mariner 6 flew within a few thousand miles of Mars. 5 (took place in 1969)

E. Mariner 4 provided images of Mars. 4 (took place in 1967)

Timeline Example (1 cm ~400 years):



Chemistry and Mars Exploration

Directions: Complete the table below to describe the form (gas, solid and/or liquid) and location of chemicals found on Mars by Mariner 6 and 7.

CHEMICALS

	Forms found on Mars	**Location where found on Mars**
Carbon dioxide (CO_2)	Gas Solid	Atmosphere
Water	Gas Solid Liquid	Gas - atmosphere Solid - surface Liquid – presence of goethite indicated liquid water on surface in the past
Goethite	Solid iron oxide	surface; provided evidence that liquid water was once on Mars

IR SPECTROSCOPY

Directions: After reading the article and viewing the video (10 minutes) at http://bit.ly/ACS-spectrum, answer the following questions about infrared (IR) spectroscopy and its role onboard Mariner 6 and 7.

1. Define spectroscopy, and describe what information it can reveal about molecular compounds.

Spectroscopy is the study of the interaction of light and matter. It can provide information about the structure of a molecule.

2. In IR spectroscopy, a compound is irradiated with IR light. What are the different ways the compound can interact with IR light?

The compound can absorb or transmit the light. If it absorbs light, bonds in the compound can stretch, bend or twist.

3. What are the wavelengths of IR light? Can it be seen or felt?

IR light has wavelengths ranging from 700 nm to 1 mm. It is invisible to the human eye but can be felt as heat

4. Molecules absorb light at specific wavelengths associated with particular functional groups, producing an IR spectrum that is characteristic of that molecule. If the IR spectrum of a compound shows a peak corresponding to an "OH stretch," what does that tell you about the compound's molecular structure?

The compound contains an OH (hydroxyl) group.

5. Why were IR spectrometers used on Mariner 6 and 7? How was the data they collected later confirmed?

They were used to detect chemicals in Mars' atmosphere and on its surface. Experiments were later done on Earth in simulated space conditions to verify and expand the findings of the short Mariner mission encounters.

Mars Exploration, IR Spectrometers and You

How does the exploration of Mars affect you now or in the future? Write a paragraph or two to explain, using information from the article.

Teacher notes:

- Instead of writing paragraphs, consider having students prepare a poster or infographic about the exploration of Mars. The infographic at https://tinyurl.com/ACS-infog will be helpful for this activity.

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Suggested Rubric:

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding. Includes specific information regarding how Mars exploration affects people on Earth today and/or in the future.
3	Good	Complete; few details provided; demonstrates some understanding. Provides vague information regarding how Mars exploration affects people on Earth today and/or in the future.
2	Fair	Incomplete; few details provided; some misconceptions evident. Provides little or no information regarding how Mars exploration affects people on Earth today and/or in the future.
1	Poor	Very incomplete; no details provided; many misconceptions evident. Does not relate information to student's life.
0	Not acceptable	So incomplete that no judgment can be made about student understanding.