Planet Designer: Retro Planet Red

High School Grades

Lesson Summary

Students learn about Mars past and present before exploring the pressure and greenhouse strength needed for Mars to have a watery surface as it had in the past.

Prior Knowledge & Skills

- Introductory understanding of the greenhouse effect
- Experience with variables
- Ability to use data tables
- Experience interpreting data to form arguments

AAAS Science Benchmarks

The Physical Setting

The Universe

The Earth

Forces of Nature

NSES Science Standards

- **Science as Inquiry:** Abilities necessary to do scientific inquiry
- **Earth and Space Science:** Energy in the Earth System

Teaching Time: One-to-two 50-minute periods

Materials

Each student will need:

- Copy of "Making a Splash on Mars, " "NASA Data Suggest Water Flowing on Mars," and "The MAVEN Mission" articles
- Copy of Student Directions
- Access to a computer with Flash
- Poster paper
- Markers or colored pencils
- Glue (optional)
- Scissors (optional)

Advanced Planning

Preparation Time: 20 minutes

- Make copies of the student hand outs and instructions
- For homework, have students read the articles, "Making a Splash on Mars," "NASA Data Suggest Water Flowing on Mars," and "The MAVEN Mission"
- For reference, pass back student work from, "Planet Designer: Kelvin Climb"
- Prepare a computer room to run the Flash interactive (if Flash is supported) or download the executable file on each computer if Flash is not available. The interactive can be found here: http://lasp.colorado.edu/home/education/k-12/project-spectra/
- Open the Flash Interactive, "Planet Designer: Retro Planet Red"

Why Do We Care?

The Mars Atmospheric and Volatile EvolutioN (MAVEN) mission will collect data to help scientists trace Mars' atmospheric history to determine what happened to the flowing water.

Mars once had liquid water, maybe even oceans. How much it had and when in history it had it is still being discovered. The amount of atmosphere Mars had, and the strength of the greenhouse effect Mars would have needed to maintain the liquid water, is a hotly debated topic. If we can figure out when Mars had flowing water, and for how long it had it, we can establish whether Mars was once a habitable world.

Suggested background reading

MAVEN website: http://lasp.colorado.edu/maven/

Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

Activity Dependency It is recommended for students to have completed the activites "Goldilocks and the Three Planets," and "Planet Designer: Kelvin Climb."

Group Size 1-2
Expendable Cost per Group US$0.30

Engineering Connection (See also Engineering Connection from "Planet Designer: Kelvin Climb")
Mars has geologic evidence of liquid water flowing on the surface throughout its history. At some point, around 3.8 billion years ago, a large part of Mars' atmosphere went away, along with the flowing liquid water that is now either found frozen in the polar caps and below the surface, or it escaped as water vapor along with the rest of the atmosphere into space. The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission instrumentation will measure the rate of atmospheric escape. The Imaging Ultraviolet Spectrometer (IUVS) instrument onboard the MAVEN mission is designed, in part, to measure the hydrogen escape rate in the atmosphere. Since the hydrogen that is escaping comes from water in the atmosphere, knowing how much hydrogen existed throughout time will also help constrain the amount of liquid water Mars had flowing on the surface.

Learning Objectives
After this activity, students should be able to:
- Explain, in general terms, how much atmospheric pressure is needed on Mars to maintain surface water.
- Explain why Mars does not have surface water today.

Introduction / Motivation (See also Introduction / Motivation from "Planet Designer: Kelvin Climb")

There is evidence water once flowed on the surface of Mars, and even more evidence that reservoirs of frozen water exist below the surface of the planet, but no direct evidence exists that water currently flows on the surface. And, how could it? The average surface temperature is roughly -50^{o}C. The temperature can get up to 25 ^{o}C (depending on the season and latitude), but the surface pressure on Mars is less than 1% of the pressure on Earth. If you dumped a glass of water onto the Martian surface, it would either freeze or evaporate. Mars wasn't always this way, though. It's thought to have once had a thick greenhouse atmosphere that kept the pressure and temperature of the planet much higher. Water probably flowed on the surface for perhaps close to a billion years, but at some point, around 3.6 to 3.8 billion years ago, Mars lost its liquid surface water. Lakes and rivers either froze solidly or evaporated to become water vapor in the atmosphere. Water that froze to the ground became covered in thick Martian dust and is now buried. A lot of the water vapor in the atmosphere escaped into space. The MAVEN mission will help us pin down exactly what happened to the atmosphere over time since we are missing some crucial pieces in the puzzle. We don't know exactly how much atmosphere Mars had in the past, how much of the atmosphere was greenhouse gas, or even how much water Mars once had. Although MAVEN will answer the question of where the water and greenhouse gas went, a single mission can only do so much, and MAVEN won't be able to tell exactly what the greenhouse gases on Mars were in the past. For that, we'll need more missions to the red planet for information about its atmosphere, and even possibly a mission to dig deep below the surface.

Today, using a computer game, you will try to make Mars a watery world and find out what kind of atmospheric greenhouse strength, pressure, and temperature Mars would have needed to make that possible. Like MAVEN, you won't be able to tell what the greenhouse atmosphere on Mars would be like, but you'll be able to make some guesses.

Vocabulary / Definitions

Word	Definition
Triple Point of Water	The temperature and pressure where water can exist in all three states: liquid, solid, and vapor

Procedure

Background (See also: Background from "Planet Designer: Kelvin Climb")

Using the basic model the students explored in the activity, "Planet Designer: Kelvin Climb," students will estimate what temperature, pressure, and greenhouse strength Mars would require in order to maintain liquid water on the surface both today, and 3.8 billion years ago.

All of Mars' problems began around 4.1 billion years ago when it lost its magnetic field. Mars cooled down in its early history, and convection of the molten metal in the interior stopped. Convection in the interior of a planet creates a dynamo effect as moving charges circulate. Without a convecting molten core, Mars was no longer able to generate a magnetic field. The solar wind emanates from the Sun and carries particles as well as the solar magnetic field with it. Without a magnetic field, charged particles in the upper atmosphere of Mars can be efficiently carried away by the solar wind, and still are today. Astrophysicists estimate the Sun was 30% dimmer around 4 billion years ago, but had an even more vigorous solar wind.

A key element in this process is Mars' low gravity. The amount of gravity a planet or body has is dependent on its mass, and Mars is only about a tenth of Earth's mass. Escape velocity, the velocity needed to leave the comfort of a planet, is dependent on mass. The escape velocity of Earth is 11 kilometers/second (~7 miles/second), while the escape velocity of Mars is 5 kilometers/second (~3 miles/second). Any particle near the top of the atmosphere that exceeds this velocity in an upward direction will simply fly away. It's also part of the reason the solar wind could easily carry off particles—the gravity of Mars was just not large enough to hang on to them while the pied piper, the solar wind, swept past the planet. It would also be fairly easy for a comet or asteroid that impacted Mars to make a big enough splash to send portions of the atmosphere into space.

As Mars got colder over millions of years, water on the surface froze solidly and was buried over time. Once atmospheric pressures became low enough from the atmospheric loss, ground water also evaporated or sublimated forming atmospheric water vapor. When water vapor reached Mars' upper atmosphere it photo dissociated, which is when a photon from the Sun breaks the molecule apart. It's easy for hydrogen in the upper atmosphere to escape a planet. A little extra energy from atmospheric heating or from a stray particle traveling through space could give it a little boost, and away it goes! Missions like the Phoenix Lander and Mars Odyssey have helped us better understand how much frozen water is underground by either digging into the soil (Phoenix) or by using gamma ray spectroscopy to map below the surface (Odyssey). The Imaging Ultraviolet Spectrometer (IUVS) onboard the MAVEN mission, will profile hydrogen in the atmosphere and determine its escape rate to space. Once we determine the loss rate, we can calculate how much hydrogen would have been in the atmosphere 4 billion years ago, and how much water vapor would have been needed in the atmosphere to make that much hydrogen. Then, we can make an educated guess about how much water existed on Mars back in time.

If Mars had a warmer and wetter climate, it must have had a thicker atmosphere and stronger greenhouse effect at one time. The loss of hydrogen and of other gases that accompanied it caused the climate to change. How long did that take and what was the atmosphere really like before that? The MAVEN mission is the first mission to thoroughly examine Mars' upper atmosphere and its current loss rate to space to begin to answer these questions. On top of measuring the hydrogen escape rate, various instruments measure the rate of atmospheric escape due to the solar wind. MAVEN scientists want to get a lock on how long it took for Mars to become the dry, dusty world we find today, and finding the atmospheric escape rate is the key!

With the Students

1. Follow the discussion topics in the Pre-Activity Assessment
2. Take students to the computer room
3. Assist students as they add atmosphere to Mars and explore the effects on Mars' surface temperature

Assessment

Pre-Activity Assessment

Example Discussion Questions

Q: From the previous activity, "Kelvin Climb," what aspects did you change in order for liquid water to exist on the surface of your planet?
A: Distance to the Sun, albedo, atmospheric thickness (increased pressure), and greenhouse strength.

Q: What do you know about Mars?
Accept a variety of responses. Mars is dry, it has a thin atmosphere, it has polar caps, it's further from the Sun than Earth, it has less gravity than Earth etc.

Q: Is it possible for liquid water to exist on the surface of Mars today?

A: According to the article, "Making a Splash on Mars," there are some regions on Mars that have the right pressure for liquid water to exist as long as the temperature was correct. The water probably wouldn't last long, and no evidence of the water has been observed. According to the article, "NASA Data Suggest Water Flowing on Mars,"evidence of gullies carved by water have been observed by spacecraft, although we have no direct evidence they are formed by water.

Q: Mars used to have flowing water on the surface. What do you think was different about Mars in the past?
A: Mars probably had a thicker atmosphere and a stronger greenhouse effect. It would have had more atmospheric pressure.

Q: How did the Sun contribute to Mars' atmospheric loss?
A: The Sun has a solar wind, which can carry away some of the atmosphere. Mars' magnetic field protected the atmosphere from the solar wind, but around 4.1 billion years ago, the magnetic field shut off.

Q: What does gravity have to do with Mars' atmospheric loss?
A: Mars has low gravity, so it's easier for things like the solar wind or a big meteorite impact to remove some of the atmosphere.

Q: What do you know about greenhouse gases in Mars' atmosphere?
If you have done the "Goldilocks and the Three Planets" activity, students should know that Mars has a lot of carbon dioxide, and may know that it has about 23 times more carbon dioxide (by mass, in a certain volume) than Earth's atmosphere. Students may also know that Mars has a small amount water vapor and trace amounts of methane in its atmosphere.

Q: Can you explain why Mars' low pressure today makes standing liquid water on the surface of Mars difficult?
Students may have experienced water boiling faster (at lower temperatures) at higher altitudes, like in the mountains. Students may also be familiar with a pressure cooker, where increased pressure leads to higher temperatures and faster cooking speeds. Help students refine their thinking about the requirements of liquid water. If boiling water (liquid to vapor) can occur at lower temperatures when the atmospheric pressure is low, if the pressure and temperature are just right on Mars, liquid water would boil without needing to be heated.

Post-Activity Assessment
Gallery Walk: Students can make a labeled poster about Mars' atmospheric loss or another concept gained from the lesson, using "The MAVEN Mission" article, and ideas from the activity. Once students are done with the poster, hang student work around the room and have students observe and question each other's work (respectfully). One way to do this is to provide

sticky notes for students to make comments. Have an open discussion about student work with the class.

References

Baker, Victor R. 2001. Water and the martian landscape. Nature 412:228-236

Bennett, J. et al. 2010. Cosmic Perspective. Addison-Wesley. 297—300, 494

Curry, J., Webster, P. 1999. Thermodynamics of Atmospheres and Oceans. Academic Press

Jakosky, Bruce M., Phillips, Roger J. 2001. Mars' volatile and climate history. Nature 412:237-244

Stevenson, David J. 2001. Mars' core and magnetism. Nature 412:214-219

Contributors

Erin Wood
Grant Euler
David Mitchell
Jim Kellogg
David Brain
Bruce Jakosky