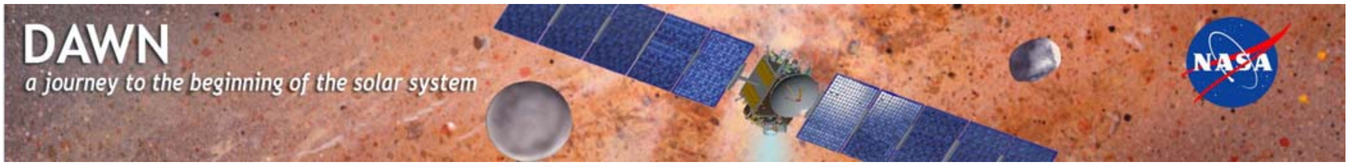


Ion Propulsion

How Do We Get There?

TEACHER GUIDE – BRIEFING

BACKGROUND
Welcome to the ion propulsion module. This module is intended for high school students who are in physical science, chemistry, or physics. Additionally, this module might be of interest to students as they conduct research in advanced technologies. As students interact with this module, they will gain an understanding of

- charges and relative charge
- momentum and frames of reference
- ionization and plasma
- how an ion propulsion system works

Just like a mission briefing for the press, the purpose of this section of the module is to provide students with some background information about the Dawn mission and the need for a spacecraft with ion propulsion in order to meet mission objectives. This lesson begins by having students consider science fact versus science fiction. Following this, students will view a PowerPoint presentation that describes some of the challenges in embarking on a mission of this length. The briefing concludes with an activity in which the students investigate the history of the development of ion propulsion using a strategy called the History Frame (Jones, 2001). This strategy helps students organize what they learn from the timeline and make sense of the "who, what, where, how, and why" of historic events such as the development of this advanced propulsion technology.

ESTIMATED TIME:
Part 1: 15 Minutes
Part 2: 30 Minutes
Part 3: 30-45 Minutes (or as homework)

The **TEACHER GUIDE SUPPLEMENT CONTAINS:**

Specific NSES Science Education Standards for this guide;
Instructions for the activity, "Where Are You?"

MATERIALS

PowerPoint "How Do We Get There?"
Projector
Television/DVD/VHS Player (optional)
Ion Propulsion Timeline
Ion Propulsion Story Mapping History Frame

Optional Video Activity

The following clips from Star Trek or Star Wars can be used to engage students' interest at the beginning of this lesson.

Star Trek (DVD): *Spock's Brain*
Chapter 1, Start through 3:06
Chapter 2, 8:16 through 9:25

Star Wars (VHS): *Episode IV*
1:03:26 - 1:04:33 (mention of TIE fighter)
1:34:00 - 1:35:50 (battle scene with TIE fighters)
1:53:30 - 1:57:00 (Death Star sequence)

Optional:

Activity, "Where Are You?" (see the Teacher Guide Supplement for materials needed)
News article, "Dawn Spacecraft Poised for Flight to Asteroid Belt"

PROCEDURE

Part 1: Science Fiction or Fact?

1. (Optional) Show two science fiction segments from Star Trek that reference ion propulsion (see box on previous page). If you show the Star Trek clip, ask students how the *Enterprise* was able to track the alien ship (by following the ion beam). It is interesting to note that even though the universe of Star Trek occurs in our future, the Federation had not yet developed ion propulsion technology that we will be using on the Dawn mission! If you show the Star Wars clips, "ion propulsion" is not mentioned, but TIE fighters are. TIE is an acronym for "Twin Ion Engine." By comparison, a long time ago in a galaxy far, far away, ion propulsion seemed to be very well developed by the empire!

2. Begin by giving students this short quiz (Student responses should identify each statement as either fact or fiction). Don't give any answers to the students at this time.
   a. Gasoline in your car is a chemical fuel. (Fact)
   b. Most spacecraft today use chemical propulsion systems. (Fact)
   c. Ion propulsion has never been tested. (Fiction)
   d. With ion propulsion, a spacecraft can accelerate very quickly. (Fiction)
   e. Ion propulsion produces a great amount of force. (Fiction)
   f. Ion propulsion systems require more fuel than chemical propulsion systems for the same trip. (Fiction)
   g. Traveling to a body in space is like trying to hit a moving target. (Fact)

3. Tell students to keep their responses to themselves. Some of these will be answered in today's lesson while others will be answered in subsequent activities. Explain to students that they will be studying an advanced propulsion system called ion propulsion that uses some of the fundamental principles that they have been studying in high school science classes. Ion propulsion will be used to propel the Dawn spacecraft to the asteroid belt.

Part 2: How Do We Get There? (PowerPoint Presentation)

1. Set up the projector and the PowerPoint presentation for students to view. You may want to print student handouts for students to use to take notes during this presentation. The presentation notes on the PowerPoint should be used when presenting to students. Augment the notes by asking students follow-up questions.

2. Presentation Notes:

Slide One: No Notes

Slide Two: Any successful journey requires careful route planning and efficient packing, and the Dawn mission is no exception. The 6.3 billion-kilometer journey will take the Dawn spacecraft almost ten years, with a major layover at the asteroid 4 Vesta and then on to dwarf planet 1 Ceres.

Optional Activity: Where Are You?

See the Teacher Guide Supplement below for an activity in which students make a model to help them to visualize the size and distance of Vesta and Ceres in relation to Earth.

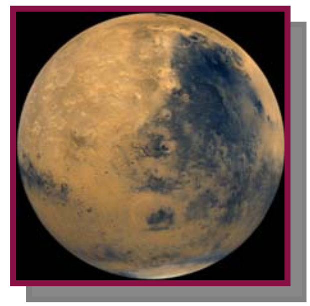
Slide Three: Imagine that you are planning a cross-country trip from Los Angeles to New York and there are no gas stations along the way. You will have to carry enough gasoline with you to make the trip.

It is 4800 km (3000 miles) from Los Angeles to New York. If your car's gas mileage averages 40 km/gallon (25 miles/gal), your car will need 120 gallons of fuel to make the trip. It will require 0.5 cubic meter (or 16 cubic feet) of space to store your fuel and, at the start of the trip, the fuel will weigh 308 kg (685 pounds).

Could you store this much gasoline safely in your car? How would the additional weight of the fuel affect your gas mileage?

If you travel 1200 km (750 miles) a day, the trip will take you four days.

Slide Four: Now, a LONGER DISTANCE trip...to get to Mars, it will take a little more planning. At its closest, Mars is about 35 million miles (about 56 million km) away from Earth. Dawn's actual travel time will be about 1 billion km (620 million miles) from Earth to Mars.



Mars
NASA Image Exchange

Even using a minimum-energy trajectory, sending a manned spacecraft from Earth to Mars, with chemical rockets alone, would require a total launch mass of greater than 1,000 metric tons—of which some 90 percent would be fuel. The fuel alone would weigh twice as much as the completed International Space Station.

Chemical rockets burn their propellant at the beginning of a flight, so, once the spacecraft is launched into trajectory, it would just *coast* the rest of the way to Mars.

Slide Five: Launching a spacecraft and directing it toward distant objects is a precise and challenging operation because the Earth is moving in its orbit and the objects (Vesta and Ceres in this case) are moving as well. It is very much like a quarterback (the Earth) moving toward the sidelines while successfully throwing a football (the spacecraft) and completing a pass to a wide receiver (an asteroid) who is also moving. Practice and coordination are required on the football field. Careful planning and precision are required on the part of the mission planning team.

At launch atop a Delta II rocket on September 27, 2007, the Dawn spacecraft will be sent on a trajectory that will take it close to Mars. The launch will be timed so that, after traveling about **17 months**, the spacecraft will arrive at the outer end of its orbit just as Mars is passing by. Dawn will get a gravity assist from Mars to send it on its way to Vesta. This means that Dawn will use the planetary motion of Mars to increase its speed and to change its direction. Note that the times that the spacecraft is thrusting (accelerating) shown with solid dark line verses coasting shown with a dotted line.

When Dawn gets to Vesta in August of 2011, it will be traveling at about the same speed as Vesta and as it passes by it will suffer gravitational capture and go into orbit around the asteroid. The spacecraft will orbit the asteroid for ten months so that the instruments in the payload can map the asteroid's elemental composition, its gravity field, mineralogy, and thermal emissions, and compile global color and topographic images.

Then it is on to Ceres, another three-year journey, to take an “up-close and personal” look at the first asteroid to be discovered by astronomers on Earth!

Optional Reading

Students wanting more information about the Dawn mission should read, “Dawn Spacecraft Poised for Flight to Asteroid Belt.” This news story describes how the Dawn spacecraft will accomplish its mission.

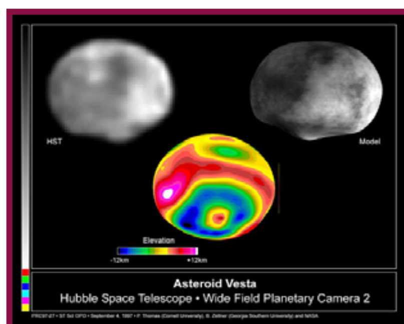
Although you can see quite a bit of “coast time” (dotted lines) on the trajectory diagram, Dawn’s Ion Propulsion System will be thrusting more than 55,000 hours (that’s more than six years). This is three times the longest powered flight by any spacecraft.

Slide Six: And Dawn will pack **only 450 kg of xenon fuel** for this almost ten-year journey! The spacecraft itself has a mass of 745 kg and the whole propellant system fits into less than 2 cubic meters of space! Dawn will use hydrazine thrusters (chemical propulsion) for trajectory correction maneuvers.

In comparison, **a trip to just Vesta,** without an ion propulsion system, would require a higher-energy rocket than the Delta II and it would require **2500 kg of propellants** aboard the spacecraft. So the Dawn mission, which includes a trip to Ceres, would not be possible without utilizing an ion propulsion system.

The solar array panels, shown folded in this image, will extend almost 10 m on either side of the propellant and instrument package. They will produce 10.3 kW of power at 1 AU from the sun and 1.3 kW of power at 3 AU. Some of this solar power will be used to produce the xenon ions that, in turn, will provide the thrust for the Dawn spacecraft.

Slide Seven: Although it will take Dawn longer to go from Earth to Vesta and from Vesta to Ceres with ion propulsion than it would with chemical propulsion, the longer time is well worth it because of the great savings in fuel. Dawn’s ion engines will require only 28 kg of Xenon fuel to reach Vesta and another 89 kg to travel to Ceres.



Asteroid Vesta
NASA Image Exchange

How can Dawn travel so far on so little fuel? It is a matter of time vs. acceleration.

At maximum thrust, Dawn’s ion engine will expend only about 0.25 kg of Xenon per day, producing a thrust of 92 milliNewtons, about the same amount of force you feel when a piece of paper is placed on your open hand. Since this small thrust changes the spacecraft’s velocity only 10^{-5} m/s every second, it will require a little over 1000 days to achieve a velocity of 1000 m/s. Compare this with the 20 minutes that it takes for 300 kg of chemical propellants to achieve this same 1000 m/s velocity by producing a thrust of 500 Newtons. In this example, the change of velocity is an increase in speed necessary for Dawn to “catch up” to its targets (first Vesta then Ceres).

Dawn is trading off time for fuel efficiency…and since Dawn has plenty of time, ion propulsion is the propulsion system of choice for this mission.

Part 3: A New Technology?

1. Conclude this lesson by providing students a history of the development of ion propulsion technology. This assignment can be done as homework or with the cooperation of the history teacher.

2. Distribute the Ion Propulsion Timeline to each student or group of students. Have them scan the timeline. Refer students back to the question they answered earlier about the testing of ion propulsion. Students should note the extensive testing and development of this technology.

3. Distribute the Ion Propulsion Story Mapping History Frame and demonstrate how this map was used to describe the early history of this technology. Explain to students that their job will be to use this framework for one or more events that are found on the timeline. Tell students that in some cases, additional research will need to be done and in other cases, not all of the information will be known (e.g., key personnel, where it happened).

4. Provide assistance for students as needed as they begin. Tell them that they should fill in as much information as they can find using web searches. The goal here is for students to organize the events that transpired, not to fill in each box. The most important part of this is for students to write a theme or lesson in the box that summarizes what happened in their chosen event. Give students a deadline for completion of this assignment.

5. Conclude this session by reviewing the correct answers from the opening quiz.
   a. Gasoline in your car is a chemical fuel. **(Fact)**
   b. Most spacecraft use chemical propulsion systems. **(Fact)**
   c. Ion propulsion has never been tested. **(Fiction—NASA's Deep Space One successfully used ion propulsion)**
   d. With ion propulsion, a spacecraft can accelerate very quickly. **(Fiction)**
   e. Ion propulsion produces a great amount of force. **(Fiction—the amount of force needed to propel a spacecraft is the same as the force you feel when a sheet of paper rests in your hands)**
   f. Ion propulsion systems require more fuel than chemical propulsion systems for the same trip. **(Fiction)**
   g. Traveling to a body in space is like trying to hit a moving target. **(Fact)**

6. Ask students to list additional questions that they have about ion propulsion engines. Record all of the questions. As students complete the subsequent activities in this module, refer students to this list of questions as they are able to answer them.

7. Tell students that in the next session, they will be studying some of the fundamental concepts involved in ion propulsion systems; charges and plasma.

Teacher Guide Supplement

NSES Science Education Standards **addressed in this guide:**

Science as Inquiry (Grades 9–12)
<u>Abilities Necessary to Do Inquiry</u>

Identify questions and concepts that guide scientific investigations

<u>Understandings About Scientific Inquiry</u>

Scientists usually inquire about how physical, living, or designed systems function. Historical and current scientific knowledge influence the design...of investigations.

Science and Technology (Grades 9–12)
<u>Understandings About Science and Technology</u>

Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.

History and Nature of Science (Grades 9–12)
<u>Science as a Human Endeavor</u>

Individuals and teams have contributed and will continue to contribute to the scientific enterprise.

<u>Historical Perspectives</u>

Usually, changes in science (and technology) occur as small modifications in extant knowledge.

Optional Activity: Where Are You?

Assortment of food items, particularly fruits and vegetables, from which students can select four food items to represent the following solar system bodies:

Earth: melon (roughly 25.5 centimeters in diameter)
Mars: grapefruit (approximately 13.6 centimeters diameter)
Vesta: raisin (1 centimeter)
Ceres: grape (approximately 2 centimeters)
(Note: The raisin and grape provide another interesting parallel to Vesta and Ceres in that Vesta is believed to be dry and Ceres has wet conditions.)
Meter sticks

In this activity, students will make a model to help them to visualize the size and distance of Vesta and Ceres in relation to Earth.

Distribute the activity "Where Are You?" to each student. This activity is found in the History of Science: Asteroids module.

Have a variety of food items of different sizes displayed in class. Some should fit the scaled-down diameters (25.5 cm, 13.6 cm, 2 cm, and 1 cm). Be sure to have other sizes as well so that students must do the calculations to select the most appropriate food model.

Explain to students that they will convert the actual diameters of several planets and asteroids to reflect the scale of 1 cm = 500 km. Ask them to show their calculations and refer to the example given for Mercury. It may be necessary to calculate a few more examples with students, before they complete the table in Part 1 themselves.

Assemble students into groups of four. As they finish their calculations for Earth, Mars, Vesta, and Ceres, ask them to go to the food display and select the most appropriate representation.

Allow time for students to respond to the questions in Part 1. Then have students share their responses to questions 2, 3, and 4 with the class.

In Part 2 of this activity, students will create a scale model of the distances of Earth, Mars, Vesta, and Ceres. After students have reviewed the table and answered question number 5, spend some time discussing why it is difficult to create one scale model of the entire solar system that reflects both size and distance.

RESOURCES

Doty, J. K., Cameron, G. N., & Barton, M. L. (2003). *Teaching reading in social studies: A supplement to the Second Edition of Teaching Reading in the Content Areas Teacher's Manual*. Aurora, CO: Mid-continent Research for Education and Learning.

Jones, J.C. (2001). *Story Mapping History Frame*. Retrieved from readingquest.org.

Stuhlinger, E. & Ordway, F. (1994). Wernher von Braun, crusader for space: A Biographical Memoir. Malabar, FL: Krieger Publishing Company.

Web Sites

http://www.grc.nasa.gov/WWW/ion/index.html
Ion Propulsion from Glenn Research Center at Lewis Field

http://space-power.grc.nasa.gov/ppo/projects/nstar/index.html
http://www.lerc.nasa.gov/WWW/RT1995/5000/5330h.htm
NSTAR (NASA Solar Electric Propulsion Technology Application Readiness) Program

http://science.nasa.gov/headlines/y2000/ast17aug_1.htm
The Indefatigable Ions of Deep Space 1

http://spaceplace.nasa.gov/en/kids/ds1fact2.shtml
Space Place with Dr. Marc

http://science.nasa.gov/headlines/y2001/ast19sep_1.htm
http://nmp.jpl.nasa.gov/ds1/
Deep Space 1

http://nmp.jpl.nasa.gov/ds1/tech/ionpropfaq.html
Frequently Asked Questions About Ion Propulsion

http://science.nasa.gov/newhome/headlines/prop06apr99_2.htm
Ion Propulsion: Over 50 Years in the Making

http://sse.jpl.nasa.gov/news/display.cfm?News_ID=5692
Ion Engine: No Tuneups, No Problems