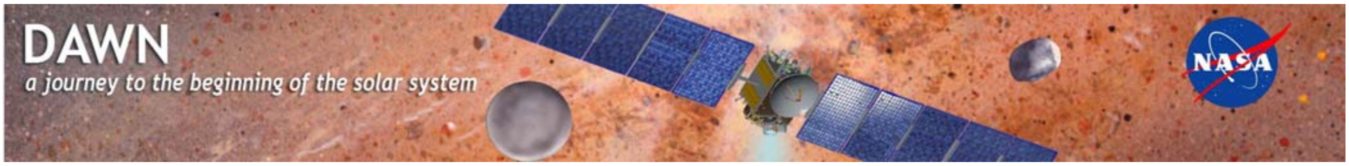
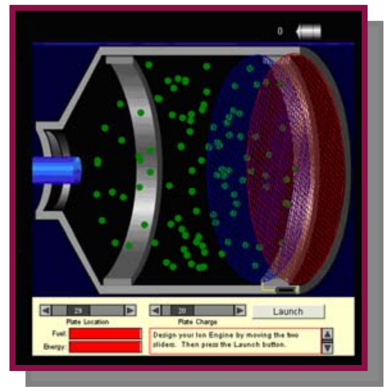


Ion Propulsion

Design an Ion Engine

TEACHER GUIDE – ASSESSMENT

BACKGROUND



As students interact with the simulation of an ion propulsion engine, they will gain an understanding of

- how an ion propulsion system works; and,
- the essential variables upon which an ion propulsion system depends

by applying the background information from this module to determine what Plate Location settings and what Plate Charge produces the most thrust for the engine.

The student activity, “Ion Propulsion Engine Simulation,” has an abbreviated description of models and describes ways in which this simulation differs from the design of a jet propulsion engine. For a more detailed text, click on http://www.mcrel.org/epo/resources/sci_modeling.asp to use for your own information or as a student introduction to the assessment assignment.

The activity sheet also refers to information that students have encountered earlier in the module, especially in “A Trip through An Ion Propulsion Engine” as it leads the students through some analysis of the results of the Plate Location and Plate Charge default settings.

The activity sheet also describes some aspects of good experimental design. You may wish to supplement these suggestions with your requirements for experimental design before students work through this activity. You also have the option of making their individual designs part of your activity assessment.

The **TEACHER GUIDE SUPPLEMENT CONTAINS:**

Specific NSES Science Education Standards for this guide;
Anticipated Test Results for the Student Activity, “Ion Propulsion Engine Simulation”
Assessment rubric for the summarizing question assignment

MATERIALS

Student Activity and Report Sheet, “Ion Propulsion Engine Simulation”
This activity is to be completed, either as an individual assignment or in pairs, at a computer with Internet access to the following URL:
http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/index.html

ESTIMATED TIME:
Part 1: 45 Minutes
Part 2: 45 Minutes
Part 3: 45 Minutes

PROCEDURE

Student Activity, "Ion Propulsion Engine Simulation"
Part 1

1. Make the necessary arrangements for students to use computers with Internet access, either individually or in pairs, to complete this activity. Make copies of the "Ion Propulsion Engine Simulation" Student Activity and Report Sheet for each student or pair of students.
2. Distribute copies of the activity and have students access the simulation using the above URL. You may also want to have copies of the "One Xenon Atom" available for student reference as they complete this simulation assignment.
3. Either by questioning or by reading Part 1, Procedure 2 with them, make sure that your students understand the following before they start the simulation:
   a. the color-scheme of the engine parts and the electrons, xenon atoms, and ions in the simulation is the same as that used in the tutorial and in the "One Xenon Atom" graphics.
   b. what they are observing on the simulation screen ─ the green xenon atoms, the blue and red grids, and the icon of the engine at the top of the engine;
   c. what the Plate Location and Plate Charge scale bars are indicating, and how the Fuel and Energy bar graphs can be read (or estimated); and,
   d. how the thrust of the engine will be indicated.

   Depending upon the experience and background of your students, you may choose to do this either by:
      i. having the "Design an Ion Engine" URL projected on a large screen and discussing the text material in Part 1, Procedure 2 with the whole class; or,
      ii. letting each individual or pair of students work their way through the activity sheet on their own and monitoring their progress by moving around the classroom.
5. After students have launched their engines using the default settings, you may wish to help them with the analysis of the results, which is only 30% of the maximum possible thrust. Ask questions that will help them recall their experience with the tutorial that began this module, in which they discovered the variables in Coulomb's Law.
6. After students have launched their engines using the maximum energy and closest grid positions, ask guiding questions similar to the following to help them recall the function of the engine parts:
   a. Did the electrons have sufficient energy to ionize the xenon atoms? [yes]
   b. What function does the positively-charged grid play in the ion propulsion engine? [It attracts the xenon ions and aligns them so that they can go through the grid and "see" the negative grid farther back in the engine.]
   c. Were the xenon ions going through the positively-charged grid, or could you tell? [It appears that at least some of them went through that grid, but they all discharged before going through the negatively-charged grid.]
7. After students have launched their engines using a Plate Location of 50 and maximum energy, ask guiding questions similar to the following to help them recall the function of the engine parts:
   a. Did the electrons have sufficient energy to ionize the xenon atoms? [no]
   b. Were the xenon ions going through the positively-charged grid, or could you tell? [Most of them went through that grid, but they all discharged before going through the negatively-charged grid.]

The text box on the next page shows the explanation given in the Student Activity sheet for so few xenon ions going through the grids as plates are widely separated. Depending upon the age of your students, you may need to be ready to explain in terms of their prior science background.

As the separation of the grids increases, there is room for more and more ions between the grids. Each ion has a 1+ charge that forms an electric field which would only repel other ions but also shields them from the negative charge on the grid that should be attracting it. So, the attractive force that our single xenon ion is feeling is either reduced or completely blocked by other positive ions. This interference is called “space charge.”

The greater the separation of the grids, the greater the “space charge” effect, and the total number ions that can pass through the grids per unit time is inversely proportional to the square of the separation. Therefore, if you increase the separation of the grids by a factor of approximately 1.4, the number of ions that will get through the grids decreases by a factor of 2.

Part 2

1. Give students your instructions and requirements for designing their investigation. You may wish to check their experimental designs in Procedure Part 2 a) before allowing them to start, so that the assignment does not become one of trial-and-error.
2. As students are carrying out their design, you might ask guided questions similar to the following as you monitor their work:
   a. Are you analyzing the changes in the amount of energy consumed as you change one variable at a time? How did that change in energy affect the thrust produced?
   b. Are you analyzing the changes in the amount of fuel consumed as you change one variable at a time? How did that change in fuel consumption affect the thrust produced?
   c. Have you found a maximum thrust for a given Plate Location when varying the Plate Charge?
   d. Have you found a maximum thrust for a give Plate Charge when varying the Plate Location?

Part 3

During the follow-up class session, have students share their answers to the last questions in the activity.

What parameter, Plate Charge or Plate Location, appeared to be most influential in determining the thrust of the ion propulsion engine? On what did you base your decision?
[Analysis of the data will show that the changing the Plate Location by one unit resulted in thrust changes in a range of 1 to 15, with the smallest changes occurring close to the optimum settings of 32–34. Changes in Plate Charge over a range of 75 to 100 at the optimum Plate Location of 32 resulted in consistent thrust changes of 1 unit. So, it would appear that Plate Location was the most influential in determining thrust.

You might want to ask the follow-up question, “Why might this be so?” [This might indicate how critical it is that the ions be aligned as they go through the first grid and come under the accelerating influence of the second grid. (See Section 2 of “One Xenon Atom”) The number of ions present in the space between the grids could also be a factor. (See Section 3 of “One Xenon Atom”)]

What other conclusions can you reach regarding the application of attractive forces between positively- and negatively-charged objects in an ion propulsion engine?
[Analysis of this simulation will vary depending upon age group and interest but, at an appropriate level, their answers should include

the awareness that processes occurring in an ion propulsion engine are more complex than just “unlike charges attract” and “like charges repel.” Coulomb’s Law is also applied, but not in the simplistic way it was applied in the tutorial.

the fact that the “charged particles,” xenon ions, are in constant motion and that they are generating and being influenced by electric fields in the engine also complicates the processes.

the efficiency (the magnitude of thrust) of an ion propulsion depends upon potential difference between two plates and the spacing of the plates.

the consideration of constraints of energy use and the causal relationships between fuel consumption and thrust.

Encourage your students to keep their experiences with this simulation activity in mind as they monitor the progress of the Dawn Mission spacecraft on its journey to the asteroid belt.

Teacher Guide Supplement

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

Science as Inquiry (Grades 9–12)

Abilities Necessary to Do Inquiry

Identify questions and concepts that guide scientific investigations
Use technology and mathematics to improve investigations and communications
Formulate and revise scientific explanations and models using logic and evidence

Physical Science (Grades 9–12)

Structure of Atoms

Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons.

Structure and Properties of Matter

- In gases, molecules or atoms move almost independently of each other and are mostly far apart.

Motions and Forces

- Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship, F = ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

  The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them. Electricity and magnetism are two aspects of a single electromagnetic force.

Anticipated Test Results
for the Student Activity, "Ion Propulsion Engine Simulation"

Sample data for Part 1, steps 4 - 7

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed
29	20	49	100	15

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed
1	100	0	100	10

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed
50	100	0	85	100

Sample data set for Part 2

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed
45	50	150	100	55
45	60	159	100	70
45	70	161	100	80
45	80	149	100	90
35	80	162	100	75
25	80	137	100	60
35	90	165	100	85
35	95	171	100	85
35	96	172	100	87
35	97	171	100	87
34	97	174	100	85
33	97	175	100	83
32	97	174	100	80
33	98	174	100	80
33	99	175	100	83
33	100	176	100	85
32	100	177	100	85
31	100	174	100	80

What happens to the magnitude of the thrust as you keep the Plate Charge constant and increase or decrease the Plate Location? [Based on a data table similar to that above, as one decreases the Plate Location, the thrust increases at first, then decreases, depending on the magnitude of the Plate Charge.]

What happens to the magnitude of the thrust if you keep the Plate Location constant and increase or decrease the Plate Charge? [Based on a data table similar to that above, as one increases the Plate Charge, the thrust increases at first, reaches a maximum, then decreases.]

Were there any settings where you did not run out of fuel? [Yes, when all the energy was used first.]

Were there any settings where you did run out of energy? [Plate Location between 40–70 and Plate Charge100]

What was the maximum thrust that your engine achieved? [177]

What were the settings for this maximum thrust? [Plate Location 32 – 34; Plate Charge 100]

You may use a rubric similar to the following to evaluate student responses to:

d) Explain in your own words how the Dawn ion propulsion system works and how the variables involved affect the thrust (or efficiency) of the engine that will take the spacecraft to the asteroid belt. Your answer should include a description of the following variables:

a) the use of energy from the solar arrays
b) the ionization of xenon atoms;
c) the role of the electrically-charged xenon ions and the grids;
d) how the ion beam is neutralized; and
e) how to optimize the spacecraft's thrust.

Assessment Rubric

3 How does *the variable* get us where we want to go?	**2 How does *the variable* work?**	**1 Awareness of *the variable***
a) The solar arrays convert solar energy to electrical energy, which is used to charge the electrical grids in the ion propulsion engine and to increase the energy of electrons emitted from a cathode into the engine chamber. b) Energetic electrons, emitted from a cathode, collide with xenon atoms with enough energy to remove an electron, forming xenon 1+ ions. c) The function of the two electrically-charged electrodes at the rear of the Dawn ion engine is to align xenon ions in the same plane and accelerate them. The xenon ions exert a strong electrostatic pull on the negative grid as they are accelerating toward it. As the ions pass through the negative grid, their change in momentum accelerates the grid, which	a) The solar arrays provide electrical energy to charge the grids and to energize the electrons. b) Electrons collide with xenon atoms and form xenon ions. c) The attraction of the xenon ions to the negatively-charged grid pulls the ions toward the grid causing the spacecraft to move forward. d) Electrons neutralize the ion beam as it is leaving the engine. e) You get the most thrust when the grids have a maximum charge and the plates are located about one-third of the maximum distance allowed. You can't get any thrust if you run out of fuel or out of energy.	a) The solar arrays provide energy for the spacecraft. b) Xenon atoms are changed to xenon ions. c) Xenon ions are attracted to and move through the electrically-charged grids. d) No answer or incorrect answer e) You have to set the Plate Location and the Plate Charge exactly right (correctly) to get the most thrust out of the engine.

3 How does *the variable* get us where we want to go?	2 How does *the variable* work?	1 Awareness of *the variable*
is attached to the spacecraft, moving the spacecraft forward with an equal but opposite thrust. d) The walls of the chamber remove excess electrons from the chamber and the cathode at the rear of the engine releases electrons to neutralize the xenon ion beam as it leaves the engine. e) To optimize the spacecraft's thrust, one must use both energy and fuel efficiently. Electrons must have enough energy to ionize xenon atoms at an optimum rate and grids must have enough potential to align and accelerate the xenon ions. The grids must also be located close enough together to attract the xenon ions and to minimize the "space charge" effect but far enough apart to accelerate the xenon ions sufficiently to provide the thrust to move the engine in a forward direction, that is, toward the asteroid belt.		