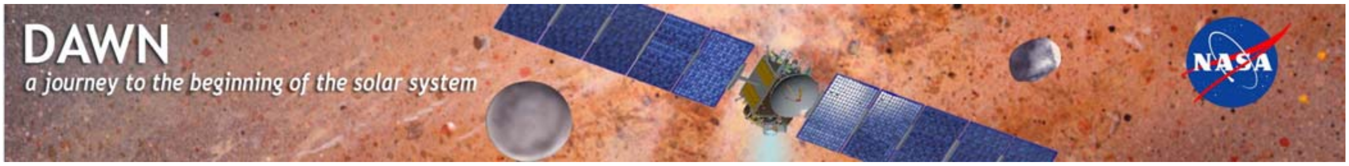

Ion Propulsion

Ion Propulsion Engine Simulation

STUDENT ACTIVITY AND REPORT SHEET

This activity must be completed at a computer with Internet access.

Part 1: Procedure
1. Go to http://dawn.jpl.nasa.gov/mission/ion_engine_interactive/index.html

2. Click on Design An Ion Engine.
The simulation model of an ion propulsion engine on the screen shows some xenon atoms (green dots), a blue positive grid, and a red negative grid. Since the xenon atoms are electrically neutral, they are neither attracted nor repelled by the electrically-charged grids. They move about randomly within the engine walls. You will use this model to explore the relationship between the variables of grid spacing and grid potential difference and the thrust of the engine.

Remember that this is a ***model*** of an ion propulsion engine. Models always have some aspects that do not accurately portray the "real thing." However, we can use models to help us understand the "real thing." Your challenge is to explore the relationship between the between the variables of grid spacing and grid potential difference and the thrust of the engine.

The Plate Location is an indication of the separation distance between the two electrically-charged grids, in a range from 0 to 90 (no units given). Remember that the distance between these grids in the Dawn engine is only about 1000 microns, the width of 10 human hairs. Through experimentation, you will determine what distance, from 0 to 90, represents this optimum distance of 1000 microns.

The Plate Charge indicates the relative voltage potential between the grids, in a range of 0 to 100 (again, no units). In the Dawn engine, this potential is 1280 volts. You will determine, by experimentation, what charge (from 0 to 100) represents that voltage.

Note also that there are bar graphs at the bottom of the simulation that indicate how much fuel was consumed and how much energy was used to power the engine. In the Dawn spacecraft, solar energy is used to charge the grids and to increase the energy of the electrons sufficiently to ionize the xenon atoms.

In the model, there are occasions when it appears that electrons move through the engine walls, but that is only an artifact of the simulation program. Electrons are, indeed, attracted to the positively-charged walls, but they do not leave the engine itself through the walls.

Even though the engine appears to remain static, its motion is represented by the rocket moving to the left at the top of the display and the thrust (again, in relative numbers with no units) is shown.

The goal of this activity is to maximize the total impulse, the thrust, provided by the ion engine.

3. The default setting for the Plate Location is 29 and the Plate Charge is 20. Record these settings in the data table below.

4. Click on LAUNCH and observe what happens. Note that electrons are emitted by the blue electrode. These electrons have enough energy to remove an electron from a xenon atom upon collision, forming xenon ions and an additional electron.

   When you have run out of fuel, record the amount of thrust as shown numerically above the engine. Record the Fuel Consumed and Energy Consumed as percentages. You will have to estimate these data from the bar graphs under the engine.

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed

5. Let's examine the results from these default settings. The grids (plates) are located about 1/3 of the maximum distance allowed from each other and the charge on the grid is only 1/5 of the maximum charge available. At these settings, we got 49 units of thrust, which is only about 30% of the maximum possible.

   Let's analyze the situation. You have two variables that you can control—distance between the two plates and the charge on the plates. These are the same variables that you experimented with in the tutorial on "Positive and Negative Charges."
   The xenon ions in the ion propulsion engine are positively charged and their speed and direction are influenced by these variables.

   Since the charge on a xenon ion is a constant (that is, it cannot be changed), let's try
   - increasing the plate charge to maximum; and,
   - moving the plates as close together as possible to decrease the distance between the ions and the negative plate.

Remember...
In the "Positive and Negative Charges" tutorial we found that the closer the positively-charge particle was to the negatively-charged particle, the greater the attractive force. And, the larger the charges, the greater the attraction.

Also, recall what happened in the tutorial when you placed a positively-charged particle on top of a negatively-charged particle.

6. Click on Stop so that you can reset the parameters. Since setting plates at a distance of 0 means that they would be touching (and, therefore, discharge) try setting the Plate Location to 1 and the Plate Charge to 100. Click on Launch and observe what happens.

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed

   a. Was this what you expected? Why or why not?

   b. How much fuel was consumed? How much energy?

   c. How much thrust was produced?

   d. What happened to the xenon ions, represented by the blue dots? Did any of them pass through the negative grid? Why do you think this happened?

   e. Was all the xenon fuel ionized?

If you wish to observe the launch at any settings a second time, click on Stop and wait until the simulation is reset. Then click on Launch again.

Evidently, there is more to designing an ion propulsion engine than just knowing about attractive and repulsive forces. Remember that the Xenon ions are strongly attracted to the negative grid, so, IF the plates are the correct distance apart, the ions move toward and through the positive grid and are then electrically accelerated **between the grids** to a speed of about 30 km/sec. The xenon ions actually pull on the negatively-charge grid which is a stationary part of the engine. This pull provides thrust that moves the engine in the opposite direction.

Increasing the charge on the plates means that more solar energy is converted to the kinetic energy of each ion. But you have a limited energy supply, so you might run out of energy before you can accelerate all the ions. Adjusting the charge too low means the plates won't convert as much solar energy to kinetic energy of the charged particles.

If the separation between the plates is not adjusted correctly, too many ions will hit the plates. If an ion or electron hits a plate or the walls of the ion engine, it will emit a brief white flash and then disappear. The energy is lost and they provide no thrust.

7. Click on Stop so that you can reset the parameters to make another trial run. This time leave the Plate Charge on 100 and change the Plate Location to 50 to allow the Xenon ions to be accelerated through a longer distance. Click on Launch and observe what happens.

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed

a. Was this what you expected? Why or why not?

b. How much fuel was consumed? How much energy?

c. How much thrust was produced?

d. What happened to the xenon ions, represented by the blue dots? Did any of them pass through the negative grid? Why do you think this happened?

e. Were all the xenon fuel ionized?

You have launched three trial runs that yielded some very interesting (and confusing?) results. You may be wondering why more of the ions didn't make it through the grids when we made the grid separation greater. Consider this:

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: Procedure
Now that you have analyzed the launch of the three trials, you need to determine the optimum charge on the plates and the optimum distance between the plates to produce the most thrust for the spacecraft.

1. Your instructor may ask you to write out your experimental design before you start. If so, write out your design below.

Just a suggestion: It is good experimental design to change only one variable at a time. You may want to start by setting both variables at the halfway point. For Plate Location, that would be 45 and for Plate Charge that would be 50. Then, keeping one variable constant, change the other by increments of 5 or 10 so that you can see the trends. When you find the settings that look the most favorable, change one of the variables by increments of 1 or 2 to find the settings that give you the maximum thrust.

2. Record your data for each setting in the table below so that you can answer the questions that follow the data table. Look for trends to help you decide what your next settings should be.

Plate Location	Plate Charge	Thrust	% Fuel Consumed	% Energy Consumed

3. Answer the following questions
   a. What happens to the magnitude of the thrust as you keep the Plate Charge constant and increase or decrease the Plate Location?
   b. What happens to the magnitude of the thrust if you keep the Plate Location constant and increase or decrease the Plate Charge?

   c. Were there any settings where you did not run out of fuel?
   d. Were there any settings where you did run out of energy?
   e. What was the maximum thrust that your engine achieved?
   f. What were the settings for this maximum thrust?

   g. Plate Location _____ Plate Charge _____

   h. What parameter, Plate Charge or Plate Location, appeared to be most influential in determining the thrust of the ion propulsion engine?

   i. What other conclusions can you reach regarding the application of attractive forces between positively- and negatively-charged objects in an ion propulsion engine?

4. 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:
   a. the use of energy from the solar arrays
   b. the ionization of xenon atoms;
   c. the role of electrically-charged xenon ions and grids;
   d. how the ion beam is neutralized,
   e. how to optimize the spacecraft's thrust.