

ION DRIVE ENGINE: DEEP SPACE PROPULSION

How can ions be used to accelerate spacecraft on long missions to explore the solar system?

Students experience the motion of ions in everyday life—for example in their television sets and in neon lights—but it still seems a mysterious process. How can the energy of ion motion be harnessed to send a spacecraft to a distant destination? This activity helps students understand the science of ionization and the advanced technology of the ion drive engine.

The U.S. space agency, the National Aeronautics and Space Administration (NASA), has created the New Millennium Program to conduct a series of flights into deep space and into orbit around Earth that will test high-risk technologies deemed critical for future space missions. The first mission, launched in October 1998, is called ***Deep Space 1***. It carries twelve new feats of technology being used as never before in a spacecraft, including the *ion drive engine*.

<i>Grade Level:</i>	<i>Elementary and middle school</i>
<i>Group Activity:</i>	<i>7-10 in a group</i>
<i>Objectives:</i>	<i>Learn the basics about ionization, then apply this understanding to learn the basics about how an ion drive engine works</i>
<i>Materials:</i>	<i>No materials needed—just enthusiastic participants</i>
<i>Timetable:</i>	<i>Warm-up, about 10 minutes; main activity, about 25 minutes</i>
<i>Vocabulary:</i>	<i>electron cloud, ion, ionization, ion engine, xenon, molybdenum</i>

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WARM-UP ACTIVITY: ELECTRON CLOUD

Back in 1897, the scientist J.J. Thomson (1856-1940) verified the reality of the *electron*, a subatomic particle that carries a negative (-) charge. We know about electrons, but no one has ever seen one—they are simply too tiny. We know, for instance, that in an atom, negatively charged electrons zing around a positively charged *nucleus* of *protons* and *neutrons*. This atomic structure has often been pictured as a miniature solar system, as if the electrons were in orbit around the nucleus. This is a powerful image, but, technically, not very accurate.

Electrons zing around in many different patterns, at many different energy levels, unlike planets in relatively fixed orbits around the sun. Electrons move around so fast and in so many places, it is as if they form an *electron cloud* around the nucleus of an atom.

Warm-up Activity Instructions *Electron Cloud, Hand to Hand*

Make one hand into a fist. This hand represents the positively charged nucleus of an atom composed mainly of protons and neutrons.

Open the other hand and move your fingers rapidly.

Now let the wiggling hand move around the closed fist in all directions, in close, out far—representing the electron cloud.

Together, this represents an atom.

Warm-up Activity Instructions *Electron Cloud, Partner to Partner*

Now, get a partner. One of you is the ion, composed of the nucleus and the inner electrons. Your body is the nucleus. Now move your arms about. Your arms are a cloud of inner electrons.

The other one of you represents an outer electron cloud (which may have one or more electrons). When this electron cloud is bonded together with the ion, we have a complete atom. But when this cloud is stripped away, we have a free negatively charged electron and a free positively charged ion.

MAIN ACTIVITY: PUTTING IT ALL TOGETHER

*The first ion propulsion engine was developed at NASA's Lewis Research Center in 1960. **Deep Space 1** is the first space mission to use this new technology as its primary means of propulsion. Success on **Deep Space 1** would give us a new way to design spacecraft.*

How Does It Work?

Ionization occurs when one (or more) electron breaks away from an atom or molecule, creating a pair of charged particles—the negatively charged electron and the positively charged ion. The motion of the ions can then be directed to provide an engine's thrust. In the ion engine used on **Deep Space 1**, electrons accelerated by solar energy bombard xenon gas particles, ionizing them. Two grids made of molybdenum attract and accelerate the positively charged ions to very high velocities (35 km/second; 18 miles/second).

By sending the ions out as a high velocity exhaust, a thrust is produced that gently accelerates the spacecraft. In space, such low-thrust ion propulsion can, over time, accelerate a spacecraft significantly. Each ion leaves with so much momentum that a little propellant (fuel) goes a long way to change the spacecraft speed, resulting in much greater fuel efficiency than other propulsion types.

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Why Use Xenon?

Xenon is a good propellant for several reasons. It is inert, making it safe for people to work with and for the spacecraft to use. (Earlier developments of ion propulsion used mercury, which was harmful to both people and spacecraft hardware.) In addition, xenon is easy and compact to store, so it does not require extreme temperatures or huge tanks. Finally, each atom (or ion) of xenon is relatively massive, so the high-speed departure of each one from the spacecraft imparts a relatively large momentum to the spacecraft. A lighter ion leaving with the same speed would give the spacecraft less of a kick.

Ion Drive Your Way Through Space

This activity introduces the science and technology of ion propulsion. As teacher or facilitator, you can use the background information and the improvisational scenario to direct the activity with enthusiasm. As students participate, they begin to get the big picture about how ion propulsion works.

IMPROVISATIONAL SCENARIO: ION DRIVE YOUR WAY THROUGH SPACE

Construct an ion engine. Students play the parts of propulsion fuel, the storage tank, the molybdenum grids, the exhaust housing, and the spacecraft itself. Put it all into action in three scenes with the aid of this improvisational scenario.

Scene 1: Xenon, the Noble Gas

Narrator: To help us all understand the space mission of *Deep Space 1*, we are going to create our own living version of the spacecraft and its ion propulsion system. What we're going to do is start with the noble gas, xenon, element number 54 (Xe) on the Periodic Chart. We need two volunteers to work together to play one xenon atom. (*Two students respond.*) One of you is the central part of xenon, where the nucleus of wild protons and neutrons and the inner shells of electrons are. When you are by yourself, you are a xenon ion. Say out loud with great nobility, "I am Ion of Xenon."

Ion of Xenon: *I am Ion of Xenon.*

Narrator: Now, let your arms move about to show a cloud of inner electrons. And you (*the other volunteer*) are the outer part of xenon where the outermost electrons are zinging around the ion. Show zinging around! Now say, "I am Electron of Xenon."

Electron of Xenon: *I am Electron of Xenon.*

Narrator: So let's see you work together to create this picture of Xenon, the Noble Gas. Show the motion. Together say, "We are Xenon, the Noble Gas."

Ion of Xenon and Electron of Xenon: *We are Xenon, the Noble Gas.*

Narrator: Xenon doesn't like to combine with other elements to create compounds, so you can put xenon atoms together and they're very happy to be with other xenon atoms. Who else would like to be atoms of Xenon, the Noble Gas. (*Four or six others, or more, in partners, respond.*) All of you say, "We are Xenon, the Noble Gas!"

All: *We are Xenon, the Noble Gas!*

Narrator: Now, let's imagine that we have put these xenon atoms into a container, a propulsion tank. (*Here, either let the xenon atoms bump around against an imaginary wall to show the container idea or have a couple of other students provide an image of the tank by extending their arms.*)

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Scene 2: The Ion Drive Engine Experiment

Narrator: Now, I need some folks to play an electron beam. (*Let seven or eight students line up closely together.*) An electron beam is the same sort of beam that creates an image on your television set. In this case we're going to use the beam to energize the outermost electrons of the xenon atoms. This is also what happens to atoms of neon (or other noble) gas in a lighted neon sign.

Now we're going to try this in ultra-slow motion so we can see exactly what happens. In real life, these events happen in *nanoseconds*, quicker than you can wink your eye or snap your fingers.

We can't really aim one electron at one xenon atom. Instead, we send in billions of electrons and count on many of them to collide with the xenon. (*Bring one electron toward one xenon pair.*) When an electron moves in and collides, the outermost electrons get so excited that some of them split off from the xenon core and fly off freely. Freeze! When that outermost electron splits off, we are left with a positively charged Ion of Xenon.

Now we need to set up our electrified molybdenum grid. Molybdenum is an exotic metal that can hold a charge and can handle all this bombarding by electrons and ions. (*Several students respond.*) Now say, "We are the Grids of Molybdenum!"

Grids of Molybdenum: *We are the Grids of Molybdenum!*

Narrator: Now, let your arms attract the xenon ions, as if you had an invisible power that could cause the ions to run faster and faster in one particular direction. But keep it ultra-slow motion, so we don't get mixed up.

One more detail: All you free electrons travel a different route, through a *neutralizer*, a tunnel of sorts. I need some people to be the neutralizer tunnel. (*Several students with their arms arched as if to play London Bridge is Falling Down.*) You Electrons of Xenon, go through here. Once you're out, you travel alongside your Ion of Xenon friends again, but as free electrons.

Let's try this scene from beginning to end, in ultra-slow motion, from electron beam, to splitting electrons off the xenon atoms, to the free Electrons of Xenon going this-a-way (*whichever way was decided*), past the electrified Grids of Molybdenum, which are motioning to the Ions of Xenon to go that-a-way and out into deep space. Ready, go! (*When the xenon electrons and ions have exited, yell*) "Freeze! Rewind!"

Scene 3: The Ion Drive Engine on Deep Space 1

Narrator: Now, we're going to build the ***Deep Space 1*** spacecraft around the ion engine. (*Volunteers form the spacecraft as a group sculpture.*) In real life, these Ions of Xenon are moving so fast their energy creates *thrust*. In deep space, there is no resistance, so a little thrust goes a long way. When the ions go back out into space, the whole ***Deep Space 1*** spacecraft moves forward in an equal and opposite direction, pushed by the same amount of momentum that the ions had. It all goes to show that for every act-***ION***, there is a react-***ION***. This ability to *accelerate* the spacecraft over a long time is what makes this ion engine a great new invent-***ION!***

Now you can ion drive your way through space!

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