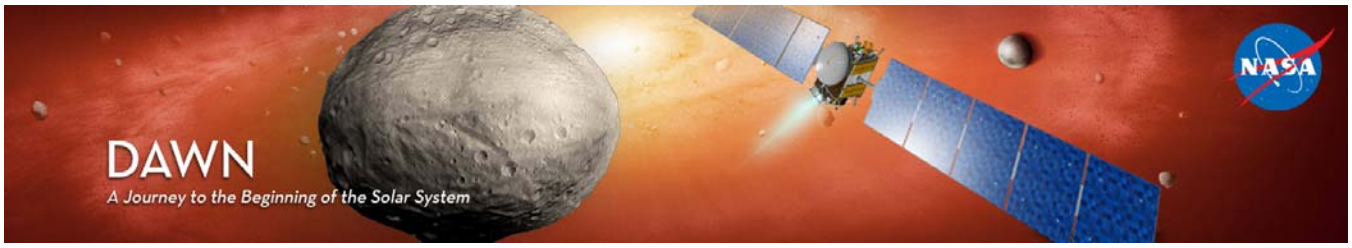


Interactions of Energy and Matter: Dawn Instrumentation

GRaND

TEACHER GUIDE

WHAT WILL GRaND "SEE" WHEN WE GET TO VESTA AND CERES?

EMR and the Dawn Mission

Electromagnetic radiation (EMR) will play a major role in accomplishing the goals of the Dawn Mission. The Dawn spacecraft instrumentation payload utilizes the interaction of specific ranges of electromagnetic radiation with the ***matter*** that comprises Ceres and Vesta. When EMR interacts with matter, including electrons and neutrons, ***radiation*** is absorbed or reflected only at wavelengths corresponding to the discrete amounts of ***energy*** that are related to the constituents of the matter. These wavelengths can then be used to identify the components of a given substance.

Dawn Mission Objectives

The mission's science goals are to understand the conditions and processes in place at the beginning of solar system formation. Scientists also hope to gain a new understanding of the role of water in asteroid evolution.

The scientific data that results from these interactions will enhance our knowledge of Vesta and Ceres by providing information about their surface composition and mineralogy, surface modification, and surface ages. When this information is incorporated into what is already known, either it will substantiate current scientific theories of asteroid origins and geologic processes or it will form the basis for new models.

Gamma Ray and Neutron Detector (GRaND)

Primary Objectives—Measure the average surface composition of the asteroid; map compositional variations and assess the extent of heterogeneity on the surface of the asteroid; search for near-surface ices to depths of a few meters.

Most science curricula emphasize how we use electromagnetic radiation in our everyday lives, using illustrations such as radios, x-ray machines, microwaves, and ultraviolet and infrared lamps. The materials in this module will introduce students to the ways that scientists, engineers, and technologists "in the real world" design instrumentation that utilize the interactions between different frequencies/wavelengths of the EMR and matter to make scientific measurements and analyze data. This section of the *Interaction of Energy and Matter: Dawn Instrumentation* module is designed to help your students understand more about how the Gamma Ray and Neutron Detector (GRaND) aboard the Dawn Spacecraft operates and what it will help us "see" when the spacecraft reaches Ceres and Vesta.

For a more information on GRaND, see page 8 of this guide.

Options for use of the *Interaction of Energy and Matter: Dawn Instrumentation—GRaND* materials

The *Interaction of Energy and Matter: Dawn Instrumentation—GRaND* materials may be used in the following ways:

1. Using the GRaND PowerPoint presentation, engage the whole class in a conversation about how this instrument uses the interaction of specific ranges of electromagnetic radiation with matter to identify the composition of Ceres' and Vesta's ***regolith***. Have individual students complete the observation sheet handout as they watch the presentation. This option, designed to be incorporated into your study of electromagnetic radiation or your study of matter-energy interactions, can be completed in 30 minutes of class time.
2. Divide the class into groups of two or three to view the GRaND PowerPoint presentation with the Student Version of the script and, as a group, complete the observation sheet handout. If you select this option, you may wish to review the characteristics of electromagnetic radiation using the information in *The Electromagnetic Spectrum* *http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/images/electromagnetic_spectrum2.jpg* and the *Characteristics of EMR* located in Appendix A of this guide before dividing the class into groups. For more information on the electromagnetic spectrum, you can also use the interactive found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html. If you use the students' observations as the basis for a class discussion of the applications of electromagnetic radiation and/or matter-energy interactions, this option can be completed in one 50-minute class session.
3. Divide the class into groups of two or three. Assign each group to view one of the series of PowerPoint presentations that feature the instruments—GRaND, VIR, and the Framing Camera—in the Dawn Spacecraft payload. They should complete the observation handout as a group for the instrument they are assigned. If you select this option, you will probably wish to review the characteristics of electromagnetic radiation, using the information in the *Characteristics of EMR* in Appendix A of this guide, *The Electromagnetic Spectrum*, and the website mentioned above before dividing the class into groups. If you use the students' observations as the basis for a class discussion to compare the applications of electromagnetic radiation matter-energy interactions in the different payload instruments, this option may require more than one 50-minute class session.

Materials

- Handout: Print PowerPoint slide three entitled *The Electromagnetic Spectrum*
- *GRaND PowerPoint* presentation from the *Interaction of Energy and Matter: Dawn Instrumentation* module at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/index.asp.
- *Student Report Sheet: GRaND* to record observed interactions of energy and matter from the *GRaND PowerPoint* presentation
- Optional: *Student PowerPoint Script: GRaND*
- Optional: Interactive website on the electromagnetic spectrum found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html
- Optional: (for the Gamma Ray Game) colored and white "flags;" colored and white index cards; paper clips; game instructions are found in Appendix B
-

Note: If you plan to use the assessment created for this module, please ask your students to keep all of their activities and handouts for use in completing the assessment entitled *Concept Maps: EMR Matter-Energy Interactions and Relationships.*

Procedure

Using the *GRaND PowerPoint* presentation with whole class

1. Start the *Interaction of Energy and Matter: Dawn Instrumentation—GRaND PowerPoint* presentation. You will find a suggested script for each screen and cues for controlling the forward progress of the presentation in text boxes.

2. As students view the title page of the GRaND PowerPoint presentation:

   GRaND is one of the scientific instruments in the payload of the Dawn spacecraft. The Dawn Mission is designed to increase our understanding of the conditions and processes that were happening during the solar system's earliest epoch. Geochemical data from GRaND will give scientists a better understanding about the material forming Vesta and Ceres, two large asteroids.

3. {click to Slide 2}

   GRaND is a Gamma Ray Spectrometer and Neutron Detector. In this section, we will be learning more about the GRaND, including what it does and how it works.

4. {click to Slide 3}
   Have students examine Slide 3 and/or handout copies of the table entitled *The Electromagnetic Spectrum*. You may also want students to review the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html.
   If this is your first lesson in the Exploration phase of this module, introduce (or ask students to review) the characteristics of electromagnetic radiation using the information in the *Characteristics of EMR* box located in Appendix A of this guide and explore the interactive information presented at the website above.

   {The answers to the **bolded student questions** are not part of the Student Version of the script. Students are prompted to answer these questions on their *GRaND Student Report Sheet.*}

   What region of electromagnetic radiation (EMR) from Ceres and Vesta will the GRaND measure? {Wait for student answers.}
   [The table indicates that GRaND will detect and measure radiation from the surface of Ceres and Vesta in the gamma ray region of EMR.]

   What frequency and wavelength regions of EMR are classified as *gamma rays*? {Wait for student answers.}
   [Wavelengths around 10^{-12} m and frequencies around 10^{20} hertz.]

   How does the energy of gamma rays compare with the energy of the rest of the EMR waves? {Wait for student answers.}
   [Gamma rays have the highest energy waves in the EMR.]

5. {click to Slide 4}
   What will the GRaND do when Dawn gets to Vesta and Ceres?

   From a circular, polar-mapping orbit, the Gamma Ray and Neutron Detector (GRaND) will measure the chemical composition over the entire surfaces of Vesta and Ceres. Using a combination of gamma ray and neutron spectroscopy, the GRaND will measure the abundance of many elements:
   {click}
   - near-surface major rock-forming elements such as oxygen, magnesium, aluminum, silicon, calcium, titanium, and iron;

   {click}
   - long-lived radioactive elements such as potassium, thorium, and uranium; and,

   {click}
   - ***volatile*** elements such as hydrogen, carbon, nitrogen, and oxygen, which are the major constituents of ices.

6. {click to Slide 5}
   What is the origin of the gamma rays that GRaND will detect?
   {click}
   Some of the gamma rays that GRaND will detect and measure result from natural decay of radioactive elements close to the surface of Ceres and Vesta.
   {click}
   Other gamma rays are produced by a "Splat!" of galactic ***cosmic rays*** that interact with the nuclei of chemical elements within the first few meters of the surfaces of Vesta and Ceres. Since neither Vesta nor Ceres have an atmosphere, cosmic rays can penetrate the asteroids' surface to depths of several meters.
   {click}
   The energies of galactic cosmic ray protons are many times greater than that of nuclear binding energies. When these protons collide with the protons and neutrons of an atomic nucleus within the first few meters of the asteroid's surface, a cosmic ray shower of many kinds of particles and energy is released. ***Fast neutrons*** are a part of this shower. These neutrons are intact particles of matter with very high kinetic energy.

   These fast neutrons interact with other atomic nuclei within the asteroid's surface, losing energy in one of three different mechanisms.
   {click}
   One mechanism is called ***neutron capture***. In this interaction, a neutron is absorbed into the nucleus of an atom, releasing gamma rays. Because each element emits unique and characteristic gamma rays, those gamma ray "signatures" can be used to identify the element.
   {click}
   Fast neutrons can also undergo ***inelastic collisions*** with atomic elements. These collisions also produce unique, identifiable gamma rays.
   {click}
   Fast neutrons can also lose energy through moderation in nearly elastic collisions, similar to billiard-ball collisions. No gamma rays are given off in these collisions.
   {click}
   Some of the fast neutrons produce ***thermal*** and ***epithermal neutrons*** as they lose energy during scattering collisions with other nuclei in the first few meters of the asteroid's surface.

   Thermal neutrons have lost sufficient energy to be in thermal equilibrium with the asteroid's surface.

Epithermal neutrons have undergone energy losses but are still not in thermal equilibrium with the asteroid's surface.

Neutrons in all three energy ranges—fast, thermal, and epithermal—leak from the asteroid's surface and can be detected by the sensitive neutron detectors in GRaND.

{Students are prompted to answer these questions on their *GRaND Student Report Sheet using a graphic organizer, labeled diagram, or outline.*}
Describe the interactions of matter and energy illustrated in the GRaND Splat! Slide.
Their descriptions should include the incoming galactic cosmic ray, the different mechanisms from which a fast neutron may lose energy, and a description of the three different energy states of neutrons. They should also include a description of the release of unique gamma rays from the interactions.

7. {click to slide 6}
This is a cut-a-way view of the Dawn GRaND instrument.

It can help us understand how GRaND measures the abundance of major rock-forming elements, as well as radioactive and volatile elements in Vesta's and Ceres' surfaces. Each chemical element has a unique pattern of gamma rays, a "fingerprint" which GRaND can analyze to determine not only the element's presence but also its abundance.

That's a pretty big job for an analytical instrument that is only 25.7 cm long, 18.0 cm wide, and 26 cm tall.
{click}
And GRaND has a mass of only 10 kg!

GRaND has two ***gamma ray spectrometers***. Each of them has its own specific detection range. These detectors will detect gamma rays escaping
{click}
from the surfaces of Vesta and Ceres.
{click} {click}
A 4x4 array of ***semiconducting*** cadmium zinc tellurium crystals is sensitive to gamma rays over a fairly restrictive energy range, 0 to 3 MeV, but it has high energy resolution and is more accurate in the low energy region of the spectrum, the region where gamma rays from many radioactive decay and nuclear reactions are found. CZT crystals detect gamma rays
{click}
from naturally radioactive elements like potassium, thorium, and uranium.
{click} {click}
The sensor that contains bismuth germanium oxide (BGO, also called bismuth germanate) crystals is a high efficiency gamma ray detector. It can measure gamma radiation over a wide energy range of frequencies.
{click}
BGO crystals are sensitive to gamma rays from elements like hydrogen, oxygen, aluminum, silicon, calcium, titanium, and iron.

{Students are prompted to answer this question on their *GRaND Student Report Sheet.}*
What interactions of matter and energy are described in this explanation of GRaND's Gamma Ray Spectrometers?
{Wait for student responses.}

Because each element emits a unique gamma ray “fingerprint,” the spectrometer is able to detect individual elements on the surface of the asteroid. The CZT crystals will detect naturally radioactive elements like potassium, thorium, and uranium. The BGO crystals will detect the lighter elements such as hydrogen and oxygen, and heavier rock-forming elements like aluminum, silicon, calcium, titanium, and iron.

8. {click to slide 7}
GRaND also has two kinds of ***neutron detectors*.**
{click}
Four boron-loaded plastic ***scintillators*** surround the
{click}{click}
BGO crystal and
{click}{click}
the CZT array. When
{click}
fast and
{click}
epithermal neutrons interact with
{click}
two of these
{click}
borated plastic scintillators, they generate
{click}
gamma rays.
{click}
A layer of ^{6}Li-loaded glass, which shields the borated plastic scintillators,
{click}
detects and absorbs thermal neutrons. The interaction
{click}
also produces gamma rays.
{click}
{click}
{click}
The gamma rays generated by the interactions of neutrons with the scintillators are measured by the
{click}
BGO and
{click}
CZT detectors.
{click}{click}
Neutrons that leak from the asteroid’s surface produce gamma rays that can indicate the presence of H, C, N, O, Fe, Ti, Cl, Gd, and Sm.

{Students are prompted to answer this question on their *GRaND Student Report Sheet.}*
What interactions of matter and energy are described in this explanation of GRaND’s neutron detectors?
Fast and epithermal neutrons interact with the borated plastic scintillators, generating gamma rays. Thermal neutrons are absorbed by the ^{6}Li-loaded glass shielding the borated plastic scintillators. The gamma rays produced by the interactions of the neutrons with the scintillators are detected by the BGO and CZT detectors. Leaking neutrons also produce gamma rays that can be detected.

9. {click to slide 8}
   Gamma rays measured by the GRaND show up as sharp ***emission lines*** in the instrument's spectrum output.
   {click}
   The energy (Pulse height in MeV) represented in these emission lines determines which elements are present; and
   {click}
   the intensity of the emission lines (Counts/sec) is related to the element's concentration.
   {click}
   Emission Spectrum is an energy distribution of a neutron source similar to that which may leak from an asteroid's surface.
   {click}
   Emission Spectrum b shows an ore sample spectrum of gamma rays from the decay of ^{214}Bi, one product of the ^{238}U decay chain.
   {click}
   Neutrons interacting with iron nuclei produced the BGO spectrum shown in emission Spectrum c.
   {click}
   The Dawn Mission is designed to yield a significant increase in the understanding of the conditions and processes acting at the solar system's earliest epoch by examining the geophysical properties of two asteroids—Ceres and Vesta. Data from GRaND will provide information about the asteroids' accretion materials, thermal evolution, and differentiation processes.

10. {click to slide 9}
    GRaND is one of the instruments on the Dawn Spacecraft that will utilize the interactions of energy and matter to collect scientific data about Vesta and Ceres.
    {click}
    {Students are prompted to answer this question on their *GRaND Student Report Sheet.}*
    What energy and matter interactions are involved in the scientific measurements made by GRaND?
    Possible answers include the following:
    Energy interacting with matter
    - Gamma rays from nuclear decay, neutron capture, and inelastic collisions interacting with CdZnTe and BGO arrays produce energy in discrete amounts that can be used to identify chemical elements involved
    - High energy in cosmic rays interacting with regolith (not mentioned in presentations)

    Matter interacting with matter producing energy
    - High energy protons in cosmic rays interacting with atomic nuclei in regolith producing fast neutrons, other particles, and energy from nucleus
    - Fast, thermal, and epithermal neutrons colliding with borated plastic and lithium glass scintillator to producing gamma rays
    - Inelastic collisions of fast neutrons with atomic nuclei releasing gamma rays
    - Neutron capture of fast neutrons releasing gamma rays

Wrap-up Session

1. If you used this PowerPoint presentation either as a class or as groups studying the GRaND instrument, relate this information as an application to your study of electromagnetic radiation and mater-energy interactions.
2. If you used this PowerPoint presentation as one of three that explained the matter-energy interactions of instruments in the Dawn Spacecraft payload, have each group of students report their findings and make comparisons of the findings as they relate to the electromagnetic spectrum and matter-energy interactions.

More Information on GRaND

The Gamma Ray and Neutron Detector (GRaND) for the Dawn mission was developed by the Los Alamos National Laboratory. GRaND is managed by the Planetary Science Institute. Tom Prettyman is the GRaND Principal Investigator.

What can scientists learn about Vesta and Ceres by analyzing the information from GRaND?

By mapping the location and abundance of key elements, the geochemical information measured by GRaND will give scientists a better understanding about the material from which the asteroids accreted, as well as constraining thermal evolution and differentiation processes (e.g., volcanism).

- The ratio of potassium to thorium concentrations will provide information about the material that grew to form the asteroids and may be useful in determining how the composition of solar nebula, the cloud of gas and dust which formed the Sun and the rest of the bodies in the solar system, changed with its distance from the Sun.
- The abundance of rock-forming elements, such as iron and titanium, provides information about how igneous rock formed from magma on Vesta.
- Measurements of hydrogen will also be used to determine the distribution of water, which may be present on Ceres as ice or hydrated minerals.
- Measurements of the abundance of hydrogen and carbon will enable scientists to understand aqueous processes that may have shaped Ceres.
- The elemental abundance data will help verify that Vesta is the source of a certain type of meteorites.

Definition of Terms

Energy Units

1 keV = 10^3 eV 1 MeV = 10^6 eV 1 GeV = 10^9eV

Cosmic rays—Ionizing radiation, mostly protons, with energies in the GeV range, that originate outside the solar system

Electromagnetic radiation (EMR)—"Waves" of electrical and magnetic "disturbance", radiated as visible light, radio waves, or any other manifestation of the electromagnetic spectrum

Emission lines—A bright line in the spectrum of a luminous object caused by the emission of light at a particular wavelength

Emission spectrum—A spectrum of energy released from a source, usually in the form of electromagnetic radiation

Energy—The capacity of a physical system to perform work; energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical, or other forms

Epithermal Neutron—A neutron that has undergone energy loss due to scattering collisions but is not in thermal equilibrium with the regolith (E = ~0.3 eV to ~600 keV)

Fast Neutron—A neutron ejected at high kinetic energy in a nuclear reaction (E = ~10^3 eV to 6 MeV).

Gamma rays—Very energetic EMR photons with energies between 1MeV and 10GeV; Gamma rays are produced in inelastic collisions. An inelastic collision is a collision between two particles in which part of their kinetic energy is transformed into another form of energy (gamma rays) – the total amount of energy remains the same

Gamma ray spectrometer—A device that detects emissions in the region of the electromagnetic spectrum having wavelengths in the range of 10^{-12} m and frequencies in the range of 10^{20} hertz

Inelastic collision—A collision between two particles in which part of their kinetic energy is transformed into another form of energy; the total amount of energy remains the same, but distinctive gamma rays are emitted

Matter—Any substance that has mass and occupies space

Neutron capture—A process in which a neutron is absorbed by a nucleus to produce an excited nucleus that transitions to ground state by emission of one or more gamma rays

Neutron detector—A device that detects neutrons. The operation of a neutron detector is based on the detection of the secondary particles formed from the interaction of neutrons with atomic nuclei

Radiation—Energy that comes from a source and travels through some material or through space; light, heat, and sound are types of radiation

Regolith—The layer of rocky or icy debris and dust that forms the uppermost surface of planets, satellites, and asteroids

Scintillator—A phosphor-containing radiation detector that absorbs a photon or ionizing particle

Thermal Neutron—A neutron produced by fission and slowed by a moderator so that it is in thermal equilibrium with its surrounding medium; (E< ~0.3 eV)

Semiconductor—A substance or material, typically crystalline, that conducts electricity better than an insulator but not so well as a conductor, because it allows current to flow only under certain conditions; common semiconductors are silicon, germanium, and gallium arsenide

Volatiles—Substances that change into a vapor at relatively low temperatures

Appendix A
Characteristics of EMR

- Electromagnetic radiation is made of transverse waves (similar to water waves) that travel at the speed of light.
- Electromagnetic radiation is classified into types—radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays—according to the frequency (or wavelength) of the radiation. For more explanation, see the Electromagnetic Spectrum chart at http://dawn.jpl.nasa.gov/DawnClassrooms/3_instrument/images/electromagnetic_spectrum2.jpg and/or the interactive information found at http://earthguide.ucsd.edu/eoc/special_topics/teach/sp_climate_change/p_emspectrum_interactive.html.
- The frequency of electromagnetic radiation is inversely related to the wavelength of the radiation. See the Electromagnetic Spectrum chart and/or the interactive information referenced above for more explanation.
- The energy of electromagnetic radiation is directly proportional to the frequency of the wave.
- Electromagnetic radiation interacts with matter by transmission, absorption, or reflection.

Depending upon the age and background of your students, these characteristics should be forthcoming:

- Electromagnetic radiation consists of an electrical field that varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field oriented at right angles to the electrical field.
- Electromagnetic radiation has energy and momentum, which may be imparted when it interacts with matter.
- Electromagnetic waves can impact matter, causing atoms to vibrate, release heat, or cause electrons to oscillate, depending upon the wavelength of the radiation.

Appendix B
The Gamma Ray Game

Explain to students that they are going to play a game that demonstrates how gamma rays are formed and released when cosmic rays strike a planetary surface. You may need to review the properties of the particles that make up the atom—protons, neutrons, and electrons. The protons and neutrons that make up the nucleus of the atom are closely packed and can only exhibit vibratory motion. Protons are positively charged and neutrons are neutral. Electrons are negatively charged, are much smaller than protons and neutrons, and have high translational movement (i.e., move very fast outside the nucleus).

In this simulation, students will take on the role of individual neutrons, nucleus of an atom, or they will represent the safety monitors.

Materials
White flags (i.e. strips of white fabric, white bandanas, etc.)
Colored flags (i.e. strips of colored fabric, colored bandanas, etc.)
White index cards
Colored index cards (preferably, all one color)
Blindfolds
Copies of Slide 5 from the *Interaction of Energy and Matter: Dawn Instrumentation – GraND* PowerPoint
Computer with Internet access
GRaND Interactive (http://dawn.jpl.nasa.gov/technology/GRaND_inter.asp)

Roles
Neutrons in the nucleus of a central atom impacted by a galactic cosmic ray
Nuclei of other atoms
Safety Monitors to keep blindfolded students from walking into things

Note: The number of students in each role (Neutrons, Nuclei, and Safety Monitors) depend completely upon the number of students in the class. The diagram shows set up for a class of 30.

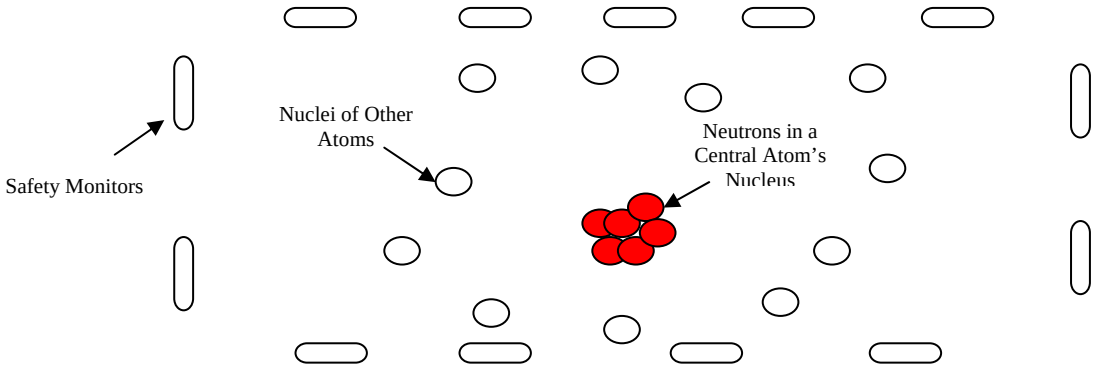
Procedure

1. Provide each "individual neutron student" with a colored flag and a colored index card (representing a gamma ray). Have students place the colored flag in their back pocket or in their belt (similar to flag football). Students simply hold the colored index card in their hand. These students represent part of the nucleus of a central atom in the center of the playing area (representing the planetary surface).

2. Blindfold the students with colored flags and have them stand close together in the center of the playing area. When they are free to move, they can move only in a straight line until they have contact with another person.

3. Other students, representing the *nuclei of other atoms*, should each have a white flag and a white index card (representing a gamma ray). These students should stand on the outside of the playing area, where they can run in place and/or turn in a circle but not move to another location.

4. The students without flags are the Safety Monitors stationed around the playing area to prevent blindfolded students from running into furniture, walls, etc. They are there simply to prevent accidental injury of the blindfolded students.



(Example beginning layout of game)

5. The game play begins when the teacher or a student rings a bell (representing an incoming galactic cosmic ray), releasing the individual neutrons from the central atom's nucleus.

6. *Object of the Game*: The students with the colored flags (representing the neutrons of a central cosmic-ray-impacted atom's nucleus) walk out in a straight line and try to capture a white flag. The students with the white flags (representing nuclei of surrounding atoms), running and/or turning in place, try to capture a colored flag. Use the following rules:
   - If a student with a red flag and a student with a white flag capture each other's flags, then they have to stay together, stand still, paper clip their cards together, then release their paper clipped cards to the floor. (*Neutron capture*)
   - If only one student captures the flag, the students must lock arms, release the gamma ray card (white or colored) corresponding to the captured flag (white or colored) to the floor, and move together outside the play area. (*Inelastic collision*)
   - If neither student captures a flag, the colored flag student simply keeps walking forward until they are out of game play. The white flag student continues to walk and/or turn in place. (*Moderation*)

7. After a certain amount of time, call stop. The students who still have their flags at this time hold onto their gamma ray cards.

8. Pick up the gamma ray cards from the floor. Tally the dropped colored cards, dropped white cards, and the cards still in students' hands in a chart. Compare dropped to not dropped, ratio of colored to white dropped, etc. Run the simulation a few times, allowing students to change roles, so as to provide data that can be compared.

9. Have students return to their seats. Use slide 5 (GRaND SPLAT! slide) from the *Interaction of Energy and Matter: Dawn Instrumentation—GraND* PowerPoint or run the GRaND interactive (found at http://dawn.jpl.nasa.gov/technology/GRaND_inter.asp) for the whole class. This image is called "SPLAT" by the scientists at Los Alamos National Laboratory who developed GRaND

because when cosmic rays interact with the surface of an asteroid like Vesta or Ceres they produce a spray of energy and particles, including neutrons.

10. Debrief the game with your students, using the game as a model for the SPLAT! graphic. You may want to make copies of the SPLAT! PowerPoint slide for the students to use as reference.

Possible debrief

a. Using the GRaND SPLAT! slide or GRaND interactive (see link in number 9) as a guide, what do you think the ringing bell represented? [The ringing bell represented an incoming galactic cosmic ray colliding with the nucleus of an atom on the asteroid.]

b. What happened after the ringing bell allowed the red flag students to move out in a straight line? (Accept student explanations, encouraging them to be specific in their connections between the game and the graphic. Explain that since neither Vesta nor Ceres have an atmosphere, cosmic rays can penetrate their surfaces to depths of several meters to interact with the nuclei of atoms in the asteroid's regolith. These interactions:
   - occur when cosmic ray protons collide with the nucleus of an atom with energies *many times higher than the binding energies of the nucleus*; and
   - release fast neutrons as a part of a cosmic ray shower made up of many other kinds of particles and energy from the nucleus.

c. After the bell rang, what did the students do? How were their movements related to the movements of the neutrons in the diagram? [The colored-flagged students moved forward in straight lines, representing neutrons from a central nucleus that were impacted by a galactic cosmic ray. Because the incoming cosmic ray had higher energy than the binding energy of the representative colored-flagged-nucleus-students, the students moved out in all directions. The white-flagged students ran and/or spun in place, representing the nuclei of other surrounding atoms and their associated kinetic energy.]

d. Once the students with the colored flags moved out of the center of the play area, what was something that happened next? [Based on student answers, provide the following information: Fast neutrons interact with other nuclei, losing energy in the process. Three basic interaction mechanisms are illustrated in the diagram and interactive:
   - Game: Both colored and white flags were captured, students stood together and the paper clipped gamma ray cards were dropped on the floor. Raise your hands if this happened to you.
     - Corresponding interaction in SPLAT diagram: *Neutron capture*, in which a neutron is absorbed into the nucleus of another atom and characteristic gamma rays are emitted
   - Game: Either a red or white flag was captured. One gamma ray card was dropped on the floor; the students locked arms, and then moved out of play. Raise your hands if this happened to you.
     - Corresponding interaction: *Inelastic collisions,* which produce characteristic gamma rays, two or more objects collide and stick together, moving together with collective kinetic energy.
   - Game: Students were unable to capture flags and eventually would run out of energy until "time" was called. Raise your hands if this is what happened to you.
     - Corresponding interaction: *Moderation* in which neutrons lose energy in billiard-ball-type <u>nearly</u> *elastic collisions.*

e. Ask students what happened to the gamma ray cards at the end of the game.
   - The teacher (or student) picked some of them up.
   - Corresponding action in the diagram. The GRaND instrument on the Dawn spacecraft will detect the gamma rays resulting from these three types of interactions.
   - GRaND can also detect the presence of gamma rays emitted by naturally radioactive elements in the asteroid's regolith.

f. Direct students to view slide three while they listen to an audio explanation of the diagram by GRaND Principal Investigator Tom Prettyman found at http://dawn.jpl.nasa.gov/technology/popups/tp_splat.asp.
   A transcript of Dr. Pettyman's explanation can be found at http://dawn.jpl.nasa.gov/technology/GRaND_inter/TP_SplatDiagram.pdf.

g. In small groups, ask students to think about the limitations of this model as compared to what is actually happening with these interactions. Use the GRaND interactive (http://dawn.jpl.nasa.gov/technology/GRaND_inter.asp) and the SPLAT! slide from the GRaND PowerPoint as support for their conversations. This is also a good opportunity to discuss the limitations of models, in general. Students might respond that:
   - In the actual interactions the cosmic rays cause the nucleus to break apart because the energy is greater than the binding energy of the nucleus. Whereas the ringing bell just set the game in motion and did not break any forces holding the students together.
   - In neutron capture, one neutron is absorbed by another nucleus. In the game, the two students just stood together.
   - In the game, students who still had their white flags released a gamma ray card to the floor. The card is matter and was dropped to the floor. In the actual interaction, gamma rays are energy that is released into space.

Continue using the script that accompanies Slide 6.