Audience
Grades 6-8

Time Recommended
45-60 minutes

AAAS STANDARDS

- 1B/1: Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.
- 3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

NSES STANDARDS

Content Standard A (5-8): Abilities necessary to do scientific inquiry:

c. Use appropriate tools to gather, analyze and interpret data.

e. Think critically and logically to make relationships between evidence and explanations

Content Standard E (5-8): Science and Technology:

b. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis.

MATERIALS

- Printed copy of the cartoon found in the activity (one per student)

CRaTER: The Discovery and Nature of Cosmic Rays

Learning Objectives:

- Students will learn how cosmic rays were discovered and what they are. They will understand how small and fast they are.

Preparation:

None

Background Information:

The Lunar Reconnaissance Orbiter (LRO) is a spacecraft orbiting the Moon. LRO carries onboard seven scientific instruments. The primary one for analyzing the Moon's radiation environment is the Cosmic Ray Telescope for the Effects of Radiation, or CRaTER. With it, scientists study both the radiation itself and how it might affect the human body.

We usually think of astronomers studying very big things like stars and galaxies. Astronomers also talk about vast distances like thousands of light years. But. did you know astronomers also study some of the smallest known objects in the universe? An important example of such tiny objects is the cosmic ray. Even though cosmic rays are small, believe it or not, they are still the most energetic particles in the universe.

The discovery of these small but energetic particles began accidentally in the early twentieth century, when scientists found that their electroscopes could not store charge indefinitely. An electroscope is a device that stores electric charge. It contains a neutral gas to insulate the stored charge. The fact the charge could leak from electroscopes surprised scientists; this meant the gas was not neutral. Somehow the gas inside the electroscopes was becoming slightly ionized, creating a route to short out the charge. No matter the amount of shielding, such as lead, an electroscopes' charge still leaked. A very penetrative type of radiation must have been ionizing (charging) the gas.

Radiation refers to the emission of energy. There are two types: electromagnetic radiation and particle radiation. Electromagnetic radiation includes radio waves, microwaves, infrared, visible, ultraviolet, X-rays, and gamma rays. Scientists refer to all types of electromagnetic radiation as "light," though most non-scientists use the term "light" to refer only to the visible part of electromagnetic radiation. The latter, energetic particles, which can be protons, ions, or electrons, are types of particle radiation.

Questions to be asked during the lesson:

QUESTION 1:

Can you think of some common examples of particle radiation?

Answers:

- *Older TVs or computer monitors combine both particle and electromagnetic radiation. A small apparatus (electron gun) at the back of the monitor shoots electrons at the screen. These electrons are particle radiation—energy emitted in the form of particles. The screen has a special coating on the inside called phosphor. When electrons hit the screen, they transfer their energy to the phosphor atoms. These atoms re-emit the energy in the form of electromagnetic radiation. In other words, the visible light that we see was created by the energy from particle radiation.*
- *Radioactive materials, such as uranium, emit both particle and electromagnetic radiation.*
- *Particle accelerators accelerate particles to extremely high speeds (99% the speed of light). The largest example is in Switzerland and operated by CERN (a French acronym for European Organization for Nuclear Research). Some hospitals have much smaller particle accelerators to create energetic protons to treat cancer. So instead of using electromagnetic radiation in the form of X-rays, doctors at such hospitals use particle radiation to kill the cancer cells.*

QUESTION 2:

Some type of particle or electromagnetic radiation was creating the charge leakage in the electroscopes. What are the possible sources of radiation that could account for the leakage?

Answer:

- *Three possible sources are radioactive materials in the Earth, radiation within the atmosphere, or radiation from outer space.*

QUESTION 3:

What would you do to discover whether one or more of those possible sources are correct?

Answer:

- *There are three possible sources: Earth, the atmosphere, and space. Since we are near Earth but not space, a good idea would be to get as far away from Earth and as close to space as possible. If Earth were the source, the charge leakage would decrease with distance from Earth. If space were the source, then the leakage would increase with distance from Earth. If the atmosphere is the source, then the leakage would reach a maximum somewhere between Earth and space.*

QUESTION 4:

Can you guess how many protons are in your body?

Answer:

- *Over ten octillion (10^{28})! Write this number out: 10,000,000,000,000,000,000,000,000,000. That is one hundred thousand times the number of stars in the known universe! It's a good thing you don't have to keep track of all of them.*

QUESTION 5:

Is the energy from cosmic rays much less than, about equal to, or much more than the energy from starlight?

Answer:

- *The energy from cosmic rays is about the same as the energy from starlight. The reason we notice starlight more is because our eyes can see the electromagnetic radiation (light) from the stars. Our eyes, however, do not detect particle radiation very well. (This question was adapted from* Thinking Physics Is Gedanken Physics, *by Lewis Carroll Epstein, San Francisco: Insight Press, 2005.)*

QUESTION 6:

How fast does your car go on the highway? How much faster does a cosmic ray go if it travels at one-tenth the speed of light?

Answer:

- *Your car travels at about 130 km/hr (60 mph), or a little over 30 m/s. A "slow" cosmic ray will travel at about one-tenth the speed of light, or 30,000,000 m/s. That means a cosmic ray is one million times faster than your car. I wonder what the speeding ticket would be?*

Procedure:

1. **Ask Question 1** and/or **Questions 2 and 3** here.

2. **Discuss the following background information:** in 1910, a Roman Catholic priest named Theodor Wulf created an experiment to determine the source of the leakage in electroscopes. He thought the source might be radioactive rocks within the Earth. He carried an electroscope to the top of the Eiffel Tower to see whether the leakage rate would decrease. It did decrease, which implied that some of the radiation was from radioactive materials in the earth. Thus, the farther from Earth Wulf moved his electroscope, the less radiation affected it. The decrease in the leakage, however, was less than expected. Another radiation source must also be at work. His results implied the source of radiation was outside the atmosphere in outer space.

3. **Discuss:** The next year, an Austrian physicist named Victor Hess began a series of balloon trips—some of them dangerous—with electroscopes to measure the leakage. He discovered with increasing altitude, the rate at first decreased and then began to increase. At an altitude of about 1.5 km (5000 ft.), the leakage was greater than at sea level. He measured the rates even up to 5 km (higher than the Rockies), where the leakage was several times greater than at sea level. (At that time, airplanes were unable to reach such altitudes, nor could they stay aloft for the amount of time necessary for his experiment.) His work conclusively demonstrated that the radiation had an extraterrestrial source. He received the Nobel Prize for his discovery. Fifteen years later, in 1926, Robert Millikan, better known for his work on the electron's charge, helped coin the term "cosmic ray" to describe this radiation raining down on the Earth.

4. [**Optional Information:** We now know that cosmic rays are charged subatomic particles. This is because charged particles do not travel in straight lines in the presence of a magnetic field. Earth has a large magnetic field; this is why you can use a small magnet called a compass to find magnetic north. The physicist Arthur Compton discovered in 1932 that Earth's magnetic field curved the cosmic rays' paths. That meant that the cosmic rays are charged particles and not electromagnetic radiation.] We now know that cosmic rays are subatomic particles. They are electrically charged particles. Cosmic rays are mostly protons and ions, which have positive charges. However, a small percentage are electrons, which have negative charges.

5. [**Optional Information:** About 83% are protons, 13% are helium nuclei (also called alpha particles), 3% are electrons, and the final 1% are atomic nuclei more massive than helium (some examples are carbon, oxygen, and iron nuclei).]

6. **Discuss:** cosmic rays, even though we call them "rays" (like light rays), are not a form of electromagnetic radiation; they are a type of particle radiation. Scientists used that name before they knew what cosmic rays were; some thought that they were high-energy gamma rays. We now know that cosmic rays are charged subatomic particles traveling almost at the speed of light. Most of them are protons, but the name still sticks.

7. **Ask Question 4**.

8. **Do the following activity:**

   a. Provide a copy for each student of the cartoon (located in worksheets section).

   b. Ask the following questions to students:

Assume your classroom is 10 m (33 ft) across. Each hair on your head has a diameter (NOT length!) that is much smaller than the width of your classroom. How many hairs would you have to lay side by side to reach across the room?

Answer:
Each hair has a diameter of about 100 micrometers. Therefore 100,000 hairs laid side by side would reach across the room. That is about all the hairs you have on your head!

A hair from your head has a diameter of about 100 micrometers. Can you guess how many atoms would fit side by side along your hair's diameter?

Answer:
The atom hydrogen is about 10^{-10} m across. That means that one million atoms could fit side by side along the diameter of a single hair!

A typical atom is about 10^{-10} m across. Can you guess how many protons would fit side by side along the atom's diameter?

Answer:
A proton has a diameter of about 10^{-15} m (that is one femtometer). That means that one hundred thousand protons would fit along the atom's diameter. To give you an idea of what this means, imagine increasing an atom to be the size of your classroom. The diameter of the increased proton at the center of the atom would be the same as the diameter of your hair, where as a classroom is 100,000 hairs across, and an atom is 100,000 protons across respectively.

Essentially, atoms are mostly empty space! In this analogy, the simplest atom, hydrogen, would have a hair-sized proton at the center with an even tinier electron zipping along the walls of the classroom.

Atoms are very small objects, but subatomic particles, like protons, are much, much smaller. This exercise shows why cosmic rays can travel through your body without hitting anything: you are mostly empty space! The exercise also emphasizes the minuteness of cosmic rays.

c. **Optional Information:** Energy in the form of electromagnetic radiation from the stars continually "rains" down on Earth. Similarly, the energy from cosmic rays (particle radiation) is "raining" down on Earth all the time. **[Ask Question 5 here.]**

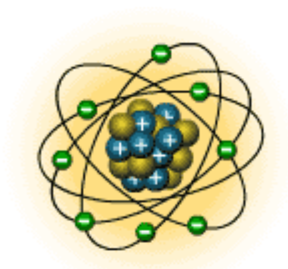
In addition to being subatomic charged particles, cosmic rays are very fast. They are so fast they travel at almost the speed of light, which is 3 x 108 m/s (fast enough to go around the earth seven times in one second). Most cosmic rays travel at one-tenth that speed. But, some have been detected traveling at more than 90% of the speed of light. These cosmic rays have the same energy of a fastball thrown by a major league pitcher. Imagine all that energy crammed into a single subatomic particle!

9. **Ask Question 6**.

10. **Discuss:** cosmic rays are charged subatomic particles traveling almost at the speed of light. What makes them move so fast (i.e., have so much energy)? This question continues to puzzle astronomers. Many, if not most, cosmic rays apparently received their "energy boost" when stars much bigger than our sun explode—an event called a supernova. A supernova is one of the most energetic events in the universe. It releases an enormous amount of energy in a short time (more energy than all the other approximately hundred billion stars in the Milky Way galaxy!); some of this energy can go into boosting charged particles to high speeds. Scientists continue to search for other sources of cosmic rays.

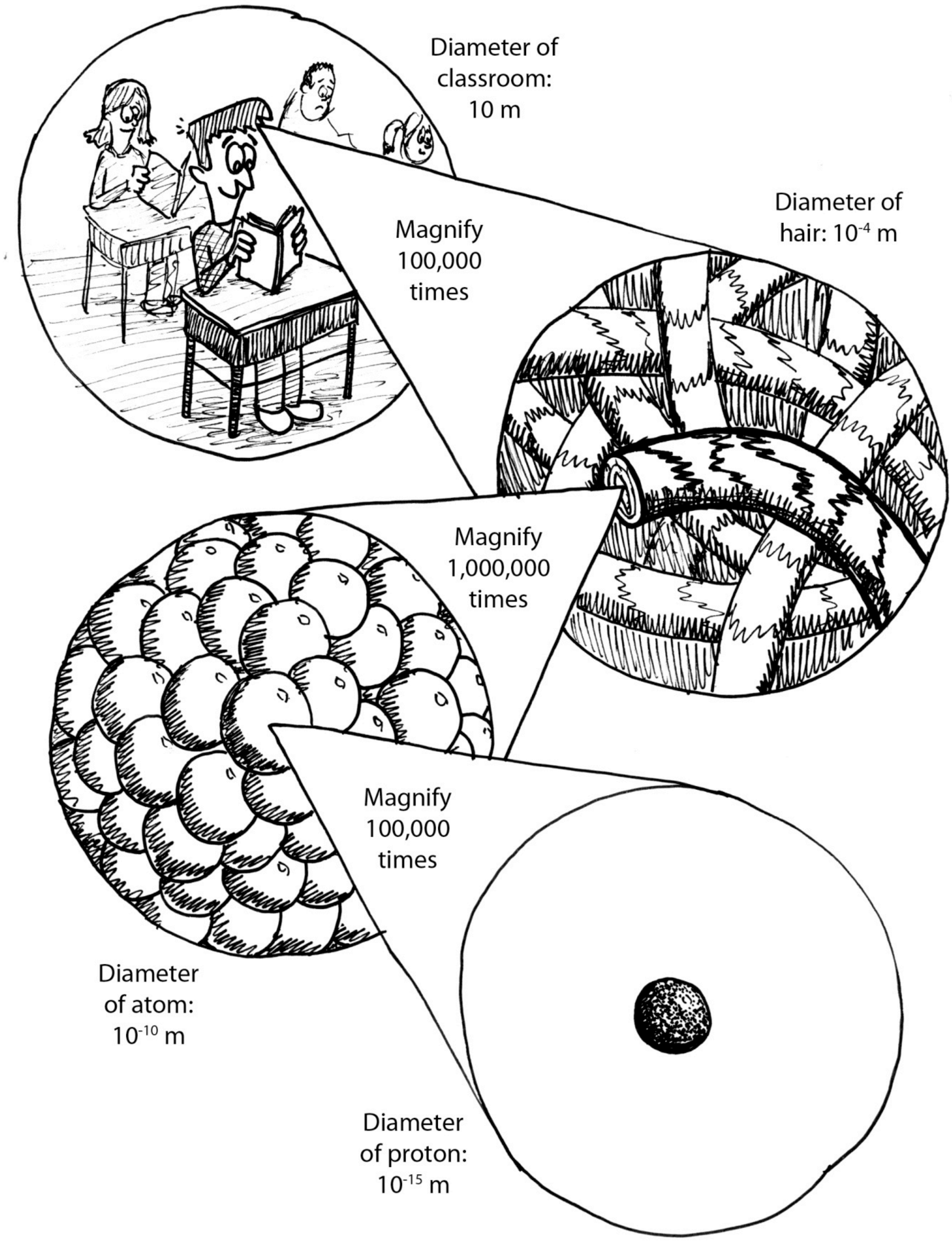
Note: Misconception

Many textbooks show pictures of atoms that look something like this (from a NASA web page):



While it is okay to have pictures that are not to scale, they can be misleading because they make the nucleus appear to be almost as big as the atom itself! In reality, the diameter of the nucleus is about 100,000 times smaller than that of the atom. You would be unable to see it in this picture!

worksheet


Diameter of classroom: 10 m
Magnify 100,000 times
Diameter of hair: 10^{-4} m
Magnify 1,000,000 times
Magnify 100,000 times
Diameter of atom: 10^{-10} m
Diameter of proton: 10^{-15} m

Assessment:

Write down three questions about cosmic rays that you now know the answers to. Trade your questions with a classmate and see if you can answer each other's questions.

SUPPLEMENTAL IMAGES/ MATERIALS/ RESOURCES:

Resources:

Information about CRaTER and LRO

LRO site:
lunar.gsfc.nasa.gov

CRaTER's website:
crater.unh.edu

A video in which the man responsible for CRaTER describes cosmic rays and the instrument:
www.nasa.gov/multimedia/nasatv/on_demand_video.html?param=http://anon.nasa-global.edgesuite.net/anon.nasa-global/ccvideos/GSFC_20090416_LRO_CRaTERvideo.asx

General information about cosmic rays

A Thin Cosmic Rain: Particles from Outer Space (previously published as Cosmic Rays), Cambridge, MA: Harvard, 2000.

Cosmicopia: An Abundance of Cosmic Rays (a NASA Goddard website about cosmic rays):
helios.gsfc.nasa.gov/cosmic.html

Cosmic ray comic book:
www.scostep.ucar.edu/comics/books, then click on the file labeled cosmicrays_e.pdf.

Air shower movies generated from the ARIES (Air shower Extended Simulations):
http://astro.uchicago.edu/cosmus/projects/aires

Space Radiation

Space Radiation Analysis Group at Johnson Space Center:
http://srag-nt.jsc.nasa.gov

Eugene N. Parker, "Shielding Space Travelers," *Scientific American,* March 2006.

M.G. Lord, "Are We Trapped On Earth?" *Discover,* June 2006.

Cosmic rays and cataracts:
http://science.nasa.gov/science-news/science-at-nasa/2004/22oct_cataracts

A NASA 6-12 educators guide to radiation math, with worksheets for students:
www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Radiation_Math.htm

Glossary:

ALFMED: Apollo Light Flash Moving Emulsion Detector, designed to detect whether cosmic rays create small flashes in astronauts' vision

ALTEA: Anomalous Long Term Effects in Astronauts' Central Nervous System; a device onboard the ISS to determine how cosmic rays affect the human brain

Atom: the smallest particle that still has the chemical qualities of an element; composed of a nucleus and electrons

Cosmic ray: an ion or electron in space that travels at a speed similar to that of light

CRaTER: Cosmic Ray Telescope for the Effects of Radiation; an instrument on the Lunar Reconnaissance Orbiter designed to study particle radiation near the moon

Electroencephalograph: an instrument that records the brain's electrical activity

Electromagnetic radiation: energy emitted in the form of electric and magnetic waves

Electron: a negatively charge subatomic particle; one of three particles to comprise atoms

Electroscope: a scientific tool used to store electric charge

Emulsion: a gel-like substance used to detect electromagnetic or particle radiation

ISS: International Space Station

LRO: Lunar Reconnaissance Orbiter; a spacecraft designed to study the moon's resources and radiation environment

NASA: National Aeronautics and Space Administration

Nucleus: the core of an atom, consisting of at least a proton (in hydrogen), or protons and neutrons

Particle radiation: energy emitted in the form of subatomic particles

Phosphor: a material that, when stimulated, emits electromagnetic radiation

Proton: a positively charged subatomic particle; one of two particles to comprise atomic nuclei

TEP: tissue-equivalent plastic, which has radiation-absorbing properties similar to human tissue

Radioactivity: the condition of a substance to emit ionizing particles or electromagnetic radiation