

Teacher's Guide

Cosmic Rays and Cloud Chambers

Background Information:

Cosmic rays are not really rays; they are subatomic particles that are found in space that have high energies as a result of their rapid motion. Cosmic rays are streams of positively charged nuclei, mainly those of the hydrogen atom. Cosmic rays may also contain electrons, protons, gamma rays, positrons and neutrinos. Positively charged helium nuclei are referred to as alpha rays and streams of high-energy electrons are referred to as beta rays. These rays filter through the earth's atmosphere and can be studied using special detectors. Today we will be building a Cloud Chamber, which will help us to study these exotic particles from the far reaches of outer space.

In the past, cosmic rays were called "galactic cosmic rays" because we were unaware of their origin. Since these rays are atomic particles with an electric charge, they are deflected by the magnetic fields that occur throughout our galaxy, which means that we cannot tell where they came from. The space between stars is teeming with cosmic rays. It has been determined that the sun discharges a large number of lower energy cosmic rays, called "solar cosmic rays". Our sun, along with the explosion of dying stars, called supernovae, produces most of the cosmic rays that reach the Earth.

As mentioned earlier, cosmic rays are made up of subatomic particle, such as protons, electrons and atomic nuclei. About 87% of the cosmic ray nuclei are from hydrogen atoms that contain a single proton. Approximately 12% of the cosmic rays are from helium atoms that contain two protons and two neutrons and are referred to as alpha rays. The nuclei of heavier elements are also present in cosmic rays, but in much less numbers. When these rays travel through space at near the speed of light, electrons are stripped off of the rays. Beta rays are the name given to these high-speed electrons. As the cosmic rays travel through the earth's atmosphere, they smash into gas atoms that reside in the upper atmosphere. The fragments that are left over from the collision either evaporate or constantly shower down onto the surface of the Earth. These secondary rays are passing through your body as you read this sentence.

When the cosmic rays collide with particles in the Earth's upper atmosphere, they disintegrate into smaller particles such as pions, muons and neutrinos. These particles are monitored and measured at the Earth's surface by devices called neutron monitors. The majority of the cosmic rays that we will be viewing in the cloud chamber today are muons. Muons are formed when the protons in the alpha rays are carried from outer space through the earth's atmosphere and undergo nuclear decay. The alpha rays break down first into pions and continue to decay into muons and neutrinos. Gamma rays, which are a type of cosmic ray composed of electromagnetic waves similar to light, are created from neutral pions that break down into additional electron and positron particles that can be seen in the cloud chamber.

How a Cloud Chamber Works:

A cloud chamber is a device that makes visible the paths of particles emitted as a result of radioactive decay. With the chamber, we have created an enclosed environment filled with alcohol vapor. There is a temperature gradient between the top and the bottom of the box. This means that we can produce more alcohol vapor at the top of the box that becomes super-cooled by the time it gets to the bottom of the box where the temperature is too low for the vapor to exist. This allows the vapor to easily change into a liquid.

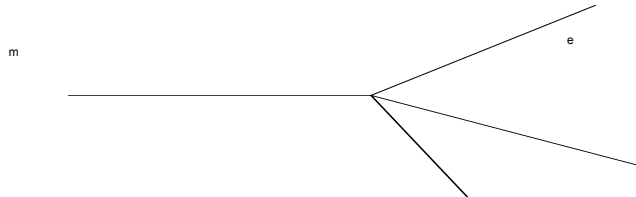
When an electrically charged cosmic ray comes along, it collides with air or alcohol vapor molecules, ionizing the vapor by ripping away the electrons on some of the gas atoms along its path. This leaves behind positively charged atoms. Nearby atoms are attracted to these ionized atoms, which initiate the condensation process. Eventually, enough atoms are attracted together to create visible liquid droplets which form “tracks”. These tracks mark the path left by the particle moving through the chamber. Different types of particles will leave different trails based on their mass and charge.

What to Look For In the Chamber:

- A skinny track which goes straight
 - These are usually high energy muons barreling through the detector.

μ —————

- A track which goes straight, then “kinks off to the left or right sharply.”
 - This is a muon decay: $\mu \rightarrow e \nu \bar{\nu}$
 - Since you can only see *charged* particles in the chamber and since neutrinos are neutral, you will not see the neutrinos.



- Three tracks that meet in a single point.
 - In these events, one track is an incoming cosmic ray. The particle hits an atomic electron and knocks it out of the atom. The outgoing tracks are the electron and the muon (deflected).
- A track that zig-zags a lot.

This is “multiple scattering”, as a low-energy cosmic ray bounces off of one atom in the air to the next.

Real World Applications:

Cosmic rays pass through your body constantly. The area the size of your hand receives cosmic rays at a rate of about one particle per second. Many of these particles are harmless to the human body and pass through unnoticed. Research being conducted recently has suggested that muons could cause damage to your body on a molecular level. Scientists believe that muons travel past your skin and ionize (strip off electrons) some of the atoms that are in your body. This ionization produces hydroxyl molecules, called free radicals, which can eventually interact with your DNA. To eliminate this concern, scientists suggest that people consume antioxidants, molecules that counteract the negative affects of the free radicals.

Alpha particles, formed when heavy nuclei decay into helium nuclei, are constantly emitted from the sun due to the nuclear fusion process that fuels the sun. These charged particles are trapped by the Earth's non-uniform magnetic field, spiral around the Earth's field lines from pole to pole. The charged particles, mostly electrons and protons, surround the Earth in a doughnut shaped pattern or regions that are called the Van Allen radiation belts. When these charged particles are in the Earth's atmosphere over the poles, they often collide with other atoms, causing them to emit visible light. This is the origin of the Aurora Borealis, or Northern Lights.

Additional Information on Cosmic Rays:

Roughly once a second, a subatomic particle enters the earth's atmosphere carrying as much energy as a well-thrown rock. Somewhere in the universe, that fact implies, there are forces that can impart to a single proton 100 million times the energy achievable by the most powerful earthbound accelerators.

There are two categories of cosmic rays: primary and secondary cosmic rays. Real (or "primary") cosmic rays can generally be defined as all particles that come to earth from outer space. These primary cosmic rays generally do not make it through the earth's atmosphere, and constitute only a small fraction of what we can measure using particle detectors at the earth's surface.

As we shall see, we do measure particles at sea level in such detectors. What we measure, however, are mostly the remains from interactions of primary cosmic rays with the upper atmosphere. These remnants are also particles, referred to as "secondary" cosmic rays.

From the above we see that secondary cosmic rays are neither "rays" nor "cosmic": they are particles rather than rays, and they come from the upper atmosphere rather than outer space. Where do primary cosmic rays come from?

Cosmic rays are atomic nuclei traveling near the speed of light. When these cosmic rays collide with the atoms of atmospheric gas high above the earth, a significant fraction of the incoming energy is converted to matter in the

form of subatomic particles, including muons, which in turn collide violently with other atoms in the atmosphere to create a shower of additional particles and high energy radiation. Due to conservation of momentum, most of the matter created travels in the same direction as the initial cosmic ray, but photons may be emitted in essentially all directions. Muons and some of the other particles from the shower will reach the ground, where they can be detected.

The acceleration of charged particles to extremely high energies takes place almost everywhere in the universe, very far away from us and at our front door. Particles are accelerated on the Sun, in interplanetary space, at the edge of the solar system, in the blast waves of supernova remnants, in neutron stars, and probably in black hole systems.

When atomic nuclei cross a supernova shock front, they will pick up energy from the turbulent magnetic fields embedded in the shock. A particle may be deflected in such a way that it crosses the boundary of the shock hundreds or even thousands of times, picking up more energy on each passage, until it escapes as a cosmic ray.

Little is known for certain about the origin of cosmic rays. Astrophysicists have plausible models for how they might be produced but no definitive answers. Here are four sources of cosmic rays:

1. Galactic cosmic rays come from outside the solar system but generally from within our Milky Way galaxy. GCRs are atomic nuclei from which all of the surrounding electrons have been stripped away during their high-speed passage through the galaxy.,
 - **Typical energy range : 1 GeV – 10^{21} eV, fully ionized.**
 - **Particles: 85% protons, 12% He nuclei (alpha particles), and the rest are electrons and nuclei of heavier atoms.**
2. Anomalous Cosmic Rays – coming from the interstellar space at the edge of the heliopause (solar system).
 - **Typical energy range: ~10 MeV, singly ionized.**
3. Solar energetic particles (SEPs) are atoms that are associated with solar flares. They move from the Sun due to plasma heating, acceleration, and numerous other forces.
 - **Typical energy range: < 1 MeV and usually partially ionized.**
4. Unknown – Most of the particles are accelerated by a mechanism incapable of imparting more than about 10^{15} eV. The relative excess of ultrahigh-energy particles indicates an additional source of acceleration whose nature is as yet unknown.
 - **Typical energy range: > 10^{15} eV and usually partially ionized.**

References/Resources:

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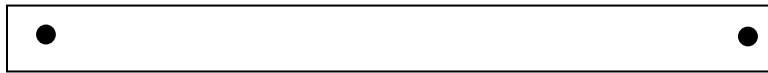
Teacher's Guide Building a Cloud Chamber

Materials:

1 clear plastic box	6 binder clips
4 cable ties	Isopropyl alcohol (91%)
4 paper towels/napkins	Scissors
Aluminum plate	Plastic tray
Electrical tape	Dry ice, (crushed or sliced)
Slide projector / two strong flashlights	

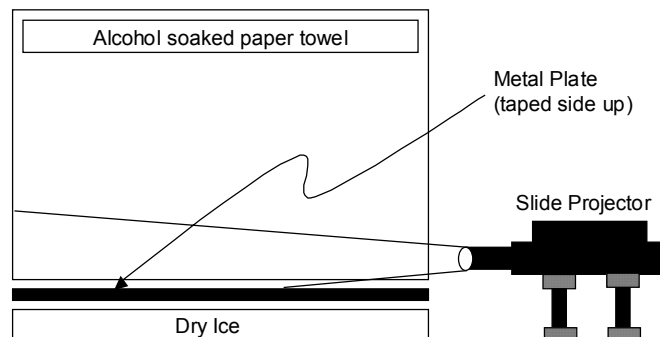
Procedure:

1. Cover the top face of the aluminum plate with black electrical tape (use the wide tape, if you have it). Leave one side untaped and one side completely covered.
2. Take the plastic box and flip it over so the open side is up. Make sure there are 4 cable tie mounts fastened to the bottom inside of the box.
3. Cut a paper towel into two strips ~ 2 inches wide and as long as the length of the plastic chamber. Make a hole in either end:



4. Insert a cable tie into each of the four cable tie mounts on the *inside* of the box, but DO NOT CLOSE the cable tie, yet.
5. String the paper towel onto the cable tie, and fasten the cable tie. Then, pull to tighten it.
6. Now you are ready to work with the isopropyl alcohol, so put on the safety goggles. Use the squeeze bottle to liberally apply the isopropyl alcohol to the paper towel strips inside the box.
7. Flip the box over and place it on the taped side of the aluminum plate.
8. Make sure the aluminum plate completely covers the bottom of the box. Then, use the thick black electrical tape to tape together the aluminum plate and the box. Use long strips of tape so you can get a good seal. You don't want the tape to restrict your ability to see the bottom of the box.
9. After you've taped the two together, use some binder clips to clip to the box to the aluminum plate.
10. Finally, place the box/plate combo aluminum side down on the tray containing crushed dry ice. **Use gloves. Do not touch the dry ice with your bare hands!** Turn on the projector and project the light long way through the box. You will have to wait about 10 minutes for the

atmosphere inside the box to get cold before you see anything. Your setup should look like this:



What To Look For:

1. Wait about 10 minutes for the air to cool sufficiently inside of the container. Check for leaks around the outside of the container. Reseal if needed.
2. Place the slide projector or flashlight to one side of the container and turn it on. The beam of light should shine through the container.
3. Turn off the lights and watch for tracks to form. Be patient! At first, all you should see is mist forming inside of the chamber. After about ten minutes, look towards the bottom of the container to see the streaks that form and last for a second or two.
4. If it is difficult to see the tracks, try repositioning the flash light beam. Also try placing your hand on top of the container and pressing down. This helps to reinforce the seal and creates a more dramatic temperature gradient.

Observations:

Describe in detail what you observe during the first five to ten minutes. Take special note of any sounds, droplets, formation of clouds, movement of clouds, frost and any other interesting phenomena.

Encourage students to take their time with this section. This is a great opportunity for them to work on their observation skills.

After you have spent some time observing the track formations, draw some of the shapes that you see. Do all of the tracks appear the same? Are some longer and skinner? Short and wide? Twisted or straight?

Refer to the section in the Teacher's Guide labeled: "What to Look for in the Chamber".

Questions:

1. What is the purpose of the dry ice? Is there a temperature gradient inside of the cloud chamber? Explain.

The bottom of the cloud chamber will be cold because the dry ice absorbs heat from below. Since cool air is denser than warm air, the air will not circulate very much. This allows for a temperature gradient to form horizontally within the chamber. Some convection (movement and mixing) will occur horizontally because the walls are warmer than the interior.

2. Why does “mist” inside of the cloud chamber come from and why does it sink towards the bottom of the cloud chamber and not rise to the top?

The air inside of the chamber gradually becomes saturated with alcohol. Unobservable vapor droplets (a substance in gaseous form) will form near the top of the chamber where it is warm first. As the vapor falls towards the bottom of the chamber, a “mist” or “rain” can be observed as the alcohol vapor condenses into liquid droplets. Because the bottom of the chamber is colder than the top, the concentration of alcohol vapor will decrease towards the bottom as the vapor condenses around particles and forms visible liquid droplets.

2. Cosmic rays are not really rays, but are sub-atomic particles. The particles that you can see in the cloud chamber are either positively or negatively charged. Using the words “ionization” and “condensation” in your response, describe why tracks are left behind in the wake of these traveling sub-atomic particles.

When a charged particle travels quickly through the chamber, it can rip electrons off of molecules, creating positive ions as it cuts a path through the air. Free electrons may attach themselves initially to neutral molecules, creating negative ions. Many of the projected positive ions may themselves crash into, or rip electrons away from, other molecules, resulting in a cascade of ions. Alcohol molecules, which are neutral and therefore are attracted to either positive or negative ions, will form droplets around the ions. A pattern of tiny droplets appears in the air around the path of the charged particle.

Experimental Design:

With the help of your lab partner, design an experiment that would allow you to determine how many cosmic rays travel through your classroom in one minute. Write down the procedure steps involved in the experiment below. Conduct the experiment yourself and come up with results that you can share with the rest of the class. Remember: The more data you can collect and average, the more accurate your results will be!

Possible Inquiry activity. Answers will vary.

Name: _____

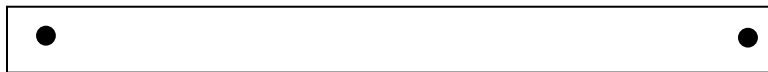
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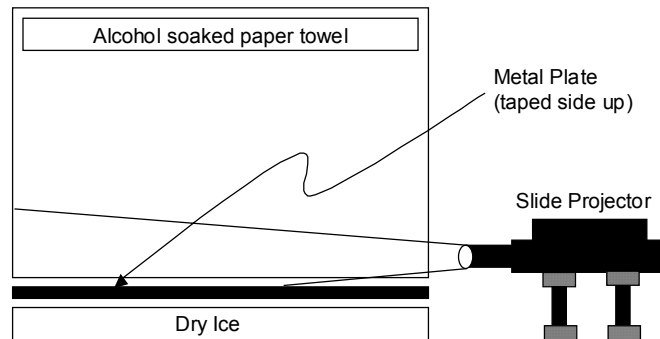
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