Stars in the Clouds
Teacher's Guide

Objective:

- Define what cosmic rays are and list the various types.
- Explain how a cloud chamber allows viewers to observe cosmic rays.
- Observe vapor tracks of various types of secondary cosmic rays.

Background:

Cosmic rays are subatomic particles that travel at very high speeds through the universe (cosmos). They are so small and travel so rapidly that they are able to pass through solid objects. At this very moment, they are passing through you! Your hand is probably being penetrated by a cosmic ray every second!

Recent research has shown that cosmic rays passing through you may cause molecular damage. Muons passing through ionize (strip electrons) atoms in your body producing hydroxyl molecules. These free radicals can interact with your DNA. Scientists now recommend people consume antioxidants to counteract the negative effects of free radicals on your tissues.

Incoming cosmic rays are responsible for both the Aurora Borealis (northern lights) and the Aurora Australis (southern lights). When their charged particles enter the thinner atmosphere over the Earth's polar regions, they collide with atoms, causing them to emit visible light. A similar subatomic process has been harnessed into a useful medical application known as a Positron (PET) scan. Doctors use interpretations of PET scans to help in the detection of malignant tumors and early diagnosis of Alzheimer's disease.

These particles are everywhere and are also known as natural radiation. Because they are deflected by magnetic fields throughout the Milky Way galaxy, we cannot determine exactly where they are from. While the source of many cosmic rays is unknown, particle physicists know of three possible sources of these rays:

1. ***Galactic:*** from outside our solar system, but usually from within our galaxy (the Milky Way).
2. ***Anomalous:*** from interstellar (between stars) space at the edge of our solar system.
3. ***Solar energetic particles (SEP):*** associated with solar flares.

Cosmic rays consist of electrons, protons, positrons, and neutrinos. They are primarily positively charged nuclei, mostly from Hydrogen atoms (about 87% of them). Roughly 12% come in the form of ***alpha particles*** which are positively charged Helium nuclei. These particles consist of two protons and two neutrons bonded together. ***Beta particles*** are high energy electrons. ***Gamma rays*** (similar to electromagnetic waves) break down into electrons and positron particles.

Cosmically derived particles are ***primary cosmic rays.*** They are atomic nuclei traveling at almost the speed of light. When they encounter the Earth's upper atmosphere, they collide with gas molecules that make up the atmosphere. These collisions produce ***secondary cosmic rays*** made up of new particles such as pions, muons, and neutrinos. Although these particles are incredibly minute, we can detect them in the classroom. Most of those we will see are muons. They form through the decay of alpha particles; they are larger than electrons, but smaller than protons. Alpha particles break down into pions which then break down into muons and neutrinos.

To observe the particles emitted through the radioactive decay of secondary cosmic rays, scientists use a ***cloud chamber.*** This apparatus contains an alcohol-vapor cloud created by a temperature gradient between the top and the bottom of the chamber.

When these charged particles pass through the supersaturated cloud, they "part" the molecules in the cloud by ionizing the vapor. During ionization, the passing cosmic particle "tears" away electrons from the gas atoms, positively charging the surrounding gas atoms. These positively charged particles attract droplets of the alcohol vapor causing them to condense on the path. This creates the track that you see.

Safety Precautions:

- Do not touch the dry ice with your bare hands; always use insulated gloves.
- When crushing the dry ice, wear safety goggles to prevent ice entering your eyes.
- Isopropyl alcohol is toxic. Do not breathe in the fumes or drink it.

Materials:

- Transparent plastic box (must have flat sides and an open top). Acrylic boxes about 6" x 12" and 6" high work well.
- Aluminum plate, about 5 mm thick, slightly larger than the opening of the box
- Black felt (large enough to cover the bottom of the container) or black blotter paper
- Gorilla glue (or other adhesive that is solvent resistant)
- Black electrical tape
- Small styrofoam cooler lid or shallow insulated box
- Dry ice (approximately 1 lb.), crushed
- Very intense, concentrated light source (strong flashlight, projector, etc.)
- 91% Isopropyl alcohol (**NOT** the 70% commonly found in stores)
- Insulated gloves (for handling dry ice)
- Gloves (for handling alcohol)
- Safety goggles

Procedure:

1. Using the Gorilla glue (solvent resistant adhesive), attach the black felt to the bottom of the plastic box.
2. Completely cover the aluminum plate with black electrical tape.
3. Wearing safety goggles, crush the dry ice into small pieces. Place the crushed ice into the styrofoam cooler lid and mix it with some of the isopropyl alcohol to create a slurry.
4. Saturate the black felt in the bottom of the container with the isopropyl alcohol. **Do not** over soak it. You do not want excess alcohol dripping and forming puddles on the metal plate.

5. With the open side of the plastic box facing upwards, place the aluminum plate with the electrical tape covered side face down over the opening.
6. Secure the plastic box to the aluminum plate with the electrical tape. It is important that the box be airtight.
7. Turn the container over (felt should be on the top and the aluminum plate on the bottom) and place it on top of the dry ice slurry. Make sure the dry ice/alcohol mixture doesn't overflow its container.
   a. The entire piece of aluminum plate should be in contact with the dry ice slurry.
8. The cloud chamber should now be assembled in the following order from top down (Figure 1):
   a. Bottom of plastic container
   b. Black felt saturated with isopropyl alcohol
   c. Metal plate covering the top of the plastic box (black electrical taped side facing upward)
   d. Dry ice slurry
   e. Styrofoam cooler lid
9. Allow the cloud chamber to equilibrate for about 10-15 minutes.
10. Shine the concentrated light source through the side of the plastic box, aiming it slightly downward toward the metal plate.

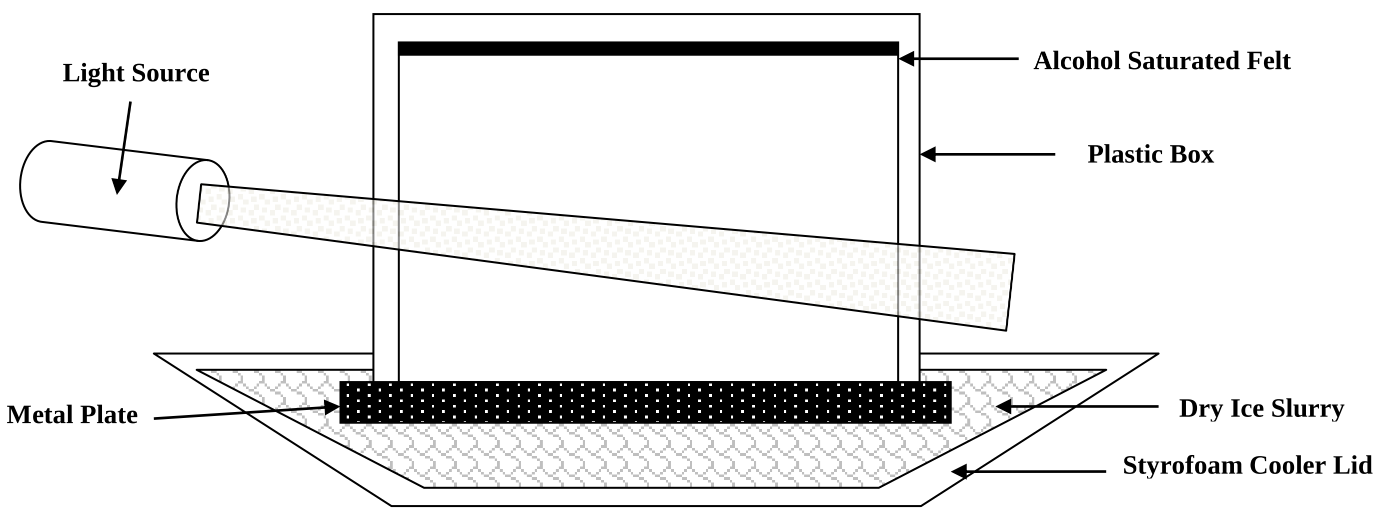

Figure 1: Cloud Chamber Assembly (modified from CERN Cloud Chamber Workshop, 2004)

Observation:

Initially, you will see tracks that look similar to spider webs. These are from cosmic rays. They will appear several times a minute. Some may be bright, while others will be faint. You may actually be able to identify the type of cosmic particle based on the appearance of the trail. ***Muons*** (μ) will leave behind a well defined track that is straight (Figure 2). Tracks that begin in a straight path and then suddenly move sharply off to the right or left are formed by the decay of a muon. The muon breaks down into an electron (e^-) and neutrinos (*v*) (Figure 3). The angled path is the electron; the neutrino is not visible because it is not a charged particle. When three separate tracks meet at a single point, you're seeing a single cosmic ray that hits and electron and dislodges it. The resulting tracks are the electron and the deflected muon (Figure 4). A track that wildly zigzags is caused by a low-energy cosmic ray that is bouncing off the atoms of the alcohol vapor (Figure 5).

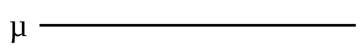

Figure 2: Muon Track

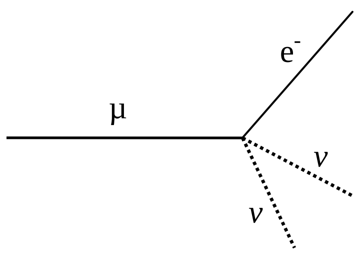

Figure 3: Track formed from Muon Decay

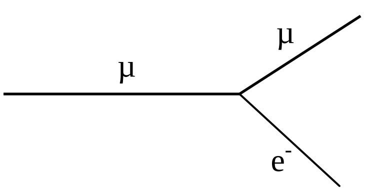

Figure 4: Track formed from an Electron Colliding with a Muon

Figure 5: Low Energy Cosmic Ray

1. In detail, describe what you see during the first 5-10 minutes. Notice and record any sounds, droplets, cloud formation, cloud movement, frost, and other interesting occurrences.

   Student answers will vary.

2. Once tracks begin to form, sketch some of the tracks that you see. Are they all the same? Are any longer and thinner? Short and wide? Straight or zigzagged?

   Student sketches and descriptions will vary.

Questions:

1. How does the dry ice help form a temperature gradient?

   The dry ice underneath the chamber absorbs heat causing the lower portion of the chamber to be cold. The cool air is more dense than the warmer air at the top which causes a horizontal temperature gradient.

2. Where does the mist in the cloud chamber come from?

   The air toward the top of the chamber will become saturated with isopropyl vapor. As it falls toward the bottom of the chamber, the vapor will condense into fine liquid droplets. The bottom is colder so the vapor concentration decreases and the droplets condense around particles causing them to become visible.

3. Cosmic rays are not actually rays, but are sub-atomic particles. What you see in the cloud chamber are either positively or negatively charged. Describe why these particles leave tracks behind them as they pass through the cloud chamber.

   The charge particles are moving extremely rapidly through the chamber. As it does so, it "rips" electrons off the isopropyl molecules creating positive ions. Any free electrons in the chamber might attach to neutral molecules and create negative ions. Isopropyl alcohol molecules are neutral and will be attracted to both positive and negative ions causing droplets to condense around the particles. This pattern of droplets appears along the charged particle's path.

Extensions:

1. Try to create a video of the tracks created in your cloud chamber.
2. Place a very strong magnet beneath one end of the chamber. The track created by the particles should be deflected by the magnetic field, causing them to bend.
3. Research the PET scan and write a short report on how it works.
4. Using your observations of the cloud chamber, design an experiment to determine how many cosmic rays are traveling through your classroom every minute.

Troubleshooting Your Cloud Chamber:

1. **Cannot see any tracks:**
   - Make sure the light is shining near the bottom of the chamber.
   - Check that the dry ice has good contact with the metal plate.
   - Make sure the chamber is well saturated with alcohol vapor.
   - Make sure there are no air leaks in the chamber.
2. **Can see mist, but cannot see tracks:**
   - Make sure you've waited long enough for the chamber to equilibrate. This will take 10-15 minutes.
   - Make sure you use the correct type of alcohol (70% isopropyl alcohol will not work).
3. **Big clouds of alcohol vapor line the edges of the chamber:**
   - Make sure the edges are completely sealed so no air leaks exist.

What you should be seeing:

Here are a couple of links to videos that show the cosmic ray tracks in cloud chambers. You should be able to see something similar in the cloud chamber you create. You may want to share these with your students prior to the demonstration/lab so they know what they're looking for.

1. MIT TechTV: http://techtv.mit.edu/videos/3141-cloud-chamber
2. San Francisco's Exploratorium: http://youtu.be/zxHvqWcTfMk