Title:	**The Cloud Chamber**
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Appropriate Level:	Physics, Grades 9-12
Abstract:	Cosmic rays are impacting our atmosphere all the time. These cosmic collisions produce large quantities of high-energy particles that are scattered in all directions, some of which reach us here on the surface of the planet. However, most people are unaware of this constant bombardment; the particles are often smaller than an atom, and they do not stimulate any of our senses. Using a cloud chamber, students can visualize the paths of actual particles that result from these cosmic rays.
Time Required:	At least two 40 minute class periods (depending on extensions)
NYS Physical Setting Core Curriculum Standard 5: **Next Generation Science Standards (NGSS) met:**	**5.3h:** Behaviors and characteristics of matter, from the microscopic to the cosmic levels, are manifestations of its atomic structure. The macroscopic characteristics of matter, such as electrical and optical properties, are the result of microscopic interactions. **5.3i:** The total of the fundamental interactions is responsible for the appearance and behavior of the objects in the universe. **WHST.9-12.7:** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem. **HS-PS3-5**: Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
Special Notes:	**The Cloud Chamber** is a kit available from the Xraise Equipment Lending Library, Xraise.classe.cornell.edu. An extension to this activity is available to borrow a table-top particle detector that closely resembles those used by CERN. See Extension Activity on Muon Detectors at the end of this investigation.

Behavioral Objectives:

Upon completion of this activity, students should be able to:

- Explain the occurrence of cosmic ray interactions with Earth
- Model an experiment to determine how many particle interactions occur in a given space
- Explain how a cloud chamber produces a cloud and why particle tracks are visible

Class Time Required:

40 minutes to build chambers and observe particles. Extra time to complete activity questions and readings can be assigned outside of class if desired.

Teacher Preparation Time Required:

Teachers must provide dry ice and isopropyl alcohol. Dry ice is very inexpensive and can be purchased from many grocery stores, ice cream stores, and many retail markets. Call ahead to ensure availability. 91% Isopropyl alcohol is available at all major grocery stores and pharmacies.

Cloud Chamber Laboratory Investigation

Guiding Question: How can we determine if particles from outer space ever reach the surface of Earth?

Pre-Lab Questions: (Answer to the best of your ability; research may be necessary!)

1. When you hear the word "particle", what comes to mind?

2. Can you see individual particles with your naked eye? If yes, what should they look like? If no, why not? What are sub-atomic particles?

3. How many different types of particles are there? Will we come in contact with all of these in our lifetime, or are there some particles we will never interact with?

4. What is a cloud?

5. How do clouds or fog form in our atmosphere?

6. What conditions must we create to allow a cloud to form inside a small chamber?

7. What is the phase change from gas to liquid called?

Materials:

Cloud Chamber Kit

Dry ice (crushed is best, approximately 2 pounds per kit)

91% Isopropyl alcohol

Squeeze bottles (if available)

Strong flashlight

Safety goggles

Gloves or handling dry ice

Procedure:

Assemble the Cloud Chamber using the following steps:

1. Place the four corners of the felt pad into each of the four clips found mounted to the top of the chamber. Make sure the felt pad is secure.
2. Fully saturate the felt pad with 91% Isopropyl alcohol, but do not use so much that it begins to run out of the pad. Wipe up excess with a paper towel.
3. Close the chamber with the black aluminum plate. Use the four binder clips to attach the plate. Mount each clip so that it can grip both the lip of the chamber and the edge of the plate. Place one clip on each side of the chamber. Fold the binder clip handles to rest flat against the chamber and aluminum plate.
4. While wearing gloves, scoop some crushed dry ice into the bottom of the Styrofoam container. Spread the dry ice into an even layer approximately 1⁄2 inch thick across the bottom of the Styrofoam container. Remove any large chunks of dry ice that create an uneven surface.
5. Place the cloud chamber with the aluminum plate side facing down (Cloud Chamber label facing up) onto the crushed ice. Make sure all of the plate is touching the dry ice and no gaps exist between the plate and ice.
6. Turn off the classroom lights and turn on the flashlight(s). Project the light long-ways through the box. Wait 5-10 minutes for the air to cool sufficiently inside of the container. Check for leaks around the outside. Reseal if needed.
7. Aim the light source through the bottom of the chamber near the plate.
8. With the classroom lights off, 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 at the bottom of the container to see the streaks that form and last for 1-2 seconds.
9. 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 of a temperature gradient between the top and bottom of the chamber.

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. Aim to make **many** observations; more than 10!

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 skinnier? Short and wide? Twisted or straight?

Post-Lab Questions:

1. What is the purpose of the dry ice? Is there a temperature gradient inside of the cloud chamber? How does this help a cloud form?

2. Where does the "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?

3. Why does the felt pad need to be fully saturated with alcohol? How is this related to cloud formation in the atmosphere?

4. 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.

5. Many of the particles that leave their evidence in your cloud chamber were not the original particles that entered the atmosphere from space. Why do you think this is?

6. The tracks that you see forming within the cloud are areas where the alcohol vapor is condensing. Are the particles the same width as these tracks?

7. What can these high energy particles do to living tissue? Please read the following article:

https://www.technologyreview.com/s/528781/cosmic-rays-neutrons-and-the-mutation-rate-in-evolution/

What are the implications of this? How might this phenomenon affect humans within our lives?

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. Do not repeat the steps to assemble a cloud chamber; those are already given! 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!

Step 1: ____

____

Step 2: ____

____

Step 3: ____

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Step 4: ____

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Step 5: ____

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Step 6: ____

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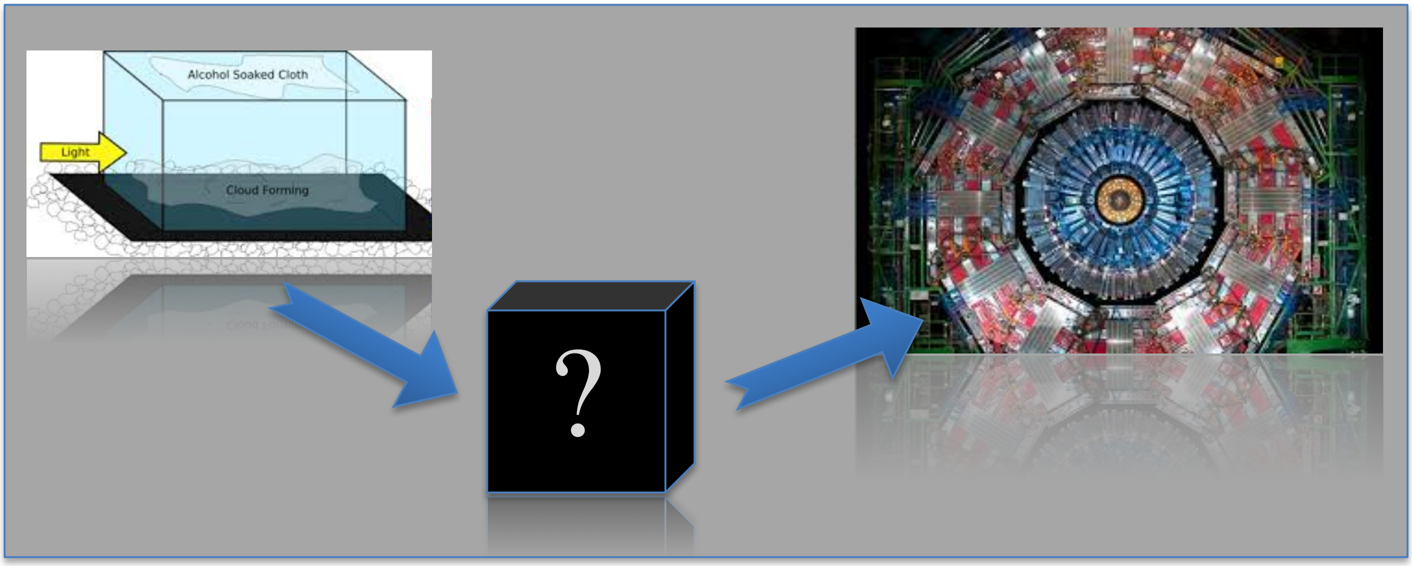
Answering the "Guiding Question":

How can we determine if particles from space ever reach living organisms on the surface of Earth?

Use the following space to write a concluding essay that answers the Big Question and suggests important implications to this new knowledge. Use extra paper if needed.

Extension Activity: Using a Muon Detector



Your cloud chamber allows you to visualize the presence of particles that are the result of cosmic ray interactions with matter. However, the capacity for collecting or analyzing data is limited. With this kit we have included a table-top particle detector capable of detecting muons. This device gets us closer to simulating the detection work that scientists at the Compact Muon Solenoid conduct during particle collisions of the Large Hadron Collider.

The Muon

Muons are one variety of particle that comes out of the cosmic ray interactions with our atmosphere. Muons are similar to electrons with a charge of -1 elementary charge, but they are much more massive and have a lifespan which is quite long in the world of particles, about two millionths of a second. Muons have a tendency to pass through most matter without issue; even a dense substance such as lead does not stop them unless it is extremely thick. Muons are one of the components of the Standard Model, the current model that explains all the matter and interactions in the Universe!

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$

Mathematical representation of the Standard Model of particle physics.

Education, Communications and Outreach Group, February 2017 CERN-Brochure-2017-002-Eng, courtesy of CERN

The Detector

https://eljentechnology.com

Some materials, called scintillators, will emit a tiny amount of light when a particle, such as a muon, passes through. The photo to the left, courtesy of Elijentechnology, shows some examples of scintillators just like the one we are using. However, our scintillator **must** remain wrapped in black tape to block out all visible light. With our detector, the scintillator is connected to a photo-multiplier. This is a device that detects the small amount of light, creating an electric signal that a computer can read. Once the electric signal is amplified, an Arduino microcontroller keeps track of how many signals have been created. With this detector, we can now count the number of muons that are passing through our scintillator!

Your Task

Remember, these particles are the result of cosmic rays that have hit our atmosphere. Our detector has the ability to count the number of muons that pass through our 5cm x 5cm x 1cm scintillator, wherever it is, in a given amount of time. With this technology, what questions can we begin answering? Below, brainstorm a list of questions that we could use our detector to answer. Some examples have been provided.

1) *How many muons pass through our bodies every day?*______________________________

2) *Do the number of muons that reach the detector change based on certain factors, like......?*

3) ____

4) ____

5) ____

6) ____

7) ____

Now, choose your team's favorite questions, check it with your teacher, and begin writing a procedure to answer it!