Build your own cloud chamber

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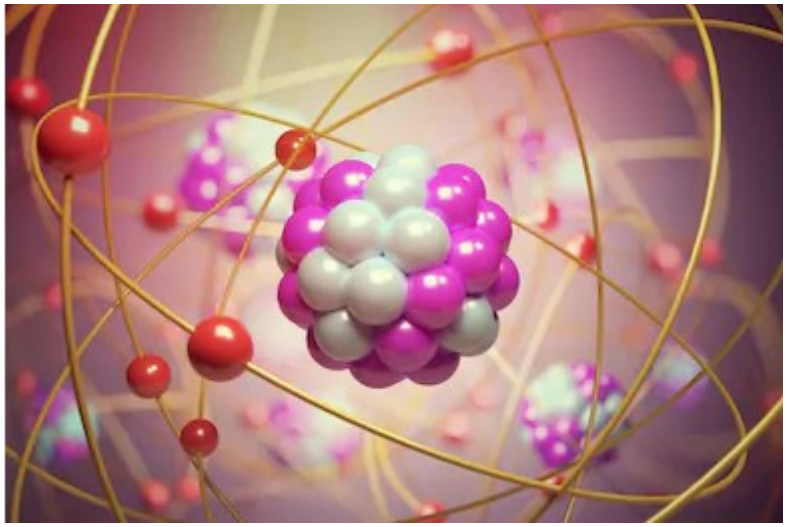
Orienting & Asking Questions

Orienting: Provide Contact with the content and/or provoke curiosity

Have you ever wondered how we detect subatomic particles?



To understand the magnitude of the problem at hand, imagine that we are discussing about particles at least smaller by a factor 1,000,000,000 than the width of the human hair. They are effectively invisible!

Their masses are also very small compared to the sensitivity of our everyday equipment. A hydrogen atom (consisting of a proton and an electron) weighs as much as 1,63*10^-27 kg. How big is that? You can imagine that if we take approximately 10^27 hydrogen atoms and stuff them together, they will weigh 1kg. Therefore masses at this level are very difficult to measure with our everyday equipment.

Some particles like the proton and the electron are electrically charged, whereas others like the neutron and the photon are electrically neutral. Moreover, even the highest energy particles produced at particle collisions at CERN have energies of the order of a millionth of a Joule: Roughly the kinetic energy of a bee flying with a speed of 20cm/sec.

This makes these particles notoriously difficult to detect. How would you do it?

Define Goals and/or questions from current knowledge

The aim of this activity is to detect ionizing radiation yourself!
In order to identify an elementary particle, one has to detect its interactions with a sensitive detector. By finding the particle's unique "footprint" in the detector, one can derive its identity. We can understand how this works with a metaphor: A friend of yours is searching for her dog which was lost at the beach. You decide to help her.

Together, you reason that you can search for the dog's footprints in the sand and by putting them together you can figure out where it went.

Fig.2: Dog footprints in sand

What exactly is it that you see, though? You have your "detector" which is the sand itself. Your "particle", in this case the poor dog, interacts with the "detector" (sand) as it walks on it and leaves a traceable "signature" (or footprint). By observing the footprint we can infer that the dog was there. By putting these footprints in a row, one can identify the dog's path in the sand.
A similar approach is used for the detection of elementary particles. However, here you do not use sand and regular footprints. You need to identify which properties (or "footprint") of the particle you want to measure, and set up an experiment (or "footprint hunting") which uses detectors sensitive to the desired footprint.

Hypothesis Generation and Design

Generation of Hypotheses or Preliminary Explanations

In order to "catch" the "footprint" of ionizing radiation, we need to understand what ionizing radiation is, how it creates "footprints" and what experimental technique we can use to observe these footprints.

What is Ionizing radiation?

It is radiation which carries sufficient energy to detach electrons from atoms or molecules, thus "ionizing" them. It usually refers to high speed particles such electrons, alpha particles, protons or to high energy electromagnetic radiation).

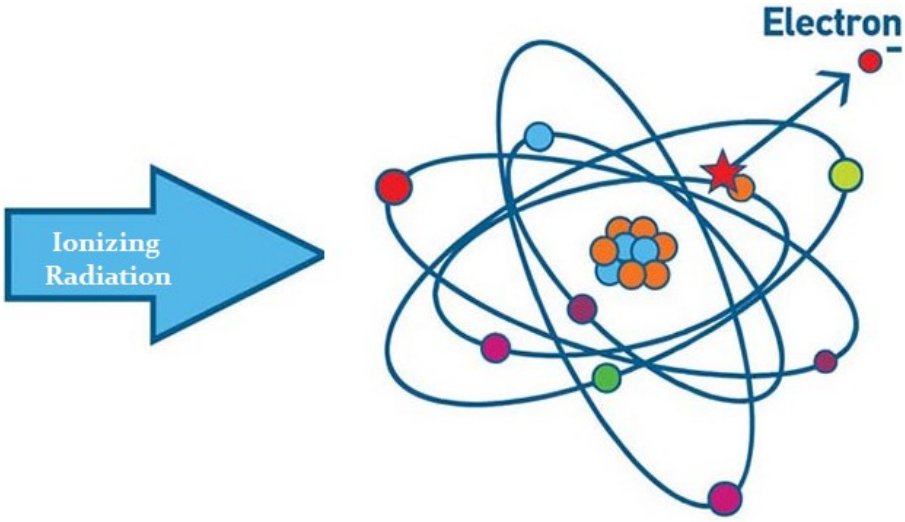


Fig. Schematic description of ionization

Whenever ionizing radiation traverses a medium, it leaves a trail of electron-ion pairs at its passage. These are its footprints which are artistically depicted below:

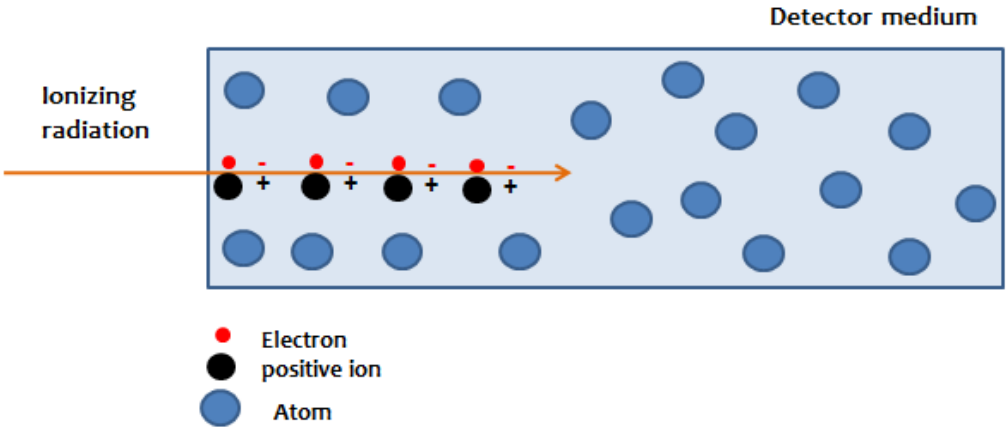


Fig. Ionizing radiation enters the detector medium and ionizes atoms of the medium (blue) in its passage, thus creating pairs of electrons (red) and positive ions (black).

Since we know that ionizing radiation can leave "footprints", our goal is to find a way to detect them. This is what C.T.R. Wilson did back in 1911 when he was trying to create clouds in his lab. The detector is called: "the cloud chamber".

Cloud chambers: Making visible the invisible

Could you actually fit a cloud in a chamber? What is the connection between clouds, chambers and elementary particles? A cloud chamber is a particle detector used for visualizing the passage of ionizing radiation through it. How does it do it?
Remember that invisible, high energy ionizing radiation leaves electron-ion pairs behind it as "footprints". A cloud chamber provides a way to "catch these footprints". According to the amount of these footprints one can infer the properties of the original ionizing particle. There are two types of cloud chambers: the expansion cloud chamber and the diffusion cloud chamber.

The expansion cloud chamber:

The original cloud chamber created by C.T.R Wilson was called the "expansion" cloud chamber. In this, water vapor was sealed within a container, the bottom of which was moveable, allowing expansion of the container without allowing heat exchange with the environment. As the container expands, the gas within it expands. We assume that the gas is ideal.
However, since no energy is exchanged between gas and environment, the expansion of the gas- called an adiabatic expansion- produces "work". The energy needed to achieve that will be removed from the internal energy of the gas which is proportional to the gas's temperature. As a result, the gas temperature will drop and therefore, the water vapor will get close to condensing.

We say that at some point, the gas becomes supersaturated: It will contain more water vapor than it would originally be able to "hold". This results in the creation of a "cloud".
You can do it yourself: https://www.youtube.com/watch?v=MtMmgcZoTSA

Fig. C.T.R. Wilson's original expansion cloud chamber.

Teacher guidelines
There are many interesting curriculum connections one can make with their students in the framework of this activitiy.
You can connect this activity to adiabatic expansion, you can discuss supersaturation and solubility of a solution in chemistry (https://www.youtube.com/watch?v=zqZw2mOMr94).

So what happens when an ionizing particle passes through the expanding cloud chamber? What happens is that the ionizing particle ionizes atoms of the gas and the ions formed act as points of condensation for the surrounding vapor. They electrostatically attract tiny vapor droplets around them and thus they build up visible droplets around them.

By observing the trail of the droplets, one can observe the trail of the electron-ion pairs and thus: the trail of the ionizing radiation! If we illuminate and photograph this trail, we have succeeded in making visible the invisible!

Teacher guideline
You may want to try such a cloud chamber in your classroom. Guidelines on how to do it can be found here: https://spark.iop.org/expansion-cloud-chamber#gref

You can see an expansion cloud chamber in the following video.
https://www.youtube.com/watch?v=kz3SEI2BZ7g

Teacher guideline
You can discuss with your students that a problem of an expansion cloud chamber is that in order to photograph a particle trail, we need to trigger an expansion. When we do that, we need to make sure that ion trails from previous expansions have been removed. This is why we make use of the 1000 V high voltage.
Finally, in order to make sure that we will observe something when you expand your chamber, you need to have a radioactive source which emits a constant stream of ionizing particles. In the 1940's, when cosmic ray researchers were using cloud chambers to observe particles, they usually placed another detector , such as a Geiger counter, on top of the cloud chamber. If an ionizing particle passed through the Geiger counter, an electrical signal was emitted and it signaled the expansion of the counter and the triggering of the photographic machine. You can refer to P. Blackett's Nobel Lecture to learn more about this:
https://www.nobelprize.org/uploads/2018/06/blackett-lecture.pdf

The Diffusion cloud chamber

A common type of cloud chamber, often encountered nowadays in various exhibits or demonstrations is called the "Diffusion cloud chamber". This one works quite differently than the "expansion cloud chamber": Instead of expanding the gas container, we keep its volume constant and we focus on the variation of temperature to create supersaturated vapor.

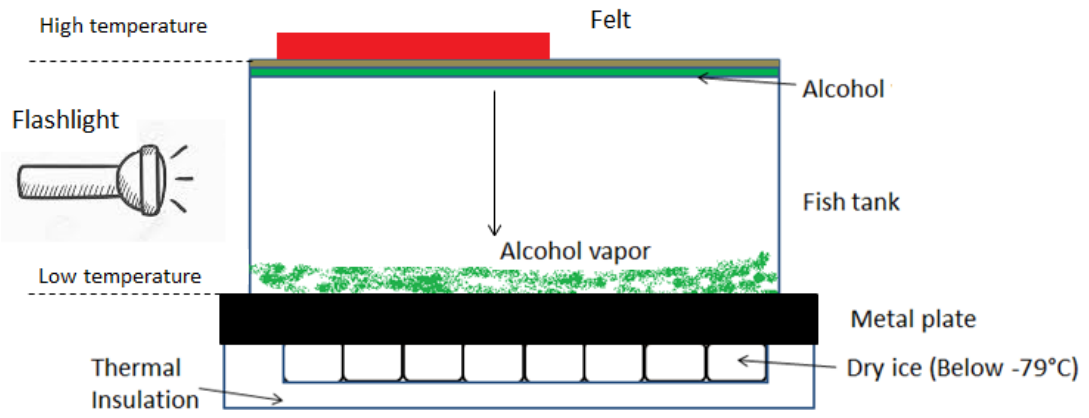


Fig. Anatomy of a diffusion cloud chamber

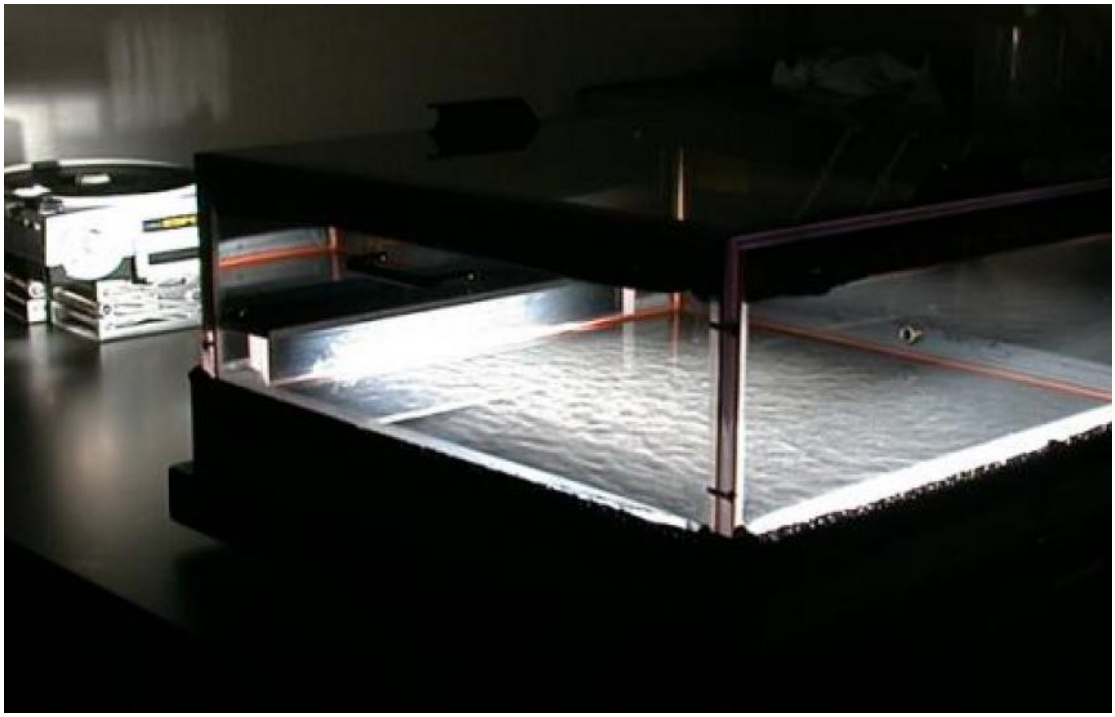


Fig. A diffusion cloud chamber. Image taken from: https://pirt.asu.edu/demo/7d3060

The air at the top of the chamber should become saturated with alcohol vapor. We place a flask of hot water on the top of the chamber, in order to help evaporate the alcohol. Any air that sinks to the bottom of the chamber is cooled by the dry ice underneath. This makes the air super-saturated and the vapor will condense if given the opportunity. Therefore, when an ionizing particle passes through the supersaturated alcohol near the bottom plate, we should be able to observe it.

Now we have learned both what ionizing radiation is and how we can visualize its "footprints" using a cloud chamber!

Design Model

We have seen that by observing the trail of the droplets created when ionizing radiation passes through a cloud chamber, one can observe the trail of the electron-ion pairs and thus: the trail of the ionizing radiation! If we illuminate and photograph this trail, we have succeeded in making visible the invisible!

Now, try to draw what do you believe would happen if two particles with same energies, same mass but different charge entered the cloud chamber. Which one would create more prominent ionization?

If you have two particles of the same charge, but one was very heavy while the other was very light, would you observe any difference in their experimental signature?

Teacher guideline

For a comprehensive list of particle "footprints" in a cloud chamber, you can consult this article: https://www.symmetrymagazine.org/article/january-2015/how-to-build-your-own-particle-detector

Planning and Investigation

Plan Investigation

In our activity, we will investigate if the cloud chamber helps us observe any kind of ionizing radiation and see the potential this instrument provides in order to obtain a deeper understanding in the workings of nature at such small scales.

Your investigation is focused on the creation of a cloud chamber in the classroom.

Perform Investigation

You are hereby invited to create a simple diffusion cloud chamber in the classroom. The materials are very easy to find (most of them are school lab equipment or household items) and cheap to purchase (in the case of dry ice).

You will need:

- A transparent box (a fish-tank for example)

- A cold plate on bottom of the box.

- A hot water container

- Dry ice to keep the one metal plate cold.

- Glue

- A felt

- Isopropyl alcohol with more than 90%vol alcohol

- A flashlight

Teacher guideline
Dry ice costs about 20 euros/ 5kg. It will remain useful for ~3 days after you aquire it. Therefore, make sure that you do the experiment close to the day you receive it. Be very careful on handling it due to its very low temperature.

Metal plates like the one described here can be found in any household.

A fish tank may be acquired by a student or bought with less than 30 euros.

Isopropyl alcohol is very cheap and so is the felt.

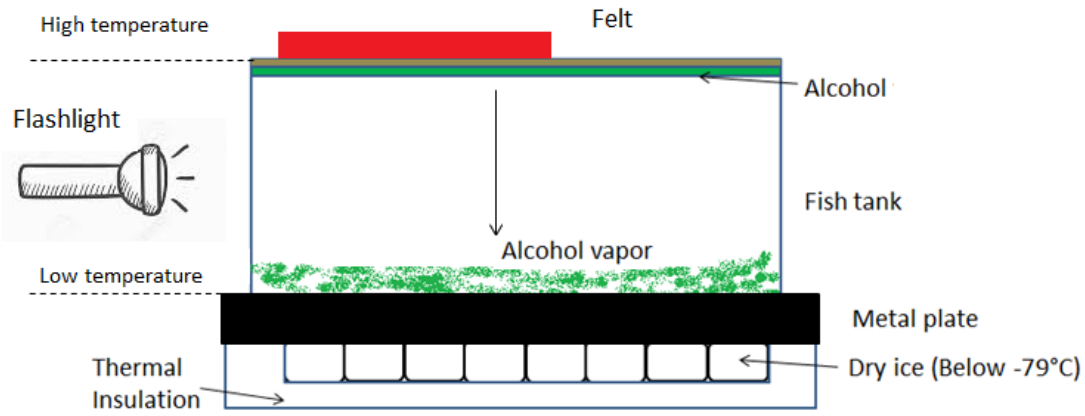


Fig. Anatomy of a diffusion cloud chamber.

Follow the guidelines to build your own diffusion cloud chamber:

1. Place the dry ice in a thermally insulated container. Attention! You need to use gloves because dry ice has temperature less than 79 degrees Celsius.

Fig. Dry ice in a thermally insulated container

2. Adapt a metal plate on top of the dry ice.

Fig. metal plate.

3. Pour a generous dose of alcohol on the felt and glue it on the inside of the fish tank. The more you pour the better.

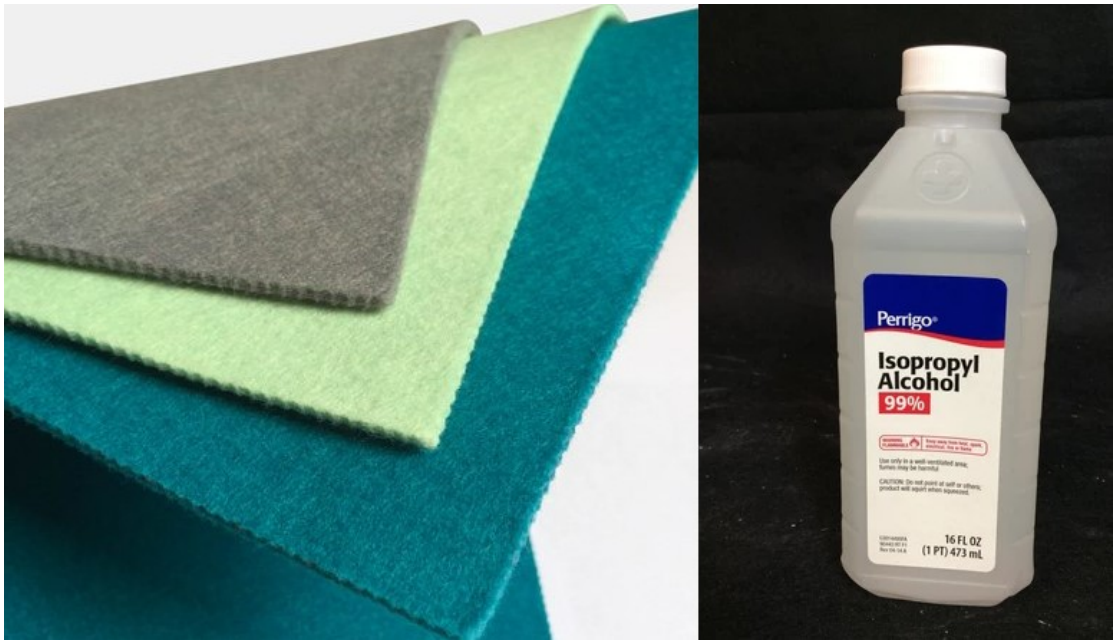


Fig. Felt and isopropyl alcohol

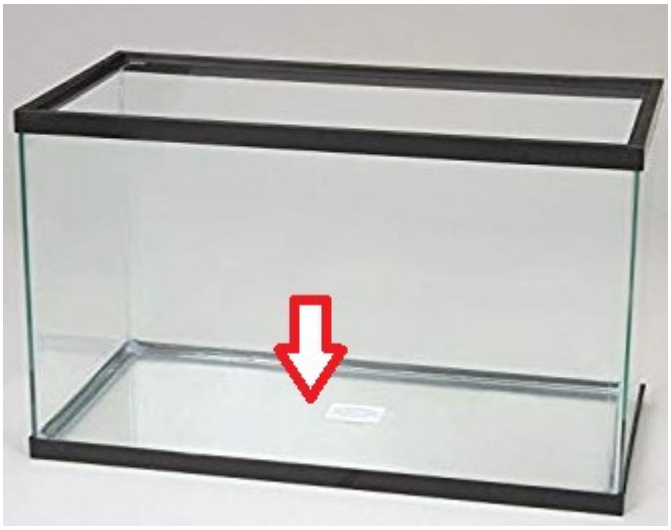


Fig. Fish- tank and the place to glue the felt.

4. Turn around the fish-tank and glue it on the plate.

Your setup will look like this:

Fig. a “do it yourself” cloud chamber.

5. Place a hot water container on top of your “upside-down” fish-tank.

We are almost there. The last two steps are:

6. Try to turn off any light source at your disposal.

7. Use a flashlight to illuminate the cloud chamber.

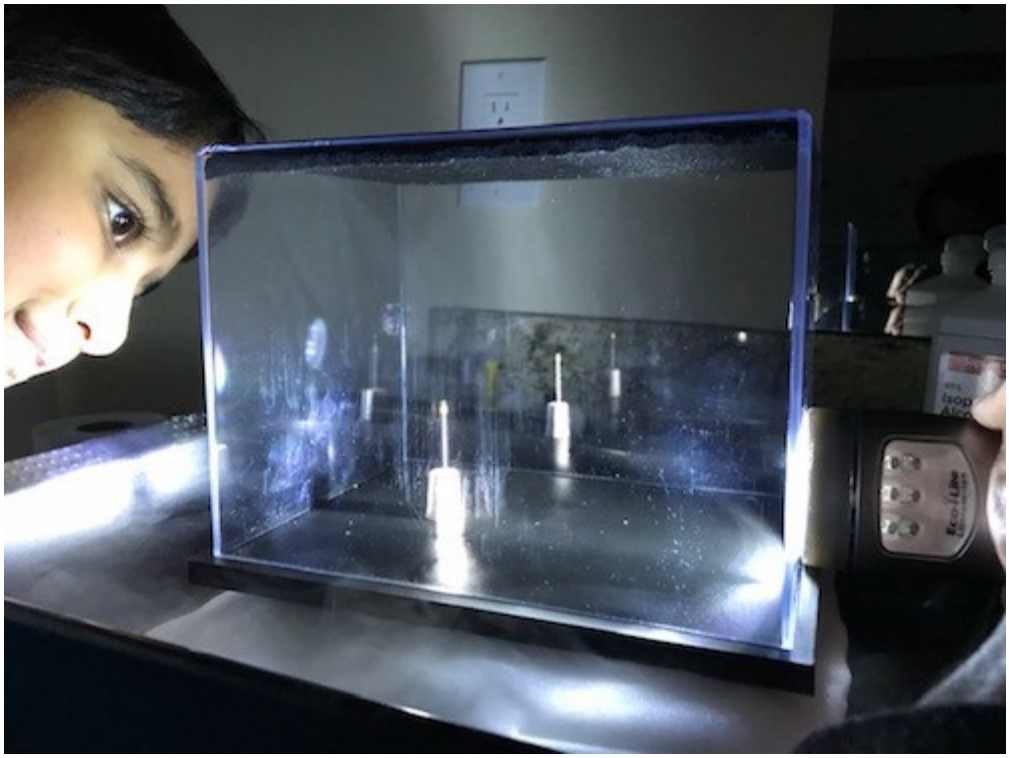


Fig. An operational “do-it-yourself” cloud chamber.

If you have been successful, then you will be able to observe a layer of “fog” on the bottom.

Do you observe any “horizontal long trails” forming inside the chamber?

Fig. What trails we can look for in our cloud chamber.

Observe for quite some time. Try to take a snapshot of them if you find any. If you made it, then congratulations! You detected your first elementary particle!

Teacher guideline

You can divide your students in groups and create more than one cloud chambers. Make sure that when you test your setup you will achieve as much darkness as possible. If you are lucky, you will be able to observe long straight trails of muons, the heavy cousins of electrons which are created by the interactions of cosmic rays in the atmosphere. Most muons come down vertically, however due to the low thickness of the alcohol vapor you might be able to observe the more "rare" horizontal muon events.

Try the following investigation:

Observe for some time and count how many long trails you observe. Try to repeat your experiment in a place with greater overburden: for example the basement of your school. Try to repeat your experiment in a place with less overburden (for example near the rooftop of your school. Do you observe any differences?

Teacher guideline 1

If we increase the overburden, more muons will be absorbed, and thus the rate of their arrival will be reduced. This detector is not suited for precision measurements, but rather for demonstrator purposes. However, this change of rate can trigger a discussion about how we can use muons to map the inside of structures such as the Pyramids or Fukushima! See more about muon tomography here:
https://www.youtube.com/watch?v=34iuc8Wt59Q
https://www.youtube.com/watch?v=bnkrYKjBHaI

Teacher guideline 2

You could try to place a radioactive source (e.g Americium from an old smoke detector or a source from your lab) in the cloud chamber and observe the produced tracks.

Analysis & Interpretation

Analysis and interpretation : Gather result from data

Your cloud chambers have hopefully provided you with some nice photos of long straight tracks. Answer the following questions to the best of your ability.

- Do the tracks look “bright” or “dim”?
- Can you estimate how long are the tracks?
- Do they originate inside the cloud chamber or do they come from the outside?
- What changes if I change the overburden?

Write a short report and provide it to your teacher.
The tracks you observed correspond to the particles called “muons”. Muons are heavy cousins of your well known “electrons”. With almost 200 times higher mass, they are created in the atmosphere and travel towards the earth. They are “unstable” meaning that they will decay after some time has passed. But let us not worry about that yet..

Find out about muons here:
https://www.britannica.com/science/muon

Conclusion & Evaluation

Conclude and communicate result/explanation

Create a short video showing your experimental procedure and your results. You can present this video to other classmates of yours to explain them how a cloud chamber works and what it detects!

You can observe this overview video which summarizes the use of a cloud chamber
https://www.youtube.com/watch?v=fWxfliNAI3U

Now you can read the following article to learn more about signatures of particles in a cloud chamber:
https://www.symmetrymagazine.org/article/january-2015/how-to-build-your-own-particle-detector

Evaluation/Reflection

- Reflect on the experimental procedure you performed. Was it easy or difficult? What would you do different? What other investigations could you do with this detector?

  - If you have made more than one setups, then compare your results and optimize your detectors.

In your investigation, you searched for natural sources of ionizing radiation with your cloud chamber. In summary, there are two other sources of particle tracks that we can potentially observe in the cloud chamber if we don't place any radioactive sources near the detector:

a. We will observe particle tracks coming from cosmic rays interacting with the cloud chamber. These can be muons, primary alpha particles, nuclei, protons, neutrons or gamma rays. The higher the altitude that we place our cloud chamber, the higher the rate that we will observe cosmic particle tracks.

b. We will observe particles produced by natural radioactivity.

Now watch the following video to see cosmic rays observed in a cloud chamber placed in more than 2500 m altitude compared to a cloud chamber placed in 40m altitude. Use your newfound knowledge to identify as many types of particles as possible.
https://www.youtube.com/watch?v=Z73T_ZHplaw

What are the differences with altitude? Why do such differences exist?
Can you conclude, taking into account these differences with altitude, if the particles you observe come from the earth or from outer space?

Teacher guidelines
The difference with altitude can initiate a discussion for the existence of cosmic rays.
https://www.youtube.com/watch?v=91801Y1lsCg
http://230nsc1.phy-astr.gsu.edu/hbase/Astro/cosmic.html