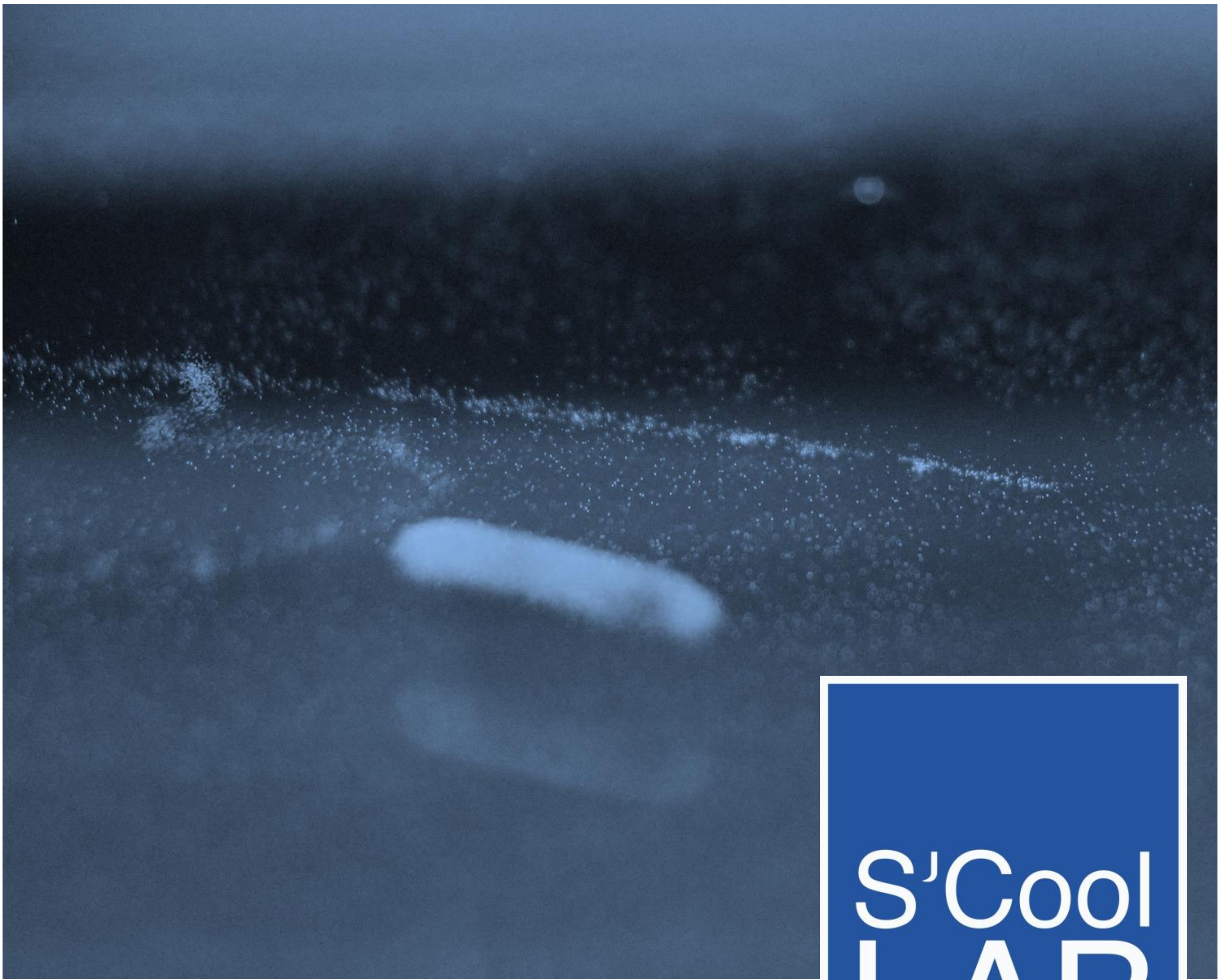


Cloud Chamber

Do-it-yourself manual

Julia.Woithe@cern.ch 5/3/16 S'Cool LAB

BUILD YOUR OWN PARTICLE DETECTOR!

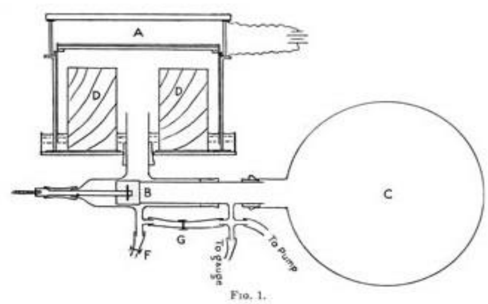
Particles coming from the universe are crossing the earth all the time – they are harmless but invisible to us. Cloud Chambers are detectors which make the tracks of the particles visible. Some decades ago these detectors were used at CERN in the first particle physics experiments. The following instructions will help you to build your own Cloud Chamber at home.

HISTORY

The cloud chamber is one of the oldest particle detectors, and it led a number of discoveries in the history of particle physics. It also was involved in two Nobel prizes!

Charles T. R. Wilson (1869 - 1959)

This Scottish physicist actually wanted to study cloud formation and optical phenomena in moist air. He discovered soon, that by accident he had invented a particle detector. He perfected the first (expansion) cloud chamber in 1911 and received the Nobel Prize in 1927.

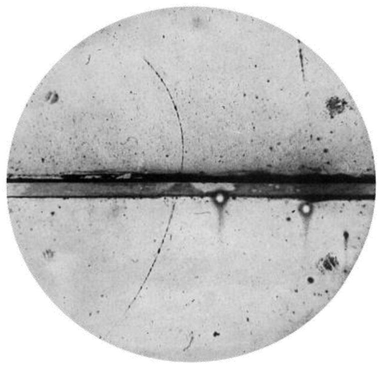


A diagram of Wilson's apparatus. The cylindrical cloud chamber ('A') is 16.5cm across by 3.4cm deep.

Wilson, C. T. R. (1912). On an Expansion Apparatus for Making Visible the Tracks of Ionising Particles in Gases and Some Results Obtained by Its Use. *Proc. R. Soc. Lond. A.* 87, 277-292. *doi:*[10.1098/rspa.1912.0081]

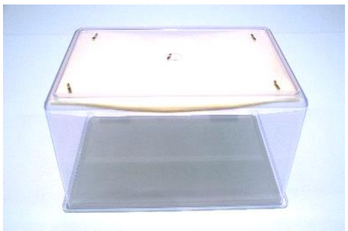
Carl Anderson (1905 - 1991)

This American physicist discovered the positron in 1932 and the muon in 1936 using a cloud chamber. He received the Nobel Prize in 1936. His invention: He used alcohol instead of water to form a more sensitive mist.



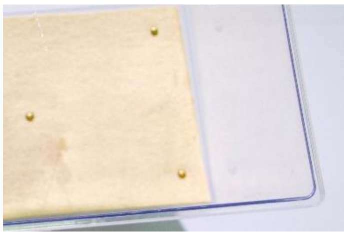
Anderson, C. D. (1933): The Positive Electron. *Physical Review 43, 491–494. doi:*[10.1103/PhysRev.43.491]

SHOPPING LIST PART 1



Plastic Container

clear, see-through box-like plastic container
with an open top
roughly 20 x 30 x 15cm
S'Cool LAB: Aquarium 11 l
Alternatives: any plastic box, plastic cup, …



Felt

a thick felt (few mm) to be attached to the bottom of the plastic box
S'Cool LAB: 5 mm thick white felt
Alternatives: sponge, …

Split Pins

to attach the felt to the inside of the bottom of the box
Alternatives: cable ties, wire, …

Box

a box that is just a little bit larger than the metal plate
will contain the dry ice plates and the metal plate
the sides should not be much higher than 5 cm, otherwise they will block the view
S'Cool LAB: Plastic box isolated inside with Styrofoam and foam rubber
Alternatives: Cardboard, styrofoam or wooden boxes, …

Metal Plate

to be placed on top of the dry ice (good heat conductivity important)
to cover the open side of the container completely
needs to be black and could have little grooves matching the side walls of the plastic box (for isolation of the air volume inside)
S'Cool LAB: anodised aluminium plate (d = 5 mm) with CNC milled groove
Alternatives: Baking tray, frying pan, book holder, metal plate and black electrical tape on top of a metal plate

Shopping list part 2

Light Source
a very intense, bundled light source
S'Cool LAB: LED Torch Light
Alternatives: overhead projector, LED strip, …

Protective Equipment
to handle isopropanol and dry Ice it is necessary to wear personal protective equipment

- safety goggles (for dry ice and Isopropanol)
- nitril protection gloves (for Isopropanol)
- leather protection gloves (for dry ice)

Dry Ice
Solid carbon dioxide at -78°C **Read the safety instructions!!!**
touching it directly will cause burns
evaporating dry ice will enrich the air with carbon dioxide
only use in well ventilated rooms
dry ice in airtight containers will build up high pressure
Where to buy:

- google "dry ice online shop"
- have a look at www.dryicedirectory.com

Other sources: Universities (chemistry institutes), fish processing, dry ice cleaning, …

Isopropanol / Isopropyl alcohol
Pure (>90%) isopropyl alcohol
Read the safety instructions!!!
Keep away from children
never drink it, handle with gloves and goggles
Where to buy:
drug store (e.g. as "Alcohol First Aid Antiseptic")

STEP BY STEP INSTRUCTIONS

1. Prepare the metal base plate

If you were not able to get a black metal plate, wrap one side of a metal plate completely with black electrical tape. This will make it much easier for you to see the “white particle tracks” later on in front of a black background. The bottom will be in contact with alcohol when you run the chamber, so do not use alcohol-soluble tape or glue to attach it. Alternatively you can use black nail polish or spray paint. If you have already a black metal plate you can skip this point.

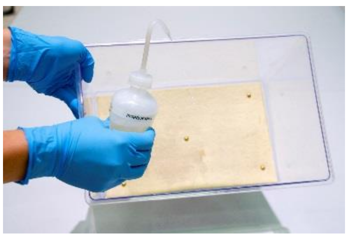
2. Prepare the alcohol dispensing felt

Drill small holes carefully in the bottom of your plastic container, e.g. aquarium. Attach the felt with the split pins to the bottom of the box. Later on this felt will be soaked with alcohol and will produce a rain- like mist of alcohol. Don’t use glue – the alcohol will solve it fast.

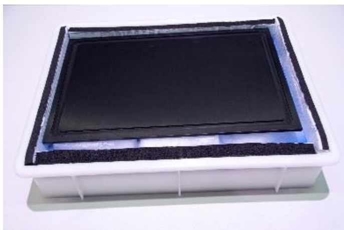
3. Assembly of the Cloud Chamber

Put on leather gloves and safety goggles.
Cover the bottom of your box with dry ice.

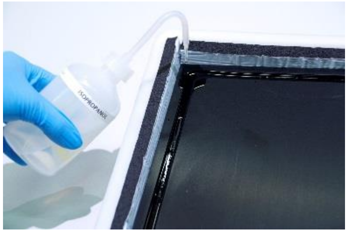
Next you will add the Isopropanol to the chamber. Make sure you wear plastic gloves and safety goggles. Again – never drink the alcohol and keep it away from children! It is very crucial that you use the right alcohol – the chamber will not work with another one.



Soak the felt with Isopropanol. This Isopropanol will later form the mist in which you see the tracks appearing. Tilt the chamber when you fill in the Isopropanol. You will see when the felt is completely soaked once there is a little “lake of Isopropanol” in one corner. Fill back this Isopropanol to the flask or use it late to fill the groove of the metal plate.

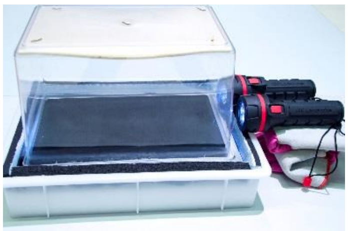


Place your black metal plate onto the dry ice. Make sure you have already soaked the felt inside the plastic container! If your plate becomes cold, the water vapour in the air will condensate/freeze on it and form a white "snow layer" after a few minutes. Since you need a black surface for contrast reasons, you would have to clean the plate.

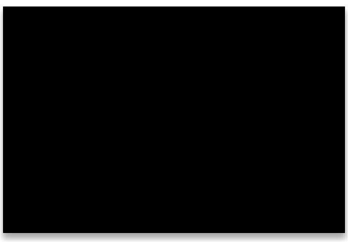


Use Isopropanol to fill the groove of your metal plate - if you have it. This will help sealing the box.

Place your plastic container upside down onto your metal plate. Fit the box so that the box walls fit the grooves in the metal plate. Now your chamber is ready to detect particles. It will only take a few minutes until everything has cooled down and a stable sensitive area has formed.



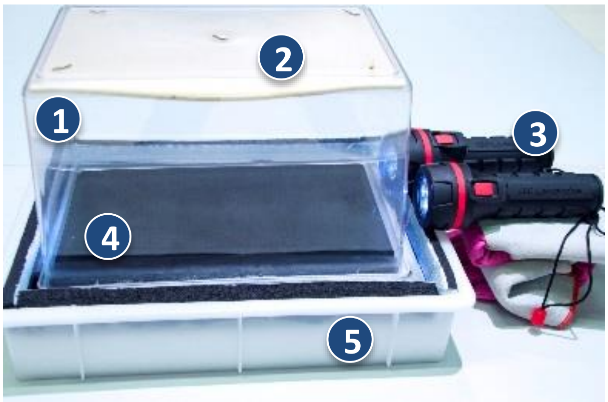
At first, you will only see a rain-like mist of alcohol. Place your torch lights in a way, that they illuminate the alcohol mist right above the metal plate – that is the sensitive area of the chamber.



Turn off the room lights and turn on your light. After a few minutes, you should start to see the tracks of particles passing through. The tracks look a little like spider's threads going along the chamber floor. You should be able to see a couple of tracks per minute. If needed, you can add extra alcohol through the holes in the top of the box without reopening the box.

HOW DOES THE CLOUD CHAMBER WORK?

At the top of the box Isopropanol evaporates from the felt (i.e. exists in gaseous form) and slowly sinks down in the direction of the bottom of the chamber, since Isopropanol vapour is heavier than air. The dry ice keeps the bottom very cold, therefore the isopropanol cools down rapidly when falling. The result is a so called supersaturated environment. This means, the alcohol is in vapour form, but at a temperature at which vapour normally can't exist. Therefore, it will very easily condense into liquid form if anything disturbs its equilibrium. Now what happens if an electrically charged particle crosses the chamber? The particle will *ionize* the vapour: it tears away the electrons in some of the gas molecules along its path. This leaves these molecules electrically positively charged. This is enough to start the condensation process: Small droplets of alcohol form along the path of the initial particle through the chamber. The ordered accumulation of these droplets are the tracks you see appearing.[1]



1 See-through box

2 Felt

3 Torch light

4 Black metal plate

5 Box with dry ice

What are cosmic particles?

Different types of particles come from stars, galaxies and other sources in the universe. For example, protons, helium nuclei and electrons travel through the universe all the time, as well as neutrinos and photons. These particles are also called cosmic particles. Their energy ranges from about 10^9 electron volts (eV) to about 10^{20} eV. For comparison: The currently largest particle accelerator LHC at CERN, accelerates protons only to a ten million times lower energy (maximum 10^{13} eV).

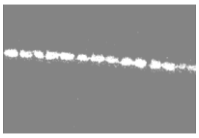
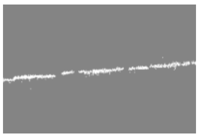
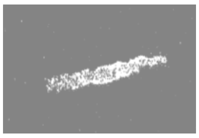
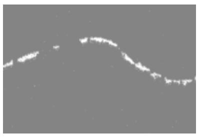
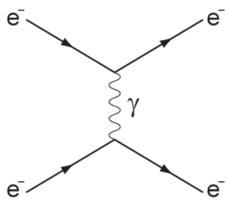
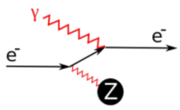
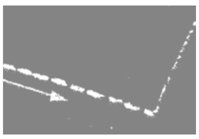
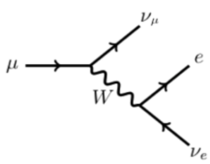
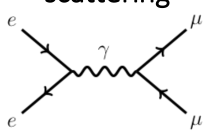
Test of special relativity

Most of the tracks you see in the cloud chamber are caused by muons. Muons have similar properties than electrons but are much (approx. 200 times) heavier and therefore are not stable but have a really short mean lifetime of 2.2 µs. They transform into an electron and two neutrinos. This actually provides an interesting test of special relativity: muons are typically produced around 15 km up in the atmosphere, when cosmic particles interact with the atmosphere and thereby transform into lighter particles. To reach the surface of the earth, muons at the speed of light would need 50 µs - over 20 muon lifetimes! Thus we would expect only very few muons to make it. However, when applying Einstein's rules of special relativity to the very fast muons, time in the their frame of reference is significantly dilated as seen by an observer on Earth, meaning that a significant fraction can, in fact, make it to the surface. On average, 1 muon passes through the palm of your hand every second with an energy of typically 1 GeV to 1 TeV.

[1] Look up (Nuffield Foundation, 2016) for more information about this process.

WHAT CAN YOU SEE?

You will see different kinds of tracks, which differ in length, thickness and shape and are produced by different types of particles.

Pictures © Karlsruher Institut für Technologie (KIT)	Particle	Explanation
	**muon or anti-muon**	Thin straight tracks - fast particles with high kinetic energy - they ionise molecules without scattering - high energy muons, electrons or their corresponding anti-particles - source: secondary cosmic particles
	**electron or positron**	
	**α particle system**	Thick straight tracks (approx. 5 cm): - alpha particle systems (2p2n) - massive particle systems with high "ionisation density" (for alpha: 1 MeV/cm) - source: Radon-222, natural radiation
	**electron** 	Curly / curved tracks: - slow electrons scatter with other electrons via electromagnetic interaction - the lower the momentum of a particle, the easier it scatters - Photoelectrons are low energy electrons set free by high energy photons (via Photoelectric effect) - Source: beta emitters, photoelectric effect
	**photoelectron** 	
	**muon transformation** 	Kinks: This could be a muon transforming into an electron and two neutrinos!
Y	**electron-muon-scattering** 	Y-shape: This could be a muon knocking off an electron (bound to an atom) via electromagnetic scattering.

TROUBLESHOOTING AND FAQ

Although cloud chambers are a very reliable research tools, things might not work from the beginning and you might encounter some of the following challenges or questions.

Challenge / Question	Solution
"I don't see any tracks!".	Vary the position of your light source – make sure that the sensitive layer of the detector (approx. 1 cm above the metal plate) is well illuminated. Make sure the dry ice is in good contact with the metal plate. If your dry ice is rather old, scrape off the surface layer of the ice blocks to get rid of water ice which freezes onto the dry ice. Add more isopropanol to make sure the chamber is well saturated. Check that the chamber is airtight, you can use tape or plasticine to seal it.
"I only see mist, and no tracks."	Wait. It takes approx. 5 minutes for the chamber to get to the right temperature. Make sure that you use the right alcohol – other alcohol have different "activation energies" that so that cosmic rays will not be able to start the condensation process.
"I see big clouds at the edges of the chamber."	This probably means you have an air leak. Make sure that the chamber is tightly sealed.
"I can't see tracks because the black metal plate has a cover of snow."	This sometimes happen, if the metal plate is exposed to normal air and dry ice at the same time: The water vapour from the air freezes onto the metal plates procuring a white icing. Start again, make sure to close the chamber as soon as possible e.g. by preparing the felt with isopropanol before you place the metal plate on top of the dry ice.
"I have read that some cloud chambers use high electric fields. Why?"	A strong electric field (approx. 100 V/cm) is often used for professional cloud chambers to pull ion tracks down to the sensitive region of the chamber. As ionising particles pass above the sensitive area of the chamber, they leave an ion trail behind but no condensation start. When pulled down to the supersaturated layer, condensation around the ions starts and droplets can be observed.
"I have learned that magnets deflect electrically charged particles but my fridge magnet has no effect."	To see the curvature of high energy particles in a magnetic field with your bare eye, you need very strong magnetic field of several Tesla. For example: the bending radius of a high energy electron ($m_e = 0{,}51 \frac{MeV}{c^2}$) with $E = 1\ GeV$ in a magnetic field of $B = 2\ T$ is $1.7\ m$! $E = \sqrt{m_e^2 \cdot c^4 + p^2 \cdot c^2} \approx p \cdot c\ (for\ m \ll p, highly\ relativistic\ particles)$ $p \cdot c = e \cdot r \cdot B \cdot c \Leftrightarrow r = \frac{E}{e \cdot B \cdot c} = 1.7\ m$
"What is the squeaking sound when I put the metal plate on top of the dry ice?"	When the metal plate is placed on the dry ice, a strange loud noise is produced. This happens because the dry ice sublimates instantly upon contact with the warm metal plate. The gas bubbles burst because of the pressure by the metal plate – that is causing the noise.

More about cloud chambers

Alternative setups

There are many different versions of cloud chambers you can find on Youtube or in Education Journals. Here some examples:

- Fish Tank Cloud Chamber (Green, 2012)
- Cloud Chamber build with gel ice packs instead of dry ice (Kubota & Kamata, 2012)
- Cloud Chamber build with a water ice / salt mixture (Yoshinaga, Kubota, & Kamata, 2014)
- Cloud Chamber build with liquid nitrogen (Zeze, Itoh, Oyama, & Takahashi, 2012)

"Modern" Cloud Chamber at CERN: CLOUD experiment

Learn about clouds and the climate and why CERN is investigating cloud formation (Kirby, Richer, & Comes, 2016).

Hiking with cloud chambers

What happens to a cloud chamber in 4300 meters height? Carl Anderson took a cloud chamber to Pike's Peak in 1936 (Anderson & Neddermeyer, 1936).

Bibliography

Anderson, C. D., & Neddermeyer, S. H. (1936). Cloud chamber observations of cosmic rays at 4300 meters elevation and near sea-level. *Physical Review, 50*(4), 263-271. doi:10.1103/PhysRev.50.263

Green, F. (2012). Making a fish tank cloud chamber. *Physics Education, 47*, 338-341. doi:10.1088/0031-9120/47/3/338

Kirby, J., Richer, C., & Comes, I. (2016). *Cloudy climate change: How clouds affect Earth's temperature - Jasper Kirkby* . Von TEDEd Lessons Worth Sharing: http://ed.ted.com/lessons/cloudy-climate-change-how-clouds-affect-earth-s-temperature-jasper-kirkby abgerufen

Kubota, M., & Kamata, M. (2012). Simple cloud chambers using gel ice packs. *Physics Education, 47*, 429-433. doi:10.1088/0031-9120/47/4/429

Nuffield Foundation. (2016). *Alpha Particle Tracks*. Von Practical Physics: http://www.nuffieldfoundation.org/practical-physics/alpha-particle-tracks abgerufen

Yoshinaga, K., Kubota, M., & Kamata, M. (2014). Simple cloud chambers using a freezing mixture of ice and cooking salt. *Physics Education, 50*, 23-27.

Zeze, S., Itoh, A., Oyama, A., & Takahashi, H. (2012). A sensitive cloud chamber without radioactive sources. *Physics Education, 47*, 574-578. doi:10.1088/0031-9120/47/5/574