Notes & News

Cosmic rays | Build yourself a cloud chamber

Costing less than £50, this design reveals a world of sub-atomic particles that have travelled across the galaxy.

Dr Steve Barrett
Department of Physics, University of Liverpool

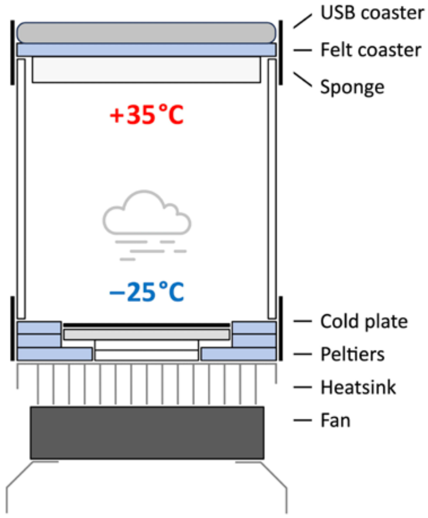

Figure 1. Overview of the cloud chamber. ***Left:*** Schematic diagram of the cloud chamber shown as a section. The blue-shaded rectangles are the felt coasters. The one at the top separates the USB-powered mug-warming coaster (grey) from the sponge holding the IPA. The multiple layers of coasters at the bottom help to thermally insulate the cold plate (black) and Peltier modules (white) from the ambient warm air outside the chamber (see Figure 2). ***Right:*** The cloud chamber sits on four Meccano pieces to lift the cooling fan off the table. The 3D-printed, black plastic collars at the top and bottom of the cloud chamber help to keep all the components located securely in position. Though not necessary, they make the chamber less prone to 'rapid unscheduled disassembly' if accidentally knocked.

Cosmic rays

High-energy charged particles are continually raining down on the Earth. Where do they come from and how do they gain so much energy? There is still much to be learnt about the origins of cosmic rays,[1] the stream of particles discovered in the early 1900s by Victor Hess that won him the Nobel Prize in Physics in 1936.[2] We know that sub-atomic particles – mainly protons, alpha particles, and some heavier atomic nuclei – exist in interstellar and intergalactic space. There are many space-based instruments that have been recording incoming cosmic ray particles for decades (including, for instance, those on the *Voyager* spacecraft and more recently on the *International Space Station*).[3,4]

The Earth's magnetic field protects us from many of these particles, but enough get through to hit atoms at high altitudes in our atmosphere, creating showers of secondary cosmic rays. The particles created in these air showers that survive to reach sea level – particles such as muons, electrons and protons – are the ones that can be detected by ground-based observatories.

Despite over a century of study, there are still many aspects of cosmic rays that are perplexing. Although we know what they are, we do not know from where they originate nor how the particles gain such extreme energies – the highest cosmic ray energies observed are many millions of times higher than the energies we have been able to achieve in particle accelerators such as the Large Hadron Collider at the Conseil Européen pour la Recherche Nucléaire (CERN). Many astrophysicists believe that the shockwaves that result from supernovae (in our galaxy) or the jets emitted by supermassive black holes (in other galaxies) can accelerate charged particles to these extreme energies. However, although these objects may well be responsible for the particle acceleration, the details of the mechanisms involved are not well understood and are active areas of research.

Building a cloud chamber

Inspired by sightings of the Brocken spectre from the top of Ben Nevis in 1894, Charles Wilson developed chambers for studying cloud formation and optical phenomena in moist air.[5] In 1911, he perfected the first cloud chamber and soon realised that when charged particles passed through it, water droplets condensed to form visible tracks. Just as an aircraft flying at high altitude can leave a condensation trail (contrail) as it passes through air laden with water vapour, so particles can leave condensation tracks in a cloud chamber if the temperature and pressure conditions are right. The cloud chamber was the first type of detector that allowed the passage of cosmic ray particles to be seen and photographed. Wilson's cloud chambers had an important role in experimental particle physics for decades and in 1927, he was awarded the Nobel Prize in Physics for the 'most original and wonderful instrument in scientific history'. While modern cosmic ray observatories use large numbers of sophisticated electronic detectors to determine the tracks of particles,[6,7,8] identify them, and measure their energies, a hundred years ago, the detectors were much less complex. Hence, these are more suitable for amateurs to reconstruct today.

I wanted to build a cloud chamber to provide a practical demonstration of how we can visualise cosmic rays and other particles, collectively known as background radiation. I intended to use it as part of a talk on cosmic rays and take it to space-related outreach events as a table-top demonstration. These requirements led to the design criteria. It had to be: compact and light enough to transport in one travel case; able to run continuously for at least two hours without intervention and without the need for any dry ice; and easy to make out of readily available components at a modest cost of ~£25 to £50, depending on what items were already at hand, to allow others to copy the design and construction.

Making a 'cloud in a jar' requires a few basic elements: (i) a substance that is a vapour when warmed and a liquid when cooled; (ii) a source of heat; and (iii) a source of 'cold'. For clouds that form in the sky, the substance is water and the variation in temperature (from 20°C at sea level to −70°C at high altitude) provides the right conditions for their formation. If water vapour is just at the point of wanting to condense into a cloud, then the passage of an aircraft can 'trigger' this process, forming a contrail of water droplets. The passage of a charged particle through a cloud chamber can produce a visible track of liquid droplets in the same way.

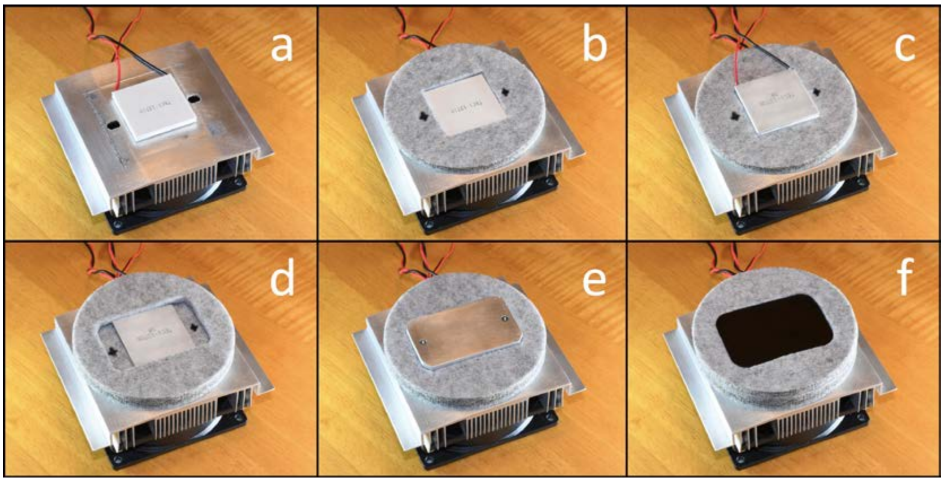

Figure 2. Building up the refrigeration platform, step by step. **(a)** An off-the-shelf refrigeration kit comprising a Peltier module, a heatsink, and a fan. **(b)** A felt coaster with a square cut out of its centre placed over the Peltier module. **(c)** An additional Peltier module stacked onto the first (see the Technical Appendix of 'Building a Cloud Chamber' for details).[10] **(d)** A second coaster with a rectangular cut-out to accommodate the cold plate. **(e)** An aluminium cold plate keeps both the Peltier modules clamped in place. **(f)** A black plate provides a dark background for the particle tracks to make them easier to see.

Components & construction

My cloud chamber (Figure 1) is a distant cousin of Wilson's original invention. I chose isopropyl alcohol (IPA) rather than water to be the substance in the chamber because its liquid and vapour forms can exist over a temperature range that is not too far from room temperature. My design also benefits from technology that was not available to Wilson a century ago. Rather than using the expansion of gases to achieve the cooling effect necessary to condense vapour into liquid, my cloud chamber uses semiconductor devices called Peltier modules.[9] A Peltier module uses electrical power to remove heat from one side of a slab of semiconductor material and dump that heat onto the other side of the slab, where it is usually removed with a heatsink cooled by a fan. The 'cold side' will stay cold for as long as the device is supplied with electrical power. The cold side of the Peltier module cools a cold plate (usually a small piece of aluminium a few cm in size) which needs to be brought into contact with the base of the cloud chamber to cool the IPA vapour inside. Hence, this design of cloud chamber does not need any external source of 'cold' such as dry ice, making it much simpler to realise if obtaining cryogenic materials is difficult.

Providing a source of heat to evaporate the IPA is easy enough, as the temperature required is somewhere above room temperature and below the temperature of a cup of tea. My design uses a USB-powered mug-warming coaster (~£10) because they are a suitable size and provide just the right amount of heat to keep an IPA-soaked sponge at the top of the cloud chamber at a temperature above 30–40°C. Providing the cooling required to condense the IPA vapour back into a liquid is a little more problematic. The key to building a compact cloud chamber is the availability of small and relatively cheap (~£15) refrigeration kits comprising a Peltier module, a heatsink and a fan. These kits have two functions: they are the source of 'cold' and the platform on which the chamber itself stands. The chamber can take many forms, including a simple and cheap glass jar, but after some experimentation I found the optimum size/shape is a glass cylinder 10 cm in diameter and 10 cm tall.[10] They are sold as 'candle holders' or 'hurricane glass' and can be bought in various sizes.

The essential function of a cloud chamber is to set up the thermal gradient that will create IPA vapour at the top of the chamber and condense the vapour into liquid as it falls slowly towards the base. As the IPA condenses, a mist of droplets forms at the base of the chamber and drizzles down onto the cold plate of the refrigeration platform. This is where the particle tracks become visible. The cheapest of the refrigeration kits do not get quite cold enough for the IPA to condense into a mist. I found that two Peltier modules, back-to-back, work better than one to get the temperature below −20°C, the base temperature required for effective operation of the cloud chamber. Figure 2 shows how the two-Peltier refrigeration platform is built up, step by step.

Note that my pdf article 'Building a Cloud Chamber' gives all the details of the components and construction of the cloud chamber, including a Technical Appendix that details how I tested various prototypes before deciding on the final design.[10]

Operation

The Peltier modules in the refrigeration platform require a power supply of nominally 8–9 V to provide the necessary cooling. Having a variable-voltage bench power supply has the advantage of being able to vary the power to see the effect on the base temperature reached by the cold plate. However, a fixed-voltage power supply ►

► should be fine providing it can supply the necessary current. Many amateur astronomers use a 'power tank' to power telescope mounts, cameras, dew heaters, etc, and these should provide plenty of power for the Peltier modules. If you do not have one, fixed-voltage power supplies are reasonably priced – for instance, a 9 V / 6 A power supply can be bought for ~£10–£15.

The sponge located inside the glass jar or cylinder should be soaked with about 5 ml of IPA. I have found that this amount, when heated to about 30–40°C by the mug-warming coaster, allows operation for at least two hours. As a rough guide, the Peltier modules will cool from room temperature to −20°C in 5 minutes and the IPA-soaked sponge will warm from room temperature to 30°C in 10 minutes. When the IPA starts condensing, a mist will appear at the bottom of the chamber as tiny droplets of IPA drizzle down onto the cold plate. This should be visible after about 5 minutes.

What you can expect to see

Cosmic rays will pass through the cloud chamber and leave visible tracks every few seconds. A simple torch should be enough to allow you to see the particle tracks – illuminate the inside of the chamber from the side as viewed by the observer(s) or camera. Figure 3 shows images of the various types of cosmic ray tracks that can be identified: muons, electrons, and protons.

The appearance of the tracks will depend on the ability of the particles to ionise the atoms in the air. Protons have a large mass and a high ionising power; hence, they leave bright tracks. Muons have a lower mass than protons and so produce fainter tracks. Electrons have a very low mass, so their tracks tend to appear stragglier than the straight tracks of muons or protons.

In addition to cosmic rays, you may see tracks from alpha particles. These have four times the mass and twice the charge of a proton and so produce very broad tracks. Alpha radiation is emitted by radon, the radioactive gas formed by the decay of the small amounts of uranium that occur naturally in all rocks and soils. Radon concentrations vary across the UK and are higher in regions rich in granite, such as the Southwest.

Summary

More than a century on from Wilson's first cloud chamber, my design is compact, cheap to make and, most importantly, easy to operate – just add a little alcohol, switch it on, and wait for the sub-atomic particles from the cosmos to reveal themselves.

References

1 'Cosmic ray': **tinyurl.com/433wtuxa**
2 'Victor Francis Hess': **tinyurl.com/56b35dzz**
3 *Voyager* CRS: **tinyurl.com/2bn45bwr**
4 ISS AMS: **tinyurl.com/4vhztuse**
5 'C. T. R. Wilson': **tinyurl.com/yunpuesw**
6 Pierre Auger Observatory: **auger.org**
7 IceCube Observatory: **icecube.wisc.edu**
8 Cherenkov Telescope Array: **cta-observatory.org**
9 'Peltier effect': **tinyurl.com/y2dsvawb**
10 **liverpool.ac.uk/~sdb/Astro/Cloud-Chamber-JBAA.pdf**

Components

Item/s	*Nominal size/number*	*Estimated cost (£)*
Basic components		
A container, such as a glass jar or cylinder	100 × 100 mm tall	2
A source of heat, such as a mug-warming coaster	100 × 8 mm thick	10
A source of 'cold', such as a small refrigeration kit	120 × 100 × 60 mm	20
Also needed		
Sponge	90 × 15 mm thick	1
Alcohol	250 ml of IPA	2
A few hand tools (screwdriver, craft knife, etc.)		
Optional extras		
Digital thermometers with LCD displays	Set of three	7
Felt coasters for thermal insulation	100 × 5 mm thick	3
LED torch for illuminating the particle tracks		
Odd bits of Meccano or 3D-printed pieces		
		Total ~ £35–45

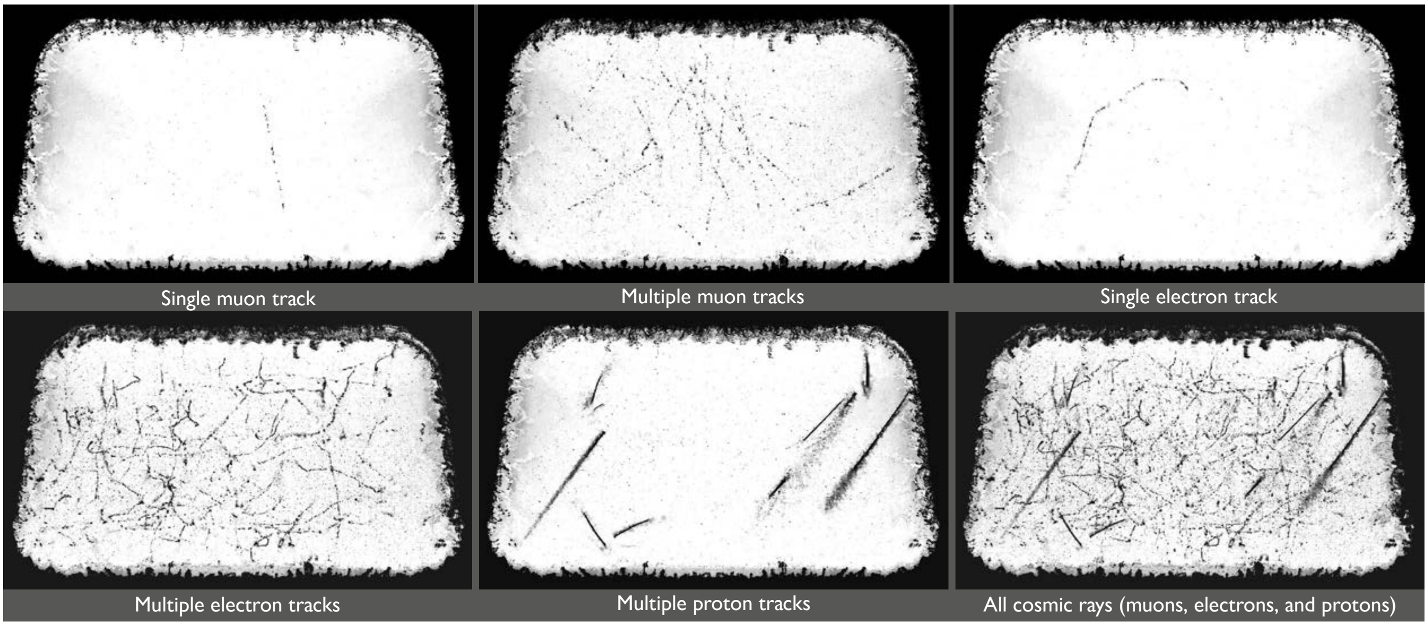

Figure 3. Particle tracks (black and white inverted, for clarity). These images are either snapshots of single particle tracks or composite images of multiple tracks observed over an extended period (typically an hour). The composite images were made by manually selecting, extracting, and superimposing dozens of still frames from a video.