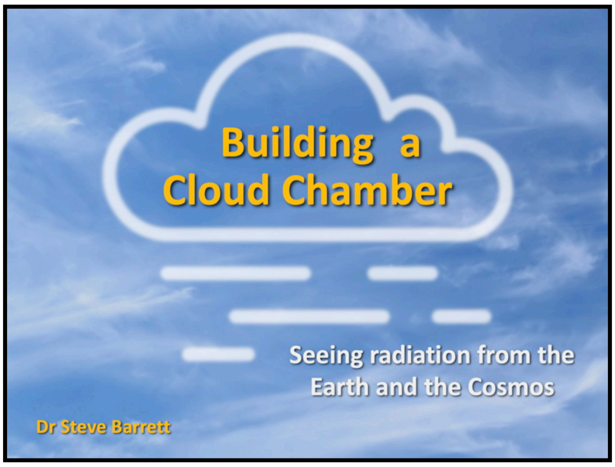
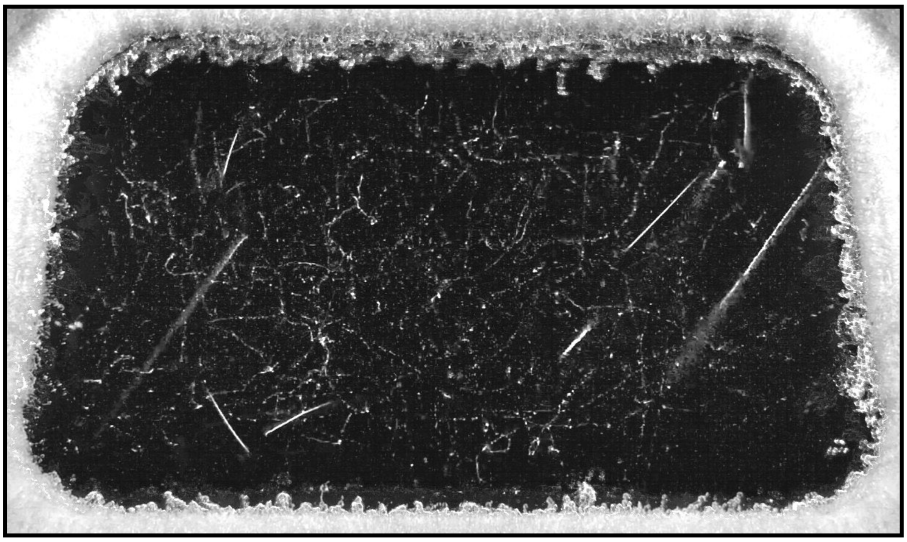


A cloud chamber is means of visualising the passage of invisible particles. Just as an aircraft flying at high altitude can leave a condensation trail (contrail) in the sky as it passes through air that is laden with water vapour, so particles can leave condensation tracks in a cloud chamber if the temperature and pressure conditions are right.

I decided to design and build a cloud chamber to provide a demonstration of how we can visualise cosmic rays and other particles collectively known as background radiation. I wanted to be able to use it as part of a talk on Cosmic Rays and also take it to other outreach events as a table-top demonstration.

Cloud chamber



Composite image of multiple cosmic ray tracks

It had to be compact and light enough to transport all the components in one aluminium case and be able to run continuously for at least two hours without intervention. To allow others to copy the design and construction, I also wanted it to be easy to make out of readily available components at a cost of about £25 – £50 depending on what items were already on hand.

In summary, it had to be:

- Compact
- Light
- Cheap
- Easy to construct
- Easy to run

In practice, that meant:

- Must fit into one travel case
- Mass less than 1 kg in total
- All components total < £50
- No need for specialist tools
- No need for any dry ice

Background

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 with altitude (from 20 °C at sea level down to –70 °C at high altitude) provides the right conditions for clouds to form. 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.

Aircraft contrail

Alcohol

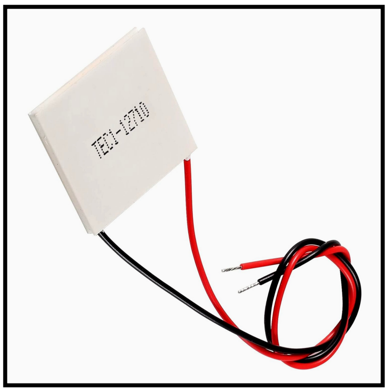
In this cloud chamber the substance is chosen to be alcohol because liquid and vapour can exist over a temperature range that is not too far from room temperature. The most suitable alcohol for a small cloud chamber is isopropyl alcohol (aka IPA, aka isopropanol, aka 'rubbing alcohol').

Hot and cold

Providing a source of heat to evaporate the alcohol is easy enough, as the temperature required is somewhere above room temperature and below the temperature of a cup of tea. Providing the cooling required to condense alcohol vapour back into a liquid is a little more problematic. Various ways of achieving the necessary cooling have been found: liquid nitrogen (–196 °C), dry ice (–78 °C), gel packs (–20 °C) and thermoelectric cooling. The first three have their limitations: liquid nitrogen can be difficult to obtain and store; dry ice can cost up to £50 for small amounts; gel packs might not reach the required low temperatures. Also, using something that warms up over time means that the demonstration would be time-limited — when the dry ice has evaporated or the gel packs have melted, the demonstration is over. More dry ice, or more gel packs from the freezer, would be needed. Using thermoelectric cooling has the advantage that no 'cold stuff' is used up and so it allows demonstrations to continue indefinitely. The electrical power required for thermoelectric cooling costs only a few pence for many hours of operation.

Thermoelectric cooling

A Peltier module is a semiconductor device that uses electrical power to remove heat from one side of a slab of 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. Small refrigeration kits comprising a Peltier module, a heatsink and a fan are readily available from online retailers.



Peltier module

Overview

The cloud chamber that I built went through a few design changes as construction and testing proceeded. The original idea based on an inverted glass pickle jar evolved via an acrylic cylinder into the final design based on a glass cylinder. In this document I will refer to the body of the chamber simply as the 'jar' for the sake of brevity. The reasons for the various design changes are documented in the Appendix for anyone interested in the details.

The final version of the cloud chamber using an open-ended cylinder rather than a pickle jar is shown in Figures 1 and 2.

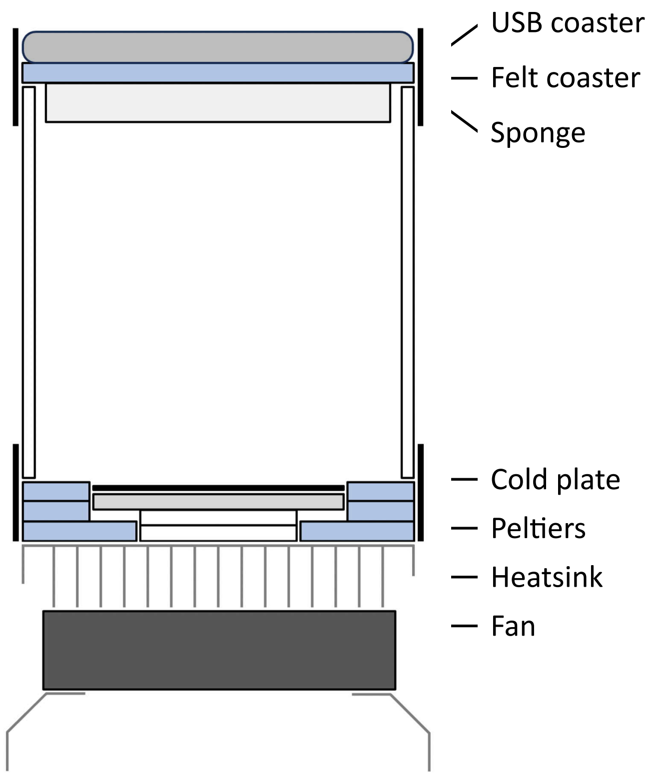


Figure 1

Cross section of the cloud chamber. At the base of the chamber the cold plate (black) and two Peltier modules (white) are embedded in felt coasters (blue) to provide thermal insulation. See page 6 for construction details.

Figure 2

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 strictly necessary, they make the chamber less prone to 'rapid unscheduled disassembly' if accidentally knocked.

Step 1 – Components

	Nominal Size	Cost
• *Required components*		
The basic components are ...		
◦ A container such as a glass jar or cylinder	100 mm ∅ x 100 mm tall	£ 2
◦ A source of heat such as a mug-warming coaster	100 mm ∅ x 8 mm thick	£ 10
◦ A source of 'cold' such as a small refrigeration kit	120 x 100 x 60 mm	£ 20
Also needed are ...		
◦ Sponge	90 mm ∅ x 15 mm thick	£ 1
◦ Alcohol	250 ml of IPA	£ 2
◦ A few hand tools (screwdriver, craft knife, etc)		
• *Optional extras*		
Non-essential but quite handy items include ...		
◦ Digital thermometers with LCD displays	Set of three	£ 7
◦ Felt coasters for thermal insulation	100 mm ∅ x 5 mm thick	£ 3
◦ LED torch for illuminating the particle tracks		
◦ Odd bits of Meccano™ or 3d-printed pieces		
	Total ~	**£ 35 – 45**

If you don't already have a mug warmer, sponges, IPA, thermometers, coasters, etc, lying around then they can be sourced from various online retailers such as Amazon (other suppliers are available):

USB mug warmer:	www.amazon.co.uk/dp/B08X3GM37N
Peltier cooling kit:	www.amazon.co.uk/dp/B0C4HTD88D
Additional Peltier:	www.amazon.co.uk/dp/B0CBTHX2VV
Set of sponges:	www.amazon.co.uk/dp/B0BPDDH6QF
250 ml bottle of IPA:	www.amazon.co.uk/dp/B096KXJCV6
Set of thermometers:	www.amazon.co.uk/dp/B074BSC1XD
Set of felt coasters:	www.amazon.co.uk/dp/B09HSJ238Y

This list is not an endorsement of these particular products, nor do I wish to imply that only these products will work as components of a cloud chamber. They just happen to be the items that I used. Note that prices and availability may have changed since late 2023.

Step 2 – Construction

- *Add a Peltier module to the refrigeration kit*

  An off-the-shelf refrigeration kit (~ £15) will probably have only one Peltier module, as shown in Figure 3 on the following page. I have found that two modules work better to get the temperature below –20 °C. See Appendix for details of how I came to that conclusion.

  Surrounding each Peltier module with a thermal insulator, such as a felt coaster, reduces heat leaking in from the surrounding air and so allows them to reach a slightly lower temperature (Figures 4 – 6).

- *Make the cold plate black*

  Particle tracks show up better when illuminated against a black background, so if the cold plate is bare aluminium then either: (i) paint it black; (ii) apply a black sticker; or (iii) attach a black plate onto the cold plate (Figure 7).

- *Attach some legs to the bottom of the fan*

  To ensure unobstructed air flow through the fan and heatsink, lift the fan off the table top using whatever you have available. I used small pieces of Meccano™ with rubber caps over the feet to avoid scratching the table.

- *Connect the Peltier modules and fan to a power supply*

  For the two modules that I used, I found that a 8V / 6A / 50W supply was sufficient.

  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 haven't already got one, fixed-voltage power supplies are reasonably priced – for instance, a 9V / 6A power supply can be bought for ~ £10 – £15.

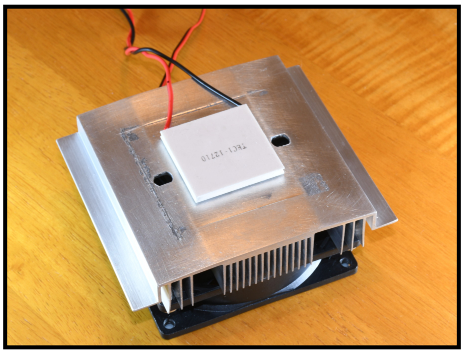


Figure 3
Peltier module on heatsink and fan (a refrigeration kit)

Use a thermal paste in between the Peltier module (white square) and the heatsink to ensure the best possible heat transfer across the surfaces in contact

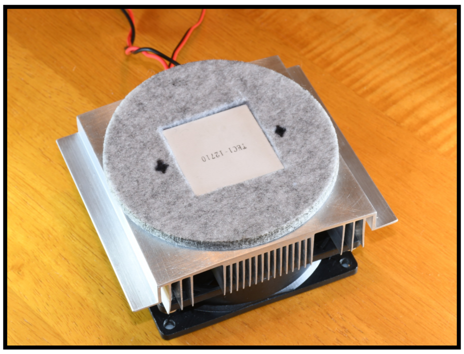


Figure 4
Peltier module surrounded by a felt coaster

A felt coaster with a square cut out of its centre can be placed over the Peltier module to provide good thermal insulation

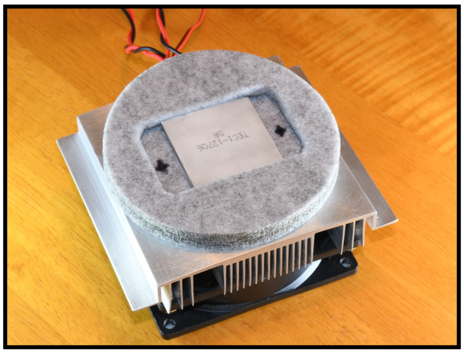


Figure 5
Second Peltier module stacked onto first

Use a thermal paste in between all surfaces in contact to ensure the best possible heat transfer from the cold plate to the heatsink

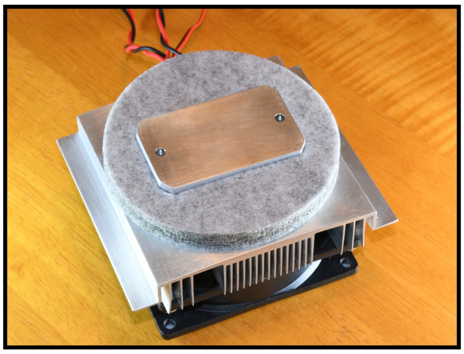


Figure 6
Aluminium cold plate

The cold plate keeps both the Peltier modules clamped in place and provides the 'source of cold' for the cloud chamber

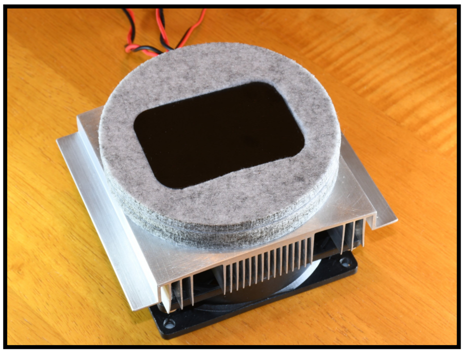


Figure 7
Black plate on cold plate

A black plate provides a dark background for the particle tracks to make them easier to see

Step 3 – Preparation

- *Place a sponge on the inside of the top of the jar*

  The size of the sponge is not important, but it should be enough to soak up a few ml (cc) of IPA. A circular cosmetic sponge with a diameter less than that of the jar and ~1 cm thick is ideal. If using a pickle jar, glue the sponge inside the base of the jar so that it is at the top when the jar is inverted. If using an open-ended glass cylinder then the sponge can be glued to the underside of a felt coaster and the coaster placed onto the top of the cylinder.

- *Pour/spray about 5 ml (5 cc) of IPA onto the sponge*

  The sponge should soak up the IPA. If it doesn't then either the sponge is too small or you have gone overboard with the IPA.

- *Place the jar onto the cold plate of the Peltier module*

  The air in the jar needs to be in good thermal contact with the cold plate to ensure that the IPA vapour gets cooled enough to condense into a liquid. If using a jar with a lid, some thermal paste between the lid and the cold plate will improve the transfer of heat, especially if the lid is not absolutely flat. Placing the jar onto the cold plate without the lid in place makes the heat transfer more efficient. Using an open-ended glass cylinder gives the same results as using a jar without its lid.

- *Place the USB mug-warming coaster onto the top of the jar*

  This will provide heat to the top of the jar and hence the IPA-soaked sponge inside. Only a modest level of warming to about 30 – 40 °C is required, but some USB coasters get quite hot (above 50 °C). Hence you can either: (i) keep the coaster the right way up so that the heat getting through to the *bottom* of the coaster warms the jar; or (ii) invert the coaster but use something to separate the hot surface of the coaster from the jar. I used a felt coaster 5 mm thick to do this.

  If your budget doesn't stretch to a USB mug-warming coaster (~ £ 10) then you can try carefully placing a cup of tea onto the top of the jar. It will probably provide all the heat required, but may need replacing with a fresh cup every once in a while. I call this the "Cuppa Cloud Chamber" option. Try it at your own risk.

Step 4 – Operation

• *Plug the Peltier cooling module(s) into a suitable power supply*

• *Plug the mug-warming coaster into a USB port*

The time taken for the cloud chamber to reach the optimal conditions for observing particle tracks will depend on the amount of IPA inside the jar and the temperatures at the top and bottom of the jar. As a rough guide, I found that ...

- Peltier modules will cool from room temperature to –20 °C in 5 minutes.
- The IPA-soaked sponge will warm from room temperature to 30 °C in 10 minutes.

• *Shine some light into the side of the jar*

A simple LED torch should be enough. Illuminate the inside of the jar from the side as viewed by the observer(s) or camera. When the IPA starts condensing a mist will appear to form at the bottom of the jar as tiny droplets of IPA drizzle down onto the cold plate. This should be visible after about 5 minutes.

• *Wait for cosmic rays*

If you can't see any particle tracks then you can never be quite sure whether the right conditions have not yet been reached or whether there are not many cosmic rays or other particles from background radiation passing through your cloud chamber. One way around this dilemma is to place a radioactive source close to, or inside, the cloud chamber. That's not as dramatic as it sounds, as radioactive sources can be acquired without putting you on any government watchlists ...

- Many naturally occurring minerals contain uranium, thorium or potassium and contribute to background radiation throughout the world.
- Some glass objects may have had a few % of uranium compounds added to give them a characteristic greenish colouration.
- Tungsten welding rods may have had a few % of thorium added to improve the quality of the welds.

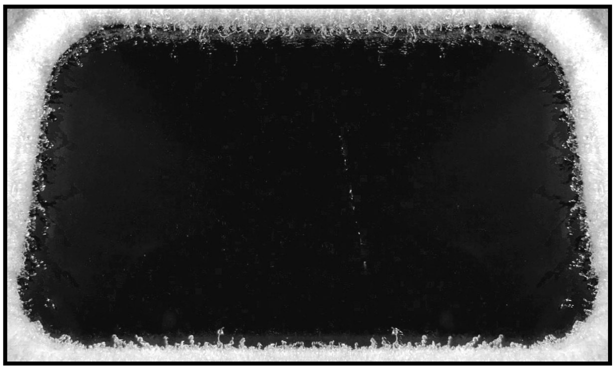
The radiation from any of these sources in close proximity will be more intense than the radiation from cosmic rays and so can be used to confirm whether or not the cloud chamber is working.

Step 5 – Seeing Particle Tracks

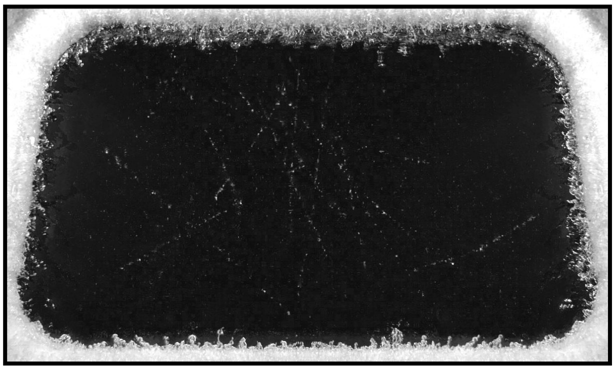
Cosmic Rays

Cosmic rays are high-energy particles that are continually raining down on the Earth, creating showers of sub-atomic particles as they pass through the upper atmosphere. The cloud chamber will show tracks from those particles that make it to sea level, including muons and electrons.

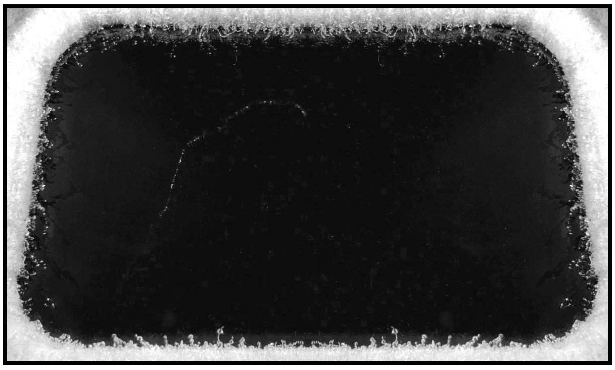
The following are either snapshots of single particle tracks or composite images of multiple tracks observed over an extended period of time (typically ~ hour). The composite images were made by manually selecting, extracting and superimposing dozens of still frames from a video.



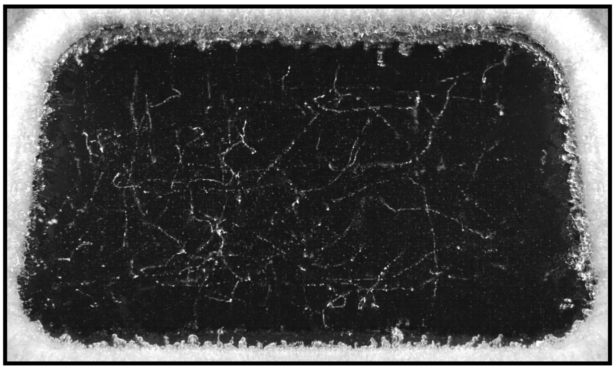
Single cosmic ray muon track



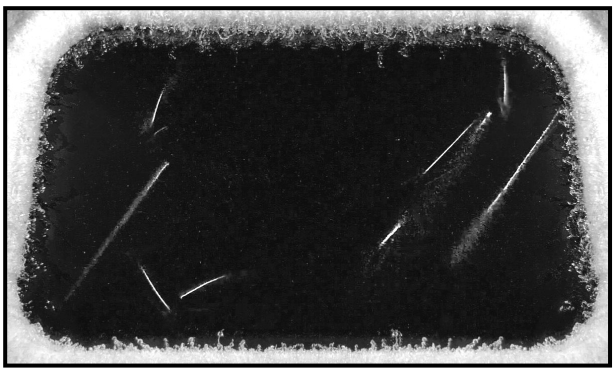
Multiple muon tracks



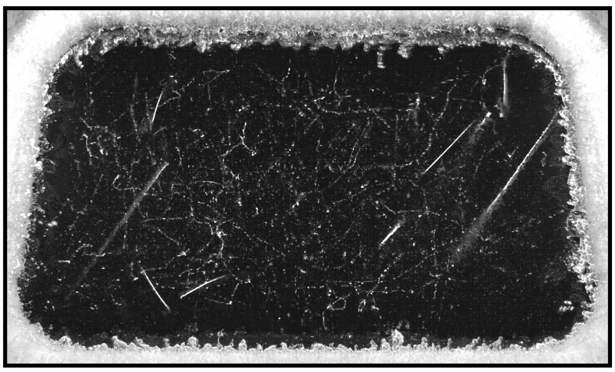
Single cosmic ray electron track



Multiple electron tracks



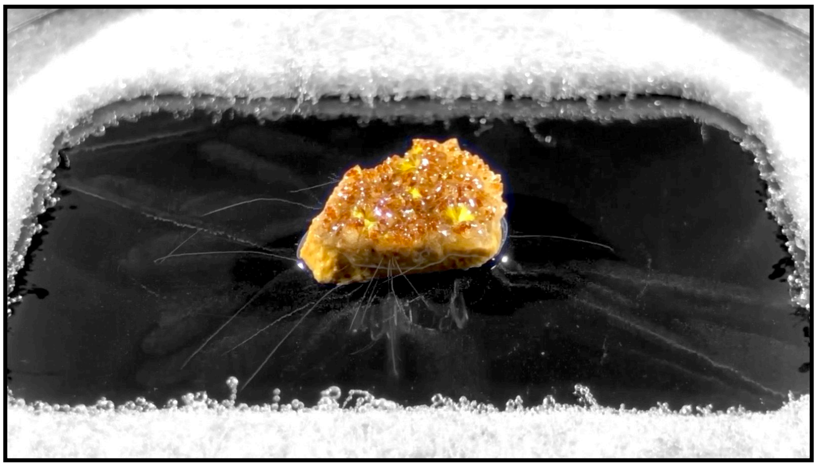
Multiple proton tracks



All cosmic rays

Terrestrial Radiation

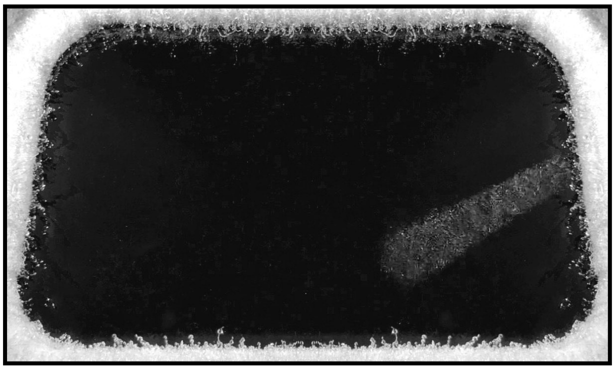
With a radioactive rock sample placed on the cold plate, tracks from alpha and beta radiation can clearly be observed.



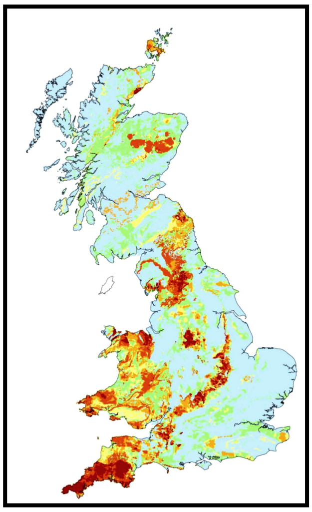
The image above shows a sample of the mineral boltwoodite that contains some uranium. The narrow tracks are beta particles (electrons) and the broader, more ghostly, tracks are alpha particles (nuclei of helium atoms). The image is a composite made from about 30 still frames extracted from a one-minute video.

Radon

Radon is a radioactive gas formed by the radioactive decay of the small amounts of uranium that occur naturally in all rocks and soils. Radon concentrations vary across the UK depending on the type of ground. For instance, radon levels are high in parts of the country rich in granite, such as Devon and Cornwall.



Single alpha particle track from radon gas



Radon map of the UK

Dr Steve Barrett
S.D.Barrett@liv.ac.uk

Building a
Cloud Chamber

Dr Steve Barrett

Technical Appendix

Documented here are some of the aspects of the early versions of the cloud chamber, some of which were superseded by improvements or refinements. They are listed here to help anyone thinking about developing their own designs. Don't reinvent the wheel.

Cooling the base of the cloud chamber with Peltier modules

Prototype #1 — Peltier module TC1-12706
This was the module that was a component of the B0C4HTD88D refrigeration kit bought from Amazon. It cooled the aluminium cold plate to **–10 °C**.

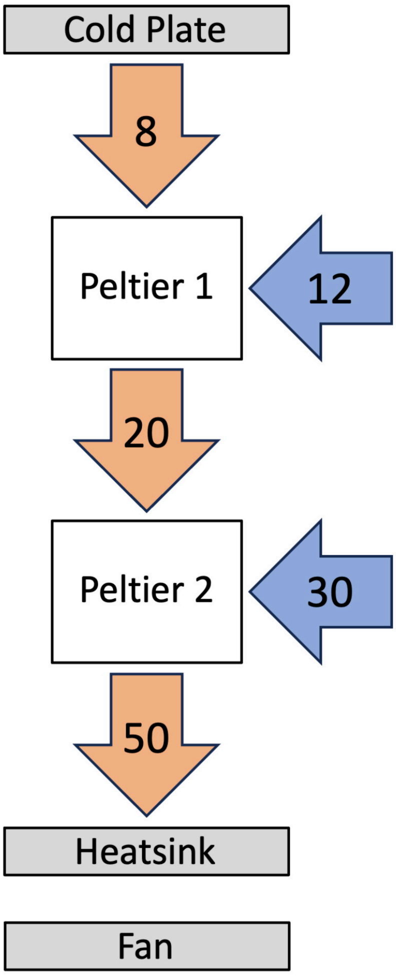
Prototype #2 — Peltier module TC1-12710
The 12706 module was swapped for this higher-power version to see if it would give a lower base temperature. Despite the higher power, it did not provide improved cooling of the cold plate as the hot side of the module got too hot for the heatsink to handle. For it to be effective it would need a much bigger heatsink and fan (which would make the cloud chamber bulkier and heavier).

Prototype #3 — Two Peltier modules 2 x TC1-12706 back-to-back
Wired in parallel, one module was used to cool the other. Again, this did not improve the cooling of the cold plate as the second module could not cope with all the heat generated by the first.

Prototype #4a — Two Peltier modules TC1-12706 + TC1-12710 back-to-back
The higher-power 12710 module was used to cool the 12706 module. The 12710 could handle the heat generated by the 12706. As a pair they cooled the aluminium cold plate to **–20 °C**.

Prototype #4b — Two Peltier modules TC1-12706 + TC1-12710 back-to-back
Adding a 1 Ω resistor in series with the 12706 module allowed the 12710 and the cooling fan to run at higher voltages, resulting in better cooling of the 12706. As a pair they cooled the aluminium cold plate to **–25 °C**.

For the final configuration of cloud chamber, the heat flow between the Peltier modules is shown schematically in Figure 8, and the electrical connections required for the Peltier modules to work at optimum levels are shown in Figure 9.



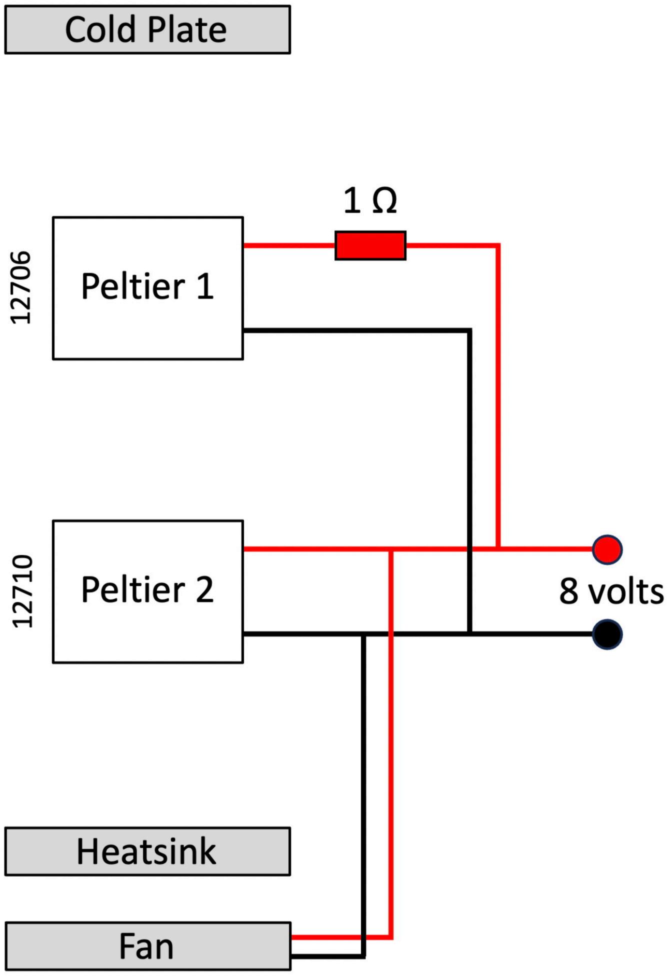


Figure 8
Heat flow (orange) between the cold plate and the heatsink and electrical power (blue) supplied to the Peltier modules. The numbers indicate the nominal power in Watts.

Figure 9
The electrical connections to the Peltier modules and the cooling fan. Peltier 1 draws ~2 A whereas Peltier 2 draws ~4 A. Peltier 2 needs substantially more power because it is pumping not only the 8 W drawn from the cold plate but also the 12 W of electrical power supplied to Peltier 1.

Choice of jars or cylinders for the body of the chamber

Choice #1 My first idea was to use a 600 ml pickle jar. They are cheap, readily available, about the right size and have a relatively wide throat. Glueing an IPA-soaked sponge into the base of the jar and then inverting the jar makes a workable cloud chamber, but the thermal mass of the thick jar base meant that it took a while for the heat to reach the sponge.

Choice #2 Replacing the glass jar with a smaller plastic jar with thinner walls reduced the thermal mass, making it easier to warm up the sponge glued to the base of the jar. The plastic was PET (polyethylene terephthalate) which is not affected by exposure to IPA.

Choice #3 To make it easier to access the IPA-soaked sponge I tried an open-ended acrylic cylinder. This allowed the sponge to be placed over the open top end, rather than glued to the inside of the jar. The sponge can be easily lifted off to replenish the IPA if and when necessary. Acrylic was chosen as it was cheap and relatively light, despite the fact that exposure to IPA could be problematic – acrylic plastics can craze or crack. If you use a chamber made from acrylic plastic then do not leave the IPA in the chamber after use – as soon as the demonstration is over open up the chamber, mop up the IPA that has condensed onto the cold plate and allow the residual IPA vapour to dissipate.

Choice #4 The final design uses a glass cylinder 100 mm in diameter and 100 mm high. They are sold as 'candle holders' or 'hurricane glass' and can be bought in various sizes. Glass is impervious to IPA and so there is no need for an immediate 'mop up' when the demonstration is over.