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Cloud chamber using Peltier cooling

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Abstract
The design of a simple, compact, inexpensive cloud chamber is described and examples of particle tracks from cosmic rays and a radioactive sample are shown. A temperature gradient is established in the chamber through the use of a simple heater at the top and Peltier modules at the base, eliminating the need for dry ice. Using a few millilitres of isopropyl alcohol it starts to show particle tracks a few minutes after being switched on and operates for over two hours without any intervention. The cloud chamber is constructed using components that can be readily obtained at a total cost of about £40.

Keywords: cloud chamber, cosmic rays, background radiation, radioactivity

1. Introduction

The benefits of using a cloud chamber to visualise sub-atomic charged particles, either from cosmic rays or from terrestrial radioactive sources, are well established. The relative merits of various types of cloud chambers, and in particular the pros and cons of using dry ice, have been discussed by White [1]. In this article I demonstrate that eliminating the use of dry ice does not mean that radioactive sources must be employed to see particle tracks. Background radiation, such as cosmic rays and alpha particles from radon, can be readily seen and imaged.

2. History

The impact of the Wilson cloud chamber on our understanding of the sub-atomic world has been profound [2]. It allowed scientists to visualise, identify and analyse the properties of different types of particles from either radioactive decay or from cosmic rays. For decades after its invention in 1911 the cloud chamber was instrumental in the discoveries of new particles such as the positron, muon and kaon. By the 1960s cloud chambers were superseded by bubble chambers and eventually electronic detectors. The legacy of the cloud chamber is succinctly captured by the quote of Ernest Rutherford: 'The most original and wonderful instrument in scientific history'.

3. Design

There are many existing designs of cloud chamber that purport to be simple and inexpensive, but they rely on the ready availability of dry ice. For some situations that may not be a problem, but with minimum purchases of up to £50 this can become prohibitively expensive when costed 'per demonstration'. Replacing dry ice with other cryogens can result in a lack of sensitivity to cosmic rays and the tracks from radioactive sources may be visible for only a limited time of ∼20 min (see [1] and references therein).

This cloud chamber (figure 1) is a distant cousin of Wilson's original invention and

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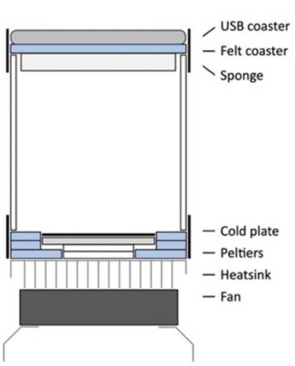

Figure 1. (Left) Schematic diagram of the cloud chamber. The blue-shaded rectangles are the felt coasters. The one at the top separates the USB-powered mug-warming coaster from the sponge holding the IPA. The multiple layers of coasters at the bottom help to thermally insulate the cold plate (black) and Peltier modules from the ambient warm air outside the chamber. (Right) The cloud chamber sits on four small Meccano™ pieces to lift the cooling fan off the table.

benefits from technology that was not available to Wilson—rather than using the expansion of gases to achieve the cooling effect necessary to condense vapour into liquid, or a cryogen such as dry ice, it uses semiconductor Peltier devices. By using Peltier cooling the limitations of cryogen-based designs can be circumvented. The most suitable alcohol for this type of cloud chamber is isopropyl alcohol (IPA, aka isopropanol) because liquid and vapour can exist at temperatures close to room temperature.

4. Components and construction

Providing a source of heat to evaporate the IPA is easy enough, as the temperature required is not much above room temperature. A USB-powered mug-warming coaster (∼£10) is an ideal size and provides just the right amount of heat to keep an IPA-soaked sponge at the top of the cloud chamber at a temperature above 30 °C–40 °C. Providing the cooling required to condense the IPA vapour back into a liquid is not quite so simple. The key to building this 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 provide a cold plate at −25 °C and also form 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 [3] the optimum size/shape was found to be a glass cylinder 10 cm in diameter and 10 cm tall. 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 a thermal gradient that creates IPA vapour at the top of the chamber and condenses 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, where the particle tracks become visible. The cheapest of the refrigeration kits do not get quite cold enough for the IPA to condense. It was found that two Peltier modules, stacked back-to-back, can get the temperature below −20 °C, the base temperature required for effective operation of the cloud chamber. Multi-stage cooling employing more than two Peltier modules would result in even lower base temperatures, but at the expense of added complexity in both the physical construction and in the electrical requirement to power each module with sufficient current to handle the heat load from the other modules in the stack. Two-stage Peltier cooling can achieve base temperatures below −25 °C and so additional Peltier modules are unnecessary. Figure 2 shows how the two-Peltier refrigeration platform is built up step by step.

5. Operation

The principal advantage of this cloud chamber over many other designs is the simplicity and speed of its preparation and operation.

5.1. Preparation

The preparation of the cloud chamber prior to its operation is minimal and takes only a minute: (i) add 5 ml of IPA to the sponge in the top of the chamber; (ii) connect the USB-powered coaster to a USB power supply; (iii) connect the Peltier modules to an 8 V/6 A power supply.

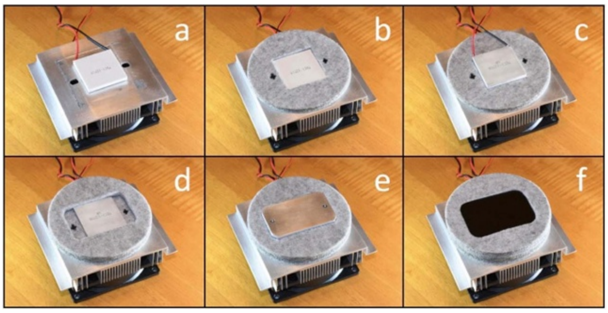

Figure 2. Building up the refrigeration platform. (a) An off-the-shelf refrigeration kit comprising a Peltier module, a heatsink and a fan. (b) A felt coaster with a square cut out of its centre placed over the Peltier module. (c) An additional Peltier module stacked onto the first (see the technical appendix of [3] for details). (d) A second coaster with a rectangular cutout to accommodate the cold plate. (e) An aluminium cold plate keeps both Peltier modules clamped in place. (f) A black plate provides a dark background for the particle tracks to make them easier to see.

5.2. Running

After being switched on it takes only a few minutes for the IPA drizzle to form and for particle tracks to appear. It has been found that 5 ml of IPA gives operational run times of 2–3 h without any intervention, sufficient for a science lesson or for an outreach talk and demonstration. In a test run with 15 ml of IPA on the sponge, the cloud chamber showed tracks continuously for 6 h. Opening up the chamber to insert/remove a radioactive sample will disturb the IPA inside, but it should settle within a minute or two and tracks should quickly re-appear.

6. Seeing particle tracks

Cosmic rays pass through the cloud chamber and leave visible tracks every second or so. A simple torch should be enough to allow particle tracks to be seen—illuminate the inside of the chamber from the side as viewed by the observer(s) or camera. Figure 3 shows a composite image of the various types of cosmic ray tracks that can be identified: muons, electrons and protons. The appearance of the tracks depends 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 and so their tracks tend to appear more straggly than the straight tracks of muons or protons.

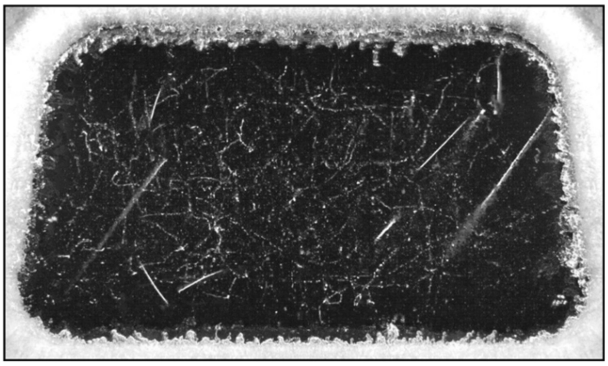

Figure 3. A composite image of hundreds of cosmic ray tracks. Electrons, muons and protons can be distinguished by the appearance of their tracks. Typically, tracks are visible at a rate of about one per second.

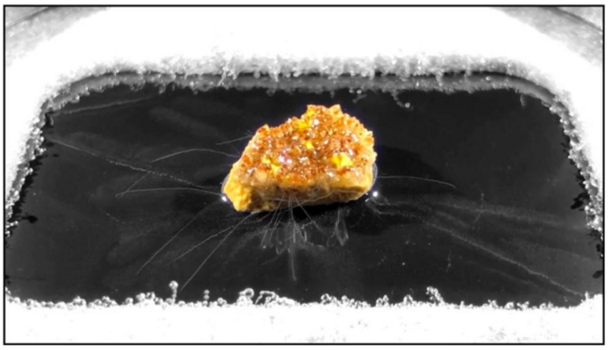

Figure 4. A composite image of alpha and beta particles emitted from a sample of boltwoodite, a mineral containing some uranium, over a period of about a minute.

In addition to cosmic rays, tracks from alpha particles may be seen. These have four times the mass and twice the electrical charge of a proton and so produce very broad tracks. Alpha radiation is emitted by the radioactive gas radon which is 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 South West.

Figure 4 shows alpha and beta particle tracks from a radioactive mineral sample placed onto the cloud chamber's cold plate.

7. Conclusion

A distant cousin of Wilson's first cloud chamber, this design is simple, 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.

Data availability statement

No new data were created or analysed in this study.

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[3] Barrett S D 2024 Details of the design and construction of the cloud chamber, including a technical appendix that describes prototypes that preceded the final design (available at: www.liverpool.ac.uk/~sdb/Astro/BCC-PhysEduc.pdf)

Steve Barrett is a Senior Research Fellow in the Department of Physics at the University of Liverpool. He has given hundreds of STEM outreach talks to schools, societies and special interest groups.