A sensitive cloud chamber without radioactive sources

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Abstract

We present a sensitive diffusion cloud chamber which does not require any radioactive sources. A major difference from commonly used chambers is the use of a heat sink as its bottom plate. The result of a performance test of the chamber is given.

Introduction

In most countries, learning the microscopic origin of nature is considered to be an important topic in science education. However, there are not many student experiments or demonstrations that exhibit the existence of individual atoms in a direct and intuitive manner. The cloud chamber experiment is a rare exception; it provides the most direct and intuitive way to convince students of the existence of microscopic particles. The beautiful tracks of the particles draw the audience’s attention and interest. Various chambers have been developed and used in the classroom [1]. Most of the simple chambers seem to be based on the results of Needles and Nielsen [2] and Cowan [3], which use a block of dry ice and a beaker filled with ethanol vapour. The great simplicity of such a chamber enables students to make a DIY chamber at home or in the classroom. This type of chamber works well if one uses a radioactive source.

Since spring 2008, one of the authors (SZ) has been working on a classroom experiment programme using a cloud chamber. The programme provides a one-day experimental course for local junior high school students. In spring 2011, some students (the rest of the authors) joined this project as part of a Super Science High School (SSH) activity. The setup of a typical chamber is shown in figure 1. A chamber is not so large; the smallest example is a glass laboratory dish with radius 5 cm and height 1 cm. The standard chamber we have used is a round glass container with radius 8.5 cm and 8.0 cm height [4]. Such chambers require a radioactive source. It is very hard to find particle tracks of background radiation in this kind of chamber. One will find a few tracks in a minute only in a very dark room.

In Japan, people’s awareness of radioactivity has increased greatly since the Fukushima Daiichi nuclear disaster following the Tohoku earthquake and tsunami on 11 March 2011. A large part of the public unease or fear about radioactivity...
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The construction of a cloud chamber

The construction of our cloud chamber is shown in figure 2. A major difference from commonly used chambers is the use of a black anodized aluminum heat sink as a bottom plate instead of a metal plate. It has dimensions of 134 mm × 134 mm × 20 mm, a weight of 622 g, and the side with the fins is placed so that they are oriented downward. As we show later, the heat sink greatly improves the performance of our chamber. Our method has an additional advantage in that the heat sink plays the role of a supporting base for the chamber, which prevents direct contact of the side wall with the refrigerant. Clear walls without a bottom and a top are placed on the heat sink. The walls and top are made of square, 5 mm thick acrylic plates. The top plate is removable. A piece of black felt E is placed along three sides of the box. The upper half of it is soaked with ethanol. The total amount of ethanol is about 10 g for each experiment. Light from a PC projector is introduced through a face without a piece of black felt. All of the above instruments are placed on a shallow styrofoam tray B. Liquid nitrogen can be directly poured into this box to this tray. Powdered dry ice can also be used. In this case, a heat sink is placed above the powdered dry ice. In the placement mentioned above, tracks of particles can be observed from above. Figure 3 is a photograph of our cloud chamber in operation. The PC projector is slanted to obtain a fine view of the particle tracks.

In closing this section, we would like to mention that our result is not new. An advantage of our chamber is its good performance in spite of its smallness and simplicity. In fact, various examples of sensitive chambers have been known in Japan. Very large and expensive chambers for display are available in some science museums [4]. A glass chamber presented in the beginning of this section is also available as a product from Rado Ltd [4]. The use of a small heat sink with liquid nitrogen was first presented in [5]. Another example of a sensitive chamber is given in [6].
Operation

Surprisingly, the very simple construction presented in the section 'The construction of a cloud chamber' is enough to see many particle tracks without any radioactive sources. An external electric field is also unnecessary. Next, we describe the operation of the cloud chamber. To begin with, liquid nitrogen was poured into the styrofoam box. Our laboratory was at room temperature, so the temperature of the bottom heat sink rose as the liquid nitrogen evaporated. During the observation, this change in temperature was measured by a thermocouple. The result is shown in figure 4. The obtained data fit well to a quadratic curve.

Particle tracks begin to appear after a few minutes. Here we present our result with a video [7] uploaded to YouTube. Figure 5 is an image captured from the video. Most thin and wiggly tracks, such as in the left picture of figure 5 frequently seen in the chamber, can be considered as those of beta particles. We can see long tracks since the bottom plate is cooled uniformly. Some of the long tracks are slightly curved even though no external magnetic field is imposed. This may be due to multiple collisions with atoms in the air. An alpha particle can also be observed as a short, thick line such as in the right picture in figure 5. One can see that many droplets are formed along a track and fall down towards the bottom of the chamber.

Although many tracks are seen in the video, there should be no influence from the Fukushima Daiichi nuclear disaster, since our city (Yokote, Akita, Japan) has not experienced an apparent rise of the air dose rate since 11th March\textsuperscript{1}.

Obtaining a high-quality video is important both for scientific analysis and publication on the web. The latter is especially important for education, since lower-quality videos found on the web are not sufficient to show the beauty and excitement that people must feel in this experiment. We find that a digital SLR camera (in our case, an EOS kiss X3) is very useful for this purpose. It has a larger CCD and a better lens for high-quality video recording. In our experiment,

\textsuperscript{1} If we do a similar experiment in Fukushima where the air dose rate is still high, more tracks will be observed. A video [8] uses soil brought from three places near the Fukushima Daiichi power plant.

![Figure 4. Change of temperature of the bottom heat sink.](image1.png)

![Figure 5. Particle tracks seen in the chamber. (A) A thin, long track and (B) an alpha particle track. Black and white are converted.](image2.png)
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the camera is placed directly on the top plate as in figure 6, but use of something more rigid is better if available.

Performance evaluation
A qualitative evaluation of the performance of the chamber will be useful for the development of a new cloud chamber and to find better working conditions. In fact, some test runs show that the numbers of particle tracks seems to differ for each run. Using a recorded video [7], we counted all of the tracks seen in the chamber regardless of their length, width and shape. Therefore, alpha particles, beta particles and other particles are not distinguished. Figure 7 shows the relation between the count per 10 s and the elapsed time. We observe that, although the fluctuation is large, the count is independent of the bottom temperature until it reaches a ‘critical’ value.

Our observation shows that the fall of the count begins at around \( -25 \, ^\circ C \). While the number of particle tracks does not change below the critical temperature, the number of background droplets affects the visibility of the particle tracks. Many droplets are seen at lower temperatures, as shown in the left of figure 8. The contrast of the whole image is reduced at such low temperatures. We also found that alpha particle tracks become thinner at lower temperatures, as mentioned in [9]. On the other hand, it becomes hard to identify particle tracks at high temperatures. Therefore, the best temperature range for observation should be the middle region in figure 7.

Perspective
We expect that our cloud chamber will be useful for various educational applications; for

Figure 6. A digital SLR camera mounted on the top of the cloud chamber.

Figure 7. Number of particle tracks per 10 seconds.

Figure 8. Photos of condensed droplets in the chamber. From the left, the bottom temperatures are \(-51\), \(-35\) and \(-26\, ^\circ C \) respectively. Black and white are converted.
example, a student research project or public demonstrations. In particular, it will be important to measure the numbers of particle tracks in a city where the dose rate is still high. Also not examined in this paper, the high-quality video enables the use of various computer analysis techniques, such as qualitative evaluation of the amount of condensation or automatic counting of particle tracks. This kind of analysis will be useful for student research projects.

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