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Optimizing Particle Visualization in the Classroom: Design, Construction, and Evaluation of Cloud Chambers and Their Use with a Cathode Ray Tube.

The cloud chamber is a relatively simple and highly effective instrument for particle detection widely used in particle physics experiments in the 20th century. It can be constructed with simple materials and therefore, cloud chambers are increasingly being incorporated into high school and early university classrooms for their educational potential[1]. However, our experience has shown that it is not easy to construct a cloud chamber that allows clear visualization of particle tracks. The particles that are usually observed are either from ambient radiation[2,3]or radioactive samples[4,5]. Both cases are very enriching, but there is no control over the particles interacting in the case of natural radiation, and on the other hand, artificial radiation sources pose logistical problems. In this work, we experimented with a more accessible source, the cathode ray tube. This device was present in household televisions until a few years ago and is still present in most laboratories. Thus, the objective of this article has been to construct several cloud chambers, analyzing the temperature gradient as a variable for visualizing ambient radiation particles. Finally, experiments were conducted using the cathode ray tube as a particle source. This entire process has allowed us to identify specific conditions for optimal observation of natural radiation particles.

Design and Construction of Cloud Chamber Models

Cloud chambers are currently being designed for educational use, utilizing Peltier cells[3,6]. It requires specific materials and construction time that teachers do not always have[7].The cloud chambers we constructed in this work are based on the designs proposed by CERN[8], whose cooling method uses dry ice (solid CO_2), a material that is currently easily accessible for teachers[9]. Considering the research objective, we designed five different cloud chambers with the following dimensions in width, length, and height, given in cm: A: 13x23x15; B: 20x35x15; C: 18x31x24; D: 25x40x28; E: 21x40x25 and finally the A and B chambers were selected. Therefore, from now on, we focus solely on these two models.

The materials used and the way to building the chambers were: a container for dry ice, a metal plate (we used a 1.5 mm thick steel sheet with a density of 8240 kg/m^3), and a transparent container (we used glass fish tanks), felt, weatherstripping, 99% pure isopropanol, and dry ice. The chamber container can be made of glass or plastic, although if using plastic (including acrylic), this material becomes opaque with use due to interaction with isopropanol. To attach the felt to the bottom of the glass container, we recommend using epoxy adhesive. To ensure the chamber is closed in a watertight compartment, we recommend using weatherstripping, which can be glued to the edges of the cloud chamber. We also applied matte black tape to minimize reflections when illuminating. We placed the dry ice in the container, placed the metal plate on top and exerted pressure on it to ensure maximum contact between the dry ice and the metal plate. One way to verify that this step is being done correctly is the loud sound emitted due to the Leidenfrost effect on the dry ice. A layer of vapor was formed due to the sublimation of the dry ice upon contact with the metal plate at a much higher temperature[10]. This layer of vapor moves when the metal plate is pressed against the dry ice, causing pressure changes and the emission of a loud sound due to the Bernoulli effect[11]. Then, the felt is soaked with isopropanol. Once this is done, we flip the cloud chamber and place it over the metal plate (Fig. 1).

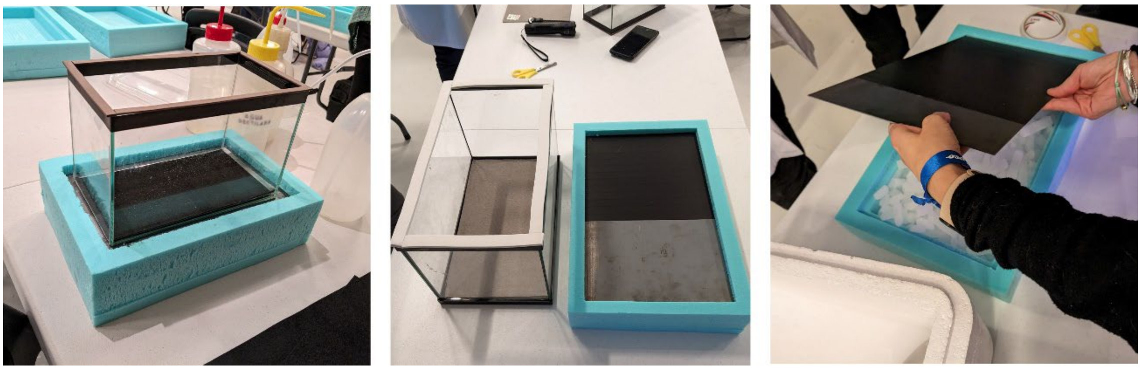

Figure 1. On the left, Chamber A. In the center, Chamber B, and on the right, placement of the metal plate.

Temperature Gradients and Their Influence on Track Visualization

The same cloud chambers used on different occasions do not always function in the same way, so several variables have been analyzed. It has been identified if the ambient temperature exceeds 23 ºC (common in a poorly ventilated classroom with many students), fog formation does not always occur. This is due to the external influence on the internal temperature of the cloud chambers. Although much has been published about cloud chambers, internal temperature values of such chambers are rarely found. Therefore, we measured the temperature inside the cloud chambers using an Arduino board and several DS18B20 temperature sensors (with a range of -55 ºC/125 ºC and sensitivity of ±0.5 ºC). A program was written to collect temperature measurements over time at different distances on the board: 0 cm (in contact), 4 cm and 10 cm. Data were collected until isopropanol condensed and no tracks were observed (Fig. 2).

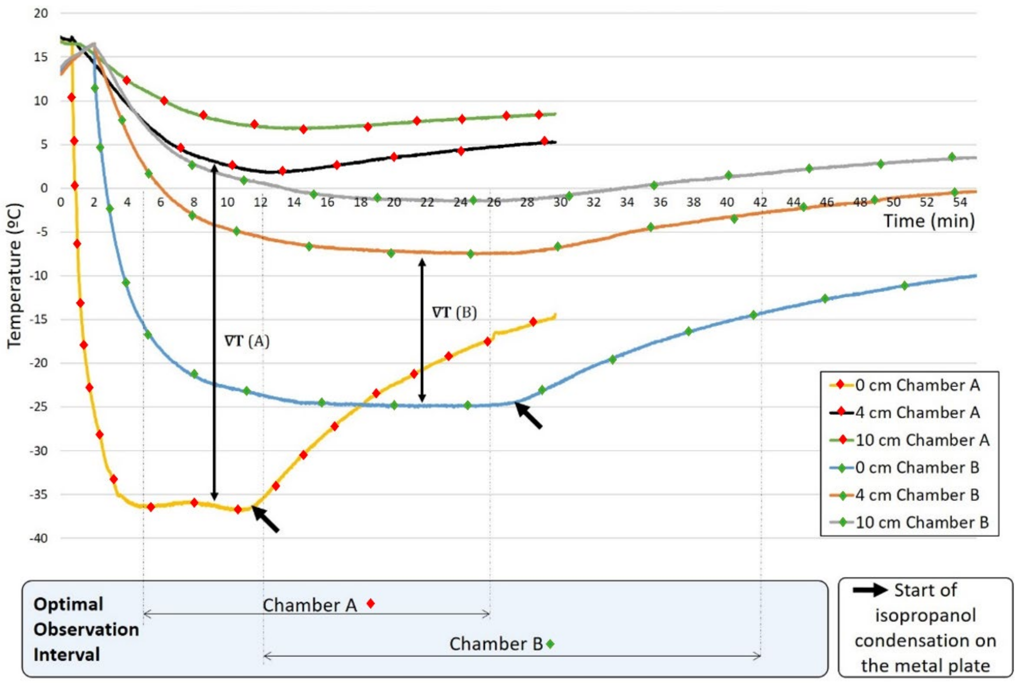

Figure 2. Temperature at different heights over time in Chambers A and B.

The optimal moment for particle observation is indicated with a black arrow. Differences such as in chamber A, the temperature decreased more rapidly and to a lower value were observed. However, in chamber A, the alcohol began to condense earlier, causing the temperature to start increasing earlier. In chamber B, the alcohol took longer to begin condensing, resulting in the minimum temperature being maintained longer. We used the same sensors, placed exactly the same way and took different measurements. The reasons for these differences may be the metal plate of the chamber B has to cool a greater volume of air above it, which in turn is in contact with a greater surface area of ambient temperature glass around it. Another reason may be that the surface area of the metal plate outside the glass container and in contact with ambient air is larger in the case of chamber B than in chamber A. In both chambers, a margin of approximately 1.5 cm was left between the glass container and the metal plate, resulting in a larger surface area in contact with the outside air in chamber B. On the other hand, the reason why the minimum temperature in chamber B is maintained longer is because the alcohol takes longer to condense in that chamber due to having a larger volume of air inside it.

Additionally, a measurement of the temperature variation was taken in chamber A (Fig. 3).

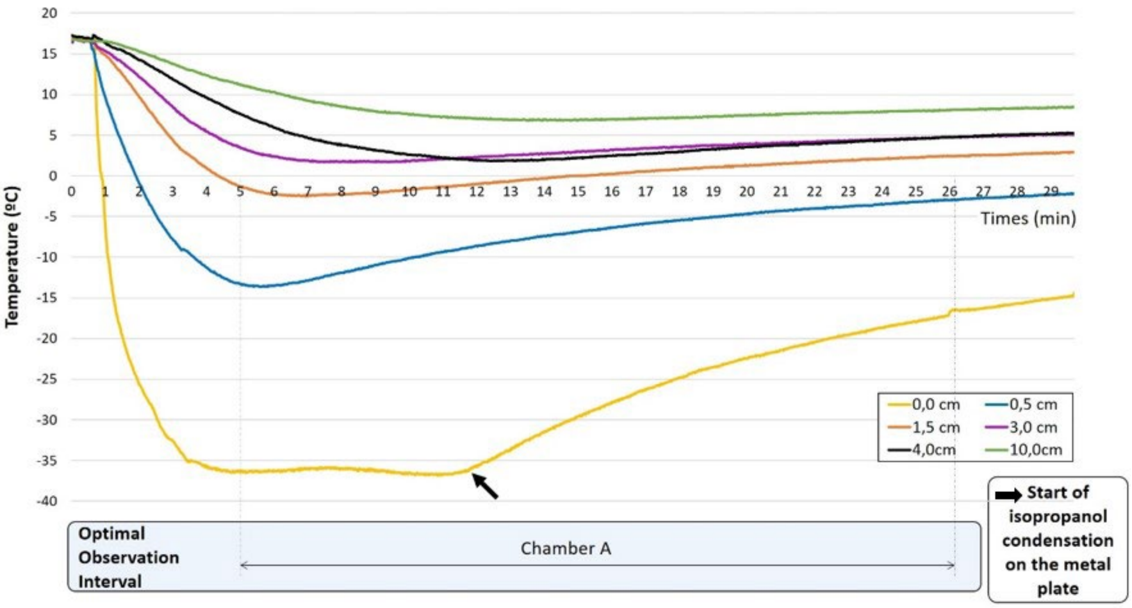

Figure 3. Temperature at different heights over time in Chamber A.

The temperature of the plate dropped in just 2 minutes and the tracks began to appear with total clarity 3 minutes later. However, after about 7 minutes, the isopropanol started to condense on the plate and, gradually, the sharpness of the tracks worsened. From 26 minutes onwards, the tracks were seen with some difficulty. We have also represented the temperature differences between different heights (Fig. 4) and the gradient along time (Fig. 5).

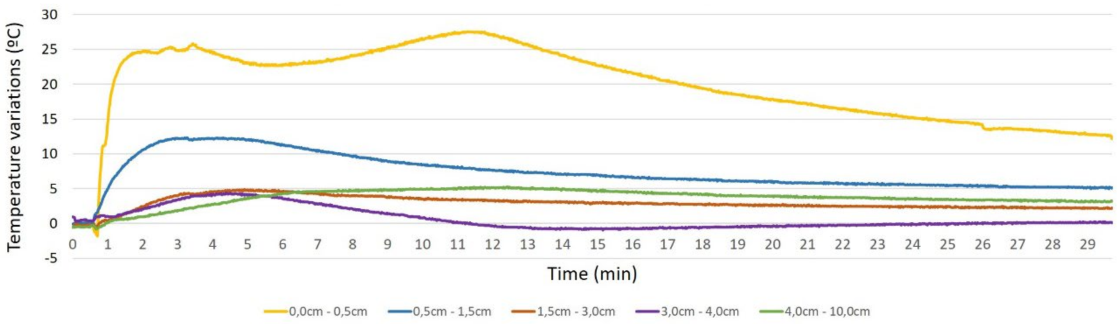

Figure 4.Temperature variations between different heights over time in Chamber A.

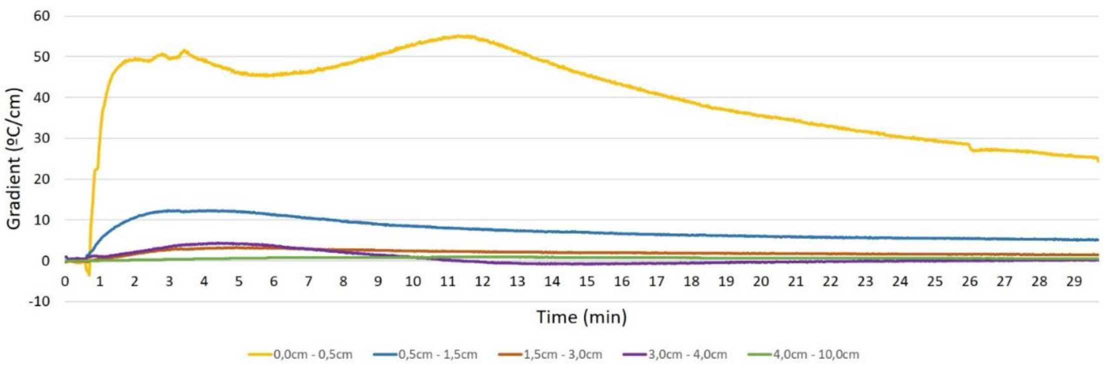

Figure 5. Gradient versus time in Chamber A.

The largest temperature differences occur up to 0.5 cm, reaching a maximum difference of 27 ºC. It is also observed that, from 3.0 cm above the plate, the temperature variation is much lower (or nonexistent at times). The temperature differences between 4.0 cm and 10.0 cm are small despite the significantly different heights. All this means that the most pronounced temperature variation is in the first centimeters above the metal plate. In Figure 6, captures of some tracks in both chambers are shown. These images correspond to frames from the multiple videos recorded[11].

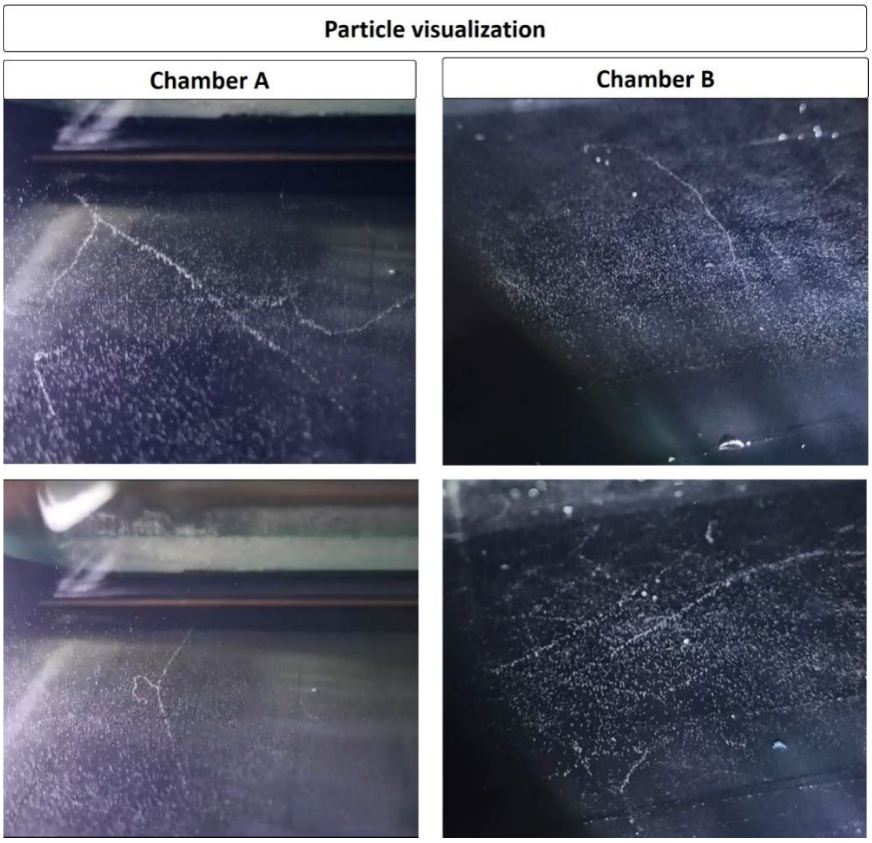

Figure 6. Particle tracks observed in Chamber A and B.

According to the provided facts, the usefulness of one or the other cloud chamber will depend on the educational objective that is proposed. If the goal is for students to observe tracks and identify some particles in a relatively short time, we recommend using the small cloud chamber (A). The drawback is that its surface area is smaller, so the probability of detecting different particles will be lower (for example, muons could only be identified if they crossed the chamber longitudinally). On the other hand, if the objective is to gather observation data to identify the highest possible number of different particles, we recommend the large cloud chamber (B). In this chamber, the surface area is larger, so probabilistically more particles will be observed, and at the same time, the optimal observation time interval is greater.

Use of the cathode ray tube

The cathode ray tube allows the generation and focus of electrons, making it a safe and accessible source for classroom use. To verify this, we positioned the cathode ray tube approximately to 5 cm from the side of the cloud chamber. Figure 7 shows a photograph of the cathode ray tube used, and Figure 8 displays screenshots of the recorded sequence[11].

Figure 7. Cathode ray tube used.

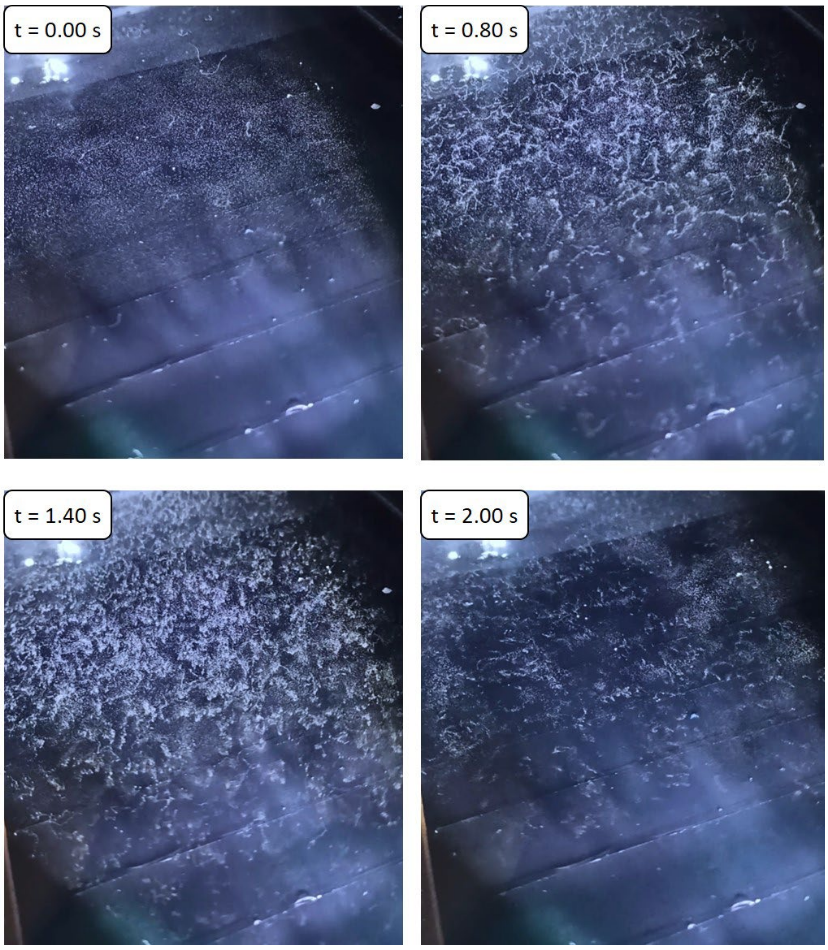

Figure 8. Sequence of enlarged frames showing the tracks of electrons generated with the cathode ray tube in the cloud chamber.

It can be observed the hundreds of tracks generated by the electrons from the cathode ray tube. The characteristics of the tracks are very similar to each other and match the tracks of low energy electrons that change direction upon interacting with isopropanol molecules.

This experiment allowed us to make different modifications to test the penetrating power of the electrons. We introduced various barriers between the cathode ray tube and the cloud chamber: a sheet of paper, a 1.0 mm thick felt sheet, a 1.5 mm thick steel plate. It is observed that, with the paper sheet and the felt, electrons continued to passed through (although fewer in the case of the felt), but the electrons were blocked by the steel plate (Fig. 9).

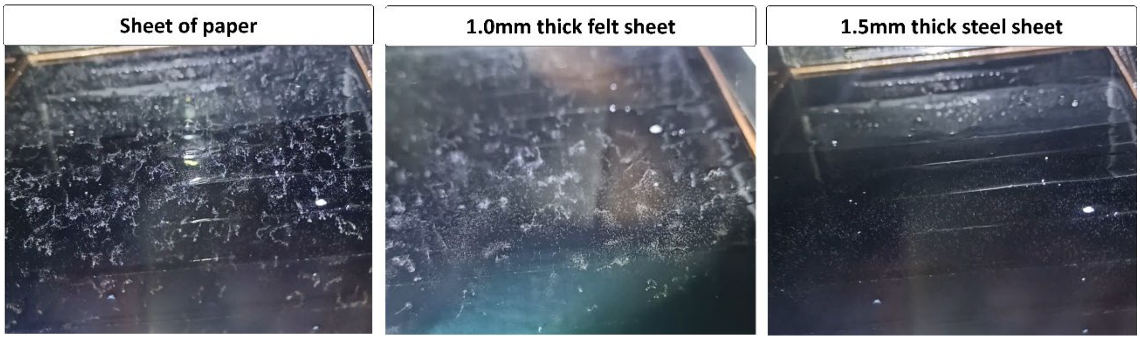

Figure 9. Tests with different barriers between the cathode ray tube and the cloud chamber.

Conclusions and teach impact

It was identified that the size of the chambers influences the internal temperature gradient and also the observation of tracks. Thus, the election of the chamber should depend on the intention of the teacher. We recommend using the small cloud chamber for activities with a large number of students, as it is possible to construct several small cloud chambers as opposed to one large one. The time until visualization is shorter and also the materials need, although they are also observed for a shorter period and the observation surface is smaller, making it more difficult to identify longer tracks (such as those of some muons). In this regard, we recommend using the large cloud chamber for longer sessions and also for small groups of students. It was also found that traces are optimally displayed where the temperature gradient was lower.

The article also concludes with the possibility of visualizing particles generated with a cathode ray tube which able to manipulate the particles penetrating the cloud chamber. It opens up the possibility of conducting other types of experiments, such as the experimental (and visual) verification of the different forms of interaction between electrons and matter.

Acknowledgements

The authors would like to thank to the students of the Clara Campoamor Institute in Zaragoza (Spain) for their participation. We also thank to the FECYT project FCT-23-19348: “Aulia. Aulas en residencia en los laboratorios de innovación abierta CESAR de la Universidad de Zaragoza“ and to the BEAGLE group of the DGA and the IUCA research institute, both from the University of Zaragoza.

1. A. F. Andrade, L. W. Souza, A. P. Perini, and L. P. Neves, “A thermoelectric cloud chamber: I. Redesign and operation”, *European Journal of Physics*. **45**(2), 025703 (2024).
2. M. Geske, C. Murray-Weston, and G. Lelack, “Measuring Atmospheric Radon Levels Using a Cloud Chamber”, *The Physics Teacher*. **60**(6), 498-500 (2022).
3. M. Akiyoshi, “Practical use of the Peltier-cooling-type high performance cloud chamber in radiological education”, *Nippon Hoshasen Anzen Kanri Gakkai-Shi*. **16**(2), 72-78 (2017). http://dx.doi.org/10.11269/jjrsm.16.72
4. L. W. Souza, A. P. Perini, and L. P. Neves, “A thermoelectric cloud chamber: II. Contributions to medical physics education”, *European Journal of Physics*. **45**(2), 025702 (2024).
5. M. Akiyoshi, “Component engineering for manufacturing the Peltier-cooling-type high performance cloud chamber”, *Nippon Hoshasen Anzen Kanri Gakkai-Shi*. **16**(2), 79-84 (2017). http://dx.doi.org/10.11269/jjrsm.16.79
6. L. A. Duc, N. M. Duy, T. N. Chat, and N. N. Hung, “Improving the Wilson cloud chamber using Peltier chips”, The Physics Teacher. **60**(1), 62-65 (2022).

7. F. V. Akuma, and R. Callaghan, "A systematic review characterizing and clarifying intrinsic teaching challenges linked to inquiry-based practical work", *Journal of Research in Science Teaching.* **56**(5), 619-648 (2019).
8. F. Barradas-Solas, and P. Alameda-Meléndez, "Bringing particle physics to life: build your own cloud chamber",*Science in School*.**14**, 36-40 (2010).
9. T. S. Kuntzleman, N. Ford, J. H. No, and M. E. Ott, "A molecular explanation of how the fog is produced when dry ice is placed in water", *Journal of Chemical Education.***92**(4), 643-648 (2015).
10. A. S. Purandare, C. Cuartas-Vélez, N. Smeman, M. Schremb, N. Bosschaart, and S. Vanapalli, "Experimental and theoretical investigation of the Leidenfrost dynamics of solid carbon dioxide discs sublimating on a solid substrate", *International Journal of Heat and Mass Transfer.* **224**, 125300 (2024).
11. Supplementary material.