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Original Paper

Radiation Observation Instruments Based on the Peltier Effect

Yiya Liu

Chengdu Tianfu Middle School, China

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Abstract

Ionising radiation consists of three types of radiation, alpha beta gamma, which are invisible to the naked eye. In order to observe ionising radiation with the naked eye, the Wilson cloud chamber was invented. The operation of Wilson cloud chamber requires the use of a disposable cold source such as dry ice, which has the disadvantage of short operating time and releasing a large amount of greenhouse gases. The semiconductor cooling chip is a solid-state thermoelectric device using the Peltier effect, which does not release any greenhouse gases during the working process. This paper explores the design and fabrication of an all-solid-state-cooled Wilson cloud chamber based on the working principle of semiconductor refrigeration discs, and fabricates an engineering prototype by means of 3D printing-based technology.

Keywords

Cloud chamber, Palladium effect, 3D printing

1. Introduction to the Background and Composition of the Study

The cloud chamber, also known as the Wilson cloud chamber, was invented by Wilson in the early nineteenth century as a particle observation device to visualise ionising radiation. It is a sealed environment filled with supersaturated water or alcohol vapour. In the cloud chamber, charged particles such as alpha or beta interact with the gas mixture through electrostatic forces generated by collisions, allowing electrons to detach from the gas molecules and producing orbital traces of ionised gas particles. At sufficiently low temperatures, a visible mist of droplets forms around the resulting particles in a "cloud" of trajectories. By comparing the differences in the orbitals and the characteristic shapes, alpha and beta particles can be distinguished (Gupta & Ghosh, 1946; Wilson, 2014).

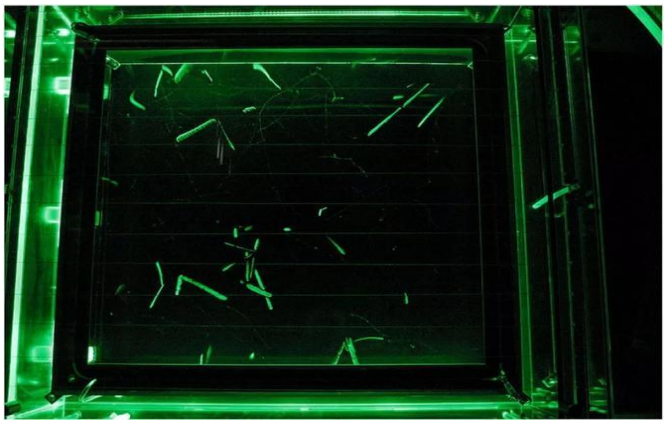


Figure 1. Schematic Diagram of the Ionisation Path

Source: http://m.ihep.cas.cn/kpdt/201811/ t20181121_5190613.html

The cloud chamber consists of the following main components: dry ice, a metal plate (aluminium), and a sealed vapour of supersaturated water or alcohol. For this traditional Wilson cloud chamber, the dry ice refrigeration is very short-lived, lasting only about ten minutes, and requires the use of 300 grams of dry ice per refrigeration session, all of which will sublimate into the atmosphere causing the release of 300 grams of carbon dioxide gas.

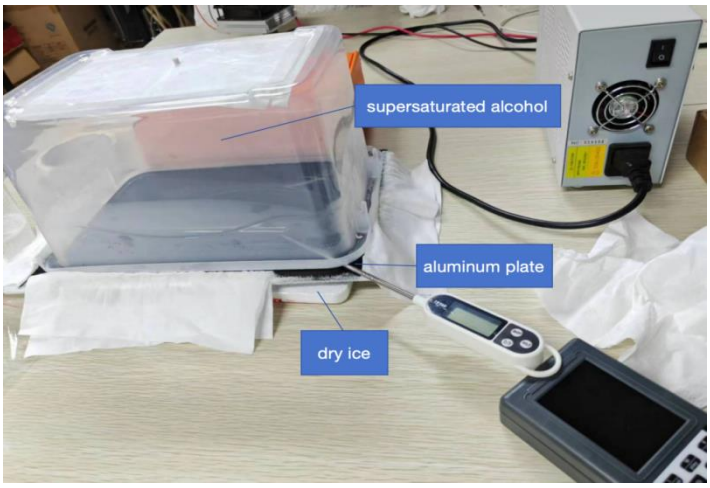


Figure 2. Traditional Cloud Chamber

The Palladium effect is the phenomenon of heat absorption or heat release observed at the joints of two different conductors when a current is passed through their circuits. This phenomenon is due to the transfer of energy from the current formed by the movement of charge carriers in the conductors to charge carriers at different energy levels in different materials. This effect is reversible, so that when the direction of the current is changed, the heat absorption and exothermic phenomena are also changed.

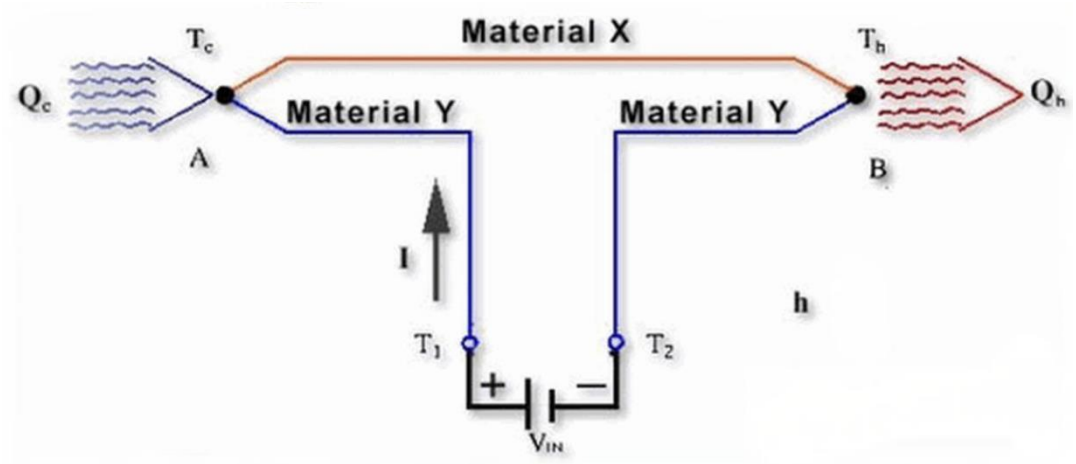


Figure 3. Operating Schematic of a Semiconductor Refrigeration Wafer

Source: https://bbs.instrument.com.cn/topic/3289365?UID=anping&sortby=asc

The semiconductor refrigeration chip, also called thermoelectric refrigeration chip, is a heat pump. It has the advantage of having no moving parts and is used in applications where space is limited, reliability is required and there is no refrigerant contamination. The use of semiconductor materials, the Peltier effect, when the DC current through two different semiconductor materials connected in series into the electric coupling, the two ends of the electric coupling can be respectively absorbed heat and heat release, to achieve the purpose of refrigeration. In this experiment, the semiconductor refrigeration disc replaces the role of dry ice, so the device will not cause pollution, but also has a higher reliability.

Figure 4. Semiconductor Refrigeration Discs Used in the Experiment

2. Design and Experimentation

In order to simulate the placement of components in real space, fusion 360 software was used for modelling fusion 360 is a design software application developed by Autodesk. I will use this application to design a suitable model.

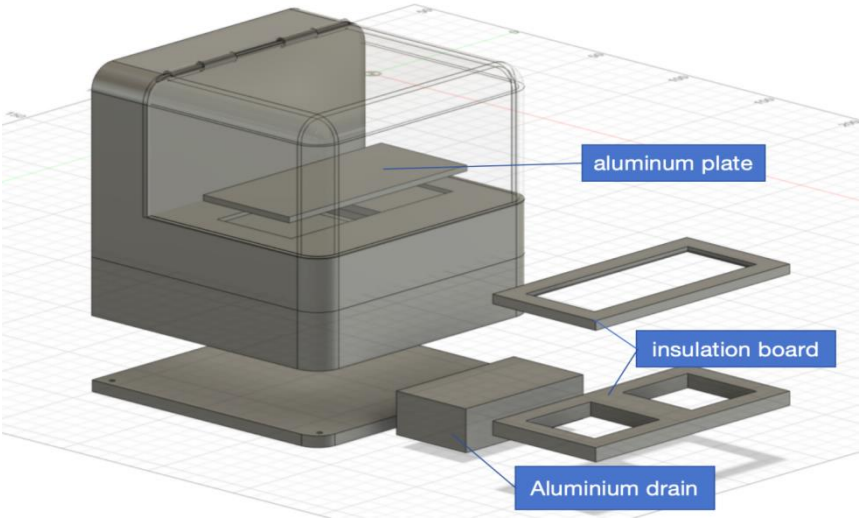
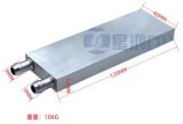


Figure 5. Models Designed in Fusion 360

On the basis of the designed model, the plastic part is built by FDM in 3D printing technology, the glass part is built by SLA, and the metal part, which is mainly responsible for thermal conductivity, is obtained by cutting the existing metal plate.

Table 1. Materials Used

module (in software)	name (of a thing)	model number
power supply	DC switching power supply (battery) 	12V 33A
thermal cycling	Thermoelectric Cooling Module 	TEC2-25410
	Water Cooling Radiator 	40*120 aluminium cold row

	water cooler 	80 rows g1/4 thread
containment	temperature sensor	18B20
	Arduino	Arduino UNO
	LED display	SSD1306 128*64

2.1 Circuit Principle

In order for the heat circulation system to be controllable by the circuit, the following circuit diagram was designed. As shown in the diagram, in an indoor environment, the user can convert 220V AC to 12V DC through a rectifier, and in an outdoor environment, a more portable battery can be used as an option (3S lithium batteries, rated at 11.1V, with a battery discharge capacity of more than 30A can be used). This circuit contains a positive and negative terminal and two cooling fans and semiconductor cooling pads in parallel.

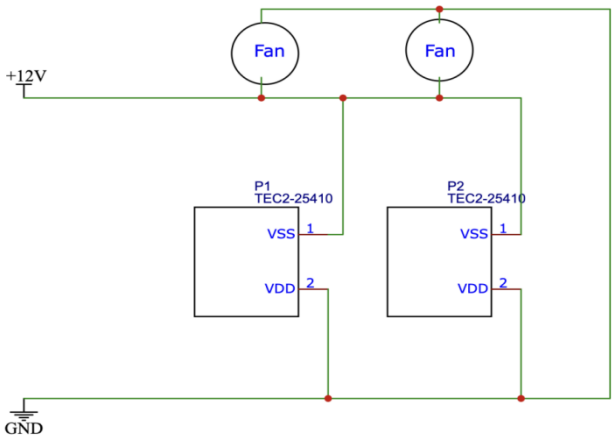


Figure 6. Circuit Diagram

2.2 Thermal Cycle Section

For the heat circulation part, under the cloud chamber, two cooling pads can ensure the temperature in the cloud chamber is around -25 degrees Celsius, and then under the cooling pads, the aluminium drain circulates the hot and cold water to ensure that the cooling pads can have an ideal cooling effect. The hot water from the aluminium drain is cooled down by the heat sink under the action of the water pump and returns to the aluminium drain, thus achieving the circulation of water and heat.

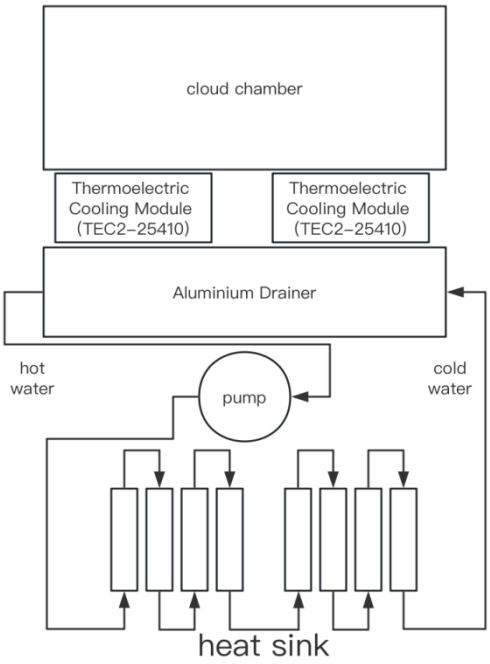


Figure 7. Thermal Cycle Diagram

2.3 Power Supply Component

To ensure stable operation of the cloud chamber in any scenario, the XT-60 plug has been added to the instrument facility, which can be used to connect to a power adapter for residential power supplies in indoor environments, or to a portable 3S lithium battery suitable for outdoor use.

Figure 8. XT-60 Plug

In order to test the instruments involved and their functionality, I built a relatively simple test scenario as shown below.

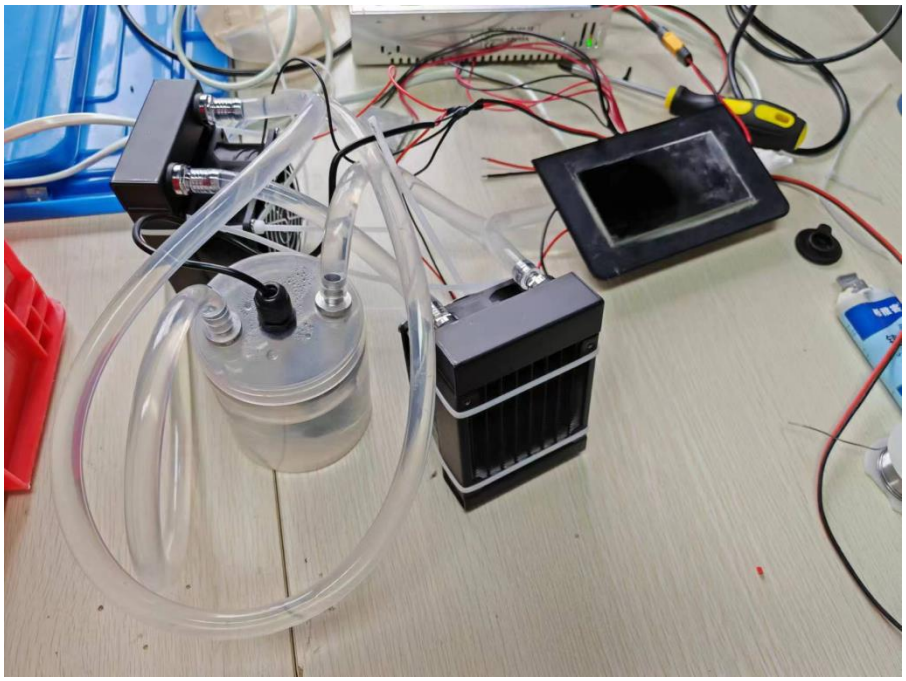


Figure 9. Test Scenario Diagram of the Complete Instrument

The picture below shows a cooling test with a single TEC2-25410 refrigeration chip, which has been tested and found to achieve low temperatures close to -20 degrees Celsius in open environments, and in scenarios where two chips are used, the cooling effect ensures temperatures of around -27 degrees Celsius.

Figure 10. Functional Test of Refrigeration Discs

2.4 Control Systems

In order to monitor the temperature of the cold end and the hot end, I chose two temperature sensors to measure the temperature of the hot and cold ends, and then programmed the display screen to show the temperature of the two ends at the same time.

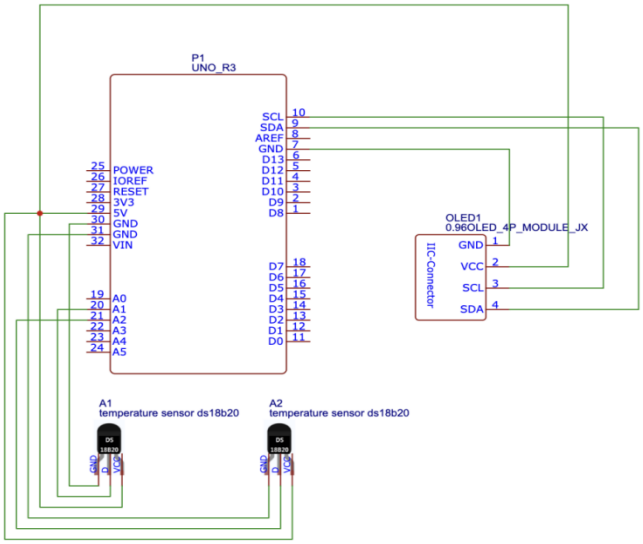


Figure 11. Schematic Diagram of the Control System

In the experiment, even though the cloud chamber allows the path of ionising radiation to appear in a more direct way to humans, the size of the cloud track is still very small and it is difficult for people to see it in great detail, so I also included a camera with microscopic capabilities. It takes up very little space, but gives the observer a very clear picture of the ionisation phenomenon.

Figure 12. Microscopic Camera

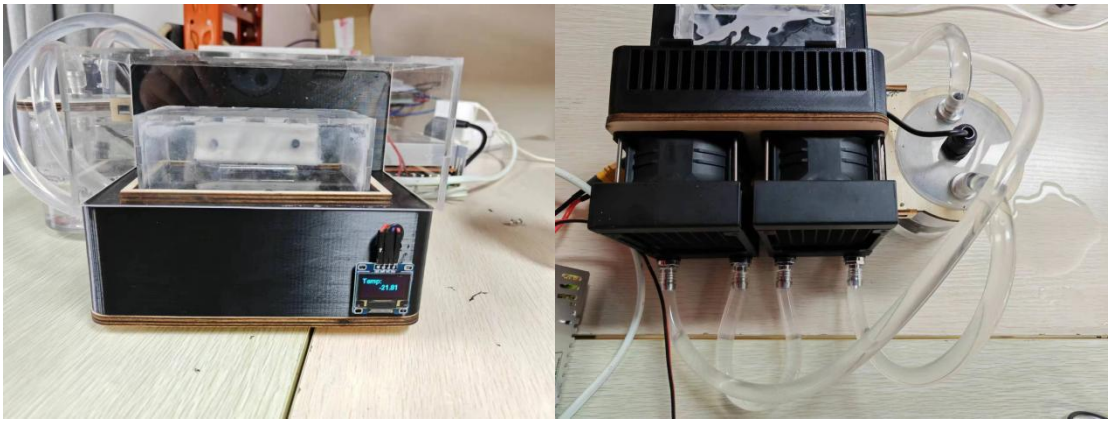


Figure 13. Complete Experimental Setup

3. Conclusion

After testing and sample fabrication, we have come to the following conclusions:

(1) The samples of the experimental results are feasible in reality, which can assist people in observing the phenomenon of ionising radiation and also achieve the original purpose of designing this product.

(2) By comparing the traditional Wilson cloud chamber, it can be seen that although the construction cost of the improved cloud chamber has increased slightly, the cost of using the chamber afterwards has been reduced significantly, including environmental and access costs. The current required for the cooling unit is about 25 to 30 Ampere, and the power is about 300 Watts per hour, which requires one unit of electricity for about three hours of operation, but the traditional cloud chamber produces about 1200g of CO2 per hour of operation. It takes about three hours of operation to consume one unit of electricity, but the traditional Wilson cloud chamber produces about 1200g of carbon dioxide in one hour of operation, and in this respect, the improved cloud chamber has a significant improvement.

(3) Because of the presence of a microcamera, the improved cloud chamber allows for more detailed observation of subtle ionising radiation phenomena, and radiation phenomena become more significant. This project can stably generate a low temperature of about -28 degrees and run for a long time, the radioactive samples can be observed through mobile phones and other devices with magnified shooting, the status monitoring of the system is simple but effective, the design of the circuit part is based on the

principle of reliability, and the high-power components and microcontrollers are isolated from each other.

4. Shortcomings and Possible Improvements

Due to the need for heat dissipation and the limited area of the heat sink, the method of increasing the wind speed is used to achieve heat dissipation, so the noise is relatively high; the system function is not automated enough, especially in the areas of sample placement, camera debugging, etc.; the whole is not beautiful enough, and if there are no more requirements for its size, the method of increasing the wind speed can be used to reduce the noise, and the use of more efficient refrigeration methods to reduce the overall power consumption.

Figure 14. Alpha Ion Trajectory Diagram

This picture shows the alpha ion track seen by zooming in and slowing down after using the camera to record the video, at the red line box, which is very small. The sample is a thorium tungsten electrode containing 1 per cent thorium oxide, and the radioactive hazard is extremely weak, so the radioactivity phenomenon is very inconspicuous, and the video recording and zoom function of the camera is necessary because of the rapid generation and diffusion of the ion trails.

References

Gupta, N. D., & Ghosh, S. K. (1946). A report on the Wilson cloud chamber and its applications in physics. *Reviews of Modern Physics*, *18*(2), 225. https://doi.org/10.1103/RevModPhys.18.225

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