Workshop

Diffusion Cloud Chamber

Centre for Research and Applied Learning in Science

Alignment to GCE learning outcomes

Physics (O level/5058)	Physics (H2/9646)	Chemistry (H2/9647)
8 (a – b) Properties of gases 8 (f – g) Relationships between gas pressure, volume and temperature	9 (i) Kinetic model 20 (k – n) Background radiation and nuclear decay	4 (a) Kinetic theory and Ideal gases

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Introduction

The environment around us is constantly being bathed in a sea of subatomic particles. While some particles such as alpha and beta particles arise from natural radioactive sources, many others originate from cosmic sources, such as the sun, other stars and even supernovae and black holes. As these cosmic rays enter the Earth's atmosphere, the highly energetic ones collide with gas molecules, producing a whole range of other particles, from common ones like electrons, to more exotic particles like muons, pions and neutrinos.

To study these particles and their interactions, scientists first needed a way of detecting them. The cloud chamber was the first such detection tool, and was instrumental in many important discoveries in subatomic particle physics. Further research led to new types of detectors such as bubble chambers, spark chambers and wire chambers – all of which are still used today by particle physicists.

Learning Objectives

The objectives of this workshop are:

- To understand the working principles of a diffusion cloud chamber
- To construct a simple diffusion cloud chamber using low cost materials
- To identify and deduce the properties of different particles from cloud chamber observations

Historical Notes

Like a number of other notable scientific discoveries, the ability of the cloud chamber to detect subatomic particles came about serendipitously. Its inventor, Charles Thomas Wilson, was a meteorologist whose research interest was in the colourful coronas and glories observed when shadows were cast upon clouds. His *expansion cloud chamber* was an attempt to recreate cloud formation in a controlled laboratory setting, and he observed that tracks appeared repeatedly under certain chamber conditions [Ref. 5]. Wilson hypothesised that these tracks were due to condensation from nuclei and ions passing through the chamber, and put his hypothesis to the test by exposing the chamber to x-rays, which coincidentally had just been discovered around the same time. As predicted, the x-rays ionised the air within the chamber, and formed condensation tracks as the ionised molecules traversed the chamber [Ref. 6]. Wilson spent a further two decades improving the chamber and studying track formation, resulting in his two classic papers in 1923 [Refs. 7 – 8]. In 1927, he was awarded the Nobel Prize in Physics, "for his method of making the paths of electrically charged particles visible by condensation of vapour".

Other physicists built upon Wilson's original work to improve upon the chamber and its particle detection ability. The diffusion cloud chamber is one such variant, developed by Alexander Langsdorf Jr. as part of his PhD thesis in the 1930s [Ref. 9]. This workshop will take an in-depth look at the construction and operation of this type cloud chamber.

Cloud chambers were significant in the discovery of the positron, the muon and the kaon, for which two Nobel Prizes in Physics were awarded. These important discoveries paved the way for the development of the Standard Model, a theory that describes how the interactions between elementary particles give rise to phenomena such as radioactive decay and electromagnetism. Although the theory of the Standard Model is not yet a complete "theory of everything", its predictions, and consequently the validity of the Model, have been borne out by many experiments, the latest of which was the discovery of the Higgs Boson at the Large Hadron Collider in 2012, for which Peter Higgs was awarded the Nobel Prize in Physics in 2013.

Safety Rules – IMPORTANT!

The following safe work procedures must be observed in this hands-on workshop:

- No eating or drinking in the lab. Wash your hands upon leaving the lab, particularly before handling any food and drink. Certain chemicals are used in this workshop are potentially toxic if ingested or absorbed through the skin.
- Some solvents used in this workshop are flammable. No open sources of flames or sparks should be used in the vicinity.
- You may be using either liquid nitrogen or dry ice in this workshop as the cryogen. Do not handle either the liquid nitrogen or dry ice with your bare hands, as they are very cold and can cause serious frostbite. Use a thick piece of cloth to handle any objects coming into contact with the cryogen, as these items (particularly metal) can be cold and also cause frostbite.
- Be careful when using sharp hand tools.

Basic Working Principles of a Diffusion Cloud Chamber

Vapour Pressure, Supersaturation and Condensation

In an enclosed system containing a single liquid, two phases are actually present, as there is a vapour phase formed above the liquid phase (Figure 1):

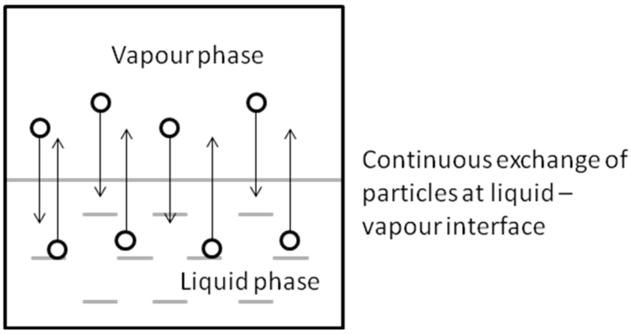

Figure 1: A system containing a liquid and vapour phase

At the liquid – vapour interface, vapour particles continuously enter the liquid, while liquid particles evaporate into the vapour. When the system is in thermodynamic equilibrium, the flow of vapour particles into the liquid is on average the same as the flow of liquid particles into the vapour. There is no net gain or loss of material in either phase, and the partial pressure of the vapour phase stays constant. The liquid-vapour system is said to have reached *saturation* at this point. The magnitude of this vapour partial pressure, also called the *saturated vapour pressure*, depends on the equilibrium temperature of the system, and each material has its own characteristic *saturated vapour pressure curve*:

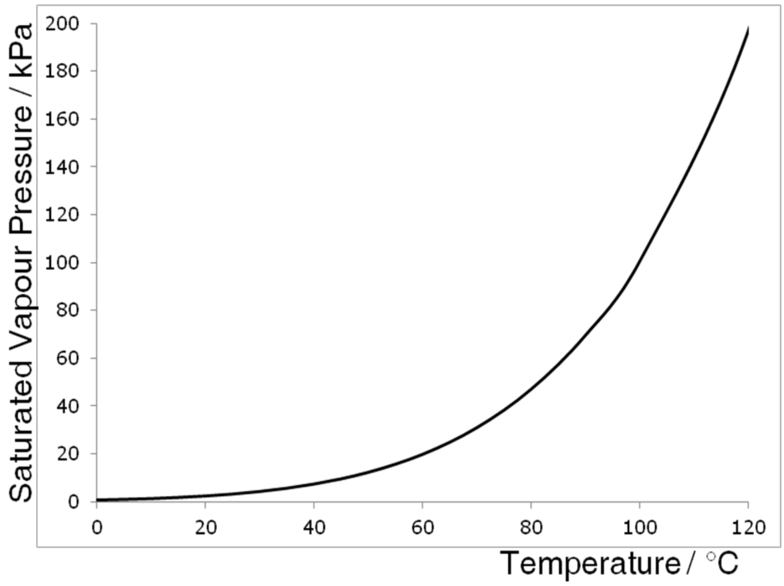

Figure 2: Vapour Pressure Curve of Water

If this system is now driven out of equilibrium, for example by sudden cooling, the vapour pressure can remain above the equilibrium vapour pressure, and the vapour becomes *supersaturated*. In this supersaturated state, the vapour molecules can easily coalesce back into the liquid upon contacting other particles in the system. These particles, or *condensation nuclei*, can comprise large ones such dirt and dust particles, or smaller ones such as ionised molecules.

Diffusion Cloud Chamber Operation

The *diffusion cloud chamber* is based on the above principle of supersaturation and condensation. One part of the chamber, typically the top, is kept at a high temperature, while the bottom is kept at a low temperature. A volatile liquid solvent source is placed at the high temperature portion of the chamber. While this temperature gradient is maintained, the solvent vapour diffuses and fills the chamber. When the solvent vapour reaches the cold portion of the chamber, a thin, supersaturated layer of vapour is formed (Figure 3).

When an ionised particle travels through this supersaturated region, solvent vapour condensation is triggered by the particle, resulting in the production of a "vapour trail". This vapour trail is an indicator of the path taken by the ionised particle through the chamber.

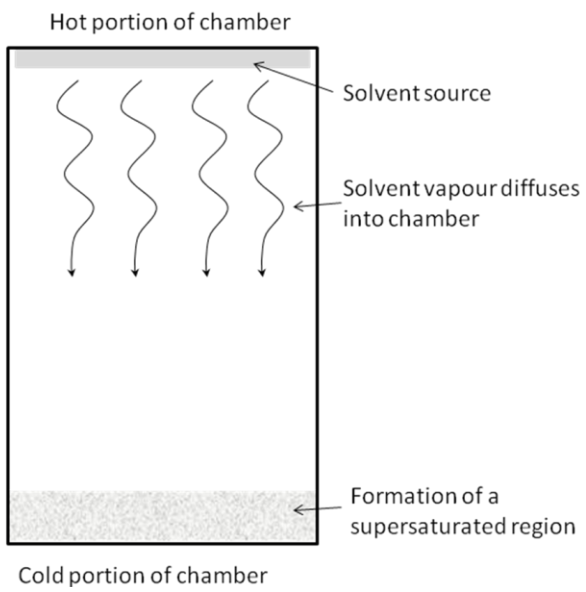

Figure 3: Operation of a Diffusion Cloud Chamber

> **Question:** How does the temperature gradient cause a supersaturated vapour region to form? Explain how this phenomena occurs, drawing reference to the equilibrium vapour pressure and phase diagram in the previous section.

Building a Cloud Chamber

A diffusion cloud chamber can thus be broken down into a number of different operating components:

- A warm solvent source
- An airtight, enclosed chamber
- A method of cooling a portion of the chamber
- A light source and contrasting background

The following materials will be used in the construction of the chamber:

- A plastic container with a tight lid
- Isopropanol (IPA)
- Black felt
- Aluminium tape
- Black vinyl
- Dry ice/Liquid Nitrogen
- A cloud chamber stand with integrated torch light

Question: What is the purpose of each of the materials in the list above? To which of the different operating components does each material belong?

The cloud chamber is constructed in the following way:

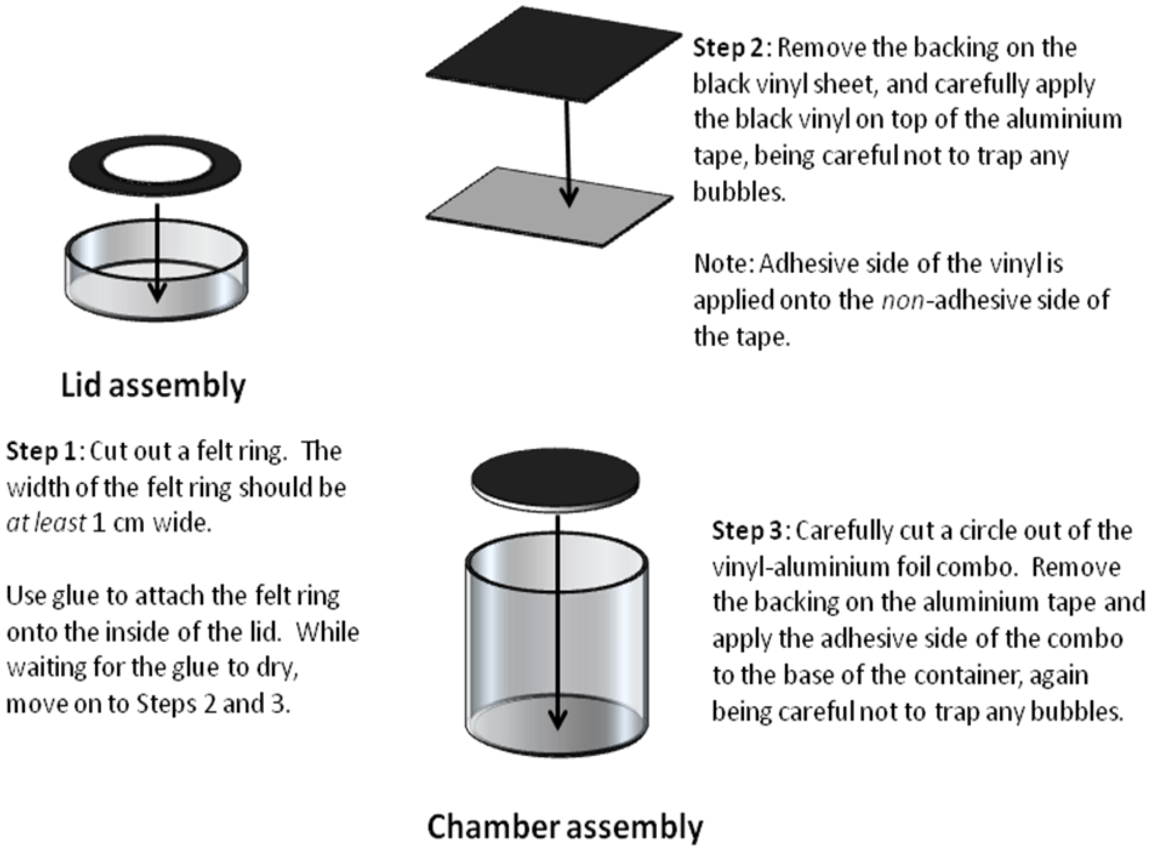

Figure 4: construction of the cloud chamber

Important Note!

Before proceeding with the construction, think through and write out the series of steps you will take. Ensure that all the necessary materials and tools are on hand and arranged neatly before you start.

When building the chamber, take note of the following considerations:

- After cutting the felt ring, vinyl-foil combo circle, check that they fit correctly into the plastic container before using any adhesives.
- Take your time to place the vinyl-foil combo onto the base of the container. Bubbles or creases in the vinyl will affect the seeing in the cloud chamber.
- Use a sparing amount of glue to stick the felt to the lid, and wait for the glue to dry before putting the lid on the chamber.

When you are done building the chamber, clean up your work area, throwing away any unused material or adhesive backing.

Operating the Cloud Chamber

Once the cloud chamber is assembled, your workshop facilitator will distribute the dry ice/liquid nitrogen and isopropanol. Set up your cloud chamber in the following way:

1. Squirt some isopropanol onto the felt ring. The felt should be well soaked, but **not** dripping any liquid (invert the container lid over a cloth to let any liquid drain out).
2. Ensure that the chamber is clean and dust free, then put the lid on.
3. Fill the Styrofoam bowl with a 1-2 cm layer of dry ice/liquid nitrogen.
4. Place the cloud chamber onto the top of the Styrofoam bowl, ensuring that the base of the base is as level as possible. The base of the container should just *hover* above the dry ice/liquid nitrogen, and not come into contact with it.

Illuminate the chamber with the LED, and carefully observe the interior of the chamber.

If the chamber is sealed and cooling well, you should observe a rain-like mist within the chamber within a few minutes.

Questions:

What do you think this rain-like mist is? Can you explain how this mist is formed?

How far does this rain-like mist region extend in height? Is it present in the entire chamber, or only confined to a particular region or height?

In what direction does the rain-like mist travel? Is there a net horizontal flow, vertical flow, a combination of both, or completely random? What causes the motion?

Particle Track Observations

Continue observing the interior of the chamber, and make notes about what you observe.

Once you have spotted tracks, make a few sketches of the various tracks that you observe (use the table on the next page to record your observations).

Questions to guide your observations:

Are the tracks of the same length? Are some tracks fatter than others?

Do the tracks always appear as straight lines? Do they curve, kink or move in a zigzag manner?

Do the tracks move in particular directions? Do they move horizontally, vertically, or in both dimensions?

Do certain types of tracks appear more frequently than others?

As you make your observations, look ahead at the questions in the next section, "*Group Discussion and Reflection*" and try to answer them. Use your observations, and any prior knowledge about ionising radiation, to justify your answers.

Group Discussion and Reflection

Share your observations with the rest of your workshop colleagues, and your own thoughts about the following questions:

- How many types of tracks do you observe?
- What particles do you think produce the different tracks that you observe?
- What phenomenon or interaction produces the kinked tracks, and the jagged tracks?
- What are the origins of these particles?

References and Further Reading

[1] "Cloud Chamber and Cosmic Rays", Cornell Institute for Physics Teachers, http://www.cns.cornell.edu/cipt/labs/CloudChamberLab.html, retrieved 19/11/12.
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