University of Birmingham

Ogden Trust Internship

Particle Physics - Cloud Chambers Activities for Schools

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CONTENTS

1 INTRODUCTION

Physics is a subject that contains challenging abstract concepts. When studying hard to visualise concepts, this becomes troublesome. For example, when learning about the incredibly small, like the atomic structure, students struggle to visualise and comprehend what is occurring. Therefore the importance of bringing practical activities into physics lessons is high. Creating this fish tank cloud chamber will aid students in their understanding of the difference between radiation and radioactive decay.

Despite how useful the concept is of making a fish tank cloud chamber, this experiment can be temperamental. The aim of this document is to lead on from previous work and improve the model, resulting in a reliable experiment.

2 HISTORY OF THE CLOUD CHAMBER

We are unable to see radiation with the naked eye however the invention of the cloud chamber allows us to see the ionized tracks created by radiation such as alpha and beta. The first cloud chamber, known as a Wilson Cloud Chamber, was created by Scottish physicist Charles Thomson Rees Wilson in 1911. He won a Nobel Prize for his invention in 1927 which he shared with Arthur Compton.[1]

Inside a cloud chamber there exists a supersaturated environment of either water or alcohol vapour. When an energetic charged particle, such as a beta particle, passes through the chamber, it reacts with the vapour and ionizes the gas particles. Resulting in visible tracks alike those created by aeroplanes in the sky. Particles are identified through the specific shape of a track. Use of cloud chambers gave birth to the discovery of the positron, muon and the kaon.[2]

Inside the cloud chamber, a supersaturated environment exists due to the presence of ethanol and a large temperature gradient throughout the tank. The base is cooled by dry ice as the top is heated by a hot water bottle or electric blanket. Additionally a thoriated rod is placed in the chamber and this rod is a low radioactive source which is the source of alpha and beta radiation for the experiment.

3 IDENTIFYING TRACKS

In this experiment, four main tracks will be identifiable with each track corresponding to a different particle.

The following information and images are referenced from 'Symmetry Magazine' a joint publication of Fermilab and SLAC. [3]

Short Tracks

Figure 1: Short fat tracks show the presence of **alpha particles**. In comparison to other radiation, alpha particles are heavy as they are made from 2 neutrons and 2 protons (the nucleus of a helium nucleus). Due to their size and low energies they do not travel far and therefore produce short tracks.

Curly Tracks

Figure 2: These unusually shaped tracks are produced by **beta particles**, better known as electrons and/or positrons. A positron is the anti-particle to an electron and has the same mass but the opposite charge to its sister particle. As electrons are much lighter than alpha particles, we see longer tracks. The unusual pattern is as a result of being bounced around by heavier air molecules.

Long Straight Tracks

Figure 3: These tracks confirm the presence of **muons**. Like electrons, muons are leptons however they have a greater mass. As they are heavier than electrons, they are not so easily displaced by air molecules resulting in a long straight track. You may be lucky enough to see these tracks as they are not very common. These muons are produced by cosmic rays interacting with our atmosphere. If you would like to know more about cosmic rays, go to the appendix of this document.

Forked Tracks

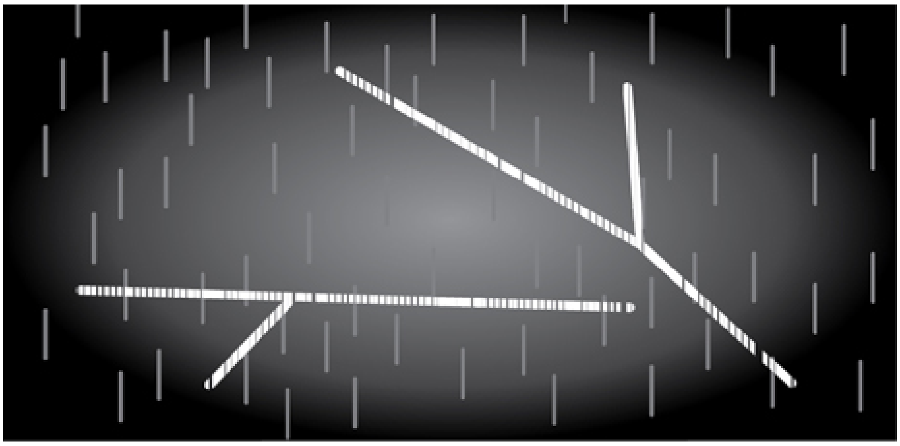


Figure 4: These tracks are the signature of particle decays. Unstable particles want to become stable and therefore decay until they are. This decay process can be seen through the forked tracks.

4 MAKING THE CLOUD CHAMBER

4.1 Safety

Dry Ice

Dry ice has a temperature of approximately -80°C which is cold enough to cause serious freezing injuries. Never touch or consume dry ice. Always handle with care and wear protective gloves.

Dry ice is solid carbon dioxide so when heated becomes carbon dioxide gas. If left in a confined space or an unventilated room, the carbon dioxide will displace oxygen in the air and will cause difficulty breathing. Make sure the room is ventilated or doors and windows are open.

Do not store dry ice in an airtight container. The dry ice will convert into its gaseous state and expand. This may lead to an explosion.

Ethanol

Ethanol is highly flammable. Do not use ethanol near any open flames or anywhere near strong oxidants. Do not ingest, inhale or get in the eyes. No eating or drinking around ethanol and wash hands thoroughly after use.

Thoriated Rod

This source is below background and is safe to use. However, if a different source is used, care must be taken when handling radioactive material. The guidelines given with the source must be followed. For more information please go to the thoriated rod section in this document.

4.2 Equipment

- A small fish tank.
- A baking tray which is larger than the base of the fish tank
- A thoriated rod
- Self-adhesive felt
- Duct tape and masking tape
- Ethanol
- Aluminium foil
- Polystyrene
- Hot water bottle/ electric heater

4.3 Instructions

1. **Making the polystyrene box**
    - This is the most lengthy part of the process and should be prepared in advance.

- Start by measuring your baking tray.
- Make a polystyrene base that is larger than your baking tray.
- Make a rectangular ring which your baking tray can fit. You will also need to create some height to fit your tray on top of your dry ice.
- Secure your base and your rectangular ring with duct tape. Make sure to cover the whole base as polystyrene will fall apart over time.(Figures 5 and 6)
- When creating the base, make sure the tray fits snuggly inside as shown in figure 14.

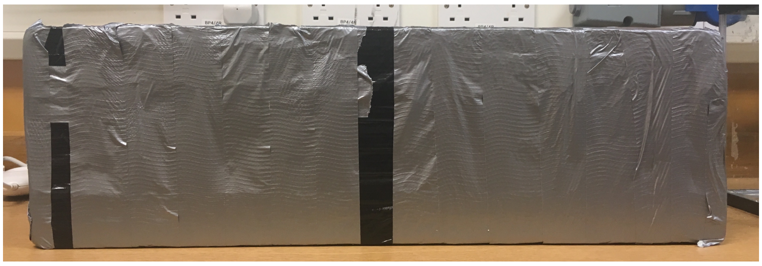


Figure 5: An example base from the side. Bottom of the base has dimensions: 10cm x 40cm x 60 cm.

Figure 6: An example base from a top view. Top of base (rectangular ring) has dimensions 10cm deep and 5cm wide around long edges and 7cm wide around short edges.

2. **Preparing the inside of the fish tank**
   - Fix felt to the top of the fish tank (which will later be the top of the cloud chamber). You can use self adhesive felt or ordinary felt and glue. (Figure 7)
   - When you are ready to begin the experiment, you should coat this felt with ethanol. You should use a generous amount. Any

ethanol that is not absorbed by the felt should be poured away. (Figures 8 and 9)

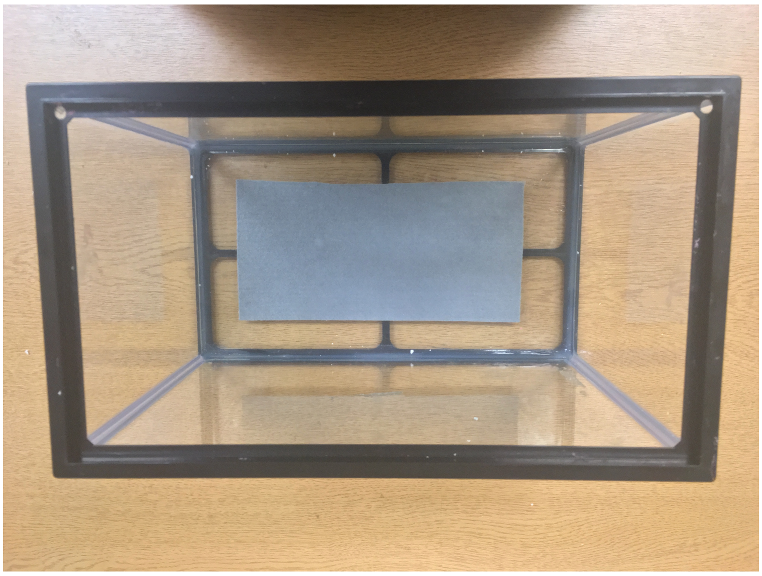


Figure 7: Adhesive felt stuck to the bottom of the fish tank.

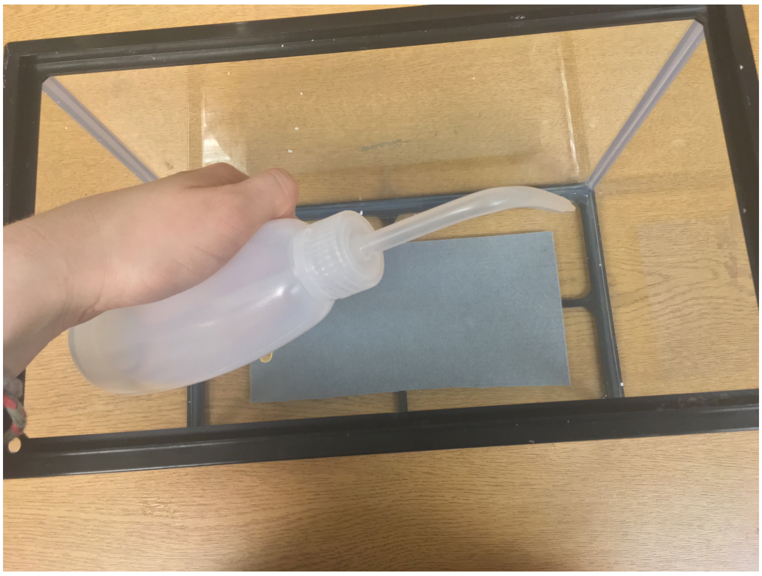


Figure 8: A squirty bottle is ideal for coating the felt in ethanol.

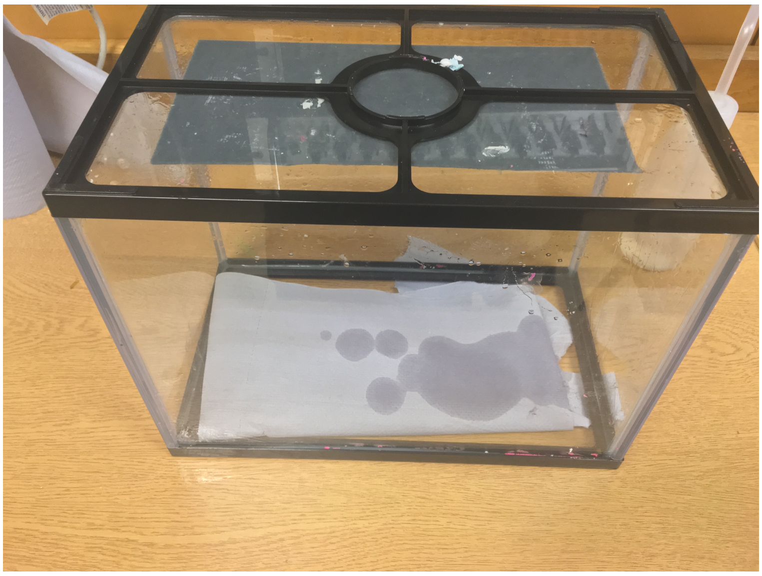


Figure 9: A fish tank turned upside down so that excess ethanol can be removed.

3. **Making the tank air-tight**
   - Before making the tank air tight, the thoriated rod needs to be placed inside the tank either just placed inside on top of the felt. When you turn the tank upside down in a later step, the rod will fall to the new bottom of the tank and will be at the base of the chamber. If you do not wish to do this, you can stick the rod onto your sheet of aluminium foil with a piece of blutack. Additionally, the felt needs to be soaked in ethanol. (Figure 10)
   - Cut a sheet of aluminium foil to a size slightly larger than that of the base of the fish tank. (Figure 11)
   - Place your foil over the top of your fish tank in order to seal the tank. Use duct tape to fix the foil to the fish tank. Make sure there are no gaps and the foil is tort. (Figure 12)
   - Once the foil has been fixed you can now turn your fish tank upside down. Take care when doing this as the thoriated rod will fall to the bottom of the tank and may rip the foil.

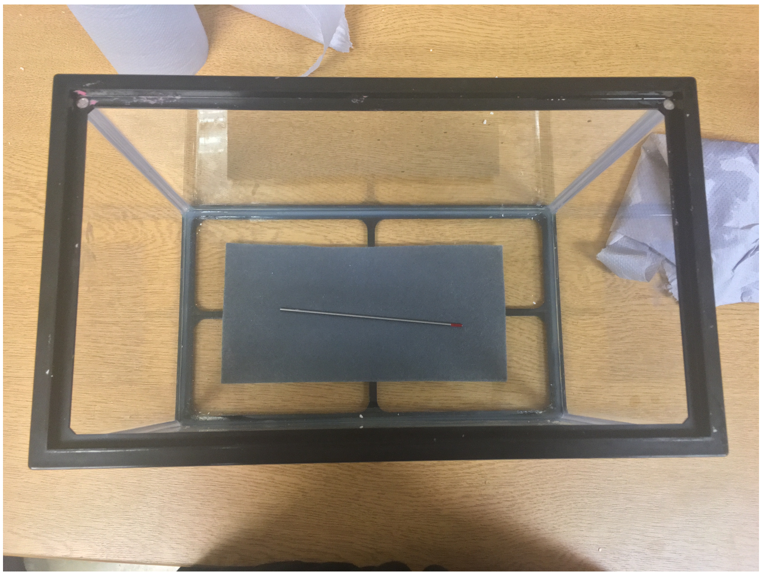


Figure 10: The fish tank with felt coated with ethanol and the thoriated rod placed inside.

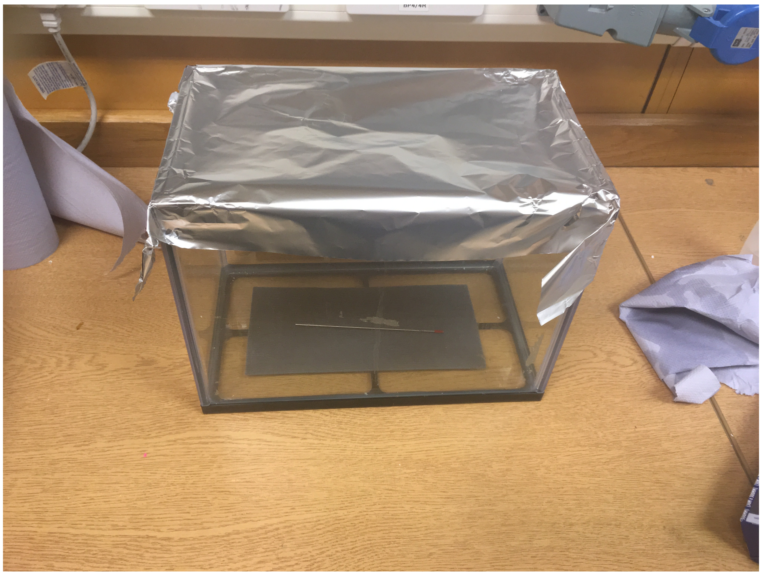


Figure 11: A sheet of tinfoil placed over the open side of the fish tank.

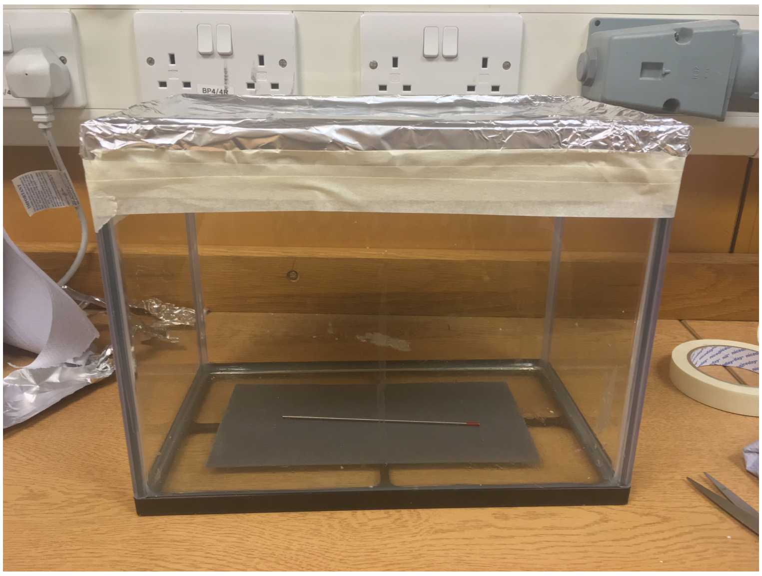


Figure 12: The tinfoil taped to the fish tank making the tank air tight.

4. **Preparing the cloud chamber**
   - Place your dry ice into your polystyrene base. (Figure 13)
   - Place the baking tray on top of the dry ice. (Figure 14)
   - Now put your fish tank on top of the baking tray, aluminium foil touching the tray. (Figure 15)
   - Now put a hot water bottle on top of the tank. (Figure 16)
   - Wait around 10 minutes for the system to stabilise
   - Shine a torch or two (two works better) along the base of the of the cloud chamber and observe particle tracks!
   - You can also cover the tank with a black cloth to increase track visibility. (Figure 17)

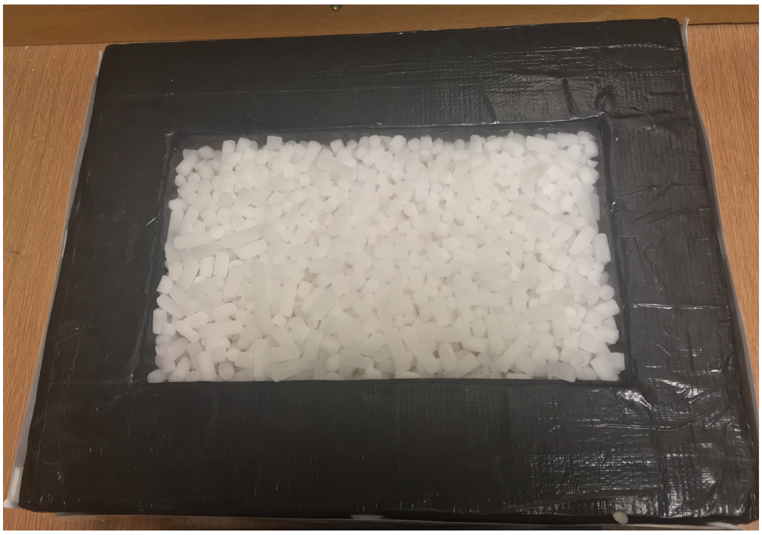


Figure 13: Dry ice inside polystyrene base.

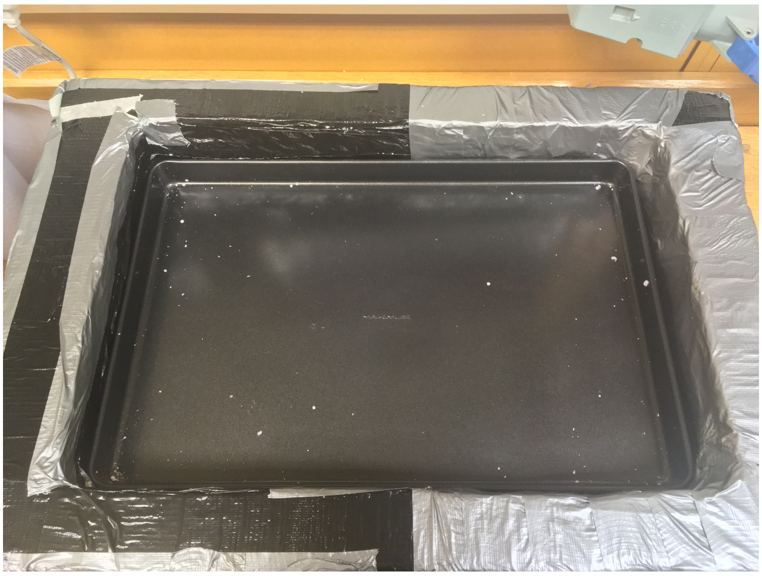


Figure 14: Tray over dry ice in base.

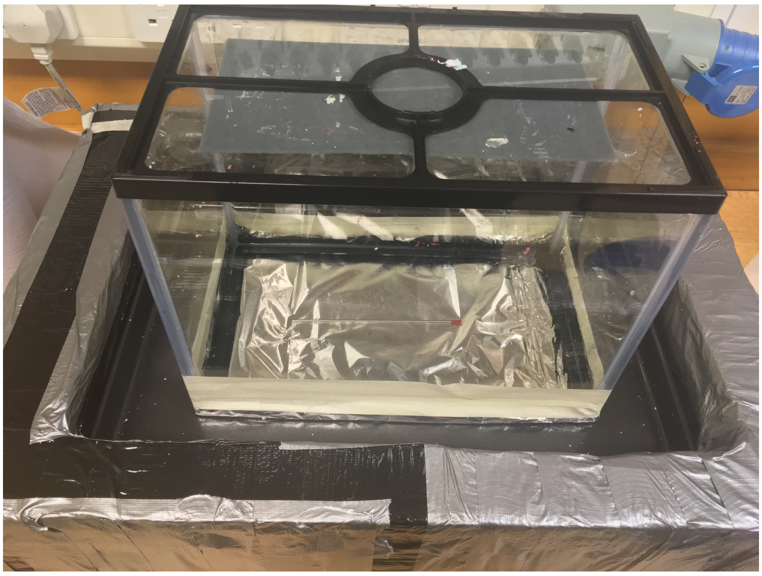


Figure 15: Cloud chamber setup.

Figure 16: Cloud chamber set up with electric blanket. Can also be created with a hot water bottle or without any heating.

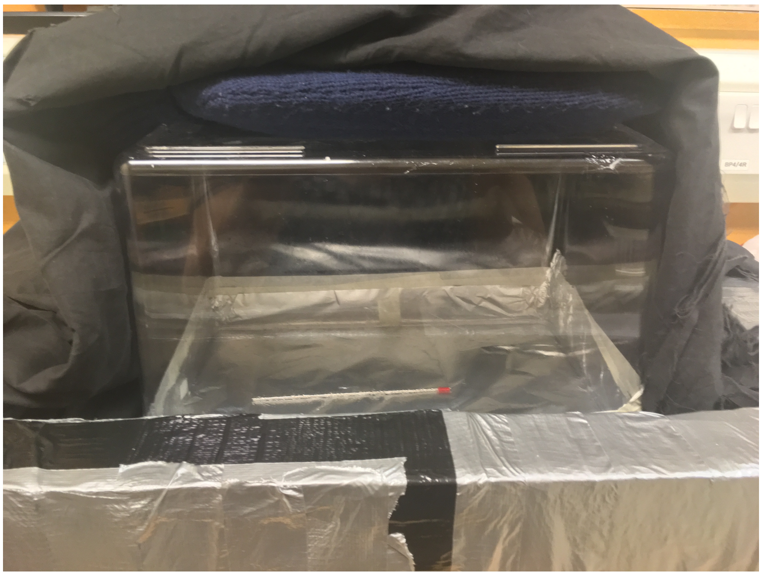


Figure 17: Cloud chamber set up with a black cloth to increase visibility.

5 EXTRA CLOUD CHAMBER ASSISTANCE

5.1 Where can I get this equipment?

- Thoriated Rod - Easy to find on Amazon by searching Thoriated Tungsten Electrodes. The price is around £10 for 10 rods.
- Small fish tank - Search on Amazon for 'small plastic fish tank'. Cost is no more than £15. You can also get a very basic fish tank from Wilko for £7.
- Baking tray can be found at home or any homeware store.
- Self-adhesive felt - can be found on Amazon for a few pounds.
- Polystyrene - can be found on Amazon. 25 sheets costs around £20.
- Electric Heater - once again can be found on Amazon for around £20.
- Hot water bottle can be found at home or any homeware store.

5.2 Possible Variations and Modifications

It is possible to not use a hot water bottle or electric blanket in this experiment, however, I believe the tracks are clearer when a heating element is used.

If you do not wish to make your own cloud chamber, please read the later section entitled "Cloud Chamber Loan Scheme" to find out how to loan a cloud chamber from the University of Birmingham.

5.3 Trouble Shooting

<u>I have a thin layer of *cloud* at the bottom of my chamber</u>
Your cloud chamber is not air-tight. Try sealing your cloud chamber to the metal base with playdoh.

<u>The bottom of my tank has frozen over.</u>
You may have used too much dry ice. You can also fix this problem by making the polystyrene base taller so more of the polystyrene covers the bottom of the fish tank. If you would like to do this, I would recommend cutting a hole in one side of the base so you are still able to shine a torch into the bottom of the tank.

<u>My cloud chamber isn't working at all.</u>
Firstly, you will usually need to wait around 15 minutes one the cloud chamber has been set up, to see any results.
If you have waited for more than 15 minutes and seen nothing, make sure you can feel a temperature difference between the top of your tank and the bottom. If the top of the tank is too cold, try adding a hot water bottle or an electric blanket to the top of the tank. The top of the tank should have a temperature of around 30°C. The bottom of the tank should be as cold as the dry ice so make sure the dry ice is in constant contact with the metal base.
It is also important to check that your cloud chamber is air-tight and that

you have added a significant amount of ethanol. You should place your ethanol at the top of your cloud chamber so it is able to evaporate and create a supersaturated state. You should not, however, have too much ethanol in your tank as it will drip and leak over your experiment. You can make sure that you don't have too much ethanol in your felt by placing the felt inside your tank, covering it with ethanol, turning the tank upside and wiping up any excess ethanol.

6 ACTIVITIES FOR STUDENTS

Inspiration for these activities has been taken from Richard Bonella's work on 'Loaning a Diffusion Chamber'.[4] If you are interested in some other example activities, please view Richard Bonella's work.

6.1 KS2

Radioactivity and the structure of the atom are not featured in the KS2 curriculum however that doesn't mean that this area of physics is inaccessible! Set up the cloud chamber as described in section 4.

Topics for Discussion		
What do you see?	**Familiar Examples**	**What is the underlying Physics?**
Puffs of smoke and smoky trails	Trails left in the sky by planes. You can often see the trails left by a plane but you don't always see the plane. By looking at the trails we can see how far the plane has travelled and in what direction.	In this experiment we can see the the tracks left by particles but not the actual particles themselves. This is because these particles are so small that they cannot be seen with the naked eye. By looking at the we can that there was a particle.
Different tracks with different shapes and sizes	Animal tracks in the snow. We can tell what animal has walked through the snow but looking at their paw prints.	Each particle leaves a distinctive track. By looking at these tracks as explained in section 3, we are able to identify what particle we see in the cloud chamber.

After discussing what you can see, introduce the different types of radiation. Just like there are different types of animals (mammals, invertebrate, etc) there are different types of radiation. Here it would be good to introduce alpha being the big fat radiation and beta being the little skinny radiation. You can also discuss some radioactive sources. You can talk about the Sun is the main source of radiation and that there are some 'special' rocks that emit radiation. I believe it is important to tell students that radiation is not all evil and that it has some good uses for example in medicine and smoke detectors.

6.2 KS3-KS4

In these key stages, students need to understand atoms and radiation. A cloud chamber is an interactive way of introducing students to different types of radiation and their properties.

Initially teach the students the basics of alpha, beta and gamma radiation. Explain to them what each radiation is, ie alpha is a helium nucleus.

Once completed, introduce the students to the cloud chamber. Have a discussion regarding what they can see. Explain to them that they are seeing the tracks left behind by particles much like the tracks that planes leave behind in the sky and not the actual particles and these are far too small to see with the naked eye.

Then ask them to identify what type of radiation produces what track. The aim here is for them to begin to understand that the short tracks are produced by alpha particles because these particles are heavy and are short-lived. This leads on to a discussion about ionising ability. The same goes for beta, long tracks are because beta is less ionising than alpha. It is also light and easily deflected by the ethanol molecules. Students will not be able to see gamma radiation. This is because gamma radiation is not ionising like alpha and beta and does not react in the cloud chamber. This leads to an opportunity to talk about the properties of gamma radiation.

Next steps are to talk about why elements decay. Every isotope wants to be stable. Ask the students what tracks they would expect to see if they could see a chain radioactive decay? The answer is the forked tracks mentioned in section 3. You will now be able to talk about particle half-lives.

6.3 KS5

At this level, knowledge of particle decays, the classifications of particles and particle interactions are required. The discussion topics suggested for KS3-KS4 would act as a quick recap for KS5 students. Using the same set-up as previously listed, students would be able to calculate the rate of alpha particles being emitted from the thoriated rod. Information for this activity can be found in the attached PDF created by C. Lazzeroni and R.Lietava at the University of Birmingham. If you would like to find out more about any particle physics outreach work that the University of Birmingham do please look at the University of Birmingham Particle Group's Outreach website:

https://www.birmingham.ac.uk/schools/physics/outreach/Educators-and-General-Public/resources.aspx [5]

For those looking for an extension try to derive the equations found in Lazzeroni's work. For the solutions please look at the following PDF entitled *Deriving the Equations found in "Cloud Chamber and Thorium Radioactive Decay"*.

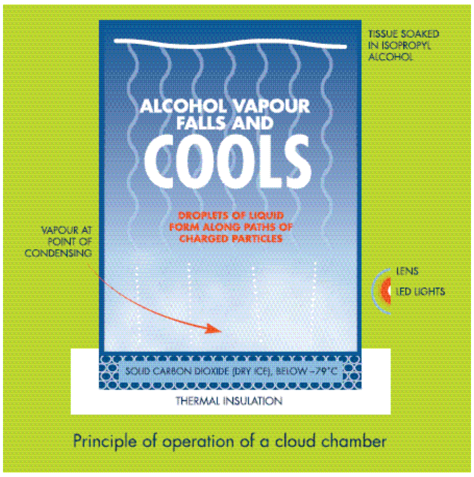
In addition to this, the topic of cosmic rays can be discussed. Cosmic rays are high energy particles that primarily come from the Sun. These particles are called muons. KS5 students are expected to know what a muon is and their properties. Muons are sometimes visible in cloud chambers and they leave a long straight track. The fact we are able to detect muons is very fascinating. Muons only have a lifetime of 2μs and travel at nearly the speed of light. If we take the nearest source for muons to be produced, the Sun, which is around $1.5 x 10^{11} m$ away. By completing a quick calculation, in order for us to be able to detect muons on Earth, they must have a lifetime of at least 500s otherwise they would decay before they reach Earth. Clearly, 500s is much larger than 2μs, so how are we able to detect muons on the surface of the Earth? When things are travelling very close to the speed of light, special relativity comes into play. Muons experience length contraction/time dilation which means that to them, the distance to the Earth is much shorter than it actually is and therefore they are able to reach the Earth during their lifetimes. Students at this age find special relativity fascinating and this is a good practical example to explain the basic principles.

Cloud Chamber and Thorium Radioactive Decay

(C. Lazzeroni and R.Lietava, University of Birmingham)

1.) Cloud Chamber Principle

A diffusion cloud chamber visualises charged particle tracks. It was used in research from the beginning of 20 century. It was used for demonstration of particle properties of light (Compton effect, Nobel Prize 1927) and discovery of antimatter (positron, Nobel Prize 1936). Today it demonstrates the principle of how particle detectors work. Passing through matter, charge particles knock out electrons from atoms leaving trail of electrons and ions. Detection of these trails is the basic principle on which most of the particle detectors work.



The principle of a diffusion cloud chamber can be understood from this picture. Fish tank contains air and alcohol vapour which diffuses from the container on the top. The temperature of the tank is -79° C at the bottom and 30° C at the top. The alcohol vapour follows the change of the temperature (see figure 2) and in the layer at the bottom of tank it is in oversaturated state when it almost condenses to liquid (see figure 3). The trail of charged ions created by charged particle passing the chamber leads to condensation of the vapour in the trail, producing clouds which you observe as a particle track.

More Physics

1) **Ionisation**: charged particle traversing matter is knocking out electrons from atoms creating positively charged ions and free electrons.
2) **Saturated Vapour Pressure**: is the pressure exerted by a vapour in equilibrium with liquid at a given temperature in a closed system.
3) **Oversaturated Vapour**: the vapour pressure is higher than saturated vapour pressure.
4) **α – particle:** nucleus of ^{4}He, it consists of 2 protons and 2 neutrons.
5) **Radioactive decay:** nucleus spontaneously emits particle. There are 3 types – α decay (α particle is emitted), β decay (electron or positron is emitted) and γ (photon is emitted)
6) **Half-life time of radioactive element**, abbreviated $t_{½}$, is the period of time it takes for the amount of a substance undergoing decay to decrease by half.
7) **1 eV –** energy unit used in particle physics. It is the amount of energy gained by the charge of a single electron moving across an electric potential difference of 1V.

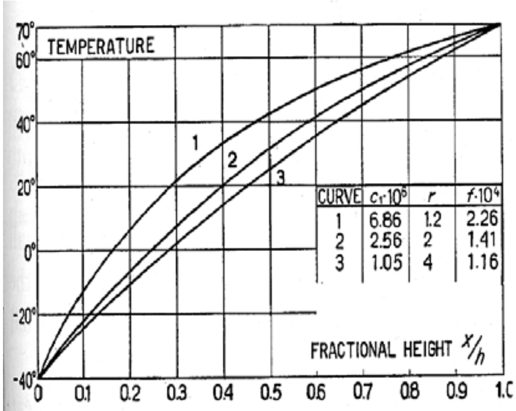


Fig. 2. Temperature distribution for different vapour fluxes according to Langsdorf (Rev. Sci. Inst. 10 (1938) 91).

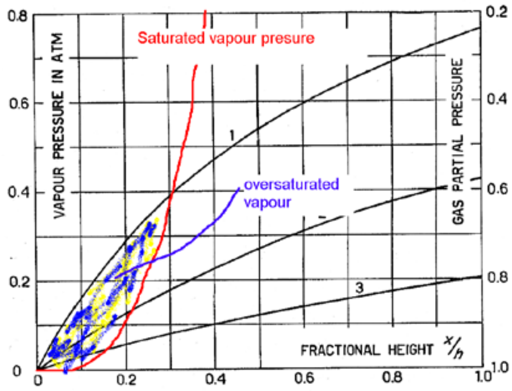


Fig. 3. Vapour pressure distribution for the vapour fluxes given in fig. 2, according to Langsdorf (Rev. Sci. Inst. 10 (1938) 91).

2.) Rate of α-particles from welding rod (Measurement)

The welding rod you have is made of tungsten with 2% of thorium oxide. Thorium is a naturally radioactive element which decays emitting an α particle with half-life time $t_{1/2}=1.4\times10^{10}$ years. The kinetic energy of an alpha particle is 4 MeV. It travels several cm in air and 2.2 micrometers in tungsten. Your goal is to measure the rate of the decay, i.e. the number of decays per second. In the second part of the exercise you will compare your measurement with the theoretical estimate.

1.) Set up the cloud chamber according to the procedure described in section 4.)
2.) Count the number of tracks n from the rod during the time interval T. Recommended time interval T is between 30 seconds and one minute. Rate R of α particles is defined as $R= n/T$.
3.) Repeat the rate measurement N times, so you obtain N measurements of the rate $R_1,\ldots,R_i,\ldots,R_N$
4.) Calculate average rate $<R>$ as:

$$< R >= \frac{\sum_{i=1}^{N} R_i}{N} .$$

5.) Plot a frequency histogram of the rate R, and from the width of the distribution estimate uncertainty of the measured rate due to random fluctuations in number of tracks, the so called statistical error. This should compare well with the result of the formula:

$$e = \sqrt{\frac{\sum_{i=1}^{N} (<R> - R_i)^2}{N(N-1)}} = \sqrt{\frac{<R^2> - <R>^2}{N-1}}, \text{ where } <R^2> = \frac{\sum_{i=1}^{N} R_i^2}{N}.$$

6.) Think about other biases in your measurement which may lead to a difference between your rate measurement and the actual rate, the so called systematic errors.

3.) Rate of α-particles from welding rod (Calculation)

1.) Calculate the mass *m* of Th in the rod. There are 2% of ThO_2 in the rod. You can use scales and calliper to measure mass and dimensions.. *Optionally, check 2% assumption by comparing measured rod density with theoretical density* $\rho_{rod} = \frac{1}{0.02/\rho_{ThO_2} + 0.98/\rho_W}$; $\rho_{ThO2} = 10 g/cm^3$ *and* $\rho_W = 18.8\ g/cm^3$.

2.) Calculate the number of thorium atoms *N* corresponding to the mass *m:* $N = \frac{m}{M_{Th}} N_A$. $M_{Th} = 232g$ is the molecular mass of Th. $N_A = 6.023 x 10^{23}\ mol^{-1}$ is the Avogadro number.

3.) Calculate the rate – number of decays per second – assuming an exponential decay $N(t) = N(0) x 2^{-t/t_{1/2}}$. The thorium half - lifetime is $t_{1/2} = 1.4 x 10^{10}$ years. Since the half-life time is much bigger than 1 second you can use the approximate formula: $Rate = \frac{N(t) - N(0)}{t} = \frac{\ln(2) N(0)}{t_{1/2}}$

4.) For the final result, take into account that the typical range of α-particles in tungsten is δ=2.2 micrometers. So only the α-particles close to the surface survive. You need to calculate the effective rate as

$$Rate_{effective} = Rate \cdot g \cdot \frac{V_{shell}}{V_{Tot}},$$

where $g \approx 1/6$ is the geometrical factor taking into account the direction of α-particles. V_{shell} is the volume of thin slice close to the surface and V_{tot} is the volume of the full cylinder. (Show that $V_{shell} / V_{tot} \approx 2\delta/r$, where *r* is the rod radius.)

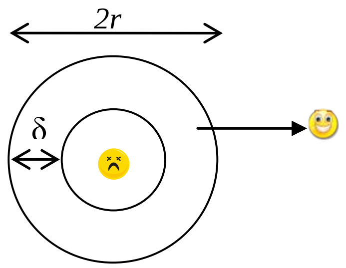


Figure: Happy face indicates a α-particle which is lucky enough to escape from the rod as it is created close to the surface of the rod. Unhappy face is an α-particle which is absorbed in the rod as it is created far from the surface.

5.) Compare the result with your measurement. Is the calculation consistent with your measurement? If not, what can the possible reason be ?

4.) Cloud Chamber Manual

List of parts:

- fish tank with metal base
- black taped base container for dry ice
- foam sheet
- fish tank cover – black metal plate with hole in the middle
- alcohol in plastic squeezable bottle
- plastic container for alcohol
- two wire hooks
- metal heater for alcohol
- 1 power supply
- lights
- welding rod

Start up:

1. Switch on the power supply of the metal heater 10 minutes before chamber operation. Voltage should be ~ 20 V with current about 0.3 A. Take plastic container, put the metal heater inside and fix the container to the top of the chamber with wire hooks.
2. Put the rod inside.
3. Add alcohol to the container (1 cm)
4. Take one bowl of dry ice.
5. Put the foam sheet inside the black-taped base container.
6. Put the dry ice on the foam and spread it evenly.
7. Put the fish tank inside the black-taped base container on the dry ice. It squeaks.
8. Close the fish tank with the black metal cover.
9. Check the horizontal/vertical adjustment of the chamber with a spirit level.
10. Put a black cloth on the chamber, leaving the front panel open.
11. Use LED lights to watch the base of the tank.
12. Wait 10-15 minutes until you see the tracks inside.

Close up:

1. Switch off the power supply of the heater.
2. Open the chamber and dismount the alcohol container.
3. Take off the chamber from the black-taped base and leave everything open to dry.

Safety:

- **Do not drink or inhale alcohol**
- **Do not touch live cables**
- **Do not touch dry ice without gloves**

Deriving the Equations found in "Cloud Chamber and Thorium Radioactive Decay"

Bethany Allison - Ogden Trust Intern 2018

July 2018

1 Deriving N_0

Starting from equation 1 where N_0 is the number of ThO_2 molecules, m is the mass of the rod, M_{ThO_2} is the molecular mass of ThO_2 and N_A is Avogadro's Number, equation 2 can be derived.

$$N_0 = \frac{m}{M_{ThO_2}} N_A \tag{1}$$

$$N_0 = \frac{0.02 * RodMass}{264} N_A \tag{2}$$

2 Deriving N

The radioactive decay equation is shown in equation 3 where λ is the decay constant.

$$N = N_0 e^{-\lambda t} \tag{3}$$

The half life of an element is the time it takes for a sample to halve. Therefore $N = N_0/2$ when time $t = t_{\frac{1}{2}}$ resulting in the following derivations.

$$\frac{N_0}{2} = N_0 e^{-\lambda t_{\frac{1}{2}}} \tag{4}$$

$$\frac{1}{2} = e^{-\lambda t_{\frac{1}{2}}} \tag{5}$$

$$2 = e^{\lambda t_{\frac{1}{2}}} \tag{6}$$

$$\ln 2 = \lambda t_{\frac{1}{2}} \tag{7}$$

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}} = \frac{0.693}{t_{\frac{1}{2}}} \tag{8}$$

Now that we have an equation for λ, we can substitute this into equation 3 to find a new equation for N.

$$N = N_0 e^{-\frac{0.693}{t_{\frac{1}{2}}} t} \tag{9}$$

3 Deriving R

The rate of a radioactive reaction is the rate of change of the amount of radioactive material as shown in equation 10.

$$R = \frac{dN}{dt} = N_0 \frac{d}{dt}(e^{-}\frac{0.693}{t_{\frac{1}{2}}}) \tag{10}$$

Through rearrangement we find:

$$R = -\frac{0.693 N_0}{t_{\frac{1}{2}}} e^{-\frac{0.693}{t_{\frac{1}{2}}} t} \tag{11}$$

In the limit where $t << t_{\frac{1}{2}}$, $e^{-\frac{0.693}{t_{\frac{1}{2}}} t} \approx e^0 = 1$ and therefore produces equation 12.

$$R = -\frac{0.693 N_0}{t_{\frac{1}{2}}} \tag{12}$$

4 Deriving R$_{eff}$

You will find that the rate you observed does not match the accepted value. This is because alpha radiation does not travel far and not all the radiation exits the rod. In order to correct for this, you can calculate the effective rate and this can be compared to the accepted value.

$$R_{eff} = Rg\frac{V_{shell}}{V_{total}} \tag{13}$$

R is your measured rate, g = $\frac{1}{6}$ and V_{shell} and V_{total} are explained in the equations below.

$$V_{inner} = \pi(r - \delta)^2 l \tag{14}$$

$$V_{total} = \pi r^2 l \tag{15}$$

Where r is the radius of the rod and δ is 2.2 micrometers for tungsten, and l is the length of the rod.

$$\begin{aligned} V_{shell} =& V_{total} - V_{inner} \\ =& \pi r^2 l - \pi(r - \delta)^2 l \\ =& \pi l(r^2 - (r - \delta)^2) \\ =& \pi l(r^2 - r^2 + 2r\delta - \delta^2) \\ =& \pi l(2r\delta - \delta^2) \end{aligned} \tag{16}$$

You can now find the ratio between V_{shell} and V_{total}:

$$\begin{aligned} \frac{V_{shell}}{V_{total}} =& \frac{\pi l(2r\delta - \delta^2)}{\pi r^2 l} \\ & when\ \delta \ll r \\ \approx& \frac{2\delta}{r} \end{aligned} \tag{17}$$

From this you can now substitute all you values into equation 13 to find R_{eff}:

$$R_{eff} = R\,\frac{1}{6}\,\frac{2\delta}{r} \tag{18}$$

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[1] C.t.r. wilson - biographical. [Online]. Available: https://www.nobelprize.org/nobel_prizes/physics/laureates/1927/wilson-bio.html

[2] The cloud chamber. [Online]. Available: http://www.ep.ph.bham.ac.uk/twiki/bin/view/General/CloudChamber

[3] How to build your own particle detector. [Online]. Available: https://www.symmetrymagazine.org/article/january-2015/how-to-build-your-own-particle-detector

[4] "Schools' equipment loan scheme diffusion cloud chamber." [Online]. Available: http://epweb2.ph.bham.ac.uk/user/lazzeroni/outreach/cloud-chamber/cloud-chamber-manual.pdf

[5] Particle physics outreach resources. [Online]. Available: https://www.birmingham.ac.uk/schools/physics/outreach/Educators-and-General-Public/resources.aspx

A LOANING A CLOUD CHAMBER

The following PDF includes information regarding loaning a cloud chamber from the University of Birmingham. If you are interested please contact either Prof. Cristina Lazzeroni cl@hep.ph.bham.ac.uk or Dr Maria Pavlidou M.Pavlidou@bham.ac.uk.

There is also a manual for a more complicated style of cloud chamber for those who are more adventurous!

Schools' Equipment Loan Scheme - Diffusion Cloud Chamber

Richard Bonella (Original)
Revised by Bethany Allison - Ogden Trust Intern 2018
University of Birmingham
School of Physics and Astronomy
Particle Physics Group

July 2018

1 The University of Birmingham particle physics equipment loan scheme

As part of its work in support of schools, the Particle Physics Group within the School of Physics and Astronomy at the University of Birmingham is establishing an equipment loan scheme. This is to provide schools with equipment that they may not have or find impractical to maintain. Schools can borrow equipment for a short period at the appropriate point in the school year. The first item available in this loan scheme is a diffusion cloud chamber.

Cloud chambers reveal the trajectories of some sub-atomic particles. They do not make the particles visible, but show where the particles have been. The shape of the tracks provides some very useful information about the particles. Whilst the click of a Geiger-Muller tube and counter is the stuff of movies, cloud chambers provide visible evidence of the speed, range and intensity of particle radiation, and provide starting points for many different threads of discussion in teaching. Their evolution, from a tool designed for quite different research, through mainstream use in various forms for several decades, is an interesting example of the development of research technology.

Although some schools have cloud chambers, they are often small and some designs are unreliable. Professor Cristina Lazzeroni has adapted an existing design for a chamber that is simple to set up and provides a stable saturation gradient in which ionising radiation from a thoriated rod produces clear alpha tracks. Tracks from secondary cosmic radiation may also be seen and can be clearly distinguished from those from the thorium. The thorium decay chain includes beta decays; tracks from such decays are less substantial but may also be seen. This manual explains how to set up the chamber, suggests some teaching uses beyond simple demonstrations for primary (Key Stage 2) and secondary (KS3 to 5) classes, and provides background information for teachers.

The only consumable items for this equipment are dry ice (solid CO_2) and propanol or ethanol. Dry ice can be made in school using liquid CO_2 from a pressure cylinder and a suitable expansion nozzle. Schools may wish to consider buying it from the University (at a discounted rate) or elsewhere: see Section Ten. Links to sites suggesting ideas for using surplus ice for other demonstrations are in Section Nine We also suggest that schools buy their own thoriated rods, to avoid complications in transporting them to and from the University. For detailed information on these rods, see Section Eight below. The cost of buying drying ice and the need for storing thoriated rods may suggest that secondary schools could usefully provide demonstrations for local primary schools using materials that they have acquired for their own use. Experience of showing the chamber to a Year Six class shows that it can lead to a very constructive discussion; see Section Four for a suggested 'line to take'.

Schools wishing to borrow a cloud chamber should contact: Professor Cristina Lazzeroni in the Particle Physics Group at the University of Birmingham - cl@hep.ph.bham.ac.uk. Or contact Dr Maria Pavlidou the outreach officer for the School of Physics and Astonomy - M.Pavlidou@bham.ac.uk.

- Please include the name and full postal address of the school, a contact name and telephone number, and the dates between which the equipment is required.
- Loans will normally be for one to two weeks. Schools will be asked to collect and return the equipment at the University; collection and return times are by agreement and can be after 4 pm if necessary.
- Hire of a chamber costs £5.00 for a week or £1 a day. Cheques should be payable to University of Birmingham. Schools using the purchase order system should send an order to Dr. Cristina Lazzeroni, School of Physics and Astronomy, University of Birmingham, B15 2TT, after arranging the dates of the loan.

Alternatively, and depending upon her other commitments Cristina may be able to visit schools, bringing the chamber with her and talking about it to a group. The school would be asked to pay her travel expenses and for the dry ice.

2 Using cloud chambers in schools

A cloud chamber brings us as close as we can get to seeing sub-atomic particles, whether originating from the decay of radioactive isotopes such as thorium-232, or from the decay of the products of collisions between out atmosphere and primary cosmic radiation.

The particles themselves are too small to be seen with the naked eye or, indeed, with an optical microscope. A-level students should understand why this is so. What we can see is condensation along the track of the moving particle, as ions produced by collisions act as nuclei for droplets of ethanol. This process is similar, though not identical, to the production of visible vapour trails behind aircraft which may be flying so high as to be almost indiscernible from the ground.

The source of radiation recommended for this demonstration is thoriated welding rods. These are cheap, of low activity and conveniently shaped to provide a source through the whole depth of the chamber. There is more about them in Section Eight of this manual and an interesting article in the June 2011 issue of the ASE's School Science Review[1].The vapour is provided by soaking a paper towel in ethanol, and the supersaturation is caused by cooling the bottom of the tank with solid carbon dioxide ('dry ice'). It is easier to see the trails if the room is darkened and the tank then illuminated from the side. Strips of LEDS, either mains or battery-powered, provide a convenient way of doing this.

Observing the tank should demonstrate the rate at which decays occur in a very weak source, the range of the particles emitted, and the continual but random nature of the decay. The appearance of trails that clearly do not originate from the thoriated rod is evidence for the existence of background radiation, usually from cosmic rays.

[1] R. Whitcher, Practical work using low-level radioactive materials avail- able to the public, School Science Review, vol. 92, no. 341, pp. 6574, 2011.

3 Setting up the cloud chamber

3.1 Preparation

Connect the heater to a power supply. Make sure to not use a voltage greater than 20V and a current of 0.3A. Wait for the heater to reach operational temperature before placing it inside the ethanol pot. (Figure 1)

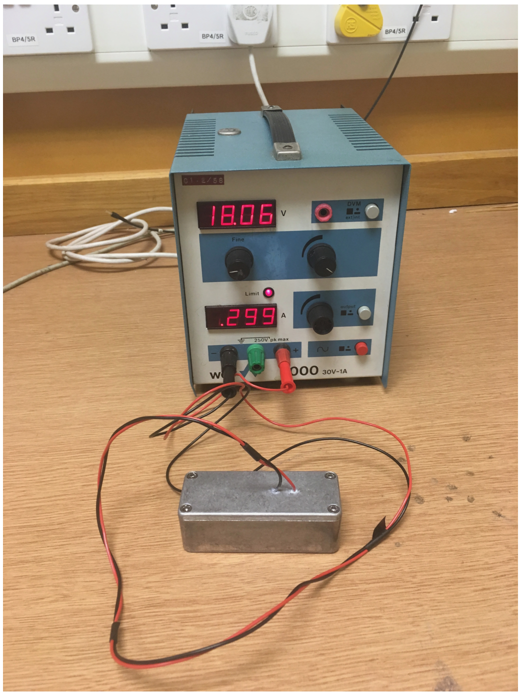

Figure 1: Immersion heater connected to a power supply.

3.2 Setting up the inside of the cloud chamber

Place the throriated rod inside the cloud chamber (figure 2). Clip the ethanol pot to the inside of the top of the cloud chamber (figure 3) and fill with ethanol. Add enough ethanol until it's a few cm deep. Then add your heater once it has heated up (figure 4).

Figure 2: Tank with thoriated rod inside.

Figure 3: Ethanol pot attached to the top of the tank.

3.3 Adding the Dry Ice

Using gloves and wearing ice protection, add the dry ice to the base of the cloud chamber (figure 5). You do not need lots of dry ice, just enough to completely cover the bottom. Once this is done, you can place the cloud

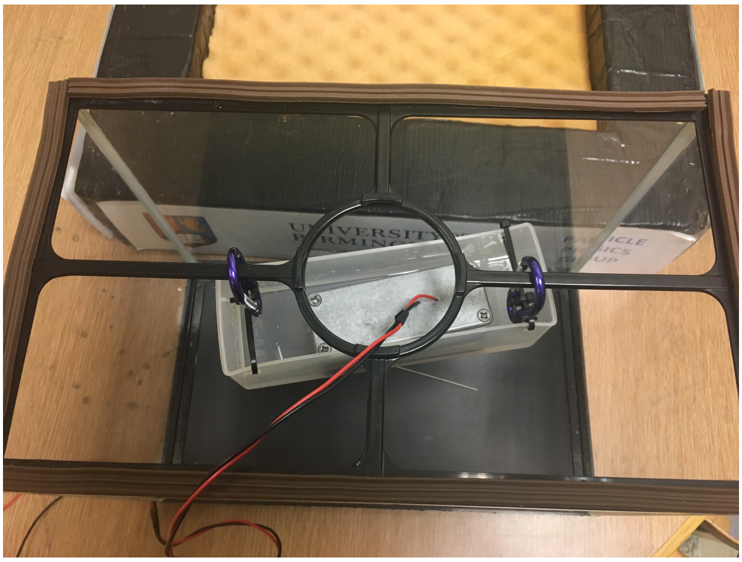

Figure 4: Ethanol and heater inside tank.

chamber on top of the base (figure 6) then add the lid to the tank (figure 7).

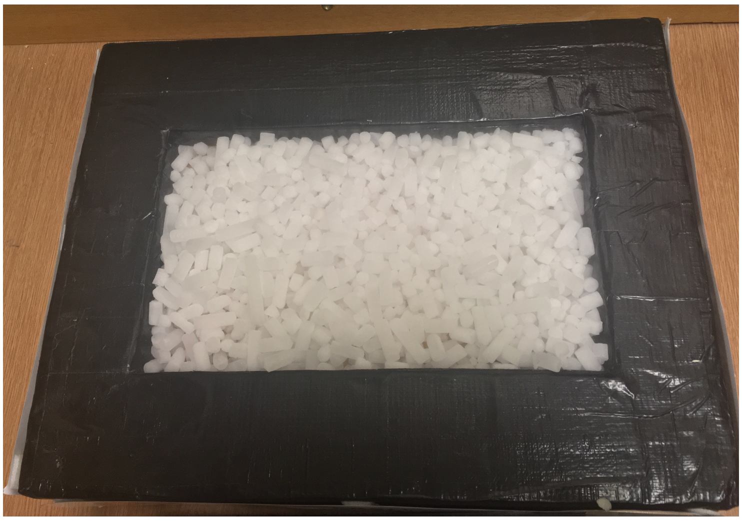

Figure 5: Dry ice added to the polystyrene base.

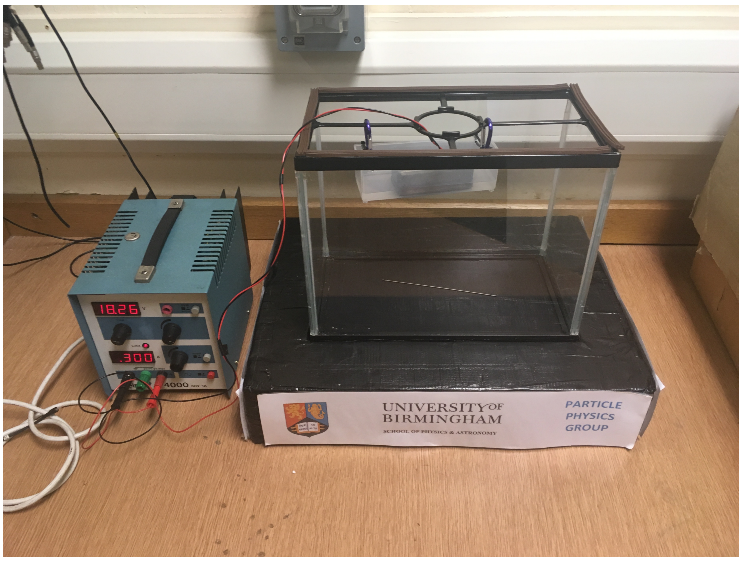

Figure 6: Tank added to polystyrene base.

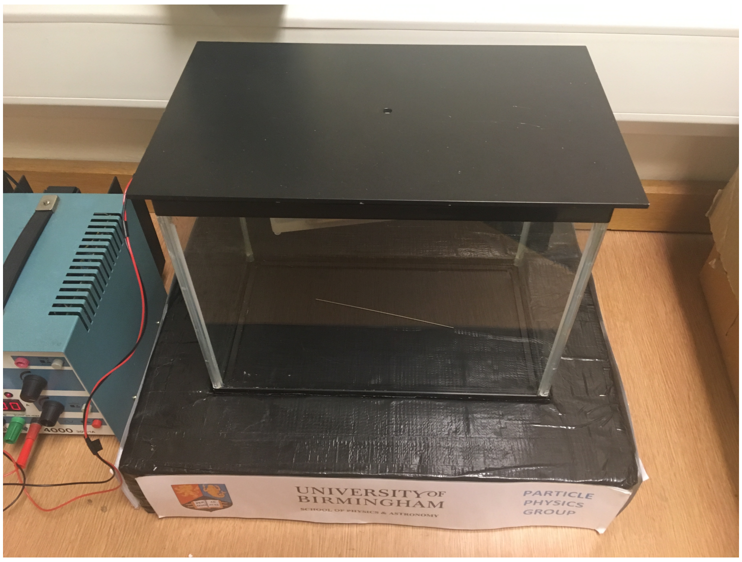

Figure 7: Lid added to the top of the tank.

3.4 Finishing Touches

The cloud chamber is now set up. Wait around 10 minutes for the system to stabilise and then you should see tracks. If you are not in a dark room, you can cover the tank i a black cloth to increase visibility (figure 8). You will also need to illuminate the bottom of the tank and you can do this with torches.

Figure 8: Final set up of cloud chamber with black cloth to increase visibility of particle tracks.

B CLOUD CHAMBER PHYSICS

The following PDF is the revised version of the old cloud chamber manual written by Richard Bonella. This document now only contains the physics and history behind cloud chambers. There is also information on thoriated rod safety and where to purchase dry ice. Additionally there are the instruction on how to make your own comets using dry ice.

Original Cloud Chamber Manual

Richard Bonella
University of Birmingham
School of Physics and Astronomy
Particle Physics Group

March 2012

Section 5

Early Particle Physics

Until about a century ago, scientists had little knowledge of what matter was. The idea of chemical elements, different varieties of matter that combined with each other in consistent ways, had been developed by Boyle (1627-1691) and then Dalton (1766-1844) in Britain, Lavoisier (1743-1794) in France and Avogadro (1776-1856) in Italy. But how or why did elements have distinct properties?

The Russian chemist Dimitri Mendeleev[8] (1834-1907) published what would become the Periodic Table of the elements in 1869. He knew of only 60 elements, rather than the more than 100 that we know today, but he saw a pattern in their properties. Using this idea, he successfully predicted the existence of then-undiscovered elements. It was widely, but not universally, believed that there must be a different kind of atom – the smallest piece that could exist – for each element. The simple objection to this idea was that no such atoms could be seen, and therefore their existence could not be demonstrated.

At the end of the 19th and in the early 20th century, evidence for the existence and nature of atoms was assembled, sometimes deliberately and sometimes as a consequence of other investigation.

In 1897, J J Thomson (1856-1940) investigated the 'cathode rays' that were known to be emitted when an electric potential ('voltage') was applied across two electrodes in a low pressure gas. -The cathode rays were visible because they glowed. Thomson showed conclusively that the rays were streams of electrically-charged particles: electrons. Measurements of the way in which the beam of particles was deflected by electric and magnetic fields showed that the particles had the same mass, regardless of what metal they came from, and that it was far less than that of even the lightest atom[9]. The metal electrodes remained unchanged: no chemical reaction had taken place. It appeared that atoms contained other, smaller particles; they were not indivisible.

In the previous year, 1896, the French scientist Henri Becquerel (1852-1908) had been investigating phosphorescence. This is the phenomenon by which certain compounds absorb electromagnetic radiation (visible light, ultra-violet or X-rays) and then re-emit the energy over a period of time. Becquerel accidentally discovered that uranium salt emitted radiation even without previously being exposed to it[10]. This radiation was not visible but was able to pass through paper and affect old-fashioned photographic plates just as though they had been used in a camera. Radioactivity seemed to be a property of the uranium that did not diminish with time. Becquerel shared the 1903 Nobel Prize for Physics with Marie and Pierre Curie for his discovery.

In the following couple of years, the New Zealand-born physicist Earnest Rutherford (1871-1937) and the French chemist Paul Villard (1860-1934) showed that there were three distinct types of radiation from these radioactive elements. The least penetrating, but most highly ionising (alpha radiation: α) was shown to be identical to the nuclei of helium atoms. It was identified both from the ratio of its electric charge to its mass and from its chemical properties. The second type of radiation (beta radiation: β) was found to be identical to the charged particles whose flow made up an electric current in solids and to 'cathode rays': electrons. The third type (gamma radiation: γ) had the greatest penetrating power and was identified as a high frequency, high energy part of the electromagnetic spectrum, similar to the recently-discovered X-rays. Matter, whatever it was made of, was capable of emitting matter particles (alpha and beta radiation) and electromagnetic energy (gamma radiation) in an apparently unending stream.

For those still sceptical as to whether atoms actually existed, rather than simply being a convenient notion for the mathematics of chemistry and physics, 1905 was the year in which decisive evidence was identified. It was not new

[8] http://www.rsc.org/education/teachers/learnnet/periodictable/pre16/develop/mendeleev.htm

[9] http://www.vias.org/physics/bk4_02_06.html

[10] www.rsc.org/images/essay1_tcm18-17763.pdf

evidence, but it took a fresh eye to realise its significance. Albert Einstein (1879-1955) proposed that the random movement of tiny, solid particles suspended in a liquid was due to transient imbalances in the impact of liquid molecules on the particles[11]. This phenomenon had been observed in 1827 by the botanist Robert Brown. He spent a considerable time investigating the movement of pollen grains, and then other fine particles such as soot, in liquids, but was unable to account for it. Jean Perrin, whose work on cathode rays had preceded that of Thomson, confirmed the idea experimentally[12] and used it to determine Avogadro's number[13]; this in turn, provided more precise values for the mass of individual atoms.

In a famously busy year, Einstein also produced a convincing explanation for the way in which some metals, exposed to light of certain colours, emitted electrons. This was the work for which he was awarded the 1921 Nobel Prize and which, appropriately, contributed to a better understanding of the phenomenon of phosphorescence, which had led Becquerel to discover radioactivity.

The existence of atoms, and the fact that they were not fundamental (indivisible) particles was beyond doubt. The next questions were: if negatively-charged electrons can escape from atoms, leaving a positive ion behind, what is the ion made of and how are the particles in an atom arranged? Rutherford, having been a student of Thomson's, and working in Canada and then in Britain, did a great deal to provide answers.

Atoms are much smaller than the wavelength of visible light and hence cannot be studied with optical microscopes. Rutherford's technique was to fire a narrow beam of alpha particles from a radioactive element towards a very thin sheet of metal. He wanted to find out whether the alpha particles would all stop, or all pass through, or ...? To observe the paths of the alpha particles, he used a detection method devised by Sir William Crookes (1832-1919). When alpha particles strike some compounds – zinc sulphide was commonly used – their kinetic energy is emitted as a brief flash of light. Only a small proportion of the alpha particles were deflected at all, and a very few came bouncing back. These were the ones that had, by chance got very close to a small, dense, positively charged atomic nucleus in an otherwise empty space. Later work showed that atomic nuclei contained a number of positively-charged particles: protons. The number of protons in each atoms accounted for the number of electrons and hence for the chemical properties of the element. There were not enough protons to explain the relative masses of the elements: helium with two protons has approximately four times the atomic mass of hydrogen with one. Rutherford predicted the existence of another, electrically neutral particle and, in 1932, James Chadwick demonstrated[14] that neutrons did exist, although not in the form of an electron-proton pair as postulated by Rutherford.

The particles that make up ordinary matter had been identified and described. This was only the beginning, however. The theoretical and experimental work that had been set in train by Becquerel's discovery was to lead to the realisation that there was a 'Particle Zoo' awaiting discovery[15].

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[11] *http://www.aip.org/history/einstein/brownian.htm*

[12] *Nott M (2005) 'Molecular reality: the contributions of Brown, Einstein and Perrin' School Science Review, June 2005, 86(317) pp 39-46*

[13] *A measure of how many atoms there are in a quantity of matter; defined as the number of atoms of carbon-12 in 12 grams*

[14] *http://www-outreach.phy.cam.ac.uk/camphy/ neutron/neutron1_1.htm*

[15] *http://math.ucr.edu/home/baez/physics/ParticleAnd Nuclear/particle_zoo.html*

Section 6

Cosmic radiation

The term cosmic radiation (or cosmic rays) has been used to cover a variety of phenomena. Clearly, the whole electromagnetic spectrum is 'radiation', and photons with a wide range of energies arrive at the upper layers of the Earth's atmosphere. Here, however, we are concerned with energetic matter particles. NASA's Cosmicopia site[16] is a useful source of information and links to stories on recent developments in the field.

Primary cosmic radiation consists of largely of atomic nuclei, travelling with energies[17] from MeV up to at least 10^{20} eV. The relative abundance of various nuclei reflects the abundance of each element in inter-stellar dust[18]: 89% H (ie, a single proton), 10% He and 1% others. Some light nuclei are over-represented: this is believed to be the result of heavier nuclei fragmenting in collisions. The relative proportions of radioactive isotopes and their daughter nuclei indicate that the mean age of cosmic radiation particles is about 10 million years.

It has been suggested that the particles in cosmic radiation acquire their kinetic energy from the blast waves produced by supernovae. They may reach speeds greater then $0.99c$ (speed of electromagnetic radiation in a vacuum). Since the particles are electrically charged, they are susceptible to acceleration by magnetic fields. Again, the fact that they are charged means that they radiate photons when accelerated; they are one of the sources of gamma radiation[19].

It is important to note that neither its direction of arrival at the Earth, nor the distance that it has travelled (implied by the speed and age of individual particles), tell us where cosmic radiation particles originated; their trajectory through space is not a straight line.

When these particles collide with others, short- lived exotic particles[20] may be produced. In particular, collisions in our upper atmosphere produce kaons and pions. Some of these decay[21] into muons, which reach the surface of the Earth and can be detected. The fact that large numbers of muons do reach the surface of the Earth, despite this transit apparently taking much longer than the half-life that they have when observed at rest[22], was one of the early observations that supported the theory of special relativity.

Following the discovery of radioactivity, measurement of radiation levels away from known sources lead to interest in the sources of this background radiation. It was supposed that such radiation must come from radioactive minerals in the soil, and perhaps from dust in the air. However, measurements at the base and at the top of the Eiffel Tower, by Theodor Wulf[23] in 1910, suggested that radiation flux increased with increasing altitude. This was confirmed by Hess in 1911, who measured increasing flux as he ascended to 5 300 m in a balloon. The citation[24] for his Nobel Prize (1936) is an interesting reflection on what was known, and what was not known, at the time. Hess won the Prize jointly with Carl Anderson. Anderson was honoured in 1936 for his discovery in 1932 of the positron, the anti-electron whose existence had been predicted by Paul Dirac; in 1936 he also discovered the muon. This work was done with cloud chambers.

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[16] http://helios.gsfc.nasa.gov/

[17] http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/051102a.html

[18] http://imagine.gsfc.nasa.gov/docs/science/know_l1/cosmic_rays.html

[19] http://helios.gsfc.nasa.gov/gcr.html

[20] http://en.wikipedia.org/wiki/List_of_particles

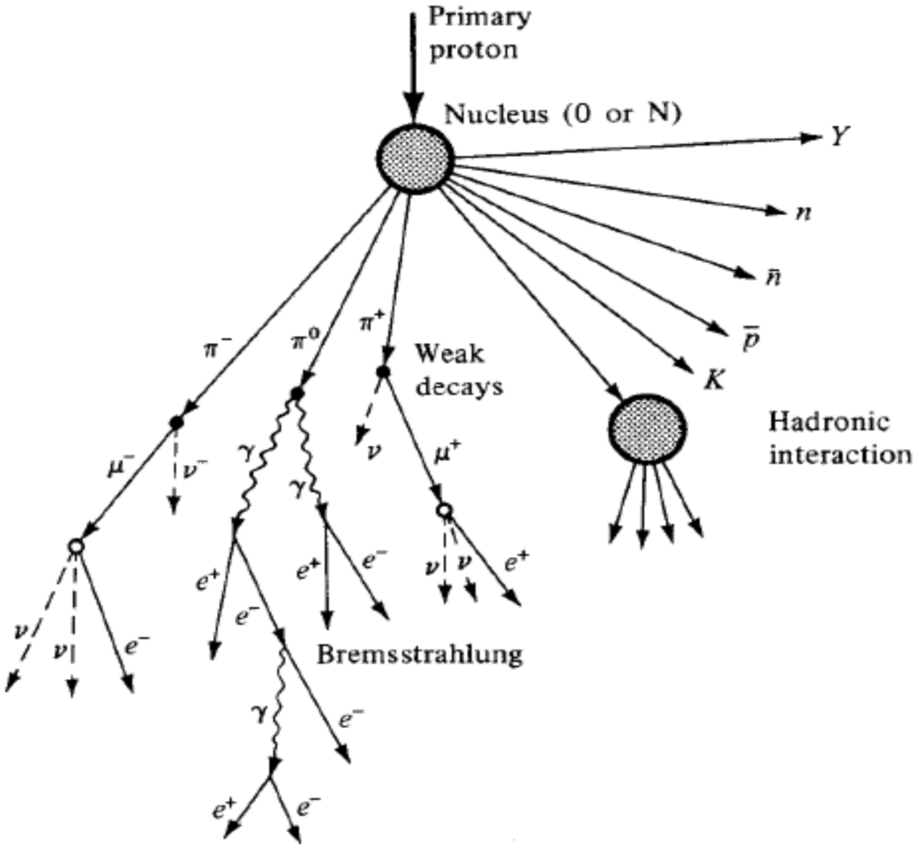
[21] http://hands-on-cern.physto.se/ani/part_fire/intro_eng.swf

[22] http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/muon.html#c1

[23] http://www.bonjourlafrance.com/france-tourist-attractions/eiffel-tower.htm

[24] http://nobelprize.org/nobel_prizes/physics/laureates/1936/press.html

As particle decays were identified and understood it became clear that muons, which of necessity could not originate very far from the point at which they were detected, were part of cosmic radiation decay sequences such as those illustrated here:



Taken from Lim B & Ruben D (2005), Investigation of Combined Positive and Negative Muon Decay in a Scintillator, Cornell University
http://www.cs.cmu.edu/~byl/publications/phys410%20lab2%20report.pdf

Section 7

A short history of cloud chambers

The earliest experimenters in particle physics, such as J J Thomson, the Curies and Rutherford, had a limited repertoire of techniques for following the tracks of particles. For example, they knew that:

> Charged particles passing through low-density gases produced a diffuse glow of light. Their kinetic energy was being converted into electromagnetic energy: what we would now call photons. This provided evidence of the movement of particles, but not precise information about trajectories.
>
> Charged particles hitting atoms in solids and liquids could cause light emission. This would show that particles were arriving at some position, but did not give information about their route from their source.

Charles Wilson, a Scotsman who studied in Manchester and went on to work with Thomson at Cambridge, introduced a highly effective new tool, the cloud chamber. Wilson was interested in the formation of clouds, and in electrical and optical phenomena associated with clouds. He developed the chamber in 1894-5, as a way of making small clouds in the laboratory. His cloud chamber contained a saturated vapour, ready to condense into liquid droplets. He used it for a variety of investigations into the formation and disappearance of liquid droplets from saturated vapour. In 1899 JJ THomson used a Wilson cloud chamber in the Cavendish Laboratoty to make an early estimate of the charge of an electron[25].

C. T. R. Wilson (1912)
Proc. Roy. Soc., A, vol 87, Pl.8.

In the first decade of the twentieth century, his fellow physicists were working on the task of identifying and describing the sub-atomic particles emitted by radioactive materials. Wilson realised in 1910 that his cloud chamber could contribute to this study. If an ionising particle passed through saturated vapour, the vapour would condense into droplets along the path of the particle, where ions provided nuclei for the condensation process.

Wilson's first design used air saturated with water vapour in a glass-walled chamber a few centimetres in diameter. The bottom of the chamber could be pulled downwards. This would allow the air and vapour to expand, but conservation of internal energy led to a reduction in the temperature of the gas and vapour[26]. At this lower temperature, the vapour was super-saturated and would readily condense. If charged particles, or electromagnetic radiation such as X-rays, passed through the chamber, liquid droplets would condense around the ionised atoms along the path of the particles. These tracks could be photographed from different directions, to provide a permanent record.

The tracks would show how far the particles went and whether their paths were straight, curved or erratic. Frequent changes of direction would indicate frequent interaction with gas molecules; alpha particles exhibit this behaviour. If the particles were charged, applying electric or magnetic fields across the chamber would cause them to move in curves. The shape of the curve would provide information about the size, sign (positive or negative), speed or mass of these particles. The appearance and disappearance of tracks in the middle of the chamber could indicate particle decays. The picture on this page is one of Wilson's[27]. It shows the paths of electrons ejected from atoms by X-rays passing through a chamber. Wilson received the Nobel Prize for Physics in 1927.

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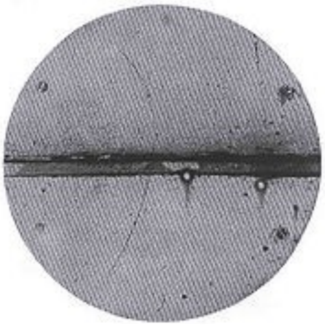
25 http://web.lemoyne.edu/~giunta/ea/THOMSONann.HTML

26 http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/firlaw.html

27 For more photographs, see: http://www.practicalphysics.org/go/Experiment_584.html;jsessionid=al-il9orCix9

Rutherford called Wilson's cloud chamber: "the most original and wonderful instrument in scientific history". [28] Not surprisingly, it was widely used and developed., by Carl Anderson among many others.

Anderson's cloud chamber photograph of a positron (e^+) *track*. Photo: wikepedia



The track is curved because the particle is charged and is passing through a magnetic field that is directed into the plane of the picture. The tighter curve of the track in the upper part of the photo shows that it is slower here. It entered from below and was slowed by the lead plate in the centre of the chamber. The fact that it curves left, rather than right, shows that it is positively charged.

Wilson's original design[29] was modified by Patrick Blackett (1897-1974, later Lord Blackett), who included a spring-mounted diaphragm that could be moved up and down several times per second. Each compression-decompression cycle provided the right conditions for particle tracks to form. Given the time and patience required to identify new and interesting tracks, this was a useful way of speeding up research work.

Blackett and the Italian physicist Guiseppe Occhialini (1907-93) also devised a way of linking a cloud chamber camera to a Geiger counter, so that it only took photographs when a particle was known to have traversed the chamber. Blacket received the Nobel Prize in 1948 for detecting strange particles in cosmic ray decays by using this system. Nowadays, triggering systems are key parts of detectors such as those in the Large Hadron Collider.

In 1936, the American nuclear physicist Alexander Langsdorf (1912-96) devised a variation of the cloud chamber: the diffusion chamber. This usually contains alcohol vapour, and is cooled from below, often with solid carbon dioxide ('dry ice'). Because the vapour in the chamber experiences a temperature gradient from top to bottom, there is a region which is always super-saturated. As a result, a diffusion cloud chamber can detect particles continuously[30], rather than only immediately after a pressure reduction. Langsdorf's design is widely used in schools[31] and can even be copied at home[32], given a source of dry ice.

[28] http://nobelprize.org/nobel_prizes/physics/laureates/1948/press.html

[29] http://www.rhunt.f9.co.uk/Experiments/Expansion_Cloud_Chamber/Cloud_Chamber_Page1.htm describes how to make a simple expansion cloud chamber. It has the advantage of not needing dry ice, but only gives 'snapshots' of particle tracks at the instant that pressure is reduced.

[30] http://upload.wikimedia.org/wikipedia/en/8/89/Cloud_chamber.ogg

[31] http://www.practicalphysics.org/go/Experiment_583.html?topic_id=40&collection_id=78

[32] http://teachers.web.cern.ch/teachers/document/cloud-final.pdf

Section 8

Thoriated welding rods

Thoriated welding rods have only a very low level of radioactivity and are part of the Schools' Standard Holding defined in CLEAPS[33] leaflet L93 http://www.cleapss.org.uk/download/L93.pdf. This document includes a model risk assessment for thoriated rods, as it does for other sources suitable for use in schools. Schools that do not normally hold radioactive sources or have a person designated to look after such material may wish to consult their local authority science adviser on the interpretation of CLEAPS advice, noting that thoriated rods are available for purchase over-the-counter by anyone.

Is it safe to carry these rods in your pocket? Common prudence would suggest caution, but Oak Ridge Associated Universities website (http://www.orau.org/ptp/collection/consumer%20products/weldingrod.htm) quotes an annual dose of 80 microsieverts (8 millirem, in US units) per year for a welder who carries 3 thoriated rods in a shirt pocket for 40 hours per week. Given that the mean UK dose from background radiation is 2 600 microsieverts per year, we need not worry unduly when using these rods for a few minutes.

These rods are used for TIG (Tungsten in Inert Gas) welding, on aircraft for example[34]. The thorium reduces the electrical resistance of the tungsten rod and decreases the extent to which the rod material contaminates the weld. You may come across references to the health hazards associated with thoriated welding rods A very small quantity of thorium is vaporized as a welding rod is used, and small quantities are released when the tip of the rod is reground between uses. Neither of these hazards arises when using the rods as alpha sources. You may wish to demonstrate good practice by handling the rods with tongs, but they are a clumsy method of picking up rods. It might be preferable to ask your pupils why handling weak alpha sources with bare hands (or gloves?), as a welder would, is acceptable.

When buying rods, you will be looking for "thoriated red tungsten welding rods". The red tip indicates that they contain 2% thorium. Yellow-tipped (1%) rods exist, apparently, but I have not seen them offered for sale. Orange-tipped thoriated rods contain 4% thorium and are considerably more expensive; you won't need them unless you plan to weld a new container for your nuclear reactor.

For our purposes, it does not matter whether thoriated rods are made for use with AC/DC or DC only (the latter are cheaper) , and the 1.6 mm diameter will do fine. Prices seem to vary widely, but hey should cost around £4 for a pack of 10; alternatively, you can buy bulk packs of 200 or more for under £20:00 if you are looking for an unusual Christmas present.

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[33] CLEAPS leaflets are normally available only to organisations that subscribe to the service, but this one is available to the public.

[34] http://www.ridgenet.net/~biesiade/weld.htm

Section 9

Other uses for dry ice

Buying dry ice will probably be the largest single expense for a school when borrowing a cloud chamber. Unless you plan to load the chamber several times over several days, you will almost certainly have surplus ice. Listed below are some websites that suggest other uses for the spare ice. Many of the ideas are essentially demonstrations of the large increase in volume (or decrease in density) that occurs as the ice sublimes. There are others, such as using CO_2 in a balloon to focus sound waves, which provide simple demonstrations of phenomena that we otherwise only describe.

I have looked at all these sites, and all seem to be safety-conscious, but you will want to assess hazards and risks for yourself, in the light of your intended venue and audience. The obvious hazards are to bare skin from very cold ice, to respiration from a build-up of gaseous CO_2 at ground level and to 'life, liberty and the pursuit of happiness' from explosions when solid CO_2 sublimes in a sealed container.

Brian Wesley Rich's Science Website at http://www.west.net/~science/co2.htm. His link to Youtube clips of accidents with dry ice is worth following.

There is a good section on the Deep Science site, although I can't vouch for the stuff on the home page: http://www.deepscience.com/experiments/dryiceday.html

The ideas on Steve Spangler Science are presented as Halloween entertainment, but they include a kit list and could be talked up into something suitable for discussions of states of matter, density and so on. See: http://www.stevespanglerscience.com/experiment/awesome-dry-ice-experiments

Continental Carbonic's site offers good safety advice and ideas for CO_2-filled balloons, at http://www.continentalcarbonic.com/dryiceexperiments/index.php

Rockit Science offers a really cool (sorry) video, with a narrative approach to using dry ice: http://www.rockitscience.com/videos/videodryice.html

Science Castle has videos of several different demonstrations: http://sciencecastle.com/sc/index.php/scienceexperiments/search?p=0&t=m&v=mr&c=0&cl=13

A good, hands-on project is to build your own comet. The recipe below came via Anu Ojha, Director of Education and Space Communications at the National Space Centre in Leicester:

Comet Ingredients

Water in a jug (about half the amount of dry ice)
Bin liners Dry Ice (about 2-3 x 600ml container fulls)
1 Spoonful of sand 1 Spoonful of carbon dust
Few dashes of worcester sauce (organic component);
Few dashes of whisky/red wine (optional – the methanol/ethanol component)
Bowl Disposal Bucket Rubber Gloves Wooden Spoon
Clear screen Polystyrene container for dry ice

Method

1. Take a bin liner and use it to line the bowl.
2. Add the ingredients of your comet – water, sand, carbon dust, worcester sauce. These replicate the compounds that real comets are composed of. Volunteers of the audience can add some of these. Mix well with wooden spoon.

A note on the significance of the ingredients:

- WATER - how comets have large amounts of H_2O, and in the past it is believed comets could have brought water to earth!
- The SAND, The CARBON, ALCOHOL, and the WORCESTER SAUCE for the organic component. Comets have all the right ingredients for life, but the mixture is not under the correct conditions for life to exist.
- THE DRY ICE – frozen CO2, the frozen gas that holds together our comet and sublimates when it interacts with the solar wind and solar radiation to form the coma and gas tail.

3. Finally add the dry ice. Wearing gloves feel around the bin liner and mould the comet into one lump. Don't compress it too hard as the comet may break, allow steam gas to escape.

4. When the demonstration is completed place the comets inside the bin liner in a bucket.

Safety Precautions

1. When handling the dry ice wear gloves and goggles. Do not touch, swallow or taste the dry ice. Do not allow students too near the dry ice. Give the audience clear instructions on the hazard and the distance they should be seated form the dry ice as the comet may 'spit'
2. Do not seal the dry ice into a container as explosive outgassing may result!
3. Transport dry ice in a plastic bag inside a box.
4. Dispose of comet outside in a well-ventilated area where students can't access it.

The Science

Dry ice is frozen Carbon Dioxide (-78.5°C, or -109.3°F), or CO_2, which is a gas under standard temperature and pressure conditions. The atmosphere contains about 0.035% of this gas. CO_2 is a greenhouse gas, which means it absorbs light at infrared wavelengths. An increase in the concentration of this gas may cause an increase in the atmosphere's average temperature. The high concentration of CO_2 (>96%)in the atmosphere of the planet Venus contributes to that planet's high average temperature.

At normal atmospheric pressure on this planet, frozen CO_2 doesn't melt into a liquid, but rather evaporates directly into its gaseous form - hence the name 'dry ice'. This process is called sublimation and is responsible for the formation of a comet's coma. We can see CO_2 gas subliming away from our comet from where water vapour in the air condenses around it.

Section 10

Sources of material: solid CO2 and thoriated welding rods

We have no connection with any supplier. If you find any one to be particularly helpful, please tell us.

Dry Ice

Schools can buy a box of dry ice to use with the cloud chamber from the University for £25:00. It may be a good idea to time the purchase so surplus dry ice can be put to good use: see Section Nine above.

Air Liquide has produced a useful set of safety guidelines for working with dry ice. You may wish to discuss this with pupils: http://www.uk.airliquide.com/file/otherelement/pj/guidelinesforsafetransdryice44602.pdf

For advice on CO2 cylinders and on making solid CO2 see the Institute of Physics website. Specifically:

http://www.practicalphysics.org/go/Apparatus_348.html

http://www.practicalphysics.org/fileLibrary/mov/making_dry_ice.mov

and the Nuffield Foundation's Practical Physics site:

http://www.practicalphysics.org/go/Guidance_24.html?topic_id=$parameters.topic_id&collection_id=%24parameters.collection_id

Note that you need a CO2 cylinder with a diptube. Such cylinders are normally marked with a white line, running the length of the cylinder, on either side[35]. The tube goes to the bottom of the cylinder and delivers liquid CO2 to the nozzle; cylinders without diptubes deliver gaseous CO2 from the space above the liquid. The advantages of the diptube when making solid CO2 should be clear to A-level students who have studied kinetic theory and adiabatic expansion.

Air Liquide sells 'Snowpacks', with which you can make dry ice using a CO2 cylinder:

http://www.uk.airliquide.com/en/products-and-services/equipment.html

There are many companies selling ice and some also sell dry ice. Suppliers delivering in the West Midlands include:

Air Liquide Ltd: http://www.uk.airliquide.com/en/products-and-services/dry-ice/our-expertise-3.html

Green Gases Ltd: http://www.green-gases.com/schools.htm

Linde Gas UK Ltd: http://www.cylex-uk.co.uk/company/linde-gas-uk-ltd-13448936.html

It should cost about £40:00 for 10 kg of ice pellets - rather than a slab, which you would have to cut - delivered in a coolbox. Note that 5 kg may be no cheaper than 10 kg. Keep this in the coolest place that you have available. From experience, it should last for at least three days after delivery, provided that the polystyrene box is closed and resealed after ice is removed.

Thoriated Welding Rods

A list of suppliers of welding equipment in the West Midlands can be found at: http://www.iwestmidlands.co.uk/local/welding-equipment-sales-and-service/ or try 'thoriated welding rods suppliers west midlands' in a search engine.

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[35] http://gascylindersuk.co.uk/pages/cylinder-chart.php