Design and Construction of Thermal Diffusion Cloud Chamber

A Senior Project

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Bachelor of Science

By

Alexander Donoghue

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Abstract:

This paper will cover the theory behind a thermal diffusion cloud chamber. In addition to that it will cover the process, thought and material used to construct two different cloud chambers. It will also discuss the effects of materials used in each chamber on the working of the chamber.

Theory / Background:

The first cloud chamber was invented by Charles Thomson Rees Wilson. He was a Manchester and Cambridge University educated Scottish physicist. (1)   His chamber consisted of enclosed chamber filled with water vapor with a transparent window at one end. The pressure inside the chamber was increased rapidly causing the water vapor to supersaturate. For his creation he received the 1927 Noble Prized in Physics. (2) The Wilson chamber was improved upon by Patrick Maynard Stuart Blackett who won the 1948 Nobel Prize in Physics for improving and extending the use of that chamber. (3)

Cloud chambers are separated into two main categories based on how they work. Both types of chamber use vapor contained in a sealed box. The first type of chamber uses a quick change in pressure to cause the vapor to supersaturate. These are know as Wilson chambers. The other type uses a temperature difference between the top and bottom of the box to create a mass flux within the chamber. A mass flux is a flow of mass, in our case ethanol vapor, through a region with a certain direction; similar to magnetic flux but with mass rather than magnetic field. This mass flux starts at the warmer end of the chamber and flows toward the colder end of the chamber. Causing an increase in the pressure at the colder end of the chamber; the increased pressure causes the vapor in that area to become supersaturated.

Supersaturation for a vapor occurs when the partial pressure of the vapor exceeds the equilibrium partial pressure of the vapor; that is to say when the vapor pressure of ethanol inside the container is greater than the vapor pressure of ethanol would be in atmospheric conditions. Supersaturation is an unstable condition for the vapor to be in. When an impurity is added to the region that is supersaturated it will cause the vapor to condense into liquid. In a cloud chamber the impurities are caused by ions left behind by charged particles passing though the chamber. These ions serve as places for the vapor to condense; leaving behind a string of liquid droplets or tracks. The vapor also condenses on random impurities in the air of the container; creating a background cloud. The tracks look like a line of water drops, much darker than the background cloud. These tracks can easily be seen by the naked eye; allowing a person to see the effects of the unseen atomic particles.

The particles that will cause tracks to form in the chamber are α-particles from the decay of Radon gas in the chamber, slow electrons from environmental processes, secondary muons and Compton scattered electrons, and particles from cosmic ray collisions in the upper atmosphere. Those particles will leave different types of tracks. Alpha particle will have very short and dark tracks due to their high charge and short mean free path. Electrons, β-particles, and muons will have similar tracks due to their similar charge. (4)

Design, Construction, and Testing:

Before we started to design and build our own cloud chamber some research was done into the effects of certain materials on the operation of the chamber. Steve Soderberg (Cal Poly Physics Tech) had a demonstration cloud chamber that was used to due those tests. It is an A. U. Physics Enterprises Diffusion Cloud Chamber. The chamber consists of a plastic cylinder with a removable lid. The lid is clear to allow the viewing of the tracks. To illuminate the tracks created six amber LEDs imbedded in the bottom portion of the cylinder. The bottom of the chamber is cooled by a solid state cooling device (Peltier Device); the heat created by the Peltier Device is removed by cold water pumped through a heat exchanger connected to the hot side of the Peltier Device. There is also a paper wall liner that lines the inside of the cylinder; it covers the entire inside of the cylinder.

Different types of material for the wall liners were tested using this cloud chamber. Using the liner provided with the chamber a baseline was found to compare the other materials to. The first material tried was white wool felt, McMaster Carr part # 8334K15. A ring with a 15 mm difference in the inner and outer diameters was cut out of the felt in order to line the bottom of the chamber. This is will be referred to as configuration #1. So looking down on the chamber there is a ring of felt stretching from the outer edge of the chamber 15 mm towards the middle, leaving a circle in the middle of the chamber bottom not covered in felt. A picture of this can be seen in figure one.
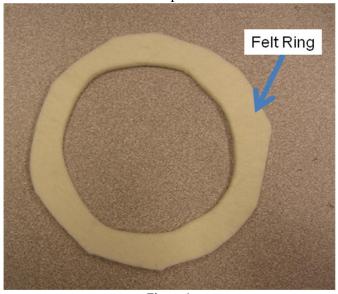

Figure 1

Figure one is a diagram showing the first configuration of the felt wall liner used in the demonstration cloud chamber. It consists of a ring of felt at the bottom of the chamber.

The idea behind this configuration was that the felt would soak up the ethanol and bring it to a higher temperature, allowing the ethanol to evaporate and rise to the top of the chamber replenishing the vapor that flowed to the bottom of the chamber. To test this configuration the chamber was filled with enough ethanol to cover the bottom of the chamber with ~2mm deep pool. After running the chamber for 30 minutes no cloud appeared, however when the lid of the chamber was removed a faint cloud was created

for a few minutes and there were particle tracks visible in the cloud. The cloud was caused by the ethanol vapor at the bottom of the chamber being pulled to the top by the suction created by the removal of the lid. Then as the vapor cooled it fell back to the bottom of the chamber and supersaturated; creating a cloud and particle tracks.

The next configuration, # 2, tested used the same felt cut into two strips, 2 cm wide strips and as tall as the interior of the chamber. After running the chamber for 30 minutes a cloud formed that was fainter than the one formed opening the lid with the felt ring at the bottom. Tracks could be seen but were very faint.

After finishing that test, two 2 x 12 cm pieces of felt were cut and placed around the bottom of the chamber, configuration #3, so the bottom two cm of the wall of the chamber would be lined leaving the top of the chamber unlined. The cloud that was formed with this wall liner was of similar strength to the one created with the two felt strips extending from the top to the bottom of the chamber.

From these tests it was concluded that the original wall liner worked the best followed by the configuration #3 then configuration #2. With configuration #1 being the worst, it did not create a cloud in the chamber.

In addition to those conclusions, we conclude that there needs to be a significant pathway for the ethanol to travel from the bottom of the container to the top. The type of material used for the liner has a significant effect on the amount of ethanol that can be transported from the bottom to the top of the container. In addition to the material that was used to make the liner the shape of the liner affected the strength of the supersaturated layer. We also learned that the lighting of the cloud and tracks should be done close to where the cloud and tracks are formed. Also the chamber needs to have some way of viewing the tracks created.   Using the information learned in these tests we started to design our own cloud chamber.

A suitable container for a cloud chamber should have some way of opening and closing the camber so that the alcohol can be introduced and removed from the chamber without much difficulty. It should also be chemical resistant; the alcohols used in cloud chambers can be caustic to certain materials. The chamber should have some way of viewing the tracks created in the supersaturated zone. Instead of using a container with one clear side to view the tracks, we decided to use an entirely clear chamber which would allow for the tracks to be seen from multiple angles. It would also allow for extra material to be put in the chamber and not have that material block the only way to view the tracks. A less important feature was that the chamber should not be too hard to work with. We do not have access to an extensive machine shop to do a significant amount of machining. Time would be saved if we could do work on the chamber in the limited Physics Department machine shop.

The first idea for a chamber was a bell jar. Bell jars are used to create a vacuum in which experiments or processes can be run. They are usually made of glass, can be sealed, and are chemical resistant. The jar meets the requirements laid out above for a cloud chamber container. However, upon doing some research into bell jars it was found found out that they were very expensive and only come in small sizes, 6 inch diameter. A larger chamber would allow for a larger number of tracks to be created and seen.

With bell jars ruled out as chambers another other container was needed to use as the chamber. After some discussion a kitchen storage container was selected. This was chosen because they come with a lid that seals the container, forming an airtight chamber,

they are easily procured, cheap, easy to work with, clear and chemical resistant. A Glass Lock Container was purchased from Bed Bath and Beyond. The container measured 6" X 6" X 2 ¾", had a locking lid with a rubber seal, and the rest of the container excluding the lid is made of clear glass.

Dry ice was chosen to cool the bottom of the chamber. It is easy to use; it can be placed on a countertop with the chamber placed on top of it. It is also inexpensive and readily available. The physics department has a device for making dry ice out of compressed CO_2 gas. Dry ice does have one downside; it will only cool the chamber for a limited amount of time. That problem will be addressed in later designs of the chamber. The stock kitchen storage container was modified due to of the insulating nature of both the glass and plastic components of the kitchen storage container box. If the container lid or glass side was set on dry ice the chamber would not get cold enough because the glass or plastic lid would insulate the inside of the chamber from the dry ice. To increase the cooling of the chamber a copper plate was installed in the lid of the Glass Lock Container. A hole was cut in the lid (4" x 4") and a copper plate of the same size was glued in to the hole, as shown in figure one. The cutting of the copper plate and the hole in the lid was done by David Arndt (Physics Department Tech). The epoxy that was used was purchased from McMaster Carr, 'Epoxy in a Squeeze Tube'.
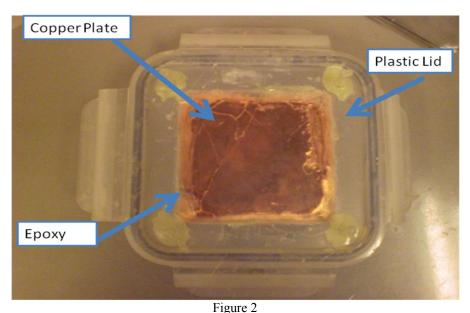

Figure 2
Figure two is a picture of the outside of the plastic lid of the Glass Lock container box with a copper plate glued in using epoxy.
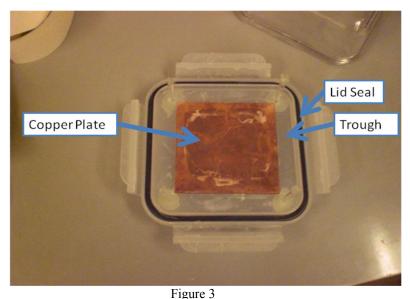
Figure 3
Figure three is a picture of the inside of the plastic lid, showing the copper plate, trough and lid seal.

The plate was glued in so that the plate would be flush with the outside of the lid. This creates an area where the ethanol would pool. We expected the copper plate to cool the vapor in the box causing it to diffuse downward and condense on the plate. The liquid would then run off into the trough, shown in Figure 3. It was though that there might be a temperature difference between the copper plate and the trough. We hoped that this temperature difference would allow the ethanol evaporate and rise to the top of the chamber; replacing the vapor that would be flowing toward the bottom of the plate. This would create a circular mass flow inside the chamber, allowing continuous operation of the chamber, until the dry ice all sublimated.

To test this configuration the trough in the lid was filled with enough ethanol to create about a 1mm pool. The container was sealed and placed on a puck of dry ice. Four minutes into the test, bubbles were seen coming through the epoxy between the lid and copper plate. Bubbles were also seen coming through the seal between the lid and the glass box. Both sources of the bubbling stopped after four more minutes. At this point the amount of ethanol in the trough had reduced significantly. It appeared that the ethanol had leaked past the holes in the epoxy where the air had bubbled in earlier. The test was ended and the ethanol was removed from the chamber. After the ethanol was removed the epoxy seal between the copper plate and the lid was inspected. It was very brittle and the two pieces were separated with little effort. The remaining epoxy was easily removed from the lid and the copper plate. The conclusion was drawn that the ethanol had reacted with the epoxy and caused it to loosen its bond with the plate and lid. The lid seal that was used in this test was not the original seal that came with the container. The original seal was removed and replaced with an o-ring ordered from McMaster Carr. This was done because it was thought that the original seal would not be able to withstand the ethanol.

The second of these two problems was easily fixed. The o-ring was removed and replaced it with a length of Viton Fluoroelastomer Rubber Bulb Seal. The shaft of the P

seal was removed leaving just the bulb. The ends were glued together with Gorilla Super Glue to form a continuous ring. That ring was placed in the position for the seal in the lid.

To solve the problem with the seal between the copper plate and the lid the same epoxy was used to glue the lid and copper plate back together. When the epoxy dried the space between the copper plate and lid on the inside of the lid was sealed with silicone, GE Premium Waterproof Silicone Caulk. This way the ethanol would contact the silicone caulk rather than the epoxy. The hope was that the silicone would withstand the deleterious effects of the ethanol.

The same procedure was used to test the new gluing configuration, ~1mm ethanol in the trough and the chamber was placed on a block of dry ice. After 30 minutes no cloud was visible in the container. The only change was the increase in the amount of fluid that had condensed on top of the copper plate inside the container. At this point in the test this gluing configuration had outperformed the previous one used. We had also concluded that there was not a significant pathway for the ethanol to travel from the bottom to the top of the chamber. The chamber was removed from the dry ice and opened to add a pathway for ethanol to travel from the bottom to the top of the chamber. While the chamber was apart the seal between the copper plate and lid was inspected and it was noticed that the seal had been degraded and was not providing an adequate seal. The two parts were easily separated from each other; it was concluded that the silicone did not stop the breakdown of the epoxy caused by the ethanol.

 In order to find glue that would not be degraded by ethanol, Dr Dane Jones and Dr Ray Fernando of the California Polytechnic State University Chemistry Department were consulted. They suggested using Gorilla Glue to seal the copper plate to the lid. Using the Gorilla Glue the copper plate was glued on to the lid of the Glass Lock container. After the glue had set the seal was tested by filling the container with water and turning the chamber over so that the water was on the seal between the lid and copper plate. This test was done because the glue had a significant number of bubbles in it and the holes could form a pathway from the inside of the chamber to the outside. When the box was turned over water leaked through the Gorilla Glue. The copper plate and lid were separated to allow for a second gluing with Gorilla Glue. The second time pressure was applied to the copper plate while the glue was setting. It was thought that the pressure would reduce the amount of bubbles in the glue eliminating any leaking. After the glue had set the same test was performed; water leaked through the Gorilla Glue. After the two tests it was decided that Gorilla Glue would not be a good glue to use for the seal between the copper plate and the lid.

The next glue that was tested was Loctite Quick Set Epoxy. The epoxy was chosen because it is described as 'water and solvent resistant', it was hoped that this epoxy would withstand the ethanol used in the chamber. After using the epoxy to glue the copper plate to the lid the seal was tested by adding ethanol to the chamber and setting in on the table. The chamber was not replaced on top of a block of dry ice. This test was done to test the resistance of the epoxy to the ethanol. After one hour and 45 minutes later the seal was not leaking. At this point we were satisfied that the epoxy would not be degraded by the ethanol. Next a paper wall liner was placed in the trough of the lid and the chamber was placed on a puck of dry ice. After 30 minutes with the chamber on top of a dry ice puck ethanol was leaking out of the chamber past the seal between the copper

plate and the lid. This meant that the ethanol was not causing the breakdown of the glue rather it was the low temperature of the dry ice.

During the tests of the glue different wall liners were tested, creating a path for the ethanol to move from the bottom of the chamber to the top. The first material that was used was construction paper; the paper was similar in weight to the liner in the A. U. Physics Enterprises Diffusion Cloud Chamber. A strip 12 inches x 2.25 inches was cut from the paper. The strip was bent so that it would stand up vertically in the chamber. The liner can be seen in Figure 4.
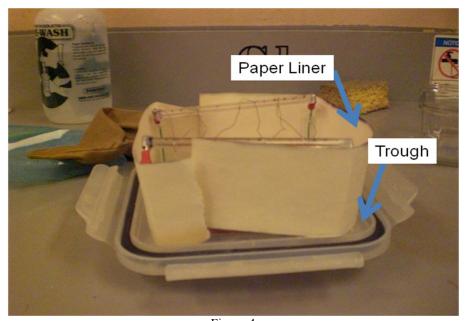

Figure 4
Figure four is a picture of the chamber lid with the paper wall liner standing in the lid trough

The paper wall liner was tested after the completion of the glue test without the chamber placed on the dry ice. The trough was filled with ~1mm of ethanol, the paper wall liner was soaked with ethanol and the chamber was placed on top of a puck of dry ice. Fifteen minutes after starting the test a cloud could be seen in the chamber. The cloud was fainter than the one created in the A. U. Physics Enterprises Diffusion Cloud Chamber. Over the next fifteen minutes a few tracks were visible by they could have been an illusion due the fact that the inside of the glass was very dirty. The test was ended at this point due to ethanol leaking past the seal between the copper plate and lid.

To prevent the destruction of the glue seal the decision was made to try and achieve the same temperature gradient without using dry ice to cool the bottom. In order to do this the top of the chamber needed to be heated in some way.

A 50 foot roll of Omega Engineering Incorporated heating wire was purchased to construct a heating wire array. The wire creates heat when a current is run through it; the amount of heat created is directly related to the amount of current running though the wire.

To hold the heating wire inside the chamber and at the top of the chamber, electrical wire, glass tubes, four 22-18 gauge snap connectors and Loctite Quick Set Epoxy were used; the epoxy used was the same as used to glue the copper plate and the

lid together. Four holes were drilled in the four corners of the trough; the holes were slightly larger than the 6mm outer diameter of the glass rods. Four glass rods 6.5 cm were cut out of the larger lengths of tubing. A length of wire was fed through the glass tubing, and then a snap connector was attached to one end of the wire. The glass rods were then glued into the four holes in the lid using the Loctite epoxy, leaving a few millimeters between the top of the glass box and the end of the snap connector. To create a heating wire array seven 4 3/8 inch wire segments were cut from the roll of Omega heating wire, then using Bernzomatic Metal Work Acid Core Solder they were soldered together in a ladder pattern. With two segments forming the sides of the ladder and five segments forming the rungs of the ladder, each rung was separated by one inch. The array was connected to a power supply, with current and voltage adjustments, to test its heating capabilities. When the voltage was tuned up and it hit a plateau and would not increase. This happened because the power supply had current limited, maxed out the current provided by the supply. This indicated that the resistance value of the wire array was too low; not allowing the proper amount of voltage across the wire. To remedy this problem certain portions of the wire array were cut out in order to create one long wire. Alternating portions of the two rails of the ladder were removed to do this, forming a zigzag pattern. After doing this the wire was no longer flat, it had bent so that it almost touched the copper plate. This arrangement would not create a uniform heating of the top of the chamber; leading to a non-uniform mass flux. That would not lead to a layer of supersaturation. To keep the wire at the top of the chamber two pieces of glass tube were glued horizontally between the vertical glass tubes glued in to the lid. This created two rails that the heating wire could be wrapped around. This can be seen in figure four.
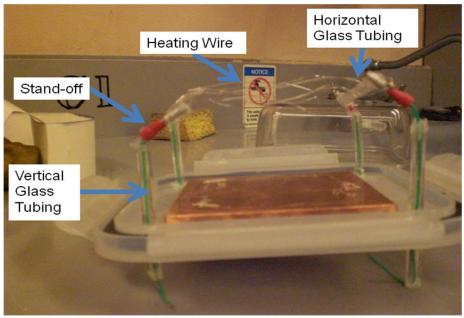

Figure 5

Figure five is a picture of the chamber lid with the vertical glass tubing, horizontal glass tubing, heating wire, and stand-off labeled. The heating wire is wrapped around the horizontal glass tubing and connected to the stand-offs so they can be connected to a power supply.
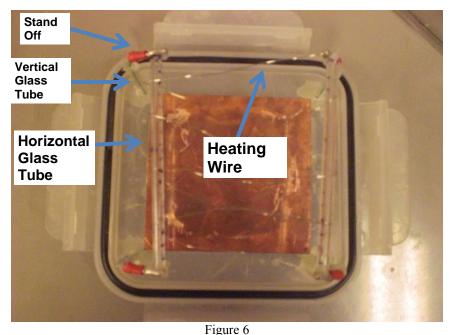
Figure 6
Figure six is a picture of the lid of the Glass Lock Container; showing the vertical and horizontal glass tubes, heating wire and standoffs.

To test the heating wires' effect on the creation of a supersaturated layer the trough was filled with ~1mm of ethanol. The paper wall liner used in previous tests was inserted into the chamber and soaked with ethanol. The chamber was placed on top of a beaker full of ice and brine; the beaker had enough ice in it so that the ice would be touching the copper plate. The heating wire array was then connected to a power supply and the current was turned up to 0.6 Amps. After 20 minutes condensation appeared on the inside of the glass and no cloud was visible in the chamber. Ten minutes later more ice was added to the beaker. Another 44 minutes passed with no changes. The test was ended after that. At the end of this test the conclusion was drawn that no cloud was formed because the temperature gradient was not large enough or the heating wire had heated the whole chamber not allowing for a temperature gradient. The latter was supported by the appearance of condensation on the inside of the chamber. To check the validity of the second conclusion the same test was run again with the current running through the wire reduced to 0.3 Amps. The test was run for 48 minutes and there was no cloud in the chamber or condensation on the inside of the glass. From this test the second conclusion drawn in the previous test, over heating of the chamber, was eliminated as a cause for the lack of cloud in the chamber, leaving the first conclusion as the only reasonable cause for the lack of cloud in the chamber. To check the validity of the first conclusion, lack of temperature gradient, the chamber was removed from the ice and brine filled beaker and placed on a puck of dry ice. The heating wire amperage was turned up to 0.6 Amps. After ten minutes of this a cracking noise could be heard emanating from the chamber. This was assumed to be the epoxy breaking away from the copper plate; the aroma of ethanol was present around the chamber and there was no cloud in the chamber. For the next 20 minutes the cracking continued and there was no

cloud. At the end of those 20 minutes a majority of the ethanol had leaked out of the chamber and the test was stopped.

At this point in the testing the decision was made to use a different container for a cloud chamber. This was done because of the problems had with the Glass Lock Container used with for a chamber. The glue between the copper plate and lid kept being degraded by the cold temperature. A different chamber that did not use glue to affix the copper plate to the bottom needed to be found. Using any type of glue to attach the copper plate to the chamber was ruled out because of the difficulties experienced with the previous chamber. To solve this problem the new container would have a copper plate covering one side of the container, so no glue or epoxy would have to be used to seal the copper to something else. A White Label Lucite Tissue Cover was purchased. The box was chosen due to it being clear, easy to machine, square, and chemical resistant. The box needed to be square so that that amount of machining needed to be done to copper would be reduced (it is much easier to cut a square rather than a circle or other shape).

To affix the copper plate to the box four holes were drilled into the copper plate and in the Lucite box. The holes in the box were drilled in the top edge of the Lucite box; threaded posts were inserted into the holes. The posts would pass through the copper plate and protrude from the top of the chamber. Nuts were threaded onto the posts so that the copper plate could be tightened on to the Lucite box, forming a better seal.

Two materials were used to make the seal between the copper plate and the Lucite box. The first was two rubber o-rings. One o-ring could not be used because it was too small to stretch around the entire circumference of the box; instead two o-rings were cut and glued together; forming one larger o-ring. Then the o-ring was glued onto the top of the Lucite box using Gorilla Glue Super Glue. After the glue had dried the box was filled with water and the copper plate was tightened onto the box. When the box was turned over no water leaked out of the box, indicating that the seal was working. However, when ethanol was added to the chamber it leaked past the seal. After removing the ethanol from the chamber the o-ring seal was removed from the top of the chamber. It was replaced with a P shaped rubber seal. The leg of the P was glued to the inside of the box, so that the round part of the seal would be resting on the top of the copper plate, nuts, threaded post and P seal can be seen in figure five.
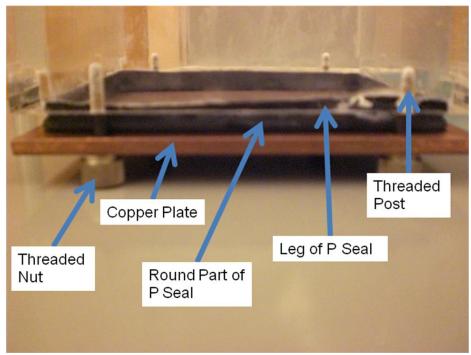
Figure 7

Figure seven is a picture of the bottom part of the chamber made out of the Lucite box; showing the threaded nuts, copper plate, the two parts of the P seal, and the threaded posts.

The new seal was checked by adding ethanol to the chamber and turning it over; no ethanol leaked past the seal.

To move the ethanol from the bottom to the top of the chamber different materials were tested. The first to be tested was white construction paper. Four 150mm x 30mm strip were placed in the four corners of the box, configuration #4. They can be seen in figure eight. The four strips were chosen to allow for viewing of the cloud from all angles. A full paper wall liner, similar to the one in the A. U. Physics Enterprises Diffusion Cloud Chamber, would not have allowed for the viewing of any tracks created in the chamber. This wall liner was tested by filling the Lucite box with ethanol so a ~1mm pool would be on top of the copper plate and soaking the wall liner with ethanol. After sealing the box it was placed on a puck of dry ice. Six minutes in to the test a faint cloud appeared and faint tracks could be seen. Nine minutes later the cloud disappeared. After this test the conclusion was drawn that the ethanol was not being transported to the top of the chamber from the bottom. So when the ethanol evaporates from paper at the top of the chamber it is not replaced by more ethanol from the bottom of the chamber. This paper wall liner was removed from the chamber. The next liner that was used was heavier construction paper (Mi-Teintes). This time slightly larger strips were used, 6cm x 16.5cm, to line the four corners of the chamber in the same way as configuration #4, this will be referred to as configuration #5. Testing of this liner was done using the same process as with the previous wall liner. After four minutes a faint cloud and tracks were visible, four minutes later the cloud and tracks disappeared. Again the conclusion was drawn that not enough ethanol was being transported from the bottom to the top of the chamber. The next material that was tested was wool felt; four 150mm x 30mm strips were glued to the corners of box. The strips were glued vertically along the corners,

configuration #6, in the same ways that the tests of configurations #4 and #5 were done. This wall liner was tested using the same method as the previous wall liners. Fifteen minutes after starting the test a cloud formed, denser than the clouds created with other wall liners. However, the cloud disappeared after another 30 minutes passed. Again the conclusion was drawn that not enough ethanol was moving to the top of the chamber from the bottom. The cloud lasted longer due to the increased amount of ethanol held in the felt at the top of the chamber. The idea of transporting the ethanol from the top to the bottom of the chamber was discarded; rather the amount of ethanol held at the top of the camber would be increased. To do this four 2cm wide strips were used to line the top of the chamber. This configuration, #7, of wall liner can be seen in figure nine. When this liner was tested the cloud lasted for one hour; the test was stopped at that point.

Out of the four wall liners #7 performed the best; it had the cloud that lasted the longest. #6 produced a similar cloud to the #7 but it did not last as long. Configurations #5 and #4 produced a much weaker cloud.
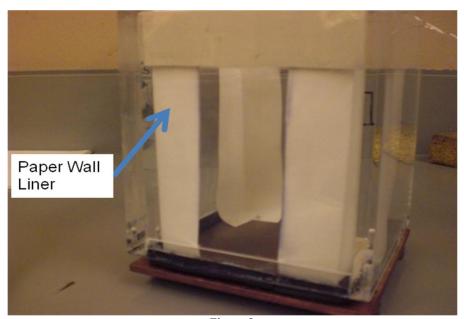

Figure 8

Figure eight is a picture of the Lucite box chamber with paper wall liner shown. This liner is the first of the three liners tried in the vertical configuration. Each of the subsequent wall liners were placed in this configuration.
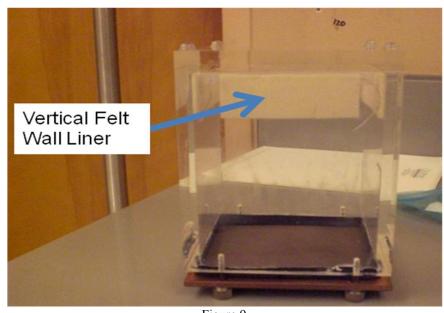
Figure 9

Figure nine is a picture of the Lucite box chamber with the horizontal felt wall liner shown.

During the wall liner tests a flash light was used to illuminate the chamber and view the tracks. The tracks and cloud could only be seen if the light was shined in the direction the viewer was looking into the chamber. The viewing of the tracks in the chamber was hampered by the glare from the copper plate and the surrounding light in the room. To solve this problem black paper was taped to the outside of three sides of the chamber and to the inside surface of the copper plate. The black paper made it much easier to see the cloud and tracks. However, when the chamber was taken apart the ink from the black paper had run causing the ethanol to be black rather than clear. The black paper inside the chamber was replaced with brown paper that did not bleed ink.

To attempt to create a greater temperature gradient and therefore a greater region of supersaturation, a heating wire array was installed in the top of the chamber. To do this two 10mm x 10mm x 108mm pieces of Lucite were cut from the unused lid of the Lucite box. Ten holes were drilled in these pieces, 10mm apart with the last one 5mm from the end. The wire guides were glued to the top of the chamber; two holes were drilled to the side of the Lucite box to allow the heating wire to pass from the outside of the box to the inside. The Omega heating wire was strung through the wire guide in a shaking pattern. The wire guides and wire can be seen in figure ten.
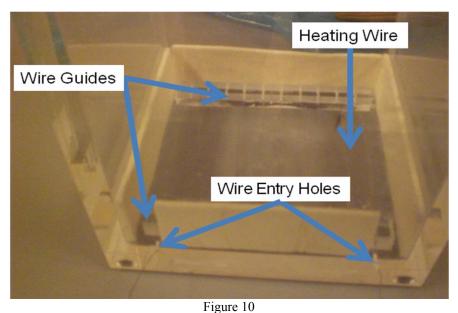
Figure 10
Figure ten is a picture of the top of the Lucite chamber showing the heating wire, wire guides and wire entry holes.

The heating wire tests were run at the same time as the wall liner tests. During the test of the second paper wall liner (configuration #5) the heating wire had 0.6 Amps running through it. The addition of the heating wire did not improve the strength of the cloud. It was the same strength as the cloud formed with configuration #4, which had no power running to the heating wire. The heating wire had 0.6 Amps running through it when configuration #6 was in the box and the effect was minimal. To test the effect of the heating wire on the cloud the heating wire was turned off and on for a period of time during a test. With the horizontal felt wall liner in the box the current in the heating wire was turned up to 1.6 Amps. Three minutes after the test was started a cloud could be seen but it did not flow downward and it was not a solid cloud. Rather the cloud was in vertical ribbons in the chamber. After another two minutes the cloud started to flow downward and there was a significant amount of condensation inside the chamber, mostly towards the top of the chamber. It was concluded that the chamber had been overheated by the heating wire, not allowing for the mass flux to flow toward the bottom of the chamber; the heating wire was tuned off and the chamber was allowed to cool down. After the chamber had cooled the heating wire was turned on so that 0.5 Amps running through the heating wire and the horizontal felt wall liner soaked with ethanol. Five minutes later a faint cloud and faint tracks could be seen. After another five minutes the current in the heating wire was turned up to 1.0 Amps. One minute later the cloud became much denser but no tracks were seen. The current was turned up to 1.6 Amps, the cloud stopped flowing down and no tracks were seen. The current was left at 1.6 Amps for 3 minutes then it was turned back down to 0.5 Amps. Ten minutes after that the cloud returned to the density it had when the test was started. This indicated that the optimum current level for the heating wire array is 0.5 Amps, which produced the most visible tracks. It was also noted that the cloud created the best tracks when it was less dense. With the heating wire array at 1.0 and 1.6 A the cloud was very easily seen but no tracks were seen.

During the wall liner and heating wire tests the chamber was illuminated by a flashlight borrowed from the dark room in the Solid State Laboratory. The light was dim and yellowish; it was hard to see the cloud and tracks with this light. During the final heating wire test this flashlight died and an LED bike light was used instead. The brighter and whiter light allowed the tracks and cloud to be seen with greater ease.

At this point in the construction of the cloud chamber we thought that the maximum degree of supersaturation was achieved in the chamber under atmospheric conditions. To increase the visibility of the tracks in the chamber the effects of changing the pressure inside the chamber on the supersaturated region in the chamber were investigated. Raoult's Law relates the vapor pressure of a liquid at temp T, total pressure of the system, mole fraction of vapor of a component in the solution, and mole fraction of a component in the system by equation one (5).

$$x_{ivapor} * P = x_i * P_i^*$$

Equation 1

Equation one is Raoult's Law relating vapor pressure of a liquid at temp T (P_i^*), total pressure of the system (P), mole fraction of vapor of one component in the solution ($x_{ivapor)}$, and mole fraction of one component in the system (x_i)

Using Raoult's Law shows that an increase in pressure in our chamber would increase the vapor pressure of the ethanol. This would increase the difference in partial pressure between ethanol under atmospheric conditions and in the chamber. The increased difference would cause a greater degree of supersaturation. This idea was not pursued due to concerns about the integrity of the chamber that was being used and how effective this method would be. Also research into this topic showed the temperature gradient had a larger effect on the cloud and tracks than changes in pressure. (6)

At this point we were satisfied with the cloud and tracks formed in the chamber but we wanted a way to operate the chamber without using dry ice. It only allows the chamber to run for a limited amount of time. A Peltier or thermoelectric cooling device was picked to replace the dry ice. It is basically an electric heat pump, moving heat from one side of the device to the other using doped semiconductor material. They also have the added feature of being small. These devices are characterized by two parameters, Q_{max} and DT_{max}, in addition to the physical and electrical (physical size, max voltage and current) parameters. Q_{max} is the maximum about of energy the device can move from one sided to the other per second, stated in watts. DT_{max} is the maximum difference in temperature between the two sides of the device. To increase the DT_{max} of a device two devices can be connected together forming a two stage device. Using these parameter a **TE-2-(127-127)-1.15** made by TE Technologies Inc was purchased. It has a ΔT_{max} of 84 ^{o}C and a Q_{max} of 34.0 Watts. This device was chosen due to its high ΔT_{max}. Having a high ΔT_{max} would allow the copper plate to be cooled to temperatures near that of the dry ice previously used, the hot side would be around 20 ^{o}C and the cold side could be around -60°C near the temperature of dry ice, -78°C.

The hot side of a Peltier Device must be cooled by a heat sink or the hot side will overheat and the device will be destroyed. To do this a Cooler Master Hyper 212 Plus CPU cooler was purchased. This heat sink was chosen because it has large heat sink area and the fan can be removed from the heat sink. They would also reduce the number of components connected to the chamber.

To connect the heat sink to the Peltier Device thermally resilient glue is needed, the hot side of the Peltier Device will be operated at ~20°C and the cold side of the device will be cooled to ~ -60°C. Glue was chosen over a clamping mechanism because of the ease of use and reduced fabrication required. Hysol US1152 was used to attach the heat sink and Peltier Device to the copper plate. It has a temperature ratting of -85°F (-65°C) to 257°F (125°C) and a thermal conductivity of 0.18W/m K. These temperatures are with the range that the Peltier Device will be operating at. When this urethane was applied to the copper plate, Peltier Device and heat sink it was not viscous enough to cover all the components at once. To solve this problem a dam made of silicon was constructed around the devices then the urethane was poured over the components. The urethane was left to set overnight, and then the silicon dam was removed; leaving just the urethane behind.

A Peltier Device can be run straight from a regulated power supply. However we wanted to be able to control the cooling of the bottom of the chamber. To do this using a transistor as a current source for the Peltier Device was investigated. The basic circuit can be seen in figure nine.
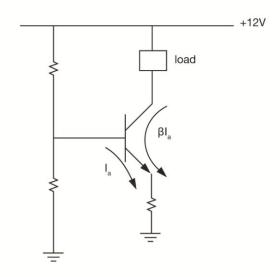
+12V

load

βI_a

I_a

Figure 11
Figure eleven is a circuit diagram of a transistor being used as a current source for the load.

When the current from the base to emitter is changed the current from the collector to emitter follows that change but the current is β times bigger; β is usually around 100. The base to emitter current could be adjusted by changing the resistance values connected between the power supply and base. This would allow the control of a large current by a much smaller one, limiting the number of high power circuit devices needed, and therefore the amount of power needed to run the entire circuit.

Dr. Thomas Bensky of the California Polytechnic University at San Luis Obispo agreed that my circuit design would work. He also suggested that an oscillator with an adjustable duty cycle and a solid state relay could be used to run the device. The basic idea is that the oscillator turns the relay on and off for adjustable amount of time. The relay then transfers that signal to the load but at a much higher voltage and current, again

allowing for a small amount of power to run a much larger amount of power. This method for powering the device was chosen because all of the components were readily available from the electronics lab and the Cal Poly Physics Department techs (Jim, Steve and David). Also β of transistors fluctuate depending on each transistor, making it hard to find a transistor with the β that we wanted. (7)

   To create an adjustable duty cycle signal a 555 chip in a multi-vibrator circuit was used. When a 555 chip in a multi-vibrator circuit is provided with a DC voltage it will output a square wave pulse. The chip circuit is show in figure eleven.
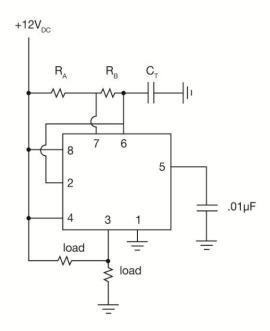

Figure 12
Figure twelve is a wiring diagram of the multi-vibrator circuit for the 555 chip, with C_T, R_A and R_B labeled.

 If adjustable resistors are placed in the positions for R_A and R_B the duty cycle can be adjusted. Equations two and three relate the changes in resistance values to the changes in on and off times of the square wave output.

$$\text{Time Up} \approx C_T(R_A+R_B)LN(2) \qquad \text{Eq 2}$$
Equation two relates the up time of the square wave to the capacitance value C_T, resistance values R_A and R_B

$$\text{Time Down} \approx C_T * R_B * LN(2) \qquad \text{Eq 3}$$
Equation relates the down time of the square wave to the capacitance value C_T and the resistance value R_B

The circuit used in this device had two 10kΩ adjustable resistors for R_A and R_B and a 5.9μF capacitor for C_T.

   The output of that circuit was connected to the control side of the relay. The relay would transfer that signal from the control side to the power side which was connected to the Peltier Device. There by turning the Device on and off for an adjustable amount of time. The Peltier Device, relay and 555 circuit were run off of one power supply. That configuration can be seen in figure thirteen.
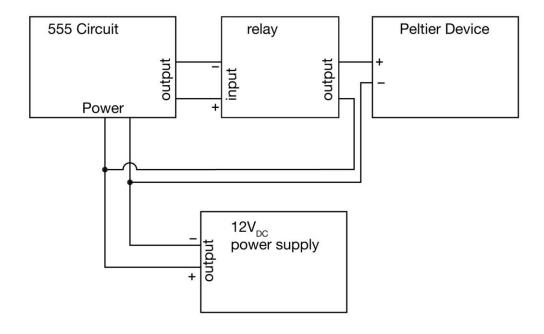
Figure 13
Figure thirteen is a diagram of the control circuit for the Peltier Device; consisting of a 555 circuit, power supply, relay, and Peltier Device.

During the initial tests of the 555 circuit an Opto22 DC60S5 Solid State Relay was used. The relay worked fine, transferred the signal from the input side and the outside. However, the DC60S5 is rated for 5 Amps DC on the output side which is less than the maximum current rating for the Peltier device, 5.8 Amps. So the DC60S5 was replaced with a 240D25, which is rated for 25 Amps AC on the output side. The circuit did not work after this. The output of the relay would not turn off after it had been turned on by the control side. When power was disconnected from the control side the relay would not turn off. It would only turn off if the power to the output side was turned off. The relay data sheet suggested adding a resistor in parallel to draw the leakage current. When the relay is in the off position it has a leakage current of 15mA, this current could make it appear that the load was still on when the relay was in the off mode.   This solution did not work. Three different 240D25 were tested and the same problem occurring in all three. The conclusion was drawn that the error was in the use of the relay not the relay itself. To check the basic functionality of the relay the oscillating circuit was disconnected from the relay along with the Peltier Device. The control side of the relay was then connected to a DC power supply and the control side was connected to another DC power supply with a 10 kΩ resistor on the output side to act as a load. A voltmeter was added across the resistor to see if the relay was on or off. When the relay was tested with this setup the same problem occurred; the relay would not turn off after being turned on. No solution could be found after consulting Dr. Thomas Bensky, Dr. Matthew Moelter, Jim Hilsinger, and Dr Jennifer Klay. However, after a call to an Opto22 engineer the solution was found. The two different relays that were used in the circuit

were designed to switch only AC or only DC not both. The 240D25 is meant to only switch AC; the relay would turn off the output side when the AC signal went through zero. The DC60S5 is meant to switch a DC load on and off. A DC relay with a higher current limit than the DC60S5 could not be found so the DC60S5 was used. This decision was made because the 555 circuit was up and running and it would take more time to build a different control circuit. The Peltier Device would be run at a lower current so that the relay would not be destroyed. With the DC60S5 installed in the control circuit for the Peltier Device the circuit was able to switch the Device on and off with an adjustable duty cycle.

With the control circuit working the rest of the components could be chosen to complete the device. The current required to run the Peltier Device and other components of the system was around 12 Volts and 5.8 Amps:

	Current	Voltage
Peltier Device	5.8A	$12V_{DC}$
Peltier Device Control Circuit	~50mA	$12V_{DC}$
Cooling Fan	~100mA	$12V_{DC}$
Lighting	~70mA	$3.8V_{DC}$ For each LED

Table1

Table one contains the amount of current and voltage required to run each of the components.

The highest voltage of the system is the Peltier Device so a power supply with that output voltage was chosen, all the other components could be run for 12Volts or a resistive divider could be used without excess power loss. After consulting Jim Hilsinger a power supply was found in the electronics lab; a Lambda Model number LNS-W-12 with a 12 Volt 8.5 Amp output.

To illuminate the chamber three 5mm, 1100 mcd, white LEDs were used to illuminate the chamber. They were held in a 95 mm x 10 mm x 8 mm piece of the Lucite box lid with three 5mm holes drilled in it. Each resistor has two 220Ω resistors in series connected to the positive side of the LED. The resistors provided the correct current and voltage to each LED, reducing the 12V supplied from the power supply to 3.6 V (typical voltage drop across each LED) and limiting the current to 20mA (typical current for each LED). The three LEDs were connected in parallel and then to the terminal block and switch.

The heating wire was connected to a 6.8Ω 10 Watt and a 5Ω 10 Watt resistor in series so that 0.52 Amps will be supplied to the heating wire.

The components mentioned above were housed in a Lambda power supply box. This box was chosen because of its accessibility, removable lid, pre drilled holes for the LNS-W-12 power supply, and its size. The box came with a main power switch, indicator light, and fuse (250V 10A fast acting) already installed. The power supply was installed in the left hand side of the box. The AC input went through the fuse then through the switch to the power supply. When the main switch was turned on it turns on an indicator light and the power supply. The power supply was connected to a ten terminal block; the terminal block was split into two groups of five, one positive and one negative, with each group of five connected together; allowing multiple loads to be connected to the power supply. Those loads consist of the heating wire, cooling control circuit (555 circuit and

relay), Peltier Device, heat sink cooling fan, and the LEDs. The heating wire, cooling control circuit, and light were connected to a switch, SPST Submini Toggle Switch 3A 125V, and a red indicator light then to the terminal block. The indicator light had a 470Ω resistor connected in series to the positive side of the LED. The positive side of the LED was connected to one end of the switch and the negative side of the LED was connected to the terminal block. When the switch was tuned on it would turn on the indicator light and the load connected to the switch. The heat sink fan is directly connected to the terminal block so when the main power switch is turned on the fan will turn on, allowing for the heat sink to be cooled off when the Peltier Device is turned off. To install the switches and indicator lights six holes were drilled in the front of the box, three for the switches and three for the indicator lights.

Two additional holes were drilled in the front of the box to allow for the installation of two banana plug sockets. The sockets were connected to the output of the 555 circuit, allowing the user of the cloud chamber module to connect the banana plugs to an oscilloscope and see the square wave powering the Peltier Device.

One more hole was drilled in the front of the box and a 10 kΩ adjustable resistor was inserted into that hole. It was connected to the 555 circuit as resistor R_B. This allows for the user of the cloud chamber module to adjust the duty cycle signal powering the Peltier Device without having to open up the box and put a different resistor in to the R_A slot.

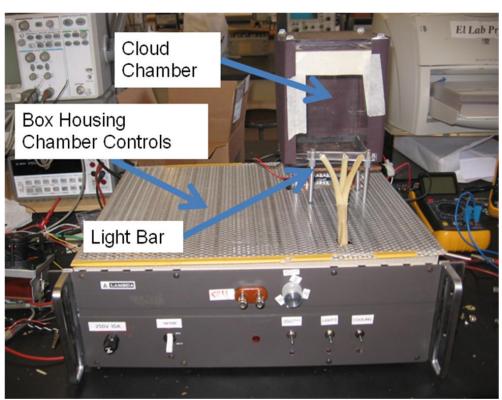The components described above are shown in the following figures.

Figure 14
Figure fourteen is a picture of cloud chamber, light bar and the box housing the chamber controls.
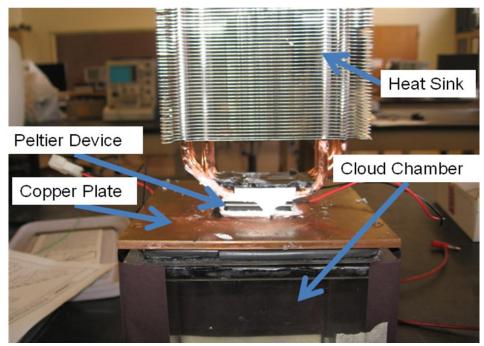
Figure 15
Figure fifteen is a picture of the bottom of the cloud chamber showing the Peltier Device, heat sink, copper plate and cloud chamber. This picture was taken before the urethane was applied.
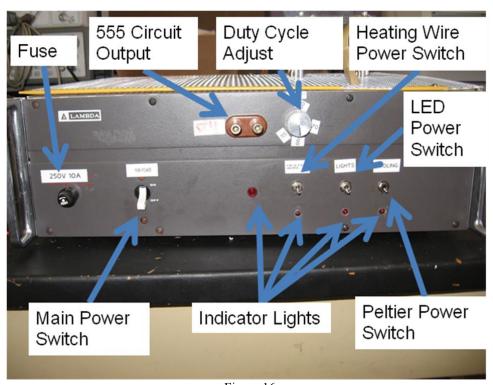

Figure 16
Figure sixteen is a picture of the front of the box housing the cloud chamber controls. Showing the fuse, 555 banana plug sockets, duty cycle adjust knob, main power switch, indicator lights, and switches for the LEDs, heating wire and chamber cooling.
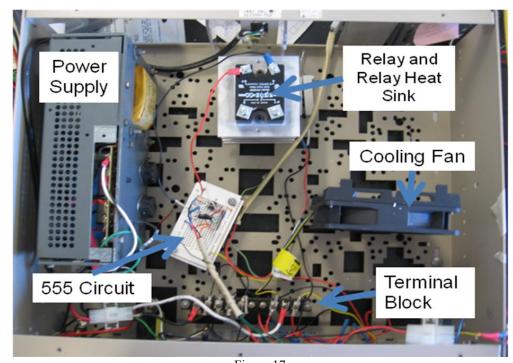
Figure 17
Figure seventeen is a picture of the inside of the box housing the chamber controls. Showing the cooling fan for the heat sink attached to the Peltier Device, 555 circuit, relay, terminal block and power supply

After completing the construction of all of the components the entire device was tested. To perform the test the felt wall liners were soaked with ethanol then the copper plate was attached to the chamber. The side of the copper plate exposed to the atmosphere was covered with a quarter inch thick layer of Styrofoam insulation. The Peltier Device was connected to the output side of the relay and the duty cycle was set to 55%. Five minutes after the Peltier Device was turned on there was barely any change in the temperature of the copper plate. The duty cycle was then turned up to 98%. After another five minutes there was no change in the temperature of the copper plate. It was thought that this indicated that the control circuit was not providing enough power to the Peltier Device. So to increase the power provided to the Device the 555 circuit and relay were removed from the circuit and the Peltier Device was connected directly to the 12V power supply. With the power supply turned on the current through the device was 2.77 Amps, lower than the maximum of 5.8 Amps. It was though that the power supply was not providing enough current to the Device. So the Device was connected to a second Lambda LNS-W-12 power supply. When this supply was turned on it provided the same amount of current as the first. The voltage across the Device was around $8V_{DC}$, below the $12V_{DC}$ written on the power supply. When discussing the problem with Jim Hilsinger a solution was found. The power supplies were wired for an input voltage of $240V_{AC}$ rather than the $120V_{AC}$ they were connected to. The power supplies were rewired for an input of $120V_{AC}$. This was done by removing the A and B wires from the D terminal on the transformer and moving A to the AC1 terminal and B to the AC2 terminal. After doing this the power supplies were tested and supplied an output of 5.8A at$12V_{DC}$. The fixed power supply was connected to the Peltier Device and the same low current problem occurred. Indicating that the problem was with the Peltier Device not the power supply.

The Peltier Device and heat sink was removed from the copper plate. After the urethane was removed from Device it was connected to the Lambda power supply and clamped to the heat sink and copper plate. The power supply was turned on and two minutes later the copper plate was colder than when the Device was glued to the heat sink and copper plate; the heat sink was also much hotter. This indicated that the cause of the low current problem was the urethane used to glue the Device, copper plate and heat sink together. After the urethane was removed from the Device its functionality improved immensely.

Although a fully functioning chamber was not completed in time for the preparation of this paper, a few minor fixes to the chamber and control hardware would fix the problems outlined above, creating a fully functioning thermal diffusion cloud chamber. These fixes will be made during the summer of 2010 at California Polytechnic University at San Luis Obispo.

References

1) Columbia Electronic Encyclopedia, 6th Edition; "Cloud Chamber"
2) Columbia Electronic Encyclopedia, 6th Edition: "Wilson, Charles Thomson Rees"
3) Columbia Electronic Encyclopedia, 6th Edition: "Blackett, Patrick Maynard Stuart"
4) Supersaturated Environments, "About Cloud Chambers", cloudchambers.com, 2008
5) Levine, Ira N. Physical Chemistry, McGraw-Hill, New York, 1978
6) Bevan, A. R. "Optimum and Limiting Operating Conditions for Downward Diffusion Cloud Chambers"; Journal of Scientific Instruments, Volume 31 Number 2, 1954
7) Conversation with Dr Matthew Moelter

List of Materials Purchased

1) Silent Boost RX K8 fan and heat sink: Radio Shack
2) 5 pack of snap connectors 22-18 gauge: Radio Shack
3) Glass Lock Kitchen Storage Container with locking lid: Bed Bath and Beyond
4) 2- 6mm out diameter x 2.7mm inner diameter x 12 inches: McMaster Carr
5) 6 feet Viton Fluoroelatomer Rubber Bulb Seal: part # 2072T11: McMaster Carr
6) 1- 12" x 12" x 1/16" Adhesive Backed White Wool Felt: part # 8334K15: McMaster Carr
7) 1- 12"x 12" x 0.187" copper plate (110 Alloy): McMaster Carr

8) Omega Engineering Inc 50ft roll of 26 gauge heating wire: Omega Engineering Inc

9) 5 pack 140mm inner diameter 4mm width rubber o-ring: part # 9262K376: McMaster Carr

10) Epoxy in a squeeze tube, 5 oz, black: part #7524A12: McMaster Carr

11) Epoxy in a squeeze tube, 5 oz, white: part #7524A13: McMaster Carr

12) GE Premium Water Proof Silicone Caulk, 2.8 oz: Home Depot

13) Gorilla Glue, 2 oz: ElCorral Bookstore

14) Loctite Quick Set Epoxy, 25mL: Home Depot

15) Bernzomatic Metal Work Solder, Acid Core: Home Depot

16) Silver Bearing Solder: Radio Shack

17) Grader Glass Cutter: Home Depot

18) White label Lucite Tissue Cover: Bed Bath and Beyond

19) Black Construction Paper, 12" x 16": ElCorral Bookstore

20) Mi-Teintes Paper, White, 20" x 25.5": ElCorral Bookstore

21) Blue construction paper, 9" x 12", ElCorral Bookstore

22) Brown construction paper, 9" x 12": ElCorral Bookstore

23) Cooler Master CPU Cooler Hyper 212 Plus: Newegg.com

24) Hysol US 1152 urethane, 50mL dual cartridge: McMaster Carr

25) Opto22 240D25 solid state relay: Dr Thomas Bensky

26) Opto22 DC60S5 solid state relay: Jim Hilsinger

27) Lambda regulated power supply, LNS-W-12, 12 volt 8 Amp: Jim Hilsinger

28) 4-position interlocking connector, 22-18 gauge, polarized: Radio Shack

29) 3- 2-position interlocking connector, 22-18 gauge, polarized: Radio Shack

30) Spade tongues, 10 pack, 12-22 gauge: Radio Shack

31) Screw-Cap Panel Mount Fuse Holder, 250 Volt 10 Amp, for 1 ¼" x ¼" fuses: Radio Shack

32) 3- 5mm white LED, 1100mcd, 3.6 V typical 4V max, 20mA: Radio Shack

33) 3- SPST Submini Toggle Switch, 125V AC 3A: Radio Shack

34) 4-pack fast acting fuses, 250V 10A: Radio Shack

35) Assorted pack of heat shrinkable tubing; Radio Shack

36) 22 gauge hook up wire, 3 25" rolls, green red black: Radio Shack

37) 2- **TE-2-(127-127)-1.15** solid state cooling device: 40mm x 40mm x 8.5mm with a DT_{max} of 84°C and a Q_{max} of 34 Watts: TE Technologies Inc

38) Lambda Power Supply Box: 17" x 5.25" x 14" metal with removable lid, power switch and fuse installed: Jim Hilsinger

Special Thanks

I would like to thank the following people for there help with this project:

Jim Hilsinger
Steve Soderberg
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Dr Ronald Zammit
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Dr Dane Jones
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