

COUNTING ON THE MOUNTAIN TOP

As a first experiment we can go on a mountain top. A hill or a small elevation will not be enough. The mountain has to be more than a few thousand feet high to obtain a noticeable effect. Some of you may go into the mountains in the summer. If so, take your Geiger Counter along and it will be useful for prospecting too. Before you start on your trip check the counting rate at the starting point or at sea level if possible. As you get higher in the mountains check the counting rate at each elevation. In Denver or in places equally high you will notice that the counting rate is appreciably higher than at sea level. As you progress to still higher altitudes the rate increases more quickly.

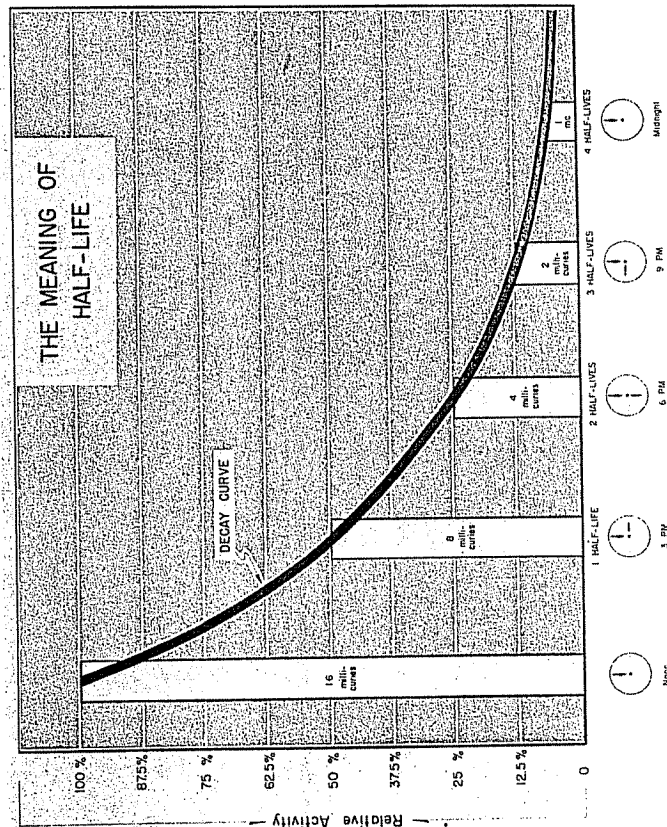


Photo courtesy of the Atomic Energy Commission

Figure 1-8. A RADIOACTIVE DECAY CURVE
All radioactive atoms obey the same kind of decay rule, decreasing in activity by 50% at the end of the first half-life and by another 50% at the end of the second half-life. Thus one curve applies to all atoms whether they are long lived or very short-lived. For clarity a set of values for cesium-134 with a 3 hour half-life has been included.

COUNTING IN AN AIRPLANE

The modern commercial aircraft customarily travels at quite high altitudes especially on trips of any length. If you happen to take a trip by air, be sure to carry your Geiger Counter along. You can ask the stewardess for the various altitudes as the plane climbs or dives and perhaps the captain will allow you to visit the cockpit where you can read the altitude for yourself. Be careful in taking your measurements to get a background reading at sea level for many aircraft have numerous radiant dials on the instrument panel and to a lesser extent throughout the cabin. You will notice that at high altitudes the count is quite high. This increase in counting rate is due to cosmic rays.



Figure 1-9. EXPERIMENTING WITH THE GILBERT GEIGER COUNTER.

HALF LIFE

Another important term which is often used in nuclear physics is Half Life. Figure 1-8, the decay curve, illustrates the meaning of half life. The half life of a material is the period of time in which half of the initial amount of the radioactive material will have disappeared. Thus, it will take 4.5 billion years for 100 atoms of U-238 to decay so that only 50 are left. At the end of another 4.5 billion years only 25 of the initial 100 U-238 atoms will be present.

Some radioactive substances have very short half lives. For example, in the uranium series, radium C' has the value of $1/6000$ th of a second. On the other hand Tellurium 130 has a half life of 1.56 trillion years.

The great range of half life values from billions of years to billionths of a second is a colossal one. Yet the same behavior so far as decay is concerned is observed by the longest and the shortest live atoms. Let us consider as a specific case a radioactive emitter which has a half life of 3 hours. Since we are going to deal with very large numbers of atoms it is not convenient to talk about a million or a billion atoms, for these units would in many cases be too small for our purposes. A single gram of radium emits 37 billion alpha particles per second and physicists have elected to use this value as a standard and to give it the name of one curie in honor of the discoverers of radium.

Smaller units are the mille curie (abbreviated mc) and the micro curie (uc) corresponding to 1,000 and 1,000,000th of a curie respectively. Later on we will explore further the meaning of this unit of radioactivity, but for the present we should think of it as merely a unit which tells us how much radioactivity there is in a sample of material.

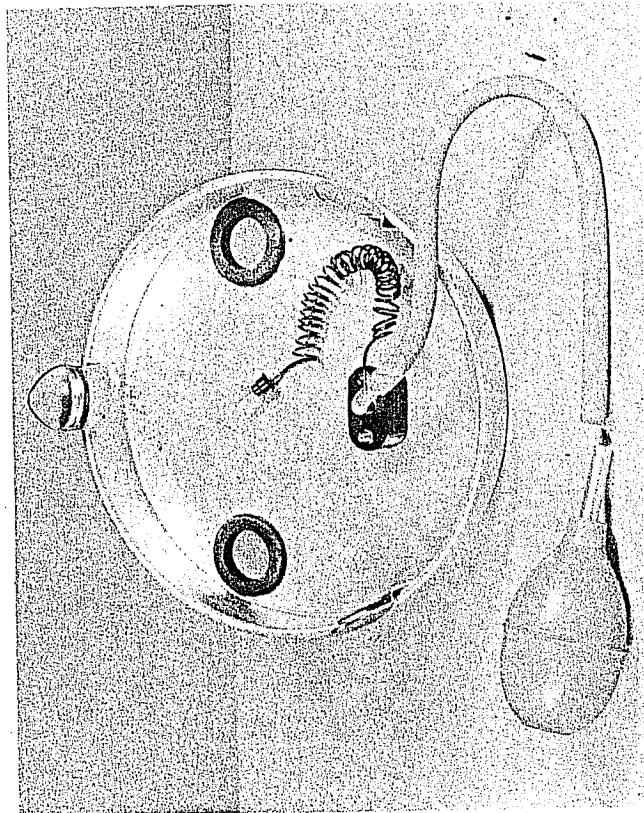


Figure 2-2. BOTTOM VIEW OF THE GILBERT CLOUD CHAMBER

SECTION II SEEING WITH THE CLOUD CHAMBER

Of all the Atomic instruments, the Gilbert Cloud Chamber is the most striking in its ability to show the nature of radioactivity. You may wonder why we have waited until now to discuss its use. The reason for this is that we wanted to introduce you to gamma rays first, before going on to describe other types of rays. It happens that the Cloud Chamber will not show gamma ray tracks.

Here is how the Cloud Chamber is assembled.

- 1) Lay out some newspapers or a plastic sheet on a flat table to serve as a working space. The papers will protect the furniture in case you spill any alcohol or ink. On the table place the aluminum Cloud Chamber base (the round plate with the three legs).

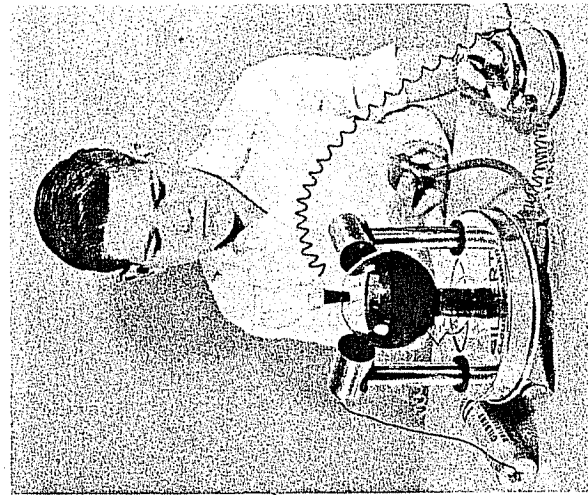


Figure 2-1. THE GILBERT
CLOUD CHAMBER,
READY FOR OPERATION

- 2) Fasten the rubber mounting block (with the cylindrical lip placed up-wards) to the underside of the base. (See Figure 2-2.)
- 3) Insert the metal tubing into the rubber mounting block with the long end of the tubing up. (See Figure 2-2.)
- 4) To the tube projecting from the underside of the base fasten the bare end of the black wire and the plastic tube and rubber bulb. Make sure that all connections are tight, for they must hold liquid without leaking. (See Figure 2-2.)
- 5) Place the large stopper in the neck of the glass flask. Moisten the end of the metal tubing which extends through the base and with a gentle screwing action squeeze the rubber stopper (in the pyrex flask) over the metal tube. Be sure to moisten the tube or you will find it very difficult to squeeze the flask onto the tube. Make sure that the flask now stands securely on the base and that the connection is tight. (See Figure 2-3.)
- 6) Now remove the stopper in the top of the flask and, using the small funnel provided with the lab, pour into the top hole of the flask approximately one pint of rubbing alcohol. Any brand of rubbing alcohol with the exception of aromatic rubbing alcohol is satisfactory. The 70% solution known as isopropyl rubbing alcohol provides the best results. One pint of alcohol should fill the chamber just to the level of the side hole in the flask.



Figure 2-3. SECURING THE CLOUD CHAMBER FLASK

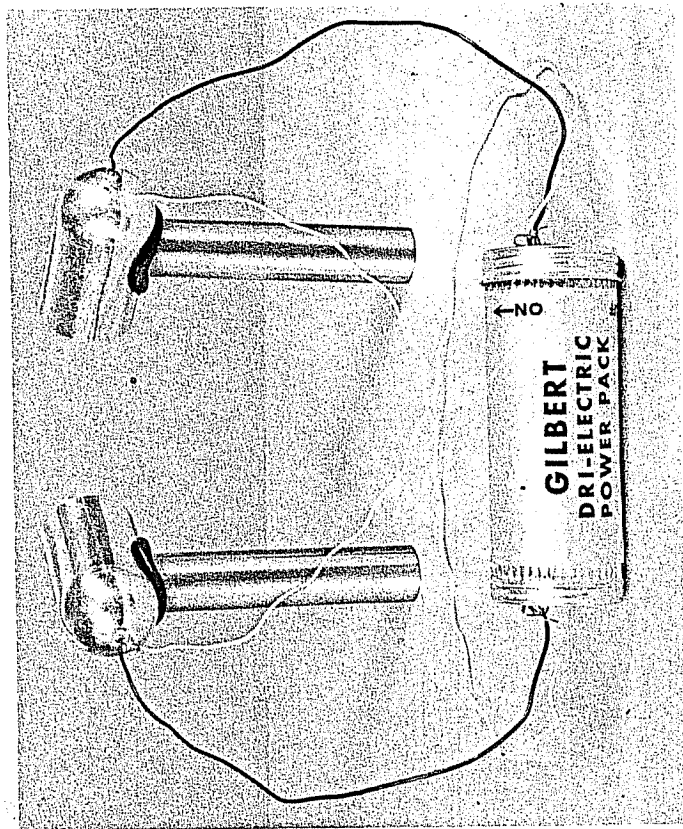


Figure 2-4. THE GILBERT DRI-ELECTRIC POWER PACK WITH LIGHT HOUSING

- 7) Depress the grey rubber bulb several times to eliminate air from the system and check all connections for leaks. Alcohol may harm certain furniture finishes so care must be exercised in its use. When you depress the grey bulb alcohol may be forced above the level of the side hole; to secure against leaks at this point force the rubber stopper (this comes fixed in the flask) firmly into the hole on the side of the flask.
- 8) Now add a few drops of blue-black ink to the alcohol. You may do this by using a fountain pen. Insert it into the top of the flask. Enough ink should be added to color the liquid medium blue. Ordinary ink is satisfactory for this purpose.
- 9) Replace the stopper in the top of the chamber.
- 10) Assemble the lighting system as shown in the illustration. (See figure 2-1.) Take care to moisten the rubber grommets before trying to force the aluminum legs into place. Align the lights so that the center of the light housing is just about the level of the liquid. Adjust the light housings so that both lights are aimed at the center of the chamber.
- 11) Connect both black leads from the light housing to one terminal of the Dri-electric Power Pack. Then connect the yellow leads to the other ter-

minimal. (See figure 2-4). Both lights should now be on and you can readjust the light beams so that the chamber is fully illuminated.

12) The only item left to be connected is the Deionizer. Plug the red lead from the Deionizer to the metal projection on the rubber plug on the top of the flask. Plug the black lead from the underside of the Cloud Chamber base into the black opening on the side of the deionizer. Now plug the service plug into a house outlet and the Cloud Chamber is ready to operate.

Now that you have everything in order, squeeze the grey rubber bulb, forcing the liquid to rise in the chamber. Do this fairly slowly by pressing down on the bulb with a steady motion. Otherwise you will cause the liquid to squirt up violently and this is not desirable. A little practice will allow you to control the compression of the chamber in a steady way. We say "compress-ion" because, by forcing liquid into the flask, the trapped air is forced to a smaller space and therefore it is compressed. When you release the bulb quickly, the liquid level drops and the gas expands.

If you squeeze the rubber bulb, then wait for a moment so that the liquid is no longer in motion, and then release the bulb, you will see that a fine mist or fog fills the air space in the chamber. Observe how gracefully the fog descends. If you do not observe any fog formation make sure of two things. First, be sure that you pause after squeezing the bulb. Second, it may happen that you have not squeezed the bulb firmly enough. Try this and if after a number of attempts you still do not produce fog, it is probably because you do not have enough liquid in the chamber. Add a few ounces of alcohol to the chamber and you should be able to produce fog.

If the two rubber stoppers at the top and side of the glass flask are so loose that air rushes out when you squeeze the bulb, you will never obtain proper operation of the instrument. To correct this, wet the stoppers and twist them firmly into the flask.

Why does fog form in the Cloud Chamber? Fog is produced in the chamber for exactly the same reason that it is produced out of doors. Tiny droplets of water condense onto invisible specks of dust. In the case of the Cloud Chamber, the expansion of the air causes cooling and the air contains so much water vapor (in invisible form) that the slightest disturbance causes

this vapor to condense into small droplets of water which are then visible as fog. Very tiny particles of dirt and dust in the air will be enough disturbance for the water vapor to condense out on these tiny particles. This is what happens in the Cloud Chamber when you compress and expand it.

In the event that there are radioactive materials, such as the active wire which is in the Gilbert chamber, shooting out radiations into the gas, then there will be broken-up atoms or ions present which will also start the formation of fog. If the ions are along a path, the fog will form along the path and make it visible, showing us where a radioactive ray has streaked across the flask a split second before. This will look something like the vapor trails which high-flying airplanes sometimes produce in a clear sky.

EXPERIMENTS WITH FOG

Before we set off in our experiments with cloud tracks of particles, let's see what we can learn about the fog itself. First, let us show that the particles on which the fog forms actually cannot be seen. To do this expand the chamber several times until the fog gets thinner and you can distinctly make out the swirling lines within the fog as it drops toward the surface of the liquid. Now expand the chamber, causing fog to form, and then, before the fog disappears, compress the chamber again until all of the fog vanishes. Then release the rubber bulb and note that the fog which is seen forms along the same swirling lines as before. Clearly, these invisible particles must be in the chamber when no fog is present. Our experiment catches the invisible particles and makes them visible by means of forming droplets on them.

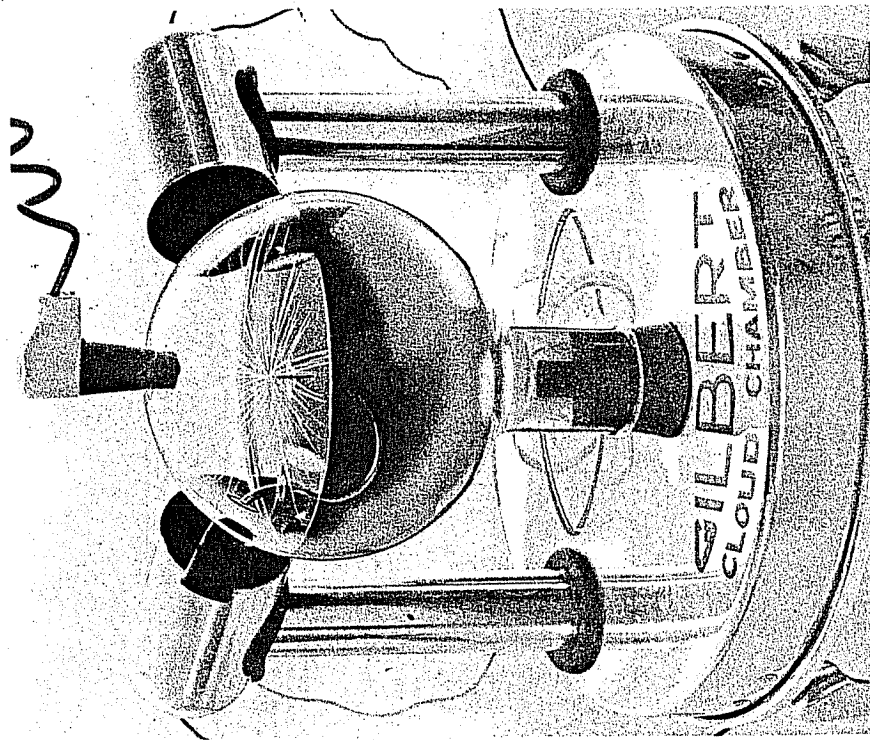


Figure 2-5. CLOSE-UP OF ALPHA TRACKS IN THE GILBERT CLOUD CHAMBER. ALPHA PARTICLES ARE TRAVELLING 3,600,000 MILES PER HOUR.

We can also use our chamber to make super-clean air. To do this we squeeze the bulb several times, allowing the fog to drop into the liquid after each squeezing. Little by little the fog will become thinner and after awhile no fog will form. At this time the air above the surface of the liquid will be superclean, far cleaner than air which you may find on the clearest day.

Another trick which we can do with the chamber is to make the colors of sunrise and sunset. Everyone has at some time or other marvelled at the gorgeous display of sunrise or sunset colors. These colors are even more beautiful when they appear in clouds near the horizon. The tiny droplets of water which make up the clouds scatter the rays of light and produce many hues. You can make these sunset colors on a very small scale in your Cloud Chamber. Look into the chamber so that you gaze almost directly at one of the lights. Then squeeze the bulb fully and observe the colors produced in the fog. Better results can be obtained if you use only one dry cell to power the lamps.

TRACKING DOWN THE ALPHA PARTICLES

Fix the position of the radioactive wire by moving the rubber stopper slightly, one way or the other; make sure that the end of the wire points upward and is even with the surface of the alcohol when the bulb is squeezed. Depress and quickly release the rubber bulb several times; this will serve to clear the chamber and make it ready for operation. Depress the rubber bulb. Press down the black push button on the Deionizer and hold it down a moment. Release the push button and quickly release your hold on the rubber bulb. Observe the dense white tracks which shoot out radially from the wire. (See Figure 2-5.)

Obtaining good clear tracks is done more carefully than merely making fog in the chamber. You will have to try a few times before you are proficient at making alpha tracks. Once you have fixed the position of the alpha source (the radioactive wire in the flask) so that neither too many nor too few particles shoot out into the air space of the flask, you can then change the amount of compression given to the air by squeezing the rubber bulb. By raising the end of the radioactive wire you can allow more alpha particles to escape to the air space.

Our source, the radioactive wire, shoots out about 740 alpha particles per second. Not all of these escape from the surface of the wire and many are absorbed in the liquid, so that when the chamber is expanded you see only a few of the many particles shot out in each second from the source.

DO THE ALPHA PARTICLES COME FROM THE WIRE?

If you doubt that the alpha particles really are shot out by the wire source, you can easily see that this is true by performing a very simple experiment. At this point in your experimentation, you ought to be developing an inquiring attitude with which you think about the experiments before they are written out in cook-book fashion.

When you have doubts about the statement that the alpha particles actually come from the source (radioactive wire) you should ask yourself: What facts

do I have to prove this point? First, you know from our experiments that the alpha tracks seem to start at the tip of the wire. Second, you know that when more of the wire is exposed, there are more alpha tracks in the flask. As a final experiment, you can completely cover the wire with liquid. When you do this all the alpha tracks should disappear from the chamber.

You may draw another conclusion from the experiment just performed. Because you allowed only a thin layer of liquid to come between the wire from the air space, you can see that the alpha particles are easily absorbed in liquid.

THE RANGE OF ALPHA PARTICLES

It is one thing to say that alpha particles are easily absorbed in matter, and another to describe this absorption so that everyone will be able to talk about the same thing. Let us see how we might be able to define the units in which alpha absorption can be measured. In expanding your chamber and watching the tracks from alpha particles, the first thing you notice is their straightness. If we watch the alpha tracks very carefully we will see that the tracks really end in the gas of the chamber. Adjust your alpha source (radioactive wire) so that it is well above the liquid level and note that the many tracks shoot out like the spines on a porcupine and, like these spines, they are all of about the same length. Most of the tracks seem to reach to about a half inch from the wall of the glass flask. If we estimate the distance that each track covers we find it is about 1-1/2 inches.

Since all the tracks seem to have about the same length we can now adopt as our unit of measurement for alpha particle absorption the number of inches the particle travels before stopping; this distance we call the range of the alpha particle.

ABSORBING ALPHA PARTICLES IN A SOLID

This experiment requires a little skill on your part, but you should be able to carry it out without too much trouble. We shall try to show that the alpha particles shot out by the radioactive wire cannot go through even a very thin sheet of aluminum foil.

To make the foil properly choose the thinnest aluminum or metallic foil which you can find and then shape it around the blunt end of a large needle so that it forms a cap which can be slipped over the tip of the radioactive wire. Make the cap about half an inch in length and gently slide it over the end of the Cloud Chamber radioactive wire. Now put it carefully back into the chamber and adjust the tip as before. Expand the chamber a number of times and see if you can note any alpha particles. No alpha particles should be able to sneak through the metallic cap. Your experiment proves that even very thin foil effectively absorbs alpha particles.

A word of caution when you are handling the Cloud Chamber alpha source in this experiment. Do not break off the tip or otherwise damage the radioactive wire. When you leave the equipment for any length of time, be sure that this source is kept in the Cloud Chamber.

CLOUD CHAMBER PHOTOGRAPHY

Photographs are usually taken with a large Cloud Chamber of the variety illustrated in Figure 2-6. The Cloud Chamber shown is much larger than the Gilbert type and it is cylindrical in shape. At the top of the apparatus is a glass cylinder which serves as the expansion chamber. Equipment shown below the chamber is used to expand the chamber and to control this expansion.

One usually places very strong lights around the chamber and a mechanism to flash these lights for a fraction of a second just after the chamber is expanded. A camera then photographs the picture of the tracks. Still another type of Cloud Chamber is shown in Figure 2-7.

Constructed at the University of Minnesota, this rectangular chamber is a marvel of ingenuity, for it operates while suspended from huge balloons which soar up to 100,000 feet above sea level. Here, in the happy hunting ground for cosmic rays, this outfit performs a large number of operations and photographs cosmic rays which pass through the chamber. Later, the equipment parachutes to the earth below, and the film in the camera is developed to reveal the tracks of the kinds of rays which exist 20 miles up in the stratosphere.

In Figure 2-7, you will notice that there is a Geiger Counter placed above the chamber. Although you cannot see it, there is also another one below the chamber and these two form a telescope which serves as a watchdog to detect whenever a certain kind of cosmic ray goes through the chamber. When the Geiger Counter detects a ray it trips the camera and a photograph is made of the ray as it passes through the chamber.

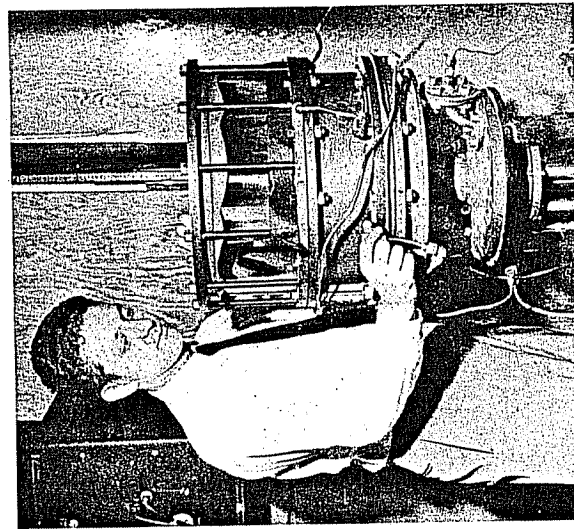


Figure 2-6.
A MODERN RESEARCH
CLOUD CHAMBER
Photo shows a cylindrical
chamber in use at Columbia
University. See text for
details.

Photo courtesy of Columbia University

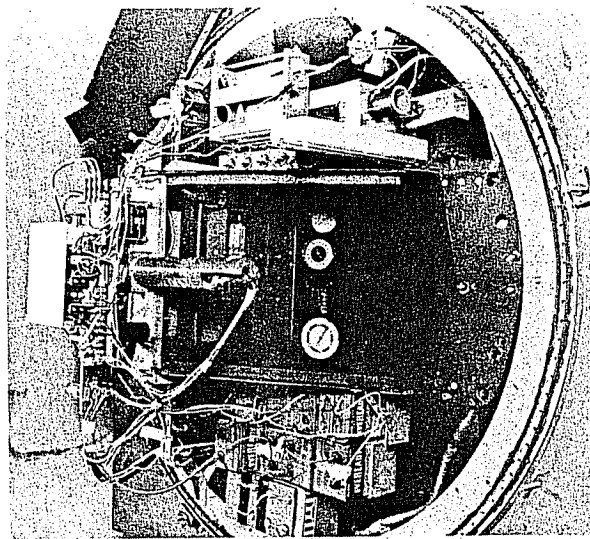


Figure 2-7. A CLOUD CHAMBER FOR USE IN THE STRATOSPHERE.
The apparatus is completely automatic and uses a Geiger counter telescope to 'trigger' the expansion. As sent aloft in the gondola of a balloon the equipment is sealed in an aluminum sphere about 4 feet in diameter.

Photo courtesy of Department of Physics, University of Minnesota

CLOUD CHAMBER BETA TRACKS

It requires some skill to get your Gilbert Cloud Chamber adjusted so that you have just the right amount of liquid and the right expansion to produce good, sharp beta tracks. Alpha tracks (as you have undoubtedly discovered) are easy to see in the chamber. Turn the rubber stopper that holds the alpha source so that the alpha source is submerged in the liquid. Then mount your beta source on the glass wall of the chamber by using some Scotch tape. See if you can detect the beta tracks. Also try the beta source at a distance of about one foot and level with the liquid. Many of the beta particles will be absorbed in the glass wall of the chamber, but, since our beta source produces very energetic rays, you may be sure that quite a number pass into the chamber. Do not be too disappointed if you do not see the beta tracks. It will be an accomplishment if you do.

You may make the particle tracks more visible by "souping up" the light in the chamber. One way to do this is to get a pair of automobile headlight bulbs and put them in place of your flashlight bulbs. (This requires a 6 volt battery.) Rather than keep them on all the time you may put a switch in the lamp circuit so that you flash the lights on when the chamber is expanded.

SECTION III

DETECTING PARTICLES ELECTRICALLY

So far we have used the Geiger Counter and the Cloud Chamber to track down nuclear particles. Our tracking has concentrated on the alpha particle and the gamma ray. We have found that the alpha particle, despite its high energy, is easily absorbed in a few inches of air or in a sheet of paper. The gamma ray is capable of penetrating fairly large thicknesses of material, going through most books without difficulty. In this section we shall use a new instrument called an "Electroscope." With it we shall explore again the alpha particle and the gamma ray and in addition we shall investigate the beta ray in greater detail.

We know from our previous experience that the alpha particle strips off electrons from neutral atoms and converts them into ions. These ions, or electrically charged atoms, would normally find other electrons wandering around in the gas and recombine to form neutral atoms again. But if we have an Electroscope, with an ionization chamber in which there is a collecting electrode to attract the ions, they will rush toward this wire so fast that most of them will not have time to pick up any electrons and become neutral. This rush of ions through the air of the ionization chamber forms what we call an ionization current.

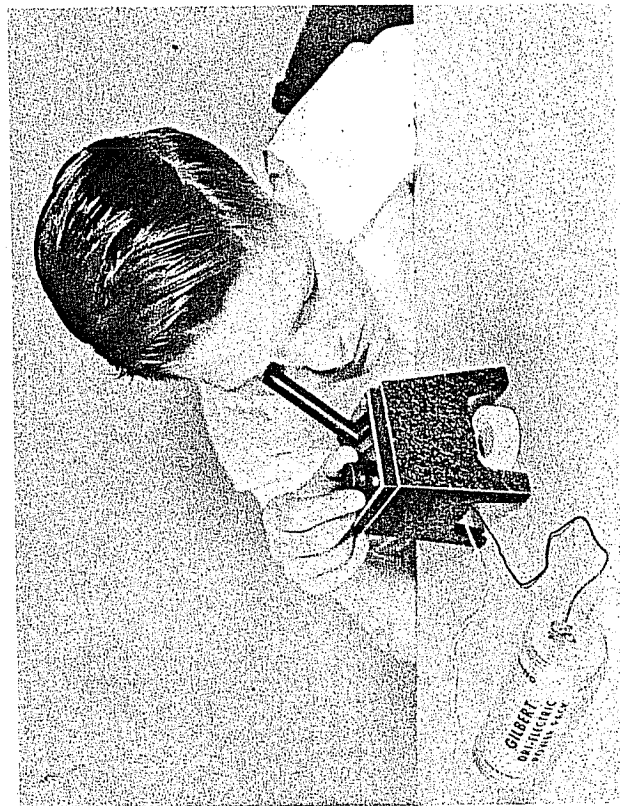


Figure 3-1. PHOTOGRAPH OF BOY ADJUSTING ELECTROSCOPE

OPERATING THE ELECTROSCOPE

To operate your Electroscope connect the two wires to the Gilbert Dri-Electric Power Pack terminals. (See Figure 3-1.) This will light up a small bulb under the base of the chamber and it will enable you to see the screen inside the thin black tube. You will probably just see the graduated divisions on the scale. Grasp the black knob behind your viewing tube and move it until a fine image of the ion chamber needle crosses the field of view. (See Figure 3-2.) Move the knob very slowly at first until you gain experience in recognizing the image and moving it across the field. (See Figure 3-3.) Then rotate the charging knob continuously until the fiber is to the right of zero on the scale. Now rotate the knob in the opposite direction to bring the fiber to zero. A slight backing off of the knob will then stop movement of the fiber. You have now charged the Electroscope to about 200 volts.

Set the needle so that it remains at the zero mark. You may find that the needle is not always clearly visible over the length of the scale. Now bring the alpha source up under the chamber and, using a wrist watch, note how long it takes for the needle to swing across the scale. (See Figure 3-4.) The stronger the alpha source, the more rapidly will the needle swing. Thus the Electroscope can be used to measure alpha radioactivity.

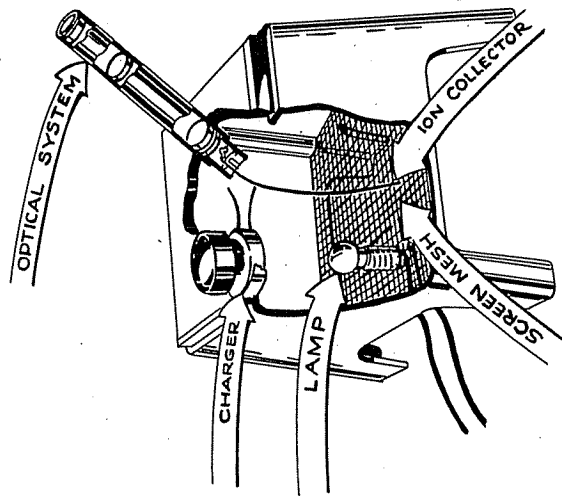


Figure 3-2. CUTAWAY VIEW OF THE ELECTROSCOPE

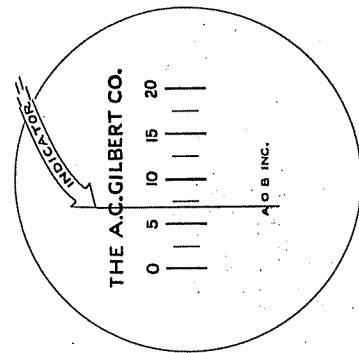


Figure 3-3. ELECTROSCOPE INDICATOR AND SCALE

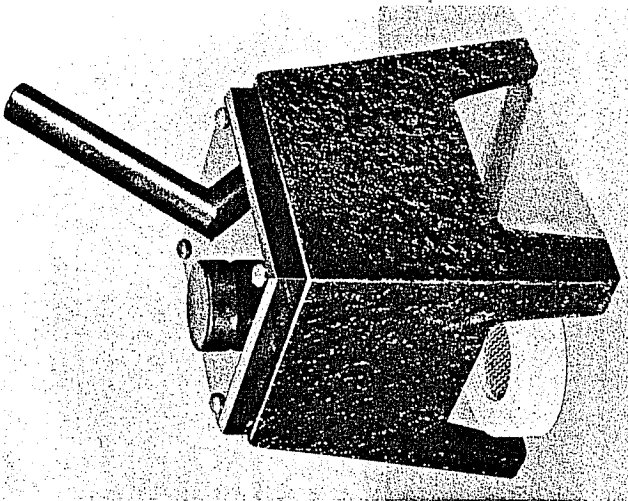


Figure 3-4.
ALPHA SOURCE IN PLACE
UNDER THE ELECTROSCOPE

EXPERIMENTING WITH THE ELECTROSCOPE

First, let us find out how the Electroscop behaves with no radioactive materials near. Adjust the needle of the Electroscop so that it rests at zero. Note the time in your notebook. Then follow the course of the needle as it drifts along the scale. Record the needle position every few minutes. The drift rate of the needles should be very slow. It should take several hours for it to travel all the way across the scale. It may happen, however, that your drift rate will be appreciable. Now, whenever you take a measurement with a radioactive source you should subtract the drift rate from your reading. You can, of course, set aside your instrument until a less humid day when the drift rate will be low.

In the following sections we will outline experiments for you to perform with your alpha, beta, and gamma sources. When you carry out these measurements it is well to keep in mind the difference between a Geiger Counter and an Electroscop. The Geiger Counter operates with the passage of a single ray. The Electroscop, on the other hand, does not count each particle but operates due to ionization produced in the Electroscop by radiation. Alpha rays produce the strongest ionization and therefore the Electroscop is very sensitive to these rays. Beta rays are less powerful ionizers and the Electroscop is less sensitive to them. The Electroscop is only slightly sensitive to the measurement of gamma rays, which have a very low ionizing power.

THE RANGE OF ALPHA PARTICLES

From our Cloud Chamber experiments we know that the maximum distance (range) which an alpha particle will travel in air is less than two inches. To measure the range of alpha particles in air by means of the Electroscop, set up your instruments according to Figure 3-5. Your plastic scale, with centimeter and inch division marks, should be taped to the box or support that holds the alpha source, so that the zero centimeter end just touches the screen of the Electroscop.

The support is leveled so that the alpha source is lined up with its center in line with the collecting electrode. (The collecting electrode is a small wire which you can see by looking into the underside of the Electroscop.) In this way the instrument lies on its side with the Electroscop tube facing upward. You will note that the scale of the Electroscop is now shifted in position, but this should not cause you any trouble.

Place the alpha source so that the actual surface of the alpha-emitting substance is five centimeters from the wire screen. Since the metal containing the radioactive material is two millimeters away from the surface of the plastic disc, this means that you must set the forward edge of the plastic disc 4.8 centimeters from the screen. Record the rate of swing of the indicator (quartz fiber) at this position. Make sure that you do not disturb the arrangement of the apparatus. Now, move the source one centimeter closer to the screen. Take a series of readings changing the distance one centimeter each time and record the data in your notebook in a neat row of figures.

Before taking any more data prepare a rough draft of the few readings you have, plotting the points as shown in Figure 3-6. Then look over the graph, noting where you need to take more data at other scale readings in order to see more accurately the range of the alpha particles. You will notice that you must get some readings in the distance between two and three centi-

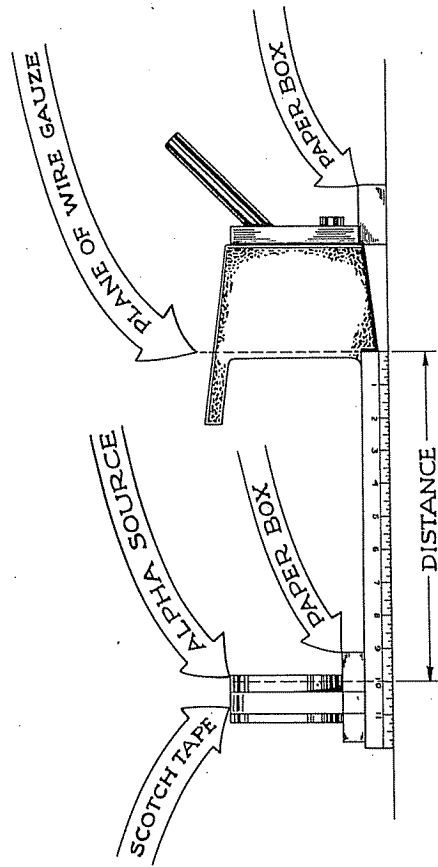


Figure 3-5. SET-UP FOR ALPHA RANGE DETERMINATION

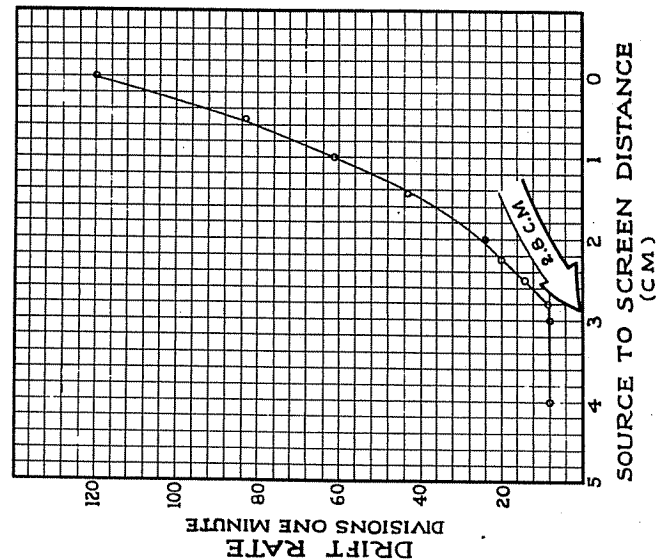


Figure 3-6.
THE RANGE OF ALPHA
PARTICLES

meters from the screen. It is a good rule to spot your observations over a wide range before taking data at small intervals. This saves time and makes for more accurate work.

Now that you have taken more data and plotted it on a graph you can see that up to about 2.8 centimeters from the screen the drift rate is fairly steady and therefore the ionization current is fairly steady. At 2.8 centimeters the ion current starts up sharply and continues ever faster until you reach the end of your scale. The reason for this is that as the source moves closer to the screen more alpha particles come within range of the Electroscopie chamber. Remember that alpha particles emerge from the surface of the source going in every direction, like bits of popcorn popping out of a hot pan. Some will come out headed right for the chamber, and others will shoot out in other directions.

Off hand, it would seem that the figure 2.8 centimeters which we read from our graph is the range of the alpha particle. However, this does not agree with textbooks which state that the range is given as 3.8 centimeters. What is the reason for this one centimeter difference? If you look closely at the under side of the Electroscopie you will note that the collecting electrode does not extend all the way to the wire screen. Measurements made with a general purpose Electroscopie, such as the Gilbert model, need a correction factor; you must add one centimeter to the measured range of the particle to get its true range, from the source to the chamber.

ABSORPTION OF ALPHA PARTICLES

Besides measuring the range of alpha particles in air, we can measure their absorption in thin sheets of material like paper. To prove that even a sheet of ordinary writing paper is thick enough to absorb the alpha particles, mount the alpha source on a small paper box or other support so that it is up against the screen of the Electroscopie.

You can do this experiment with the instrument right side up but take care that you do not get the plastic source tilted on the little nut which holds the lamp on the screen. With the alpha source in this position take the drift rate. It should be very high. Remove the alpha source from the screen and place a single sheet of paper over it, after which replace the source under the screen as before.

The drift rate now should be very much less, depending upon the thickness of the paper you use. You can perform a series of experiments using very thin tissue paper. For example, a single sheet of onion skin paper (as used for typewriter carbons) will allow some of the particles through. If you use two sheets of regular onion skin paper, you will find that this is enough to stop all of the alpha particles. See Figure 3-7 for absorption of alpha, beta, and gamma rays.

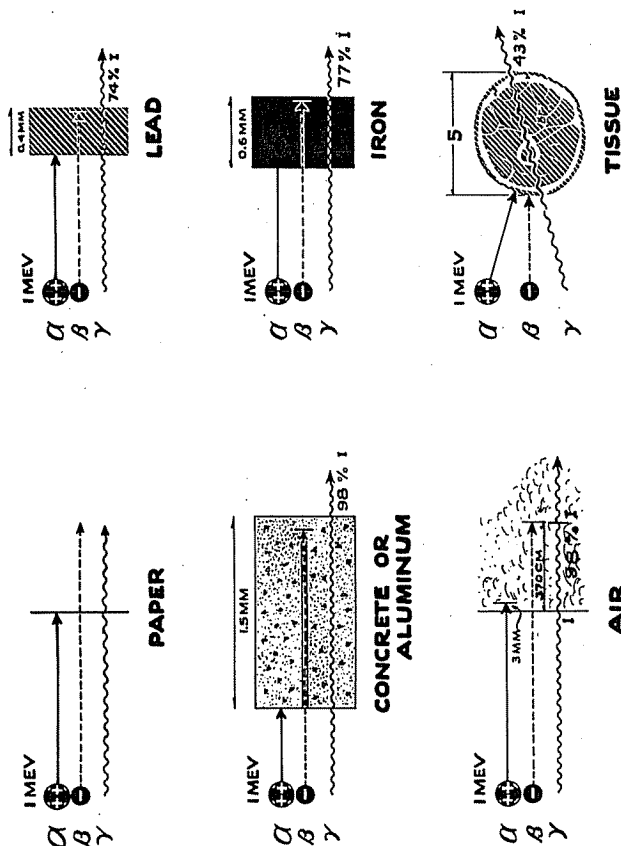


Figure 3-7. ABSORPTION OF ALPHA, BETA AND GAMMA RAYS