

GILBERT

Atomic Energy

MANUAL

INSTRUCTIONS FOR OPERATING GILBERT ATOMIC ENERGY LAB



YOUR GILBERT ATOMIC ENERGY LAB AND ITS VARIOUS PARTS AND INSTRUMENTS

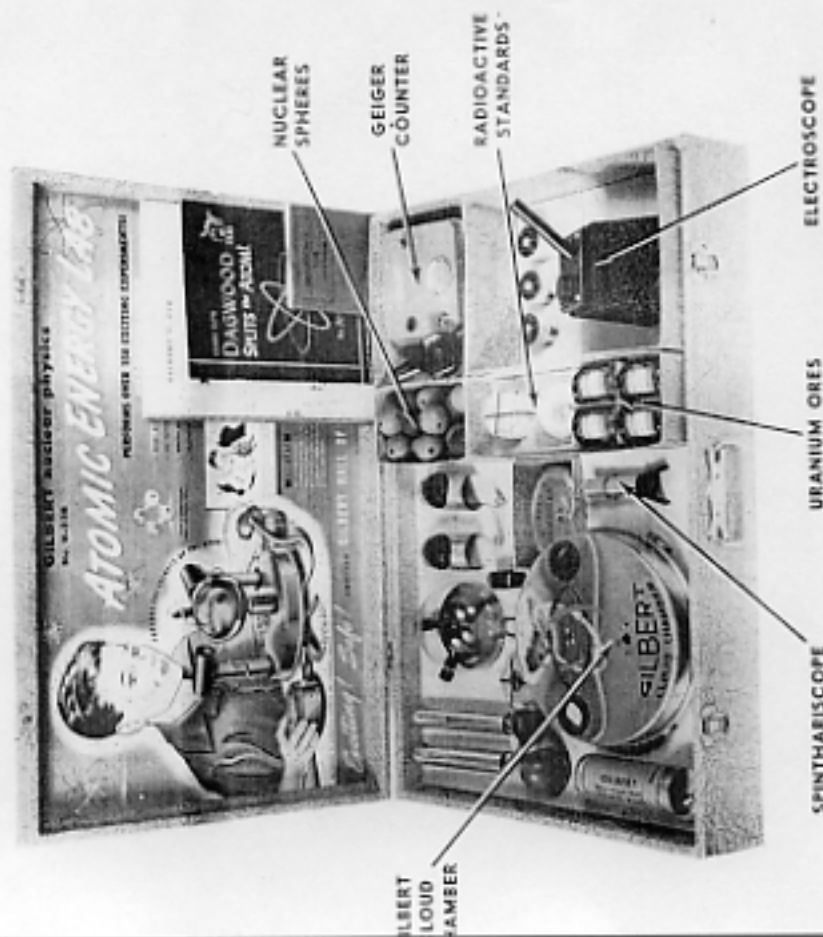


Figure 1-7. EXPERIMENTING WITH THE
GILBERT GEIGER COUNTER.

Gilbert Radioactive Source is held near the counter to produce a clicking in the headset. Neon tube flashes simultaneously with clicks.



SECTION I EXPLORING WITH THE GEIGER COUNTER

One of the first things that will intrigue you when you open your Atomic Energy Laboratory is the Geiger Counter, which is located in the upper right hand corner of the box.

To operate your Geiger Counter, follow these steps. First, remove the circular cap on top of the counter for installation of the battery. Second, insert one of the flashlight batteries in this space, making sure that the positive terminal of the battery is pointing down. (The positive terminal can be distinguished by the small circular stud at the center of the end.) Now look for the on-off switch which is located on top of the box. Switch to the on position and allow your Geiger Counter to warm up. It is now ready to operate.

You can use your Geiger Counter in either of two ways; (a) You can count the number of flashes occurring in the neon lamp which is mounted flush with the rubber grommet in the lid of the box. (b) You can listen to the clicks in the earphone.

You will find several small plastic sources mounted inside your Atomic Energy Lab. One of these is marked Radioactive Standard-Gamma Source. Remove this source from the Lab and bring it close to the Geiger Counter. When you do this you will note that the number of flashes or clicks will increase rapidly until you can hardly count them. Removing the source will cause the clicking sound or the flashing light to slow down. Later on we will go into detail and explain what the clicks and flashes are and what they mean. Meanwhile, we will merely say that each click or flash corresponds to the detection of a radioactive ray going through the Geiger Counter.

One thing that you can immediately do with the Geiger Counter is to ferret out a hidden radioactive source. Let someone in your family hide the gamma source while you are in another room. Then, using the ferret, explore the room. Soon, by noting the increased number of flashes or clicks, you will be able to locate the hidden source.

If you have a luminescent dial wrist watch or pocket watch or any other luminescent material try bringing it close to your Geiger Counter. You will discover that your Geiger Counter will detect these things. In fact, there are a great many items that are in every day use which are radioactive. Some of them, indeed, have quite a powerful intensity.

There has been so much misinformation about radioactivity that we pause here to reassure you and your parents that the radioactive sources supplied to you are not dangerous in any way. They have been carefully designed by some of the nation's top scientists to be instructive and harmless. We assure you that no harm will come to you through daily contact with the radioactive sources supplied with your Atomic Energy Lab.

Figure 1-1 shows what is inside the Geiger Counter. You will note the long slender tube which is supported by two copper electrodes. This tube is the

actual device which detects the penetrating rays and is known as a Geiger-Mueller Counter Tube. Now that you have an inside view of the Geiger Counter we can explain to you why the instrument hums when the switch is turned "On."

Although the Geiger-Mueller Counter Tube requires almost a thousand volts of electricity to operate satisfactorily, our only source of power is a 1-1/2 volt flashlight battery. Here is the way that we obtain the high voltage necessary from our low voltage source. First, we have a vibrator unit. This simple device chops up the direct current from the dry cell and converts it into pulsating current. You will notice that there are two coils wound on the vibrator and these together form a transformer. When the pulsating current feeds into the transformer it is boosted from a low voltage to a high voltage sufficient to operate the Geiger-Mueller Tube.

Anyone who uses a flashlight continuously knows that the battery will wear out. In the same way, your Geiger Counter will stop operating if you run it continuously for several hours. This does not mean that your instrument has burned out. It simply means that you must replace the flashlight battery. Any similar flashlight battery will be suitable. Just as a flashlight will work for weeks if it is used only for short periods of time, so, too, will the Geiger Counter run for a long time on a single battery if you use it for only a short time each day. You should remove the flashlight battery from the Counter if you are not going to use it for a long period of time. This will prevent battery leakage in the counter and insure longer life for your batteries.

The A. C. Gilbert Company has manufactured thousands of Geiger Counters and, while it has taken great pains to insure that each Geiger Counter will reach you in working condition and remain that way, it appreciates the fact

that out of the thousands of these sensitive instruments some will fail to function after a time. Here's what you should do in the event your instrument does not operate properly.

- 1) Make sure that the "On" switch is pushed to the "On" position.
- 2) Make sure that the battery has not worn out. Replace with a spare or a new battery in case you have any doubt.

If no hum from the vibrator is heard after these checks are made, the chances are that the vibrator has been damaged or has failed. However, it may happen that the vibrator will work properly but the instrument will not respond to the radioactive gamma source. Make sure that it is the gamma source that you are using. If the neon tube does not flash at all the Counter requires repair. If the neon tube flashes almost continuously in the absence of the radioactive source it also requires repair. Do not attempt to shake the battery or otherwise fix the Geiger Counter. Return it to The A. C. Gilbert Company per instructions given in the appendix.

MEASURING RADIATION WITH YOUR GEIGER COUNTER

While it is interesting to have fun with your Geiger Counter by hunting for hidden sources and showing the instrument off to your friends, it is far more interesting to make actual measurements as a scientist would. To go about this we first need a watch or a clock equipped with a sweep second hand. Start by seeing how our Geiger Counter behaves when there is no radioactive material around. The counting rate with no sources present is called the natural background of the instrument. It is very important for you to know the background count and to check this periodically to make sure that your instrument is performing properly. Record the number of counts for each 15 second period for an interval of five minutes. Your data should look something like that tabulated below:

	0-15 Seconds	15-30 Seconds	30-45 Seconds	45-60 Seconds	Total Seconds
1st Minute	3	4	2	3	12
2nd Minute	5	4	3	5	17
3rd Minute	4	4	3	3	14
4th Minute	3	3	5	3	14
5th Minute	5	3	5	4	17
				Total	74

To obtain the average counting rate, you must divide the total count 74 by time interval, thus obtaining about 15 counts per minute. Note that in any one minute the counting rate may swing as high as 17 or as low as 12. This makes it clear that in order to obtain a reliable average figure we must take counts over a long enough time to iron out the variations which occur during any short time period.

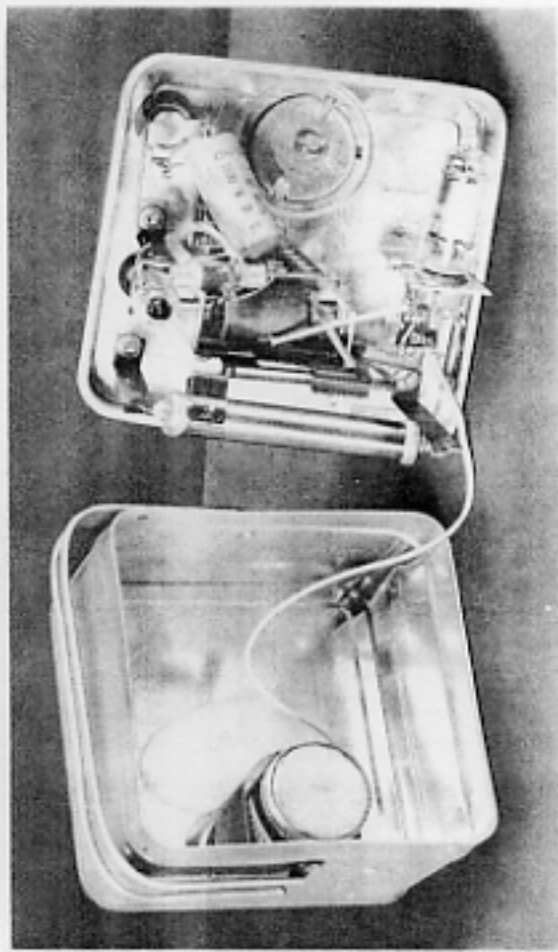


Figure 1-1. COMPONENTS OF YOUR GEIGER COUNTER

You can do an interesting experiment by simply jotting down on a piece of paper the exact time (reading on a stop watch or a sweep second hand) when each count occurs. Take data for five one half minute intervals. The data you obtain should look something like that listed below:

1st Minute	2nd Minute	3rd Minute	4th Minute	5th Minute
5	3	2	4	1
9	7	5	6	7
13	11	11	16	14
19	18	13	24	21
24	23	21	29	27
30	25	23		
	30	27		
		30		

RANDOM OCCURRENCE OF COUNT

Note that the occurrence of a count is completely random; that is, there is no observable regularity to the time when a click occurs.

GRAPHICAL REPRESENTATION OF RANDOM COUNT

The random nature of the count can also be readily seen from a graph. This is what you do. On a piece of graph paper mark off a unit that is to represent a minute and divide this minute into smaller units which are to represent seconds. Now, by using your watch, time the occurrence of the counts of your Geiger Counter. As each count occurs make a line on your graph corresponding to the time that it occurred. When the minute has elapsed mark off another set of units and repeat the above procedure. When you have done this four or five times you will note by comparing the graphs that the pattern of counts on your graphs is not the same. This is what we call a random count."

The background counting rate of your Geiger Counter should remain nearly constant even though you make the measurements on different days. You must make sure, however, that you always remove the radioactive sources from the vicinity of the counter when you make this measurement. It is also desirable to perform the experiment in the same place each time. The reason for this is that everything about us has some radioactivity and as we move to different places we are likely to encounter different amounts of radioactivity. Even the human body is slightly radioactive. The air we breathe contains small amounts of radioactive material. The earth and building materials contain more significant quantities of radioactive elements. No matter where we go we can never really be free from some small amount of radioactivity. We call this residual counting rate the radioactive background.

THE RADIOACTIVE SOURCES

Perhaps by now the user of the Atomic Energy Lab has been impatient to explore the properties of the radioactive sources marked alpha, beta, and gamma. First, bring the source labeled alpha up to the counter. Note that it has no recognizable effect on the counter. This should not disturb the user for there is nothing wrong with the source. It means that the type of ray emitted by this source is much different from the gamma ray. We call it the alpha ray. Alpha rays are easily absorbed in any solid substance or even in air and they are not able to penetrate the walls of the Geiger Counter.

The source marked beta does have an effect upon the Geiger Counter. In order to observe it, the source must be brought close to the Geiger Counter. Obviously the ray emitted from this source is more penetrating than the alpha ray, but it still is no match for the powerful gamma ray. We call these rays emitted from the beta source beta rays. We shall later learn that beta rays are simply high speed electrons. For the time being, however, we will concentrate our attentions solely upon the gamma rays.

One can have a great deal of fun playing hide and seek with the gamma ray source. Obviously, this game takes two or more people to play it. The person who is selected to find the gamma ray source is given the Geiger Counter and told to wait outside the room while the others hide the source. Then, after the source has been hidden, the outsider is invited in and told to look for it. Prizes can be awarded to the person who finds it in the shortest time.

HOW FAR AWAY CAN THE SOURCE BE DETECTED?

Let us see how far away from the source we can get with the Geiger Counter and still detect the presence of the source through an increased counting rate. To perform this experiment, place the source in the open, let's say in the center of a large room. Then lay a tape measure in a straight line away from the source. Starting at a distance of six feet away from the source, make a measurement of the counting rate. You will find that at this distance the rate is about that of the background count. Now, move the source a foot closer to the Geiger Counter. The Geiger Counter tube inside the Geiger Counter is located almost entirely under the words "Model U239" and this is an excellent spot to measure from. We can then speak of the source to counter distance in exact terms. Move the source in steps of a foot or a half foot closer to the Geiger Counter. Record the counts per minute for each distance. You should be able to take measurements up to six inches from the Geiger Counter.

At this point the counting rate will be very high. The count may be over 200 counts per minute. (Counts per minute is often abbreviated to read c.p.m.). You need to use a trick to count so rapidly. On one of your data sheets, make a large cross so that you can record data in four groups. In each quadrant, or section, of the cross make a pencil dot for all counts occurring in a 15 second interval. In this way you do not need to keep counting, but simply jab at the paper every time a click or a flash occurs. By dividing the data into four 15 second intervals, you can look at the consistency of your counting. At your leisure you can count up the number of dots in each quadrant and, with a little practice, you will be able to count 200 c.p.m. with fair accuracy.

counting rate. If you are not familiar with the technique of plotting points on graph paper and if it is not readily apparent to you how this is done, you may check with your science teacher for some assistance.

To plot our data on the graph, we take a given set of readings, say 43 c.p.m. at 18". We run a pencil along the horizontal scale until we find 18" (1.5 feet). Here we make a mark. Then we run a pencil line upward (parallel to the vertical scale), stopping at a point which is opposite 43 on the vertical scale. Similarly we establish points for the other sets of data until all the data is plotted. Now we can sketch in by hand a smooth curve connecting all these points.

Now, you can estimate the intensity of gamma radiation at any point from six inches to thirty six inches. It is done like this. From some random distance on your horizontal scale draw a line parallel to the horizontal scale over to the vertical scale. At this point on the scale you can read off the counts per minute which is the approximate count for your random distance. Thus one reads intensity of 15 c.p.m. at a distance of 2.5 feet. Figure 1-2 illustrates the relationship between the distance from the Geiger Counter to the gamma source and the counts per minute (c.p.m.).

Relationship Between Intensity and Distance

The most obvious fact to learn from the curve in Figure 1-2, or the curve that you have drawn, is that the intensity (c.p.m.) of gamma radiation drops off very rapidly with increasing distance from the source. Let us look a little more closely at the exact way in which this intensity drops off and see if there is any rhyme or reason to it. The intensity at one foot is roughly 100. If we double the distance we find that at two feet the intensity drops to about 1/4th of its one foot value. Thus, by doubling the distance, we decrease the intensity by a factor of 4, or, to put it another way, the number of counts is 1/4th as many when the distance is doubled. There are only about 1/9th as many counts when the distance is tripled. Examine your curve or Figure 1-4 and you will see that this is true. Whenever a quantity behaves this way it is said to obey the Inverse Square Law.

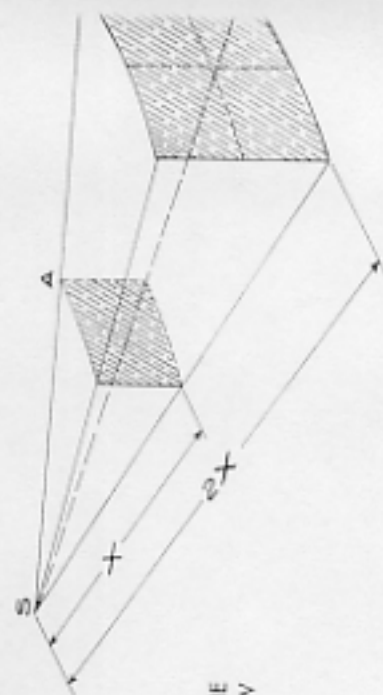


Figure 1-3.
UNDERSTANDING THE
INVERSE SQUARE LAW

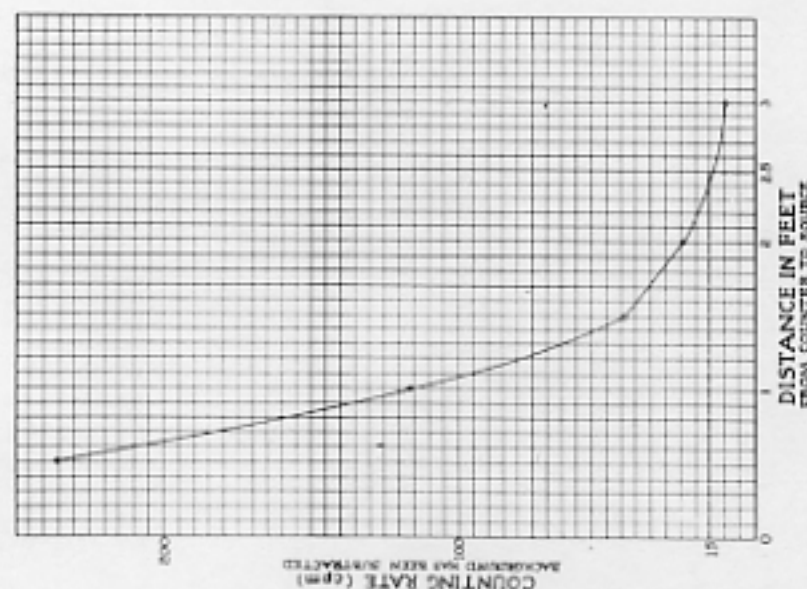


Figure 1-2.
COUNTING RATE AT
VARIOUS DISTANCES
FROM THE GAMMA
SOURCE

From each reading, subtract the background counting rate. Your data should then appear as follows:

Distance	Counting Rate (C. P. M.)
6"	236
1 ft.	104
18"	43
2 ft.	23
3 ft.	10
Greater than 3 ft.	Close to Background Count

Since the counting rate really expresses the number of gamma rays at any one point we may call this the intensity. Thus, we have obtained experimental data on the intensity of gamma radiation (rays per minute) from a small source for various distances away from this source.

We have taken data for a number of distances. Now, we shall put this data on a chart or graph so that we can read off the intensity or counting rate at any distance. To do this we take a piece of graph paper, preferably one ruled with large squares. We mark off on the horizontal scale the distances in feet, which represent the distance separating the source from the counter in our experiment. Then on the vertical scale we mark off appropriate units for the

The Inverse Square Law is one which is good for more than just gamma rays. It applies to radiation emitted by an ordinary light. You can verify this fact by taking a light meter such as the direct reading type used by photographers and take readings of the light intensity at various distances from a lamp bulb. You should find that the observations will confirm your experience with gamma rays.

By glancing at Figure 1-3 you may be able to see a little more clearly how the Inverse Square Law works. We have a source located at S. At some arbitrary distance which we shall call X, we measure the counts or radiation intensity. Let us say that 100 rays pass through the area at X distance from the source. Now looking at the next area which is 2X, or twice as far from the source as the first area, we see that it has an area 4 times as large as the first area.

As the 100 rays are still radiating in the same direction, we find that the 100 rays are passing through 4 times the area, while in any small portion of that area there are only 1/4th as many rays as before. So it may be concluded that, as the distance is doubled, the intensity, or the number of rays passing through the same amount of space, is divided by four or 1/4th as much. The same situation would prevail if the distance were tripled, except that there would be 3 squared or 9 times the area and the intensity would be divided by 9 or be 1/9th of the original intensity.

More About Gamma Rays

The experiment which we have done with gamma rays may not yield the same data to all observers. To check this assertion, try making the same kind of measurements varying the local conditions. Perform the experiment first on a concrete floor. Then, prop your source and counter up on two cardboard boxes so that you make the experiment up in the air away from heavy materials such as concrete. You will observe differences and they will depend upon precisely what solid objects are close to the gamma source and to the Geiger Counter. Gamma rays can penetrate concrete and are also scattered by concrete.

Absorbing the Gamma Rays

So far we have investigated the effect which the distance from the source to the counter has upon the counting rate. Now, let us turn our attention to the problem of seeing what effect various materials have upon the counting rate. One of the most common materials that one usually has around the house is wood, so we shall use this for our first experiment of measuring the absorption of gamma rays.

For this experiment it will be most useful if one selects pieces of wood (if wood is not readily available, you may use books instead) one inch in thickness and larger than the width and depth of the Geiger Counter. Set up the equipment as shown in Figure 1-4. First, with no slabs of wood in between

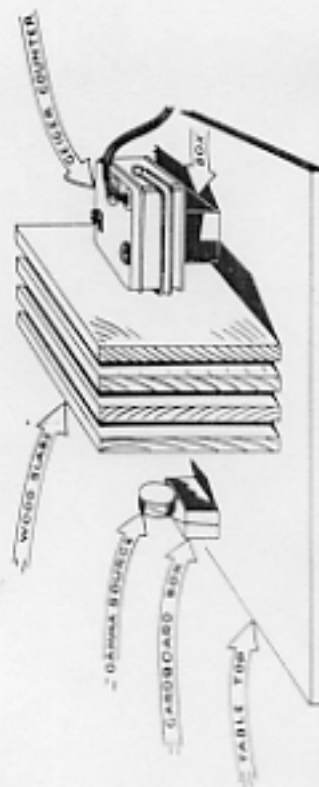


Figure 1-4.
HOW THE GAMMA RAY ABSORPTION EXPERIMENT IS SET UP

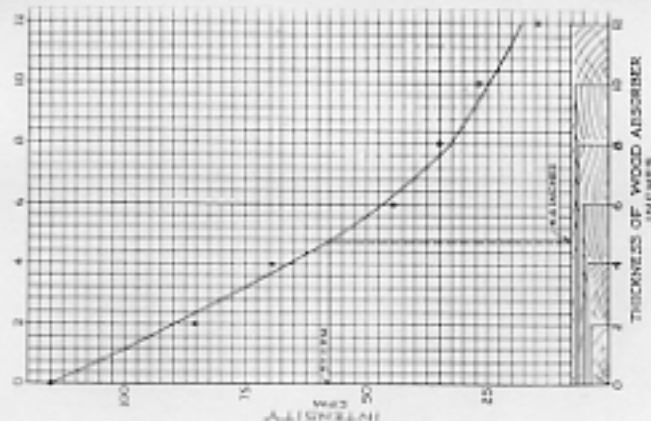


Figure 1-5.
GRAPH SHOWING HOW WOOD THICKNESS AFFECTS INTENSITY

the counter and source, measure the counting rate and put this value in y note book as shown below:

Thickness of Wood	Counting Rate* (C.P.M.)
0 Inches	115
3	86
4	69
6	44
8	35
10	27
12	14

*Counter to source distance = 12 inches

Then, insert one piece of wood and measure the counting rate carefully. Repeat this measurement for each piece of wood added until finally the counting rate is so low that it is almost the same as the background count.

By inspecting the various counting rates we can see that the intensity of the gamma rays drops off sharply. To be more scientific, we have to resort to graphical means of representing the data which we have thus obtained.

Figure 1-5 shows just how we construct a simple graph. The horizontal scale represents the thickness of wood used as an absorber. The vertical scale shows the counting rate. As before, we plot each set of points on the graph remembering that we must use the corrected counting rate; that is, the measured counts per minute minus the background count. When we have the string of points spotted on the graph, we draw a continuous line through them as shown in Figure 1-5.

You may find that your points if connected by a series of straight lines would make a rather ragged curve. This is due to the uncertainty in each measurement plus effects due to the scattering of the gamma rays. You may avoid this difficulty by drawing a smooth curve on the graph which seems to come closest to all the points.

Half Thickness

Now that we have a smooth curve we can pick off the graph the intensity for any thickness of wood or we can determine what thickness of wood is required to reduce the initial intensity (with no absorber) by a given amount. The thickness of absorbing material which just reduces the counts per minute by $1/2$ is called the half thickness. Examine Figure 1-5 and you will note that the number of counts per minute is halved at a thickness of absorber material of about four and one half inches. Check the graph that you have made, and determine the half thickness of the material that you used as an absorber.

While you may not have realized it in doing the experiment on absorption, it is important to keep the source and the instrument at a fixed distance from each other. If one did the experiment by simply sandwiching the absorber between the counter and source then no simple relation between absorber thickness and intensity would be obtained. Every time a new absorber would be added to the sandwich the relative distance and therefore the counting rate would be changed. The size of the absorber itself has some influence on the observed intensity for some of the radiation is scattered and introduces a complicating effect.

As a gamma ray whizzes through matter it completely disregards the atoms of the matter through which it is passing; that is, until it finally makes one collision with a single atom. Then it hands over all of its energy to an electron in this atom. Thereupon, the electron is quickly stopped because it, unlike a gamma ray, does not disregard the influence of atoms around it. When a gamma ray is emitted from the gamma source, it may either travel through a fraction of an inch in the wood or it may travel through all twelve inches. On the average, considering the mass behavior of thousands of gamma rays, there is a higher probability, however, that the gamma ray will be stopped in the first few layers of the absorber.



Figure 1-6. COMPARING DIFFERENT MATERIALS AS ABSORBERS

Shown above are the half-thicknesses of wood, water, aluminum, iron, and lead. Thus $3/4$ inch of iron will absorb as much gamma radiation as 4 inches of water.

Different Kinds of Absorbers

Let us now see how materials other than wood work as absorbers. Perhaps the easiest material to obtain is iron or, in some cases, aluminum may be readily available. Such objects as a frying pan or other kitchen utensils are good examples. Other obtainable materials with which you can experiment are tin, glass, crockery, rubber, plastic, cloth, paper, sand, brick, lead, brass, putty and so on.

Using absorbers of whatever material you can obtain repeat the absorption experiment. As before, plot your results on a graph. Note that the same kind of curve is obtained as we found for wood but that the half thickness value for iron or aluminum is much less than for wood. If you have sheets of lead available, you will be able to verify that the half thickness is still less for this heavy element. Our use of the half thickness is a convenient yardstick by means of which we can compare the gamma ray absorption in different materials. By it we can say that one inch of wood is equivalent to one-tenth of an inch of lead. In other words, lead absorbs gamma rays 10 times better than wood. Now, if you had access to all the different common elements and could carry on experiments with them, you would be able to obtain half thicknesses for these and make a graphical comparison such as is shown in Figure 1-6.

Physicists customarily use an abbreviated unit for measuring gamma ray energy. This unit is called the Electron Volt, and more often a larger unit, one million electron volts is used. This is abbreviated one MEV. This unit we shall use in talking about gamma rays. Our Atomic Energy Lab gamma source for example is found to emit a 1.14 MEV gamma ray.

The advantage of having a convenient unit for talking about gamma rays is that we no longer have to be so vague as to say, "In this experiment we use a soft gamma ray..." Rather we can be accurate and say "Here we use a 0.35 MEV gamma ray..." The larger the MEV of a gamma ray, the greater is its half thickness and the greater is its penetrating power. Gamma rays having energy above one MEV are usually thought of as being high energy ra-

RADIOACTIVE ORES

Included with your Atomic Energy Lab are four glass bottles containing samples of radioactive ore. Sample No. 100 contains some pieces of Carnotite taken from the Colorado plateau region. Carnotite is bright yellow in color. Your sample, however, may be of greyish or brownish cast due to the presence of iron. Consult your booklet, "Prospecting for Uranium," for more information about the occurrence of this ore.

To make a rough measurement of the radioactivity of your sample, place the glass bottle next to the Geiger Counter, locating it as close to the Geiger tube as possible. The counting rate that you will obtain will depend upon the strength of your particular sample. It should be somewhere between 35 and 100 counts per minute.

Make the same test to determine the radioactivity of the other samples and record the data in your note book. You will probably find that the Carnotite is the most active of the samples with the Autunite being the next most radioactive. The Torbernite and Uraninite will be quite weak and may only register about 50% over the background rate.

All these samples except the Autunite have been sealed in bottles so that you will not open them. The Autunite is not sealed and you can remove the pieces from the jar. The other samples have been sealed for they tend to flake and crumble and you would run the risk of having radioactive ore spread out in your laboratory. This will raise the level of the background count. The Autunite is sufficiently hard so that it does not crumble readily and you may handle it outside of the container. It is well, however, to place pieces of the ore in a thin paper sack so that small bits of the ore do not contaminate your laboratory.

Place the packaged Autunite next to the Geiger Counter and again record the counting rate. You should note a very decided increase in the count. Your counting rate should increase at about a factor of four or five. How do we account for this big increase? It is true that we have spread the old sample out more so that more of it is closer to the Geiger Counter. This, however, would not account for such a big increase. We must conclude that the ore emits some kind of radiation which is absorbed by the thick glass wall of our sample bottle. We can verify this by slipping a plate of glass in between our Geiger Counter and this Autunite and determining the counting rate again. This time we will find that it drops off, showing that we were correct in assuming that some other easily absorbable radiation is present. This type of radiation consists of beta rays which are also emitted by our beta source.

Introducing Beta Rays

Up until now our experiments have been mostly with the gamma rays. We deliberately refrained from introducing the beta source in order not to confuse you by meeting many new particles in the early part of your experimenting. Now we shall describe beta radiation very briefly, leaving until a later chapter the more detailed discussion of the subject.

Absorption of Beta Particles

Let us first measure the absorption of beta particles in some light material such as cardboard. Take some stiff cardboard, not of the corrugated variety and cut up a dozen or so pieces large enough to cover the beta source. Prepare the beta source by taping it to a little paper box and face it toward the side of the Geiger Counter which contains the Geiger Counter tube. Place the Geiger Counter about 12 inches or so from the source. At this distance you will get a counting rate of about 100 or more c.p.m. Now place one piece of cardboard after another between the source and the counter taking a reading for each absorber added. You will find that a one centimeter layer (a little larger than 1/3 of an inch) of cardboard absorbs most of the beta rays. Two as many centimeters of cardboard absorbs the beta rays completely. Use the plastic rule supplied with your Atomic Energy Lab in order to change from inches to centimeters.

As another experiment you can substitute thin sheets of metal for the cardboard and note that the beta particles are completely stopped by as little as seven-tenths centimeters of aluminum or three-tenths centimeters of iron. From this we can conclude that our Geiger Counter would not be able to detect beta rays at all if the Geiger Counter tube were packaged in a heavy steel box.

In working with your Geiger Counter and beta source you may often find that an experiment will produce a puzzling result, or two experiments which you think should produce the same result will yield inconsistent data. For example, if you place the beta source a given distance from the Geiger Counter and have the beta source suspended in air so that nothing solid is close to it, you may find that the results with the Geiger Counter are considerably different from those obtained with the source placed upon a table top or backed with wood. Furthermore, even in air the course of a beta particle is not a straight line, but an irregular path. Thus, in making absorption measurements, it becomes important that you consider where you place your absorber in respect to the source and to the Geiger Counter. Furthermore, the size of the absorber becomes important since this will affect the scattering of the beta particles.

PROSPECTING FOR URANIUM

As a result of our war-time development of Atomic Energy the element uranium has assumed great importance in our national affairs. Uranium is a very heavy metallic element, but it does not occur in metallic form in nature. Nevertheless, there are over 100 minerals which are uranium bearing. These are widely distributed over the face of the earth. There are, however, only a very few deposits of uranium ore which are rich in uranium. Most of the uranium which has been mined has been taken from veins of pitchblende located as follows: Shinkolobwe in the Belgian Congo, Eldorado in Canada, and Joachimsthal in Bohemia. In these localities, especially in the Belgian Congo, uranium occurs in very rich deposits.

A prospector equipped with a Geiger Counter can use his instrument as an aid to discovering deposits of uranium ore. There are, however, some v.

shielding is in place. The exact amount of the decrease will depend upon amount or type of shielding, but in general a thick shield on all sides should decrease the counting rate by about a third.

Since we have successfully reduced the effect of radiation from the surroundings we are justified in asking what the Geiger Counter registers when it is shielded. One might suspect that the radioactivity in the shielding material might be the culprit, but we know from experience that lead is not radioactive so we can eliminate this as a contributing factor. What then do we have as the cause of the remaining clicks in the Geiger Counter?

Evidently the radiation which continues to cause the Geiger Counter to click even with very heavy layers of lead or iron around it is much more penetrating than the rays which are emitted from our radioactive sources. Scientists, such as Robert A. Millikan and Arthur H. Compton have devoted much of their life work to the study of these very penetrating rays which we shall call Cosmic Rays. These rays are quite different in their nature from beta rays. They are actually sub-atomic particles traveling with very high speeds. These new particles are called Mesons although the name Meson is so times used too.



Figure 1-7.
YOUNG PROSPECT
HOLDING THE GIL
GEIGER COUNTER NE
ROCK FORMATION TO
FOR RADIOACTIVITY.

definite difficulties in prospecting for uranium and you should not feel that you can dash out and discover new deposits of the precious ore. First, while uranium is a relatively abundant element (ranking with lead in terms of abundance) it is usually found in very little concentrations so that detection is difficult. Secondly, the ore may be covered over with non-radioactive rock in which case the radioactivity of the ore itself is smothered by absorption in this rock. The booklet entitled "Prospecting for Uranium" included in your Atomic Energy Lab contains details about uranium prospecting. The booklet is an official one prepared jointly by the Atomic Energy Commission and the U. S. Geological Survey. No matter where you go on the surface of the earth, you will find that your Geiger Counter never ceases to have a steady background counting rate. By and large this background rate does not vary much from one place to another, although, if you happen to be standing near a pitchblende deposit the rate would be increased. If we do not consider such a special case we know that the background is ordinarily fairly constant. It must be due to radiation in the immediate vicinity of the counter.

Suppose we list the various sources of radiation which may cause clicks in the Geiger Counter:

- 1) We know that radioactivity in the earth bombards the counter.
- 2) We know that building materials contain a small fraction of radioactive substances which also contribute to the counting rate.
- 3) We know that the materials in the Geiger Counter itself are very slightly radioactive and give rise to counts.
- 4) Finally we know that there is a slight amount of radioactive material in the air and human beings which might contribute to the counting rate.

SHIELDING

In order to eliminate some of these sources of radioactivity let us surround the Geiger Counter with layers of heavy substances on all sides. Allow the cord to the ear phones to come out one side of shielding material so that the counting rate may be measured. Lead is an ideal substance for you to use for this experiment, but since you may not have this in your home, you may substitute another material such as iron or copper. If you happen to be an apartment dweller with no such items at hand, then you may perform the experiment in your science laboratory at school. Shielding the counter on all sides with an inch or two of solid lead, or with a thicker layer of less dense material, would be expected to reduce the radiation from sources in the vicinity of the counter. It would not, of course, shield against the radioactivity materials in the counter itself, but, we can easily show by using another Geiger Counter that the radioactivity of the instrument itself is very small.

Make a careful measurement of the counting rate with the shield in place. Count for at least 10 minutes in order to get a good average rate. Then, make a similar measurement of the counting rate with no shield around the counter. You should obtain a definite decrease in counting rate when the

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.

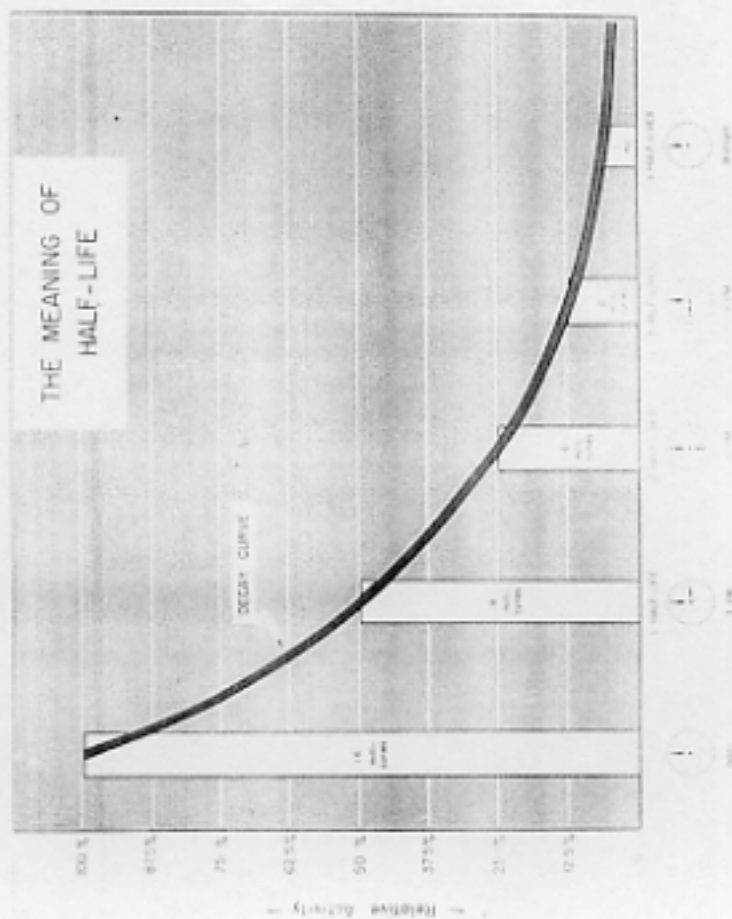


Photo courtesy of the Atomic Energy Commission

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 altitude 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.

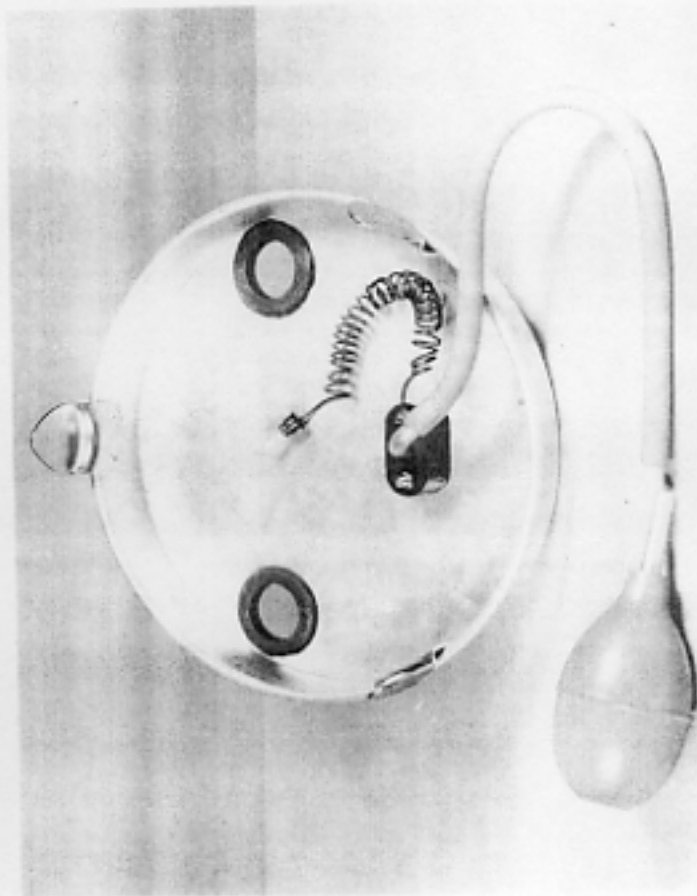
HALF LIFE

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 $1/60000$ 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.



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 have waited until now to discuss its use. The reason for this is that we want 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 alcohol or ink. On the table place the aluminum Cloud Chamber base (the round plate with the three legs).

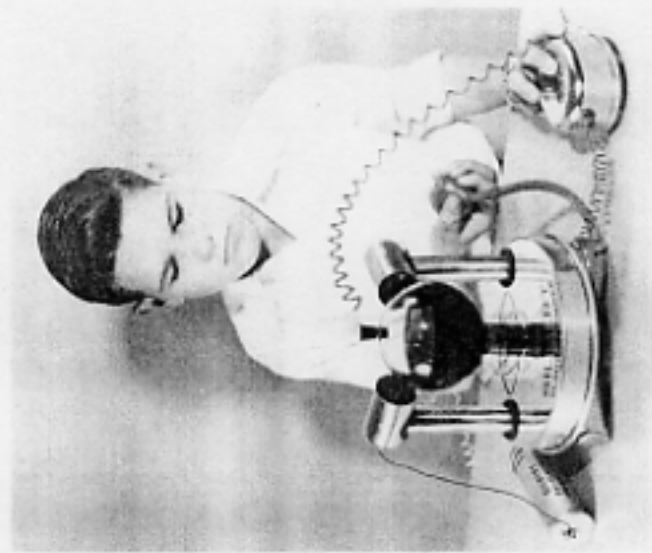


Figure 2-1. THE GILBERT
CLOUD CHAMBER,
READY FOR OPERATION

2) Fasten the rubber mounting block (with the cylindrical lip placed upwards) 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 lead 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

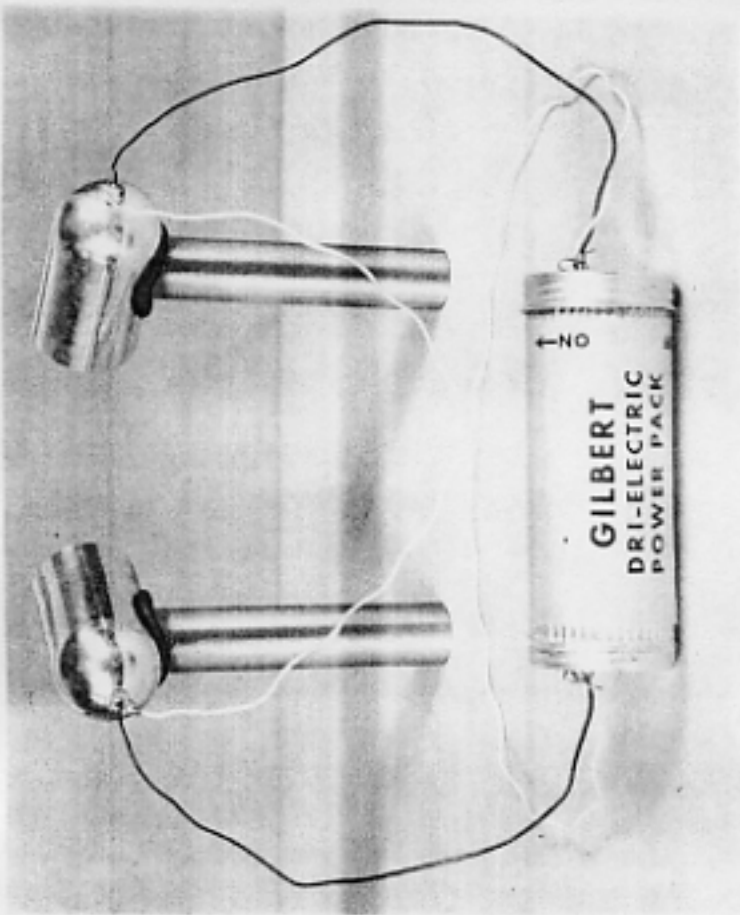


Figure 2-4. THE GILBERT DRI-ELECTRIC POWER PACK WITH LIGHT HOUSING

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 seal 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 "compression" 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 the chamber when no fog is present. Our experiment catches the invisible particles and makes them visible by means of forming droplets on them.

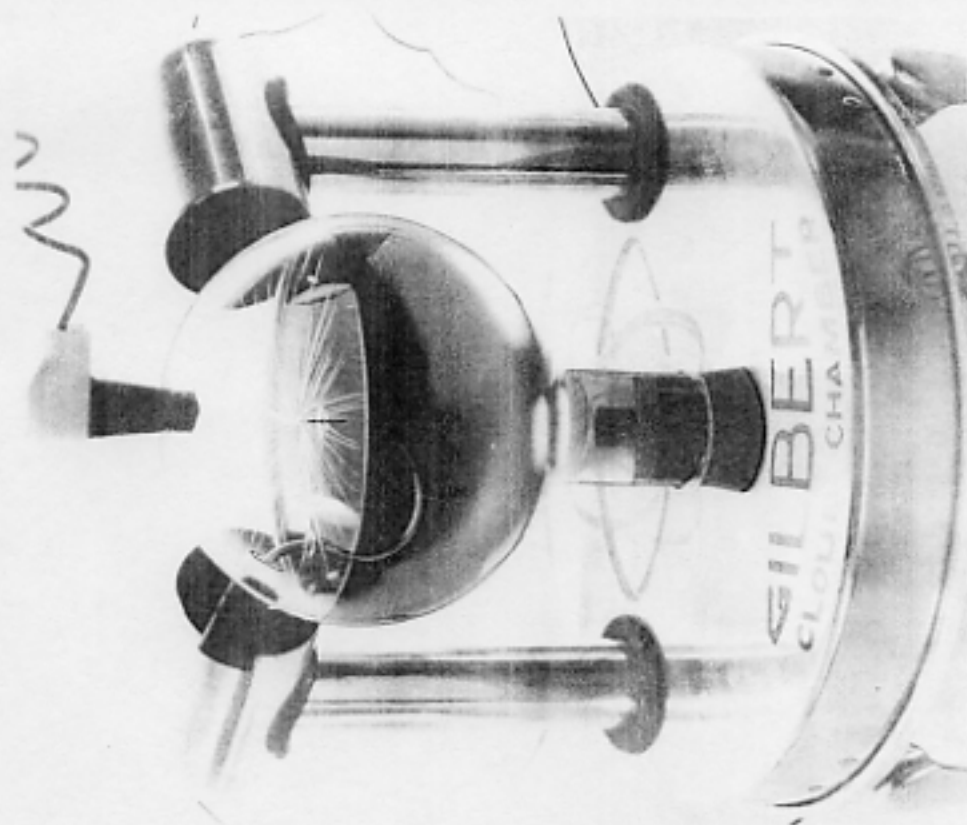


Figure 2-5. CLOSE-UP OF ALPHA TRACKS IN THE GILBERT CLOUD CHAMBER. ALPHA PARTICLES ARE TRAVELLING 3,600,000 MILES PER HOUR

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 track really ends 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 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 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 this source is kept in the Cloud Chamber.

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

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.

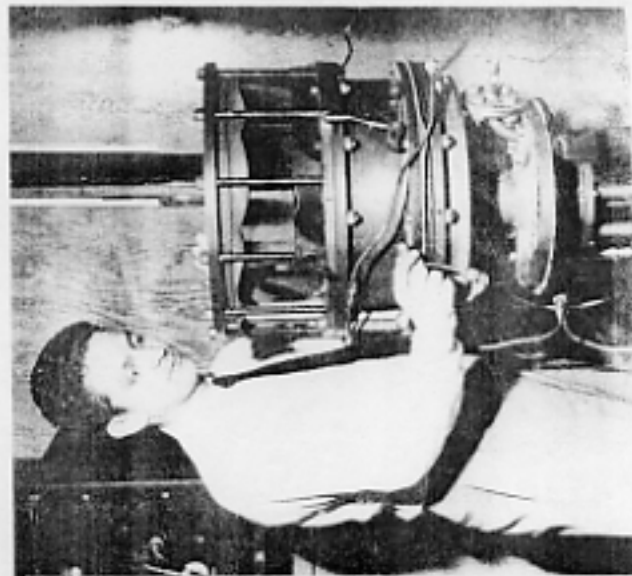


Figure 2-6.

A MODERN RESEARCH
CLOUD CHAMBER

Photo shows a cylindrical chamber in use at Columbia University. See text for details.

Photo courtesy of Columbia University

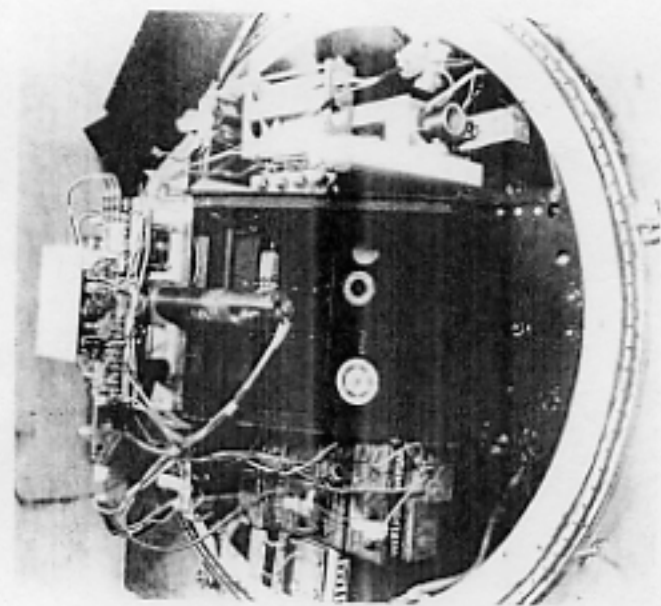


Figure 2-7. A CLOUD CHAMBER FOR USE IN THE STRATOSPHERE.

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 move 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.

OPERATING THE ELECTROSCOPE

To operate your Electroscope connect the two wires to the Gilbert Dry-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 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 it fiber to zero. A slight backing off of the knob will then stop movement of 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.) Stronger the alpha source, the more rapidly will the needle swing. Thus Electroscope can be used to measure alpha radioactivity.

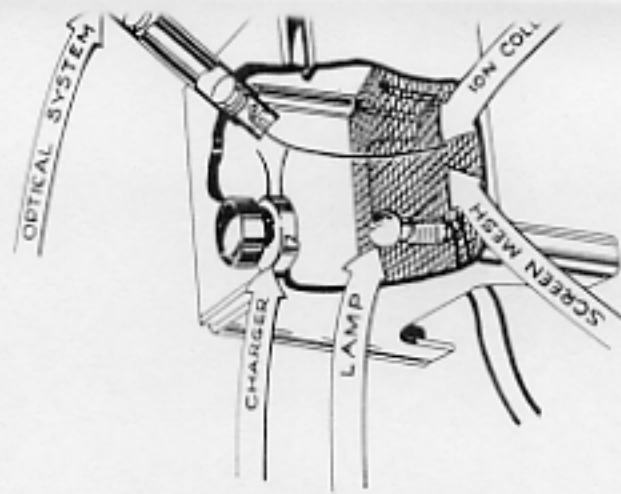


Figure 3-2.
CUTAWAY VIEW OF THE
ELECTROSCOPE



Figure 3-3.
ELECTROSCOPE INDICATOR AND SCALE

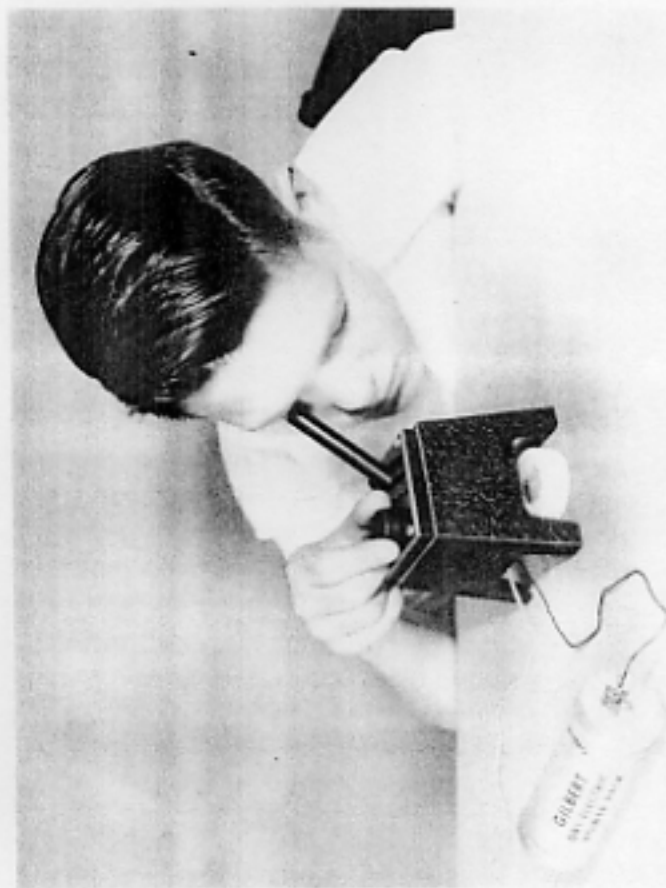


Figure 3-1. PHOTOGRAPH OF BOY ADJUSTING ELECTROSCOPE

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. measure the range of alpha particles in air by means of the Electroscopic. 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 Electroscopic.

The support is leveled so that the alpha source is lined up with its center line with the collecting electrode. (The collecting electrode is a small wire which you can see by looking into the underside of the Electroscopic.) In this way the instrument lies on its side with the Electroscopic tube facing upward. You will note that the scale of the Electroscopic 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 container of 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-

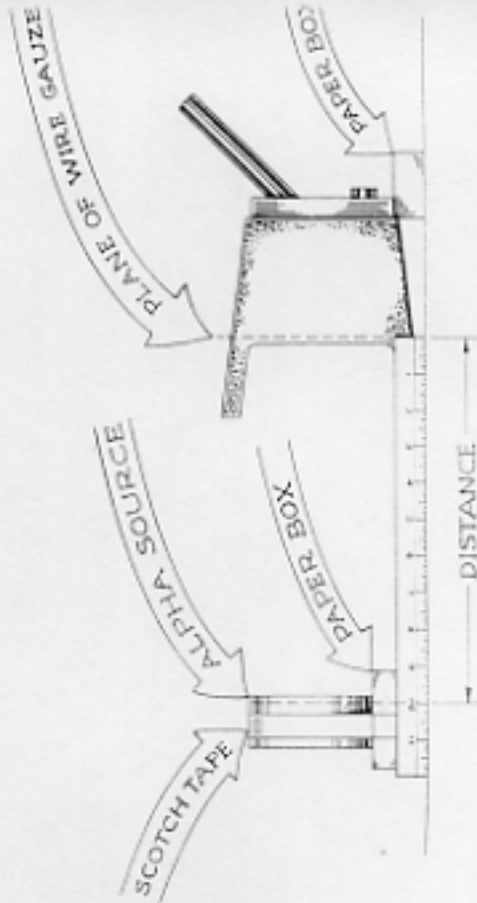


Figure 3-5. SET-UP FOR ALPHA RANGE DETERMINATION

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

EXPERIMENTING WITH THE ELECTROSCOPE

First, let us find out how the Electroscopic behaves with no radioactive materials near. Adjust the needle of the Electroscopic 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 Electroscopic. The Geiger Counter operates with the passage of a single ray. The Electroscopic, on the other hand, does not count each particle but operates due to ionization produced in the Electroscopic by radiation. Alpha rays produce the strongest ionization and therefore the Electroscopic is very sensitive to these rays. Beta rays are less powerful ionizers and the Electroscopic is less sensitive to them. The Electroscopic is only slightly sensitive to the measurement of gamma rays, which have a very low ionizing power.

ABSORPTION OF ALPHA PARTICLES

Besides measuring the range of alpha particles in air, we can measure the 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, move the alpha source on a small paper box or other support so that it is up against the screen of the Electroscopic.

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 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.

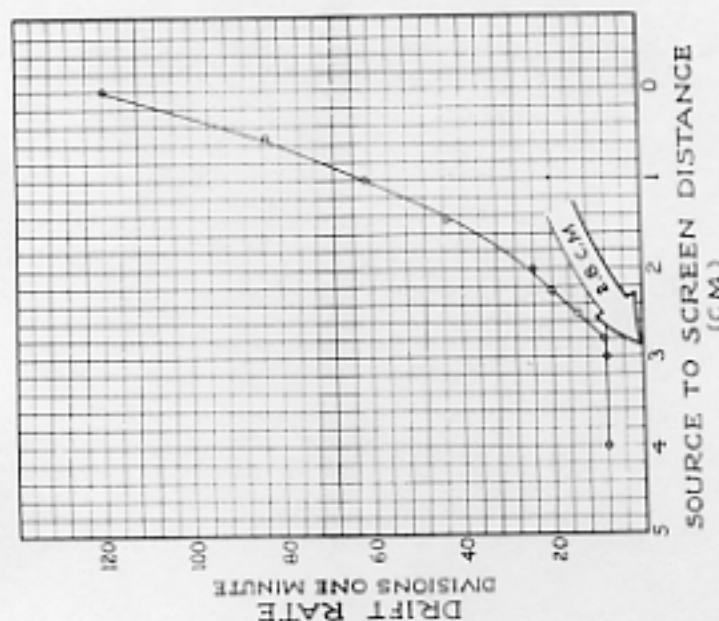


Figure 3-6.
THE RANGE OF ALPHA PARTICLES

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 Electroscopic 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 Electroscopic you will note that the collecting electrode does not extend all the way to the wire screen. Measurements made with a general purpose Electroscopic, 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.

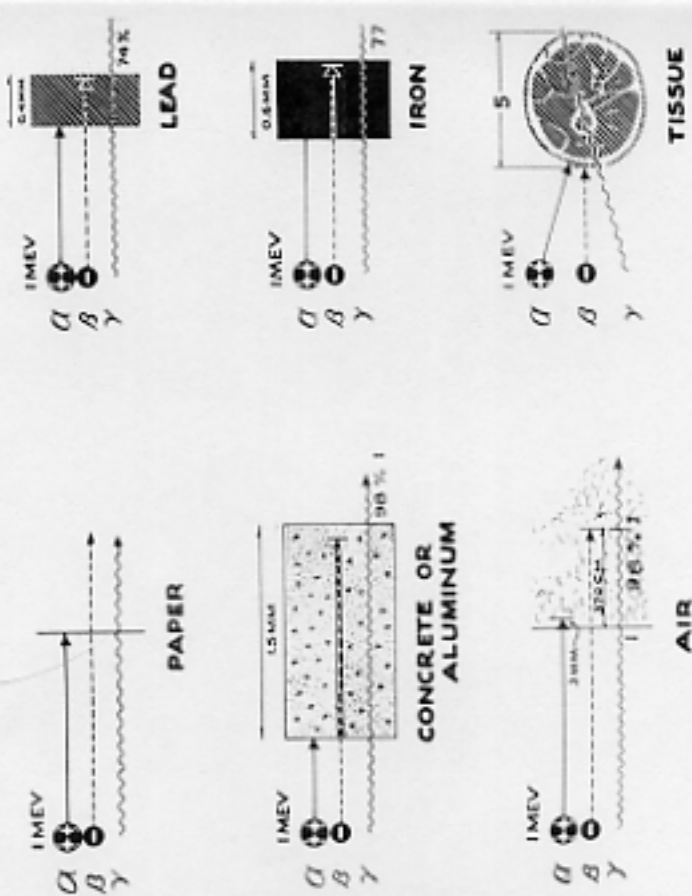


Figure 3-7. ABSORPTION OF ALPHA, BETA AND GAMMA RAYS

OTHER EXPERIMENTS WITH ALPHA PARTICLES

There are many other experiments which you can perform with the alpha particles emitted by your alpha source. It is hoped that you will devise experiments in your own mind and carry them out in a systematic manner. First, ask yourself what property of the alpha ray you want to investigate and then plan your experiment.

You can make a very simple gadget for giving you an alpha ray beam, although you cannot change the direction of the alpha particles as they come from the source so that they will go in one direction.

But, follow this procedure; take a small paper tube, or a small paper box such as is used to hold gummed labels. Punch a hole in each side of the box and place this over the alpha particle source. Only those particles will emerge from the second hole which are going in the same direction as the two holes. Actually, you have created an alpha ray beam. The number of alpha particles in this beam will be quite small for you have made it by eliminating a large number of particles.

USING THE GAMMA RAY AND THE ELECTROSCOPE

Mount the gamma source on a small box so that it is lined up with the collecting electrode of the Electroscopic as we did in the case of the alpha source for range measurements. Take a series of readings starting with a source-to-screen distance of 12 inches and space your observations at 6, 4, 3, 2, 1, and 0 inches.

Remember that the real position of the radioactive material inside the plastic disc is 1/2 inch from the surface. Plot your data on a graph as before. Rather than label the upright axis of the curve as "drift rate" we shall now become more adult and call it the ionization current, but we can still use the same units, that is, divisions per minute.

You will note that using an Electroscopic is much easier than trying to do the same experiment with a Geiger Counter. With the Electroscopic, all you have to do is to take a reading, leave the instrument alone for a while, then go back and take another reading. Furthermore, the instrument is quite accurate. To demonstrate this, you can now repeat the experiment of measuring the absorption of gamma rays in a solid material.

EXPERIMENTING WITH BRICKS

First, let us try some building bricks. Set up the Electroscopic on its side and place the gamma source about 9 inches away from the screen. You can check the ionization current at this position by taking a reading. Make a series of measurements after each observation adding another brick. In this way, you can construct an absorption curve simply by plotting the ionization current against the thickness of brick between the source and the Electroscopic. Your exact results will depend upon your set-up as well as upon the kind of brick which you used.

A heavy brick will absorb more gamma rays than a light brick. Then, too, small bricks will allow some radiation to scatter around them and reach the Electroscopic chamber without passing through the brick. As a rule of thumb, you should find that 2 or 3 inches of brick will reduce the intensity of the gamma rays by about one-half.

Besides using bricks for absorbers, try using a number of other materials such as wood, concrete, aluminum, iron, and lead. You may also very profitably try using water and earth as absorbers. This requires that you use a container to hold the earth or the water. If you can obtain some lead try making a gamma-ray howitzer. You can do this in the following way: drill a 1/2 inch hole in a block of lead and place the gamma ray source at the end of this hole, surrounding it with lead blocks so that a beam of gamma rays emerges through the hole. If lead is not handy, try using a 1/2" pipe and surrounding it with some heavy metal. Then you can perform absorption experiments on a beam and note the difference in absorption that results.

The howitzer produces a weak beam and you will have to be more exacting the way you carry out your measurements for the currents will be smaller and it will take more time to get accurate data.

THE BETA PARTICLE OR BETA RAY

We have already seen that our Geiger Counter has walls which are thin enough to let through beta particles and have measured the absorption of beta rays, finding them to be more penetrating than alpha particles but less than gamma rays. We shall now look at beta rays more carefully, using the Electroscopic to give us new data about these rays.

Experiments with the beta particle source must be carried out carefully. We shall see by direct experiment that the presence of any objects near the beta source is apt to scatter the electrons markedly. Thus, in doing any experiment, we must be sure that we keep the experimental conditions the same as we are to compare the results. If in one set of experiments you carry out your measurements on a concrete floor and in another you perform the work on a light wood table, you are apt to obtain different results.

As a first experiment measure the intensity of the ion current in the Electroscopic for various distances of the source from the chamber and plot your results in the usual manner. Be careful to keep the Electroscopic and beta source in line with each other. You can do this by securely mounting the beta source to some object, such as a box, and moving only the Electroscopic. It is a good idea to perform your experiment on a thin sheet of plywood on which you can tape the beta source in an upright position. You may also mark off the distances directly (in inches and centimeters using your plastic ruler) on the plywood surface.

The exact shape of the curve you obtain for intensity of beta particles versus distance will depend upon how you have the experiment set up. You can see this is true by mounting the beta source and the Electroscopic well away from any surface and making a series of measurements in air with a little solid material close to the source or the chamber. Compare these results with data taken on a table top.

THE RANGE OF BETA RAYS

While we cannot make a real measurement of the range in air of beta particles, we can make an accurate measurement of the range in some material like glass, paper, lucite, or aluminum. All of these are common materials that should be available in the home or from a hardware store. Aluminum is the material usually used in making beta range tests. Thin sheets of aluminum are best.

Using a little scotch tape, tape your beta source to the table or to your plywood board. Place the Electroscopic over it in an upright position and line it up so that the legs straddle the source evenly. Mark with a pencil the position of the legs so that you can easily line up the Electroscopic in the same position each time. With no absorber in place, check the intensity of the ionization current. Now, slipping one sheet of material over the source, take an accurate reading, record your data, and add another sheet. Be sure to take time for your observations as more sheets are added over the source, or your readings will not be accurate.

Your results, plotted, should look like the curve presented in Figure 3-8. The results given in the illustration were made using heavy cardboard as absorbers. The dotted line in Figure 3-8 illustrates what the curve would be like for aluminum.

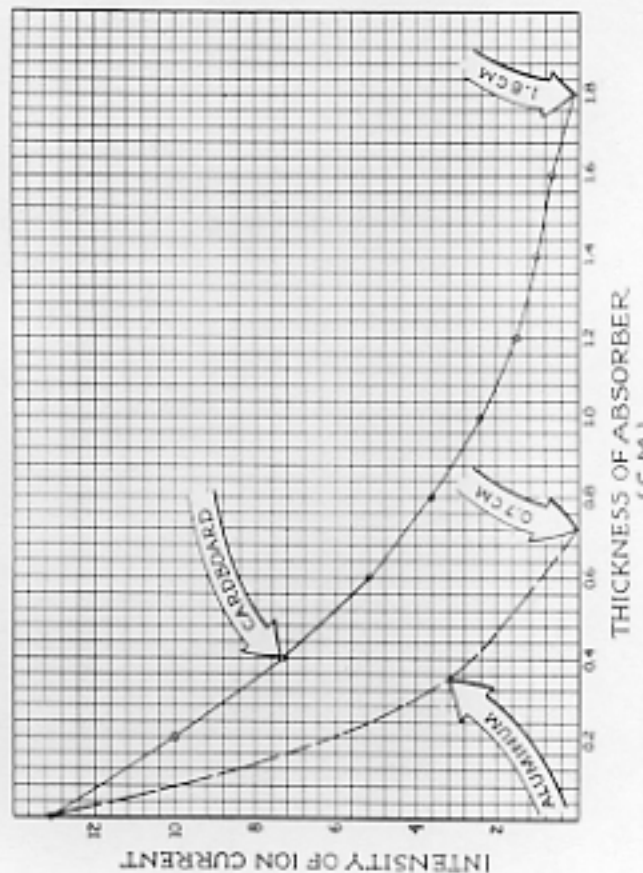


Figure 3-8. THE RANGE OF BETA PARTICLES FROM Rb-106

RADIOACTIVE ORES AND THE ELECTROSCOPE

The radioactive ores will also produce a movement of the Electroscopic indicator. Proceed with this experiment as you did in Section I when you used the Autunite Ore with the Geiger Counter.

RADIOACTIVE HAZARDS

We speak of the hazards of alpha and beta radiation as internal hazards, for they in general are only harmful when they get inside the body. We have seen that these particles don't penetrate as much as the gamma ray, but they might be harmful, for once they are inside the body they are, perhaps, there for a lifetime.

As we have seen, alpha particles travel only a short distance in the tissue, but they can do much damage if this tissue is important to the body's functions. If something like radium is deposited in the bone, where it can shoot the alpha particles into the blood-forming marrow at close range, serious damage may result. This can happen if radium is inhaled or is somehow taken into the body.

We shall tell you more information about radiation hazards later in the manual. Don't be alarmed by these things. They are just to inform you about the dangers that may exist. These hazards have been greatly exaggerated in the modern world. People often fear something they know very little about. The only way to make them forget these fears is to give them the facts of radiation hazards. Throughout the manual you will find these facts which show you that you can deal with radioactivity if you can recognize it.

SECTION IV

FILMS AND CRYSTALS

We have described several ways in which alpha, beta, and gamma rays may be detected. We have used the Geiger Counter, the Electroscope, and the Cloud Chamber to make various measurements of the range of the rays and their penetrating power. Now we want to look at these rays in a little different manner. We want to see how they affect photographic film. Later on in the section you will discover how they affect certain crystals.

We shall now describe some experiments which involve the use of photographic film. We shall mention something about procuring and processing of this film. The sensitivity of ordinary film is very low for beta and gamma rays and if you try to carry out experiments with such film you will find that it takes a very long time for exposure.

X-RAY FILM

Your dentist, however, regularly uses x-ray film in his work. Perhaps you have had an x-ray taken of a tooth and noted that you had to hold a small white rectangle of cardboard behind the tooth. This package is called a dental packet and it contains a small piece of x-ray film $1\frac{1}{4} \times 1\frac{3}{4}$ inches in size. It is protected against exposure to light by being sealed in the paper container.

Visit your dentist (going to the dentist on your own volition may start a new trend in the history of dentistry!) and ask him for a few packets. Packets may also be obtained from your medical supply house. The A. C. Gilbert Company could not supply film with the Atomic Energy Lab because continuous exposure to the radioactive sources would fog the film.

FILM DEVELOPING

The technique of film development is very simple and is especially easy for the experiments with radioactivity. If you are unfamiliar with the technique, you are urged to purchase the few items required for developing film and to try your hand at the work. But if you prefer not to do this you can have your film developed for you. Your local photographer will develop the film for you or you can ask your dentist to have them developed for you. By far the more instructive procedure, however, is to do the work yourself.

A GAMMA RAY PHOTOGRAPH

Take your gamma source and place under it a thick lead washer (such as plumbers use) or some object which you wish to photograph. The object must be dense and it should not cover the entire surface of your dental packet. Place the dental packet (some packets have a thin lead foil backing next to the film; this side should be placed away from the source) under the washer. Hold the sandwich together with a heavy weight or a vise.

It may be well for you to fix the three objects in place by taping them to a small board. You may also take two photographs at once by putting another object (such as a key) and film on the other side, making the radioactive source serve as a filler for a "sandwich." Now put the apparatus where it will not be disturbed. After 24 hours remove the dental packets and develop them. You should see the shadow of the washer or object imprinted on the negative. If you use film which is not of the x-ray type, then it will take considerably longer for your exposure.

EXPOSURE

In order to determine the best exposure you may perform two more experiments. Instead of a washer use a few small lead sheets or iron sheets each shorter than the other, so that the rays from the gamma source have to travel through different thicknesses of metal to reach the film. Then you should obtain a gamma ray photograph showing steps across the film which show the transmission through the various layers of metal.

As regards exposure time you can use a series of dental packets, exposing them for various time intervals and noting the blackening which is obtained for each exposure time. For uniform results in comparing these negative blackenings, you should develop all your films at the same time. Otherwise you are liable to produce different degrees of blackening by overdeveloping or underdeveloping the various films.

Pictured in Figure 4-1 is a shadow photograph of a key done in much the same way that you did yours. This photo was made by putting a key between a film and some pitchblende ore. You can well see how the emitted particles photograph the key. Figure 4-2 is a sample of what can be done with your own Atomic Energy Lab. This photo was made with the beta source, a glass and a film.

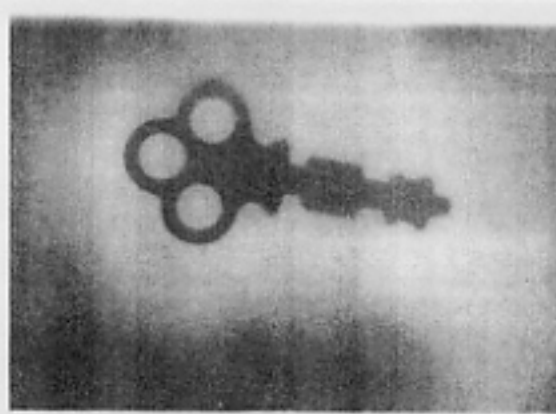


Figure 4-1.

HOW RAYS PENETRATE

A shadow photograph made with penetrating rays emitted from a pitchblende ore taken from the Caribou mine. The negative was sealed in a black envelope, a key placed over it, and a piece of ore placed on top of this. After three days the negative was developed. This experiment duplicates the one which Becquerel performed in 1896.

Photo courtesy of the Canadian Radium and Uranium Corp.

A BETA RAY RADIOGRAPH

Now, it is not easy for you to make a real radioautograph, for it would involve the handling of radioactive materials in a solution which is prohibitive. You can, however, do some experiments with your beta source and at least one can simulate a radioautograph.

As a first, and comparatively crude experiment, take a strip or two of some metal (lead or copper will do), form them in the shape of a cross over your beta source, and then place a dental packed over the cross. Use some tape to fix the "sandwich" firmly in place and allow about 24 hours for exposure. Then develop the film as before and note that the beta rays have been stopped by the lead cross, leaving a clear cross pattern on the darkened film.

Do not be surprised if the film does not become very dark, for it takes about 50,000 beta particles to produce appreciable darkening on even a very thin section of film. Your beta source is an extended one, being about 20 square cms. in area and, for this reason, it takes a considerable time for enough beta particles to be emitted to darken the film. Repeat the experiment using your gamma ray source and compare your results.

RADIOAUTOGRAPHS

It is possible to make films or plates which are especially sensitive to beta rays. In effect a radioautograph is simply a radiograph in which the source of radiation is distributed throughout the object and is thus a radioactive "self portrait."

Consider, for example, the marine life that inhabits the Bikini Lagoon where an atomic bomb was exploded below the surface of the water. Some of the fish feeding on small marine bodies accumulated traces of the radioactive

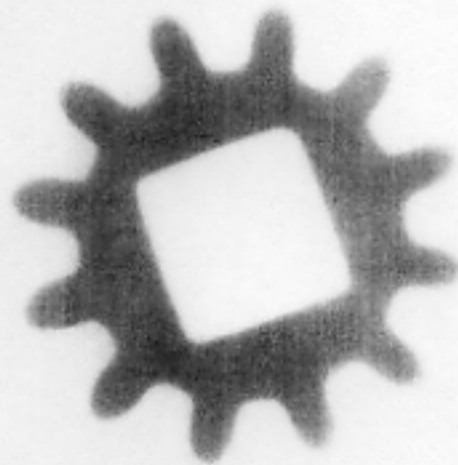


Figure 4-2.
BETA RAY RADIOGRAPH OF GEAR
This photo was made with a gear, a film and the beta source from your Atomic Energy Lab.



Figure 4-3. PHOTOGRAPH AND RADIOAUTOGRAPH OF A BIKINI FISH
(a) Top photo is a conventional photograph of a damselfish taken from Bikini lagoon. (b) Lower photo is taken by placing the fish on a piece of x-ray film. Radioactive deposits in the fish show up clearly on the resulting negative.

Photos courtesy of University of Washington

products of the bomb explosion. Figure 4-3 is an actual photograph of a damselfish caught in the Bikini lagoon. When this fish was placed on a sheet of photographic film, it took its own (hence the "auto" in the word "radioautograph") picture which is reproduced in Figure 4-3.

The conclusion to draw is that the damselfish concentrated radioactive material in its digestive tract. Smaller white spots on the top fins and tail indicate radioactive particles on the fish.

In Figure 4-4 you will see how a radiograph is made commercially. This photograph shows how, by using a radioactive source and a photographic plate, defects in materials can be discovered.

THE SPINTHARISCOPE

The small tubular instrument with its rubber eyepiece looks much less sensational than some of the other atomic instruments, but in the history of science it has played an important part. Lord Rutherford, the famous British physicist, carried out his first experiments on atomic structure using fluorescent screens as detectors for alpha particles.

Our Spint Hariscope (see Figure 4-5) is a metal tube with a zinc sulfide screen at one end and a lens in the center. You will be able to detect the presence of alpha particles by doing the following experiment.

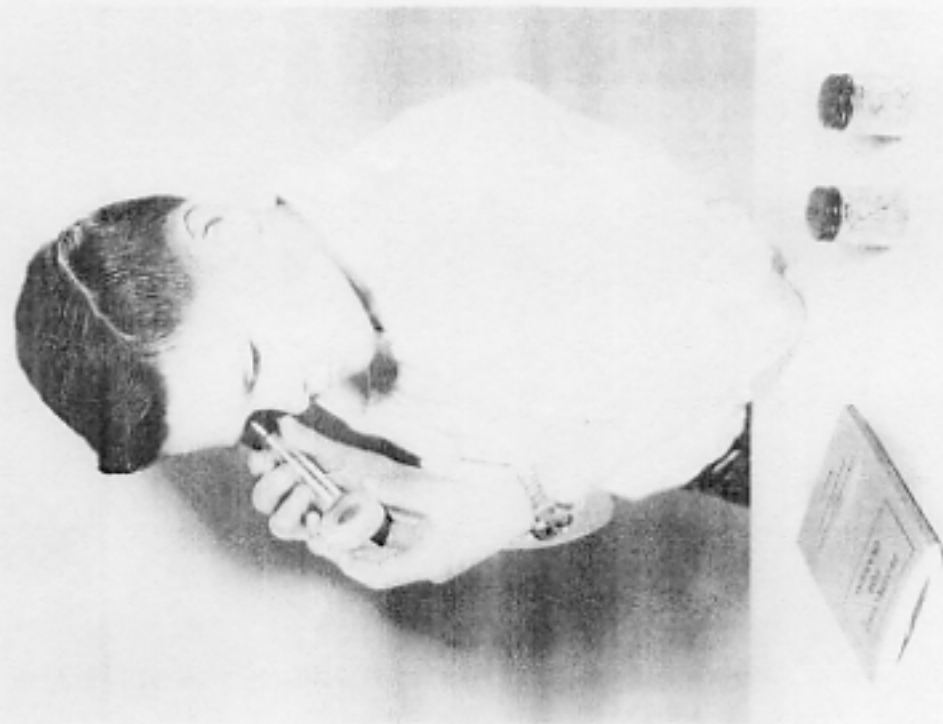


Figure 4-6. BOY DEMONSTRATING THE USE OF THE SPINTHARISCOPE

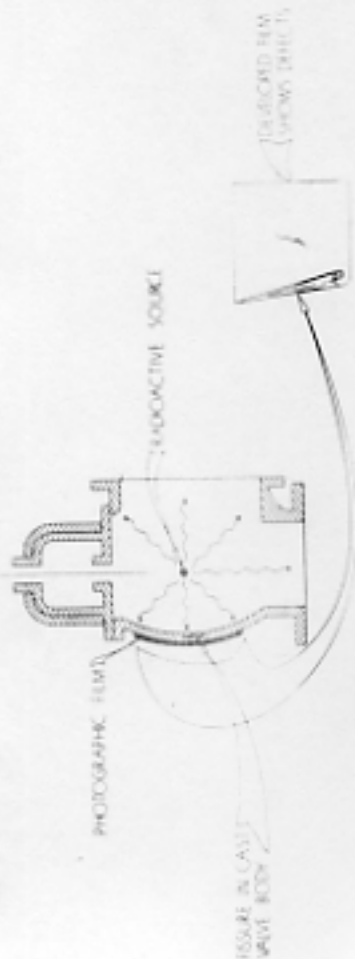


Figure 4-4. SET-UP FOR COMMERCIAL RADIOGRAPHY
A radiocobalt-60 source is suspended in the center of a valve body. Photographic film is placed on the outside of the body.

Courtesy of Atomic Energy Commission

DETECTING RADIATION WITH CRYSTALS

We shall now discuss the action radiation has on certain crystals. From the earliest days it was recognized that a screen coated with a layer of special crystals would glow under the action of x-rays. The glow is termed fluorescence or, often, luminescence, and is produced only in certain crystals such as zinc sulfide. Watch dials of the luminous type are coated with a mixture of zinc sulfide and radium.

Alpha particles emitted by the radium activate the tiny crystals and produce a flash of visible light. We can see this by using the Spint Hariscope which is provided with the Atomic Energy Lab.

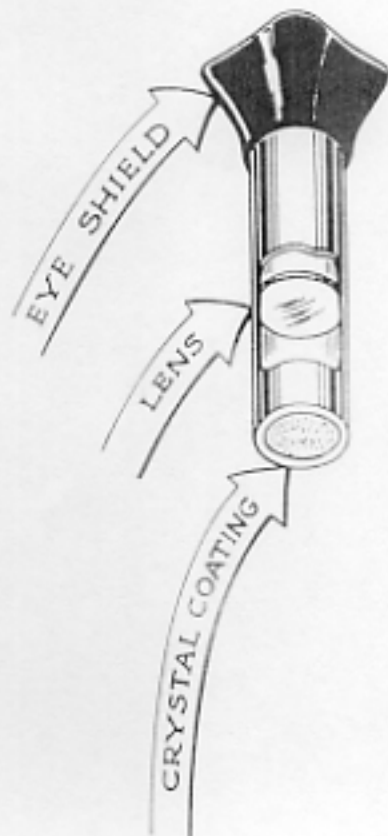


Figure 4-5. DIAGRAM OF THE SPINTHARISCOPE

FLASHES ON THE SCREEN

For this experiment it is necessary that your eye be accustomed to almost complete darkness, and therefore the experiment must be carried out in a darkened room. If you simply snap off the light switch and try to do this experiment right away you will not obtain any results, for the eye takes a little time to adjust itself to the darkness.

You have probably noticed when you enter a darkened theater that at first you can see nothing (especially if you come in from bright daylight) and then gradually things begin to take shape and you can see rather well. Perhaps you have also noticed that older people seem to fumble around, unable to see in the darkness, long after the younger people have become accustomed to the lack of light. You will find that it will take a few minutes for your eye to adjust itself, but do not be dismayed if this process takes much longer, especially if you are more advanced in years.

Take your alpha source, place it snugly against the screen end of the Spinthariscopes, and then look into the eyepiece. (See Figure 4-6.) If your eye is well adapted to the darkness you should see a number of tiny greenish flashes (scintillations) on the screen. At first it may be difficult for you to see them because of the fact that you are not used to focusing your eyes in the darkness. You should try to focus your eyes on the screen. If you do not see anything, it is possible that your eyes require more adaptation and you should wait for five or ten minutes before trying the experiment again.

To make sure that these tiny flashes are really produced by the alpha particles from the alpha source, you can slip a piece of paper between the source and the screen. The flashes should stop, thus proving that the alpha particles are responsible for the effect.

The Spinthariscopes will also detect alpha radiation from your radioactive ores. To do this, merely follow the same procedure as you did in your other experiments, using the Geiger Counter and the Electroscope.

Beta and gamma rays are less efficient in causing flashes in your Spinthariscopes.

SECTION V

THE ATOM AT WORK IN PEACE

Now that we are familiar with some of the particles emitted by radioactive materials we are going to do a little more exploring. This time you will be physically working with the instruments of your Atomic Energy Lab in search of the elusive alpha, beta, and gamma ray, but rather you will be exploring briefly the fields of science where these small particles of radio activity are used.

We shall see what an atom smasher looks like, how a high voltage apparatus works, and the like. And then we will see how atomic energy is put to work in the fields of medicine, agriculture, and industry.

Scientists are people who have an extraordinary zeal for probing into the secrets of nature and puzzling over what they find. What you see here is the result of one man's work or one day's work, but of many men's endeavor over a thousand years. Even these may be the beginnings of other, much better things. But now let us see what has been developed in the science of atomic energy.

Modern scientists, in their search for an understanding of the atom and the nucleus, are leaning heavily on highly technical and complicated apparatus. Much of their apparatus is designed to bombard the atom by artificial means. They study the effect of this bombardment on the atom and by so doing are learning the secrets of the atom itself.

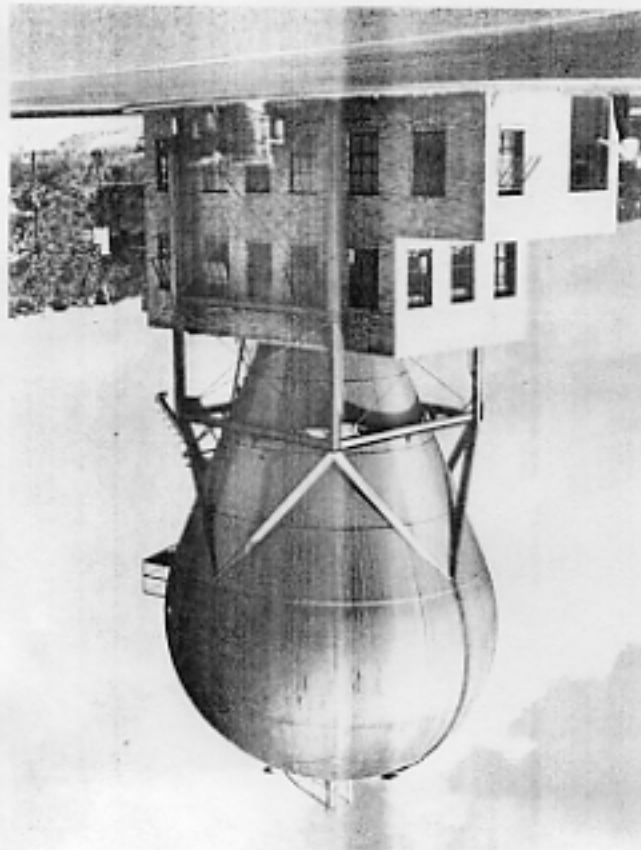
Atomic and nuclear bombardments require some means of obtaining high velocity particles. In general, they are obtained by means of very high voltages or powerful magnets. One of the first such machines was the Van de Graaff Generator.

ATOM SMASHERS

Professor Van de Graaff at the Massachusetts Institute of Technology devises a very clever means of producing high voltage which has many features that make it an ideal piece of equipment for physical research.

A photograph and a diagram of a Van de Graaff machine is shown in Figure 5-1 and 5-2. Impressive as this machine appears, it is not at all complicated in its principle of operation. In fact, it is extremely simple in theory. In typical Van de Graaff machine a large porcelain (insulating) cylinder is used to support a metal sphere on top.

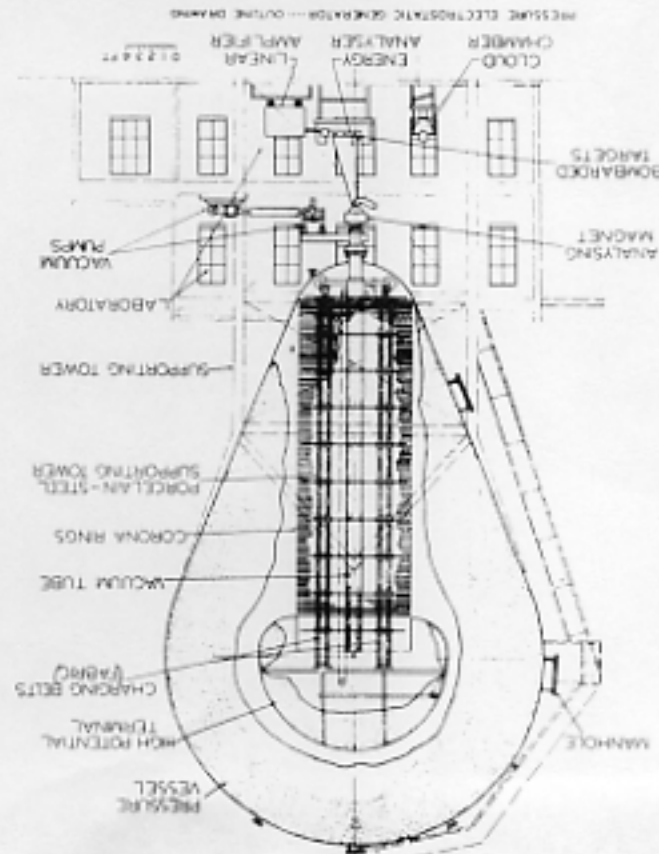
Inside of this structure is a long endless belt that runs up and down over two pulleys. These pulleys are whirled around by high speed motors and they cause the insulating fabric belt to whirl around them at 70 miles per hour.



Figures 5-1, 5-2. PHOTOGRAPH AND SKETCH OF A WESTINGHOUSE ATOM SMASHER

On the left is shown an outline drawing of the machine which appears on the right.

Courtesy of Westinghouse Research Laboratories



Actually, the belt is nothing more than a conveyor for electric charge. The belt collects a negative charge at the bottom (sprayed on to it by a charge generator) and carries it up to the top where it is picked off by a special set of discharge brushes. The negative charge is distributed over a large sphere while the positive charge goes down the other side of the belt and grounds. In this way large quantities of negative charges collect on the sphere and, as a consequence, the machine charges up to a high voltage.

SPEEDING ELECTRONS

Machines like the Van de Graaff Generator in conjunction with other apparatus are frequently used to accelerate electrons up to speeds approaching that of the speed of light.

An electron travelling at 99.9 per cent of the speed of light no longer has the same mass as it did when remaining still. Its new weight is 22 times greater than its normal weight. This is no imaginary increase in weight nor is it the dream of some theoretical physicist; it is a very real thing.

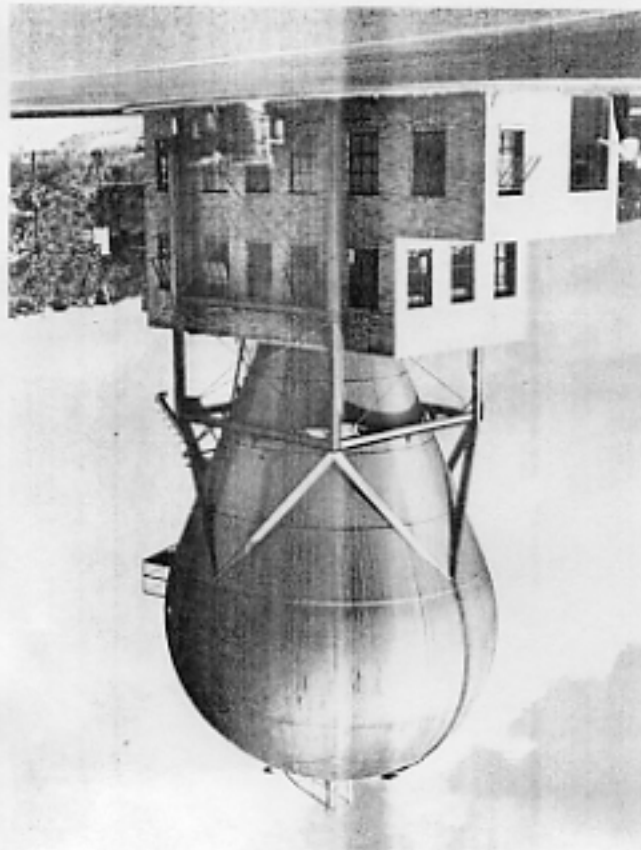
The mass increase can actually be measured accurately, and these measurements show that the faster an object goes, the more it weighs. With the ordinary objects of our daily experience, such as a speeding train, the effect is not noticeable, for the velocity of the train represents a minute speed as compared with that of light.

It is only when we invade the realm of atomic particles that we encounter what is called the relativistic mass increase. Professor Einstein's Theory of Relativity predicts that high speed atomic particles should increase in mass. We shall not attempt to go into this theory; it is enough if we can understand that the mass increase is a real one and one which presents a barrier in accelerating particles to very high energy in a cyclotron.

You may be interested to know that in your television set the electrons which strike the fluorescent screen are about 5% heavier when they hit the screen than when they start out from the heated filament inside the tube. The electrons which are accelerated in a 500,000 volt x-ray tube actually weigh about twice as much when they smash into the tube target as when they start out from the filament.

Figure 5-3 is a photograph of the huge 184 inch super cyclotron, called a synchro-cyclotron, which has been constructed high on a hilltop overlooking San Francisco Bay. The big machine has a yoke type magnet, just as do smaller cyclotrons, and it has enormous magnet coils to supply the magnetic field. The gap between the pole pieces is so large that it is possible to walk between the poles.

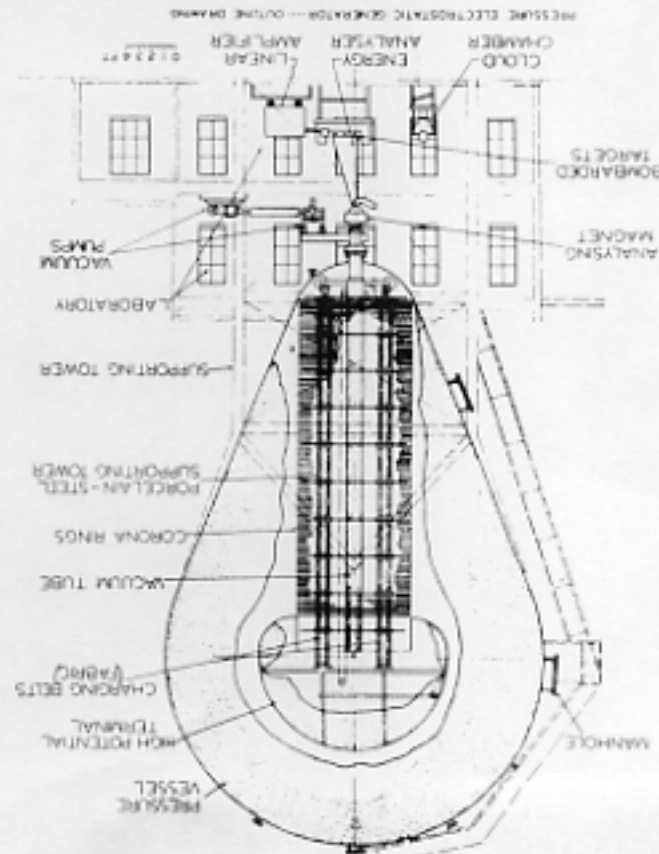
When the machine is running, there is a large amount of penetrating radiation produced and the entire apparatus has to be shielded with concrete to protect personnel in the vicinity. Huge blocks of concrete are used for this purpose.



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USES FOR ATOMIC ENERGY

On a large scale the explosion of the U235 atomic bomb is most sensational; yet on a very small scale the "explosion" of minute amounts of radioisotopes is just as sensational to scientists.

When a radioisotope, such as radiophosphorus, disintegrates and emits radiation, it provides the physicist, chemist, biologist, or technician with a most powerful tool for tracing the secrets of nature. It is in the life sciences that radioisotopes have found most application.

MEDICINE USES THE ATOM

Consider as an example the tracing of a sample of sodium chloride injected into the human body. By tagging the NaCl molecule with radiosodium (radioisotopes) sodium has a half life of 14.8 hours and emits both beta and gamma rays, and by measuring the radiation emitted from the radiosodium, one has a means of tracing the sodium chloride throughout the body.

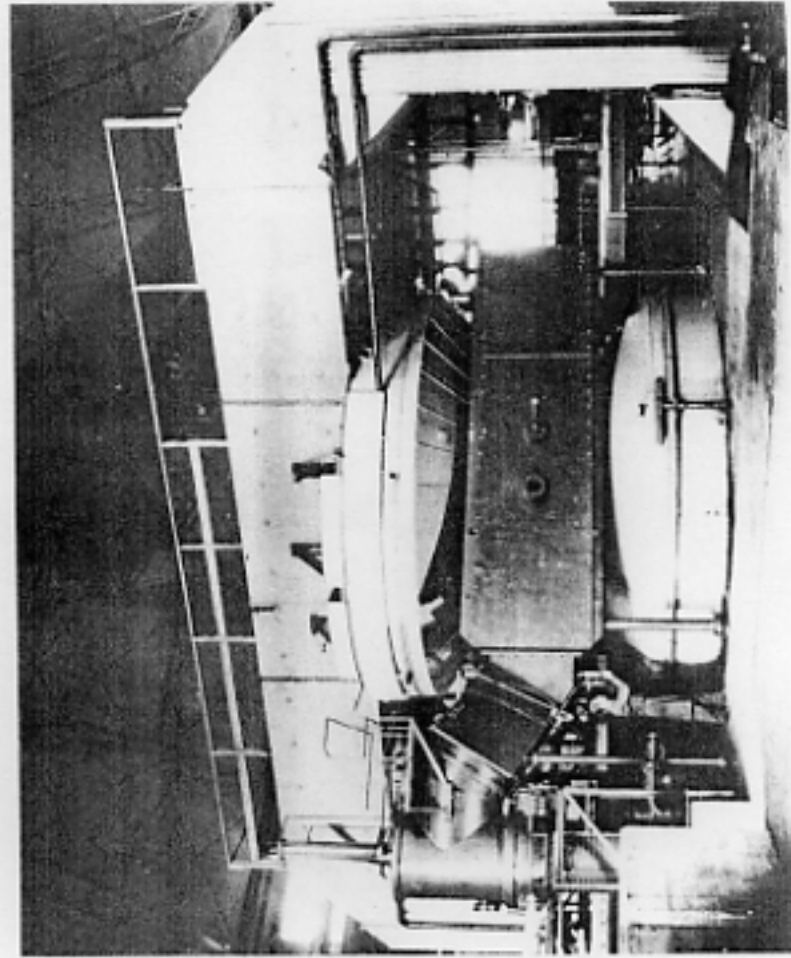


Photo courtesy of Radiation Laboratory, University of California

Figure 5-3. THE 184 INCH BERKELEY SYNCHRO-CYCLOTRON

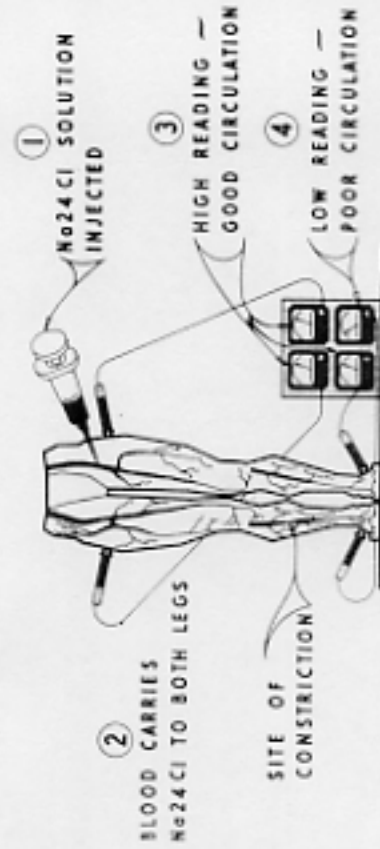
Physiologists have found that salt thus injected into the body goes into the veins, into the body cells, and is converted into sweat by the body's sweat glands. It appears on the surface of the skin in the astonishing time of less than one minute. Only because of the tagged sodium atoms can one trace such a fast reaction process.

As another example of the use of the atom in the field of medicine, radiosodium is used in tracing the circulation of blood through the body. This is especially useful in cases where circulation is obstructed. Figure 5-4 illustrates graphically the technique used in tracing blood circulation.

INDUSTRY USES THE ATOM

The use of radioisotopes is not confined to medicine. In industry radioisotopes are used not only as a means of studying an industrial process, but they are often used to control this process. Many studies on the structure, corrosion, alloying, and friction of metals have been carried out. For example, radioiron produced in a piston ring has been used for friction analysis of a moving piston. By using the easily absorbed radiation emitted from

RADIOACTIVE SODIUM - Na24 FOR DETECTING NORMAL AND RESTRICTED BLOOD CIRCULATION



ADVANTAGES:

- 1-GIVES PATTERN OF BLOOD FLOW
- 2-PERMITS EXACT LOCATION OF ARTERIAL CONSTRICTION
- 3-METHOD QUICK AND NO DISCOMFORT TO PATIENT

Courtesy of Atomic Energy Commission

Figure 5-4. ATOMIC ENERGY IN MEDICINE, DETECTION OF BLOOD CIRCULATION

USES FOR ATOMIC ENERGY

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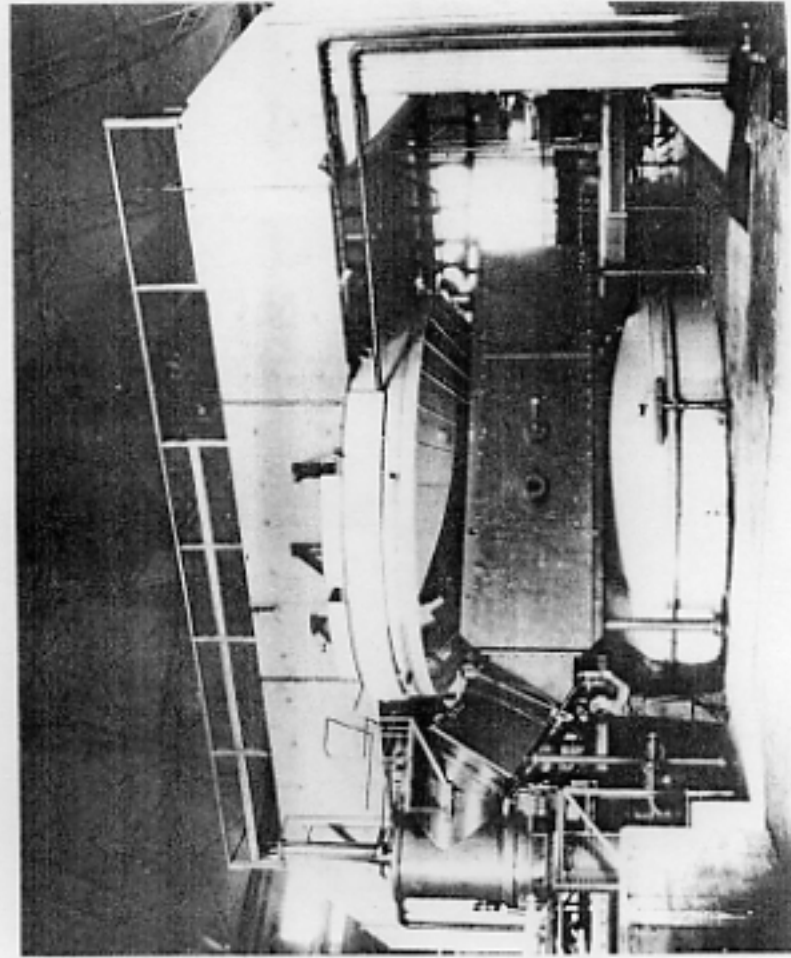


Photo courtesy of Radiation Laboratory, University of California

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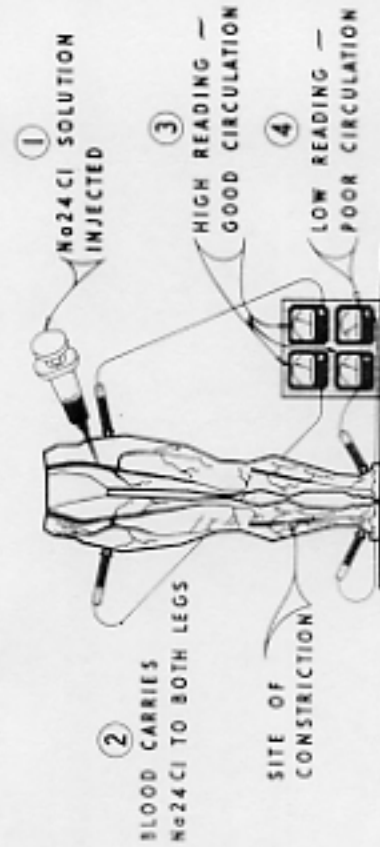
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As another example of the use of the atom in the field of medicine, radiosodium is used in tracing the circulation of blood through the body. This is especially useful in cases where circulation is obstructed. Figure 5-4 illustrates graphically the technique used in tracing blood circulation.

INDUSTRY USES THE ATOM

The use of radioisotopes is not confined to medicine. In industry radioisotopes are used not only as a means of studying an industrial process, but they are often used to control this process. Many studies on the structure, corrosion, alloying, and friction of metals have been carried out. For example, radioiron produced in a piston ring has been used for friction analysis of a moving piston. By using the easily absorbed radiation emitted from

RADIOACTIVE SODIUM - Na24 FOR DETECTING NORMAL AND RESTRICTED BLOOD CIRCULATION



ADVANTAGES:

- 1-GIVES PATTERN OF BLOOD FLOW
- 2-PERMITS EXACT LOCATION OF ARTERIAL CONSTRICTION
- 3-METHOD QUICK AND NO DISCOMFORT TO PATIENT

Courtesy of Atomic Energy Commission

Figure 5-4. ATOMIC ENERGY IN MEDICINE, DETECTION OF BLOOD CIRCULATION

beta active isotopes, thicknesses of films and sheets can be measured without touching the material.

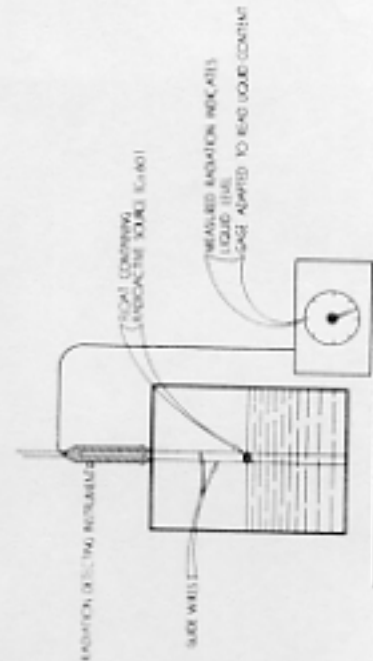
The steel industry has found use for radioisotopes in the study of process control of pig iron. In the printing industry, radioisotopes can be used to measure the amount of ink applied to paper.

Petroleum scientists have also found extensive use for radioisotopes. Using radiocarbon, the Shell Oil Company and the California Research Corporation have been able to follow changes in oil as it goes through a modern refiner. Sealed sources of radioactive materials are used in determining the level of liquids inside windowless containers (Figure 5-5). Technicians have even been able to determine the rate of flow of certain liquids through metal pipes by using radiation techniques.

AGRICULTURE USES THE ATOM

Radioisotopes are becoming increasingly important in agricultural research and in food processing. For example, extensive studies have been made on the efficiency of fertilizers as a source of plant food. Each year American farmers spend over one half billion dollars on fertilizers, so it is extremely important to know how plants utilize fertilizer.

RADIOACTIVE COBALT Co 60 FOR LIQUID LEVEL GAGE



- ADVANTAGES
- 1-CONTINUOUS RECORDING
 - 2-MEASUREMENT MADE ON CLOSED SYSTEM
 - 3-ADAPTABLE TO AUTOMATIC CONTROL

Figure 5-5. ATOMIC ENERGY IN INDUSTRY, LIQUID LEVEL GAGE

Courtesy of Atomic Energy Commission

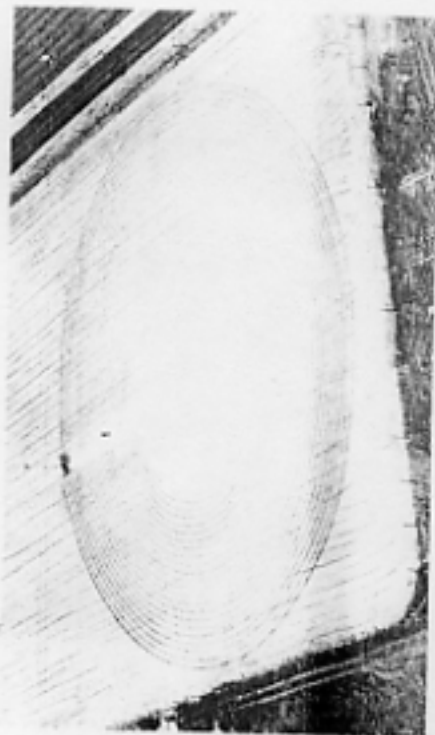


Figure 5-6. STUDYING THE EFFECT OF GAMMA RAYS ON PLANT GROWTH. At the center of the field a strong radiocobalt source is placed on a pole. Crops are planted in circular around the source so that they receive different doses of gamma radiation.

Photo courtesy of Brookhaven National Laboratory

One study showed that corn makes maximum use of phosphorus from fertilizer during the early period of growth. Another investigation showed that potatoes use phosphorus throughout the growing season. Still other studies reveal that the manner of applying the fertilizer is often very important. Phosphorus, for example, seems to slow up the growth of potato plants when it is placed very close to seed potatoes.

The Department of Agriculture is very interested in learning how plant diseases and pests develop and attack crops. In this connection, radioisotopes are being used in tagged fungicides, such as sulfur and DDT, to determine how these compounds act.

At the same time, investigations are being carried out with tracers to learn how milk, eggs, and meat can be produced most efficiently. Government experimental stations working with university research units are making considerable headway in these researches.

EXPOSING PLANTS TO RADIATION

Still another line of investigation in the realm of plant studies lies in exposing plants to the direct rays of radioactive sources. Workers at the Brookhaven National Laboratory have mounted an intense radiocobalt source in a field (see Figure 5-6) and planted crops at varying distances from the source. The radiocobalt is placed on a pole at the center of the field and the plants are arranged in regular circular patterns. In this way some plants close to the source receive large quantities of radiation whereas those farther away receive proportionately smaller amounts. Plants can then be studied for radiation effect by comparison with those at the edge of the field which receive a very few gamma rays.

NUCLEAR POWER PLANTS

We may expect that the first practical nuclear power plants will be used as stationary units to demonstrate the practicability of this new power source. Both the Navy and the Air Force will put in high priority requests for power plants which can be used for propulsion. The U.S. Navy has already contracted with the Westinghouse Corporation and is said to have completed the initial design of a nuclear reactor for powering a naval vessel. It will probably be from 2 to 5 years before the naval propulsion pile is unveiled.

If a reliable propulsion unit is developed we may expect that the Navy will want to use piles for powering its undersea fleet. The submarine is very limited by conventional methods of propulsion, but with the nuclear reactor as a source of power, a true submarine could be built.

By a true submarine, we mean one which can stay submerged almost indefinitely and speed along undersea. Such a submarine would have a truly great advantage over one powered by diesel-electric units. A modern submarine with a 25,000 kilowatt power pile as the prime source of power could cruise for months without having to refuel, and it would possess the high underwater speed which is necessary for successful battle tactics.

A 25,000 kilowatt power pile would not be excessively heavy and could be installed in a submarine without undue trouble. Figure 5-8 is a model of an artist's conception of a nuclear-powered submarine.

In the field of nuclear power for the production of electricity, great strides are being made. It will, however, be perhaps several years before nuclear fuel will compete with coal. Furthermore, since the major cost to the consumer of electricity is the cost of transmission of the electricity from the power plant to the consumer, no great saving will result even if a nuclear power plant is feasible.

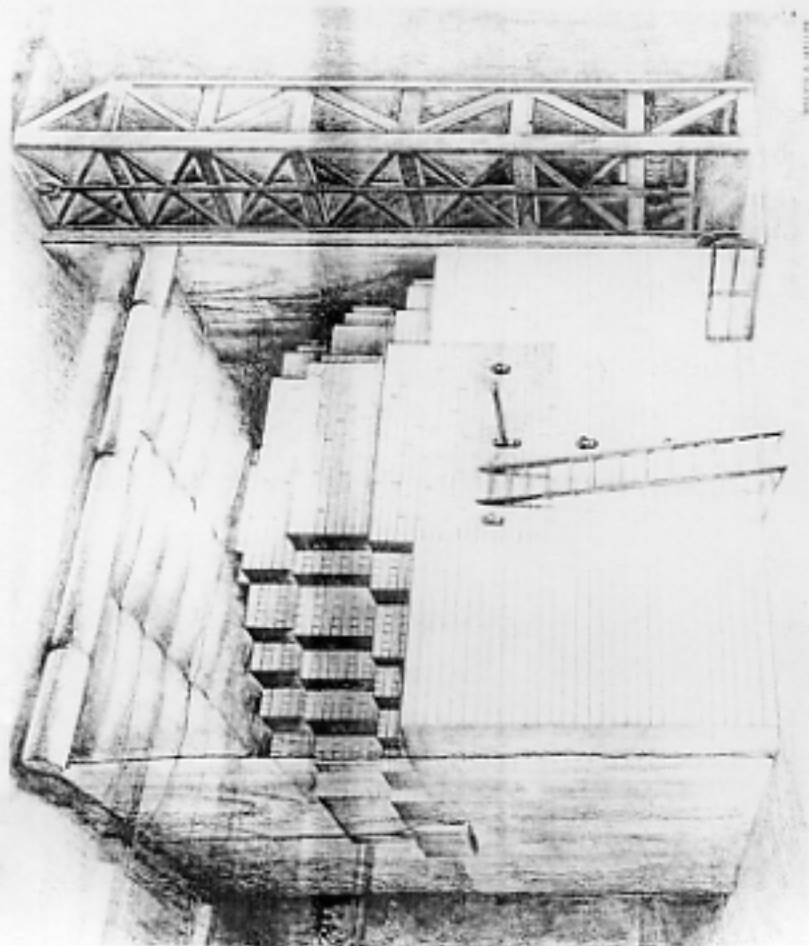
INTO THE FUTURE

Estimates of what may happen in the future of science can often be prefaced with the apology that the "Unexpected Usually Happens." Too often the layman is led to believe that a scientist provided with sufficient money can produce anything that is desired. People point to the Manhattan Project as an



Figure 5-8. MODEL OF A NUCLEAR-POWERED SUBMARINE

Courtesy of POPULAR SCIENCE MONTHLY, July, 19



U. S. Army Photograph, Courtesy Department of Defense

Figure 5-7. THE FIRST ATOMIC PILE. Built in a squash court at the University of Chicago, the world's first chain reaction was sustained on Dec. 2, 1942. Shown above is the cubical assembly of graphite blocks in which were imbedded metallic uranium and uranium oxide. A control rod is seen to the right of the top rung of the step ladder.

ADVANCES IN BASIC SCIENCE

Today highly significant advances are being made in our understanding of the fundamental physics of nuclear particles. For the most part what we know as basic research was neglected during war. Prior to the war the pump of science had been primed sufficiently full of fundamental facts so that the development and engineering could be emphasized. The end products such as the atom bomb, the proximity fuse, and radar all had their origin in basic knowledge acquired prior to the war.

As a result of this fundamental background, physicists, chemists, and engineers had a fairly good basis on which to proceed. However, the tempo of wartime research and development became so great that often scientists were compelled to go off in the dark for the lack of fundamental knowledge.

example and think that the expenditure of two billion dollars produced the atomic bomb.

Money and concentrated effort may help in a development-engineering project but it cannot automatically remove the physical limits imposed by nature. For example, Einstein's equation $E = Mc^2$ shows that the amount of energy in a U235 atom is 230 billion electron volts of energy. This is more than a thousand times the energy released in U235 fission. Yet this thousand-fold more abundant energy cannot be tapped no matter how many billions of dollars we spend.

Scientists can accomplish what to the layman may seem to be miracles, but they are forever bound to obey the laws of nature. Thus, in making predictions of what to expect in the future, it is well to remember that nature is a stern taskmaster.

Science is not a magic black box from which one conjures up miracles at will. Rather we should say that science is a treasure chest which overflows with the basic ingredients for developing things of use to mankind. The basic ingredients are the hard-won discoveries of physicists, chemists, and the life scientists. Provided with basic knowledge, other scientists and technologists can apply themselves to the task of converting ideas into practical tools for man's benefit. Science is such an unpredictable thing that one never knows just where the greatest benefits will arise.

Today we are witnessing a flood of beneficial contributions from science and technology, and so great is the flood that we are at a loss to single out any one field of science as the source of these benefits. Just as a flood arises from the concurrence of many small streams, so, too, does the present abundance of wonder drugs, radioisotopes, jet aircraft, and a million other developments result from the individual contributions of many diverse fields of science.

An electron microscope developed as a scientific tool is found to be essential in isolating a biological virus. Radar developed for wartime application is adapted to marine navigation. The list of such examples is too long to detail but it does illustrate the magnitude of the peacetime benefits which are possible for scientific developments.

Working, as you have, with radioactive sources and with the instruments for measuring their radiations, you have been introduced to but one field of science. It is an exciting and a basic field of endeavor and its off-shoots enter into almost every other field of science.

From our present outlook, it would seem that there will be no single atomic development which will constitute the greatest benefit to mankind. Rather the totality of the many aspects of atomic energy will be most significant. It is in the life sciences that the stimulus of atomic energy will probably have its greatest impact. Here we may expect that the modern tools and techniques of atomic science will contribute substantially to biological and medical research. With these sharpened tools the attack upon the diseases of man, upon cancer, infantile paralysis, tuberculosis, and other dread afflictions will intensify and succeed. If the benefits of modern science and technology are used constructively, man will have within his reach the attainment of a truly more abundant life.

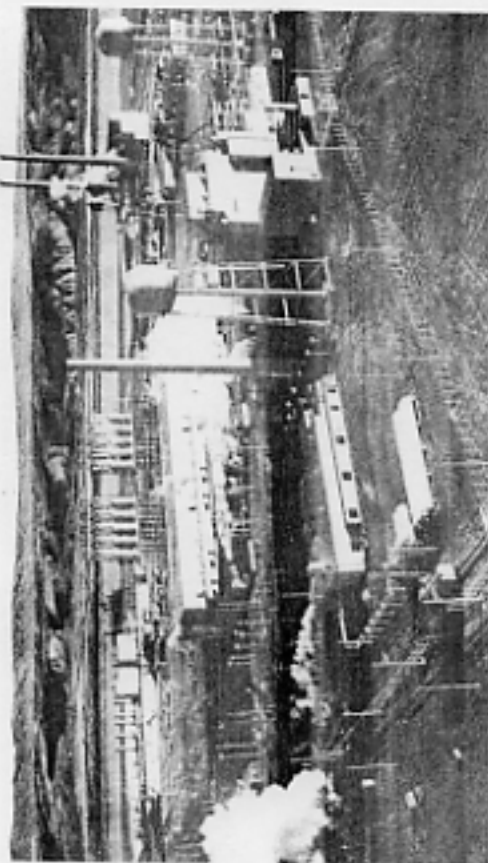


Figure 5-9. AN AERIAL VIEW OF A HANFORD PLUTONIUM PLANT Located 15 miles northwest of Pasco, Washington on the mighty Columbia River, the Hanford plant comprises a number of plutonium factories as shown above. The central smokestack (from which no smoke ever comes) is used to discharge radioactive gases into the atmosphere. This is done without harm to plant personnel.

U. S. Army Photograph, Courtesy Department of Defense



Figure 5-10. A "CONCRETE CANYON" AT HANFORD, WASHINGTON Here the intensely radioactive slugs of uranium are processed to remove the plutonium. All operations within the plant are remotely controlled behind thick concrete walls. Total concrete used in this structure is enough for a 30 mile highway. At the left is a 200 foot stack for disposing of waste gases.

Photo courtesy of Atomic Energy Commission

IMPORTANT!

The radioactive sources contained in your Gilbert Atomic Energy Lab will not last indefinitely and will, in a period ranging from 1 to 50 years, need replacement.

The life of the Alpha source is approximately 50 years, while the Beta and Gamma sources will remain radioactive for about 2-3 years. The source for the Gilbert Cloud Chamber will deteriorate in about 1 year.

When replacement is needed for these sources, please write to The A. C. Gilbert Company, New Haven 6, Connecticut and state where and when you purchased the set and which radioactive source or sources are required. You will then be informed regarding shipment, cost, etc.

Defective or damaged instruments should be returned to The A. C. Gilbert Company for repair. An estimate will be provided before repairs are undertaken.

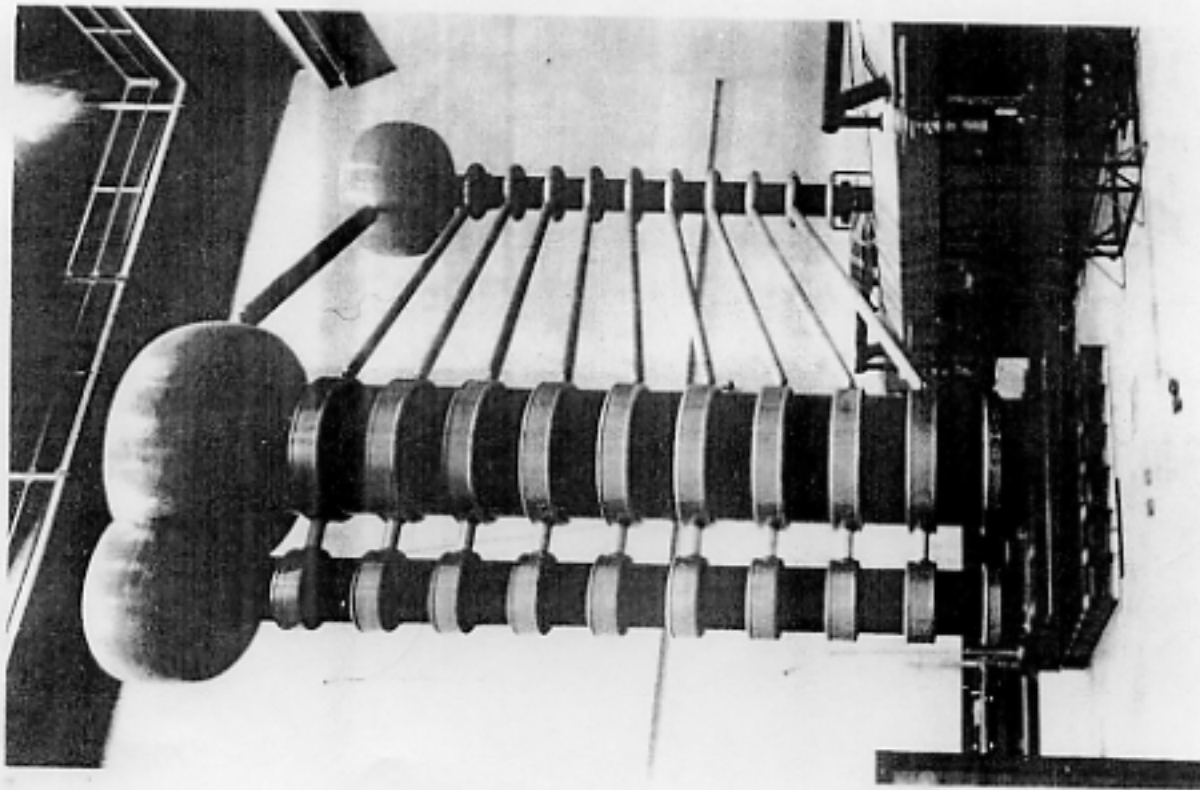


Figure 5-11. HIGH-VOLTAGE UNIT AT THE NATIONAL BUREAU OF STANDARDS. The two foremost columns are almost 40 feet high and consist of ten sections of transformer-rectifier units. The column on the extreme right contains a ten section x-ray tube. Potential is transferred to the x-ray tube by the horizontal tubes.

Courtesy X-ray Section, National Bureau of Standards, Washington, D.C.