THE GEIGER APPARATUS FOR THE PHOTOGRAPHIC REGISTRATION OF ALPHA AND BETA PARTICLES.

BY J. E. SHRADER.

IN 1908 Rutherford and Geiger[1] devised an electrical method for counting alpha particles given off by radio-active substances. The method may be briefly described as follows: Through a small opening the alpha particles were allowed to enter a strong electric field between a wire and a coaxial cylinder. The entrance of each single particle produced ions, which in this strong electric field gave rise to a current by collision between the wire and the cylinder. The current, thus produced, was detected by a quadrant electrometer, which was connected to the wire while the cylinder was connected to the negative terminal of a high potential battery. The gas in the cylinder was carbon dioxide at reduced pressure.

The difficulty encountered in this experiment was that ionization or "natural disturbance," as the authors call it, arose from the walls of the cylinder, as they explain, and gave a deflection of the electrometer when no alpha particles entered the vessel. By using a cylinder of small diameter and carbon dioxide at reduced pressure they found that these disturbances could be made very small.

In order that a greater number of particles might be counted Rutherford and Geiger[2] devised another form of apparatus to be used with a string electrometer and a photographic registration apparatus.

The ionization chamber was a cylinder 3 cm. long with a hemispherical end. The rays entered the chamber through a small mica window in the hemispherical end. A rod with a spherical knob was insulated in the axis of the cylinder. This rod was connected to a string electrometer which was connected to earth through a high resistance of alcohol and xylol. A high negative potential was applied to the cylinder. The gas used in the chamber was helium at about 20 cm. pressure. This gas greatly decreased the deflections due to "natural disturbances."

Later, Geiger[3] used a fine point inside a cylindrical ionization chamber and was able to get a discharge at atmospheric pressure with a positive

[1] Proc. Roy. Soc. (A), 81, 141, 1908.

[2] Phil. Mag. (6), 24, 618, 1912.

[3] Deut. Phys. Gesell., 15, 534, 1913.

potential of about 1,200 volts applied to the cylinder. The cylinder was 2 cm. in diameter and 4 cm. long. The end of the cylinder was closed except for an opening 1.4 mm. in diameter through which the rays entered. The point which was a fine steel needle extended to within .8 cm. of the end. The difficulty encountered was to find a point which was free from "natural disturbances." The choice of a point was made on examination with a microscope. The point was cleaned with alcohol and if it gave "natural disturbances" it was heated in the Bunsen flame. This treatment often removed the difficulty.

An investigation along the line of Rutherford and Geiger's original experiment was made by Myssowsky and Nesturch.[1] They were not able to secure conditions which were free from "natural disturbances." Their conclusions were that the method was untrustworthy and could not be used to determine with accuracy the number of particles given off by radioactive substances.

At the suggestion of Professor Pegram, of Columbia University, the author began an investigation of the conditions for readily getting the result observed by Geiger.

In these experiments an ionization chamber of the same type as that used by Geiger was employed. Not having a string electrometer at my command, I made a Wilson tilted electrometer, which, with a liquid resistance of alcohol and xylol served the purpose very well. With this arrangement thirty or forty deflections per minute could easily be counted. A diagram of the arrangement is shown in Fig. 1, *a*.

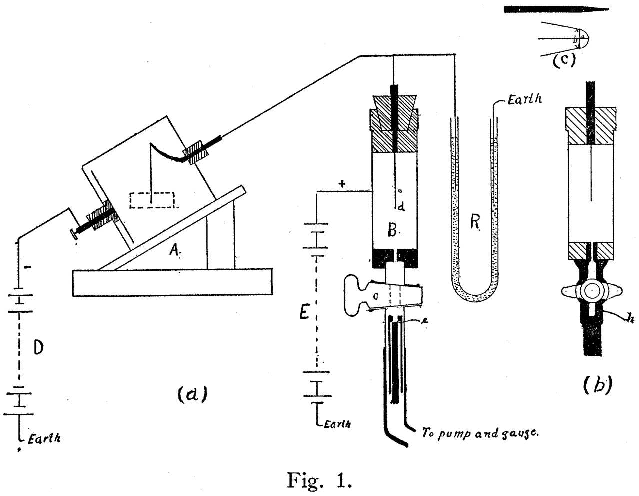

Fig. 1.

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[1] Ann. der Phys., 43, 461, 1914.

Much difficulty was experienced in finding points which were free from "natural disturbances." These "natural disturbances" are shown by a deflection of the gold-leaf of the electrometer when no rays enter. These disturbances may be intermittent or continuous. When they are intermittent they give rise to a sudden deflection of the gold-leaf. This is due to its gaining a charge which immediately leaks off through the high resistance bringing the leaf again to its zero position. If the disturbances are continuous the leaf remains deflected as long as the discharge continues. When a deflection is due to an entering particle the fact can be determined by removing or screening the source of radiation, upon which the leaf will remain quiet. To distinguish the discharge caused by an entering ray from the discharge caused by a "natural disturbance," I will refer to it as the *ray discharge*.

In the preliminary work, long slender needles were used as points. The smoothest and finest points were selected on examination with a microscope. These were carefully cleaned with alcohol and if they gave "natural disturbances" they were carefully heated in the Bunsen flame. Occasionally this would remedy the difficulty. It was observed that best results were obtained by heating just enough to blue the point. If the point was heated until it turned gray it could not be made to give the ray discharge. Careful heating in the oxidizing flame of the blast lamp always gave best results.

Among a number of samples of needles two types of points were found. One type has a rounding slope toward the end, which, as seen through the microscope, seems very blunt. The other kind, called "sharps" by the manufacturer, has two slopes toward the point, the last slope bringing the needle to an extremely sharp point. Most slender needles have the first kind of point. Even among the kind called "sharps," the finer needles do not have better points than those which are coarser.

A dozen of number 9 "sharps" were selected to be tested. Of these, five gave the ray discharge while the others gave only "natural disturbances." The other remaining seven were heated by the blast lamp and five of these were made good, so that only two out of the twelve failed altogether. However none were entirely free from disturbances and these became very numerous if the voltage applied to the cylinder was increased over a short range. These twelve needles were now laid carefully away exposed to the air of the room. Four days later they were again tested under the same conditions. Only one, and this one had been previously heated by the blast lamp, would now give the ray discharge. Four days later they were tested again. The one previously in good order now failed, but two of the others gave the ray discharge. Upon reheating all except one were made good.

From the foregoing results it would appear that the points were continuously undergoing a change in their surfaces. This might be due to collection of dust particles, condensation of water vapor, or the formation of a gas layer. To investigate this point further it seemed desirable to use a platinum point so that it could be heated without destroying the shape of the point or roughening the surface. Accordingly a platinum wire (no. 20, B. & S.) was pointed by grinding on an emery stone and turned true in a jeweler's lathe with a smooth fine-grained stone until it was fairly sharp. The finishing was done by hand on the stone. In this way a good point, even sharper than could be found on the best needles, was made.

All points at first gave natural disturbances. These were now heated in the blast lamp at intervals and tested. The disturbances became less frequent as the heating proceeded and after prolonged heating ceased altogether. Dipping the point while red-hot into nitric acid seemed to help remove the disturbances. Many times when the point gave a good deflection for the ray discharge I have watched for ten minutes at a time without detecting a single disturbance. Occasionally, on standing for some time with no potential applied some disturbances would appear. These disturbances may be due to occlusion of gases, condensation of moisture on the point or the collection of dust particles. The two latter causes seem the more obvious since the introduction of fresh air into the apparatus often results in disturbances. These disturbances, however, disappear upon reheating and dipping into nitric acid.

If a fresh point is heated just enough for the ray discharge to appear it is more sensitive than if heated thoroughly. This sensitiveness gradually decreases until in the course of a half of an hour it is about one sixth of its former value. The change in the sensitiveness now changes more slowly and finally reaches a very small value. When heated thoroughly the sensitiveness of the point remains constant, no change being observed during the greater part of a day.

If, in any circumstance, a spark discharge passed inside the cylinder, the point always developed disturbances. This is undoubtedly due to the deposit of a foreign substance on the point during discharge, though in such a small quantity that it could not be detected by the microscope. Reheating and dipping into nitric acid usually removed the difficulty, though sometimes a repolishing of the point was necessary.

Use of Different Materials as Points.

Various metals were used as points. Among these were, copper, brass, aluminum, silver, iron and 20 k. gold. All of these oxidize on heating. Though many attempts were made to get the ray discharge from these, none were successful except in the case of silver. A successful silver point was always more difficult to obtain than a platinum point so that no further trials were made with the other metals. Undoubtedly the reason a steel needle gave the ray discharge and the pointed iron wire would not was owing to the polish of the surfaces. This would result in unequal oxidation upon heating, in the case of the hand-pointed points.

The Effect of the Sharpness of the Point.

A sharpening of the point always results in a lowering of the potential to produce a constant deflection for the ray discharge. A well-seasoned platinum point was used. It was first made quite blunt. It was then heated and tested, noting the potential necessary to give a deflection of ten scale divisions in the telescope. The point was gradually made sharper, then it was heated again and tested under the same conditions. The diameter, $b = 2a$, as shown in Fig. 1, c, was measured with a microscope. The results of the variation of the diameter of the point with the potential of the point necessary to give a constant deflection of ten scale divisions are shown in Fig. 2. It can be seen that as the point becomes very sharp the potential drops very rapidly.

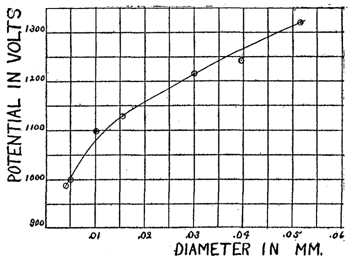

Fig. 2.

The Effect of the Size of the Cylinder.

In Rutherford and Geiger's original experiment they gave as the cause of the "natural disturbances" the radiations from the sides of the chamber. They found that if a smaller cylinder was used these disturbances became smaller and less frequent. In their second experiment they used helium in the chamber and largely got rid of these disturbances. To test the effect of the size of the cylinder, several cylinders varying in diameter from .9 cm. to 5.3 cm. were made. The result showed that with a thoroughly seasoned point one size of cylinder was as free from disturbances as another. The only difference observed was in the potential to give a ray discharge. In the case of the largest cylinder, the point had to be brought quite close to the end to produce the ray discharge with the potential, 1,400 volts, which I had at my command.

A piece of apparatus similar to that used by Rutherford and Geiger in their original experiment was now made. A small platinum wire was stretched centrally in the axis of the cylinder and fastened to larger brass wires passing through ebonite ends in the cylinder.

While the air was being pumped out an electric current was sent through the wire until it became incandescent. The large brass wires did not extend through to the inside of the chamber so that the extreme ends of the platinum wire which would not be heated to incandescence were not exposed inside the cylinder. When tested before heating the wire, with the chamber partially exhausted, both with the cylinder at positive and then at negative potential, numerous natural disturbances were given off. As the heating proceeded these disturbances became less numerous but could not be removed entirely even though heated for many minutes. The heating was stopped as the wax which secured the ends began to melt. Finally the wire was removed from the cylinder, cleaned and thoroughly heated in the blast lamp and replaced. Now the highest potential (+ 1,400 volts) which I had available failed to show any disturbance or to give the ray discharge though the pressure was reduced to a few millimeters of mercury. This part of the work was not pursued further.

These observations show that the seat of the disturbances is in the point or central wire and that they are not due to the chamber or the contained gas provided it is dry and dust free. This latter will be more fully shown in later observations.

The Effect of Various Gases in the Cylinder.

To study the effect of various gases in the chamber the apparatus shown in Fig. 1, *a*, was used. The platinum point was firmly held in the ebonite end by a brass rod. A one-hole rubber stopper slipped over this rod and fitted into the ebonite end. By this arrangement the point was held firmly in place, the chamber was made air-tight and the point could easily be removed. The other end of the cylinder was closed with a metallic end into which was sealed a glass stopcock in which was placed the active rod, *e*. The rays could be cut off by closing the cock. Through the cock the chamber could be exhausted and various gases introduced. Connected to the stopcock was also the pump and pressure gauge.

The gases used were air, oxygen, hydrogen and carbon dioxide. Observations were taken by varying the pressure and observing the potential necessary to give a constant deflection of ten divisions with Alpha rays. The observations were taken with the point at negative and then at positive potential.

Air from the room was at first used. Then the effect of drying it by bubbling it through sulphuric acid and passing it through a calcium chloride tube was observed. Drying the air makes an increase in potential necessary to secure a constant deflection. This is more noticeable at the higher pressures. The introduction of moist air always produced natural disturbances. All other gases were carefully dried. The same point was used throughout these observations. Before a new gas was introduced the point was removed and reheated.

When the pressures were low a small change in potential often resulted in a spark discharge. In this case the point had to be removed and reheated. Many times at the lower pressures disturbances entered which were entirely absent at higher pressures. The number of these were small in comparison to the number of ray discharges so that no attempt was made to get rid of them.

No noticeable difference in the operation of the apparatus was apparent whether the point was negative or positive except that in all cases the potential had to be raised when the point was positive. From the appearance of the curves in Fig. 3 this difference tends to disappear at very low pressures as the curves tend to converge toward the origin. The difference in the negative and the positive potential for the ray discharge for hydrogen is much less marked than for any other gas. The potentials for constant deflection at a certain pressure increases with the density of the gas.

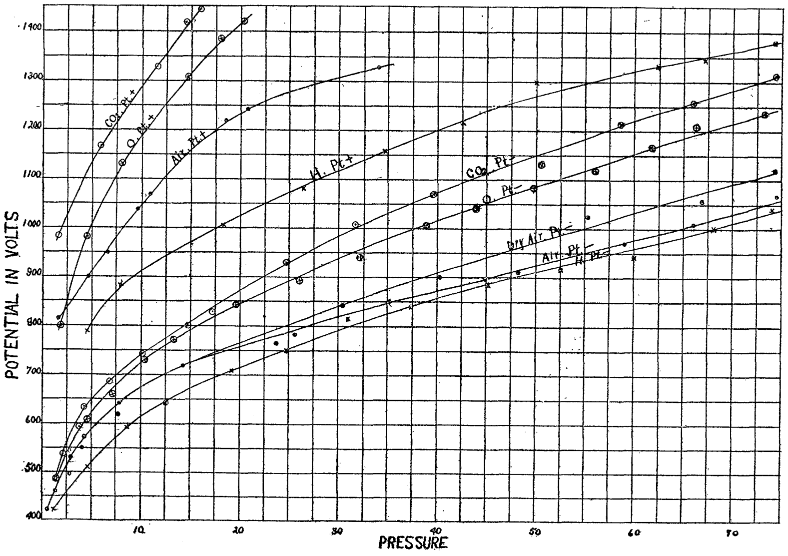

Fig. 3.

The Effect of Geometrical Distribution of the Particles Inside the Ionization Chamber.

In order that Geiger's method may be effective in determining the number of alpha or beta particles given off by radioactive substances it is quite necessary to know that every particle that enters the chamber is registered. Scattering always occurs when alpha or beta rays penetrate matter or pass through a gas. By scattering in the gas in the cylinder the rays may be distributed at varying distances from the point. The question to be settled is how close to the point must the particle come in order to be registered. To determine this the cylinder previously used, was fitted with a brass end containing several openings 1.4 mm. in diameter distributed at varying distances from the center. These openings were made of larger diameter on the outside so that a brass tube containing a rod made active by exposure at negative potential to thorium emanation could be inserted, the source of radiation being three centimeters from the opening. The distance of the point from the opening was varied from 10 to 25 mm. The active rod was inserted in the openings at various distances from the center of the end. Under these conditions the number of deflections for five minutes was noted. An ebonite end similar to the brass end was now used and similar observations taken. The voltage used throughout was 1,200 volts. The magnitude of deflection did not differ much in the two arrangements when the point was farther from the end. When the point was near the end the deflections were larger with the brass end than with the ebonite end. The results are shown in the following table:

The active rod did not have the same strength in the two cases, so that no comparison can be made as to the number of alpha particles registered by the two arrangements.

These results show that the field from the end of the cylinder to the point is stronger near the center, so that when rays enter to one side, only those that are projected in a favorable direction are registered. If all rays enter this strongest part of the field they are very apt to be registered. If the point should happen to be displaced even a little from the center the rays could not enter the strongest part of the field and would not all be registered. This was tested, and it was found that a small displacement of the point from the center resulted in a diminution of the number of deflections, especially when the point was near the end. With an ebonite end the rays enter a fairly uniform field so that all are more apt to be registered. It is seen that as the point is removed farther from the brass end the number registered is practically the same whether the rays enter at the center or to one side. This last statement is practically

L = length of cylinder; *d* = distance of the point from the end; *r* = the distance from the center of the opening through the particles entered; *N* = number of deflections in five minutes.

Brass End.				Ebonite End.			
L	*d*	*r*	*N*	*L*	*d*	*r*	*N*
4 cm.	25 mm.	0 mm.	37	4 cm.	25 mm.	0 mm.	46
"	"	2	34	"	"	2	44
"	"	3	34	"	"	3	41
"	"	4	25	"	"	4	43
"	"	5	29	"	"	5	45
3.5	20	0	37	3.5	20	0	43
"	"	2	36	"	"	2	43
"	"	5	35	"	"	3	41
				"	"	4	46
3	15	0	37	"	"	5	40
"	"	2	30				
"	"	3	18	3	15	0	45
"	"	4	14	"	"	2	40
"	"	5	3	"	"	3	39
				"	"	5	42
3	10	0	37				
"	"	2	6	3	10	0	46
				"	"	3	40
				"	"	5	38

true in the case of an ebonite end for all distances of the point from the end.

In Geiger's experiment he placed the point 8 mm. from the end. Since this produces a less uniform field, one would not expect to get the same size deflections for all particles, hence at the smaller potentials the smaller discharge would not be shown. That this is true is shown in his table of results; for the potential has to be increased considerably above the voltage at which the ray discharge begins to take place before the number registered becomes constant. With an ebonite end the number registered at all potentials is constant. To show the truth of the last statement some further observations were made, using the chamber shown in Fig. 1, *b*. The point was kept at negative potentials varying from 1,020 to 1,400 volts. Unfortunately I did not have a stronger source of radiation so that a greater number of deflections could be made per minute. In each case the number of deflections in five minutes was observed. The deflection of the electrometer was not quite proportional to the potential to which the leaf was raised, hence the scale of the telescope was calibrated in terms of volts applied to the leaf and the deflections recorded were made numerically equal to the voltage of the leaf. The instrument was made less sensitive for the higher potentials applied to the point. The results are shown in the following table:

Alpha Rays.

Volts.	Deflection.	Number Observed in Five Minutes.
1,020	13	87
1,070	24	85
1,120	35	82
1,180	58	88
1,230	64	87
1,300	86	87
1,340	100	85
1,400	140	81

Beta Rays.

Volts.	Deflection.	Number Observed in Five Minutes.
1,220	18	32
1,280	26	31
1,340	43	31
1,400	62	30

This table shows that the number of particles registered remains practically constant for all voltages. In Fig. 4, curve 1 shows the variation of deflection with voltage. Curve 2 shows this variation for beta rays.

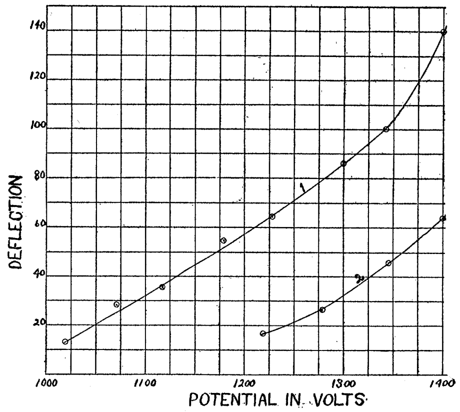

Fig. 4.

The highest potential to which the leaf of the electrometer was raised was 140 volts. This was obtained with 1,400 volts applied to the point. This was the highest potential I had available. Judging from the form of the curve, which is an ionization by collision curve, the application of higher potential might raise the leaf to a potential nearly twice as high before a spark discharge would occur.

USE OF THE APPARATUS FOR DECAY MEASUREMENTS.

The apparatus was now used to determine the rate of decay of thorium B by counting the number of alpha particles given off by its products. The value found was 10.4 hours. Considering the fact that the source of radiation was weak, this is in very good agreement with the accepted value, 10.6 hours.

CONCLUSIONS.

By the use of a platinum point which can be thoroughly heated without destroying the point the "natural disturbances" can all be driven out so that without any difficulty a point can be secured which will give only the ray discharge.

If protected from moist fresh air "natural disturbances" show no tendency to develop during the use of the apparatus.

The seat of the "natural disturbances" is in the point and their number is not affected by the size of the ionization chamber.

At constant pressure, the potential at which the ray discharge occurs is a function of the sharpness of the point.

With a thoroughly heated platinum point, air, hydrogen, oxygen and carbon dioxide, if thoroughly dried, can be used equally well in the cylinder. The only difference is one of the value of the potential necessary to produce the ray discharge.

No more difficulty is experienced in using the point at positive potential than at negative potential. When the point is positive the higher potential is necessary.

With an ebonite end in the ionization chamber quite uniform deflections are obtained for entering rays. As a result, the number of particles registered is constant for all potentials of the point for discharges which give measureable deflections.

The apparatus has been used to determine the rate of decay of thorium B and the agreement with the accepted value is good.

The simplicity of the apparatus and the certainty of the results when a thoroughly heated platinum point is used makes it adaptable to many kinds of radioactive measurements.

WILLIAMS COLLEGE,
May 4, 1915.