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A COMPARISON OF SOME
" STANDARDS OF RADIOACTIVITY.

by

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A Comparison of Some Standards of
Radioactivity

by

Merle Randall, A. B.

Introduction.

Ever since Becquerel made his study of the photographic action of uranium salts (1) various compounds of this element have been used as a standard, to which the radioactivity of the several ^{radio}active elements could be referred. At first the methods of measurement were rather crude and a rough standard was sufficient to meet the needs of investigators.

As late as 1904 we find Strutt (2) in his study of the radioactivity of ordinary materials using as a standard the activity of a "crystal of uranyl nitrate four by twelve milli-

(1) Becquerel, H. Comptes rendus, 122, pp. 420, 501, 599, 689, 762, 1086, 1896.

(2) Strutt, R. J., Phil. Mag., 5, 680, 1903; Nature, 67, 369, 1903.

(8)

meters". Allan (1) studied the activity of freshly fallen snow and took as his standard the activity of a given weight of uranium, in uranium oxide.

Elster and Geitel (2) studied the radioactivity of clay and spring sediments. They took for comparison the activity of uranyl potassium sulphate. Blane (3) used as a standard an equal weight of uranium nitrate.

McCoy (4) has proposed to use as a stand-

(1) Allan, S. J., *Physic. Rev.*, 16, pp. 237, 306, 1903.

(2) Elster and Geitel, *Physik. Z.* 5, 321, 1904.

(3) Blane, G. A., *Phil. Mag.*, 9, 148, 1905.

(4) McCoy, H. N., *Ber. d. Chem. Gesell.*, 37, 2641, 1904; *Physic. Rev.*, 20, 381, 1905; *J. Am. Chem. Soc.*, 27, 391, 1905; *Phil. Mag.*, 9, 176, 1906.

Goettsch, H. M., Thesis, University of Chicago. The Absorption Coefficients of Uranium Compounds.

McCoy and Ross, *J. Am. Chem. Soc.*, 29, 1698, 1907.

and of activity the ionization produced between parallel plates by the alpha rays from one square centimeter of urano-uranic oxide (1) of sufficient thickness to give the maximum alpha ray activity. McCoy has shown (2) that this standard is reproducible with a high degree of accuracy.

Boltwood (3) has used the ionization of thin films of urano-uranic oxide which had a negligible amount of alpha rays absorbed by the film itself as a standard.

The ratio of radium to uranium in an old natural mineral is a constant (4). Boltwood has

(1) McCoy and Ashman, *Am. Jour. Sci.*, 26, 528, 1908.

(2) McCoy, *loc. cit.*

(3) Boltwood, B. B., *Am. Jour. Sci.*, 21, 409, 1908.

(4) Boltwood, B. B., *Am. Jour. Sci.*, 18, 97, 1904; *Nature*, 70, 80, 1904; *Phil. Mag.*, 9, 599, 1905.

Rutherford and Boltwood, *Am. Jour. Sci.*, 20, 56, 1905; 22, 1, 1906.

(10)

suggested that the quantity of radium emanation associated with one gram of uranium in a natural mineral be used as a standard of radioactivity(1).

As only a part of the equilibrium quantity of the radium emanation is retained by the mineral (2) the quantity lost must either be determined and corrected for, or a solution of the mineral must be stored for at least forty days so that the quantity of radium emanation may reach a maximum.

McCoy, H. N., Phil. Mag., 10, 176, 1907.

McCoy and Ross, Physic. Rev., 24, 124, 1907.

Boltwood, B. B., Am. Jour. Sci., 25, 269, 1908.

(1) Boltwood, B. B., Am. Jour. Sci., 18, 381, 1904; Phil. Mag., 9, 599, 1905.

(2) Boltwood, B. B., Phil. Mag., 9, 599, 1905.

Strutt, R. J., Proc. Royal Soc., 77, 472, 1906.

(11)

The various methods of using this emanation standard will be described below.

The compounds of radium have also been used as standards of activity. The purity of radium chloride or radium bromide can be ascertained by measuring the heat given off spontaneously by a known weight of radium preparation in equilibrium with its products(1). This method has been used extensively by Curie and others (2) but is not generally available both on account of the high cost of radium preparations and of the difficulty of ascertaining the purity of the specimen.

The Röntgen Society has proposed (3) that one milligram of pure radium bromide be taken as the standard of radioactivity, and that the

(1) Rutherford and Barnes, Phil. Mag., 8, 202, 1904.

(2) Curie and Laborde, Comptes rendus, 138, 1150, 1904.

Eve and McIntosh, Phil. Mag., 14, 231, 1907.

(3) Röntgen Ray Society. Nature 77, 543, 1908. Journal Röntgen Ray Soc. Feb. 1908.

(12)

ionization due to the gamma rays, after passing through one centimeter of lead be taken as the measure.

The conductivity of gases has been extensively studied (1), the conductivity of the air being used as a standard. It has been shown (2)

(1) Strutt, R. J., Proc. Royal Soc., 68, 126, 1901.

Thomson, J. J., Proc. Camb. Phil. Soc., 11, 505, 1902.

Börnstein, R., Ber. d. Deutsch Phys. Gesell., 22, 404, 1903.

Burstead and Wheeler, Am. Jour. Sci., 16, 328, 1903.

Himstedt, F., Ann. d. Physik., 13, 573, 1904;
Ber. d. Naturf. Gesell. Freiburg, 14, 181, 1904.

Blane, G. A., British Association Reports , Camb., 71, 1904.

(2) Elster and Geitel, Ann. d. Physik., 2, 425, 1900; Physik. Z. 2, 560, 1901.

Saake, W., Physik. Z., 4, 626, 1903.

Wood and Campbell, Phil. Mag., 13, 265, 1907.

(13)

by Elster and Geitel and others that the normal conductivity of air varies at various times during the day, and from place to place so that the air standard is at once excluded in any series of measurements where accuracy is required.

The activity of many spring waters and other ordinary materials (1) has been expressed in terms of volts fall of potential of a charged body per hour, without data regarding the electrostatic capacity of the body, or the size of the vessel in which the ionization took place. Since the rate of fall of potential of a charged body is ^{inversely} proportional to the electrostatic capacity of the system for a constant ionization(2) this system of expressing

(1) Himstedt, F., Ann. d. Physik., 12, 107, 1903; Ber. d. Naturf. Gesell. Freiburg, 13, 101, 1903.

Rausch, H. F., Physik. Z., 5, 130, 1904.

Costanzo and Negro, Physik. Z., 7, 350, 1906.

Hayek, H. V., Z. d. Ferdinandeums für Tyrol u. Vorarlberg, 50, 524, 1907.

(2) Rutherford, E., Radioactivity. 2nd. Edition. Camb. Press., p. 100.

(14)

the results of radioactive measurements cannot be used when comparative results are desired.

Numerous results on the radioactivity of water samples, gases, and other ordinary materials (1) have been expressed in the C. G. S.

(1) Gerdien, H., Physik. Z., 4, 632, 1903.

Mache, H., Wien. Ber., 113, 1329, 1904.

Curie and Laborde, Comptes rendus, 138, 1150, 1904.

Engler and Sieveking, Z. anorg. Chem., 53, 1, 1904.

Campbell, N. R., Proc. Camb. Phil. Soc., 13, 132, 1905; Phil. Mag., 11, 217, 1906.

Mache and Travis Rimmer, Physik. Z., 7, 617, 1906. Radium, 3, 289, 1906.

Sury, Jos., Mitt.naturf. Gesell. Freiburg Chem. II, 1, 78, 1906; Chem. Zentral. I, 1282, 1907.

Koch, K. R., Physik. Z., 7, 806, 1906; Ber. d. Physik. Gesell., 8, 846, 1906.

Henrick, Ferd., Physik. Z., 8, 112, 1907.

Ehler, E., Z. angew. Chem., 21, 737, 1908.

electrostatic units. In some cases the size and shape of the testing vessel was given and in others not. This method of expressing the activities was first employed by Gerdien, then by Mache,^{Curie and Laonde} and later by Engler and others (1) . This is the method generally employed on the continent of Europe for expressing the activity of the air, water samples, minerals, etc.

Since so many standards of activity exist it would seem desirable that we should be able to convert the results obtained , using any one standard , into those of any other standard.

The present investigation was commenced with the intention of comparing the McCoy urano-uranic oxide standard with the Boltwood emanation standard and with the C. G. S. electrostatic standard. After some three months had been spent in constructing an electroscope and in the preparation of the standards for the comparison of the McCoy standard with the C. G. S. electrostatic standard McCoy and Ashman published this ratio. (2). They

(1) Loc. cit.

(2) Loc. cit.

(16)

found the ionization current due to the alpha rays from a thick film of uranouranic oxide was 5.79×10^{-13} amperes, or 1.737×10^{-3} C. G. S. electrostatic units, per square centimeter. The specific activity of uranium, defined as the total ionization current from one gram of uranium when all the ^{alpha} radiation is absorbed in air, is 796 McCoy units(1). The total ionization current from one gram of uranium free from its products is then 4.61×10^{-10} amperes or 1.38 C. G. S. electrostatic units.

Boltwood has shown (2) that if the activity of uranium be taken as 1.00 for his electroscope, that the activity of the radium emanation in equilibrium is 0.62, that of the radium A is 0.52, that of the radium B is 0.04, and that of the radium C is 0.91, or a total of 2.11 times as active as the uranium with which they are in

(1) McCoy, H. N., Phil. Mag., 11, 176, 1906.

McCoy and Ashman, J. Am. Chem. Soc., 29, 1698, 1907.

(2) Boltwood, B. B., Am. Jour. Sci., 25, 297, 1908.

(17)

equilibrium. Now if the equilibrium quantity of radium emanation from one gram of uranium was introduced into an electroscope, and the equilibrium amount of radium A, radium B and radium C allowed to accumulate, the activity would be 4.61×10^{-10} X 2.11 or 9.73×10^{-10} amperes, or 2.92 C. G. S. electrostatic units, if all the alpha particles had the maximum range in air. In terms of the Boltwood standard the specific activity of uranium would be $1/2.11$ or 0.475 .

As has been pointed out above the investigators on the continent of Europe have used the C. G. S. electrostatic standard, while those in England and this country have generally used the Boltwood radium emanation standard. Now McCoy and Ashman have already (1) determined the relation between their standard, the Boltwood uranium oxide standard, and the C. G. S. electrostatic standard. I have calculated above the theoretical relation which should exist between the Boltwood radium emanation standard and the C. G. S. electrostatic standard.

(1) Loc. cit.

(18)

Since these last named standards have been used so extensively in the investigation of the radioactivity of gases , waters, rocks, and other common materials I have attempted to investigate the various methods of removing the radium emanation from solution , and to ^{study} ~~determine~~ the relation between these two standards experimentally, using various forms of electroscopes.

The general method of procedure was as follows:- The electrostatic capacity of the electroscopes was first determined. Definite quantities of the radium emanation were separated by the several methods and introduced into the electroscopes. From the rate of leak the current in amperes and C. G. S. electrostatic units was calculated.

Experimental Part.

Source of Radium Emanation.

The uranium mineral used as a source of radium emanation was a uraninite of unknown origin purchased from the firm of Eimer and Amend. A large sample, about five hundred grams, which showed no signs of alteration was ground to pass

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a brass sieve one hundred and twenty meshes per inch. The sample was then thoroughly mixed in order to obtain a perfectly uniform sample.

The Determination of the Uranium
in the Standard Uraninite.

The analytical determination of the uranium in the sample of standard uraninite was conducted by ^athe slight modification of the method described by Boltwood (1). The procedure was as follows:-

The finely powdered mineral was dissolved in pure diluted (1:1) nitric acid. After the first action was over the solution was evaporated to dryness on the water bath. Two cubic centimeters of concentrated hydrochloric acid were then added and the solution again evaporated to dryness. The residue was moistened with concentrated hydrochloric acid, and thirty cubic centimeters of distilled water was added. The solution was then heated to boiling and the residue of silica, gangue, etc. was filtered off, and

(1) Boltwood, B. B., Phil. Mag., 9, 603, 1905.

(20)

and washed with distilled water until free from acid.

The filtrate and washings, which had a volume of about one hundred and fifty cubic centimeters were heated to boiling, and hydrogen sulphide (1) passed into the solution for one and a half hours. The brownish black precipitate of sulphides was filtered off and thoroughly washed with hot distilled water. The filtrate was boiled to remove the excess of hydrogen sulphide, and evaporated to a volume of one hundred and fifty cubic centimeters on the hot plate.

The salts in solution in the concentrated filtrate were oxidized with four cubic centimeters of concentrated nitric acid. About 0.1 gram of microcosmic salt (sodium ammonium hydrogen phosphate) was added to the solution .

(1) The hydrogen sulphide was prepared from ferrous sulphide and dilute sulphuric acid, and washed by passing through distilled water.

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which was allowed to cool somewhat, and then poured into a solution of five grams of anhydrous sodium carbonate dissolved in one hundred and fifty cubic centimeters of distilled water, and heated to about fifty degrees Centigrade. The mixture was heated to boiling and boiled ten minutes, cooled to about fifty degrees Centigrade, and ten grams of ammonium chloride added. The mixture was again heated and gently boiled for about five minutes, and then allowed to stand until cool. The precipitated phosphates were filtered off and washed with distilled water. The filtrate was reserved, and the residue on the filter paper was dissolved in dilute nitric acid in the same vessel in which the precipitation took place. The nitric acid solution of the phosphates was again poured into a solution of five grams of sodium carbonate dissolved in one hundred and fifty cubic centimeters of distilled water and treated exactly as in the first case. The precipitated phosphates

were then carefully washed and the filtrate and washings added to the first filtrate.

The combined filtrates and washings were boiled in a large casserole until the greater part of the ammonium carbonate was driven off, and the uranium phosphate was precipitated from the solution. Just enough dilute nitric acid was added to dissolve the precipitate, and the solution was boiled to remove the last traces of carbon dioxide. The solution was then concentrated on the water bath to about four hundred cubic centimeters, and 0.2 gram ammonium phosphate was added. Then ten grams of sodium thiosulphate crystals were added. The precipitate which was formed was very finely divided, so ten grams of ammonium acetate were added (1). The solution was boiled twenty minutes and the precipitate of sulphur and uranium phosphate, which does not clog the filter paper, filtered

(1) Brearley, H., Analytical Chemistry of Uranium. Longmans, Green and Co., p. 10.

(23)

and washed with distilled water .

The filter paper and precipitate ^{were} ~~was~~ placed in a platinum crucible and ignited at as low a temperature as possible, until all the carbon was burned off. The residue of phosphate was then dissolved in the smallest possible amount of hot concentrated nitric acid, and the excess of acid almost neutralized with dilute ammonium hydroxide. The clear solution was then poured into a solution of three grams of ammonium carbonate dissolved in thirty cubic centimeters of distilled water. A slow current of hydrogen sulphide was passed into the solution for two minutes and the liquid heated cautiously just to boiling. The liquid was allowed to cool and the precipitate which in all cases was very slight was filtered off and washed with distilled water.

In order to see if the precipitate obtained by treatment of the ammonium carbonate solution with hydrogen sulphide contained any uranium, the residue was dissolved on the

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filter paper by dilute hydrochloric acid, the acid was nearly neutralized with ammonium hydroxide, and potassium ferrocyanide added to the solution obtained. A reddish precipitate would indicate that uranium was present, but in no case was such a precipitate found.

The main filtrate was now boiled to remove the excess of ammonium carbonate, acidified with dilute nitric acid, and 0.2 gram of ammonium phosphate added. The uranium was then reprecipitated as phosphate by adding ten grams of pure crystallized sodium thiosulphate and ten grams of ammonium acetate. The solution was boiled twenty minutes, filtered, and washed. The residue was ignited in a platinum crucible at a very low temperature until the sulphur was removed, and then at a red heat until all the carbon was burned off. The crucible was then allowed to cool in a desiccator, and weighed.

The uranium contained in the green pyrophosphate of uranium thus obtained was calculated on the assumption that the green

(25)

salt contained 68.55 per cent of uranium(1), an assumption which has been verified by Boltwood (2).

Three determinations were made using the air dry uraninite, which gave results as follows:-

0.6830 gram uraninite gave 0.5292 gram green phosphate of 53.12 per cent uranium.

0.2442 gram uraninite gave 0.1887 gram green phosphate or 52.98 per cent uranium.

0.2525 gram uraninite gave 0.1952 gram green phosphate or 52.99 per cent uranium.

Mean of the three determinations on the air dry uraninite, ground to pass a seive one hundred and twenty meshes per inch, 53.03 per cent uranium.

It is well known that the moisture content of finely powdered minerals changes materially. In order to have a check on the moisture content of the powdered uraninite

(1) Brearley, H., Loc. cit.

(2) Boltwood, B. B., Loc. cit.

(26)

two samples were weighed out into platinum crucibles, placed in a steam oven, and allowed to remain two hours. At the end of this time they were placed in a desiccator, cooled, and weighed. It was found that,

0.6830 gram uraninite lost 0.0055 gram equivalent to a loss of 0.80 per cent.

0.7368 gram uraninite lost 0.0058 gram equivalent to 0.79 per cent loss.

Two determinations gave a mean loss by heating two hours at one hundred degrees Centigrade of 0.80 per cent.

The percentage of uranium in the mineral when referred to the finely powdered material heated two hours at one hundred degrees is 53.46 per cent uranium.

The Standard Solutions of Radium

Emanation.

This sample of uraninite, carefully standardized gravimetrically, was used in the preparation of the various solutions of definite content

of radium emanation.

Five stock solutions of the standard uraninite to be designated as solutions A, B, C, D, and E were prepared from four separate portions as follows:-

A sample of the finely ground material, 1.8860 gram, corresponding to one gram of uranium was weighed into a beaker and digested with diluted (1:1) nitric acid. The solution was heated on the water bath until all the uranium was dissolved and the residue white. One cubic centimeter of concentrated hydrochloric acid was now added. Eve (1) has shown that when hydrochloric acid is added to a solution of a radium salt that none of the latter is deposited upon the sides of the vessel. The solution was now diluted to about two hundred cubic centimeters, heated nearly to boiling, and filtered. The residue was washed with distilled water, and the combined filtrate and washings transferred to

(1) Eve, A. S., Am. Jour. Sci., 22, 4, 1906.

(28)

a liter graduated flask, and the volume made up to the mark with distilled water. One cubic centimeter of this solution contained 0.001 gram uranium. This stock solution was known as solution A.

Fifty cubic centimeters of solution A were measured out with a pipette into a five hundred cubic centimeter graduated flask, and the solution diluted to the mark with distilled water. This solution was designated as solution B. From this solution, one cubic centimeter of which contained 0.0001 gram of uranium, the samples of very small radium content were prepared.

Solution C was made up three weeks later from a new portion of 1.8860 gram of uraninite, in exactly the same manner as was solution A. One cubic centimeter of solution C contained 0.001 gram uranium.

Solution D was made up in a very similar manner. A sample of the uraninite, 3.7720 grams, was weighed out into a beaker and dissolved in

(29)

diluted (1:1) nitric acid. The solution was diluted to about two hundred cubic centimeters and filtered. The residue was washed with distilled water, and two cubic centimeters of concentrated hydrochloric acid added to the combined filtrate and washings. The solution was boiled fifteen minutes in order to completely remove all the radium emanation present in the solution. The time at which the boiling was discontinued was noted, in order to calculate the quantity of radium emanation that would accumulate during storage of the sample. The solution was then transferred to a liter graduated flask and the volume made up to the mark with distilled water. One cubic centimeter of solution D contained 0.002 gram uranium.

Solution E was made up about two hours later in exactly the same manner as solution D, using another portion of 3.7720 gram uraninite. One cubic centimeter of solution E contains 0.002 gram uranium.

Storing of the Standard Samples.

Several forms of apparatus have been used for storing samples of material containing radium salts in solution. The most generally used of these consists of a flask fitted with a tightly fitting rubber stopper. (1) When the emanation is to be boiled off the stopper is removed and the flask attached to the collecting apparatus very quickly in order to avoid loss of the radium emanation as much as possible.

Sehrlundt and Moore (2) have studied the ^{separation} loss of radium emanation from mineral waters. They found that the quantity of radium emanation lost by these solutions of very small content of the emanation when heated to ninety five de-

(1) Sehrlundt and Moore, Jour. Phys. Chem., 9, 320, 1905.

Strutt, R. J., Proc. Royal Soc., 77, 472, 1906.

(2) Sehrlundt and Moore, Jour. Phys. Chem., 9, 320, 1905.

(31)

degrees Centigrade, was ~~very~~ small (thirteen per cent). The concentration of radium emanation in the solutions ~~to be~~ studied was very much greater and it was desired to avoid any loss which might possibly occur during the change of stoppers.

After several trials with other forms, the two forms of storage flasks shown in the photograph (Fig. 1) were devised and adopted. Number I, on the left, consisted of a two hundred cubic centimeter Erlenmeyer flask (A) fitted with a two holed rubber stopper (B). one of these holes was plugged with a piece of glass rod. (A one holed rubber stopper is much to be preferred.) The other hole was fitted with a short piece of glass tubing (C) about six centimeters in length. The lower end of the glass tube (C) was just flush with the lower end of the rubber stopper (B). The upper end of the tube was fitted with a piece of rubber tubing (D) about six centimeters in length, closed by means of a screw clip (E) clamped tightly over the rubber tube just at the end of

Fig. 1. Storage Flasks.

(33)

the glass tube in order to avoid diffusion of the emanation through the rubber tube as much as possible. This design of storage flask was used for storing the ^{standard} samples prepared from stock solutions A, B, C, and E. It proved very convenient for attaching to the various forms of apparatus ^{used} for separating the radium emanation which are described below, and entirely obviated any loss of the emanation due to the change of stoppers as in the former arrangements.

Number II, on the right (Fig. 1), differs only slightly from the design just described. It consisted of an ordinary flask of about two hundred and fifty cubic centimeters capacity (A) fitted with a two holed rubber stopper (B). Into one hole of the stopper was fitted a piece of glass tubing (C) five millimeters in diameter which extended to the bottom of the flask. The other hole of the rubber stopper (B) was fitted with a short piece of glass tubing (D) the lower end of which ^{was} ~~is~~ flush with the lower end of the stopper. The upper ends of the glass tubes were

(34)

fitted with short pieces of rubber tubing, and closed by means of the large screw clip (E). By making the two glass tubes extend the same distance above the stopper one screw clip served to completely close both openings. This form of storage flask was used for storing the samples which were prepared from solution D, and from which the radium emanation was removed by means of the apparatus employed by Boltwood (1) a detailed description of which is given under the section describing the forms of apparatus for removing radium emanation.

Eleven sets of samples, eighty in all, containing from 0.001 gram to 0.3 gram uranium were prepared from the standard stock solutions and stored in the flasks just described. The samples from solutions A, B, C, and E were stored in the first described form of flask, sufficient distilled water being added to

(1) Boltwood, B. B., Phil. Mag., 9, 599, 1905.

(35)

fill the flasks to within about six centimeters of the bottom of the stopper. The samples from solution D were stored in the flasks of the second design. The contents of the flask were diluted so that the solution would fill about two thirds of the flask.

The quantity of radium emanation in equilibrium with radium attains its maximum value after the lapse of about a month.(1) The samples prepared from solutions A, B, and C were all stored over six weeks before they were boiled off, so that the quantity of radium emanation in these samples numbers 1A to 46C inclusive, reached its maximum. The samples from solutions D and E were not stored for a sufficient time to allow the equilibrium amount of the radium emanation to be formed. Under these circumstances the sample was stored at least four days. The time at which the sample was prepared was known

(1) Rutherford, E., Radioactivity, 2nd. Edition. p. 372.

(36)

and the time at which the separation of the emanation was completed was noted. From the interval t in hours the quantity of radium emanation which had accumulated was calculated according to the following equation:- (1)

$$\frac{I_t}{I_0} = 1 - e^{-\lambda t}, \text{ or}$$

$$I_t = I_0 (1 - e^{-\lambda t}).$$

where I_t is the quantity of emanation which would accumulate in t hours. I_0 is the maximum, or equilibrium amount, and λ is the radioactive constant of the radium emanation. The value of λ was taken as 0.00744 (2).

Apparatus for Boiling off
the Radium Emanation.

Inasmuch as a number of different forms

(1) Rutherford, E., Radioactivity, 2nd. Edition, p. 372.

(2) Boltwood, B. B., Phil. Mag., 9, 599, 1905.

(37)

of apparatus have been devised and used by different investigators for separating radium from solutions of radium salts, it seemed desirable to study the relative efficiency of the more common forms. In all, five types of apparatus were used, and these will now be described in the order of their adoption during the progress of the investigation.

The Strutt Apparatus. In the original Strutt apparatus (1) it is possible that some of the emanation contained in the receiver will not be introduced into the electroscope on account of the trapping of some of the gas in the connecting tubes. Also the operation of discontinuing boiling is rather difficult. The original design was, ^{therefore} slightly changed so as to avoid the trapping of any gas in the connecting tubes, and also to simplify the manipulation connected with the stop^ppage of the boiling. The

(1) Strutt, R. J., Proc. Royal Soc.,
77, 472, 1906.

(38)

improved apparatus is shown in figure two.

The storage flask (A) shown also in figure one was attached to the reflux condenser (F). The condenser was attached in turn to the three way stop cock (G). The three way stop cock could connect the receiver (I) with the condenser (F), shutting off at the same ^{time} communication with the outside air through the side tube (H). Or by a quarter turn it will cut off the receiver (I) and connect the condenser (F) with the air through (H). By another quarter turn the whole apparatus could be placed in communication with the outside air. The receiver (I) was connected with the leveling bulb (J) by means of the rubber tube (K), which connection could be closed by means of the screw clip (L). Communication with the electroscope was made through the side tube (M) and the glass stoppered U-tube (N) containing concentrated sulphuric acid and glass wool.

The manipulation of the apparatus for the separation of the radium emanation from the solution in the flask (A) was as follows:-

Fig. 2. The Strutt Apparatus.

(40)

The stop cock (P) of the U-tube (N) was closed. The three way stop cock (G) was turned to the first position, or so that it connected the receiver (I) with the condenser and cut off the communication with the outside air through (H). The stop cock (P) was then opened. The receiver (I) and the leveling bulb (J) were filled with distilled water and the level adjusted so that the water filled the receiver to the lower edge of the branch tube (M). The screw clip (L) and the stop cock (P) were then closed. The screw clip (L) was now opened and the leveling bulb (J) lowered in order to test for possible leaks. If the apparatus was tight the screw clip (E) was opened. A slow current of water was kept running through the jacket of the condenser (F). The contents of the flask (A) were heated to boiling and kept in rapid ebullition for a least twenty minutes, when the water was turned off, and that in the jacket of the condenser allowed to run out. It was *found* necessary at intervals during the boiling to

(41)

remove the flame in order to allow the condensed steam in the condenser (F) to flow back into the flask (A). After the steam had swept out all the gases in the condenser over into the collection receiver (I) the three way stop cock (G) was turned to the second position, or so that the receiver (I) was cut off, and the Flask (A) placed in communication with the outside air, after which the boiling was discontinued. The operation up to this point results in separating the emanation accumulated in the solution in the flask (A) and storing it in the receiver III.

The introduction into the electroscope of

In order to avoid [^]thorium emanation and its disintegration products, the gas was stored in the receiver (I) for at least twenty minutes before it was introduced into the electroscope.

In order to transfer the emanation, now stored in the receiver (I) into the electroscope, ^{the latter} it was partially exhausted by means of water suction. The exasuted electroscope was now connected to the U-tube (N) by means of a piece

(42)

of heavy rubber tubing. As an extra precaution to avoid any sulphuric acid being carried over into the electroscope a plug of cotton was placed in the side tube at (Q). The brass stop cock of the electroscope was opened, then the stop cock (P) of the U-tube very slowly so that about five bubbles per second passed through the sulphuric acid. When the level of the water in the receiver (I) reached the lower edge of the side tube (M), the screw clip (L) was closed and the three way stop cock (G) turned to the third position or so that the whole apparatus was connected with the outside air. After the connecting tubes had been swept free of the emanation by means of the current of air, and the pressure in the electroscope had risen to nearly that of the atmosphere the stop cock of the electroscope was closed and the U-tube disconnected. The pressure in the interior of the electroscope was equalized with that of the atmosphere by opening the stop cock for an instant when it was closed.

Schlundt and Moore Apparatus. The second form of apparatus was essentially that described by Schlundt and Moore (1). It consisted of a gas burette (H) (Fig. 3) provided with a stop cock (I) and a leveling bulb (J). The storage flask (A) described above (2) was attached to the branch tube (K). This is the apparatus essentially as described (3), but the introduction of the emanation without trapping some of it in the connecting tubes was rather difficult. The apparatus was therefore modified with a view of obviating this difficulty. A T-tube (MN) was sealed on just above the stop cock (I). A stop cock (Q) was sealed to the end (M) of the T-tube, and to the other end (N) a glass stoppered U-tube, containing concentrated sulphuric acid and a plug of glass wool was

(1) Schlundt and Moore., Jour. Phys. Chem., 9, 320, 1905.

(2) Ibid. p. 31.

(3) Schlundt and Moore., Loc. cit.

(44)

Fig. 3. Schlundt and Moore
Apparatus.

(45)

was attached by means of a short piece of rubber tubing. The branch tube of the U-tube carried a plug of cotton at (P).

The manipulation of this apparatus was comparatively simple but required close attention. After connecting the storage flask (A) to the side tube (K) of the burette, the burette and leveling bulb were filled with distilled water to the bottom of the stop cock (I). The leveling bulb (J) was now lowered so as to bring the contents under a slightly reduced pressure. In this way any small leak which might occur would be inward and no loss of emanation would occur. The screw clip (E) was then opened and the solution in the flask (A) boiled from twenty to thirty minutes. At intervals during the boiling the flame was withdrawn and the water from the burette allowed to fill the flask. In this way the greater part of the water through which the emanation had bubbled was boiled. This operation minimized the loss of emanation by absorption in the water in the burette (H).

(46)

The separated gases were allowed to stand in the burette for at least twenty minutes before being introduced into the electroscopes. The *transfer* of gas with this form of apparatus was a very simple matter. The stop cock (Q) was closed and the U-tube connected to the partially exhausted electroscope. The stop cock of the *partially exhausted* electroscope was then opened, and then those of the U-tube (S) and (T) were opened very slowly, and the pressure inside the drying train allowed to become equal to that in the electroscope. The stop cock (I) was then opened and the gas allowed to pass into the electroscope at the rate of about five bubbles per second. When the level of the water in the burette reached the level of the branch of the T-tube the stop cock (I) was closed and the stop cock (Q) slowly opened so that a slow current of air would sweep any gas in the connecting tubes over into the electroscope. When the pressure in the interior of the apparatus had nearly reached that of the atmosphere the stop cock of the elec-

troscope was closed, the apparatus disconnected, and the pressure equalized by opening the stopcock for an instant.

Schlundt and Moore Apparatus for Water Samples. This form of apparatus used by Schlundt and Moore for the separation of radium emanation from large volumes of solution (1) such as water samples is shown in figure four. The apparatus consisted of a large Liebig condenser (H) about sixty centimeters in length. It was fitted with a one holed rubber stopper through which a glass tube about fifteen centimeters in length extended about ten centimeters into the inner tube of the condenser. The lower end of the tube was connected with the usual storage flask (A). To the inner tube of the condenser a side tube (J) was fused, which connected with the tubulated leveling bottle (K) by means of a piece of rubber tubing

(1) Schlunt and Moore., Jour. Phys. Chem.,
9, 320, 1905.

(48)

Fig. 4. Schlundt and
Moore Apparatus for Water
Samples.

(49)

about one meter in length. A short piece of rubber tubing about two centimeters long was slipped over the tapering end of the condenser (H), over which a separating funnel (L) of one hundred and fifty cubic centimeters capacity was placed. The stem of the separating funnel was cut off about five centimeters above the stop cock (M). The operation of separating the emanation was carried out as follows:-

The stop cock (M) was opened and the whole apparatus filled with distilled water. Enough water was placed in the leveling bottle (K) to cover the opening to a depth of about two centimeters. The stop cock (M) was now closed and the leveling bottle (K) lowered so as to put the contents under a slightly reduced pressure. The screw clip (E) was then opened and the contents of the flask (A) heated to boiling. The evolved gases collected in the bulb (L). the boiling was continued for at least twenty minutes, and until the funnel and condenser tube were

completely filled with gas and steam. On account of the small volume of the flask (A) it was unnecessary to run water through the jacket of the condenser.

For transferring the gases to the electroscope a small drying train similar to that described on the apparatus of Schlundt and Moore (1) was used. This same form of drying train was used on three forms of apparatus, the Schlundt and Moore apparatus for water samples here described, ~~and~~ the Boltwood apparatus, and the McCoy apparatus both of which will be described later. In use it entirely avoids any trapping of gas in the drying train, and makes the operation of transferring the gas to the electroscopes a very simple matter.

It consisted of a U-tube (A) (Fig. 5) containing a little concentrated sulphuric acid, and with one limb plugged with glass wool. In the side tube (B) a plug of cotton was placed. To the other limb a T-tube (C) was sealed. The

(1) Ibid. p. 43.

Fig. 5. Drying Train.

(52)

open end of the straight portion of the T-tube was closed by means of the stop cock (D). The branch of the T-tube ^{was} ~~is~~ attached to the burette by means of a short piece of rubber tubing.

In use the side tube (B) was attached to the exhausted vessel (in this investigation the electrosopes) and the pressure reduced to that of the vessel by opening the stop cock of the vessel and then the glass stop cocks (E) and (F). The stop cock of the burette was now opened and the gas allowed to flow into the vessel at the rate of five bubbles per second. The sulphuric acid in the U-tube served two purposes, first to dry the gas, and second to give the rate of flow and so avoid extreme disturbance of the leaf system of the electrosopes. When the level of the water reached the top of the branch of the T-tube the stop cock of the burette was closed , and the stop cock (D) opened so that a slow current of air would sweep any emanation in the drying train over into the electroscope. The apparatus was disconnected exactly as was the

Schlundt and Moore apparatus described above.

The Boltwood Apparatus. The Boltwood apparatus used was essentially that described by Boltwood (1) for the collection of the radium emanation occluded in minerals. The samples to be boiled off in this form of apparatus were stored in the second form of storage flask(2). A five hundred cubic centimeter flask (G) half filled with distilled water was connected by means of a glass tube to the longer tube of the storage flask (A) (Fig. 6). This tube had a branch at (H), to which was attached a short piece of rubber tubing closed by the screw clip (I). The flask (J) which had a capacity of fifteen hundred cubic centimeters was filled at the beginning of an experiment with a dilute (one per cent)

(1) Boltwood, B. B. *Am. Jour. Sci.*, 18, 380, 1904; *Nature* 70, 80, 1904; *Phil. Mag.*, 9, 599, 1905.

(2) *Ibid.* p. 33.

Fig. 6. The Beltwood Apparatus.

boiling solution of sodium hydroxide. The burette (K) consisted of a piece of wide glass tubing, drawn out at the upper end and closed with a piece of rubber tubing and screw clip (L). The lower end of the burette was closed by means of a two holed rubber stopper. The tube (M) was bent so as to connect with the flask (J). A rubber joint and screw clip (R) permitted of detaching the burette from the flask (J) for convenience in carrying the burette containing the separated water gases. The tube (N) extended nearly to the top of the burette and connected with the bulbs (P) by means of the rubber tube and screw clip (Q). The bulbs (P) were connected to the short tube of the storage flask (A). The operation of collecting the gases was as follows:-

The sodium hydroxide solution in the flask (J) was heated to boiling. By closing the screw clip (S) the boiling solution of sodium hydroxide would be forced over into the burette (K). When the burette was filled the screw clip

(56)

(L) was closed and the screw clip (S) opened. The water in the flask (G) was boiled vigorously, and when the steam was issuing freely from the side tube (H) the screw clip (I) was closed and the screw clip (E) was opened at once. The screw clips (Q) and (R) were open. The solution in the flask (A) was kept boiling until all evolution of permanent gases ceased, which usually required about twenty minutes, after which the screw clip (Q) was closed and the screw clip (I) quickly opened to avoid the cork in the flask (G) blowing out.

The introduction of the gases was not found so simple as in the apparatus of Schlundt and Moore described above. The screw clips (Q) and (R) were closed, and the burette detached from the remainder of the apparatus. The drying train previously described was connected to the upper end of the burette (K). A glass tube the end of which dipped below the surface of some water in a beaker was attached to the tube (N). A similar tube

(57)

and beaker ^{were} ~~was~~ attached to the tube (M). The drying train was connected to the electro-scope and the pressure in the tubes reduced as explained (1). The stop cock (L) was then opened, then the screw clip (Q) very slowly until all the gas in the tube (N) was replaced ^{by} ~~with~~ water. The screw clip (Q) was then closed and the screw clip (R) opened slowly. From this point on the method was exactly as described in the former case.

The McCoy Apparatus. The McCoy apparatus was the simplest studied (2). The flask (H) of about fifteen hundred cubic centimeters capacity (Fig. 7) was fitted with a two holed rubber stopper. A glass tube (J) lead from the bottom of the flask to the beaker (L). A piece of glass tubing about six centimeters long was provided with a peice of rubber tubing and a screw

(1) Ibid. p. 52.

(2) McCoy and Ross, Jour. Am. Chem. Soc.,
29, 1700, 1907.

Fig. 7. The McCoy Apparatus.

clip (K) and inserted in the other hole of the stopper so that the lower end of the tube was ~~just~~ flush with the bottom of the stopper. A U shaped glass tube connected the storage flask (A) with the short tube. The manipulation was very simple. The flask (H) was filled with boiling dilute (one per cent) solution of sodium hydroxide, and the beaker one third filled with distilled water. The screw clips (K) and (E) were opened and the contents of the flask (A) boiled for at least twenty minutes. When most of the sodium hydroxide solution in the flask (H) had been displaced the screw clip (K) was closed and the flask (A) quickly disconnected. After standing twenty minutes, the drying train for transferring the gas to the electroscope was connected and the gas transferred as described above.

Another form of apparatus for separating radium emanation from its aqueous solutions should be mentioned. It was designed and used by Seddy and Mackenzie for the

accurate estimation of small quantities of radium emanation contained in minerals. The emanation was removed from the solution of the mineral to be tested by boiling in vacuo. The gases were passed through phosphorous pentoxide and collected over mercury. The gases were then expelled into an electroscope.

(1). This method is probably the most accurate for separating the emanation, but the necessary apparatus was not available for these experiments.

Besides studying the separation of radium emanation from aqueous solutions, some experiments were conducted to determine ^{directly} the quantity of radium occluded in the standard uraninite. The apparatus differed only slightly from the Schlundt and Moore apparatus described above.

(2). The Schlundt and Moore form of burette was used. The sample of finely powdered uraninite

(1) Seddy and Mackenzie, Phil. Mag., 14, 272, 1907.

(2) Ibid . p. 43.

Fig. 8. Apparatus for Separating Radium
Emanation Occluded in Soluble Minerals.

(62)

about 0.1 gram was weighed out into the fifty cubic centimeter flask (F) (Fig. 8.) The flask (F) was provided with a dropping funnel (E) and delivery tube (B). It was then connected with the side tube of the burette exactly as was the storage flask (A) (Fig. 3). The burette was filled with dilute one per cent solution of sodium hydroxide and the stop cock (I) of the burette closed. The dropping funnel (D) Fig. 8) was filled with diluted (1:1) nitric acid. The leveling reservoir of the gas burette was lowered below the level of the acid in the funnel (D). Then by opening the stop cock (C) about fifteen cubic centimeters of the diluted acid were introduced. The stop cock (C) was then closed and the flask heated gently until all the uranium in the uraninite had dissolved and the residue was white: If any gas collected in the stem of the funnel during this operation it was displaced by water introduced through the funnel. By withdrawing the flame sufficient water was allowed to flow from the burette into

the flask to continue the boiling for at least twenty minutes, or until all evolution of permanent gases had ceased. After storing twenty minutes the gas was transferred to the electrosopes as described above. This apparatus has been used by Beltwood, and by Schlundt and Moore in standardizing thier electrosopes(1).

The Electrosopes.

Since the object of this investigation was partially to ascertain if results expressed in terms of the Boltwood emanation standard could be converted into C. G. S. electrostatic units for different electrosopes, ^{by some simple relation} several of the standard ^{of instruments} forms, used by different investigators were constructed and used. The different instruments employed will now be described.

Electroscope Number 2. This elect-

(1) Beltwood, B. B., Loc. Cit.

Schlundt and Moore, Loc. Cit.

roscope was essentially the Boltwood modification of the C. R. T. Wilson electroscope.(1) It consisted of a rectangular brass frame 15 x 10 x 5 centimeters.(Fig. 9). Small strips of brass (s) 3 x 3 millimeters were soldered on the inside of the frame, about four millimeters from the edges. Two pieces of plate glass six millimeters thick were mounted in the recesses thus formed on the front and back of the frame.

The method of mounting these glass plates so as to make air tight joints is of particular importance. Boltwood (2) used hot sealing wax, and marine glue and piecein (3) have been used in this laboratory to some extent, but all of them up to this time have presented some difficulty in securing

(1) Boltwood, B. B., Loc. Cit.

(2) Boltwood, B. B., Loc. Cit.

(3) Walter, B., Ann. d. Physik., 18, 860, 1905.

(65)

Fig. 9. Electroscope No. 2.

Fig. 10. Electroscope No. 8.

(66)

Fig. 11. Detail of Leaf Systems.

(67)

perfectly air tight joints. In connection with the construction of the electroscopes a method for mounting the glass ^{plates} was worked out, which yeilded satisfactory results. The surface of the metal and of the glass was first thoroughly cleaned. The picein was warmed just enough to make it soft and easy to work into shape with a knife or spatula. The wax was now pressed tightly into the grove on the edges of the frame and finally struck off even with the edges of the grove with a knife. Care should be exercised to get the plate glass cut so as to fit the frame closely, or the picein will not be able to hold a vacuum in warm rooms, or in hot weather. Both the glasses were now placed on the bed of picein and the whole firmly pressed together. The frame with the glasses in position was placed front down on top of a steam oven , or over a radiator, and weighted to press the plates home. The frame was left on the radiator until the wax had softened thoroughly, and the plates had sunk

(68)

as closely together as possible. The frame was now transferred to a table front down, and the weights replaced. The whole was allowed to stand in this position for three or four hours. In this way the wax fills all the space between the glass and frame with a thin film of wax which adheres very firmly. After this method of mounting was followed no trouble was experienced with leaks around the glass plates, or with the pulling out of the wax.

The frame was provided with two good brass stop cocks as shown. These were found to be perfectly tight when they were lubricated with a stiff rubber lubricator such as is used for vacuum desiccators. After the stop cock was opened or closed the conical plug was pushed inwards.

The frame contained an opening about 2.5 centimeters in diameter near the middle of the top. This opening had a shoulder (S) which served to support the glass tube (T) about

2.5 centimeters in diameter and about eight centimeters long. The glass tubing was surmounted by a threaded brass ring, (R) into which the removeable brass cap screwed.

The glass tube was joined to the frame and ring (R) by means of picein wax. The wax was first placed on the shoulder and then the heated glass tube pressed down until the wax had become hard and solid. One of the objectionable features of this form of electroscope was this glass tube and cap. It has a slight tendency to change its position, due to the softening of the wax when placed in a warm room or near a radiator.

A small peice of glass tubing four millimeters in diameter passed through a hole in the brass cap (C). The tube was secured in place by means of wax. A brass rod was cemented inside the small glass tube by means of sulphur.

The lower end of the brass rod was imbedded in a rod of sulphur (I) five millimeters in diameter and six centimeters long, which served as the insulator for the leaf

(70)

system. At the lower end of the sulphur rod was mounted the brass plate to which the aluminum leaf was fastened. A thin piece of brass (B) (Fig. 11) was soldered to the upper end of the brass plate, in order to give a straight line of attachment for the leaf. The leaf of aluminium about ten millimeters wide and sixty millimeters wide was fastened to the piece of brass (B) by means of a little turpentine which had been exposed to the air.

A special feature of the Boltwood electroscope is the method of charging it. A small piece of soft iron wire (W) (Fig. 9) was suspended from a hook on the brass rod (M) which projects out through the cap. The wire extended just below the sulphur insulation and terminated in a loop. In its normal position the wire did not touch the blade, but it could be deflected by means of a magnet so as to make contact with the leaf system, for charging by bringing the strong magnet near it, or the contact could be made by tipping the

(71)

electroscope slightly. This device permitted the electroscope to be charged without opening it.

All the brass joints of the electroscope were soldered except the joint between the brass ring (R) and the removable cap and this was closed by means of a rubber washer. The case of the electroscope was tested and found air tight. The volume was five hundred and ninety cubic centimeters.

The frame was securely mounted on a heavy wooden base as shown in figure 10 by means of four bolts. This base also supported the cradle for the reading microscope by means of which the position of the leaf was ascertained.

The reading microscope consisted of a Ross one and one half inch objective , and a two inch eyepiece mounted in an ordinary draw tube. The eyepiece contained a scale which was divided into one hundred divisions. Since only two reading microscopes were available for four electroscopes a smaller cradle (Fig. 12)

(72)

Fig. 12. Cradle for Reading Microscope.

(73)

was designed, and constructed from brass by the university mechanician. The cradle was fastened to the wooden base of the electroscope by means of two screws. The method of mounting the microscope in the cradle is shown in figures 10 and 14. By using this device the reading microscope could be removed and replaced in the same position.

Electroscope Number 4. Electroscope number 4 was of a design which has not, to my knowlege been described in the literature. It was constructed by Prof. Herman Schlundt and consisted of a rectangular brass frame with plate glass front and back (Fig. 14) similar to the Beltwood form. The frame was provided with two large brass stop cocks made by A. Pfeiffer, Wetalar. Instead of a shoulder for holding a glass tube, the frame was provided with a threaded brass ring(R). The leaf system consisted of a brass plate, with the aluminium leaf mounted as in figure 11, attached to a copper rod. The upper end was fastened into

(74)

Fig. 13. Electroscope No. 5.

Fig. 14. Electroscope No. 4.

(75)

a hollow brass cylinder, threaded so as to fit the brass ring (R) by means of sulphur which served as the insulator. A small brass cap for the protection of the insulation was fitted over the projecting end of the brass rod of the leaf system. The electroscope was charged by touching ^{the projecting rod of} the leaf system, the case being earthed. This electroscope had a volume calculated from the internal dimensions of the case of 955 cubic centimeters, by actual measurement of 952 cubic centimeters.

The electroscope was provided with a reading microscope, a Bausch and Lomb combination of a thirty two millimeter objective and two inch eyepiece mounted in a draw tube. The microscope was mounted in a collar soldered to a circular rod, held in position by means of a set screw. This form of mounting did not possess the rigidity shown by the cradle mounting, with which the other instruments were provided. Moreover, in case the microscope was disturbed, the instrument had to be restandardized.

(76)

This electroscope was first called number 4a when the glass front cracked. After the replacement of the front the electroscope was called number 4b, then the position of the reading microscope was altered ^{by another party} somewhat, space for keeping the electroscope under lock and key not being available. A new leaf was also mounted at this time and the instrument called number 4c. After each of these changed the scale of the reading microscope was recalibrated.

Electroscope Number 5. Electroscope number 5 was constructed after the design of Schmidt(1). It consisted of a cylindrical brass vessel fitted with two stop cocks. The top of the vessel could be removed, and the bottom carried a threaded brass ring through which the electrode of the leaf system projected, and by means of which it could be attached to the frame of the electroscope with a rubber washer. The leaf system consisted of a brass plate, carrying the aluminium leaf mounted as before, attached to a brass rod. The rod of the leaf system passed through a sulphur plug in the

(1) Schmidt, H. V., Physik. Z. 6, 551, 1905.

(77)

top of the frame, and carried on its upper end a central electrode one centimeter in diameter and fifteen centimeters in length. The frame was fastened to a wooden base (Fig. 13) which carried the cradle for the reading microscope, which was the same as was used on electroscope number 2. In order to obtain greater sensitiveness the microscope was mounted so as to read the edge of the lower part of the leaf, which was approximately the same size as that of electroscope number two. While this was the position of the reading microscope when the electroscope was used in the regular experiments, it was found necessary when the electrostatic capacity was to be determined, to mount the cradle temporarily so that the microscope would read the edge of the upper part of the leaf. Considerable difficulty was experienced in getting the ionization chamber air tight due to defective stop cocks, so that the values for current given in the tables below may be somewhat low. This instrument showed the "crawl effect" to be described later to a marked degree. The leaf was also disturbed by

air currents and outside electrical disturbances which made the measurements with this instrument ^{in my hands} more or less unsatisfactory. The data obtained are added for completeness and for their qualitative value only.

Electroscope Number 8. This instrument of the same general design as number 4 but with a smaller ionization chamber, was the most reliable electroscope used. The same frame as was used for electroscope number two was used. The glass tube and leaf system were removed and replaced by a simplified leaf system similar to that of number four. The leaf was supported by a very narrow strip about one millimeter wide. With these exceptions the instrument was exactly the same as electroscope number two.

Determination of the Electrostatic Capacity of the Electroscopes.

The Standard Capacity. For determining the capacity of the electroscopes a calibrated ^{air} Harms condensers was used. The condenser as assembled is shown in Figure 15. The parts are

(79)

Fig. 15. Harms Air Condenser.

Fig. 16. Parts of the Condenser.

(80)

shown in figure 16. The Harmes condenser (1) consists of an inner cylinder (I) supported upon an amber block (A). The inner cylinder is surrounded by an outer cylinder (O) insulated by vulcanite and connected to the binding post (P). The inner cylinder is provided with an electrode (E). The whole is enclosed in a metal case (C) which is kept grounded in order to avoid outside electrical disturbances.

Source of Potential. As a source of potential, storage cells and dry batteries were used. The storage batteries were mounted in the case shown in figure (17). The set consisted of ninety nine cells connected in series so as to furnish approximately two hundred volts. Two four candle power lamps were placed in series

(1) Harmes, F., Physik. Z., 5, 47, 1904.

Instrument No. 2240 furnished by Günther and Tegetmeyer of Braunschweig. Capacity charged by induction 42.5 centimeters.

(81)

Fig. 17. Storage Batteries.

Fig. 18. Dry Batteries.

(82)

to avoid ^{ing}accidental short circuit of the storage cells.

It was found necessary to carry out these experiments with potentials over two hundred volts so dry cells were added. One hundred flash light batteries (1) were connected in series and mounted as shown in figure 18. Fifty sets were placed in each box and insulated by means of a glass plate in the bottom and glass rods between the rows. These dry batteries furnished an additional potential of about four hundred volts, so that in all about six hundred volts were available.

Determination of the Potential of the Battery and Calibration of the Scales of the Electroscopes. For determining the potential of the charging batteries a voltmeter with a scale reading from zero to three hundred

(1) Columbia Flash Light Batteries
No. OV3, made by National Carbon Co., Cleveland,
Ohio.

(83)

volts (1) was used. This voltmeter was compared with a the standard Weston voltmeter of the Engineering Department, and found correct to 0.2 volt for potentials between zero and one hundred and fifty volts.

Two difficulties presented themselves. First the potentials used were greater than could be registered on the voltmeter, and second the resistance of the batteries was great enough, that the current used by the voltmeter caused an appreciable drop of the potential.

In order to overcome the first difficulty the battery was divided into three sections, the storage batteries (SB), and dry battery sets (DB 1) and (DB 2). The electromotive force of each section was ^{then} determined separately.

(1) Voltmeter No. 74504. American Instrument Co., Type 4., scales 0-3, 0-15, and 0-300. Resistance of voltmeter 0-300 scale was about 30000 ohms.

Since the determination of the electromotive force of the batteries also involved the calibration of the scales of the electroscopes these two operations will be described as one.

The electroscopes were leveled by means of a small circular level placed on the case. (Fig. 13). The negative pole of the storage batteries (SB) was placed in contact with the leaf system of the electroscope. In the case of electroscopes numbers four and eight the contact was made with the projecting rod of the leaf system. In the case of electroscopes numbers two and five the glass back of the frame was temporarily replaced by a glass plate having a small hole seven millimeters in diameter opposite the blade of the leaf system. The positive pole of the storage batteries was connected to the negative of (DB 1), and the positive of (DB1) to the negative of (DB 2). The case of the electroscope was earthed, and to the earth connection was attached a traveling electrode, which could be attached to any of the

several points where the dry batteries were soldered together.

The next step was to find the approximate value of one scale division in volts. The negative terminal of the voltmeter was attached to the negative terminal of (DB 2) and the positive terminal to the traveling electrode. The traveling electrode was now attached to the several points of the battery in succession. The voltmeter reading and the position of the edge of the leaf on the scale were noted for each point. From these data the approximate value of one scale division in volts was calculated.

The position of the leaf with the voltmeter in and out of circuitⁱ was now noted for the several points. From the difference of the scale readings with the voltmeter in and out of circuitⁱ the drop of potential due to the current taken by the voltmeter was calculated, and then added to the voltage observed when the voltmeter was in circuitⁱ for that point. This

gave the electromotive of that portion of (DB 2) which was used.

The negative terminal of the voltmeter was now transferred to the negative terminal of (DB 1) and the positive terminal to the positive terminal of (DB 1), and the difference on scale reading with the voltmeter in and out of circuit determined. The value of one scale division had already been found so the ^{potential} drop was calculated and added to the observed voltmeter reading.

The electromotive force of the storage batteries was determined in the same way. The method of calculation will appear clear from the data given in table I, which is a specimen set of data.

(87)

Table I. Data for Calibration of the
Scale of Electroscope Number 2.

TABLE 1. 1960-1961 Season. For Name of St.											
V.	S_1					S_2				E_1	E_2
1	2	3	4	5	6	7	8	9	10	11	
a 170		84.0			93.0	9.0	9.3	179.3	365.8	375.1	
b 154	16	68.5	15.5	1.03	77.0	8.5	8.8	162.8	349.8	358.6	
c 142	28	57.5	26.5	1.05	64.5	7.0	7.2	149.2	337.8	358.6	
d 126	44	41.5	42.5	1.03	48.0	5.5	5.7	131.7	321.8	327.5	
e 114	56	29.0	55.0	1.02	35.0	6.0	6.2	120.2	309.8	316.0	
f 101	69	18.5	66.5	1.04	23.0	4.5	4.6	105.6	296.8	301.4	
g 87	83	4.0	80.0	1.04	7.0	3.0	3.1	90.1	282.8	285.9	
f 103	69	19.0	67.0	1.03	23.0	4.0	4.1	107.1	298.8	302.9	
d 124	56	40.0	56.0	1.00	45.0	5.0	5.2	129.2	319.8	325.0	
c 144	28	59.5	26.5	1.05	65.0	5.5	5.7	149.7	339.8	345.5	
b 164	16	78.0	16.0	1.00	83.0	5.0	5.2	169.2	359.8	365.0	
a 172		86.0			92.5	6.5	6.7	178.7	367.8	374.5	
SB 185		82.0			92.5	10.5	10.8	195.8			

(DB 2) was not used. The points a, b, etc., were taken from (DB 1).

Column (1) of the table gives the voltage as read off ^{from} the voltmeter. Column (2) gives the increment in V , ^{taken from point a,} column 1. Column 3 gives the scale reading S_1 corresponding to V . Column (4) gives the increment of S_1 , ^{referred to initial value of S_1 .} Column (5) gives the value of one scale division as calculated from columns (2) and (4). Column (6) gives the scale reading with the voltmeter out of circuit corresponding to S_1 . Column (7) gives the difference $S_2 - S_1$. Column (8) gives this difference reduced to volts by multiplying by the mean of Column (5). Column (9) gives the electromotive force of the section of the battery measured by the voltmeter. Column (10) gives the total electromotive force corresponding to S_1 . Column (11) gives the electromotive force corresponding to S_2 . ^(page 90) In the curve, E_1 is plotted against S_1 , and E_2 against S_2 . ^{It is seen that} All the points fall on the same straight line.

Later in the investigation one of the electroscopes was used as an electrostatic

voltmeter for determining the electromotive force of the battery. The results of the calibrations of the electroscopes are shown on **curve sheets** ^{pages 90-96} (1) to (7) which are self explanatory. The dry batteries were found to give satisfactory results for this work if care was used not to leave the voltmeter in circuit for more than two minute *intervals*.

Schmidt (1) has pointed out that the potential registered by an electroscope was not proportional to the scale divisions. This conclusion has been verified in the case of electroscope number four. With three different aluminium leaves it gave calibration curves which were not straight lines, see curve sheets 2), (3), and (4). It will be noted that the calibration curves obtained with electroscopes numbers two, five and eight were straight line **curves**, or that the potential, between the limits

(1) Schmidt, H. W., Physik. Z., 7, 157, 1905.

Potential. Volts.

of calibration were proportional to the scale reading. See curve sheets (1), (5), (6), and (7). The specific factors which affect the form of the calibration curve obtained from different electroscopes have not been ascertained, however it appears that the form of curve obtained will depend upon the form, size, and shape of the individual electroscopes as well as upon the properties of the leaf itself.

The Electrostatic Capacity of the Electroscopes. For finding the electrostatic capacity of the electroscopes the method of Harms (1) was used. The joint capacity of the leaf system and the condenser was first determined as described by Harms:-

The case of the electroscope was earthed, and the negative pole of the battery, arranged as before, placed in contact with the leaf system as described for calibrating the scale. The movable electrode was attached to the battery

(1) Harms, F. *Boc. Cit.*

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so that the leaf would be near the upper end of the scale. The position of the leaf (S_1), was read on the scale and the voltage of the battery (V_1) determined by reference to the curve sheet for the particular electroscope. The outer protecting case of the condenser and the leaf system of the electroscope were then earthed. The outer cylinder of the condenser was then charged by means of the battery whose electromotive force had just been determined as above. The inner cylinder of the condenser was earthed. After at least two minutes the earth connections with the leaf system of the electroscope, and with the inner cylinder of the condenser were broken. The connection between the battery and the outer cylinder of the condenser was then broken, and the outer cylinder earthed. In this way the condenser was charged by induction.

The electrode of the inner cylinder was now touched to the leaf system of the electroscope.

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scope, and the position of the leaf (S_2) noted. The potential (V_2) was determined by reference to the curve.

The joint capacity,

$$K = \frac{C V_1}{V_2} \quad (1)$$

in which (C) is the capacity of the condenser or 42.5 centimeters, and (K) the joint capacity.

The next step was the determination of the electrostatic capacity of the electroscope, which was carried out as follows:-

The inner cylinder of the condenser was placed in contact with the leaf system of the electroscope; the outer cylinder and case of the condenser, and the case of the electroscope were earthed. The condenser was now charged so that the leaf came on the upper part of the scale of the reading microscope. The position of the leaf

(1) K is naturally not the sum of the capacity of the condenser and electroscope, as was pointed out by Harnaps.

(100)

(S_{11}) was noted. The contact with the leaf system was broken and the condenser removed several feet from the electroscope. The position of the leaf (S_{12}) was noted and the leaf earthed for at least two minutes. The electrode of the inner cylinder was again brought in contact with the leaf system and the reading (S_{13}) noted: The potentials (V_{11}), (V_{12}), and (V_{13}) corresponding to the scale readings (S_{11}), (S_{12}) and (S_{13}) were obtained by reference to the curve for the particular instrument used. The capacity of *the electroscope,*

$$C = \frac{K(V_{11} - V_{13})}{V_{12}}.$$

An example:-

The condenser was charged by induction to a potential of 593 volts. This charge, divided between the leaf system of electroscope number four, gave a reading on the scale of 0.0 or 416 volts. From these data the joint capacity (K) is 60.6 centimeters.

The condenser and leaf system were charged to a potential (S_{11}) ~~on the scale~~ ^{reading} of 95.0. On removing the condenser (S_{12}) was 91.0., The leaf

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was earthed for two minutes, insulated, and the charge on the condenser divided. The reading (S_{13}) was 33.2. The voltages (V_{11}), (V_{12}), and (V_{13}) were 588.4, 583, and 485.3 respectively. From these data the capacity of electroscope number four without cap was 10.7 centimeters.

Some of the determinations in number four electroscope were made with the cap in place. The reading (S_{21}) was made with the electroscope charged without cap. The cap was now fitted in place and the reading (S_{22}) taken. A determination gave (S_{21}) as 97.0 and (S_{22}) as 82.7. (V_{21}) and (V_{22}) were 593 and 571 volts. The capacity of the electroscope with cap C_1 is given by the equation,

$$C_1 V_{22} = C V_{21}.$$

from which (C_1) is 11.1 centimeters.

The results of the determination of the electrostatic capacity are shown in the table II. The mean of several determinations ^{is} are given in each case.

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Table II.

Capacity and Joint Capacity of the
Electroscopes.

No. of Elect.	Joint Cap. K. cm.	Capacity C. cm.	Capacity with Cap. C ₁ cms.
2	48.9	3.01	
4	60.6	10.7	11.1
5	74.6	14.8	
8	53.4	6.13	

A "Crawl" Effect. During the early part of the investigation it was observed that the leaf, after being charged, and the battery left in contact, slowly increases its apparent potential. It was at first thought that this effect might be due to a change in the potential of the dry batteries used. The voltmeter was then connected across the terminals of the dry batteries and although the voltage remained constant the effect was still observed on charging the ~~leaf~~ ^{leaf} ~~needle~~. Later it was found that if the leaf was

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discharged and then the condenser, with the inner cylinder charged, was brought in contact with the leaf, that the same effect was still observed. The amount of increase was in some cases as much as twenty-five volts. The effect was most marked in electroscope number five, but was also observed in numbers two, eight, and four. The potential finally, after from two minutes to three hours, rose to a definite maximum for each point of the charging battery. If the electroscope was kept charged for a long time and then only partly discharged the maximum value of the potential was reached very much quicker.

This "crawl effect" made the determination of the capacity of the electroscopes very troublesome and uncertain in those electroscopes in ~~which~~ which it was observed to the greatest extent, *namely* numbers two and five. The electrostatic capacities of numbers four and eight were very much easier to determine, both on account of the lesser "crawl effect" and on account of the fact that the leaves could not be disturbed by air currents.

It was thought that the effect observed might be due to induced charges on the surface of the glass plates forming the front and back of the electrosopes. A copper gauze was fitted inside the plates and grounded, but the effect was still observed. No further experiments to determine the cause of the effect were carried out. The effect is probably due to some inherent property of the sulphur insulation used, or to some factor which has not been discovered.

The only reference which could be found in the literature which suggested the existence of such an effect as was observed was one by Dike(1). He mentioned that in calibrating his apparatus for measuring atmospheric electricity (Gerdien electroscope insulated by means of amber) that he waited one minute during the charge of the leaf for all the charges on the insulation to become neutralized, but he made

(1) Dike, P. H., Science, 29, 475, 1909;
Am. Jour. Sci., March 1909.

nonspecific mention of an upward "crawl" of the leaf after charging. I had also observed, before the above paper had appeared, that in order to obtain concordant results in the determination of the electrostatic capacity of the electroscopes, it was necessary to leave the leaf system earthed for at least two minutes, when it was discharged.

This anomalous behavior of these electrosopes may have some bearing on the observation recorded by Schlundt and Moore⁽¹⁾ in one of their papers. They state that at the maximum activity of a sample of radium emanation, three hours after its introduction into the electroscope, that the activity of the sample apparently increased during the first five minutes after the leaf was first charged, and that if the electroscope was allowed to stand discharged one hour and the observations repeated the same results

(1) Schlundt and Moore, Trans. Electrochemical Soc., 8, 292, 1905.

would be obtained. This result was tentatively explained by Schlundt and Moore as probably due to the concentration of an additional quantity of one of the products of rapid decay of the emanation upon the charged leaf system, thus causing slightly more ionization in the immediate vicinity of the leaf. This increase in activity was also observed in my experiments, but it may be explained in a somewhat different manner. The above mentioned anomalous upward "crawl" of the leaf during the first few minutes after charging, would tend to counteract the fall of the leaf due to the ionization current. Since it was observed that the leaf reached its maximum in a shorter time, if the electroscope had been charged for a time, the effect of the "crawl" would become less noticeable after two or three readings had been taken, and the time to pass a given number of divisions would become shorter.

Stewart has pointed out (1) that when

(1) Stewart, O. M., Phys. Rev., 21, 229, 1905.

quadrant electrometers were used for measuring current, that the needle must be allowed to swing at least twenty five seconds before readings of the velocity of the needle could be taken. This precaution was taken so that the needle could reach a uniform velocity. In like manner it would appear from these experiments that on account of the crawl effects, the leaf of the electroscope must be charged to a sufficiently high potential to give from one half to three minutes before the leaf comes upon the scale of the microscope. When this precaution was taken very concordant readings were obtained.

Another anomaly in the behavior of the electroscopes was observed to a slight extent with all the instruments, but more especially with numbers five and eight. It was noticed that the air leak in these electroscopes, which was rather high, apparently decreased after the leaf had been charged for some time. Several series of determinations were then taken of the air leak over periods of about seven hours. The results of several such series were always

similar in thier general tendency, ~~but~~ no relation could be deduced as regards the magnitude of the change in the natural air leak.

One of the series of observations ~~is~~ shown on curve sheets eight and nine. Curve s sheet eight shows the time to fall one scale division of the reading microscope plotted against the scale division at which the measurment was taken. Curve sheet nine shows the time to fall one division plotted against the time ~~after~~ after the beginning of the series. The electroscope had not been ~~used for three days~~ previous to the measurments here given, and was free from radium emanation.

It will be observed that the air leak grows less as the time the electroscope has been charged increases, and that if the electroscope is left discharged for a short time, the same phenomenon is observed in a less degree. It was thought that these results might be due to dust, but sweeping the electroscope out with dust free air did not have any effect.

The effect of this disturbance was just opposite to that of the anomaly described before. In this case the uncertainty of the air leak was overcome during the regular experiments by keeping the leaf charged by means of the battery during the interval between the introduction of the emanation and the final measurement. The concordant readings of time to fall the usual number of divisions, which were usually obtained after some five or ten minutes were taken as the measure of the activity. On account of the lack of time this air leak effect was not further studied. The anomaly still needs further investigation however.

Determination of the Relation between
the Boltwood Emanation Standard and the C. G. S.
Electrostatic Standard.

After the introduction of the radium emanation which had been boiled off from the standard samples of uraninite in the various forms of apparatus, into the electroscopes the ionization was allowed to reach a maximum

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which required three hours. After this time, the time for the leaf to fall a given number of divisions in the eyepiece, usually from one hundred to fifty in the case of electroscope number four, and from one hundred to twenty in the other instruments was noted with a stop watch. From the calibration curve the scale readings were reduced to potential readings, from which the number of volts fall per second was calculated. From this result was subtracted the number of volts fall of potential per second due to the normal air leak, determined in each case just before the introduction of the emanation into the electroscope.

The current was then computed from the following equations:-

$$i = \frac{C d}{300} \quad \text{C. G. S. E. S. U.}$$

or

$$i = \frac{C d_1}{9 \times 10^{11}} \text{ amperes.} \quad (1)$$

where (C) is the capacity of the electroscope

(1) Rutherford, E., Radioactivity. p. 100 .

(113)

in electrostatic units, and (d) the number of volts fall of potential per second, due to the ionization produced by the radium emanation and its products in equilibrium .

The current produced by the radium emanation in equilibrium with one gram of uranium or 3.8×10^{-7} gram of radium (1) was found by the equation:-

$$I = \frac{i}{\text{wt. of U.}}$$

where (I) is the equilibrium current for the radium emanation from one gram of uranium in a mineral.

The results thus calculated are given in table III columns (5) and (6), Column (1) gives the number of the sample, column (2) the apparatus in which the emanation was boiled off, column (3) the number of the electroscope used, and column the grams of uranium in the sample. The results of all the determinations are given .

(1) Rutherford and Boltwood. Am. Jour. Sci., 22, 1, 1906.

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It will be noted that some of the experiments are starred (#) , and these, for various reasons, are not considered as reliable as the others, as the conditions under which the experiments were carried out were not ideal (1).

(1) The separation of the radium emanation from the solutions was carried out in the qualitative laboratory, and the electroscopic determinations made in an upstairs balance room. At times there was a considerable difference in temperature in the two rooms, and also at times a large change during the interval between the transfer of the gas to the electroscope in the measurement. Both rooms were open to students, and the locker space for keeping the electroscopes and other apparatus under lock was not available.

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Table III.

Results of Electrosopic Determinations.

1 No. of Sample	2 Appfor Sep. Emanation	3 No. of Elect.	4 Grams U.	5 I Amps. 10^{-10}	6 I C.G.S. E.S.U. E.S.U.
1 A	S. & M.	4	0.01	4.10	1.23
2 A	S. & M.	4	0.01	4.34	1.30
3 A	S. & M.	2	0.01	2.36	0.71
5 B	Strutt	4	0.01	3.08	0.92
6 A	Strutt	5	0.025	4.45	1.34
7 A	Strutt	5	0.025	4.37	1.31
8 A	S. & M.	4	0.025	4.41	1.32
10 A	Strutt	4	0.035	2.98#	0.89#
11 A	Strutt	2	0.035	2.11	0.63
12 A	S. & M.	4	0.035	4.72	1.42
13 A	S. & M.	4	0.05	4.80	1.44
15 A	Strutt	4	0.05	3.93	1.18
16 A	S & M Water	4			
18 A	S. & M.	8	0.1	3.01	0.90
19 A	S. & M.	8	0.15	3.08	0.92
23 C	S. & M.	2	0.01	1.71#	0.51#
25 C	Strutt	4	0.01	3.04	0.91

Table III cont.

1	2	3	4	5	6
27 C	S. & M.	4	0.01	1.97#	0.59#
28 C	Strutt	8	0.01	2.09	0.63
30 CC	Strutt	8	0.025	2.08	0.62
31 C	Strutt	8	0.025	2.55	0.77
33 C	Strutt	8	0.025	2.33	0.70
34 C	S. & M.	5	0.025	3.90	1.17
35 C	S. & M.	5	0.025	3.81	1.14
36 C	S. & M.	8	0.025	2.68	0.80
37 C	S. & M.	8	0.05	2.92	0.88
38CC	Strutt	4	0.05	3.17	0.95
39 C	S & M Water	8	0.05	1.57	0.47
40 C	Strutt	5	0.05	2.04#	0.61#
41 C	S. & M.	5	0.1	4.26	1.28
42 C	Strutt	8	0.1	2.51	0.75
43 C	S. & M.	5	0.1	3.06	0.92
44 C	S. & M.	4	0.01	3.18#	0.94#
45 C	Strutt	8	0.025	2.28	0.68
46aC	S & M Water	5	0.025	3.40	1.02
46bC	S. & M.	4	0.025	2.49#	0.75#

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Table III cont.

1	2	3	4	5	6
56D	Beltwood	4	000563	4.10	1.23
58D	Beltwood	4	0.0632	3.68#	1.10#
75E	S. & M. Water	8	0.0565	2.48	0.72
77E	S. & M.	5	0.112	4.82	1.45
74E	McCoy	8	0.0632	2.54	0.76
Determinations on emanation occluded by uraninite					
1S ^u (1)	S. & M.	4	0.0265	4.23	1.27
2S"	S. & M.	4	0.0265	3.85	1.16
3S"	S. & M.	4	0.0265	4.44	1.33
4S"	S. & M.	4	0.0265	4.59	1.38

Discussion of Results in Table III.

The results obtained with electroscope number eight are considered the most reliable. The ionization currents obtained with this electroscope for emanation boiled off in the Strutt and the Schlundt and Moore apparatus are plotted against the weight of uranium in the

(1) I am indebted to Prof. Herman Schlundt for these determinations Nos 1S" to 4S".

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sample in the curves on curve sheet ten. Two samples boiled off in the Sehlundt and Moore apparatus for water samples were measured in this electroscope. The first sample number (39C) was boiled but the steam was not allowed to completely displace the water in the bulb. The water in the collecting bulb and side tube thus did not reach the boiling point. It will be noted that a very low current was obtained in this case. Sample number (75E) was boiled until the water had been completely displaced from the bulb. The current in this case is much higher, and lies almost on the curve for the Strutt apparatus. One sample number (74E) was boiled off in the McCoy apparatus, and measured in this electroscope. The current in this case was lower than that obtained by the use of the Sehlundt and Moore apparatus, but higher than that obtained with the Strutt apparatus. This single result must not however be regarded as characterizing the McCoy apparatus. More experiments are necessary to establish this point.

Current per Gram Uranium. Amperes $\times 10^{-10}$

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Only two reliable determinations were obtained with electroscope number two before it was converted into electroscope number eight. One of these determinations was obtained using the Strutt form of apparatus for separating the emanation, and the other using the Schlundt and Moore form. The tendency of the results with this electroscope are in the same direction as those obtained with electroscope number two.

Electroscope number four had a mounting of the reading microscope which gave considerable trouble. The results obtained using the Strutt and the Schlundt and Moore forms of apparatus for separating the emanation are very similar to those obtained for electroscope number eight and are shown in curve sheet eleven. The Boltwood apparatus was used for some of the samples measured in this electroscope. The points obtained fall between the two curves above mentioned.

Electroscope number five had poor stop-cocks, so the results obtained with this instrument are not entitled to as much weight as those obtained with the other electroscopes.

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The results however show the same general tendency. The curves on the whole

The curves on the whole show that the ionization observed in the electroscope is not proportional to the quantity of emanation in the sample. Since, if the potential used was not sufficient to give the saturation ionization current, there would be more recombination of the ions at higher concentrations of the radium emanation than at low concentrations, the ionization current at higher concentrations would then be relatively lower, which is contradictory to the observed facts in this case. The discrepancy may be explained however by assuming that there was relatively more absorption of the radium emanation by the water through which the gas bubbled in the separating apparatus, in the case of the samples of smaller concentration. The fact that at the same concentration different quantities of the emanation are separated by the various forms of separating

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apparatus also seems to indicate that absorption of the emanation may be the cause of the discrepancy.

Again in these forms of electroscopes it is possible that the ionization is not directly proportional to the quantity of emanation introduced, but no data are available upon which to make comparisons.

The determinations (15) to (45) were carried out by collecting the emanation occluded in samples of the uraninite in the Schlundt and Moore form of burette. (1) The value of the ionization current per gram of uranium is somewhat less than the equilibrium amount obtained by storing the solution forty days. ^{separately} The ^{at} smaller value is probably due to the constant loss of emanation by the powdered mineral at ordinary temperatures. It will also be noted that the results are not as concordant as those obtained by storing the solution of the mineral and then separating the emanation.

Some interesting relations between the ionization current and the volume of the elect-

roscopes appear from the data given in table IV. The value of the average ionization current per gram of uranium at the concentration of 0.05 gram of uranium separated in the Schlundt and Moore apparatus, divided by the volume of the electroscopes is shown in column (4) of the table.

Table IV.

Ratio of Current to Volume.

1. No. of Elect.	2. I _{amps.} x 10 ⁻¹⁰	3. Vol. of Elect. c.c.	4. Ratio
2	2.36	590	0.00390
4	4.80	952	0.00504
5	4.80	2840	0.00169
8	2692	555	0.00518

It will be noted that for small electroscopes of the same design, numbers four and eight, that the ionization is nearly proportional to the volume. Electroscopes numbers two, five and eight are not of the same design, and it will be noted that no proportionality between the ionization current observed and the volume in

these instruments. On the basis of the results here obtained it would appear that there is no constant relation between the Boltwood radium emanation standard and the C. G. S. electrostatic standard. It also appears that the results expressed in C. G. S. electrostatic units of current obtained with one of the forms of electroscopes cannot be compared with the results obtained in another electroscope without reference to some other standard.

C. Summary of Results.

The most important results obtained may be briefly stated as follows:-

1. The theoretical relation between the Boltwood emanation standard and the C. G. S. electrostatic standard has been calculated.
2. It has been experimentally shown that in general no constant proportionality exists between the Boltwood emanation standard and the C. G. S. electrostatic standard as ordinarily used.
3. But for small electroscopes of the

same design the ionization current observed is nearly proportional to the volume .

4. The various forms of apparatus used for separating the radium emanation from solution have been studied and the approximate efficiency of each form determined.

5. By calibrating the electroscope and the apparatus for separating the emanation for different concentrations of radium emanation fairly accurate results may be obtained with the Boltwood standard. The Schlundt and Moore form of apparatus for separating the emanation gave the most concordant results in my hands.

6. All the forms of apparatus for separating the emanation have been successfully improved so as to avoid all loss of emanation in the transfer of the gas from the collecting bulb to the electroscope.

7. Two new forms of apparatus for storing solutions of radium salts have been devised.

8. A new form of electroscope has been described and its merits proven.

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9. A satisfactory method of mounting the plate glass front and back of several types of electroscopes has been worked out.

10. A new form of mounting the reading microscope of electroscopes has been designed.

11. It has been shown that in the case of some electroscopes the potential is proportional to the scale divisions, over the range of the reading microscope. Also that in other cases that this proportionality does not hold.

12. Small flash light batteries have been used and found satisfactory for calibrating and charging electroscopes.

13. A peculiar "crawl" effect has been observed with electroscopes having sulphur insulation, and the effect of this on the rate of fall of the leaf has been pointed out.

14. An anomaly in the air leak has been observed in the electroscopes used, the rate of leak decreasing with the time interval of charge of the leaf.

From these results it is evident that the method in use for determining the radioactivity of gases, waters, rocks, and other common materials by means of electroscopes should receive more careful and extended study , in a laboratory set aside for this particular purpose.

This investigation was undertaken at the suggestion of Prof. Herman Schlundt, Professor of Physical Chemistry at the University of Missouri whom I wish to thank for the many suggestions given during the course of the study.

This thesis is never to leave this room.
Neither is it to be checked out over-
night.