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RADIOACTIVE PROPERTIES OF THE SUBTERRANEAN WATERS
OF ELLIS COUNTY, KANSAS

being

A thesis presented to the Graduate Faculty of
the Fort Hays Kansas State College in partial ful-
fillment of the requirements for the degree of
Master of Science

by

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Fort Hays Kansas State College

May 17, 1937.
Date

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Prof. of Physics

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Acting Chairman Gr. Council

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ACKNOWLEDGMENTS

My grateful acknowledgments are due to President C. E. Rarick of the Fort Hays Kansas State College, who made this project possible; they are also due Professor Roy Rankin and Dr. J. W. Chappell for furnishing various chemical apparatus and radioactive samples; and Dr. L. D. Wooster for the photograph of the apparatus. I am especially indebted to Dr. H. A. Zinszer and Dr. R. H. Zinszer for suggesting this problem and for their valuable criticisms.

INTRODUCTION

Soon after the discovery of Becquerel rays in 1896, tests were made on ordinary matter to see if all matter were radioactive. Although there is evidence to show that all matter is radioactive, to a degree and under certain conditions, it has been found that the greater part of the observable effect is due to traces of radioactive material permeating all matter in general. Thus, radium and its products being the most active of radioactive substances, the surface of the earth is covered with traces of these radioactive substances but the amount varies from place to place. Moreover, determinations of radioactivity have been made in **relatively** few localities.

Besides the scientific interest pertaining to radium and its products, there is another, the therapeutical interest. It has been found that the noted European and American springs and baths show an unusual amount of radioactivity. Hence, the theory has been advanced that the curative properties of these springs are due to the radioactivity of the water¹.

Since little work has been carried out in this part of the country on the radioactive properties of subterranean waters, the following problem was thought worthy of consideration: To determine the radioactive properties of the subterranean waters of Ellis County, Kansas; to determine the relation between

1. Ramsey, R. R. Radioactivity of Spring Water. (In Proc. Indiana Acad. Science, p.453, 1914).

these properties and depth, if any; to determine the half-life period of the emanation; and, to determine the relation between the natural leak and the relative humidity, if any.

HISTORICAL DATA (RADIOACTIVE)

The discovery of radioactivity followed closely on that of X-rays in the following manner. The first research of Rontgen showed that X-rays are produced when cathode rays strike the glass walls of a discharge tube. In January, 1896, it occurred to Henri Becquerel¹ that the rays might be connected with the phosphorescence of the glass. He conceived the idea of finding out whether or not phosphorescent substances in general emitted penetrating rays of similar character, and being in possession of an extensive collection of such material, he tried the experiment at once. The procedure was to render a substance phosphorescent by exposure to strong light, and to lay it on top of a photographic plate wrapped in black paper. On the twenty-fourth of February, 1896, Becquerel announced to the French Academy that he had obtained positive results with a salt of uranium. In a few days, however, he recognized that the phenomenon had nothing to do with phosphorescence, since non-phosphorescent compounds of uranium also affected the plate. Shortly afterwards he found that uranium was the source of the penetrating rays which he had discovered, and coined the word radioactive to describe this property. The intensity of the rays from various salts of uranium were found to be proportional to their content

1. Blackwood, Oswald H., et al., An outline of Atomic Physics. p.205

of this element. Further investigations of the radioactivity of uranium resulted in the discovery of many new radioactive substances, some of which exhibit this property to such a degree that their presence was disclosed by their radioactivity, the quantity of these substances being too small to be detected by any other means¹.

The electroscope method² of detection was found to be extremely sensitive compared with that of the photographic plate, and searches for other radioactive elements were undertaken with its aid. In April, 1898, G. C. Schmidt and Madame Curie announced independently the radioactivity of thorium. Madame Curie then made a systematic investigation of all the mineral collection available to her, but only those minerals containing thorium or uranium showed activity. However, she noted the very significant fact that certain uranium minerals possess an activity several times higher than that of uranium metal, gram for gram. This suggested the presence of a new element more active than uranium. She and her husband, Pierre Curie, set out to isolate this element chemically. The procedure was straight forward, but laborious. It consisted in tracing the active substance, by the electrical method, through fractionations and precipitations. Finally, at the end of 1898, the Curies, together with G. Bemont, were able to announce the discovery of radium, a very active element belonging to the

1. Chadwick, J., Radioactivity and Radioactive Substances, p. 1.

2. Blackwood, Oswald H., et al., An outline of Atomic Physics, p. 206.

second column of the periodic table and having chemical properties like those of barium, and the other alkali earths.

Other notable discoveries are those of actinium by Debierne and Giesel; of radiothorium and mesothorium by Hahn; of ionium by Boltwood, followed closely by Hahn and Marchwald; and finally of protoactinium by Hahn and Meitner. Today we are acquainted with almost forty types of radioactive atoms having atomic weights equal to or greater than 206. These radioactive elements are listed under three series; uranium-radium, actinium, and thorium series. Tables I, II, and III give the series with their elements, their radiations, half-life period, and atomic weights¹. In addition, potassium and rubidium are very slightly radioactive, but concerning all other elements we can only say that, if they are naturally radioactive, the effects produced are very minute.

1. Fajans, Kasimer, Radioactivity and the Latest Developments in the Study of the Chemical Elements, p. 21-23.

TABLE I

Uranium-Radium Series

Name of Radio-element	Symbol	Half-life Period	Radiation	Atomic Weight
Uranium I	U_1	4.5×10^9 y	alpha	238.2
Uranium X_1	UX_1	24 d	beta gamma	234
Uranium Z	UZ	6.7 h	beta	---
Uranium X_2	UX_2	1.15 m	beta gamma	234
Uranium II	U_{II}	2×10^6 y	alpha	234
Uranium Y	UY	25 h	beta	---
Ionium	Io	10^5 y	alpha	230
Radium	Ra	1600 y	alpha beta	225.97
Radium-emanation	Rd Em	3.8 d	alpha	222
Radium A	RdA	3.0 m	alpha	218
Radium B	RdB	26.8 m	beta gamma	214
Radium C	RdC	19.5 m	(alpha) beta gamma	214
Radium C'	RdC'	10^{-6} s	alpha	214
Radium C''	RdC''	1.32 m	beta	210
Radium D	RdD	16 y	beta gamma	210
Radium E	RdE	5.0 d	beta gamma	210
Radium F (Polonium)	RdF	136 d	alpha	210
Radium G (Radium lead)	RdG	---	-----	208

y-years, d-days, h-hours, m-minutes, s-seconds.
(After Fajans)

TABLE II
Actinium Series

Name of Radio-element	Symbol	Half-Life Period	Radiation	Atomic Weight
Protactinium	Pa	1.2×10^4 y	alpha	230
Actinium	Ac	20 y	(beta)	226
Radioactinium	RdAc	10 d	alpha beta gamma	226
Actinium X	AcX	11.5 d	alpha	223
Actinium-emanation	AcEm	3.92 s	alpha	218
Actinium A	AcA	.002 s	alpha	214
Actinium B	AcB	36.1 m	beta gamma	210
Actinium C	AcC	2.15 m	alpha (beta)	210
Actinium C'	AcC'	.005 s	alpha	210
Actinium C''	AcC''	4.76 m	beta gamma	206
Actinium D (Actinium-lead)	AcD	----	-----	206

y-years, d-days, m-minutes, h-hours, s-seconds
(After Fajans)



TABLE III
Thorium Series

Name of Radio-element	Symbol	Half-Life Period	Radiation	Atomic Weight
Thorium	Th	1.5×10^{10} y	alpha	232.15
Mesothorium 1	MsTh ₁	6.7 y	(beta)	228
Mesothorium 2	MsTh ₂	6.2 h	beta gamma	228
Radiothorium	RdTh	1.9 y	alpha beta	228
Thorium X	ThX	3.64 d	alpha	224
Thorium-emanation	ThEm	54.5 s	alpha	220
Thorium A	ThA	.14 s	alpha	216
Thorium B	ThB	10.6 h	beta gamma	212
Thorium C	ThC	60.8 m	alpha beta	212
Thorium C'	ThC'	$(10^{-11}$ s)	alpha	212
Thorium C''	ThC''	3.2 m	beta gamma	208
Thorium D (Thorium-lead)	ThD	-----	-----	208

y-years, d-days, h-hours, m-minutes, s-seconds
(After Fajans)

The tables indicate that the parent element sends out a radiation and then changes to a different element. This element gives out another radiation and transforms to the next element. Some radioactive elements have very long half--life periods, while others have very short half--life periods. The elements with the short half-life period are very difficult to separate because they change into another element before they can be separated. This transformation of the elements explains why they are nearly always found together.

The radioactivity of water may be due to traces of radium salts dissolved in the water. It may be due to some other product of the uranium-radium series, to radium emanation, usually, or to some product of the thorium or actinium series, probably an emanation. The greater amount is usually due to radium or radium emanation dissolved in the water¹.

In the tables of the radioactive series, it will be noted that when one substance changes into another a radiation of alpha, beta or gamma rays, in some cases all three, are given off. These radiations ionize the air and render it conductive. The conductivity of the air becomes a measure of the radioactivity of the substance. This is proportional to the rate at which a

1. Ramsey R. R. Radioactivity of Spring Water. (In Proc. Indiana Acad. Science, p 454, 1914).

charged body loses its charge.

"The alpha rays consist of a stream of positively charged particles, each of which has a mass of four times that of the hydrogen atom and a positive charge of two electronic unites. It is in fact, an atom of helium stripped of its valence electrons. The beta rays are also corpuscular in nature, being negative electrons moving with high velocity. They are similar to the cathode particles in a discharge tube. The gamma rays are of secondary importance, being regarded as an accompaniment of the emission of alpha and beta particles. They are similar to X-rays. A Radioactive substance may be defined as one which emits spontaneously an alpha or beta radiation!"

A given sample of radioactive substance sends out a definite number of alpha, beta, or gamma rays. The number of ions which can be produced in a given volume of a gas at a fixed temperature and pressure is directly proportional to the number of rays present. If saturation voltages are applied across the gas, all ions produced will be drawn out, due to opposite attraction. Hence, the ionization current is directly related to the number of grams of radioactive substance present. For example, one gram of radium emits 3.45×10^{10} alpha particles per second, each of which produces roughly 1.74×10^5 ions, whose individual charges are 4.77×10^{-10} e. s. u. If all of these be drawn over to the plates of an ionization

1. Chadwick, J. J. Radioactivity and Radioactive Substances, p. 3.

chamber the resulting current will be 9.62×10^{-4} amperes. In an electroscope, whose case acts as one plate of an ionization chamber and its leaf as the other plate, ions will be drawn to the leaf, if negatively charged, neutralizing its charge and causing it to fall at a rate proportional to the amount of active substance causing the ionization. Thus the intensity of a radioactive substance can be measured¹.

The unit of radioactivity, called the curie, after Madame Curie, is based on the mass of an active substance. As defined by the Radiology Congress in Brussels⁸ in 1910, the curie is "The amount of emanation in equilibrium with one gram of pure radium." This occupies 0.61 cubic millimeters (at standard pressure and temperature), and has a mass of 6.04×10^{-6} grams. The International radium standard consists of 21.99 milligrams of specially purified radium chloride prepared by Madame Curie and preserved at the Bureau International des Poids et Mesures at Sevres near Paris, France. Another unit of radioactivity intensity sometimes used is called the Mache unit and is based on ionization currents. It is defined as one thousand times the saturation current due to one curie of emanation without disintegration products when all the radiation is absorbed in the air of the ionizing chamber¹. The Mache unit is equal to 3.64×10^{-10} curies.

1. Hoag, J. Barton, Electron Physics, p. 121

Proportionately, the alpha rays produce about 100% the beta rays about 1.%, and the gamma rays about .01% of the ionization². The gamma rays are so penetrating that the absorption of them in gases is very small and they will pass through several millimeters of lead. The beta rays will not pass through two millimeters of lead, but they pass through gases easily. The alpha rays will not pass through any solid to any extent and they are readily absorbed by gases.

From the above facts it is necessary to have three kinds of electroscopes,- one to measure the alpha rays, another to measure the beta rays and a third to measure the gamma rays. The only difference in the construction of the electroscopes lies in the filter through which the rays pass before entering the electroscope proper. In the gamma ray electroscope the rays pass through two millimeters of lead so that the alpha and beta rays are shut out. In the beta ray electroscope the alpha rays are shut out, but the gamma rays are not. In the alpha ray electroscopes, all the rays are present but about 99% of the rays are alpha rays. Thus, for very weak radioactive bodies the alpha rays are used to produce the ionization.

Radium emanation was discovered in 1900 by Dorn¹ and

1. Hoag J. Barton, "Electron Physics," p. 121.

2. Ramsey, R. R., Radioactivity of Spring Water,
(In Proc. of Indiana Acad. Science, p. 454, 1914).

it is known as radon or niton. It is a strongly radioactive gas always appearing in small amounts. Chemically the gas is inert like the rare gases. It possesses a characteristic spectrum, can be liquefied and boils under normal pressure at -65°C . Ramsey and Gray¹, using a special micro-balance, weighed a measured volume of the radium emanation and thus determined its density. They found its atomic weight to be 223. Actinium and thorium also have an emanation of atomic weight of about 218 and 220 respectively. These three emanations, probably isotopes, could be present in the emanation coming from the water tested in this problem.

From the tables of the radioactive series it is seen that the disintegrated product of radium is emanation, a gas, which gives off alpha particles and changes into Radium A. Radium A has a half-life period of three minutes and disintegrates, with the expulsion of an alpha particle into Radium B. Radium B has a half-life period of 26.8 minutes and it gives off beta and gamma radiations when changing into Radium C. Radium C has a half-life period of 19.5 minutes, gives off alpha, beta and gamma particles, and changes into Radium C₂ and Radium D. Radium D has a slow half-life period of 16.5 years. This is so slow that the ionization produced by this change can be neglected in comparison with the others. Thus, about three hours after the emanation has been placed in a vessel, we have Radium

1. Fajans, Kasimer, Radioactivity and the Latest Developments in the Study of the Chemical Elements, p.11.

Em. changing through the intermediate products into Radium D giving off three alpha particles, one from Radium Em.; one from Radium A; and one from Radium C. This complex radiation has after a few hours the half-life period of the longest of the series, which is that of Radium Em., 3.85 days. Thus, if a quantity of radium emanation gas is placed in an electroscope the rate of leak of the electroscope increases for the first three hours and then slowly decreases, dropping to one-half value of the maximum in 3.85 days from the time it reached the maximum. The curve taken from Ramsey, Fig. 1, shows how the activity increases for radium emanation and its products. In like manner the actinium and thorium emanation can be traced. Fig. 2 shows how the radium emanation decays to half-life value in a period of 3.81 days.

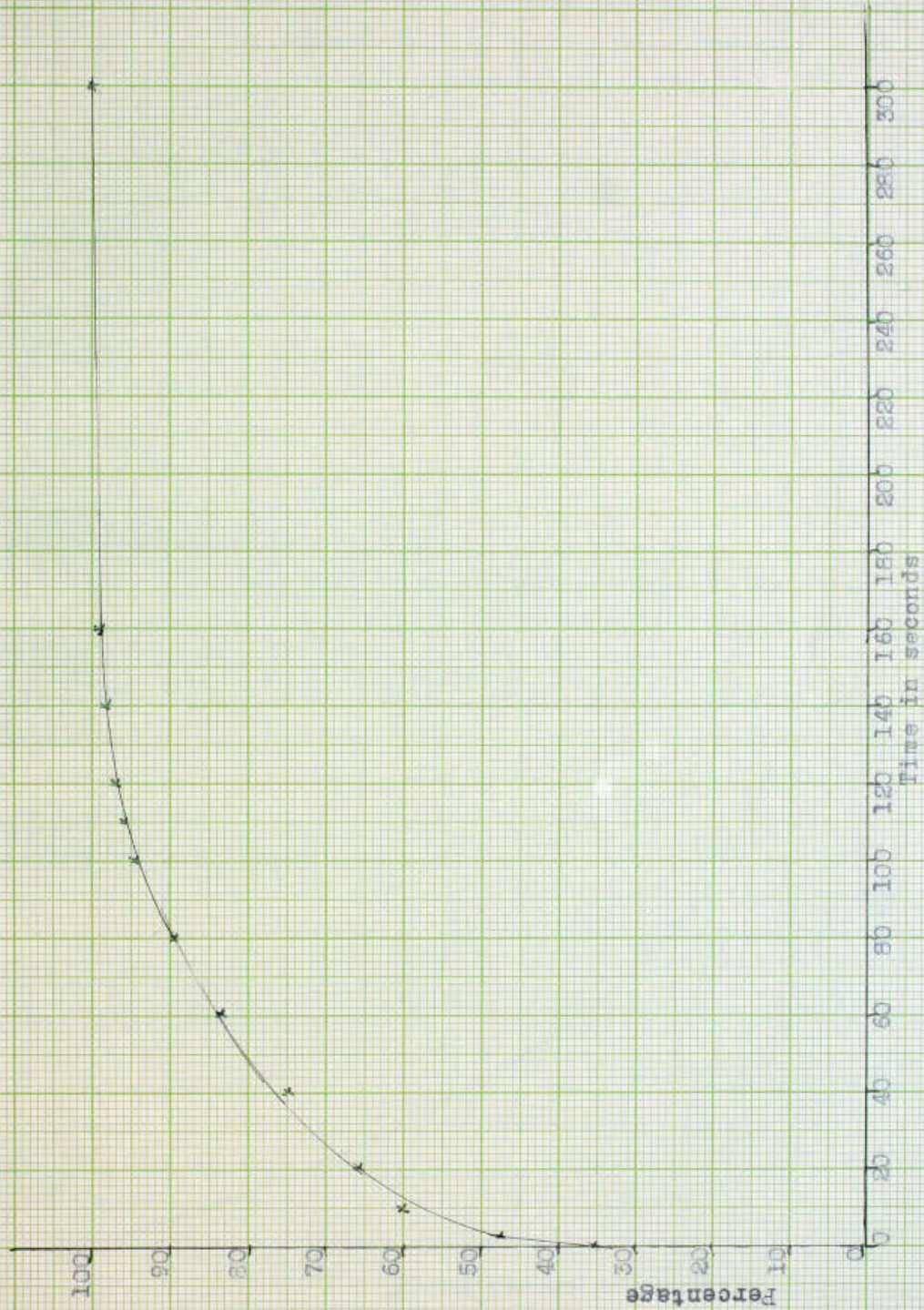


Fig. 1. Activity Curve for Radium-Tmenation.
(After Ramsey)

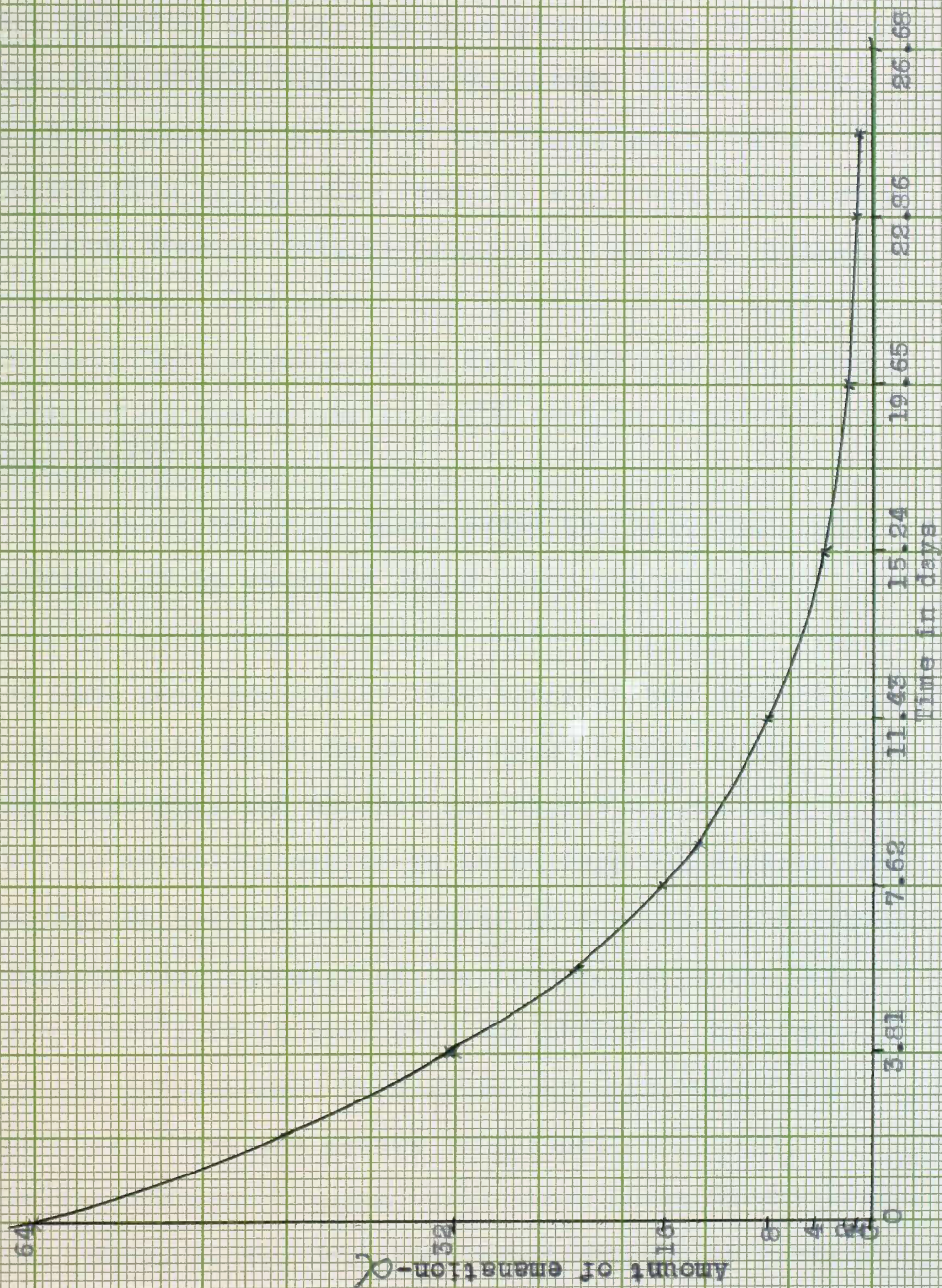


Fig. 2. Disintegration of Radium-Emanation.
(After Radiums)

There may be HISTORICAL DATA (GEOLOGICAL)

Ellis County is only a short distance west and north of the center of Kansas. It is approximately 30 miles square and contains about 576,000 acres. Ellis County lies at the eastern margin of the High Plains. Its characteristic topographic features are broad, relatively flat upland benches, deeply incised by the main drainage channels, which flow east. The altitude of the surface above sea level ranges between 2,400 feet near the southwest corner of the county to 1,700 feet in the northeastern part¹.

Most water wells in this county are less than 100 feet deep. If no water is found here, the wells are drilled to the Dakota sandstone where the water is very hard and is used only for stock. The water in the wells less than 100 feet in depth is not as hard as that found in the Dakota sandstone, and is used for domestic purposes. The Dakota sandstone varies in depth from the surface from a few feet in the southeast corner of the county to about 650 feet in the west edge of the county. From the logs given by Bass², it is seen that the layers of water are in certain formations. Then fresh (softer) waters are in the rocks above the Dakota sandstone.

1. Bass, N. W., Geologic Investigations in Western Kansas, p.1-50.

2. Ibid. p.38.

There may be several layers of water in the Dakota sandstone. The next in line is the Cimarron group, which is about 1000 feet from the surface. The next water is found in the Wabaunsee formation which lies about 2,700 feet under the surface. Below the Wabaunsee formation there are several layers of water and oil. Most of the oil is accompanied by water and they are pumped together from the ground.

There are three "pays" of oil in this county. The first pay is known as the Topeka pay, which is about 3100 feet below the surface. Very few wells find enough oil to "produce" from this pay, so they are drilled into the next pay, which is the Oswald. This pay is about 200 feet below the Topeka pay. About one-half the producing wells in this county are in this pay. The oil from this formation is accompanied by a small amount of water. Below the Oswald pay is the Siliceous. This is the last pay and is usually about 200 feet below the Oswald. The oil from the latter pay is accompanied by a great deal of water. The depth of the water and sandstones varies in different parts of the county. In some wells, some of these waters were absent and others present.

1. Lacey, H. B., Indisolvibility of spring water.

(In Trans. Indiana Acad. Science, p. 482-487, 1901.)

APPARATUS

The apparatus used in this work costs considerable if bought from the manufacturers. However, it is very simple and can be made in almost any laboratory from bits of scrap materials. The writer will describe one which was made in the laboratory at a very small cost, compared with those on the market. The apparatus used is similar to that used by Ramsey¹ in his work on the Radioactivity of Spring Water.

The electroscope proper was made up of two parts, the emanation chamber and the box containing the leaf, (Fig. 3). The emanation chamber, C, comprised a circular cylindrical, can seven centimeters in diameter and 13 centimeters long. Its lid must be fitted tightly. Two small brass stop-cocks were soldered into the sides of the can, so that the emanation could be pumped into the chamber. One stop-cock was near the bottom and the other near the top, so that the emanation will circulate within the can. The rectangular box containing the leaf was 10 x 10 x 15 centimeters. It was made of tin with the bottom soldered fast and with the lid fitting tightly. Two windows were cut in the box to enable one to see the leaf. These apertures were 8 x 8 centimeters and about two centimeters from the bottom. In the side of the box a hole was made so

1. Ramsey, R. R., Radioactivity of Spring Water,
(In Proc. Indiana Acad. Science, p. 453-470, 1914).

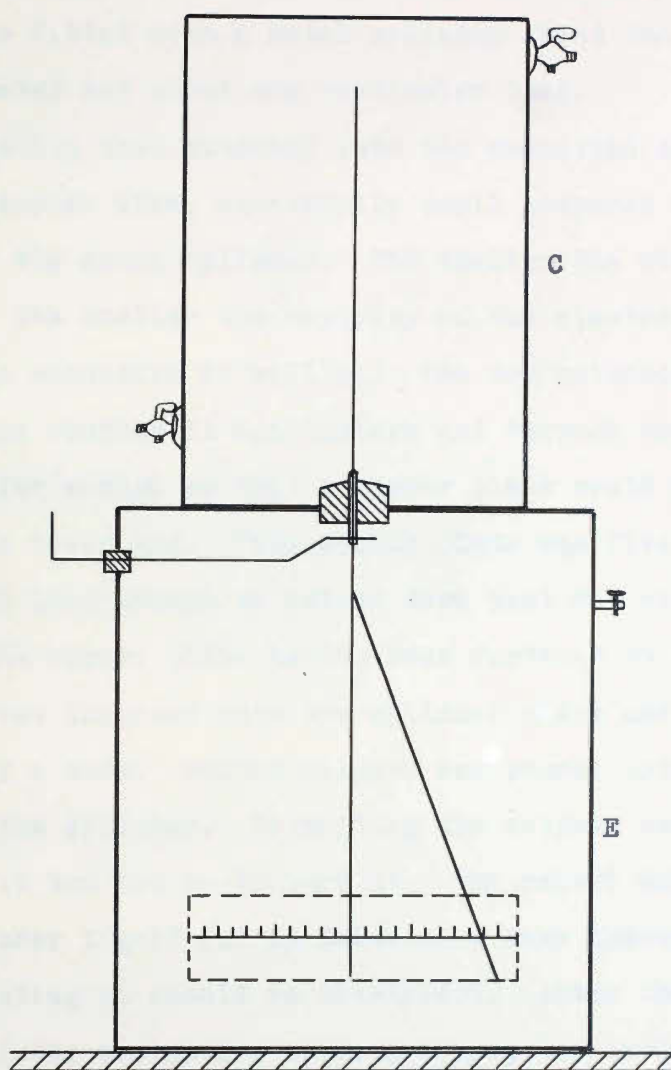


Fig. 3. Electroscope and Emanation Can.

that an insulated charging contact could be inserted. The top of the box and the lid of the emanation chamber were soldered together. A hole passing through the center of both was fitted with a metal cylinder about two centimeters in diameter and about one centimeter long.

The rod that extended into the emanation chamber was a thin copper wire, necessarily small compared with the size of the metal cylinder. The smaller the wire and leaf system, the smaller the capacity of the electroscope and the more sensitive it will be. The rod extended into the emanation chamber 11 centimeters and through the metal cylinder far enough so that a copper plate could be soldered onto the lower end. This copper plate was five millimeters wide and long enough to extend down past the windows in the box. The copper plate having been fastened to the rod, the latter was inserted into the cylinder above and held in place by a cork. Melted sulphur was poured into the other end of the cylinder. In melting the sulphur care was used not to get it too hot or to burn it. The melted sulphur was a clear amber liquid (if it takes on a waxy appearance due to over-heating it should be discarded). After the sulphur in the cylinder cooled for several hours, the cork was removed and the other end of the cylinder filled with melted sulphur. The sulphur served as an excellent insulator.

For the charging contact a small copper wire was used. It was bent so that it touched the insulated rod at one position and the case in another position. The contact wire was

insulated and fastened in the hole in the side of the box with melted sulphur. The sulphur insulators were kept free from dirt and moisture at all times. In case they became dirty they were cleaned by removing the dirty part with a knife. If the insulators collected moisture, they were renewed.

The front window consisted of a piece of ordinary glass of single thickness. Small tin clamps were soldered onto the box to hold the window in place. A contact plug was soldered on the side of the electroscope so that it could be connected to the ground. The back window was made of paper. A very fine scale was drawn on the paper and the latter was then placed in melted parafine before being stuck over the opening. The melted parafine served a two-fold purpose, first it made the paper transparent and second, it served as an adhesive for fastening the paper to the box.

The next step was to mount the leaf. Using Dutch foil, the leaf was made about one millimeter wide and four centimeters long. The foil was cut between sheets of grease-free paper with a pair of sharp scissors. The leaf was glued to the small copper plate at the end of the insulated rod. Gold foil is the best foil for leaves, but it is very difficult to cut and mount. Aluminium foil does not serve so well because it is rigid and does not swing freely, (but goes in jerks across the scale.) The electroscope was rebuilt several times before it proved satisfactory.

An ebony rod rubbed on wool was used to charge the electroscope.

The shaking can (Fig. 4) was a gallon can with two screw caps on the top. The can was fitted with two small stopcocks, one in the top of the can and the other about one-third the distance from the bottom. A thermometer was inserted through one of the screw caps in the top of the can. The lower stopcock was so placed that there was about twice the volume above it as below it. Rubber tubing was used to connect the emanation chamber to the shaking can. A small rubber bulb pump was connected in the tubing, so that the gas could be pumped from one can to the other.

The lamp was used to illuminate the scale was a small six-volt point-o-lite covered so that the light fell upon the scale. The source of illumination was kept constant and about 20 centimeters from the scale. The reading telescope was placed at the other end of the table, a distance of three meters from the electroscope. The other apparatus comprised thermometers, glass cylinder, psychrometer, ebony rod, piece of wool or fur, voltmeter, wires and a source of direct current varying from zero to 132 volts. Fig. 5 shows a sketch of the assembled apparatus, while Fig. 6 is a photograph of the entire set-up.

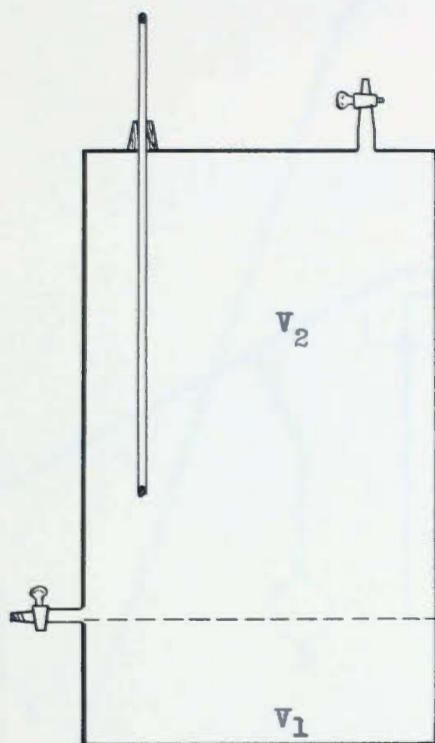


Fig. 4. Shaking Can.

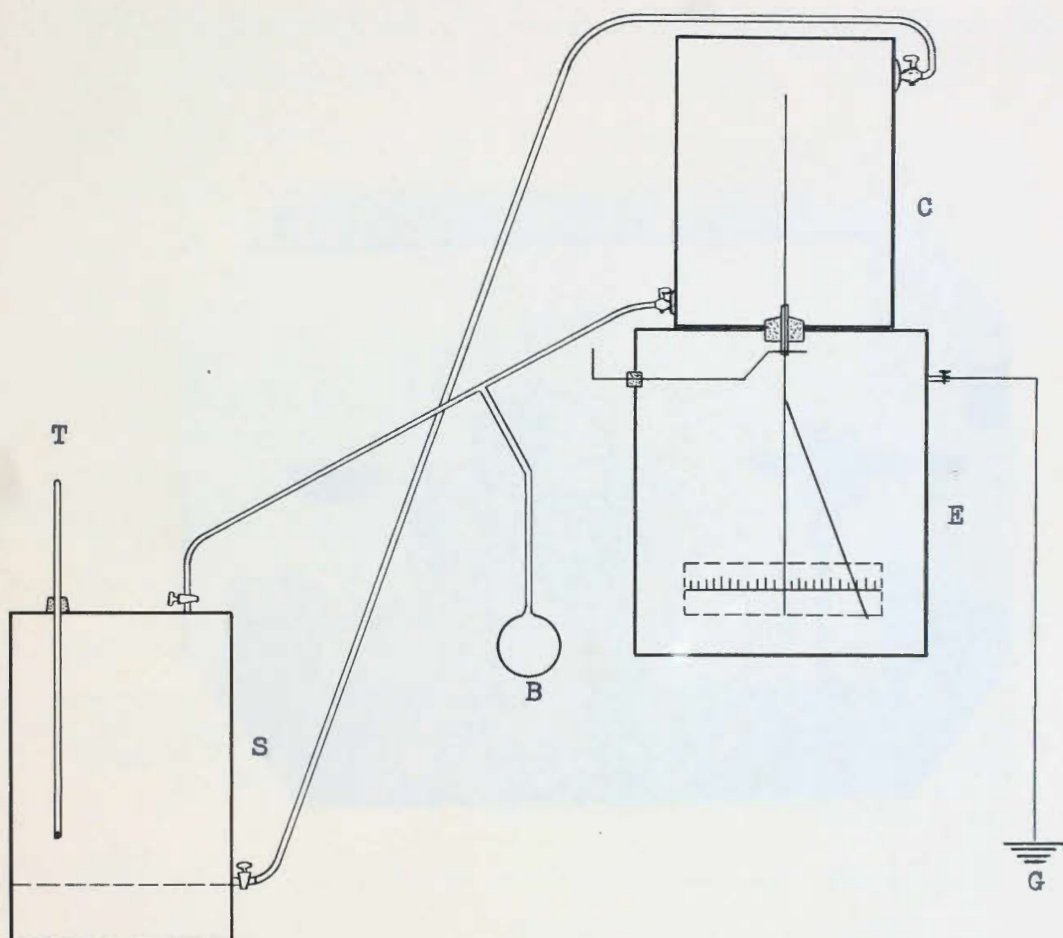


Fig. 5. Apparatus Assembled.

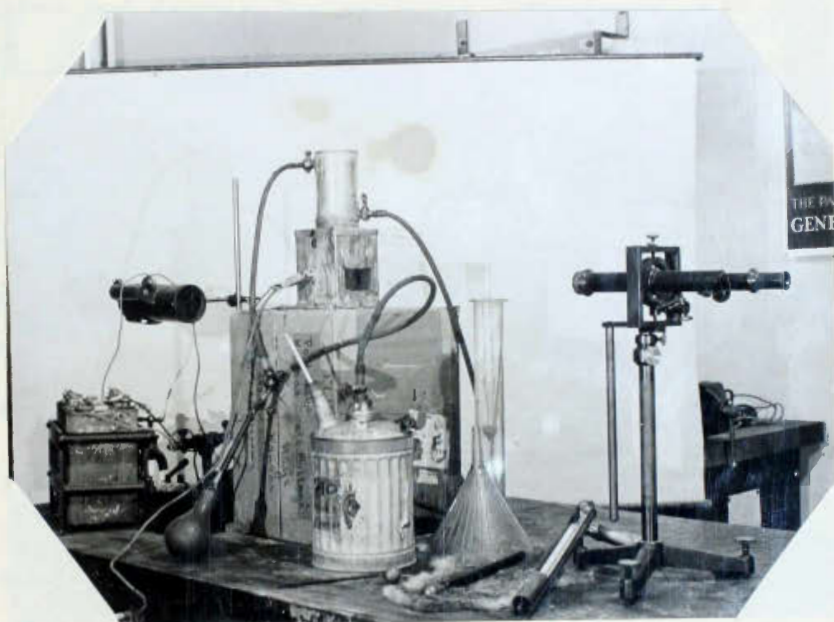


Fig. 6. Photograph of Entire Set-up.

CALIBRATION OF ELECTROSCOPE

The instrument was calibrated by connecting it to known d. c. potentials (Fig. 7) and noting the deflections of the leaf¹, the negative terminal being connected to the leaf. Readings of the leaf-deflection were taken every few volts from zero to 132 and fig. 8 plotted. Table IV gives the values for this curve. Readings were taken for increasing and decreasing voltages. The sets of deflections checked very closely. For higher deflections the following procedure was followed: the leaf was charged to maximum voltage by means of ebony rod rubbed on wool. A sphere of small capacity, small compared to the capacity of the electroscope, (1.26 cm. in this case) was mounted on an insulated handle. The sphere was grounded and then touched to the charged system. The sphere was removed, grounded and the position of the leaf noted. The leaf fell because part of the charge was taken off. This operation was repeated until the leaf fell to zero. If C is the capacity of the electroscope, and c is the capacity of the sphere; Q , the quantity of electricity on the electroscope; V_1, V_2 is the 1st., 2nd., ----potential of the leaf; d_1, d_2 is 1st., 2nd., -----deflection of leaf,

1. Ramsey, R. R., Radioactivity of Spring Water, (In Proc. Indiana Acad. Science, p. 463, 1914).

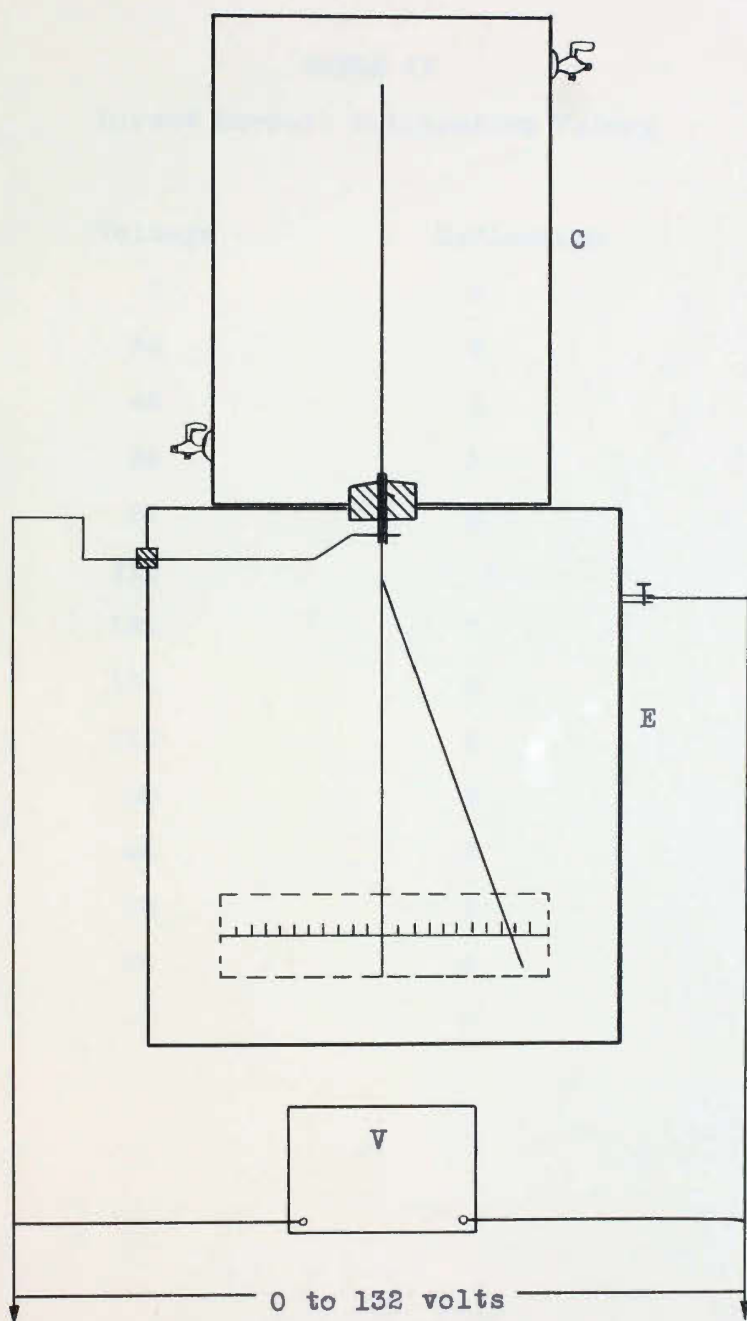


Fig. 7. Connection of Apparatus for Calibration of Leaf.

TABLE IV

Direct Current Calibration Values

Voltage	Deflection
0	0
25	0
45	1
66	2
87	3
110	4
132	5
131	5
110	4
88	3
66	2
50	1
25	0
0	0

Fig. 2. Direct current calibration curve.

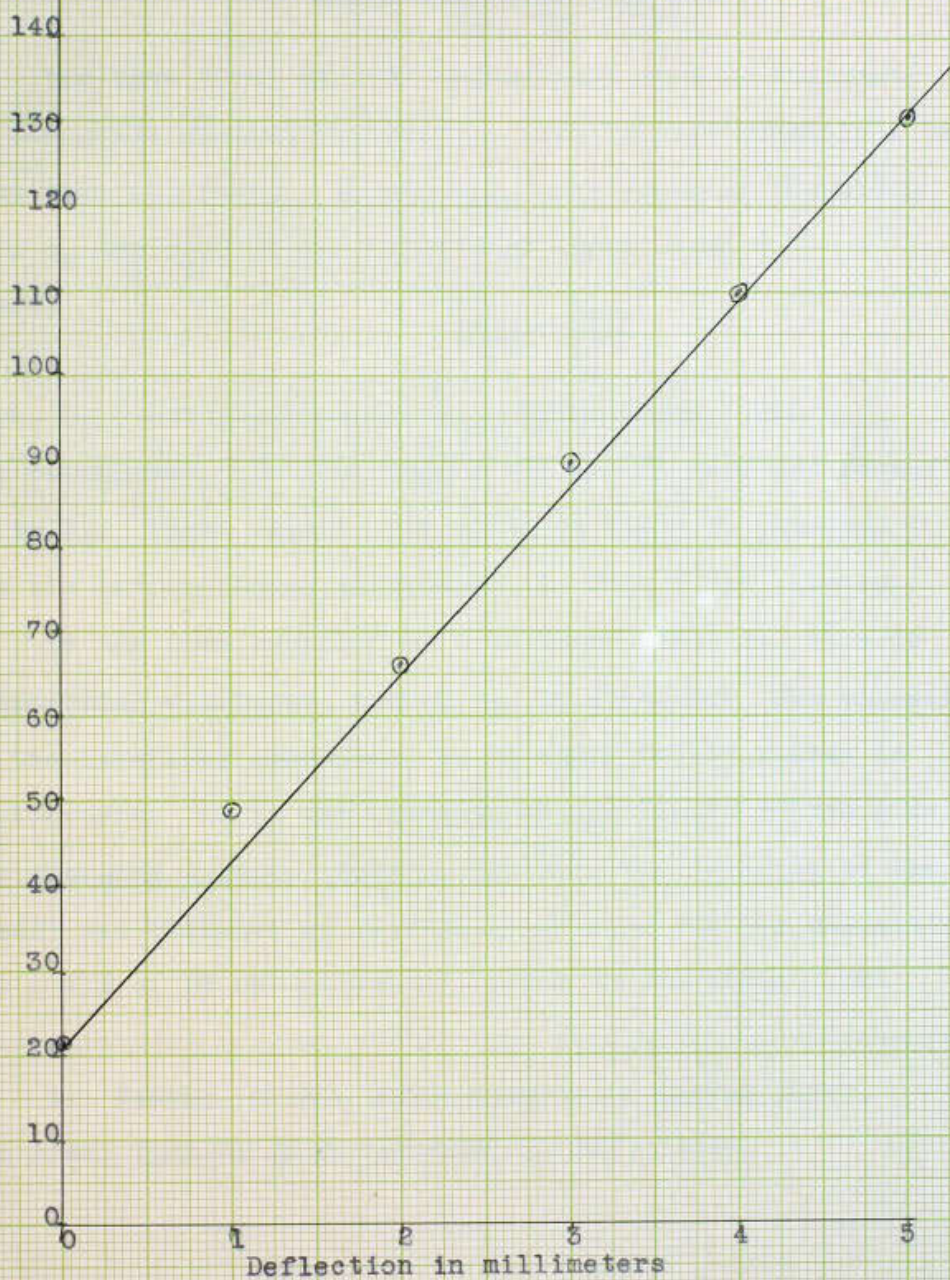


Fig. 8. Direct Current Deflection Curve.

then¹,

$$Q_1 = CV_1 = (C + c)V_2$$

$$Q_2 = CV_2 = (C + c)V_3$$

$$Q_n = CV_n = (C + c)V_{n+1}$$

$$\frac{C + c}{C} = \frac{V_1}{V_2} = \frac{V_2}{V_3} = \frac{V_n}{V_{n+1}}$$

The last three or four deflections were on the part of the scale already calibrated, that is, the potentials were less than 132 volts. V_n and V_{n+1} were found by comparing with d_n and d_{n+1} on the calibrated curve, Fig. 6.

Since,

$$\frac{V_n}{V_{n+1}} = \frac{V_{n-1}}{V_n}$$

then, V_{n-1} was calculated. V_{n-1} being known, then V_{n-2} was calculated. In like manner all the Vs were determined up to V_0 . These results are given in Table V. Knowing V and its corresponding deflection, d, Fig. 9 was plotted.

In the same equation if c is known, that is, if c is a spherical condenser, then C can be obtained. The capacity of the spherical condenser, c, is equal to its radius in centimeters. C. is the capacity of the "leaf" system plus the charging system. Knowing the sum, the capacity of the "leaf" was obtained by getting a ratio of the two capacities, $C + c$ and c, by an operation similar to the above. The

1. Ramsey, R. R., Radioactivity of Spring Water, (In Proc. Indiana Acad. Science, p. 463, 1914).

TABLE V

Static Current Determined Values

Voltage	Deflections			Av. Defl.	V in volts	C in cm.
V ₁	29.0	30.0	29.0	29.5	792	1.91
V ₂	16.0	17.0	16.0	16.5	483	1.98
V ₃	10.5	10.5	9.5	10.0	295	1.97
V ₄	6.7	6.0	6.2	6.5	180	1.99
V ₅	4.0	3.5	4.0	4.0	110	1.96
V ₆	2.0	2.0	2.0	2.0	67	1.97
V ₇	1.1	0.5	1.1	1.0	46	----
V ₈	0.0	0.0	0.0	0.0	--	----

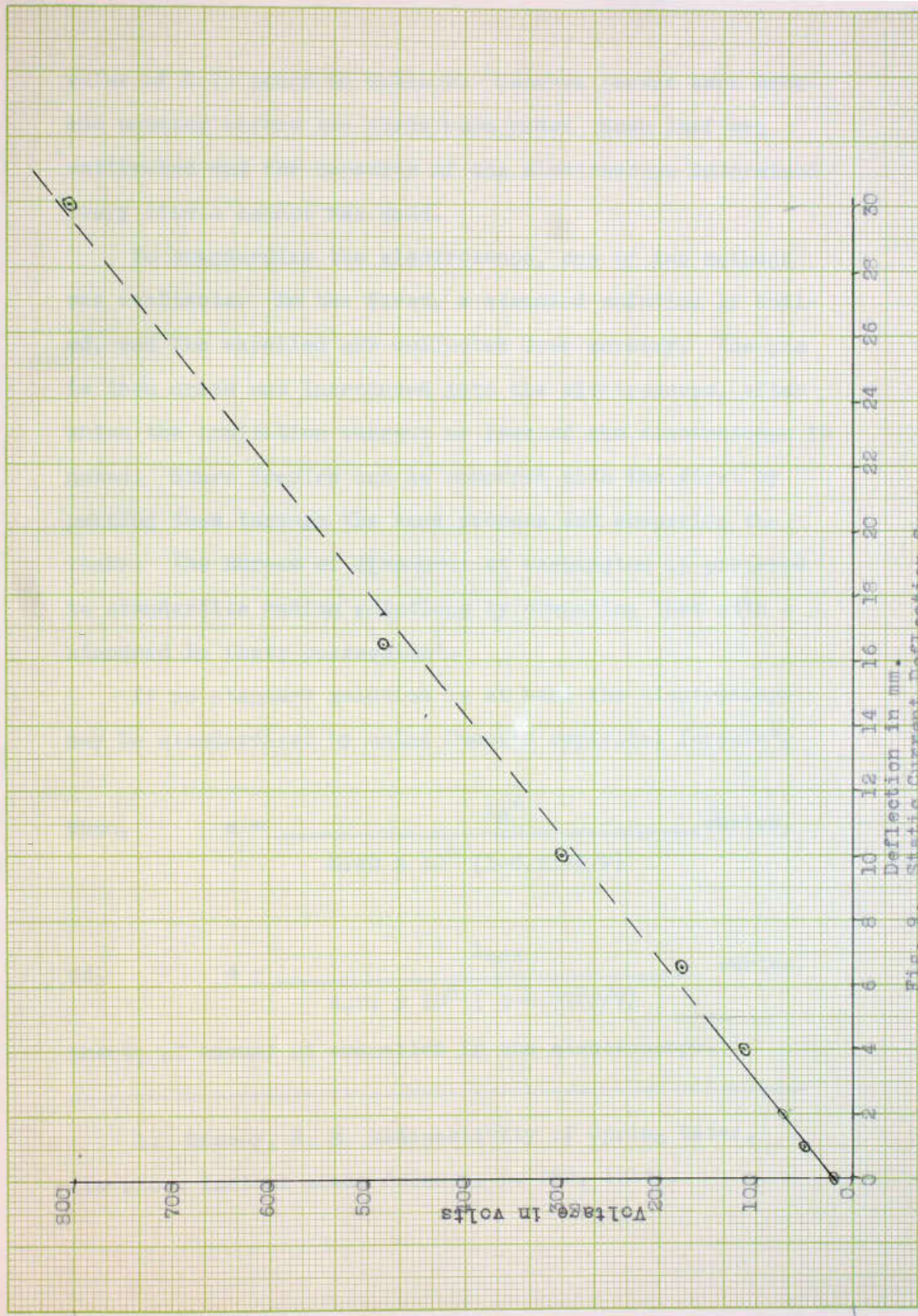


Fig. 9. Static Current Deflection Curve.

value of C is given in table V. Several leaves were made and mounted before the tests were made. Each leaf was calibrated and the capacity of the electroscope determined every time a change was made.

To standardize the electroscope, one of two methods was available. In the first, a standard solution is boiled, and the expelled gas collected over mercury. The gas is then dried and introduced into the electroscope, after which the ionization current or leak of the electroscope is noted. Other samples can be compared with the first by putting them through the same process and comparing the leaks. The Bureau of Standards at Washington is prepared to standardize radium solutions by comparing them with a standard in their possession¹.

If no standard solution is at hand the electroscope may be standardized by using Duane's empirical formula¹,

$$\text{when, } e = \frac{i_0}{2.49 \times 10^6 (1-0.517S/V)} \text{ curies,}$$

$$\text{or, } e = \frac{i_{\max}}{6.31 \times 10^6 (1-0.572S/V)} \text{ curies.}$$

Where, e = amount of emanation in the electroscope.

1. Ramsey, R. R. Radioactivity of Spring Water,
(In Proc. Indiana Acad. Science, p. 459, 1914).

i_0 = initial current expressed in e.s.u.

i_{\max} = maximum current (current at the end of three hours) expressed in e.s.u.

S = inside surface of ionization chamber of electroscope in cm^2 ,.

V = volume of ionization chamber in cm^3 .

This equation applies to a cylindrical ionization chamber with a central rod.

The ionization current, i , is measured by knowing the capacity, C , of the electroscope; the change of potential, dV , of the insulated leaf system, in the time, t ; according to the equation¹.

$$i = \frac{CdV}{t} .$$

1. Ramsey, R. R., Radioactivity of Spring Water, (In Proc. Indiana Acad. Science, p. 459, 1914).

COLLECTING WATER SAMPLES

The water was collected in one-gallon jugs from the various wells. In the wells being drilled it was taken out of the bailer. In some cases the water was allowed to stand for a few minutes to let the mud settle out. Care was taken not to dip the water with a small vessel when it was being placed in the jugs, because, if it were, some of the emanation would escape. Hence, the water was poured in the jugs as cautiously as possible. Water samples from the producing wells were taken with the oil as pumped from the well and allowed to stand until the water settled, then a siphon was used to put the water in the jugs. In other cases the water was taken from the separators. With each sample of water, the depth, the location, and if a producer, the pay was obtained from the workers. It was difficult to obtain water from wells in the process of being drilled because the times of drilling operations are uncertain. Furthermore, oftentimes there was not water in the hole being drilled. In other cases it was necessary to wait from several hours until the bailer was lowered into the well to remove the water. The samples were taken to the laboratory the same day they were obtained and the test made within 48 hours. If allowed to stand in jugs for some time, the emanation would not be a true sample of the emanation from the well.

METHOD OF PROCEDURE

After the electroscope was calibrated and standardized, the next step was to find the volumes of air and water in the shaking can. To do this the can was filled with water, then it was drained out of the lower stopcock and weighed and measured, pains being taken to have the water run out to the same level each time. This procedure was repeated several times and the average taken for the volume of air in the shaking can. The volume was found to be 2.235 liters. Next, the volume of water in the shaking can was determined. The can was filled above the level of the lower stopcock, placed on a level surface and allowed to drain until the water was level with the stopcock. Then the water remaining in the can was weighed and measured. This volume averaged 1.545 liters. The volume of the pump, tubes and connections was determined by measurements and also by filling them with water and finding the volume of water contained by them. This volume was found to be 224 cubic centimeters. The volume and surface of the ionization chamber were determined by measurements and calculations. The surface was 363 square centimeters and the volume was found to be 497 cubic centimeters.

The electroscope was set on a box near one end of a long table and connected to ground. The six-volt lamp was placed back of the electroscope so that the scale

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was illuminated. At the other end of the table the telescope was adjusted to read the deflection of the leaf. When readings were to be made, the leaf was charged for several minutes before the readings were made. The lamp was lit several minutes before the readings were taken so that the air currents, due to heat, would remain constant.

The water to be tested was filtered to remove the dirt and oil. It was then poured into the shaking can, to a point above the lower stopcock and allowed to drain out until it became level with it. Also, some of the filtered water was placed in a deep glass cylinder so that its density could be determined.

Two different methods of procedure were employed to expel the emanation from the water samples, -one, a shaking method; the other, a boiling method. In one instance a certain sample was divided into two parts, to one of which the shaking method was applied and to the other the boiling method. It was later learned that a combination of the shaking and boiling methods gave the best results, as far as the extrusion of emanation is concerned. Hence, a combination of these methods was employed throughout this investigation.

The water in the shaking can was heated to 95 degrees Centigrade, the stopcocks being closed before the heat was applied. A thermometer was inserted in the small

hole in the top of the shaking can, so that the temperature could be read. After heating the water, it was cooled to room temperature in running water. The cooling of the gas before being placed in the electroscope, eliminated two errors; first, it took most of the moisture out of the gas; and second, it cooled the gas to room temperature, thus avoiding spurious ionization effects. Had the gas been placed in the electroscope while hot, it would have had greater ionizing power than the same gas at a lower temperature¹. After the gas was cooled to room temperature it was pumped through the emanation chamber for two minutes, so that it became well mixed with the air in the tubes and emanation chamber.

A complete set of ionization observations for a given sample of gas required three hours for completion and involved two sets of readings of ten-minute periods, one at the beginning of the three-hour period, the other at the close. The leaf was charged to near maximum deflection and the charging contact was grounded through the case of the electroscope. The deflection of the leaf was noted, as was also the time. At the end of ten minutes the deflection was again noted and recorded. After the first set of readings was completed the leaf was grounded and the gas was allowed to stand in the

1. Starling, Sydney G., Electricity and Magnetism, p. 566.

emanation chamber for three hours at the end of which readings were again taken and recorded. The leaf was charged to about the same potential each time. The room was darkened so that the light intensity would remain constant, and the other physical conditions of the room were kept as nearly constant as possible.

The temperature of the gas was taken when it was placed in the emanation chamber. After the two sets of readings were taken, air was pumped through the emanation chamber for thirty minutes to remove the gas. The electroscope was allowed to stand for two hours before the next sample of water was tested. The natural leak of the electroscope was taken before every set of readings, and this was subtracted from the leak due to the gas put in the electroscope. The humidity of the air was determined by means of a sling psychrometer in conjunction with weather bureau tables¹. The density of the water was then reduced to a constant temperature density.

To find the amount of emanation in the emanation chamber, the deflections were substituted in the equations given under "Calibration of Electroscope". Hence, to calculate the amount of emanation per liter of water,

1. Marvin, Charles F., Psychrometric Tables,
(U. S. Department of Agriculture, Weather Bureau, No.
235, p. 57-81, 1915).

the following formula¹ was used.

$$E = \frac{1}{V_1} \left(\frac{V_2 + \alpha V_1}{V_1} \right) \left(\frac{V_2 + V_3 + V_4}{V_4} \right) e,$$

Where V_1 = Volume of water in shaking can, expressed in liters.

V_2 = Volume of air in shaking can, expressed in liters.

V_3 = Volume of bulb, pump, and connection tubes.

V_4 = Volume of ionization chamber.

α = Absorption coefficient of water for radium emanation (taken from Fig. 10).

e = Amount of emanation in V_4 .

E = Amount of emanation per liter of water.

To determine the half life of the emanation some water was heated and the gas placed in the emanation chamber and allowed to stand for three hours. Then the leaf was charged for 15 minutes before the reading was taken. The fall of the leaf was noted during one hour and recorded. The leaf charge was then removed and the gas allowed to stand in the emanation chamber for twelve hours, then another reading was taken. This procedure was followed for several days and the results are given in Table VI. From these results Fig. 11 was obtained.

1. Ramsey, R. R., Radioactivity of Spring Water,
(In Proc. Indiana Acad. Science, 1914, p. 465).

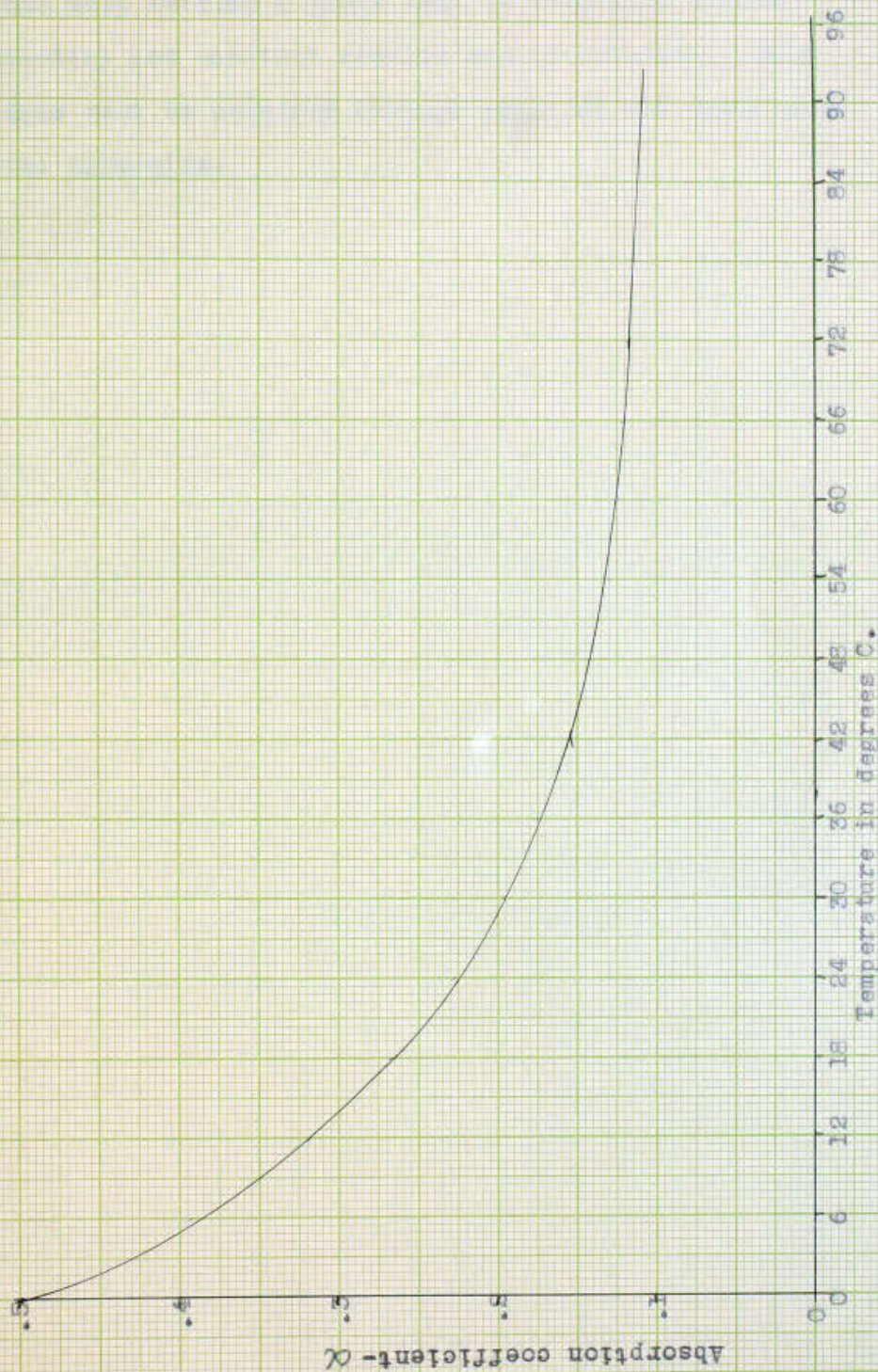


Fig. 10. Absorption Coefficient Curve.
(After Ramsey)

One must develop a great deal of technique before satisfactory and constant results can be obtained. This technique must be acquired through practice and experience with the apparatus.

TABLE VI

Half-life Period Curve Data

Leaf Drop in mm.	Time in Days
6.0	0.0
4.9	0.5
4.3	1.0
3.4	1.5
3.0	2.0
2.6	2.5
2.2	3.0
1.8	3.5
1.5	4.0
1.2	4.5
1.4	5.0
1.1	5.5
.7	6.0
.8	6.5
.6	7.0
.4	7.5
.4	8.0
.4	8.5
.5	9.0

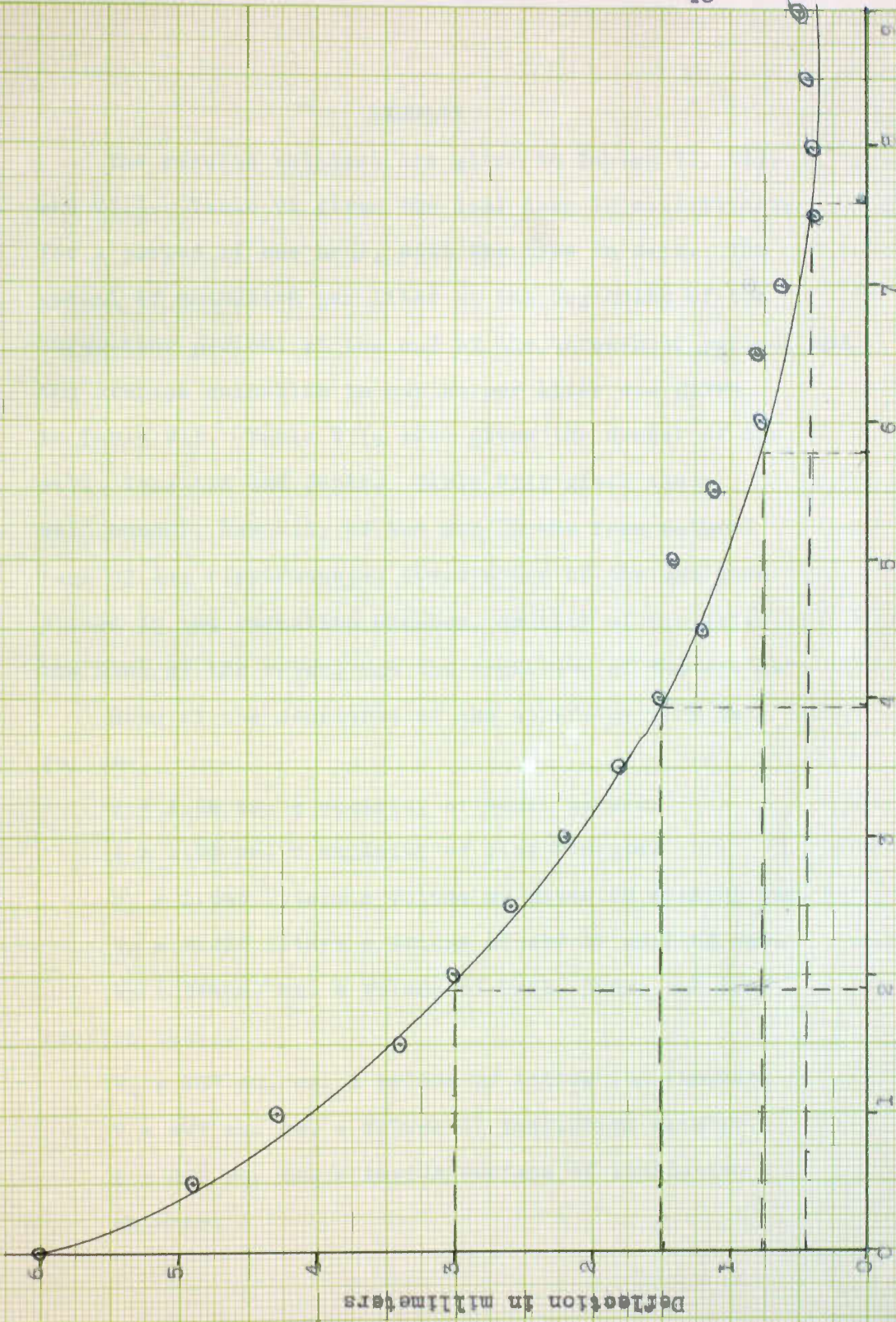


Fig. 11. Half-life period curve

RESULTS

The results obtained are given in Tables VI, VII, and VIII. Table VI gives the leaf drop in millimeters, for a period of one hour, with the time in days. The amount of emanation per liter at the beginning of the three-hour period, at the end of the three-hour period, and the average emanation in curies per liter are given in Table VII. Table VII, also gives the number of the well, location and depth. Table VIII gives the well number, humidity of the air in the room natural leak of the electroscope, temperature of the gas when placed in the emanation chamber, density of the water, the name of the water, and the condition of the weather.

Some of the constants of the apparatus were as follows:

$c = 1.26 \text{ cm.} = \text{capacity of small sphere.}$

$C = 1.96 \text{ cm.} = \text{capacity of electroscope.}$

$V_1 = 1.545 \text{ liters} = \text{volume of water in shaking can.}$

$V_2 = 2.235 \text{ liters} = \text{volume of air in shaking can.}$

$V_3 = 224 \text{ cu. cm.} = \text{volume of bulb, pump, and connection tubes.}$

$V_4 = 497 \text{ cu. cm.} = \text{volume of ionization chamber.}$

$V = 497 \text{ cu. cm.} = \text{volume of ionization chamber.}$

$S = 363 \text{ sq. cm.} = \text{inside surface of ionization chamber.}$

TABLE VII

Emanation Found

Well no.	Location	Depth in feet	$E_Q \times 10^{-12}$ curies/l.	$E_{\max} \times 10^{-12}$ curies/l.	Av. $E_x \times 10^{-12}$ curies/l.
1	S17-T15-R18W	3300	17,018	17,295	17,156
2	S17-T15-R18W	2385	18,700	20,210	19,450
3	S17-T15-R18W	350	47,300	26,120	36,710
4.	Hays City	20	21,850	11,860	16,855
5	Rain Water	----	12,560	27,250	19,905
6	S5-T12-R17W	3675	22,580	10,310	16,445
7	S32-T11-R17W	3500	39,039	29,011	34,025
8	S7-T12-R17W	3732	47,464	86,735	67,100
9	S3-T14-R17W	3300	8,760	74,384	41,572
10	S9-T13-R19W	3325	151,050	68,685	109,869
11	S9-T13-R20W	3615	16,786	116,886	66,826
12	S9-T13-R19W	64	84,656	26,553	55,605
13	S14-T13-R17W	36	88,862	25,434	57,148
14	S9-T13-R19W	3540	98,852	106,173	102,513
15	Distilled H_2O	----	000	000	000

(Continued next page)

TABLE VII (Continued)

Well no.	Location	Depth in feet	$E_0 \times 10^{-12}$	$E_{\max} \times 10^{-12}$	Av. $E \times 10^{-12}$
			Curies/l.	Curies/l.	Curies/l.
16	S24-T14-R17W	285	59,981	40,456	50,218
17	S24-T14-R17W	580	57,186	51,516	54,351
18	S7-T14-R16W	40	22,016	42,278	32,122
*19	S7-T14-R16W	40	22,263	17,550	19,906
20	S8-T14-R17W	40	21,646	25,596	23,621
21	S25-T14-R18W	28	43,018	25,434	34,228
22	S24-T12-R19W	180	8,450	10,563	9,506
23	S9-T11-R17W	25	17,073	16,870	16,972
24	S21-T11-R17W	3350	37,912	49,831	43,872
25	S24-T12-R19W	600	16,832	16,632	16,732
26	S35-T11-R18W	90	16,966	8,383	12,675
27	S6-T15-R18W	3350	29,722	25,410	27,566
28	S17-T15-R18W	3560	25,333	58,212	42,773

*- Same water as #18 with the shaking method applied.

E_0 - Emanation at beginning of three-hour period.

E_{\max} - Maximum emanation at end of three-hour period.

TABLE VIII
Additional Data.

well no.	Humid- ity %	Natural Leak	Temperature in °C.	Density	Waters	Weather
1	56	.1	24	1.037	Siliceous Oswald	Clear
2	52	.9	23	1.036	Siliceous	Clear
3	55	.3	23	1.040	Dakota	Clear
4	53	.25	27	1.007	Tap	Rain
5	55	.1	25	1.005	Rain	Rain
6	58	.5	22	1.048	Siliceous	Clear
7	58	.5	25	1.105	Oswald	Clear
8	58	.5	25	1.040	Siliceous	Clear
9	61	.5	21	1.104	Oswald	Clear
10	50	.25	23	1.120	Drilling	Clear
11	36	.5	30	1.101	Drilling	Clear
12	39	.5	30	1.001	Well	Clear
13	46	15	26	1.001	Well	Clear
14	44	.5	26	1.028	Drilling	Cloudy
15	62	.5	30	1.001	Distilled	Clear

(Continued on next page)

TABLE VIII

Additional Data (Continued)

Well no	Humid- ity %	Natural leak	Temperature in °C.	Density	Waters	Weather
16	48	.3	27	1.003	Well	Cloudy
17	54	.5	23	1.041	Drilling	Clear
18	48	.25	26	1.003	well	Clear
19	47	.5	27	1.003	Well	Clear
20	53	.25	24	1.004	well	Clear
21	38	.25	26	1.002	well	Clear
22	44	.5	29	1.003	Well	Clear
23	35	.3	27	1.002	well	Clear
24	35	.3	31	1.084	Drilling	Clear
25	42	.1	30	1.003	well	Clear
26	42	.2	29	1.002	well	Clear
27	48	.25	30	1.108	Oswald	Clear
28	53	.1	30	1.040	Siliceous	Clear

CONCLUSIONS

The emanation was measured from twenty-eight samples of water taken from different parts of the county and at different depths. The amount of emanation varied from zero curies per liter to $109,869 \times 10^{-12}$ curies per liter.

No relation between the depth of the wells and the amount of emanation was found. However, a tendency towards increased emanation appeared in samples from the west-central part of the County, (the well in S9-T13-R19W shows a much greater amount of emanation than any of the other wells).

The half-life period for the emanation was found to be about 1.85 days, which is about half as long as that given for radium emanation.

The amount of moisture in the air seemed to have no effect upon the natural leak of the electroscope; neither did the condition of the weather.

Referring to Table VII, it is to be observed that in some instances E_0 exceeds E_{\max} . This might be explained in part by suggesting that since E_{\max} was determined three hours after E_0 , the radioactive transformation of the sample had progressed to an advanced stage, and therefore considerable of its ionizing power had been previously expended. There is this possibility, however, that in the three-hour interim a portion of the emanation may have escaped through diffusion or condensation, which on the face of my technique looks rather improbable.

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