Radioactivity of Spring Water.

R. R. Ramsey.

Since the discovery of the Becqerel rays in 1896 by Henri Becqerel a great amount of work has been done on radioactive bodies; i. e., bodies which give out a radiation which, among other things, renders the air conducting. Madam Curie discovered polonium and radium in 1898. After the discovery of radium a great many workers contributed to our knowledge of radioactive bodies. Radium and polonium are now known to be transformation products in the radioactive series headed by uranium. Besides the uranium-radium series we have the thorium series, the actinium series, and the potassium series in the radioactive list.

Very early in the history of radioactivity, tests were made on ordinary matter to see if all matter is radioactive. Although there is some evidence to show that all matter is radioactive, i.e., is disintegrating, it has been found that a great part of the effect is due to slight traces of radium and other radioactive substances which are mixed with matter. Thus the surface of the earth is covered with slight traces of radium. The exact distribution of radium on the surface of the earth is not known, determinations having been made in a relatively few localities. Besides the scientific interest in the distribution of radium there is another. It has been found that a great many of the celebrated European springs and baths show an unusual amount of radioactivity. The theory has been advanced that the curative properties of these springs are due to the radioactivity of the water.

Table I gives a partial list of the measurements made on noted springs also a short list of ordinary springs, etc.

TABLE I.

Radioactivity of Noted Springs, Etc.

Kings well, Bath, Eng.			173.	$X10^{-12}$Gm. Ra. per liter.
Brembach (Saxe.)	36000.	to	720000.	$X10^{-12}$ Curies per liter.
Schweizergang, Joachimsthal			98000.	
Lake Balaton, Hungary	10300.	to	36000.	
Potable waters of Mulhause (Alsace)			2800.	
Evaux-les-Bains	1060.	to	2340.	
Evaux-les-Bains gas	3440.	to	80090.	
Japanese hot springs	237.	to	13800.	
Colorado Springs, Manitou	120.	to	4730.	
Colorado Springs, Manitou, gas	470.	to	20500.	
West Canada, Fairmount, Sinclair	3500.	to	4000.	
Yellowstone Park	2.26	to	10.4	Mache units.
Yellowstone Park gas	6.25	to	118.3	Mache units
Sixty Springs, Tyrol	.06	to	89.	Mache units.
Saratoga, N. Y., springs	39.	to	880.	$X10^{-12}$ Curies per liter.
Saratoga, N. Y., springs gas, Max			847.	
Williamstown, Mass	13.	to	216.	
Williamstown, Mass., gas	759.	to	7290.	
Caledonian Springs, near Ottawa, Can			15.	
St. Lawrence River	.25	to	1.1	
Sea water			.9	
Air, Montreal, Cambridge, etc			.1	

One Mache unit equals $364.X10^{-12}$ (Curies per liter).

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. The greater amount is usually due to radium or radium emanation dissolved in the water.

In the uranium-radium series (Table No. 2), it will be noted that when one substance changes into another a radiation of α, β, or γ rays, in some cases all three, are given off. This radiation ionizes the air and renders it conducting. The conductivity of the air becomes a measure of the radioactivity of the substance. This is proportional to the rate which a charged body loses its charge.

The ionization produced by the three sets of rays is about in the following proportions: $\alpha = 100\%$, $\beta = 1.\%$, $\gamma = .01\%$. The penetrating powers are in the inverse proportion. Electroscopes for radioactive measurements are known as α ray electroscopes, β ray electroscopes, γ ray electroscopes according to the amount of material that must be penetrated by the radiation in order to get into the electroscope. Thus in an α ray electroscope the substance tested is placed in the electroscope or very near to a window covered with a very thin sheet of aluminum or paper. The rays pass in

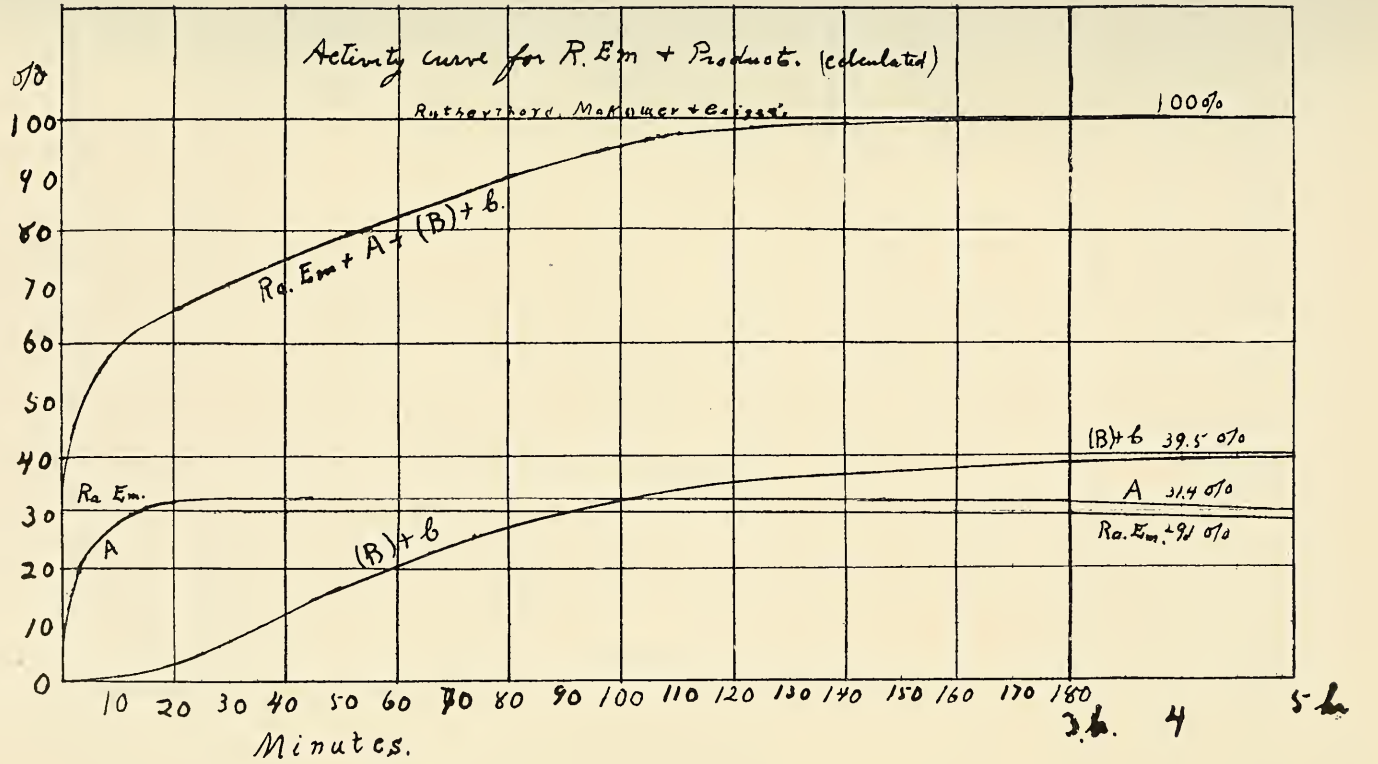

Activity curve for R. Em + Products. (calculated)
Rutherford, McKeever + Briggs.
%
100
90
80
70
60
50
40
30
20
10
0
100%
Ra. Em + A + (B) + b.
(B) + b 39.5 %
A 31.4 %
Ra. Em. 29 %
Ra Em.
A
(B) + b
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Minutes.
3 h.
4
5 h

Figure I.

without absorption and practically all, at least 99%, of the ionization is produced by the α rays. In the β ray electroscope the radiation must pass through .05 mm. aluminum, which absorbs all the alpha rays and the ionization is produced by the β rays. In the γ ray electroscope the radiation must pass through 2 mm. of lead, which completely absorbs the α and β radiation leaving the γ rays to produce the ionization. Thus for very weak radioactive bodies the α rays are used, to produce the ionization.

TABLE 2.

URANIUM RADIUM SERIES.

SUBSTANCE.	Radiation.	Half-value Period.	Transformation Constant sec^{-1}.	Range of α rays in cms. (15° C.).	Absorption Coefficients.	
					β rays Alum. cm^{-1}.	γ rays Lead cm^{-1}.
Uranium 1	α	5×10^{9} years.	$4\cdot6\times10^{-18}$	2·50		
Uranium 2	α	2×10^{6} years.	$1\cdot1\times10^{-14}$			
Uranium X	β, γ	24·6 days.	$3\cdot26\times10^{-7}$		14·4 and 510	72
(Uranium Y)	β	1·5 days.	$5\cdot34\times10^{-6}$		360	
Ionium	α	2×10^{5} years.	$1\cdot1\times10^{-13}$	3·00		
Radium	α, β	2000 years.	$1\cdot1\times10^{-11}$	3·30	200	
Radium Emanation	α	3·85 days.	$2\cdot085\times10^{-6}$	4·16		
Radium A	α	3·0 min.	$3\cdot85\times10^{-3}$	4·75		
Radium B	β, γ	26·7 min.	$4\cdot33\times10^{-4}$		13 and 91	4–6
Radium C_1	α, β, γ	19·5 min.	$5\cdot93\times10^{-4}$	6·94	13 and 53	50
(Radium C_2)	β	1·4 min.	$8\cdot25\times10^{-3}$		13	
Radium D	β	16·5 years.	$1\cdot33\times10^{-9}$		very soft.	
Radium E	β, γ	5 days.	$1\cdot60\times10^{-6}$		43	very soft.
Radium F (Polonium)	α	136 days.	$5\cdot90\times10^{-8}$	3·77		

The substances in parentheses are products not in the direct line of transformation.

Makower & Geiger's Practical Measurements in Radioactivity.

One notes in the radioactive series (Table 2), that the disintegration product of radium is emanation, a gas, which gives off an α particle and changes into Rad. A. This emanation is a gas and obeys all the gas laws. Rad. A has a half value period of three minutes and gives off an α particle and changes into Rad. B. Rad. B has a half value period of 26.8 minutes and gives off β and γ radiation and changes into Rad. C. Rad. C has a half value period of 19.5 minutes, gives off α, β and γ particles and changes into Rad. C_2 and Rad. D. Rad. D has a slow half value period of 16.5 years. This is so slow that the ionization produced by this change can be neglected in com-

parison with the others. Thus some time, about three hours, after the emanation has been placed in a vessel we have Rad. Em. changing through the intermediate products into Rad. D. giving off three α particles, one from Rad. Em; one from Rad. A; and one from Rad. C. This complex radiation has after the first few hours the half value period of the longest of the series, which is that of Rad. Em., 3.85 days. Thus if a quantity of radium emanation gas is placed in an electroscope the rate of "leak" of the electroscope in-

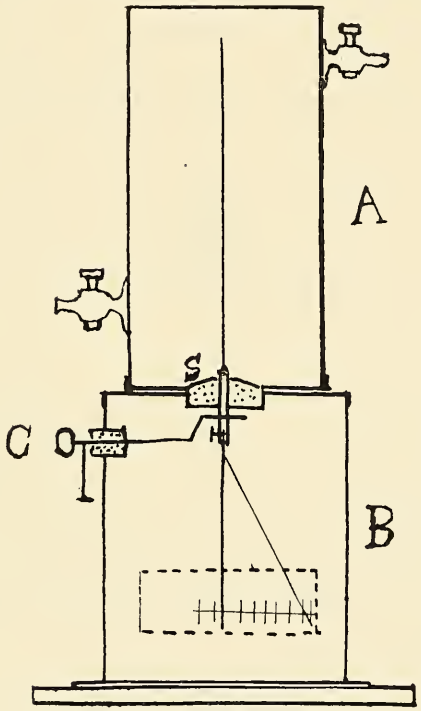


Fig. 2.

creases for 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 rise of activity during the first few hours is shown by the curves in Fig. I. These curves are plotted from data given in Rutherford's Radioactive Substances and Their Radiations, and in Makower & Geiger's Practical Measurements in Radioactivity. The final values (4 hours) are based on the number of ions produced by α particles from the various products. Thus

Rad. Em., 29.1%, Rad. A, 31.4%, Rad. (B) and C, 39.5%. Total, 100%. The line marked Rad. Em. starts initially at 30.% and in four hours has diminished to 29.1% according to the half period of 3.85 days. Rad. A. initially is zero, because initially emanation alone is placed in the chamber. Curve A rises to half value in three minutes and in 20 or 30 minutes becomes in equilibrium, that is, it disintegrates into Rad. B as fast as it is formed from the emanation. The latter part of the curve is practically a straight line parallel to the curve for emanation.

Rad. B does not give off α particles. The ionization due to the β radiation can be neglected. Rad. B changes into Rad. C whose half period is 19.5 minutes. Thus the curve (B) and C depends upon the amount of Rad. C present. This initially depends upon the formation of Rad. A and B. The

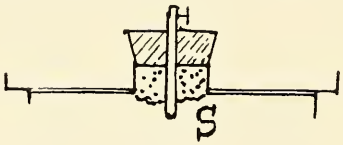


FIG. 3.

curve starts from zero and reaches its equilibrium in about four hours. The total ionization depends upon all three, so the current in the chamber, assuming that all ions capable of being produced by the α particles are used, increases according to the curve Em.+A+B+C, which is formed by summing the ordinates of the three curves. This reaches 100% in about three hours. In a chamber of smaller dimensions the effect of the slower electrons will be greater than the above, since a greater number of the high velocity ones will be absorbed by the walls of the chamber before they have produced their maximum number of ions.

The quantity of emanation gas associated with or occluded in, or in equilibrium with, a quantity of radium has been found to be directly proportional to the mass of radium. This is so true that the amount of emanation in equilibrium with one gram of radium has been measured very exactly and is called the curie. Thus one gram of old radium contains or is in equilibrium with one curie of radium emanation gas. The volume of this gas under standard conditions is .62 cu. mm.

To collect this gas the radium is put into solution, boiled and the gas diluted with air is collected over mercury and then introduced into the electroscope. The radium solution after standing one month is again in equi-

librium with the emanation and can be used again. By noting the ionization current or the "leak" of the electroscope other samples of radium can be compared with the first by putting sample No. 2 through the same process. The Bureau of Standards at Washington is prepared to standardize radium solutions by comparing them with a standard in its possession.

If no standard is at hand the electroscope can be standardized by using Duane's empirical formula. (Le Radium Vol. XI, P. 5, 1914; Ann. der Phys. Vol. 38, P. 959, 1912; Compt. Rendus Vol. 150, P. 1421, 1910; Jour. de Phys. Vol. 4, P. 605, 1905), which is,

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

or,

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

Where, e = amount of emanation in the electroscope.

i_0 = initial current, expressed in E. S. units.

i_{max} = maximum current (current at end of three hours) expressed in E. S. units.

S = inside surface of ionization chamber of electroscope.

V = volume of ionization chamber.

This equation applies to a cylindrical ionization chamber with a central rod. The volume of the chamber must be about one liter and the height is from one to three times the diameter.

The ionization chamber can be a cylindrical metallic chamber with an insulated rod extending through the center. This rod can be connected to an electrometer or to an electroscope in order to determine the potential of the rod. For very delicate measurements of small amounts of emanation a sensitive electroscope is better than an electrometer. In an electroscope the ionization current, i, is measured by knowing the capacity, C, of the electroscope; the change of potential, dV, of the insulated rod, in the time, t; according to the equation,

$$i = \frac{C\, dV}{t}.$$

In order to measure a small current in a short time, C, the capacity of the electroscope must be small and dV, the change of potential, must be

small. Therefore we wish a sensitive electroscope of small capacity. The cylindrical chamber is in reality a cylindrical condenser. Therefore we want the diameter of the rod small compared to the diameter of the cylinder, also the collar holding the insulating material should be short and have a large diameter compared to the rod. In short the dimensions of the insulated system should be as small as rigidity and other considerations will permit.

To make the electroscope sensitive the "gold leaf" should be very light and narrow. With Dutch leaf a strip between one and two millimeters wide will give a change of one mm. for a change of potential of five volts. By

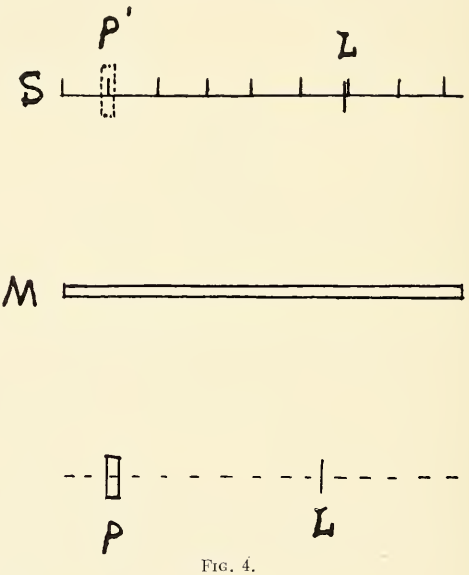


Fig. 4.

using a reading microscope with graduated eye piece a fraction of a volt can be detected. The electroscope should be made of brass tubing the thickness of whose walls is one mm. or more. Where such material is not to be had sheet tin can be used and will give satisfactory results, especially if used in a laboratory free from penetrating radiation. I will describe one which I made at a cost of a few cents and have found to give consistent results when compared with one made in Germany which cost $50.

The cylinder A, Fig. 2, is a 1 lb. coffee can. B, is a tin can made in a local tin shop, 3x3x5 inches with a lid at the top. The lid of the coffee can and the lid of the rectangular can are soldered together and a short cylinder

of brass, S, is soldered in a hole in the center. In this short cylinder the central rod system, which can be made of two or more sections, is insulated by pouring melted sulphur into the cylinder while the rod is supported in proper position by a cork, Fig. 3, which extends a short distance into the cylinder. After a few hours the cork can be removed, leaving the sulphur plug. In melting the sulphur care must be used not to get the sulphur too

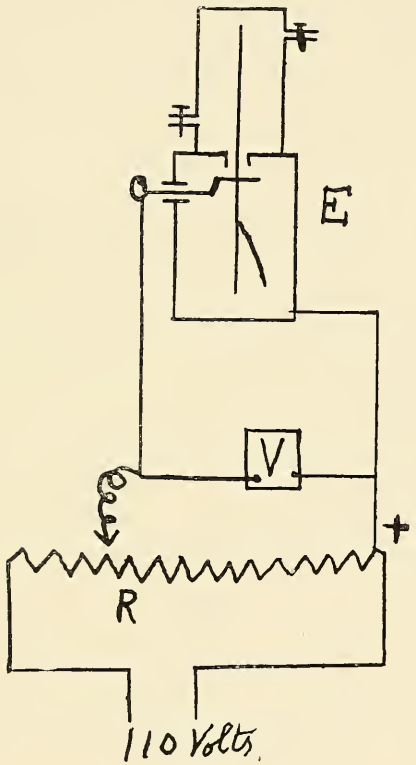


Fig. 5.

hot or to burn it. The melted sulphur should be a clear amber liquid. If the sulphur takes the waxy condition it should be discarded. The leaf is attached to a narrow plate which is attached to the lower end of the rod. The leaf which is a narrow strip of Dutch foil should be attached to the plate so as to be straight and to swing freely bending at a point near the plate.

The deflection of the leaf is observed through a small window at one

side. A similar window should be placed on the opposite side to admit light. To read the amount of deflection a scale S, as shown in Fig. 4, is mounted on one side on or near the back window. A strip of cross-section paper stuck to the glass with paraffin while hot will answer. The paraffin serves two purposes: it sticks the paper and renders the scale translucent. Half way between the scale and the plane of the leaf system a mirror, M, is mounted. Through the front window one sees in the mirror images of the plate, P, and the foil, L, at P^1 and L^1. These images are in the same plane as the scale, S, which can be viewed by looking over the mirror, M. The position of L^1 can be read on the scale, S, and at the end of a convenient interval of time its position can be noted again. By comparing the two positions with the calibration curve of the electroscope the change of potential, dV, can be obtained.

The system is charged by means of a rubber rod through the charging system, C, Fig. 2. This consists of an insulated rod with a bent wire connected so as to be in contact with the central rod while charging. While not in use this rod is rotated so as to break connection with the rod and then to come into metallic contact with the case of the electroscope.

Two ¼-inch brass drain cocks are soldered to the emanation chamber to admit the emanation.

The data of the following experiment, Table 3, carried out by two students using the "tin electroscope" and a Schmidt electroscope made by Spindler & Hoyer, Göttingen, will give an idea of the accuracy of this electroscope and also the accuracy of Duane's formula.

TABLE 3.

Electroscope	"Tin"	Schmidt.
Observer	F. G. T.	W. D. S.
Diameter of chamber	10.8 cm.	7.8 cm.
Height of chamber	12.1	20.3
Volume of chamber	1102 cc.	968 cc.
Surface of chamber	594 sq. cm.	586.6 sq. cm.
Capacity of electroscope	17.1 cm.	6.3 cm.
Observed emanation, Curies per liter	$206000.X10^{-12}$	$200000.X10^{-12}$

The two electroscopes were connected together and connected to a vessel containing emanation and pumped causing the air and emanation to pass in a circle through the three chambers until the three contained emanation of the same density.

Calibration of Leaf.—The instrument can be calibrated by connecting to known potentials and noting the deflections of the leaf. A storage battery of three or four hundred volts is convenient. Readings should be taken for every few volts from 0 to the maximum and a curve plotted. X = deflection, Y = volts. If a large voltage battery is not at hand a 110 volt D. C. circuit can be used making connection to a resistance as in Fig. 5. The voltmeter, V, should be read at the same time that the deflection of the leaf is read. A calibration curve from 0 to 110 volts can then be obtained. For the higher points proceed as follows: Charge the leaf to maximum voltage by means of a rubber rod. A body of small capacity, small compared to the capacity of the electroscope, 1 or 2 cm., say, is mounted on an insulated handle. A coin on a small rubber rod will answer. This is first grounded and then touched to the charged system. The gold leaf falls. The capacity is removed, grounded, and the position of the leaf noted. The operation is repeated until the leaf falls to 0 on the scale.

If C is the capacity of the electroscope, and
c is the capacity of the coin,
Q, the quantity of electricity,
V_1 V_2 is 1st, 2nd, ... potential of the leaf,
d_1 d_2 is 1st, 2nd, ... deflections of leaf,

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

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

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

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

The last three or four deflections should be on the part of the scale already calibrated. That is, the potentials should be less than 110 volts. If V_n and V_{n+1} are known by comparing with d_n and d_{n+1} on the calibration curve. Since,

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

then,

V_{n-1} can be calculated. V_{n-1} being known, then V_{n-2} can be determined. In like manner all Vs can be determined up to V_1. Knowing V and the corresponding deflection, d, the curve can be extended up to the maximum deflection.

Determination of Capacity.—In the same equations if c is known, that is, if c is a cylindrical condenser, then C can be obtained. Note that C is the capacity of the "leaf" system plus the charging system. Knowing the sum, the capacity of the "leaf" can be had by getting the ratio of the two by an operation similar to the above.

Removing the Emanation Gas from the Solution.—The emanation can be removed from a solution by the boiling method. The solution is boiled, driving off the dissolved gases with the steam. The steam is condensed and the gases are trapped in suitable glass tubes over mercury. The ionization chamber is then evacuated and the emanation is sucked into the electroscope. The entire amount of emanation is placed in the chamber by washing the

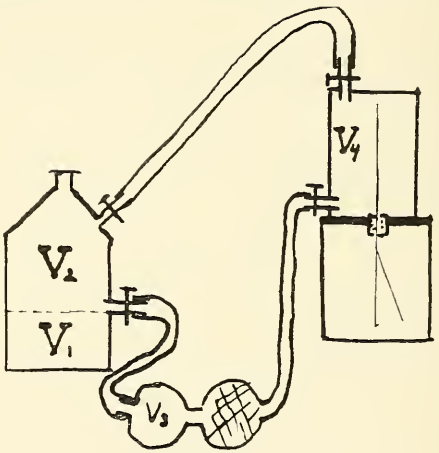


FIG. 6.

glass tube with air until the pressure of the ionization chamber of the electroscope is at normal pressure. This method is accurate but requires elaborate apparatus which can be used only in the laboratory.

Where the greatest accuracy is not wished Schmidt's shaking method can be used. (Phys. Zeit., Vol. 6, p. 561, 1905.) This method admits of determinations being made at the spring with apparatus which easily can be carried by the observer. The shaking method consists of taking a known volume of water and shaking it vigorously for two minutes in a closed vessel with a known volume of air. Then the emanation which was originally dissolved in the water is mixed in the air and water in a known proportion, depending upon the temperature of the water. Then this air is pumped through

rubber tubing from the shaking vessel into the ionization chamber and back again to the shaking vessel until the emanation is mixed through the air of both chambers in the same proportion. Knowing the constants of the electroscope and the observed change of deflection of the leaf, the amount of emanation in the ionization chamber is known. Knowing this and the various volumes of air and water the amount of emanation per liter of water can be calculated. The shaking vessel is made of a can with two brass stop cocks soldered into it. One cock is placed near the top the other is placed on the side about half way up. For convenience the position of the lower stop cock can be calculated so that the vessel will hold a certain quantity of water when the vessel is filled full and then placed on a level stand with both stop cocks open. In this manner the volume of the water is determined easily and can be made the same in each experiment. The volume of the air above the water can be had by determining the total volume of the can. To pump the air around a rubber bulb pump such as is used in pyrography outfits answers well. The volume of the air in the tubes and pump must be estimated and used in the calculations.

The formula for calculating the amount of emanation per liter, which can be derived easily in connection with Fig. 6, is as follows:

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

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.
e = Amount of emanation in chamber, V_4.
E = Amount of emanation per liter of water.

The quantity alpha, α, has been determined experimentally and has been found to depend upon the temperature. The value at any temperature can be had by referring to the curve (Fig. 7). The data for this curve is taken from M. Kofler (Akad. Wiss. Wien. Ber. 121, 2a pp. 2193; Sci. Abs. Vol. 16, 1742, 1913), and Boyle (Phil. Mag., 22, p. 840, 1911.)

As a test of the above equation the following will serve (Table 4). Three tests were made at the spring under the ordinary conditions. The

same electroscope was used, but two shaking cans were used, the larger of which had three stop cocks so that two volumes of water could be had.

TABLE 4.

C. J. S. Spring. August 5, 1914. Temperature of water 12.5° C. Temperature of air 30° C.

	I.	II.	III.
Time of beginning	11.03 a. m	11.46 a. m	2.00 p. m.
Volume of water	.707 liters	3.00 liter	5.00 liter.
Volume of air	.943	4.10	2.10.
Curies $X10^{-12}$ per liter	425. $X10^{-12}$	435. $X10^{-12}$	443. $X10^{-12}$.

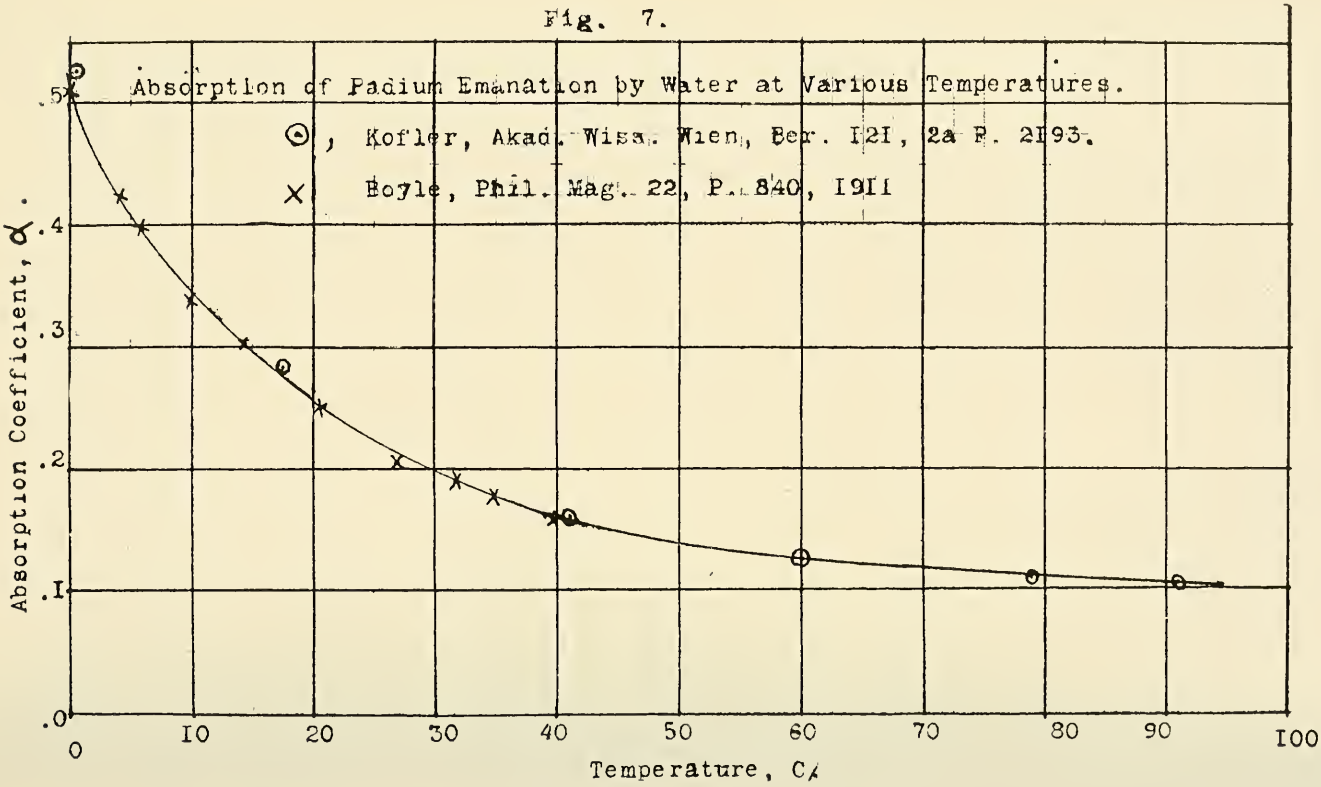
These observations were taken every minute and the mean deflection from 15 minutes to 20 minutes from the time of putting the emanation in the ionization chamber, was used. By referring to an experimental curve (Fig. 8), the maximum deflection per minute or the deflection at the end of three hours was calculated. A better agreement could have been obtained if the interval from the end of one experiment to the beginning of the next had been three hours or more.

Fig. 8 is a curve showing actual observations during a period of three hours taken with a sample of water from Hottle Spring. The observations have been reduced to a scale of 100% for the maximum. The curve marked "Decay A and C" is made by observing the deflections after the emanation has been pumped out. By means of this experimental curve observations at any time can be reduced to the maximum or three-hour values. For exact work the emanation should be placed in the electroscope and allowed to stand for three hours and several observations made and the mean used. The curve is for all practical purposes horizontal from three to four hours.

In all these observations the deflections have been corrected for the natural leak of the electroscope due to the natural ionization of the air.

Before giving results, I shall speak of some factors which may influence the results. Since the emanation gas is dissolved in the water and is removed by boiling or by shaking, care should be used in filling the shaking can. Immerse the can in a pool as close as possible to the source and allow the water to flow in gently. Filling by dipping and pouring with a smaller vessel removes some of the gas. If before the water issues from the ground it trickles over rocks in the presence of air which is not charged with emana-

Fig. 7.


Absorption of Radium Emanation by Water at Various Temperatures.
⊙, Kofler, Akad. Wiss. Wien, Ber. 121, 2a P. 2193.
× Boyle, Phil. Mag. 22, P. 840, 1911
Absorption Coefficient, α.
.5
.4
.3
.2
.1
.0
0
10
20
30
40
50
60
70
80
90
100
Temperature, C.

tion it must lose some of the emanation. This may explain the variation of springs in the same locality.

Observations made at the spring simply show the emanation content of the water. This may be due to three things. The emanation which is continually forming from traces of radium in the soil and rocks through which and over which the water passes is dissolved in the water and passes out with the water. It may be due to radium salts dissolved in the water. Or it may be due to some product of the thorium or actinium series. In the first case the water will show radioactivity by the emanation method and after standing in a closed vessel for a month will not show any emanation. In the second case it may show radioactivity the same day as taken from the spring and after standing a month in a closed vessel it will show more or less emanation than at first. In any case the emanation content after standing one month is equal to the amount of radium dissolved in the water, since one curie is the amount of emanation which is in equilibrium with one gram of radium.

All the observations given below are for the emanation content of the water as taken from the spring or well. These observations were taken from time to time on various springs and wells in Indiana and Ohio. The date of observation, approximate location of the spring, and temperature of the water at the spring is given.

TABLE 5.

SPRINGS.

NAME.	Location.	Date.	Temp. C.	Curies, Per Liter.
Ill. Cent.	Bloomington	Mar. 4, 1914.	12.5°	$600.X10^{-12}$
Young	Brown County, Indiana	Mar. 6, 1914.	16.°	355
J. C. S.	Two miles southeast of Bloomington	Mar. 13, 1914.	10.3°	430
J. C. S. Old	Two miles southeast of Bloomington	Mar. 14, 1914.	11.5°	660
J. C. S.	Two miles southeast of Bloomington	May 16, 1914.	11.5°	170
Ill. Cent.	Bloomington	May 23, 1914.	12.2°	265
Stone	Two miles southwest of Bloomington	May 23, 1914.	11.°	77
Weimer	Three miles southwest of Bloomington	May 23, 1914.	12.3°	175
Hottle	Bloomington	Sept. 24, 1914.	13.°	650
South	Morning Sun, Ohio	Aug. 24, 1914.	13.°	420
C. McQ.	One mile southeast of Morning Sun	Sept 2, 1914.	16.°	560
I. B.	One-half mile west of Morning Sun	Sept. 7, 1914.		100
C. D. McQ.	One mile west of Morning Sun	Sept. 7, 1914.	15.8°	250
C. D. McQ.	(Wood) one mile west of Morning Sun	Sept. 7, 1914.	19.5°	300
W. P. McQ.	One mile west of Morning Sun	Sept. 7, 1914.	17.°	610
C. W.	Two miles west of Morning Sun	Sept. 7, 1914.	19.5°	140
Tal. No. 1	One mile northeast Col. C. O.	Sept. 7, 1914.	17.°	350
Tal. Upper	One mile northeast Col. C. O.	Sept. 7, 1914.	17.°	350

City Water.

Location.	Date.	Temp. C.	Curies Per Liter.
Bloomington, Ind	Feb. 24, 1914.	5°	$27.X10^{-12}$
Bloomington, Ind	Mar. 2, 1914.	Hot.	41.
Indiana University	Mar. 2, 1914.	5°	45.
Oxford, Ohio	Aug. 12, 1914.	19°	70.
Union City, Ind	Aug. 18, 1914.	19°	45.
Celina, Ohio	Aug. 20, 1914.	26°	7 .

Wells.

S. R. R., Morning Sun, Ohio	Aug. 27, 1914.	15°	95.
J. S. R., Farm. One mile north Morning Sun, Ohio	Aug. 27, 1914.	.....	70.
C. McQ. One mile south Morning Sun, Ohio	Sept. 2, 1914.	13°	200.
Forest Park. Six miles east Union City, Ind	Aug. 18, 1914.	12°	185.
Melted snow water	.....	.....	6.
Boiled water	.....	.....	00.

In some papers the radioactivity of springs is given in Mache units. One mache unit = 364. X 10^{-12} curies per liter. (Le Radium, Vol. XI, p. 5, 1914.) In several papers higher ratios have been used, 500. X 10^{-12} in some cases.

The radioactivity of these springs is not great, but it is high compared with ordinary springs of some localities. There is a great deal of variation from spring to spring, but this may be explained by assuming that some emanation has been given up before issuing from the ground. The variation of the same spring from time to time is dealt with in another paper.

Department of Physics,
Indiana University, December 21, 1914.

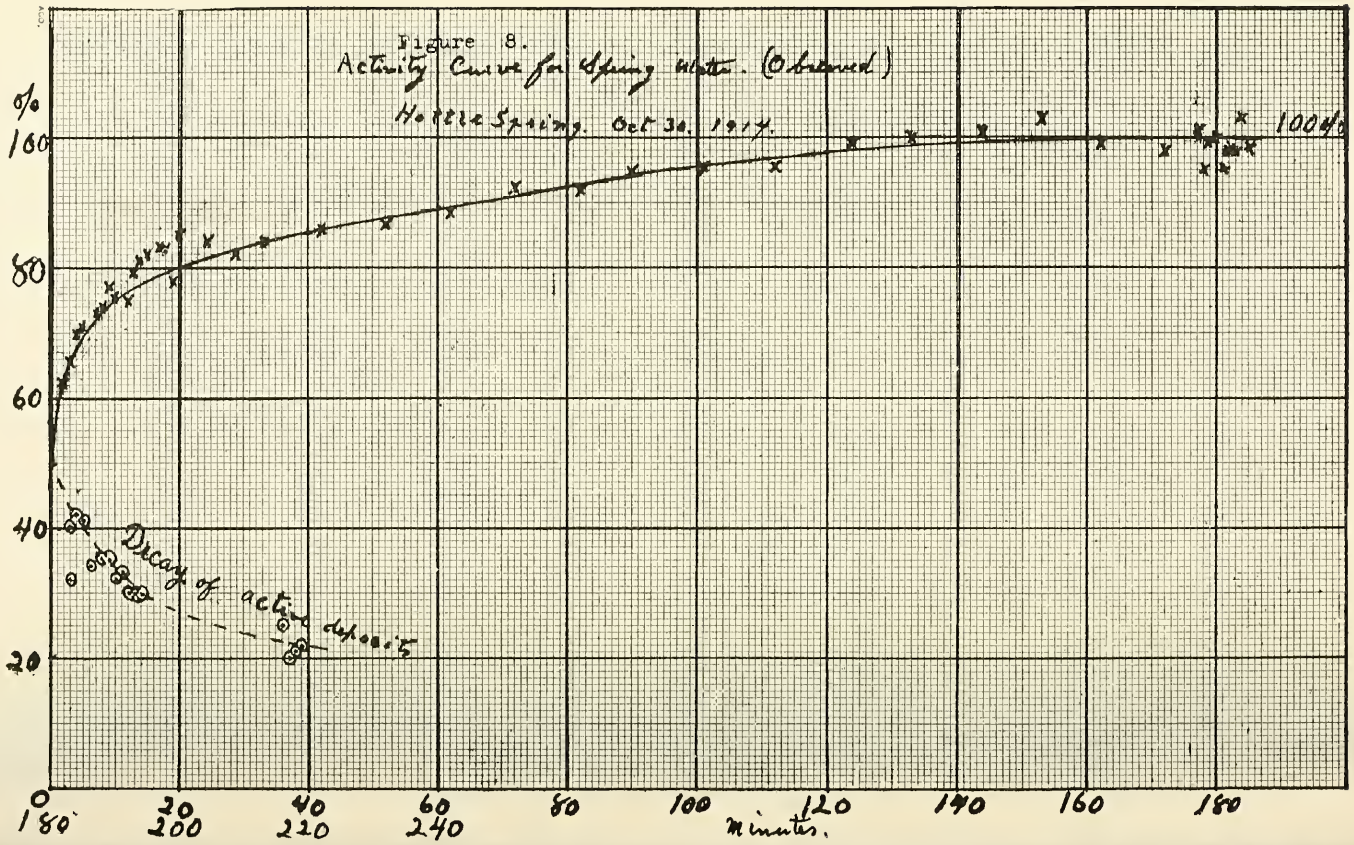


Figure 8.
Activity Curve for Spring Water. (Observed)
Hotel Spring. Oct 30. 1917.
%
100%
80
60
40
20
0
Decay of activity
180
200
220
240
20
40
60
80
100
120
140
160
180
minutes.