RADIOACTIVE PROPERTIES OF ROCKS SOILS AND WATERS OF THE SOUTHERN CALIFORNIA REGION.

Thesis

by

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ABSTRACT.

RADIOACTIVE PROPERTIES OF ROCKS, SOILS, AND WATERS OF THE SOUTHERN CALIFORNIA REGION.

This investigation includes measurements on waters from Lake Arrowhead, Arrowhead Hot Springs, Harlem Hot Spgs., Pacific Ocean, and from numerous wells and tunnels of the Pasadena and neighboring water supplies. It also includes measurements on rocks, soils, and crude oil.

The activity of the water of Lake Arrowhead is found to be about one hundred times smaller than the minimum that could be detected in the electroscopes used for cosmic ray measurements. This lake is, therefore, very suitable for the cosmic ray measurements.

The Pasadena wells yield waters approximately one thousand times as active as the Lake Arrowhead water; and is, therefore, not suitable for cosmic ray measurements.

The ratio between the activity of the soil at Lake Arrowhead and that of the soil on the campus, as obtained by Millikan and Cameron, from their cosmic ray data, is in good agreement with the results in this report.

The average radium content of the acid intrusive rocks in the vicinity of Devil's Gate Dam, according to the measurements so far made, is 2.3×10^{-12} gms. of radium per gm. of rock.

The emanation in crude oil was found to be of the same order of magnitude as that found in well water.

Pasadena tap water contains about 1 eman or 1×10^{-10} curies per liter while the average of the sources is about five times as great.

RADIOACTIVE CONTENT OF ROCKS, SOILS, AND WATER.

Introduction.

Many extensive investigations on the distribution of radioactive material throughout the crust of the earth have been carried out by Strutt[1], Joly[2], Elster and Geitel[3] and many others, but so far the Southern California Region has been almost, if not entirely, devoid of such investigation. If is, therefore, of prime importance to have data on this region that may be available for the various problems dealing with economic and physical geology.

On account of the lack of data from this region, this problem was put before me by Prof. Millikan.

A second reason for taking up this investigation was of greater importance, even than the first, at least of greater immediate importance. Namely: that of finding the activity of the soil in the vicinity of cosmic ray measurements by Millikan and Cameron[4]. Also it is essential to know the activity of the waters into which their electroscopes were lowered.

Much of the data included in this report deals with the water supply of the City of Pasadena. Numerous tunnels and wells, as well as rocks, in the vicinity of the tunnels and from the drill cores of the wells have been studied. The report also includes data on waters from the Pacific Ocean, Lake Arrowhead, Arrowhead Hot Springs, Harlem Hot Springs, and numerous sources east of Pasadena. Measurements on crude oil, on several ores, and on soils are included.

Some of the problems of interest are the relation between the activity of waters and the underground structure - especially the relation to fault lines. The problem of the influence of the heat developed by radioactive materials upon the surface history of the earth has not yet been satisfactorily solved. Furthermore, the distribution of radium throughout the crust of the earth is remarkably uniform, and so far no reason has been found for this distribution.

RADIOACTIVITY.

In this investigation I made use of only one of the radioactive gases; namely radium emanation - sometimes also designated by radon or niton. Of the three radioactive elements that remain in the gaseous state at ordinary temperature and pressure two are rather short lived. Actinum emanation having a half-value period of only 3.92 seconds and thorium emanation of 54.5 seconds. These two have disintegrated to practically zero value before any gas is drawn into the electroscope. In the main, then, what follows will deal only with radium emanation and, of course, in the case of rock, the radium with which it is in equilibrium.

Some of the characteristics of radium emanation (which will now be designated simply as emanation) of interest in the present investigation are the following.

Occlusion in solid bodies: Numerous solid bodies such as wax, celluloid, rubber, clay, platinum, etc., occluded emanation in considerable quantities. Glass and most metals occlude very minute quantities. Charcoal, especially at low temperature, absorbs practically all the emanation. Colloidal solutions also **have** absorbing qualities.

Solubility in water is given by the following eq.

where Em_w is quantity of Em in the water and V_w the volume of water and Em_a and Va the corresponding symbols for air.

$$\alpha = \frac{Em_w \cdot Va}{Em_a \cdot Vw}$$

The following values of α for different temperatures are given by Meyer and Mache.

C^o	0	10	20	30	50	70	1000
α	0.510	0.351	0.254	0.195	0.138	0.117	0.108

Emanation is about 43 times more soluble in crude oil than in water.

The influence of acids and salts on the solubility of emanation in water was studied by Eve and McIntosh[5] and others.

The coefficients of diffusion in air and water as found by various workers are approximately:

For water at 18° C $\mu = \cdot 9 \, cm^2 \, day^{-1}$

For air $\mu = \cdot 1 \, cm^2 \, sec^{-1}$

The desintegration of Ra EM is given by the eq.

$$N_t = N_0 e^{-\lambda t}$$

A table of values is given in Radioactivität by . Meyer and E. Schweidler that is very useful in n ng time corrections for the decay of Ra Em.

The following constants expressed in days and hours, where T is the half value period, λ the radioactive constant and τ the average life of an atom are of value.

$T = 3.825d = 0.918 \times 10^{2}h$

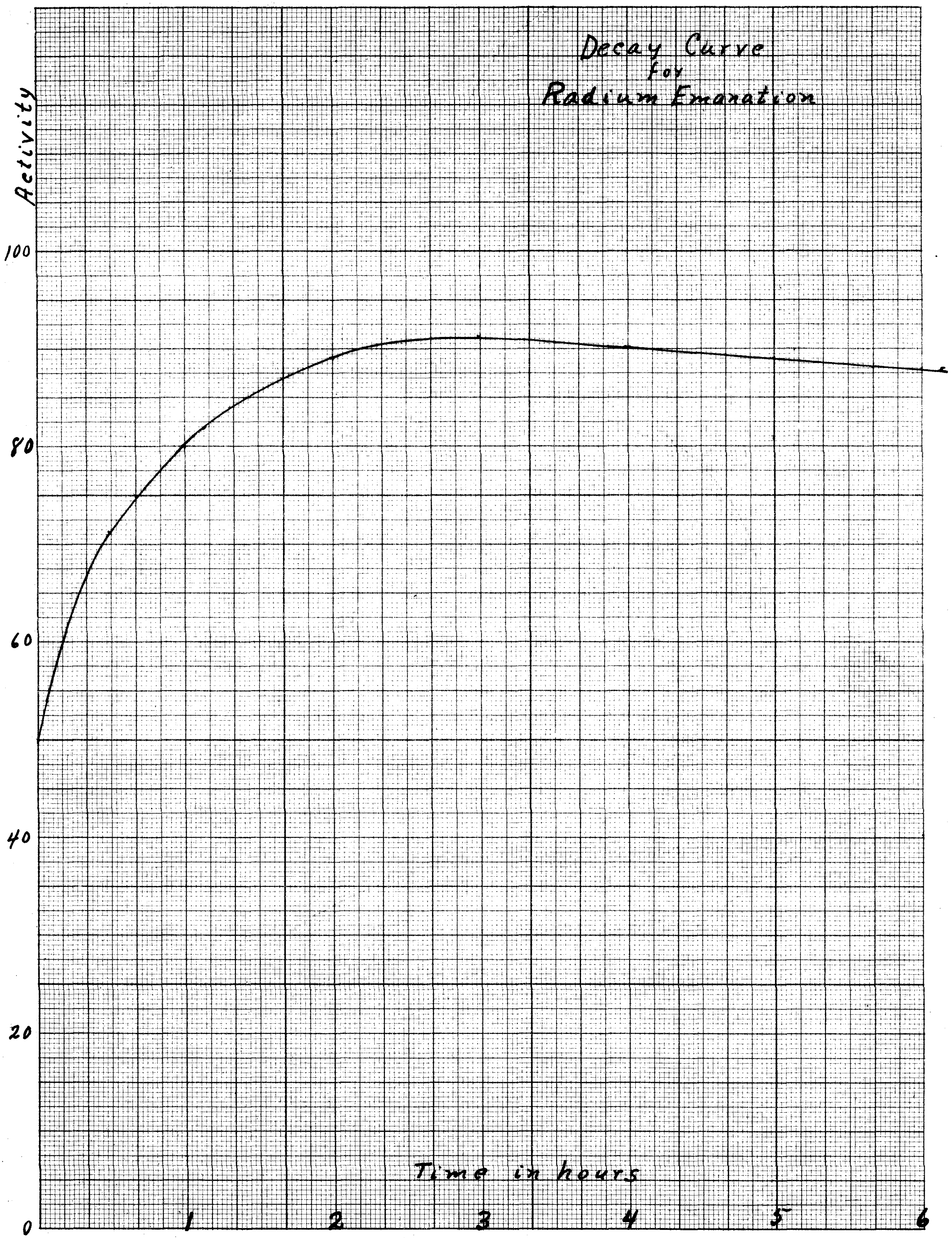
$\tau = 5.518d = 1.324 \times 10^{2}h$

$\lambda = 0.8122\ d^{-1} = 7.551 \times 10^{3}h^{-1}$

<u>Units:</u> At the Second International Congress at Brussels in 1910 the curie was designated as the quantity of emanation in equilibrium with one gram of radium. The Eman is equivalent to 10^{-10} curies. The concentration unit called the Mache unit is sometimes used.

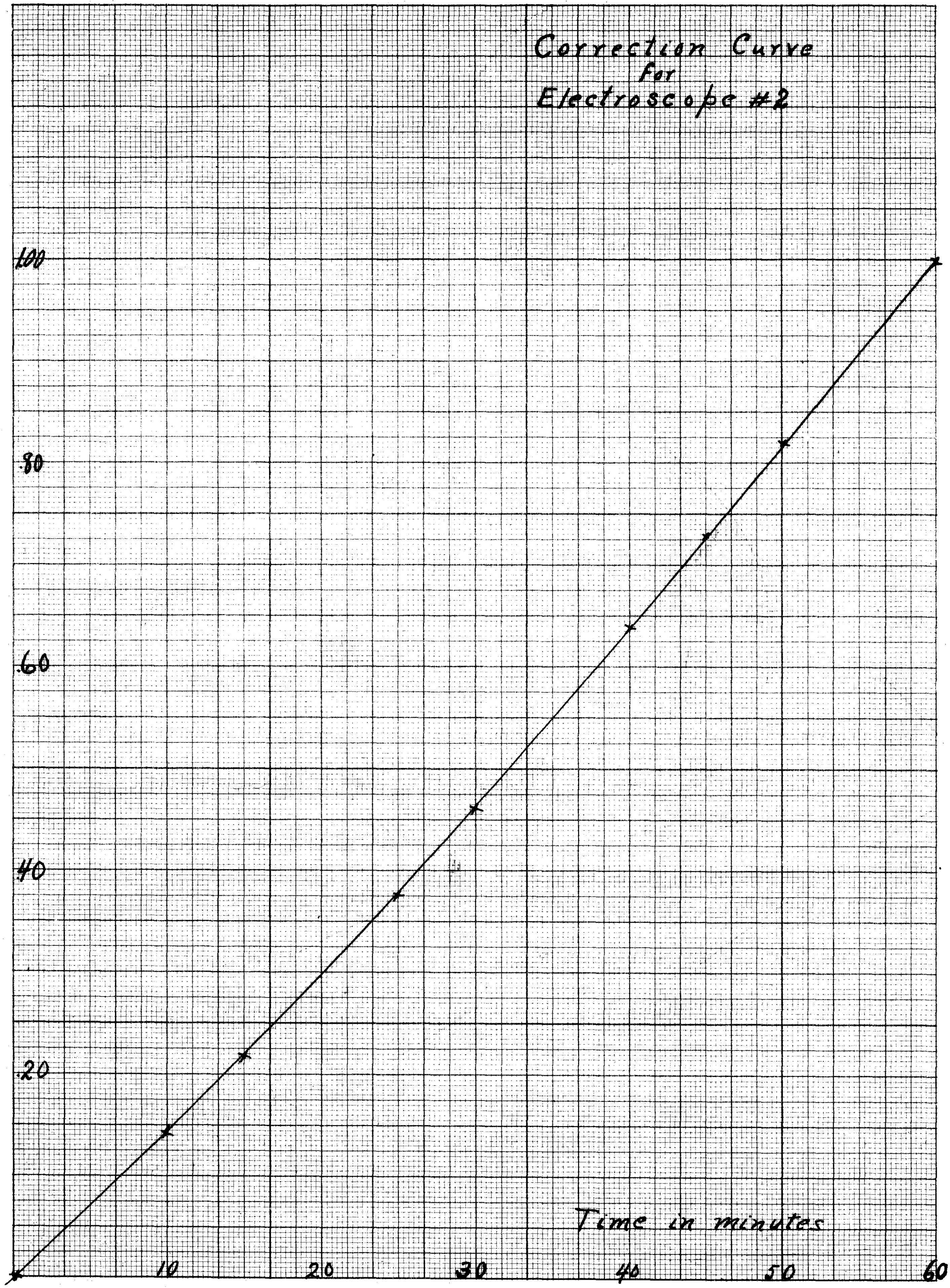
I Mache unit- = 3.64×10^{-10} curies per liter = 3.64 emans per liter.

The ionizing properties of radium emanation are greatly increased when its disintegration products are allowed to come to the equilibrium value. Thus the ionization is augmented by the product RaA, RaB, and RaC.- Furthermore, the ionization is due chiefly to α rays and to a less extent by β ray; the γ rays have a negligible effect. The activity is plotted against time in Fig. 1 and it is seen that a maximum accurs after 3 hours, and the activity remains fairly constant for about an hour. This, then, would be the ideal time to observe the electroscope leak and is the period chosen by some investigators in which to make their observations. Others prefer to make


Decay Curve
for
Radium Emanation
Activity
100
80
60
40
20
0
1
2
3
4
5
6
Time in hours

their observations during the 10-20 minute period as it was found by Satterly[6] that a slight maximum occurs at that time. Any period may be chosen so long as the calibrations are made to correspond with the interval chosen. McLennan and Satterly[7] found that the ratio between the electroscope leaks corresponding to the 3 hours period and the 10-20 minute period was 1.44 and used this ratio to check their results when time permitted to allow the emanation to remain in the electroscope for three hours.

The writer started to take readings 15 minutes after the gas was admitted to electroscope #1 and continued for 30 minutes. When electroscope #2 was used the initial reading was taken 30 minutes after the emanation was admitted, and in case the quantity of emanation was small, the final reading was taken one hour later. In case the quantity of emanation was great the time required for the leaf to pass 100 divisions of the microscope field was observed. Obviously some correction had to be made as, for example, if 100 divisions were passed in 15 minutes this does not mean that the leak per hour would be 400 scale divisions, but rather 455 as shown be accompanying curve Fig. 2. This curve was obtained by averaging a large number of curves; the ordinates being obtained by dividing the leak for time T by total

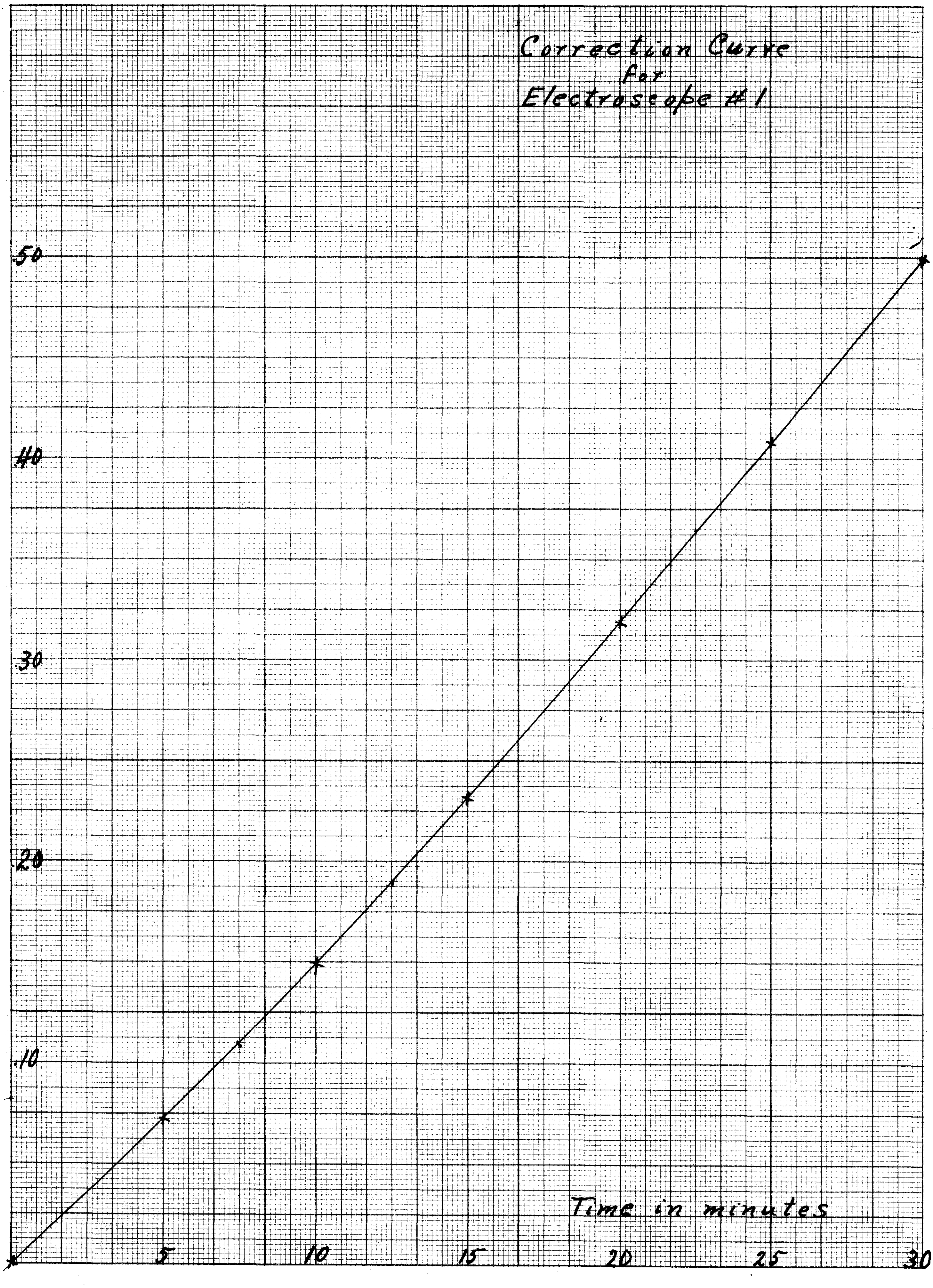

Correction Curve
for
Electroscope #2
Time in minutes
100
80
60
40
20
10
20
30
40
50
60

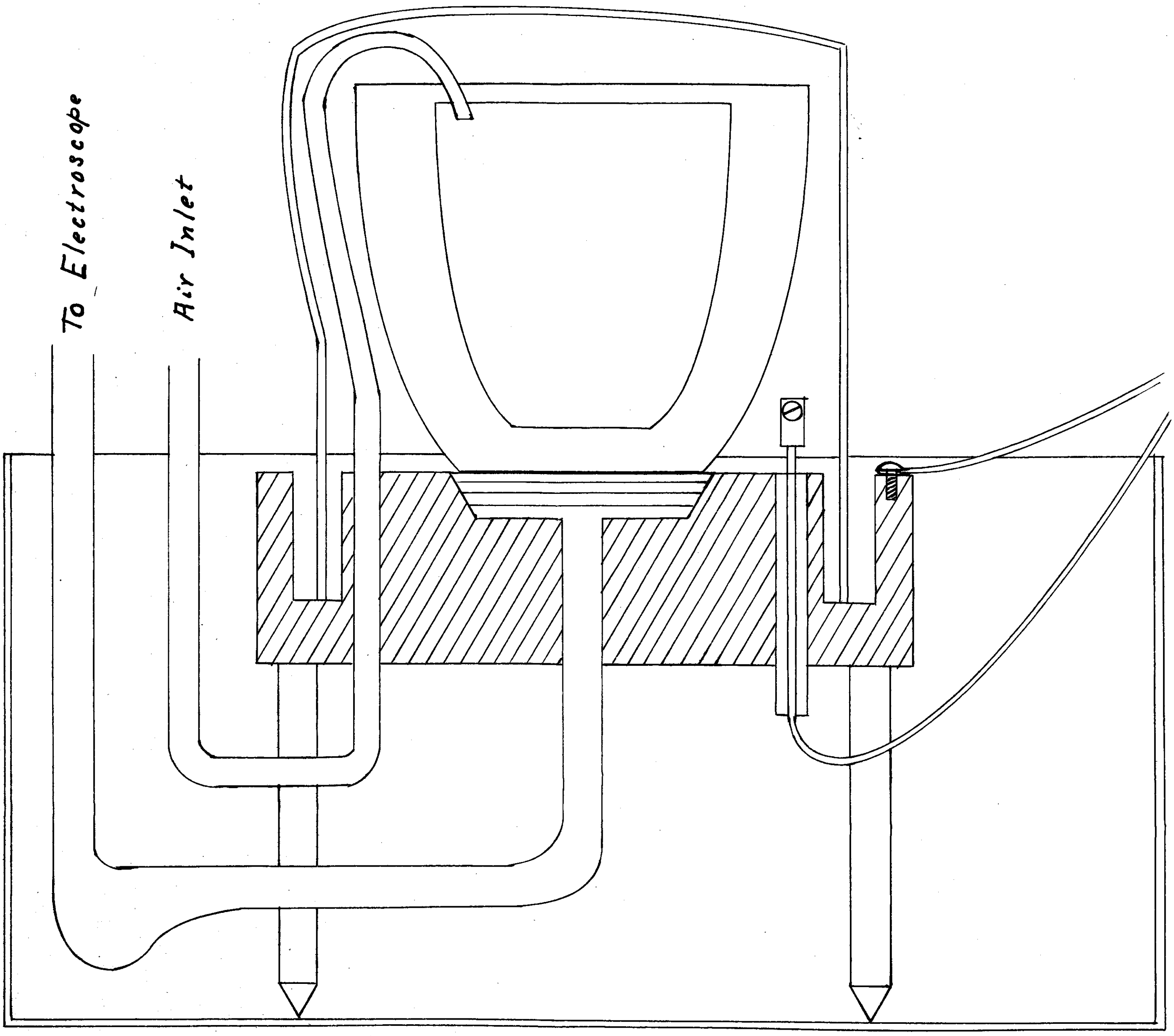
leak at T=one hour after correcting for the natural leak. This curve is not absolutely correct in that a leak from 0 to 10 is not exactly equal to, say, a leak from 90 to 100. However, the distance travelled by the leak is small and, therefore, the error also small and may be neglected. Fig. 3 is the corresponding curve for electroscope #1.

APPARATUS.

Description of the Furnace.

The furnace is almost identical with that used by Joly.[§] Fig. 4 represents a cross-section of the furnace drawn to natural size. The base, of Swedish iron, is four inches square and about one and one-eighth inches thick and has four supporting legs of brass. An annular groove about three-fourths of an inch deep is cut into it for admitting the pyrex cover. When in operation the groove is filled with mercury and the apparatus is set into a pyrex crystallizing dish which is completely filled with water thus covering the base and the mercury outside of the pyrex cover. The purpose of the water being, of course, to keep the base and the mercury seal cool when the furnace is hot. Under the pyrex cover we have a quartz crucible of about 150cc capacity resting upon several layers of asbestos for thermal insulation. Inside this quartz crucible is the heating element which is not shown


Correction Curve
for
Electroscope #1
.50
40
.30
.20
.10
Time in minutes
5
10
15
20
25
30



PLATINUM FURNACE

Fig. 4.

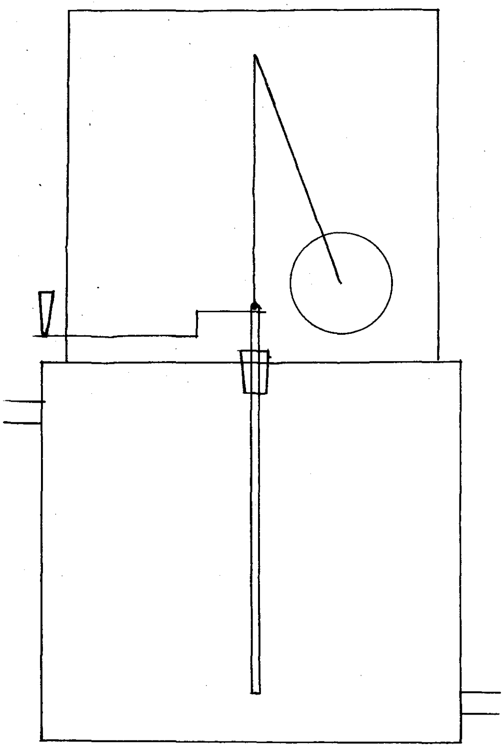
in the diagram, but which is put into position similar to that used by Joly, i.e., a sort of basket arrangement with vertical loops. One end of this heating elements, a platinum wire 1.2mm in diameter and slightly more than a meter in length, is connected to the base and the other end to the insulated terminal shown in the diagram under the pyrex cover. I found an old spark plug with mica insulation very suitable for this terminal. Finally, on the inside we have the platinum crucible of 61cc capacity. This crucible is inbedded in either magnesium oxide or aluminium oxide which serves several purposes; namely, that of electrically insulating the platinum crucible from the heating element and of thermally insulating the heating element from the outside. The platinum wire is placed as close to the platinum crucible as possible without danger of actual contact. The platinum crucible has a cover with two holes in it, one for observing the mixture while fusing, and to obtain the temperature with an optical pyrometer; and the other for admitting air to wash out the furnace to remove residual emanation. The air inlet is clearly designated in the diagram. The outlet for the emanation, air, carbondioxide, water vapor, etc., upon fusion is through the tube in the center of the base. This leads to the absorbing tubes. The bulge in the glass tubing at the bottom serves as a reservoir for the condensed water.

ELECTROSCOPES.

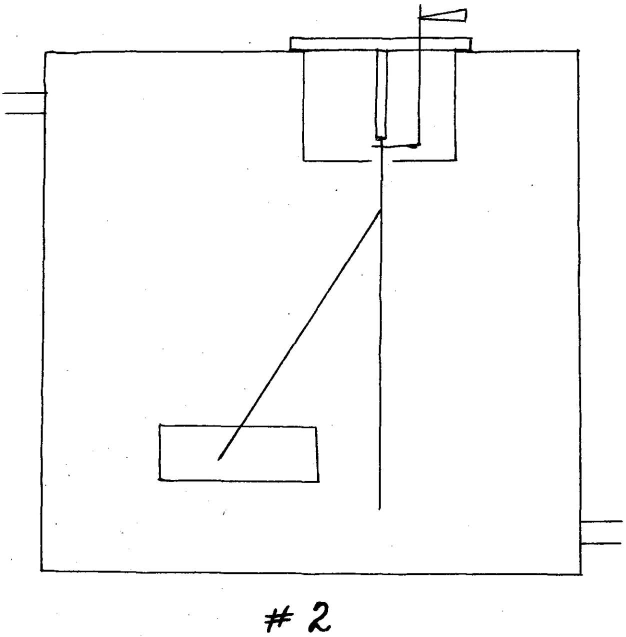
Two electroscopes were used for determining the radioactive content of water and thus one served as a check on the other when samples of the same source were tested in both electroscopes. Electroscope designated as #1 was of the ordinary gold leaf type mounted on top of an emanation chamber of about 600 c c capacity. The gold leaf (Fig. 5) was mounted on a flat nickled strip of brass, which in turn was mounted on a brass rod that extented through a quartz insulation in the top of the emanation chamber. A charging device and windows for observing the gold leaf with a Leitz microscope were provided. Electroscope #2 was of the C.T.R. Wilson type and was used for the solid materials as well as for water. Here the emanation chamber and electroscope are combined into one. A gold leaf of 1½mm width is mounted on a flat strip of polished metal which in turn is suspended from the top of the electroscope by a small quartz rod. A charging rod is provided. On account of the hygroscopic nature of quartz the admitted gases must be free from water vapor.

Apparatus for Separating Emanation from Solutions.

This is a familiar piece of apparatus and requires no more description than the accompanying sketch Fig. 6.

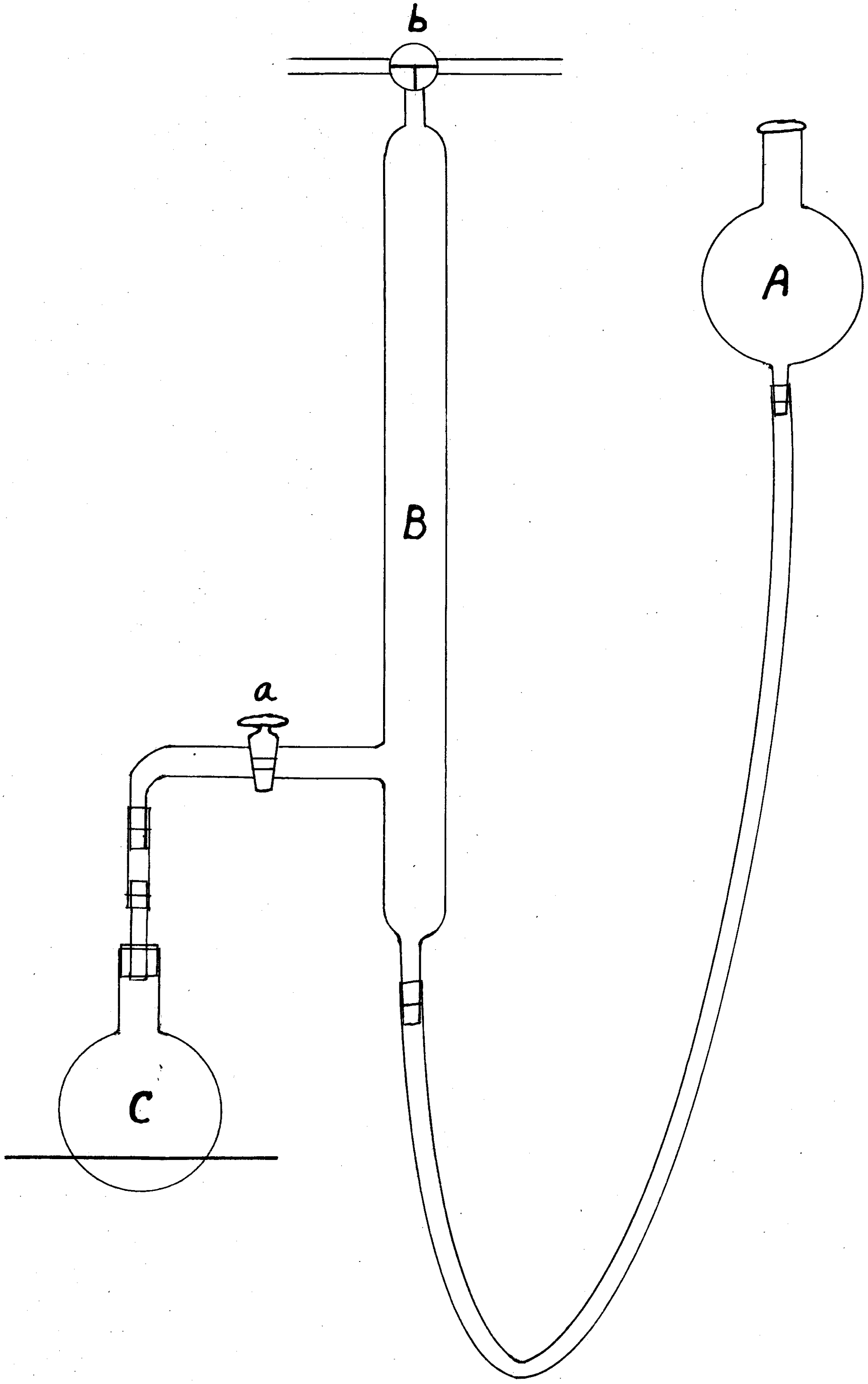


#1



#2

Fig. 5.



EMANATION APPARATUS

Fig. 6.

METHODS.

Of the various methods for determing the radioactive content of rocks and other materials there is, in my opinion, at the present time, no method that is completely satisfactory.

In this investigation I have copied almost identically the method of Joly[3] and, while it is probably as good as any, it still is not quite satisfactory for the reason that a quantity of the emanation is absorbed by the absorption tubes, the rubber-bag, and other parts of the apparatus. Also slight quantities may remain in the furnace and emanation may be lost upon grinding the material. However, these last two errors, if present at all, are quite negligible. I have drawn air through the furnace into a second electroscope after a run and found no residual emanation. According to the work of Gray and others on the loss of helium from powdered rock we can assume the loss of emanation due to this cause negligible. A compensating factor enters in that the electroscope is calibrated by the identical process followed in making determinations on rocks. If the quantity of standard ore is chosen so as to give approximately the same leak as the rock materials, and the times and temperatures are duplicated as nearly as possible, we can assume that the percentage of absorption in the apparatus is the same in all cases and the results should be correct.

Fletcher[9] drives the emanation from rocks by using an electric arc, but he uses very small quantities of material.

The solution method used by many investigators is a rather tedious procedure and often gives spurious results. It is often difficult to get the fused material into solution--usually an alkaline solution (by leaching) and an acid solution results. Sometimes the process of fusion with carbonates has to be repeated. After solution the samples have to be kept about three weeks before measureing the emanation and errors may then result if the solution is not limited, if traces of $H_2S\ O_4$ are present, or if a slight precipitate, which occludes the emanation, is present.

Eve and McIntosh[10] found that when H_2SO_4 is added to a solution of tinguaite only $\frac{1}{5}$ of the emanation present could be liberated by boiling. Levine[11] found that by adding $BaCl_2$ and H_2SO_4 to mineral water probably less than 1% of the radium remained unprecipitated.

I have used the solution method to some extent to see how the two methods compare. In calibrating the electroscopes I get a higher constant by Joly's method than I do by taking the same material and putting it into solution and again determining the constant and the results, which are again fairly consistent, are obtained by using different constants for the electroscope for the two methods. Further remarks will appear later.

A discussion of various methods is given by Joly,[8] Buchner,[12] Mache and Bamberger, and others.

Gamma rays have been utilized by Hess,[13] Dorsey[14] and Ludewig[15] in determining the radium content of materials.

I think a very satisfactory method could be developed by making use of an induction furnace and employing the absorbing power of cocoanut charcoal for emanation at low temperature and pressure. It could then be driven off by heating and passed into an electroscope.

PROCEDURE FOR WATER ANALYSIS.

Samples of water are collected in pyrex flasks which are securely stoppered immediately. The rubber stoppers are provided with a hole into which is inserted a piece of glass tubing about five inches long. This tube is sealed at the upper end so that when it is connected to the emanation apparatus it may be broken off. This prevents the loss of emanation which would otherwise occur. The size of the collecting flasks depends upon the activity of the water and also upon the electroscope used. In most cases I used two liter flasks when using electroscope #1 and 500cc flasks when using electroscope #2.

Distilled water is heated to boiling and poured into flask A (Fig. 6) into which a small stick of NaOH had first been put. The purpose of the NaOH is to remove any CO_2 that might be in the water and which would pass into the electroscope. With stopcock (a) closed and (b) open the water is allowed to rise in tube (B) so as to completely fill it. Stopcock (b) is then closed and flask (A) is lowered to a position near the lower end of tube (B). The flask (C) containing the water to be tested is placed into position and the tip of the glass tubing broken off. A flame is next applied to C and stopcock (a) cautiously opened; just partly at first and when the water starts to boil it is completely opened. The boiling continues for some time, in fact, until the water in tube B has come to the boiling point.

Vigorous boiling is usually continued for about 10 or 15 minutes to make certain that all the emanation is driven off. If the quantity of gas evolved is large it may be stored in a rubber bag by making use of the three way stopcock at the top of the apparatus. After the water has boiled for a sufficient time the flask (C) is removed from the apparatus and by lowering flask (A) air is allowed to bubble through tube (B). This tends to remove residual emanation from the NaOH solution. It is an added precaution that is hardly necessary. The gas is next drawn through H_2SO_4 and P_2O_5 into an exhausted electroscope.

PROCEDURE FOR SOLID MATERIALS.

The solid material is ground so as to pass through a sieve of 60 mesh per inch. About 4½ grams of the ground material is mixed with at least four times that weight of mixed sodium and potassium carbonates and several grams of powdered boric acid. The boric acid helps to increase the effervescence and also seems to make the melt more limpid. This mixture is placed into the platinum furnace and about 20 amperes passed through the heating element. The melting of the carbonates and the fusing of the material must be closely observed and the current regulated to prevent the melt from overflowing. Most of the effervescence takes place between 800 and 900°C. The current is gradually increased, after the effervescence ceases, so as to raise the temperature slightly over 1100°C. The current corresponding to this temperature is about 28 amperes.

During the precess of fusion the emanation is liberated from the solid material and is carried, with air and the evolved CO_2, through two tubes of soda lime and into a foot-ball bladder. After the melt has been heated to the required temperature the air and emanation are drawn through the absorbing tubes in the reverse direction into a previously evacuated electroscope. Before entering the electroscope it is made to pass through H_2SO_4 and a tube of P_2O_5. In order that the gold leaf of the electroscope may not be broken and also that the gases may pass through the absorbing tubes rather slowly; the entrance to the electroscope is made very small. This can be done by putting a piece of glass tubing with a pin hole in it at the entrance. About 13 minutes are required to fill electroscope #2. After the rubber bag is exhausted the air inlet to the furnace is opened and the electroscope is completely filled by drawing air through the furnace and the absorbing tubes. This removes the residual emanation that may be in the furnace.

An optical pyrometer is used to obtain temperature. A correction of about 15°C should be made for the pyrex cover.

CALIBRATION.

Carnotite of known uranium content was used for the purpose of calibration. For the calibration to be used with the solution method for rocks and the water analysis a carefully weighed quantity of Carnotite was fused with sodium and potassium carbonates and then put into solution. This solution was put into a flask and boiled to remove all the emanation and was then securely corked. After a number of days the solution was treated by the process given under the heading: "Procedure for water analysis."

A sample calculation is here given:

.0107 gms. Carnotite of 1.58% uranium content

2 days 172/3 hours = time stored.

.391 = part of emanation accumulated.

3.4×10^{-7} gms of Radium in equilibrium with 1 gm. of uranium

Leak of electroscope = 4.0 div. per hour

Emanation entered electroscope at	8:15
Initial reading = 1.4 at	8:45
Final reading = 34.4 at	9:45

Leak due to emanation = 33.0 - 4.0 29.0 div. per hour.

$$\frac{.0107 \times .0158 \times .391 \times 3.4 \times 10^{-7}}{29.0} = .776 \times 10^{-12} \text{ gms. Ra}$$

per scale div. = calibration constant.

For the gold leaf used in most of the water analysis the average of the calibration constants for electroscope #2 was .78 gms. Ra per scale division.

In order to check up on this value; Mr. Ransom, formerly at the Chicago Radium Institute, and now at this institute, kindly allowed me to use a standard radium solution he had in his possession. With this solution I obtained a constant of .775 gms. of radium per scale division. It is, therefore, quite certain that the calibration is correct.

To calibrate by the fusion method a quantity of carnotite was mixed with several gms. of rock, which had been previously tested and for which the electroscope leak per gram of rock was known. The reason for adding the rock was to obtain more effervescence and to meet as mearly as possible the actual conditions of making determinations on rocks. The natural leak of the electroscope and the leak due to the rock were subtracted from the total leak, and the remainder was taken as the leak due to the standard ore. The calculation of the electroscope constant was then similar to the preceding case.

Data
Activity expressed in curies per liter

Pasadena Water Supply.

Source	Electroscope #1	Electroscope #2	Average
	Wells		
Garfield	9.2×10^{-10}	9.1×10^{-10}	9.2×10^{-10}
Villa	8.4	8.3	
		7.9	8.2
Sunset		6.4	6.4
Sheldon	4.8		4.8
Oakland at Glenarm	3.5	3.6	3.6
Los Robles ~~at Allandale~~	7.5	7.1	7.3
Huntington	0.10		0.10
Busch	3.7	3.7	3.7
	Tunnels		
Richardson	5.6	5.5	5.6
Wilson		5.5	5.5
Devils Gate	5.0	5.6	5.3
Eaton #3	3.6	3.8	3.7
Post	2.1		
	1.6		1.9
Arroyo Seco Spring	0.11	0.13	0.12
Eaton Div.	0.78		0.78

Sierra Madre.

Wells.

#1	2.8	3.0	2.9
#2		3.2	3.2

Baldwin Rancho

#1		3.6	3.6
#2.	6.3		6.3
#5	5.2		5.2
#6		7.1	7.1
#7	3.3		3.3

Anita Baldwin Estate

#1	3.0		3.0
#2	3.5	3.2	3.3

Arrowhead Hot Springs.

Penyugal	2.3	2.1	2.2
Granite	1.9	2.1	2.0
Palm		3.7	3.7

Harlem Hot Springs.

	18.0		18.0

Montebello Oil Fields.

Crude Oil

Temple #15	1.9×10^{-10}	1.8×10^{-10}	1.9×10^{-10}
Temple #9	2.0	2.3	2.2

Sea Water.

Venice Pier	$.77 \times 10^{-12}$	
	1.10	$.94 \times 10^{-12}$

Lake Arrowhead

Depth	Electroscope #2	
Surface	$.63 \times 10^{-12}$	
25 ft.	1.04	
40	.49 and .51	
50	.21	$.58 \times 10^{-12}$

Radium Spa.

Electroscope #1

Jar #1	180×10^{-10} curies per liter.
Jar #2	270

Tap Water.

Lowest value	$.25 \times 10^{-10}$
Highest value	1.90×10^{-10}
Average of 20 determinations	$.97 \times 10^{-10}$

Rocks in vicinity of Devils Gate Dam.

All acid Intrusives.

1.	Granodiorite	Average	$2.6 \times 10^{-12} \frac{\text{gms. Ra.}}{\text{Gm. Rock}}$
2.	Aplite	"	2.0
3.	Quartz diorite gneiss	"	2.4
4.	Granodiorite from Arroyo Seco		2.3

Soils.

Campus	Average	$2.3 \times 10^{-12} \frac{\text{gms. Ra.}}{\text{gm. soil}}$
Arrowhead		3.9

DISCUSSION.

With several exceptions, the results obtained from all the wells, tunnels, and springs are included between the values of from 2 to 9×10^{-10} curies per liter. This would indicate that all these waters come from rock formations of approximately the same radium content. The activity of waters is, ofcourse, not an exact measure of the activity of the seat of these waters, as, for example, a large pool of water in a certain rock formation could not be expected to absorb as much emanation from the rock formation as would an equal amount of water in the same formation, but spread out into the form of a thin sheet. Another factor is the time the water is in contact with the rock formations. It is, therefore expected that the results would be only approximate.

"Eaton diversion" is a shallow stream and its low activity is easily explained by the fact that most of the emanation is lost to the air by the agitation of its waters. Post tunnel has a rather low value for the same reason.

In the case of the Arroyo Seco tunnel the low value is probably due to its waters being mostly surface water.

The Huntington Hotel well has a value of only 0.10×10^{-10} curies per liter; while the nereby well at Los Robles and Allandale has a value of 7.3×10^{-10} curies per liter. This variation is somewhat puzzling. Some of the emanation is lost as the water is rather forcibly ejected from the pump, but the loss due to that cause is not sufficient to account for the extremely low value. It may be possible that the water comes from a rather large undergroundpool that is in contact with relatively small rock surface.

The samples of crude oil had an emanation content of 2.1×10^{-10} curies per liter. However, due to the method of collecting the samples this value must be considered as being slightly below the real value. The samples could be collected only by opening a valve and releasing the oil at high pressure. The oil then came out as a spray rather than as a steady flow and some of the emanation escaped. However, due to the absorbing property of the oil the loss of emanation was not nearly so great as it would have been in the case of water. In any case, the quantity of emanation in the crude oil was of the same order as that found in well waters.

Samples of the oil were stored for one month and then tested for radium with a negative result.

Harlem Hot Spring yields water at 90°F and with an activity of 18×10^{-10} curies per liter. This is twice the maximum activity found in Pasadena. The sources of the thermal waters of Harlem and the Arrowhead hot springs are are very likely deep seated. The waters reach the surface through a fault or structural break in the granitic rocks. The Harlem Spring at the present time has to be pumped; and, according to the attendant at the Spring, the temperature of the water dropped in discrete steps from 130°F. to the present temperature of 90°F. with successive earthquake shocks. It can, therefore, be safely assumed that there is a mixture of deep seated and surface waters.

The average activity of the rocks measured is 2.3×10^{-12} grams of radium per gram of rock. This is in good agreement with results obtained by others.

The soils of the institute campus and Lake Arrowhead have an activity of 2.3×10^{-12} and 3.9×10^{-12} gms.of radium per gram of soil,respectively. These results seemed rather high at first,but repeated experiments yield the same result. Furthermore,the ratio between the two is in close agreement with the ratio obtained from cosmic ray data. The ratio from cosmic ray data is 1.5,while the ratio here obtained is 1.7. This is good agreement when it is remembered that no account is taken of the thorium content of the soils.

The measurements on Lake Arrowhead water may at first seem rather inconsistent,but due to the fact that three of the samples were 500cc samples and of low activity,the results even show the accuracy of the measurements. The values obtained from the two 21iter samples are .49 and $.63\times10^{-13}$ curies per liter.

The results show that Lake Arrowhead is suitable for cosmic ray measurements and that the Pasadena reservoirs are not.

The activity of Pasadena tap water is found to vary considerably, and on the average has an activity of only about 1/5 of the average activity of the sources. The loss of emanation is due to the water being stored in reservoirs.

For curiosities sake,two samples,taken at random from commercial water containers (Radium Spa),were measured.

This investigation is to be continued for some time, and more data will be added later. Also it may be possible find certain correlations and thus arrive at some definite conclusions.

The writer wishes to express his thanks to various members of The California Institute of Technology for their willingness to discus difficulties and to offer valuable suggestions. I am especially indebted to Mr. Engel for carefully selecting rock samples, and to Mr. Ransom for allowing me the use of a standard radium solution.

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