THE ABSORPTION OF THE RADIO-ACTIVE EMANATIONS BY CHARCOAL

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The experiments of Sir James Dewar in 1903 drew attention to the property possessed by the charcoal of cocoanut of absorbing gases in a remarkable degree. Since then this property has been investigated by several experimenters,¹ and has been applied by Sir William Ramsay in separating the inert gases, helium and neon from the air, and measuring the quantities in which they exist in the atmosphere. The results in the papers mentioned below may be summarized as follows:

1. The absorption of gases by cocoanut charcoal is greatly increased by lowering the temperature of the charcoal.
2. The charcoal has a greater "affinity" for some gases than for others, there being something of the nature of a selective absorption. In consequence of this property it is possible to separate from one another, in some degree, the constituents of a mixed gas. The best example of such separation is found in the work of Ramsay referred to above.
3. Of the inert gases of the argon family, argon is absorbed about the same as ordinary gases, but helium and neon in a much less degree, and helium less than neon.
4. The absorption is also influenced by the pressure of the gas in contact with charcoal, the pressure—concen-

¹ "The Absorption and Thermal Evolution of Gases Occluded in Charcoal of Low Temperature," Dewar, Proc. Roy. Soc., Vol. LXXIV, p. 122.

"The Separation of the Most Volatile Gases from Air without Liquefaction," Dewar, Proc. Roy. Soc., Vol. LXXIV, p. 122.

"The Determination of the Amount of Neon and Helium in Atmospheric Air," Ramsay, Proc. Roy. Soc., May 24, 1905.

"The Law of Distribution in the Case in which One of the Phases Possesses Mechanical Rigidity."

"Absorption and Occlusion," Travers, Proc. Roy. Soc., July 21, 1905.

tration curves varying in a regular manner with the temperature.

It was pointed out by Professor Rutherford, in a letter to *Nature*, October 6, 1906, that this property of coconut charcoal holds for the radio-active emanations, and in his letter are accounts of experiments demonstrating the fact. Professor Rutherford found that a slow current of air charged with the emanations of radium, thorium, or actinium is deprived of some or all of its emanation in the passage through a tube filled with coconut charcoal, and for this purpose the charcoal need only be at ordinary temperature. The complete withdrawal of the emanation only takes place when the air is passed very slowly through the charcoal; if the speed is increased, the amount of emanation emerging is increased also. In another experiment Rutherford found that if a tube containing less than a gram of the charcoal is open to a vessel containing the emanation from several milligrams of radium bromide, in the course of time the emanation is absorbed by the charcoal. If some powdered willemite is mixed with the charcoal, the gradual absorption is shown by the increasing brilliancy of phosphorescence of the willemite. It is not necessary to heat or exhaust the charcoal previously, but when either is done the emanation is more rapidly absorbed. The charcoal retains the emanation at ordinary temperature, but the greater part of it is expelled by heating to a low red heat.

The phenomenon of the absorption of emanation is not only of much interest in itself, but also in the fact that it may be of use in determining directly the amount of emanation existing in any particular gas. Mr. Eve, of this laboratory, has been utilizing the method to determine the amount of radium emanation existing in the free atmosphere.

It may be noted that since the emanation, in extremely small quantity, must be mixed with some gas, there is special interest in studying the information contained in the papers of Dewar and Ramsay concerning the absorption of the inert gases of the argon family which exist in the atmosphere. The

cases are analogous in that the emanations are believed to be chemically inert gases and are mixed with the containing gas in extremely small proportions, but there is the distinctive difference that the emanations decay with time while the gases of the argon family do not.

It is important to determine the laws which govern the absorption of the radioactive emanations, to know how far it depends on the speed of the containing gas through the absorbent, the temperature of the absorbent, and other conditions. An investigation of these points is the main object of this paper.

Preliminary work has been carried out with the emanations of radium and thorium.

In consequence of the delicacy of electrical tests for determining the presence of minute quantities of emanations from radio-active substances, it is possible to carry out experiments with quantities of emanation far too small for examination by chemical or other known physical methods, yet the measurements are capable of a high degree of accuracy.

Radium Emanation

A short account may be given of a few experiments on the diffusion of radium emanation from vessels containing the emanation mixed with air to vessels containing cocoanut charcoal. The apparatus used, Fig. 1, was an emanation electroscope, which consists of two chambers, one above the other. The lower chamber is an air-tight, cylindrical vessel of brass of about one liter cubical capacity, serving as an emanation reservoir, while the upper is a vessel covering the gold leaf system which can be observed through a mica window by a microscope with a scale in the eye-piece. The gold leaf is at the upper end of a brass rod which extends down into the lower chamber and is well insulated. The lower chamber is fitted with tubes and stop-cocks, through which air charged with emanation can be admitted or withdrawn at will by means of a pump. Connected with the emanation reservoir by a short tube of large cross-sectional area was a

glass bulb containing a few grams of cocoanut charcoal in granulated form. The outside of the electroscope was earthed and the ionization currents measured by the rate of movement of the gold leaf. The ionization current, or activity, at any time is proportional to the amount of emanation present in the emanation reservoir.

Fig. 1

When radium emanation was admitted into and retained in the electroscope, it was found that the decay of activity did not follow an exponential law, for while at the first the activity fell to half-value in 1.0 day, in the course of five or six days the rate was half-value in 1.6 or 1.7 days.

When the emanation reservoir was refilled with emanation and the charcoal vessel removed, so that the emanation could diffuse to the open air, the decay of activity did follow an exponential law, the time for diminution to half-value being 1.0 day. This result may be expected, for it means that the amount of emanation diffusing to the open air per second is proportional to the amount of emanation in the reservoir. P. Curie and Danne¹ performed experiments of this kind with capillary tubes as the communication from the emanation reservoir to the outside air, and found that the loss of emanation from the reservoir was exponential.

¹ P. Curie and Danne: *Comptes rendus*, 136, p. 1314 (1903).

It should be noticed that, in these experiments, if the emanation reservoir were sealed, so that there could be no diffusion to charcoal or to open air, the activity would fall to half-value in 3.75 days.

From the figures above, the rate of diffusion of the emanation from the reservoir to the charcoal was at first the same as the rate of diffusion to the open air, *viz.*: half-value in 1.0 day; but as time went on this rate gradually became less. A probable explanation of this fact is that the layer of charcoal first reached by the emanation acts as a good absorbent until it becomes saturated, very little emanation passing to the under layers until the top layer reaches this condition. In consequence, it will take time for the emanation to diffuse from the upper to the lower layers of charcoal, with the result of a gradual lessening of the amount of emanation absorbed from the reservoir.

Another experiment was made with the emanation diffusing to a very thin layer of charcoal, and the results obtained support this explanation. In this case the activity diminished at first at the rate of half-value in 1.3 days, but kept gradually changing until, after twenty-four hours, the rate was half-value in 3.2 days. At this stage there could be very little absorption, since the natural decay of the emanation itself is half-value in 3.7 days. We may say, then, that it took about a day to saturate the thin layer of charcoal.

In the experiments just described the charcoal has been contained in a vessel outside the emanation reservoir; when the charcoal is in the reservoir itself, the absorption takes place more rapidly, as the time for the emanation to diffuse through the connecting tubes is eliminated. In an experiment where a tray containing charcoal was placed in the bottom of the emanation reservoir, on admitting some emanation the absorption took place so quickly that there was not the usual rise of activity due to the active deposit, but, on the contrary, an immediate, rapid fall. With only a thin layer of charcoal—a sprinkling covering the bottom of the tray—there is a slight rise of activity due to the active deposit,

but not nearly in the same degree as if the charcoal had been absent.

The above experiments were all performed in a constant temperature room, so that all effects on the diffusion by changes of temperature and draughts of air were avoided.

More experiments, along the same lines as the above, are being carried on.

Thorium Emanation

In the case of thorium emanation, owing to its short period of decay—to half-value in 54 seconds—it is necessary to use a flow method of experiment. In other words, the emanation must be mixed with some gas, and conducted through tubes containing absorbing, or non-absorbing, material into a testing vessel, where it ionizes the air, and the ionization currents can be measured by means of an electrometer. The apparatus used for the experiments is represented by the accompanying diagram, Fig. 2.

Fig. 2

An air-pump supplies a current of air through a tube of thorium hydroxide, where the emanation mixes with the air and thence passes through tubes, containing absorbing or non-absorbing material, as the case may be, into a testing vessel of the ordinary cylindrical type. An accurately calibrated manometer in the circuit measures the velocity of the air current. The testing vessel is connected to one pole

of a battery of electromotive force sufficient for complete saturation, the other pole of the battery being earthed. The central rod of the testing vessel is connected with a suitable electrometer, and a condenser of adjustable capacity is placed in parallel with it. It should be noticed that, with this arrangement, absorption of the emanation can only take place after the charcoal has absorbed its full amount of the atmospheric gases.

The weight of thorium hydroxide used was 37 grams.

Using this apparatus when there is no absorbing material between the thorium hydroxide and the testing vessel, and taking observations of the ionization current with varying speed of the air current, we get a curve such as is shown in Fig. 3 (Table I), which has ionization currents (i) for ordinates and speeds of the air current in cubic centimeters per second (q) for abscissae. We shall hereafter call this the $i - q$ curve.

Fig. 3

The shape of this curve can be deduced from theoretical considerations by the following:

The thorium hydroxide, in radio-active equilibrium, gives off free atoms of emanation at a constant rate, and these are all removed by the air current. In consequence,

there will be the same number of emanation atoms leaving the thorium tube per second for any speed of the air current.

TABLE I—(Fig. 3)
Emanation Directly into Testing Vessel

Flow in cc/sec.	Ionization current in arbitrary units
0.30	91
0.37	174
0.76	380
1.12	441
1.86	464
2.52	438
3.80	291
5.18	238
6.60	224
8.40	192
10.70	169
12.60	149

The ionization current in the testing vessel is proportional to the number of emanation atoms breaking up per second in the testing vessel, and this number is λ times the number of emanation atoms present, λ being the coefficient of decay of the emanation.

Let N = the number of free emanation atoms given off by the thorium hydroxide per second,

q = the flow of the air current in cubic centimeter per second,

t = the time for the air to pass from the thorium hydroxide to the testing vessel.

Then with q cubic centimeter of air entering the testing vessel are associated $Ne^{-\lambda t}$ atoms of emanation. If we denote the number of emanation atoms per cubic centimeter of air at the entrance of the testing vessel by n_0 ,

$$\text{then } n_0 = \frac{Ne^{-\lambda t}}{q}.$$

Let V be the total free volume of the conducting tubes between the thorium hydroxide tube and the testing vessel, then $t = \frac{V}{q}$,

$$\text{and } \therefore n_o = \frac{Ne^{-\lambda t}}{q} = \frac{Ne^{-\lambda \frac{V}{q}}}{q}.$$

To obtain the total number of emanation atoms, P , present in the testing vessel, consider an element of volume dw , with a volume w between the entrance and the element as shown by Fig. 4, $\frac{w}{q}$ is the time for the air to traverse the

Fig. 4

volume w , and therefore, if n = the number of emanation atoms per cubic centimeter of air within the element,

$$n = n_o e^{-\lambda \frac{w}{q}}.$$

The total number of emanation atoms in the element dw

$$\begin{aligned} &= n dw \\ &= n_o e^{-\lambda \frac{w}{q}} dw \end{aligned}$$

$$\therefore P = \int_0^W n_o e^{-\lambda \frac{w}{q}} dw$$

where W is the whole volume of the testing vessel.

Integrating, we get

$$P = \frac{qn_o}{\lambda} \left[1 - e^{-\lambda \frac{W}{q}} \right],$$

and substituting for n_o ,

$$P = \frac{N}{\lambda} e^{-\lambda \frac{V}{q}} \left[1 - e^{-\lambda \frac{W}{q}} \right].$$

The ionization current is proportional to the number of emanation atoms breaking up per second, which is λ times the number present, *i. e.*, λP .

Hence, if i is the ionization current, $i = K \lambda P$, where K is a constant,

$$\text{and } \dots i = K N e^{\frac{-\lambda V}{q}} \left[1 - e^{\frac{-\lambda W}{q}} \right] \dots \dots \dots (1).$$

If we plot a curve with ionization currents as ordinates and flow of air in cubic centimeter per second as abscissae, we can see from (1) what the shape of the curve should be.

Denoting $-\lambda V$ as a , and $-\lambda W$ as b , we have,

$$i = K N e^{\frac{a}{q}} \left[1 - e^{\frac{b}{q}} \right],$$

from which we can at once see that $i = 0$ when $q = 0$ or ∞ . Differentiating, we get

$$\frac{di}{dq} = K N e^{\frac{a}{q}} \left[(a + b) e^{\frac{a}{q}} - a \right],$$

from which it follows that i is maximum when

$$q = \frac{a}{\log \frac{a}{a+b}}, \text{ or}$$

$$\text{when } q = \frac{\lambda V}{\log \frac{V+W}{V}} \dots \dots \dots (2).$$

The curve, then, must rise from zero to a maximum, and fall off to nothing as the speed of the air current increases to infinity.

It can be seen that the curve of Fig. 3 conforms to these conditions.

The relation deduced in (1) shows us that the ionization current depends not only on q , the speed of the air current, and on W , the volume of the testing vessel, but also on V , the free volume of the space through which the emanation has to pass before it reaches the testing vessel. When V is increased i is decreased; and, following from the condition for a maximum (2), q must be increased to give the maximum

ionization current. Hence it follows, that in experimenting to compare the absorption by different substances or by different quantities of the same substance, the free volume between the thorium hydroxide and the testing vessel should be constant. In the experiments described later, where it was desired to compare the absorption, care was taken to have this condition fulfilled.

When an absorbing material is inserted between the thorium hydroxide and the testing vessel, there is less emanation available for ionization and the $i - q$ curve is much altered. In the case of charcoal, in granulated form, it has been found that the amount of absorption depends on¹

- (a) The nature of the charcoal,
- (b) The speed of the air current through the absorbent,
- (c) The amount of charcoal surface exposed to the emanation,
- (d) The temperature of the charcoal.

In the experiments on these points, the results of which are given later, the $i - q$ curves in the cases of non-absorption were obtained by substituting for the tube containing the charcoal a similar tube containing a non-absorbing sand of the same volume and of the same size grain as the charcoal used. This precaution was necessary in order to have the same volume between the thorium hydroxide and the testing vessel in the case of non-absorption as in the case of absorption. In all experiments with a given sample of sand or charcoal, an attempt was made to have the grains of uniform size by sifting through a set of sieves and collecting separately the residues caught in the meshes of each sieve.

(a) Nature of the absorbent

Fig. 5 (Table 2) shows the $i - q$ curves, taken under the same experimental conditions, for the cases of absorption by ordinary wood, animal, and cocoanut charcoal, all of the same volume and same size grain. The wood charcoal weighed 0.77 gram, animal 2.25 grams, and cocoanut 2.17 grams.

¹ "The Effect of Temperature and of Velocity of Gas Current on the Absorption of Radio-active Emanations by Charcoal," R. W. Boyle, Transactions of Royal Society of Canada, May, 1907.

TABLE 2—(Fig. 5)
Multiply currents by 617×10^{-15} for amperes

Non-absorption		Wood charcoal		Animal charcoal		Cocoanut charcoal	
Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current
Nat. leak at beginning	3.94	Nat. leak at beginning	0.81	Nat. leak at beginning	1.46	Nat. leak at beginning	1.63
0.40	31.6	0.53	32.7	0.37	3.48	1.07	6.24
0.63	90.8	1.07	113.9	0.60	26.8	1.48	16.9
0.93	135.8	1.52	141.0	0.97	73.0	1.89	30.08
1.33	161.1	1.95	147.0	1.34	88.4	3.07	42.8
1.83	169.9	2.37	136.4	1.67	97.1	3.47	46.1
2.34	157.7	2.84	123.2	2.38	98.0	4.15	45.7
2.74	149.1	3.62	101.7	Nat. leak at end	3.42	4.91	44.4
3.46	124.3	4.76	83.6			6.09	43.7
4.20	105.9	5.95	75.2			7.64	43.9
4.78	92.5	6.80	70.7			8.77	42.0
5.51	85.7	8.40	62.9			Nat. leak at end	2.26
7.10	78.0	Nat. leak at end					
8.66	68.5						
Nat. leak at end	5.69		1.84

Fig. 5

The curves show that cocoanut charcoal absorbs the most and ordinary wood charcoal the least of the three, and that the variation in absorptive power is very marked. In fact two different samples of the same kind of charcoal can show appreciably different absorptive powers. I have had samples of cocoanut charcoal, taken from different lots, showing considerable difference in this respect, the better absorbers being softer, less gritty, and less dense than the others.

(b) Speed of the air current

An inspection of the curves mentioned above, or of any of those following, will show that the amount of absorption depends on the speed of the air current which conducts the emanation through the absorbent material.

The absorbent must have time to absorb and at quick speeds it does not get as good a chance.

The following facts, taken from Fig. 5 and tabulated, illustrate very well (a) and (b). Here the percentage absorption for any given speed is represented by

$$100 \times \frac{\text{Difference between non-absorption and absorption ordinates.}}{\text{Non-absorption ordinate}}$$

The table shows that the percentage absorption is increased as the speed of the air current is decreased.

Absorbent	Speed of air current	Ionization current absorption	Ionization current non-absorption	Percent absorption
Wood charcoal	0.7	55	93	40.9
	1.0	94	138	31.9
	1.5	139	164	14.8
	4.5	86	92	6.5
	8.0	63	66.5	5.3
Animal charcoal	0.5	11	55	80.0
	0.7	31.5	93	66.2
	1.0	62	138	55.0
	2.0	98.5	164	39.9
Cocoanut charcoal	1.5	16	164	90.3
	2.0	28.5	164	82.6
	4.5	43	92	53.3
	8.0	40	66.5	39.8

(c) The surface exposed to the emanation

It is natural to suppose that the amount of absorption will in some way depend on the amount of the charcoal absorbing surface, that, in fact, the absorption will be increased if the surface be increased.

To prove the point experiments were performed, the results of which are given in Table 3 and Fig. 6.

For a particle of material the ratio of its surface to its mass becomes greater when the size of the particle is reduced; hence one lot of charcoal, equal in mass to a second lot, will have a greater or less surface than the second, according as the size of its grains is smaller or larger than the size of the grains of the second.

TABLE 3—(Fig. 6)
Multiply currents by 617×10^{-15} for amperes

Curve I, No. 10		Curve II, No. 20		Curve III, No. 30	
Flow in cc/sec.	Ioniza- tion current	Flow in cc/sec.	Ioniza- tion current	Flow in cc/sec.	Ioniza- tion current
Nat. leak at beginning	2.16	Nat. leak at beginning	1.07	Nat. leak at beginning	1.63
0.49	4.46	0.715	3.86	1.07	6.24
0.94	37.5	1.17	20.3	1.48	16.9
1.44	73.1	1.54	39.7	1.89	30.1
1.99	92.5	2.31	54.1	3.07	42.8
2.49	93.3	2.50	61.2	3.47	47.2
3.21	86.5	2.88	61.2	4.15	45.7
3.80	82.1	3.32	59.6	4.91	44.4
4.77	75.0	4.07	57.3	6.09	43.7
5.85	71.8	4.46	54.4	8.77	42.0
7.00	69.3	5.46	54.0	Nat. leak	—
8.34	64.3	6.73	52.4	at end	2.26
Nat. leak at end	3.29	8.46	50.5	—	—
		Nat. leak at end	1.34		

Non-absorption the same as given in Table 2.

In this particular experiment three equal masses, 2.17 grams, of the *same* sample of cocoanut charcoal were used, but the size of the grain was different in each case. The $i - q$ curves were taken for all four. I is the curve for the grains which were just caught in a sieve of ten meshes to the inch, II for twenty meshes to the inch, and III for thirty meshes to the inch. It can be seen that the larger the grain the less is the absorption, or, in other words, the smaller the surface the less the absorption.

The experiment shows that it is not the mass of the absorbent on which the amount of absorption depends, but rather the amount of surface which the mass exposes to the emanation.

By increasing the quantity of charcoal of a given size grain the amount of absorbing surface is also increased, and

Fig. 6

consequently there is increased absorption. This is demonstrated by the results in Table 4, Fig. 7, which shows the experimental $i - q$ curves for 1.18, 2.17, and 3.35 grams of the same sample of coconut charcoal of the same size grain (just caught in a sieve 30 meshes to the inch).

It must be noticed that the greater the quantity of charcoal, or, for that matter, the greater the absorbing capacity by any condition, the greater must be the speed of the air current to get any effect at all in the testing vessel. Thus, up to a speed of 0.5 cc per second there is practically 100 percent absorption for 1.18 grams of charcoal, 0.8 cc per second for 2.17 grams, and 1 cc per second for 3.35 grams.

(d) The temperature of the charcoal

The experiments of Dewar showed that when coconut charcoal is used as an absorbent of gases, the absorption is

TABLE 4—(Fig. 7)
Multiply currents by 616×10^{-15} for amperes

Non-absorption		1.18 grams cocoanut charcoal		2.17 grams cocoanut charcoal		3.35 gms. cocoanut charcoal	
Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current
Nat. leak at beginning	3.94	Nat. leak at beginning	1.79	Nat. leak at beginning	1.63	Nat. leak at beginning	0.88
0.40	31.6	0.62	4.90	1.07	6.24	1.17	2.11
0.63	90.8	0.98	20.3	1.48	16.9	2.03	8.84
0.93	135.8	1.36	45.2	1.89	30.1	2.82	18.2
1.33	161.1	1.80	61.9	3.07	42.8	4.00	25.2
1.83	169.9	2.19	69.0	3.47	47.2	5.05	28.4
2.34	157.7	2.77	73.4	4.15	45.7	6.21	30.8
2.73	149.1	3.38	67.9	4.91	44.4	7.19	32.8
3.46	124.3	4.13	62.7	6.09	43.7	8.28	32.5
4.20	105.9	5.18	58.5	8.77	42.0	9.37	32.3
5.18	94.0	6.27	56.8	Nat. leak at end	2.26	Nat. leak at end	1.11
6.40	84.1	8.26	54.4				
7.32	79.4	Nat. leak at end	2.65				
8.39	73.5						
Nat. leak at end	5.69						

greatly increased by lowering the temperature of the charcoal.

Fig. 7

The same law holds for the radio-active emanations when absorbed by any kind of charcoal. To determine the point experiments were carried out at different temperatures of samples of wood, animal, and cocoanut charcoal. The weight of charcoal used was about 1.8 grams.

Temperatures were measured by a Callendar platinum-resistance thermometer, the bulb of which was surrounded by the charcoal. The stem of the thermometer was sealed into the tube containing the charcoal by an asbestos and plaster of Paris packing, so that the joint was perfectly airtight. The diagram, Fig. 8, shows the arrangement.

The lowest temperatures mentioned were obtained from a mixture of solid carbon dioxide and ether, those next above,

viz., 17.6° , 16.1° , were the temperatures of the room. The remaining were obtained by heating in a specially constructed oven so that the temperature variation was not any more than 3° or 4° .

Fig. 8

For cocoanut charcoal, curves were taken at five temperatures, *viz.*, 185° , 124° , 69.5° , 17.6° and -75.5° C, Fig. 9, Table 5.

Fig. 9

TABLE 5—(Fig. 9)—COCOANUT CHARCOAL,
Multiply currents by 6.18×10^{-15} for amperes

Non-absorption	Temperature 185° C.	Temperature 124° C.	Temperature 69.5° C.	Temperature 17.6° C.	Temperature -75.5° C.
Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current	Flow in cc/sec.	Ionization current
Nat. leak at beginning	Nat. leak at beginning	Nat. leak at beginning	Nat. leak at beginning	Nat. leak at beginning	Nat. leak at beginning
0.38	0.93	3.71	0.93	1.35	0.86
0.53	6.39	19.4	1.25	1.72	2.71
	28.5	69.0	11.9	6.63	5.51
			46.1	19.7	12.4
0.71	59.4	109.5	77.6	27.1	14.6
0.92	89.6	124.1	88.9	35.5	23.4
1.10	108.9	127.7	90.3	41.0	27.3
1.36	130.0	115.0	88.4	45.9	29.8
1.58	138.2	97.8	78.9	47.2	30.9
2.10	139.1	85.2	74.7	48.4	32.5
2.61	132.5	79.9	3.19	49.1	34.5
3.32	113.3	70.6		49.5	36.5
4.08	96.2	8.13		47.3	36.2
5.05	85.3	64.1		45.7	37.2
6.19	78.3	9.26		43.9	37.2
7.17	73.4	Nat. leak at end		1.70	36.6
8.27	68.7				
10.54	59.6	5.04			
Nat. leak at end	3.31				1.47

For wood charcoal, three curves were taken corresponding to 170°, 16.1° and -74.2° C, Fig. 10, Table 6.

Fig. 10

TABLE 6—(Fig 10)—WOOD CHARCOAL
Multiply currents by 613×10^{-15} for amperes

Temperature 170° C.		Temperature 16.1° C.		Temperature -74.2° C.	
Flow in cc/sec.	Ioniza- tion current	Flow in cc/sec.	Ioniza- tion current	Flow in cc/sec.	Ioniza- tion current
Nat. leak at beginning	1.45	Nat leak. at beginning	3.38	Nat. leak at beginning	1.73
0.86	94.5	0.53	30.2	0.83	38.8
1.18	129.2	0.93	88.9	1.20	80.3
1.91	141.0	1.30	124.7	1.73	109.2
2.72	129.7	1.66	138.7	2.31	117.8
3.27	112.6	2.10	141.0	2.92	109.2
3.99	97.8	2.82	124.2	3.52	97.8
4.84	85.0	3.38	109.1	4.16	86.0
5.84	79.6	4.02	96.5	4.99	80.4
7.04	74.4	4.81	88.3	6.11	75.5
8.54	66.1	Nat. leak at end	4.50	7.27	70.6
Nat. leak at end	2.74			8.61	63.8
				Nat. leak at end	2.61

The curves show at once that the above law holds. Wood charcoal is not under any condition a good absorber, yet it is found to be affected by temperature according to the law. The absorption by animal charcoal is affected in a similar manner, but the results are not given here. The curve for non-absorption in the case of wood charcoal is not plotted in Fig. 10, for it is virtually the same as the curve for 170°C . At this temperature there was practically no absorption.

The following tabulated facts are taken from the curves of Figs. 9 and 10:

Wood charcoal

Speed of the air current	Percentage absorption		
	At 170°C	At 16.1°C	At -74.2°C
1.0	0 (practically)	20.6	39.2
2.0	0 "	2.14	18.3
3.0	0 "	1.47	11.0
6.0	0 "	—	3.16

Cocoanut charcoal

Speed of the air current	Percentage absorption				
	At 185°C	At 124°C	At 69.5°C	At 17.6°C	At -75.5°C
1.0	35.1	64.9	92.4	98.0	100
2.0	11.2	37.3	78.7	89.2	100
4.0	6.45	20.0	51.2	68.5	98.5
6.0	4.15	—	37.8	55.3	93.7
8.0	3.00	—	31.6	47.6	85.5

In a special experiment it was determined that the cocoanut charcoal begins to give off carbon dioxide at 211°C , yet at even higher temperatures than this it showed some power of absorbing the emanation. By using a large quantity of charcoal, and keeping the speed of the air current constant at 1.65 cc per second, it was found that the ionization current in the testing vessel kept slightly decreasing, thus showing a slight but gradually decreasing absorption, up to about

300° C, when the ionization current began to increase and soon gave the same value as in the case of non-absorption. This increase was no doubt due to the loss of charcoal by oxidization, and to the increased conductivity of the gas in the testing vessel, owing to the presence of carbon dioxide. (For α -ray ionization the conductivity of carbon dioxide is 1.5 times that of air.)

In connection with the above experiments it should be noticed that it is not possible for the charcoal to become "saturated" with thorium emanation, that is, to reach a state when it cannot occlude any more emanation, as it would in the case of ordinary gases. It must be remembered that the emanation which has been occluded by the charcoal is itself decaying at the rate of half-value in 54 seconds.

In the observations of ionization currents given above, the numbers represent the current when it has reached a *steady* state. At slow speeds the current keeps increasing for a few minutes until it becomes steady, but at high speeds it takes a steady value almost immediately.

Conclusion

To conclude it may be said that the percentage absorption of thorium emanation by means of charcoal (1) depends on the nature of the charcoal used, being greatest for coconut, intermediate for animal, and least for wood charcoal; (2) is decreased by increasing the velocity of the gas current which conducts the emanation through the charcoal; (3) is increased by increasing the charcoal absorbing surface; and (4) is dependent on the temperature, following the law for ordinary gases, *viz.*, that a lowering of the temperature of the charcoal causes an increase, and a raising of the temperature a decrease in the amount of absorption.