

THE UNIVERSITY OF MINNESOTA

GRADUATE SCHOOL

Report

of

Committee on Examination

This is to certify that we the undersigned, as a committee of the Graduate School, have given Julia Frances Herrick final oral examination for the degree of Master of Arts . We recommend that the degree of Master of Arts be conferred upon the candidate.

Minneapolis, Minnesota

June 2, 1919

W. G. Swann

Chairman

H. T. Ryan

Raymond W. Brink

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Report
of
Committee on Thesis

The undersigned, acting as a Committee of the Graduate School, have read the accompanying thesis submitted by Julia Frances Herrick for the degree of Master of Arts.

They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts.

W. G. Swann
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A Method of Ascertaining the
Direction of Penetrating Radiation

A Thesis
Submitted to the Faculty of the Graduate School
of the
University of Minnesota
by
Julia Frances Herrick

in Partial Fulfillment of the Requirements
for the degree of
Master of Arts

1919

A Method for Ascertaining the Direction
of the Penetrating Radiation.

Introduction: A portion of the ionization in closed vessels is attributable to the γ ray radiation from the radioactive materials in the soil. That the whole ionization is not attributable to this cause is, however, borne out by the fact that an appreciable residual ionization is found when experiments are performed over the great oceans, in spite of the fact that the amount of radioactive material in the water and in the air above is almost negligible.

There are two views as to the origin of residual ionization: one attributes it to the presence of radioactive impurities in the walls of the containing vessel,¹ while another supposes the ~~emittance~~ ^{existence} of a true penetrating radiation of cosmic origin. Considerable evidence in favor of the existence of a radiation of this kind is afforded by the balloon experiments performed by Kleinschmidt and by Kohlhörster,² in which it was found that the intensity of the residual ionization increased very greatly with altitude; but strong additional evidence would be provided if it could be shown that the postulated radiation partook of a directive character, for it is inconceivable that such a property could be explained as the result of radioactive impurities in the walls of

¹See for example, McLennan and Trelease, Phil. Mag. 30 pp. 415-427, 1915. Also McLennan and Murray, Phil. Mag. pp. 428-434, 1915.

²Deutsch. Phys. Gesell. Verh. 16, p. 719, 1914.

the vessel.

Experiments to detect the direction of penetrating radiation have been performed by Cook³ and by Wood.⁴ The former measured the rate of discharge of the leaves of a Wilson electro-scope when shielded on different sides by lead slabs, but was unable to detect any evidence as to direction. He concluded that the radiation was of practically uniform intensity in all directions, coming equally from the floor, walls, and ceiling of the laboratory. The latter used an ionization chamber of brass with the electroscope system contained within it. A rectangular screen which could be slipped under the lower side or rested on the upper side served as a shielding device. Experiments were performed on the top floor of the building and also in the basement. On the top floor, the results showed a greater screening action when the lead was above than when it was below, while in the basement the reverse was the case.

Wood considered his result very inconclusive, in view of the fact that the irregularities of the readings were such as to make it not improbable that the effects observed were attributable to experimental error. Although he does not refer to the point, however, it is of interest to observe that his obtaining a greater shielding, on the top floor, when the plate was on the top than when it was underneath, and a greater shielding effect in the basement when the plate was underneath than when it was on top is consistent with what is to be expected as a result of absorption by the building. For such absorption would tend to make the radiation

³Phil. Mag. 6. p. 403, 1903.

⁴Phil. Mag. 9, p. 550, 1905.

From above the preponderating influence on the top floor, and that from below the preponderating influence in the basement.

The fundamental difficulty in all experiments of this kind carried out by Wood and ^{by} Cooke is that, in view of the irregularities with ~~tune~~^{time} of the main part of the ionization in the vessel, and of the small differences in the effects produced by screens on various sides, the differences in question become masked by the irregularities in the main part of the ionization. The fundamental idea of the method of investigation described in this thesis, is to provide for a means of compensation^{ng} the main part of the effect, so that the time irregularities are compensated, and, ^{so} to leave only the quantity sought as the quantity observed.

In the course of the work, certain matters in relation to the performance of the Dole-Zalok Quadrant electrometer presented themselves. While these had no fundamental bearing upon the problem in hand, they were of sufficient interest to warrant investigation, and the conclusions reached in relation to these^m are included in an appendix to this thesis.

General outline of the method.

It will be recalled that, according to the experiments of Bragg⁵, the number of electrons emitted by X-rays from a surface at which the γ rays emerge is different from, and in general greater than, the number emitted from the surface at which they enter. Speaking of the former as the emergence radiation and the latter as the incidence radiation, Bragg finds, for example, that in the case of hard γ rays, the ratio of the emergence number to the incidence is about 0.94 for lead, and for aluminum about 6.62.

⁵Studies in Radioactivity - Bragg, pp.110-134.

Further, the incidence radiation for aluminium is 0.24 times that for lead, so that the emergence radiation for aluminium is 1.69 times that for lead. Or, if, in arbitrary units, E_L and I_L refer to the emergence and incidence intensities for lead, and if E_A and I_A refer to aluminium, we have:

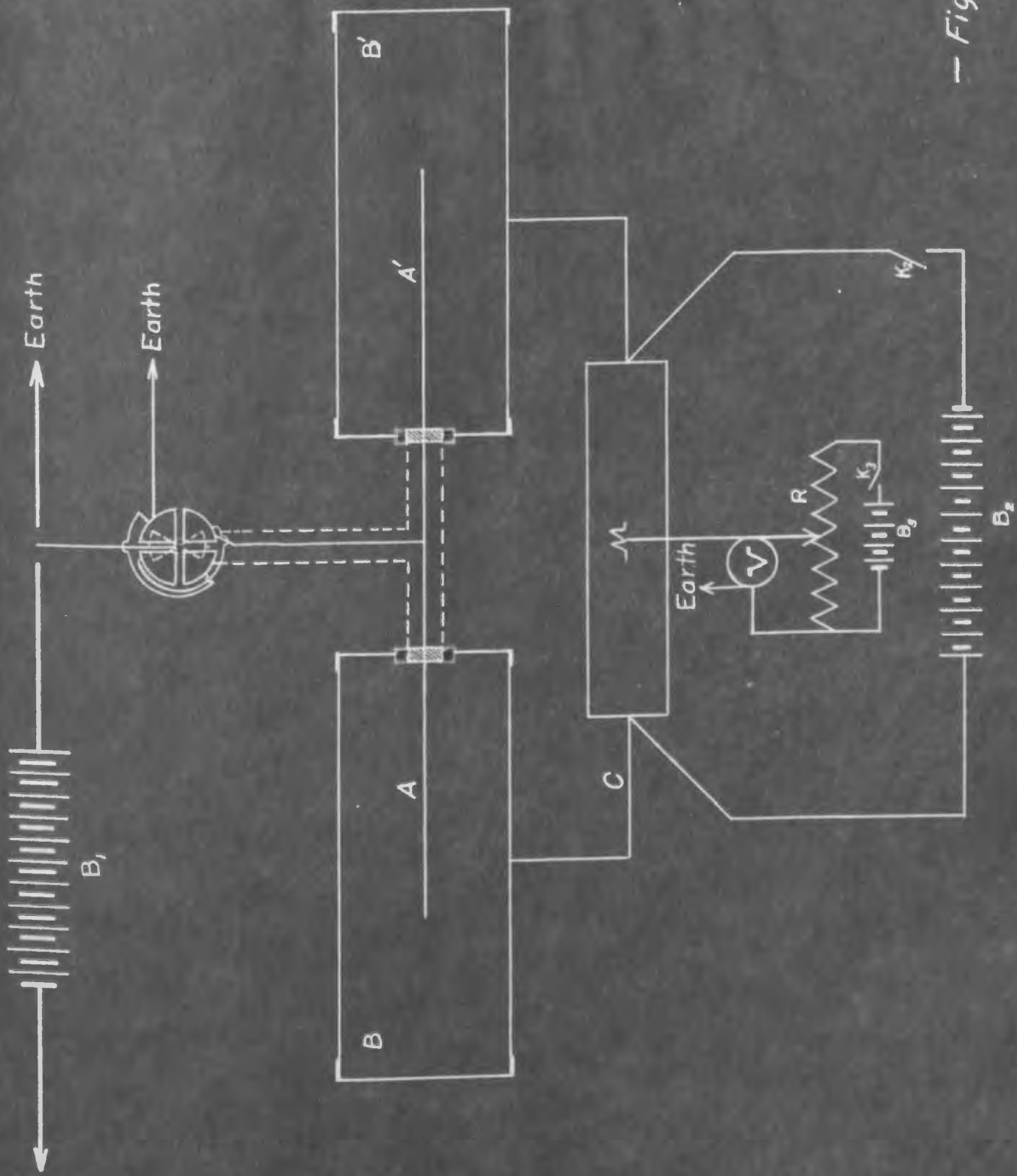
$$\frac{E_L}{I_L} = 0.94; \quad \frac{E_A}{I_A} = 6.62; \quad \frac{I_A}{I_L} = 0.24; \quad \frac{E_A}{E_L} = 1.69.$$

$$\text{Hence} \quad \frac{E_A + I_L}{E_L + I_A} = 2.2. \quad (1)$$

Suppose now, we make a cylindrical vessel one half of whose cylindrical surface is composed of lead and the other half of aluminium, and to fix our ideas, suppose that a γ radiation enters from above. Then if, for purpose of qualitative description, we neglect consideration of the fact that all of the rays do not strike the surface normally, we may conclude that, as far as order of magnitude is concerned, the number 2.2 given in (1) represents the ratio of the effect to be expected when the aluminium is uppermost to the effect to be expected when the lead is uppermost.

Thus, if the penetrating radiation is of a γ ray type, and is not uniform in all directions, we may expect that a variation in the ionization will occur as the vessel is rotated about a horizontal axis.

In practice, two such vessels were used. The central systems were connected together and to an electrometer. The two vessels were charged to potentials of equal positive and negative



- Figure 1 -

amounts respectively, so that, when the ~~vessels~~ were symmetrically arranged with regard to each other, there was compensation as regards the charge communicated to the central system, as a result of the ionization within them. On rotation of one cylinder, however, the compensation was destroyed to the extent that there was lack of uniformity in the direction of the external radiation. Practical annulment of time irregularities was always secured, however, by the system of compensation adopted.

Description of the Apparatus

The arrangement of the apparatus is shown in the accompanying diagram. The ionization vessels B and B¹ were designed as described above. A megohm, M, was connected to the poles of a 100-volt battery; its ends were connected to the vessels B and B' and, in the preliminary experiments, its mid-point was connected to earth. By this scheme, compensation was secured for fluctuations in the potential of the battery as well as for fluctuations in the radiation under investigation. The insulated central systems, A and A', were connected together and then connected to one pair of quadrants of a sensitive electrometer (1500 divisions per volt). As shown in diagram, the T-wire connecting the rods, A and A', together, and then to the electrometer was well shielded by a T-tube which was connected to earth, as was also the electrometer case, the guard rings, the second terminal of the electrometer, and the tin vessel which shielded the electrometer. The needle of the electrometer was charged by a 100 - volt battery.

The sensitivity of the apparatus was such as to make evident the Schweidler fluctuations, resulting from the emission of α particles by the radium emanation in the air contained in the

vessels; a small amount of radium emanation is, of course, always to be found in atmospheric air. In the first experiments, the mid-point of the meg-ohm was permanently earthed, and the intensity of the radiation was measured by the rate of movement of the electrometer needle when ^{the insulated system was} released from earth. In order to render the effects of the Schweidler fluctuations a small part of the whole deflection measured, it was necessary to allow the potential of the system to depart from zero to a degree which ^{was} ~~would be~~ greater than was desirable in view of the leakage which results, when the central system is not at zero potential. In order to ^covercome this difficulty, the method of procedure was modified in the following manner:

The mid-point of the meg-ohm was connected to a voltmeter, V, which was in turn connected to the sliding contact of a variable resistance. The extremities of this variable resistance were connected to a battery B. One extremity of this variable resistance was connected to the second terminal of the voltmeter and to earth. The purpose of this modified method was to establish a means whereby the needle of the electrometer would never be allowed to deflect from its zero position. As soon as the needle moved a millimeter, the voltage at the mid-point of the meg-ohm was raised or lowered, according to the direction of the deflection by means of the variable resistance. This increased voltage acted inductively on the insulated central system, thus annulling the effect due to ionization. After a definite period of time the change in voltage was recorded and the charges released. Readings were taken in this manner for various positions of the right cylinder, the left cyl-

inder remaining constant. The right cylinder was rotated in a counter-clockwise direction.

In order to ascertain the percentage which the effects obtained in this manner formed of the total effect due to one cylinder, readings were also taken with cylinder B' alone. In this part of the experiment it was necessary that B should be at zero potential so that only B' function^{ed}s. To this end, the connection C was broken and B was connected to earth. It must be observed that, under this condition, the inductive action brought about by the increase or decrease of the potential of the midpoint of the meg-ohm is only about half as great as in the case of the two cylinders. In other words, it takes about twice the potential to annul the effect of the ionization when using one vessel, that it takes to annul the effect when using both cylinders. In order to obtain the reduction factor necessary to reduce the observations with one cylinder to the conditions corresponding to those with two cylinders, deflections were obtained when a definite change in potential was produced in the one cylinder, and in the two cylinders. The ratio of the two deflections gave the necessary factor of reduction.

Experiments were also performed when a sealed tube containing $.8$ milligrams of radium bromide was brought into the same room as the apparatus, and also, when lead screens of various thicknesses were interposed between the radium and the apparatus.

The radium was placed on a shelf on a level with the geometrical axis of the cylinders, and at a distance of about 20 feet from them.

Experiment With No Radium in the Room.

Table I.

R=1.933

April 24, 1919.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent) | Remarks |
|----------|------------------------|------------|--|---------------------|
| 0° | 5.4 | 1.313 | 7.9 | |
| 30° | 4.4 | 1.313 | 6.5 | |
| 45° | 4.7 | 1.313 | 6.9 | |
| 60° | 5.2 | 1.313 | 7.7 | |
| 90° | 7.66 | 1.313 | 11.3 | Ra. in safe |
| 120° | 4.76 | 1.313 | 7.0 | |
| 135° | 6.8 | 1.313 | 10.0 | Ra. in Chem. Lab. |
| 150° | 5.4 | 1.313 | 7.9 | |
| 180° | 5.2 | 1.313 | 7.7 | |
| 210° | 9.08 | 1.313 | 13.4 | Radiation from sky. |
| 225° | 6.2 | 1.313 | 9.1 | |
| 240° | 6.2 | 1.313 | 9.1 | |
| 270° | 5.2 | 1.313 | 7.7 | |
| 300° | 4.8 | 1.313 | 7.1 | |
| 315° | 6.0 | 1.313 | 8.8 | |
| 330° | 5.02 | 1.313 | 7.4 | Ra. in soil |
| 360° | 4.9 | 1.313 | 7.2 | |

θ , angle which the diameter joining centers of lead and aluminum makes with the vertical.

δV , change of potential, ^{in volts} on sliding rheostat, per unit time when using both cylinders.

δV , change of potential, ^{in volts} on sliding rheostat, per unit time when using only one cylinder.

R, factor for reducing the sensitivity of δV to δV .

Experiment With No Radium in the Room.

Table II.

R = 1.933

April 23, 1919.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent) | Remarks |
|----------|------------------------|------------|--|---------------------|
| 0° | 4.2 | 1.313 | 6.2 | |
| 30° | 5.4 | 1.313 | 7.9 | |
| 45° | 4.3 | 1.313 | 6.3 | |
| 60° | 1.6 | 1.313 | 2.4 | |
| 90° | 4.6 | 1.313 | 6.8 | Ra. in safe. |
| 120° | 4.4 | 1.313 | 6.5 | |
| 135° | 5.6 | 1.313 | 8.2 | Ra. in Chem. Lab. |
| 150° | 4.2 | 1.313 | 6.2 | |
| 180° | 5.4 | 1.313 | 7.9 | |
| 210° | 5.8 | 1.313 | 8.5 | |
| 225° | 7.5 | 1.313 | 11.0 | Radiation from sky. |
| 240° | 6.2 | 1.313 | 9.1 | |
| 270° | 5.5 | 1.313 | 8.1 | |
| 300° | 3.0 | 1.313 | 4.4 | |
| 315° | 1.6 | 1.313 | 2.4 | |
| 330° | 5.6 | 1.313 | 8.2 | Ra. in soil. |

θ , angle which the diameter joining centers of lead and aluminum makes with the vertical.

δV , change of potential, ^{in volts,} on sliding rheostat, per unit time when using both cylinders.

δV , change of potential, ^{in volts,} on sliding rheostat, per unit time when using only one cylinder.

R, factor for reducing the sensitivity of δV to δV .

Experiments With Radium In The Room.

Table III.

R = 3.08

April 26, 1919.

Thickness of screen, 1.46 cm.

| θ | $\delta V \times 10^2$ | δV | $\frac{R \cdot \delta V}{\delta V} \cdot 10^2$ (per cent) | Remarks |
|----------|------------------------|------------|--|-----------|
| 0° | 0.36 | 2.09 | 0.4 | Forenoon |
| 30° | 2.00 | 2.09 | 2.0 | " |
| 45° | 3.04 | 2.09 | 3.0 | " |
| 60° | 5.40 | 2.09 | 5.4 | " |
| 90° | 8.96 | 2.09 | 8.9 | Afternoon |
| 120° | 8.80 | 2.09 | 8.8 | " |
| 135° | 7.30 | 2.09 | 7.3 | " |
| 150° | 7.50 | 2.09 | 7.5 | " |
| 180° | 2.00 | 2.09 | 2.0 | " |
| 210° | 2.40 | 2.09 | -2.4 | " |
| 225° | 2.80 | 2.09 | -2.8 | " |
| 240° | 5.62 | 2.09 | -5.6 | " |
| 270° | 12.80 | 2.09 | -1.26 | " |
| 300° | 8.20 | 2.09 | -8.2 | " |
| 315° | 6.40 | 2.09 | -6.4 | " |
| 330° | 5.50 | 2.09 | -5.5 | " |
| 360° | 0.36 | 2.09 | 0.4 | " |

Experiments with Radium in the Room.

Table IV

R = 1.92

April 28, 1919.

Thickness of screen 2.96 cm.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent) | Remarks |
|----------|------------------------|------------|--|----------------------|
| 0° | 0.0 | 1.62 | 0.0 | |
| 30° | 3.8 | 1.62 | 4.5 | |
| 45° | 5.4 | 1.62 | 6.4 | |
| 60° | 4.0 | 1.62 | 4.7 | |
| 90° | 8.2 | 1.62 | 9.7 | |
| 120° | 8.8 | 1.62 | 10.4 | |
| 135° | 8.0 | 1.62 | 9.5 | |
| 150° | 8.6 | 1.62 | 10.2 | Secondary radiation. |
| 180° | 5.0 | 1.62 | 5.9 | |
| 210° | 2.0 | 1.62 | 2.4 | |
| 225° | 0.0 | 1.62 | 0.0 | |
| 240° | 2.6 | 1.62 | -3.1 | |
| 270° | 6.0 | 1.62 | -7.1 | |
| 300° | 2.6 | 1.62 | -3.1 | |
| 315° | 5.0 | 1.62 | -5.9 | |
| 330° | 1.6 | 1.62 | 1.9 | |
| 360° | 0.8 | 1.62 | 1.0 | |

Experiments with Radium in the Room.

Table V.

R = 1.80

April 29, 1919.

Thickness of screen, 4.46 cm.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent.) | Remarks |
|----------|------------------------|------------|---|-------------------------------|
| 0° | 5.0 | 1.61 | 5.6 | |
| 30° | 8.8 | 1.61 | 9.8 | |
| 45° | 8.0 | 1.61 | 8.8 | |
| 60° | 9.0 | 1.61 | 10.1 | |
| 90° | 10.2 | 1.61 | 11.4 | |
| 120° | 8.0 | 1.61 | 8.8 | Reading taken after- wards |
| 135° | 11.0 | 1.61 | 12.3 | Secondary radiation |
| 150° | 11.6 | 1.61 | 13.0 | " " |
| 180° | 5.0 | 1.61 | 5.6 | |
| 210° | 7.2 | 1.61 | 8.0 | |
| 225° | 4.6 | 1.61 | 5.1 | |
| 240° | 3.6 | 1.61 | 4.0 | |
| 270° | 0.8 | 1.61 | 0.9 | |
| 300° | 0.8 | 1.61 | -0.9 | |
| 315° | 0.4 | 1.61 | -0.5 | |
| 330° | 4.0 | 1.61 | 4.5 | |
| 360° | 2.0 | 1.61 | 2.2 | |

Experiments with Radium in the Room.

Table VI.

R = 2.15

April 30, 1919.

Thickness of screen, 5.76 cm.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent.) | Remarks |
|----------|------------------------|------------|---|------------|
| 0° | 1.2 | 1.47 | 1.7 | Morning |
| 30° | 5.0 | 1.47 | 7.3 | " |
| 45° | 4.0 | 1.47 | 5.8 | " |
| 60° | 6.4 | 1.47 | 9.4 | " |
| 90° | 7.0 | 1.47 | 10.2 | " |
| 120° | 6.8 | 1.47 | 9.9 | " |
| 135° | 7.2 | 1.47 | 10.5 | " Sec. Ra. |
| 150° | 7.4 | 1.47 | 10.8 | " " " |
| 180° | 6.0 | 1.47 | 8.8 | Afternoon |
| 210° | 5.2 | 1.47 | 7.6 | " |
| 225° | 4.0 | 1.47 | 5.8 | " |
| 240° | 3.8 | 1.47 | 5.5 | " |
| 270° | 1.0 | 1.47 | 1.5 | " |
| 300° | 4.4 | 1.47 | 6.6 | " |
| 315° | 4.0 | 1.47 | 5.8 | " |
| 330° | 2.0 | 1.47 | 2.9 | " |
| 360° | 1.4 | 1.47 | 2.0 | " |

Experiments with Radium in the Room.

Table VII.

R = 2.12

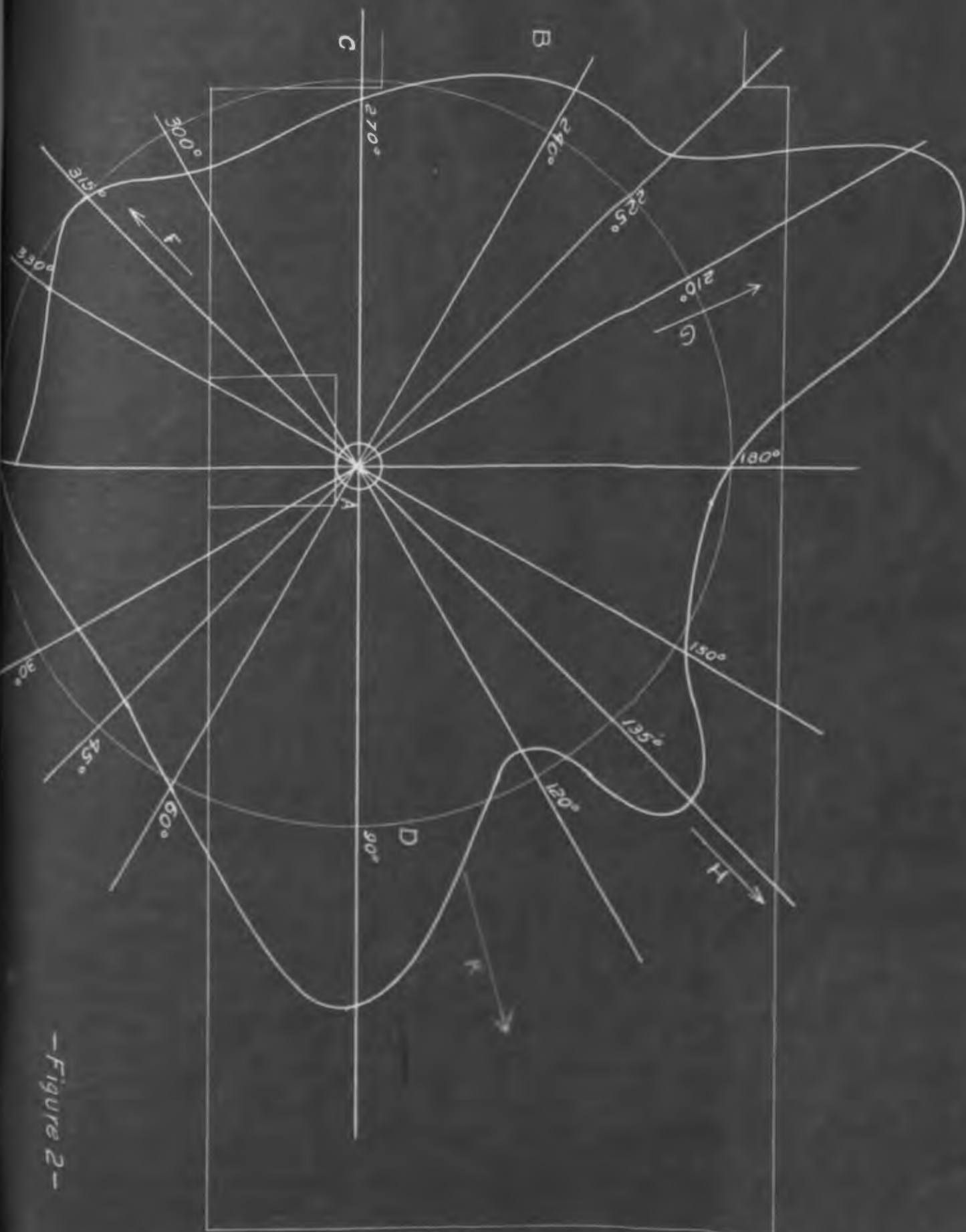
April, 30, 1919. P.M.

| θ | $\delta V \times 10^2$ | δV | $R \cdot \frac{\delta V}{\delta V} \cdot 10^2$ (per cent) | Remarks |
|----------|------------------------|------------|--|---------------------|
| 0° | 5.0 | 1.48 | 7.2 | |
| 30° | 7.8 | 1.48 | 11.3 | |
| 45° | 7.8 | 1.48 | 11.3 | |
| 60° | 5.4 | 1.48 | 7.7 | |
| 90° | 10.0 | 1.48 | 14.3 | |
| 120° | 9.2 | 1.48 | 13.2 | Secondary radiation |
| 135° | 8.8 | 1.48 | 12.6 | " " |
| 150° | 8.2 | 1.48 | 11.7 | " " |
| 180° | 9.2 | 1.48 | 13.2 | " " |
| 210° | 6.0 | 1.48 | 8.6 | |
| 225° | 6.0 | 1.48 | 8.6 | Cloudy. |
| 240° | 5.0 | 1.48 | 7.2 | |
| 270° | 2.2 | 1.48 | 3.2 | |
| 300° | 2.4 | 1.48 | 3.4 | |
| 315° | 4.8 | 1.48 | 6.9 | |
| 330° | 2.2 | 1.48 | 3.2 | |
| 360° | 2.2 | 1.48 | 3.2 | |

Results and Discussion. The experiments were performed in a large laboratory in the basement of the Physics Department, and a general view of the conditions will be gathered from the accompanying blueprint. Referring to figure 2, the cylinders were situated at A. B is a window, and C indicates the level of the ground outside. In a safe on the next floor a sealed tube containing 1.8 milligrams of radium is stored in a lead case, and on the second floor of the building an equal amount of radium bromide is contained in solution in the Chemical Laboratory belonging to the Physical Department. The arrows E, G, H, K, indicate respectively the lines pointing from the apparatus to the ground outside, a point just above the window, the radium in the Chemical Laboratory, and the radium in the safe.

The observational data are given in the accompanying tables, the data in tables 1 and 2 referring to a case where there was no radium in the laboratory in which the apparatus was set up, and the remaining tables referring to experiments performed with the tube of radium from the safe placed in the laboratory at a distance of about twenty feet from the apparatus, and on the same horizontal level as its diameter. In the experiments with the radium, observations were taken with screens of lead of different thickness as indicated in the tables.

Referring first to the observations performed with the radium in the safe, it will be seen, from tables 1 and 2, that the fourth columns of tables 1 and 2 give the percentage which the effect, with the two cylinders in opposition, forms of the total effect with one cylinder, for different orientations, of the movable cylinder.

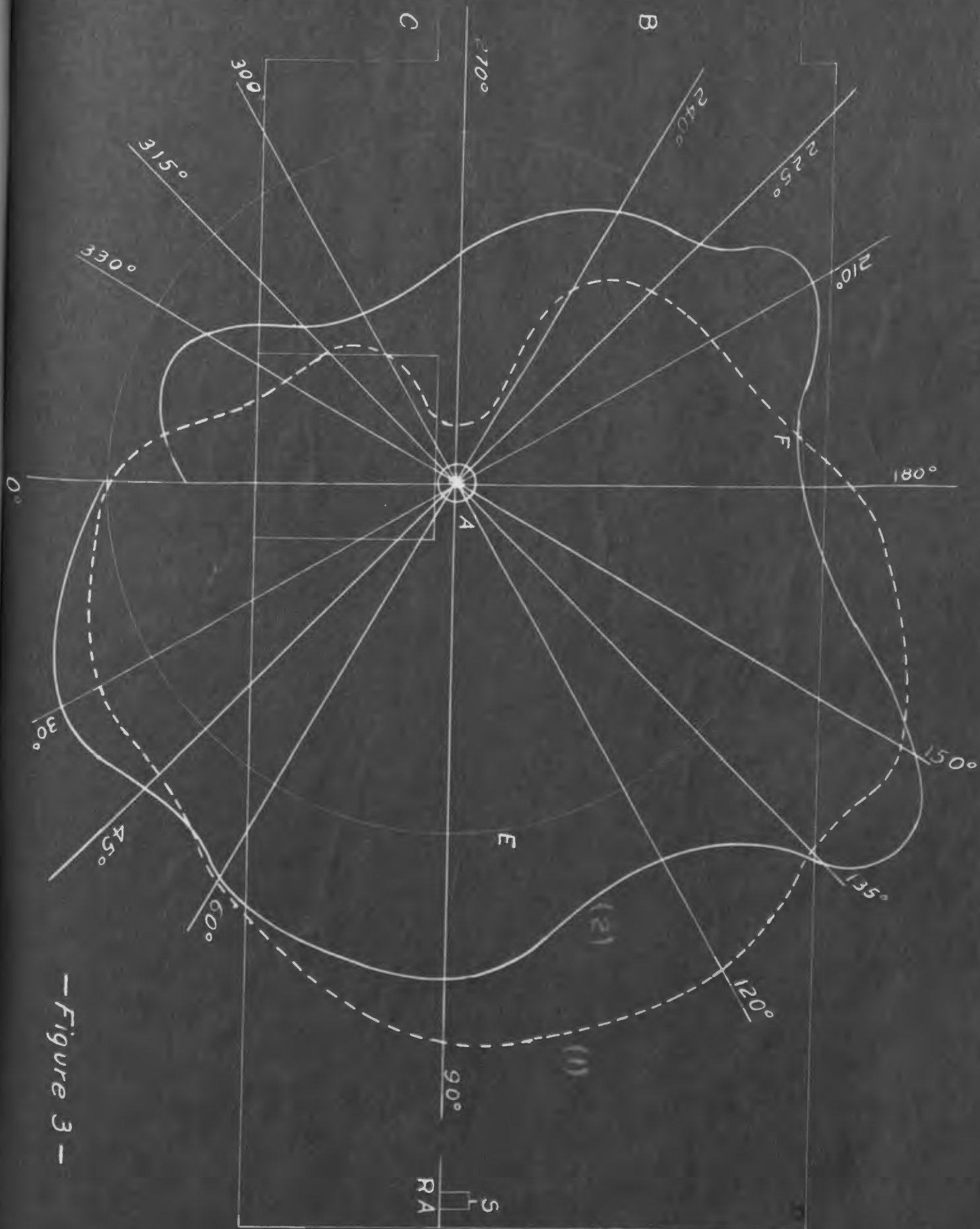


-Figure 2-

Thus, for example in table 1, the differences between the number 7.9 and the other numbers in this column indicate the effect of change orientation. This difference is represented by the distance of the polar curve in figure 2 from the circle D. It will be observed that this difference attains maxima in directions corresponding approximately with the positions of the ground outside, the window, the radium in the Chemical Laboratory, and the radium in the safe. This is what we might have expected, for in the first case the radio-active material in the soil outside the building is being detected, in the second the penetrating radiation from above shows its influence, being more powerful in the direction indicated than in an absolutely vertical direction on account of the absorption of the building. In the third and last cases we, of course, have the effects of the radium in the Chemical Laboratory and safe respectively. It is not to be expected that the maxima should exactly correspond with the directions in which the influences lie, since the superposition of curves due to the various influences tends to shift the maxima of the individual curves. Again, if one of the influences, as for example, the radiation from the sky, is variable from day to day, slight alteration in the magnitude and position of the maxima may result.

It might be thought that a maximum should be obtained from the ground immediately below the laboratory, but the absence of this maximum is not surprising in view of the existence of foundational material of an absorptive but non-radioactive nature.

Referring to table 1, for example, it will be observed that the maximum change due to change of orientation forms only 6.5 per cent of the effect due to one cylinder alone. This shows how nec-



-Figure 3-

essary is the employment of a system of compensation such as that here adopted; for, in its absence, such small effects will be masked by the fluctuations of the penetrating radiation itself.

Figure 3 shows two curves. Curve (1) illustrates the effect when the screen interposed between the radium and the cylinder was 1.46 cm. thick. Curve (2) illustrates the effect when the screen was 4.46 cm. thick. The tables giving the data for these curves are numbered (3) and (5) respectively. As in the case above, the fourth columns of these tables give the percentage which the effect of the two cylinders in opposition forms of the total effect with one cylinder.

In order to bring out the effects more clearly, the circle E has been drawn and the points plotted with reference to this circle. The points outside the circle represent the percentage decrease and the points inside, the percentage increase of the total effect with one cylinder, as a result of rotation from the zero position. It will be observed that a change occurs at F.

This is the point where the ionization in both cylinders is the same. Points outside the circle correspond to cases where the ionization was greater in the fixed than in the rotated cylinder. Points inside the circle correspond to cases where the ionization was greater in the rotated than in the fixed cylinder.

From the theory given above, it will, ^{be} recalled that, when the right cylinder is in the 90° position, a minimum number of ions is formed, and when in the 270° position a maximum number of ions is formed. Thus in the former case, the ionization in the rotated cylinder is less than ⁿ that in the fixed cylinder, while in the latter case it is greater, since the fixed cylinder occupies an ori-

entation mid-way between the 90° and the 270° orientations. These facts are well brought out by the "hump" at the 90° and 270° lines in curve (1).

Curve (2) shows the "hump" at 90° . However, a somewhat remarkable phenomenon is presented by the existence of the "hump" at about the 150° line. This "hump" is perhaps due to secondary radiation from the ceiling. The ceiling is shielded only by the lead case, while the cylinders are shielded by the lead case and lead screens. In the case where the screens were absent, it is not surprising that this "hump" is much less marked, for, in this case it would be largely obliterated by the strong direct ionization produced by the radium.

Appendix

An effect occasionally produced on charging the needle of an electrometer:

If an electrometer needle is adjusted symmetrically with respect to its quadrants and connected to a source of high potential, it should remain in its median position provided that the quadrants are at a common potential. However, some needles are deflected momentarily upon charging and discharging even when symmetrically adjusted so that they come back to their initial position after a few seconds. The purpose of this article is to explain the initial throw in question.

Considering the quadrants to be connected together, and the needle to be adjusted properly and to be charged and allowed to come to rest, it will then have the same orientation as before charging.

Considering the state of affairs after the needle has returned to its median position, we observe that in this condition it experiences equal attraction from each pair of quadrants, the two attractions annulling each other's effect. If this needle is a poor conductor of electricity, and is, moreover, unsymmetrical in its conducting properties, different parts will charge at different rates, so that, although the final distribution of charge is the same as if the needle were symmetrically conducting, during the process of charging the nature of the charge distribution will be different from that finally attained. While the needle is receiving charge, the two pairs of quadrants will act upon it with couples of different strength, so that, during this process it

will receive angular momentum. After a length of time has elapsed sufficient to enable the needle to attain its final charge and distribution, the two couples will have reached a state of equilibrium, but the angular momentum communicated to the needle persists, so that the latter experiences a throw after which it, of course, finally, returns to the median position.

On discharging the needle, a similar action should take place. The throw, however, ^{should be} ~~was~~ in the reverse direction, a result which was found to hold true in practice.

In order to verify this ^{sup} position as to the effect of non-symmetrical conductivity, a few paper needles were specially constructed so as to have non-symmetrical conducting properties, the parts which it was desired to render conducting being graphited. Fig. 1 shows just such needles. The needles were set up in an electrometer. Adjustment of the system was made so that the final position attained after charging was the same as that attained when the needle was uncharged, and the initial throws were measured for different voltages applied to the needle, the throws on charging and discharging being noted.

The sensitivity of the electrometer was such as to give ³⁴⁶ ~~164~~ divisions _{per volt} with 100 volts on the needle.

Table I shows the result for needle A. V is the potential (in volts) applied to the needle. The second column gives, for the case of charging, α_1 , the electrometer reading before the throw, α_2 , the maximum reading as a result of the throw, and α_3 , the reading to which the electrometer returned after the throw. α_1 and α_3 give an idea of the adjustment of the electrometer. The third column gives θ , the throw for the case of charging. The last columns



Figure 1

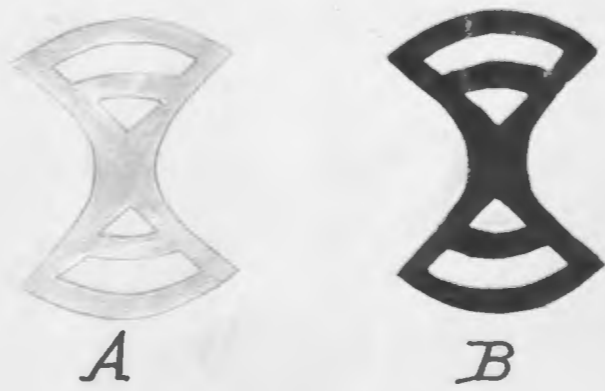


Figure 2

give the corresponding quantities for the case of discharging.

After the readings, recorded in Table I, had been taken, the needle was carefully graphited as in Figure 1, *B*. Here, as might be expected, the throws are considerably less than in the former case. See table 2.

Needles of the types as C and D in figure 1 were constructed and tested, and, as might be expected, they showed still smaller throws. Also, a needle was graphited thinly but uniformly, as shown in Figure 2, A and showed ^{no} perceptible throw. Finally, a needle was graphited heavily as shown in Figure 2, B. No perceptible throw was detected.

The conclusion cited above, as to the origin of the throw, thus, seems abundantly verified.

At first sight, it might seem that the throws on charging and discharging should be equal. The throws indicated in tables 1 and 2, for charging and discharging are, however, by no means equal. The reason for this is bound up with the fact that a portion of the momentum is communicated to the needle after it has started to move, and the amount of the momentum is not symmetrical as regards motions in opposite directions.

The Adjustment of the Needle

If a uniformly conducting needle is perfectly flat and parallel to the quadrants, the adjustment for absence of permanent deflection on charging should be independent of the level of the needle between the quadrants. In practice, however, ^{adjustment} ~~attention~~ of the level makes a very decided change in adjustment. In fact, attention ^{to the} of level is itself usually the most important adjustment in securing absence of deflection on charging. The reason for this effect

Table 1.

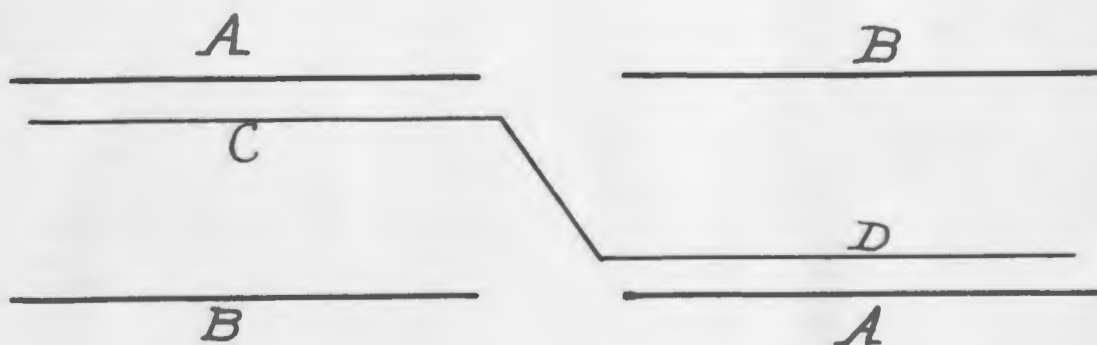
| V (volts) | Charging | θ | Discharging | θ |
|--------------|--|----------|---|----------|
| | Readings (mm.) | | Readings (mm.) | |
| 39 | $d_1 = 182$ $d_2 = 151$ $d_3 = 180$ | -30 | $d_1 = 180$ $d_2 = 205$ $d_3 = 182$ | 84 |
| 58 | $d_1 = 177$ $d_2 = 120$ $d_3 = 176$ | -56.5 | $d_1 = 176$ $d_2 = 231$ $d_3 = 177$ | 54.5 |
| 100 | $d_1 = 176$ $d_2 = 12$ $d_3 = 175$ | -163.5 | $d_1 = 175$ $d_2 = 320$ $d_3 = 176$ | 144.5 |
| 119 | $d_1 = 176$ $d_2 = \text{Off scale}$ $d_3 = 176$ | ? | $d_1 = 176$ $d_2 = \text{could not read it.}$ $d_3 = 176$ | ? |

Table 2.

| V (volts) | Charging | θ | Discharging | θ |
|--------------|---|----------|---|----------|
| | Readings (mm.) | | Readings (mm.) | |
| 100 | $d_1 = 213$ $d_2 = 153$ $d_3 = 213$ | -60 | $d_1 = 213$ $d_2 = 236$ $d_3 = 213$ | 23 |

of level becomes evident from a mathematical examination of the phenomenon.

Let A A B B represent the quadrants of the electrometer. B and A are in each case large co-planar surfaces insulated from



each other by a small air gap. Let C D represent the needle which, we shall suppose, to be not entirely plane, but twisted in a manner shown in exaggerated form in the figure.

Let t be half the distance between A B or B A, a the distance of C above, and b the distance of D below the plane mid-way between A B or B A.

Suppose, F_1 is the force tending to move the needle C in the direction M.

Then, if the needle is moved thru a distance x , the work done will be $F_1 x$. By a well-known theorem in electrostatics:

Flx = increase in the electrical energy of the system, the potentials remaining constant. Thus when the potentials of the two pairs of quadrants are alike and equal to V, we have

$$Flx = \left[\frac{lx}{8\pi(t+a)} (U-V)^2 + \frac{lx}{8\pi(t-a)} (U-V)^2 \right] - \left[\frac{lx}{8\pi(t-b)} (U-V)^2 + \frac{lx}{8\pi(t+b)} (U-V)^2 \right]$$

when V is the potential of the needle. From this we find

$$F = \frac{(U-V)^2 t}{4\pi} \left[\frac{1}{t^2 - a^2} - \frac{1}{t^2 - b^2} \right]$$

It will be observed that the force, F will be zero only when a = b.

Hence a deflection will be expected unless the screws which raises and lowers the needle is so adjusted that a = b.