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PHYSICAL REVIEW

HIGH FREQUENCY RAYS OF COSMIC ORIGIN
II. MOUNTAIN PEAK AND AIRPLANE OBSERVATIONS

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Abstract

The elimination in penetrating ray experiments of temperature and pressure effects is accomplished through *new features in the design of Wulf electroscopes*, but especially through immediate reduction in situ of all deflections to volts.

Variation of penetrating radiation with altitude and with time of day.—When suitable precautions are taken for eliminating the activity of adjacent rocks, both airplane and mountain peak observations agree in showing a definite variation of the penetrating radiation with altitude alone. Within the limits of experimental error all observations are consistent in showing no dependence of the penetrating radiation upon the time of day or upon the position of heavenly bodies.

Absorption coefficients of penetrating rays.—Absorption experiments made on Pikes Peak with lead sheets 4.8 cm thick furnish evidence for the existence on mountain peaks of copious new rays of local origin of no greater hardness than that of gamma rays. If these new rays are assumed to be homogeneous their absorption coefficient is about 3.1 per meter of water. These experiments, however, furnish no definite evidence for the existence of very penetrating rays of cosmic origin.

Necessary characteristics of cosmic rays if they exist—Such rays cannot produce as much as 2 ions per cc per sec. at sea level if they have an absorption coefficient not less than 0.25 per meter of water. If cosmic rays exist at all they must be less intense than this, or else they must be more penetrating than anyone has as yet suggested.

I. Introduction

THE sounding balloon experiments reported in Part I[1] had shown that the integrated natural leak of electroscopes at altitudes up to 15.5 km was slightly larger than the leak at the surface covering the same time interval. They had, however, shown nothing about the distribution of the leak with altitude, and they had shown nothing about the hardness of the rays causing the leak, further than to prove that if there were any rays of cosmic origin they must be very much more penetrating than had thus far been imagined in order to account for the smallness of the observed ionization. If, on the other hand, the

[1] Millikan and Bowen, Phys. Rev. **27**, 353 (1926).

small observed increase in ionization were due to radioactive materials in the atmosphere the penetrating rays should have the absorption coefficients of ordinary gamma rays.

In order to supply information upon these points a new group of experiments was planned and carried out in the summers of 1922–23. These involved (1) absorption experiments at the highest altitude to which we could transport considerable quantities of absorbing materials, and (2) experiments without absorbing screens in balloons, airplanes, and on mountain peaks to see whether altitude as such were a determining factor in the observed variations in the discharge rates, or whether there might be largely different discharge rates in different localities, thus accounting for the widely different results reported by different observers.

Suspecting, however, that these differences were due primarily to the failure to take suitable precautions against the influence of temperature upon the dimensions and elastic constants of the electroscopes, we adopted especial precautions for eliminating completely all such effects.

II. THE ELECTROSCOPE

The electroscope used is diagrammatically shown in Fig. 1 and a photograph of it inside a lead sheathing is reproduced in Fig. 3. This electroscope, which is of the Wulf type, was designed and constructed in the shops of the Norman Bridge Laboratory of Physics. Two quartz fibres of about 0.005 mm to 0.01 mm diameter and about 6 cm long, sputtered with platinum to make them conducting, are at the top soldered together into a small copper tube which is held by a set-screw in a brass cap, *A*, cemented to a long rod of quartz insulation. At their lower ends the fibres are fastened by a bead of shellac to a bow of unsputtered quartz fibre of slightly greater diameter. The ends of the bow are attached to brass pieces, *B*, whose effective lengths are adjustable, so that the fibres can be brought to the most efficient tension. This tension is one that will allow full-scale deflection when the electroscope is charged to the desired potential, but is still sufficient to make stable the fibres and to bring them together when uncharged. The screws for adjusting the tension on the fibres pass through an invar bridge which is supported in invar rods, *C*, which are in turn hung from approximately the same point in the top that supports the quartz insulator. Thus the tension is not changed by any deflection of the electroscope case due to a difference in pressure between the inside and the outside. Furthermore, inasmuch as the invar used was tested and ound to have a temperature coefficient of expansion practically equal to that of quartz, the tension of the fibres should be independent of temperature also. This was found to be the case.

The case of the electroscope was made from cylindrical brass tubing, 1.7 mm to 1.8 mm thick. The bottom was of brass, 5 mm thick, while the top was of rolled zinc and most of the metal parts connected with the top were turned from zinc castings. This case was air-tight under a pressure of 60 lbs. per square inch above atmospheric pressure. The enclosed air was kept dry by phosphorus pentoxide which filled the flat cylindrical box, *D*, at the bottom of the electroscope. This box, which is covered by a perforated top to keep the phosphorus pentoxide from being shaken out where it might cause trouble, screws onto a lug projecting from the bottom of the case.

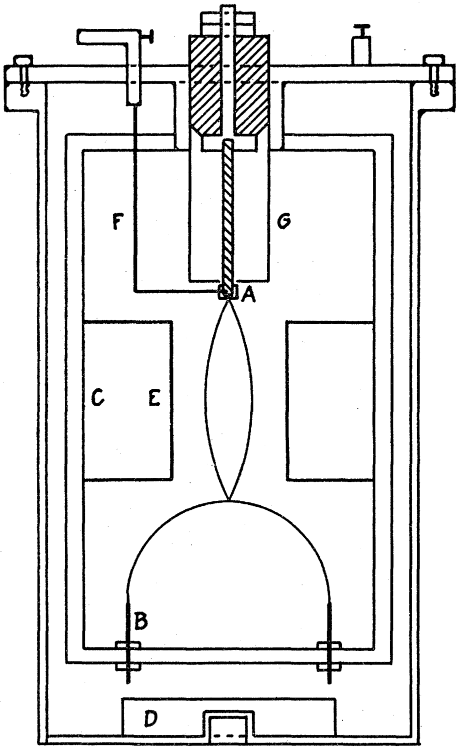

Fig. 1

The positions of the fibres were determined with the aid of a microscope having a scale in the eyepiece. A window on the opposite side of the case provided light. Sunlight was used when possible; in other cases a small flash-light bulb attached to a projection over the window was employed. The position of the objective as well as the eyepiece of the microscope could be varied, for the whole microscope fits into a tube, see Fig. 3, which extends into the case of the electroscope and terminates in a small glass window. This arrangement is very convenient because it is possible by simply removing the microscope to lower the electroscope into deep water without any protection and without fear of a leak. The fibres are kept in the focal plane of the microscope by the strengthened field due to the bent aluminum wires, *E*, projecting from the supporting invar rods. A very thick soft rubber gasket separates the top of the electroscope from the sides, so that the fibres could easily be swung into the center of the field of view by tightening the proper screws in the top.

The outside electrical connection to the fibres is made through the charging rod, *F*, which in the "on" position touches the brass cap to which the fibres are attached, and in the "off" position touches the case. This charging rod, as it passes through the case, is tapered at a very small angle to fit a greased ebonite bearing and is held tightly into contact by a strong spring.

A feature of the electroscope is that it is possible entirely to eliminate insulation loss if the loss across the thin quartz bow be neglected, and this is permissible because of the negligibly small diameter of the bow compared with the upper insulator. The quartz insulator is held in a brass rod which passes through an ebonite plug to the outside of the electroscope. This brass rod was held at the mean potential of the fibres throughout the period of observation thereby making impossible any insulation loss to the case. The brass rod and the quartz insulator are shielded from the rest of the electroscope by the shield, *G*, which is made in two parts, one of which may be rotated with respect to the other, leaving an opening to facilitate cleaning the insulator. The fact that the electroscope was designed with a view to accommodating lead screens accounts for the absence of projections from it and also for its small size. The volume was 1893 cc. The sensitivity varied in the different experiments from 1.4 to 2.1 volts per scale division. The capacity of the insulated system was found to be 1.32 cm.

III. Method of Observation

Essentially what is done in making a measurement of the penetrating radiation is to charge the electroscope to a known potential and note the drop in potential of the insulated fibres in a given interval of time. Then from these data and the known capacity of the fibres together with the volume, *V*, of enclosed air in the electroscope, and the charge, e, on an electron, the rate of production of ions per unit volume can be calculated. Thus, the number of pairs of ions per cc per second which are formed is $C_f\Delta P/3600Ve$, where ΔP is the drop in potential of the fibres per hour.

However, the simple difference in the positions of the fibres as read on the scale is not an accurate measure of the potential drop of the fibres, especially after transportation of the electroscope from one place to another. Therefore, inasmuch as the electroscope was necessarily subjected to rather severe treatment, in order to destroy all doubt as to the meanings of the readings, the electroscope was calibrated before and after every period of observation, i.e., *the electroscope deflections were always reduced to volts at once and in situ.* This was easily and accurately accomplished by charging the electroscope to four known potentials in the region in which lay the reading to be interpreted. The four points thus obtained were plotted and a straight line was drawn through them. The four points almost always lay quite close to the line and it was never possible to make any large error. Such calibration at the time of reading is very essential to accurate results, for it was found that, while the sensitivity might not change appreciably, the whole calibration curve might from time to time move to the side, thereby changing the meaning in volts of a given deflection of the fibres. Also a slight change in focusing the microscope on the fibres of course changes the volt-value of the scale. These possibilities of error were completely eliminated by the method employed in these investigations.

The diagram of connections is shown in Fig. 2. When the switch S is in position 1, the battery is connected to the charging rod and to the case; when it is in position 2, it is connected to the guard ring on the quartz insulation and to the case. The 40,000 ohms resistance, R, is inserted in the electroscope circuit to avoid destructive currents if the charging rod should accidentally be brought into contact with the case while the switch S is still in position 1. Because no current flows through the electroscope, this resistance does not interfere with the measurement of potential.

The procedure in making an observation, then, is as follows: The charging rod is in the neutral position. The switch S is closed to position 1. The voltmeter switch is closed, a suitable potential is found on the battery, and the charging rod is connected to the fibres. The deflection of the fibres and the corresponding volts are then read as nearly simultaneously as possible. The charging rod is removed to neutral and a potential about 4 volts lower is found. The fibres are again charged and the deflection and volts are read. This is repeated until four comparisons between deflection and volts have been obtained. The fibres are then charged to a potential lying in the midst of the four potentials previously applied, the charging rod is brought to neutral, the switch S is lifted to the neutral position, and the charging rod is turned so that it touches the case. The deflection and the time are then observed. This deflection is afterward interpreted in terms of volts and gives the potential at the beginning of the period of observation. The potential is now adjusted to equal the mean value of the potential of the fibres to be expected during the period of observation, the voltmeter switch is opened, and the switch S is closed to position 2, thereby putting this potential on the guard ring at the top of the quartz insulator and making impossible insulation loss. This potential need not be adjusted accurately, because the insulation loss is probably negligibly small anyway. The guard ring was used only to make it impossible to criticize the results from the standpoint of insulation loss. At the end of the period of observation, the switch S is lifted to the neutral position, and the deflection of the fibres and the time are noted. The charging rod is turned to neutral and the process of calibration described above is gone through in order that the deflection just observed may be interpreted in volts. Suitable precautions were of course taken to insure saturation at all times and to permit the activity of the radium emanation to die out after changing the air in the electroscope.

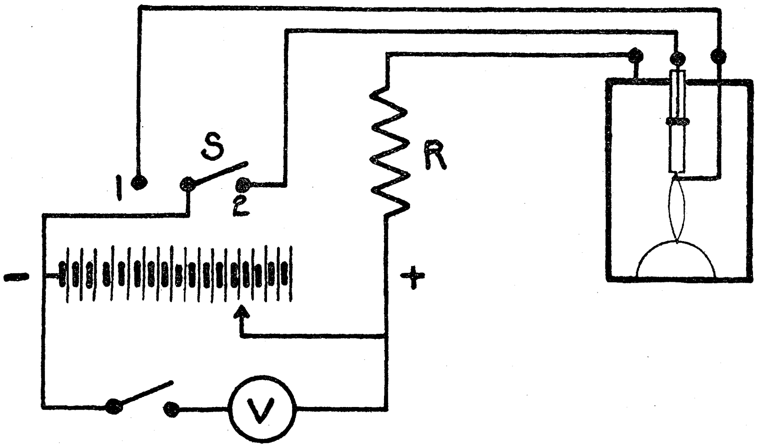

Fig. 2

IV. Measurements in Airplanes and Balloons

Preliminary measurements made in captive balloons at Ross Field, near Pasadena, by one of us (Otis) yielded results in agreement with those of other observers in that up to an altitude of 2000 meters the number of ions per cc per sec. was from 1 to 3 less than on the ground. No systematic change, however, was observed in this work at low altitudes.

The mean results of a long series of airplane flights made by Otis in 1922 at Marsh Field (near Riverside) and in 1923 at Rockwell Field (near San Diego) are shown in Table 1. These flights reached heights of more than 5000 meters. The numbers given are taken from a smooth curve drawn so as to fit as well as possible 17 observed points. In three instances these points depart from the curve by as much as 2.5 ions, out of a total discharge-rate, at the high altitudes where these points lie, of from 17 to 19 ions. The accuracy is limited by the shortness of the time, usually a half hour, during which a given altitude was maintained.

TABLE I

Airplane observations

Altitude	*Excess over ground*
500 meters	−2.1 ions/cc. sec.
760	−2.7
1200	−2.7
1750	−1.9
2500	−0.1
3400	+2.4
4200	+4.6
5200	+7.4

In these airplane flights the electroscope was suspended in front of the observer's seat by three pieces of ordinary laboratory rubber tubing, attached at their upper ends to the sides of the cockpit or to the gun-mount. The instrument was kept from swinging by another piece of tubing fastened at one end to a plug which screwed into the bottom of the electroscope and at the other end to the floor of the cockpit. The electroscope was thus made stable and free from the effect of vibration of the airplane motor.

The method followed was to go to the highest altitude attainable in a reasonable time, maintain the airplane accurately at that altitude during the period over which ionization was to be measured, then drop down to the next altitude, etc. Because of the limit to the amount of gasoline that can be carried to those high altitudes and the long time required to reach them, it was never possible to make observations at more than three different altitudes on the same day.

The results shown in Table I are in agreement with those of Millikan and Bowen[1] in that they show a markedly lower rate of leak at the highest altitudes reached than those reported by Hess and Kolhörster. However, as a whole these balloon and airplane measurements are in agreement with those of the European observers *in showing that the* *intensity of the penetrating radiation first decreases to a minimum after which it increases continuously with altitude.*

V. INDEPENDENCE OF PENETRATING RADIATION UPON TIME OF DAY

During three different summers, 1922, 1923, 1925, we have made long series of observations, not only at Pasadena but on Mt. Whitney and on Pikes Peak, to test the constancy of the ionization due to the penetrating rays. At Pasadena, where the average number of ions as measured by the foregoing unshielded electroscope is 11.6, the fluctuations may be as much as an ion, but no systematic variation whatever has been observed. On Pikes Peak, where the rate of discharge of the unshielded electroscope is nearly twice that at Pasadena no variation with time of day was found.

Table II gives in the first two columns a series of readings, each lasting two hours, taken on top of Pikes Peak inside a shield of lead 4.8 cm thick at the sides, 11 cm at the top, and open at the bottom, and in the last two columns a continuous series of twenty similar observations taken with the unshielded electroscope at altitude 4130 m on the trail to Mt. Whitney.

TABLE II

Observations showing independence of penetrating radiation upon time of day.

	Pikes Peak (4300 m) Shielded electroscope				Mt. Whitney Trail (4130 m) Open electroscope		
	Mean time of observation		Ions per cm^3 per sec.		Mean time of observation		Ions per cm^3 per sec.
9/22/23	2:43	P.M.	12.5	9/16/22	8:50	P.M.	19.2
	4:57	"	12.4		10:58	"	18.9
	7:06	"	12.1				
	9:26	"	12.7	9/17/22	1:05	A.M.	19.2
					3:12	"	18.9
9/23/23	11:31	A.M.	12.6		5:19	"	19.2
	1:38	P.M.	12.2		7:26	"	20.0
	4:05	"	12.8		9:31	"	20.7
	8:35	"	12.0		11:37	"	19.4
	10:45	"	12.0		1:43	P.M.	18.6
					3:50	"	19.8
9/24/23	12:57	A.M.	12.0		5:59	"	19.2
	3:25	"	12.2		8:03	"	19.6
	5:52	"	12.3		10:07	"	19.3
		Mean,	12.3	9/18/22	12:12	A.M.	19.4
					2:18	"	19.8
					4:26	"	20.0
					6:33	"	20.4
					8:40	"	19.9
					10:49	"	20.0
					12:54	P.M.	21.0
						Mean,	19.6

The results shown in this table are merely typical of a very considerable amount of data, all of which is consistent in showing that within the limits *of our experimental error there is no dependence of the penetrating radiation upon daylight or darkness, or upon the position of any of the heavenly bodies. Two recent observations taken in a geological basin at a time when the Milky Way was wholly beneath the horizon gave no indication of a rate of discharge lower than that found when the Milky Way was overhead.*

VI. DEPENDENCE OF PENETRATING RADIATION UPON ALTITUDE

As already indicated, the mean value of the penetrating radiations as taken by the unshielded electroscope on the Institute campus is 11.6 ions. At bench mark No. 15 of the U. S. Geological Survey on the Mt. Whitney Trail, altitude 4130 m it is 19.6. At bench mark No. 14, elevation 3660 m, the mean of two observations gave 17.3 ions. The last two observations were both taken on the granite rocks so that their difference, 2.3 ions, might be expected to represent a true altitude difference. *It is quite close to the difference shown in Table I in the readings taken in airplanes between the same levels.* Further, near bench mark No. 14 a shallow lake 1 m deep was found over which when the electroscope was floated on a raft the reading was 13.6, or 3.7 ions less than on the adjacent rocks. This difference is close to the mean of all the data heretofore collected on the change in electroscope reading in going from over land to over water. A collection of eight such differences taken by McLennan, McLeod, Kunsman, and Wulf is as follows: 3.3, 5.1, 3.8, 2.2, 4.9, 3.2, 3.8, 4.5; mean 3.8. This mean is in close agreement with the value of 3.7 here found. When 3.7 is subtracted from any of the aforementioned mountain observations they come fairly close to the readings at corresponding heights shown in Table I.

Although, then, the uncertainty due to variability in the activity of the adjacent rocks is great, *the evidence of all the foregoing mountain and airplane work is that there is a definite variation with altitude alone and that mountain and airplane observations can be brought into approximate agreement by suitable precautions for eliminating the activity of the adjacent rocks.*

VII. ABSORPTION EXPERIMENTS ON PIKES PEAK

None of our experiments so far had given us any information about the actual hardness of the penetrating rays. To obtain this information we constructed a completely encircling shield of seven sheets of lead, each a little less than 7 mm thick, the total lead shield having a thickness of 4.8 cm. The sides of the shield were made of semicylinders removable separately so as to open the electroscope to radiations from opposite directions. The top and bottom shields were circular plates of the same sheet lead.

In order to support this 300 pounds of lead it was necessary to use a steel frame consisting of two vertical rods supporting two ring-shaped plates. On the bottom plate rested the electroscope and the sides of the shield, while the top plate held the top of the shield. The bottom of the shield was placed on a steel strip and brought up to the bottom of the electroscope by nuts on the vertical rods. In Fig. 3 the electroscope is shown on its stand with part of the lead sheathing in place.

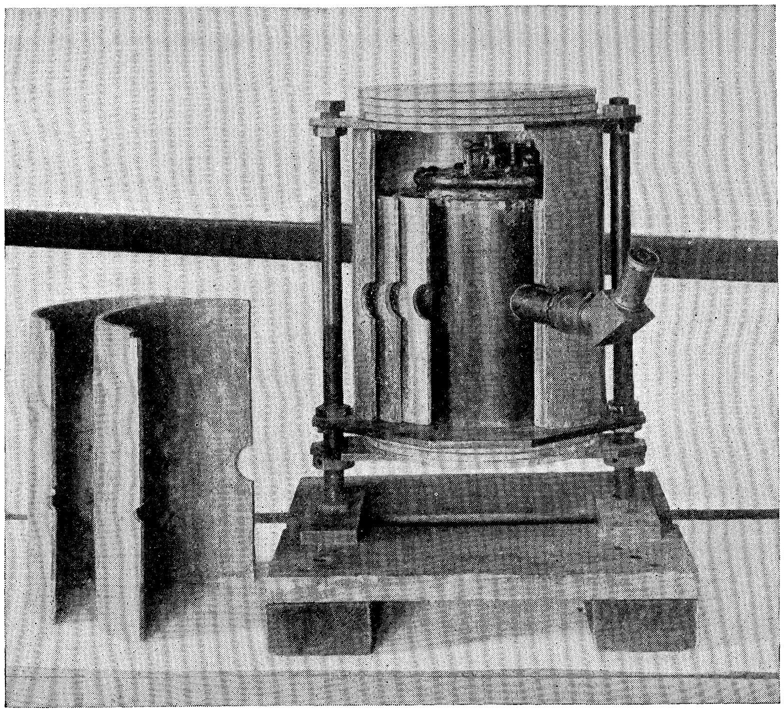

Fig. 3

TABLE III

Pike's Peak observations—out-of-doors.

A	Unshielded (mean of four one-hour runs)	23.2 ions per cm^3 per sec.
B	Shielded (4.8 cm of Pb.) (mean of four one-hour runs)	11.6
C	Top only unshielded (mean of three one-hour runs)	12.3
D	Bottom only unshielded (mean of four one-hour runs)	13.2
E	North side only unshielded (mean of four one-hour runs)	16.9
F	South side only unshielded (mean of four one-hour runs)	16.7
G	Both sides unshielded (mean of two one-hour runs)	20.55
H	On the tower (17 m high) of the building, unshielded, mean of two observations (17.1 and 17.5)	17.3

The results of all the observations taken on Pikes Peak are condensed into Tables III and IV. In Table III measurements *A* to *G* were taken out of doors on the rocks at the top of Pikes Peak. Measurement *H* was taken on the top of the skeleton steel tower above the inn. The measurements of Table IV were made inside the inn. The means of observations taken with the same apparatus in a tent on the campus of the Institute at Pasadena are given in Table V.

TABLE IV

Pikes Peak observations—indoors.

	Unshielded A	Shielded B	Top and bottom unshielded C	Bottom unshielded 16 layers on top D
		(Before the storm)		
	22.51	12.36	14.00	12.10
		12.23	15.04	12.60
		12.00	14.42	12.20
		12.63	14.54	12.80
Means	22.51	12.30	14.50	12.43
		(After the storm)		
	20.78	10.94	12.67	12.35
		11.11	12.70	11.75
			12.74	
			12.92	
			12.77	
Means	20.78	11.03	12.76	12.05

TABLE V

Pasadena observations

A	Unshielded	11.57
B	Shielded	9.37
C	Top only unshielded	9.54
D	Bottom only unshielded	9.40
E	Top and bottom unshielded	9.54
F	Both sides unshielded	10.75
G	Sides shielded, bottom unshielded, 16 layers of lead on top	9.28

There is no evidence in Table III of any difference in intensity of the penetrating radiations coming from the north and from the south, for the difference between the ionizations when the north side was unshielded and when the south side was unshielded is well within the limits of experimental error. The data show also that most of the radiation entered the electroscope through the sides, as was to be expected.

Another interesting result is that on Pikes Peak, the radiation out-of-doors was greater than that in-doors, while in Pasadena the radiation out-of-doors is a little over 1 ion per cc per sec. less than that in-doors in a concrete building. At Pasadena, then, the walls of the building add more radiation than they absorb from the outside, while on Pikes

Peak the reverse was true. This is doubtless because on Pikes Peak there is more outside radiation to absorb.

The radiation found on Pikes Peak is in substantial agreement with the measurements made at corresponding heights both on Mount Whitney and in airplanes. Thus, if the amount of radiation from the ground be taken the same as on Mount Whitney (3.7), then, following the same method as was used above, the radiation which would have been observed at the altitude of Pikes Peak (4300 m) if the ground had not contributed anything is, from the mean of all the A measurements in Tables III and IV, $22.2-3.7$ or 18.5 ions per cc per sec. The difference between this and that observed at Pasadena, from A, Table V, is $18.5-11.6$ or 6.9 ions per cc per sec. On referring to Table I it will be seen that this value fits reasonably well with the airplane data.

But it is obvious at once from Table III that there is a very much larger amount of soft radiation (of the hardness of gamma rays) on the mountain peaks than at Pasadena. Thus, while the difference between the shielded and the unshielded readings at Pasadena is but $11.57-9.37$ or 2.20 ions, on the Peak outdoors it is $23.2-11.57$ or 11.6^3, and when means are taken as above it is $22.2-11.57$ or 10.6^3. The rays producing these 11.63 (or 10.63) new ions found (unshielded) on Pikes Peak are necessarily soft rays since they are nearly all absorbed by the lead screen within which there are found all told but 2.23 more ions than at Pasadena. If these new rays found on Pikes Peak are assumed to be homogeneous, their absorption coefficient, α, computed from the relation $I=I_0e^{-\alpha d}$, comes out, since d, in meters of water, is $4.8\times 11.3 \div 100=0.54$,

$$\alpha=\log_e (11.63/2.23)\div 0.54=3.1 \text{ per meter of water.}$$

This indicates that these rays are but little harder than the gamma rays from RaC, which are taken by Kolhörster,[2] for example, as having a coefficient of 3.9 per meter of water, while for ThD $\alpha=3.3$. *In other words, a homogeneous radiation of about the hardness of the gamma rays from* RaC *or* ThD *would account for all the increase found inside and outside of lead screens in the Pikes Peak experiments. If the rays are not homogeneous, since, in any case 80% are absorbed in the lead, the great majority of them cannot be appreciably harder than gamma rays, and these must be of local origin since gamma rays are all absorbed in 500 meters or so of air.* The change from about 22 ions to 17.3 ions in going from the inn to the fifty-foot tower above it indicates that some of the new rays found on the Peak are softer than gamma rays.

[2] Kolhörster, Sitz. Ber. d. Preuss. Akad. **34,** 371 (1923).

The foregoing evidence for the local origin of the greater part of the increased radiation found at the Peak is strengthened by a consideration of the effect of the storm noted in Table IV. This was a heavy snow storm, in which perhaps a foot of snow fell. The storm began at about six o'clock one evening and lasted throughout the night. About ten o'clock P.M. we noticed the reduction in the readings, a reduction which persisted during the hours during which we kept observing continuously after the storm. We had been observing day and night for two or three days before the storm, and had obtained a consistent series of readings throughout, so that the change surprised us greatly when it came. Table IV shows that all the readings, shielded and unshielded, are smaller after the storm than before. These readings were all taken indoors where the temperature was kept essentially constant, and no instrumental causes of the change could be found.

If these changes are due to the storm, i.e., to the blanketing of the earth with snow, they should be essentially the same in the column headed B as in that headed D. Taking, then, the mean of these two changes we obtain as the average shielded reading after the storm 11.5. The change under C, which is somewhat too large to be altogether consistent with the changes under A, B, and D, forces one to admit a somewhat larger observational or instrumental error of some sort than the general consistency of the readings otherwise indicates. Nevertheless, the readings as they stand, taking 11.5 as the mean shielded reading after the storm, show a drop due to the storm of about 8 percent for the unshielded condition and 7 percent for the shielded condition. When further we subtract from both readings the 6 or 7 ions which, according to our measurements made under water, were due to the radioactivity of the walls of the vessel and hence had nothing to do with external radiations at all, we see that the rays which get through the lead screen are cut down by the storm by quite as large a percent (apparently a slightly larger one) as the rays found in the unshielded electroscope. Such a result, if correct, *obviously requires the rays to be entirely of local origin.*

Both lines of evidence presented above point, then, to the conclusion that there is on mountain peaks a copious radiation of local origin and of a hardness not greater than that of the gamma rays of radium or thorium, but they reveal thus far no penetrating radiation of cosmic origin. If such a radiation exists at all it can at the most produce but a small part of the ionization observed in electroscopes on mountain peaks.

Kolhörster[3] in 1923 assumed such a radiation which produced 2 ions per cc per sec. at sea level, and had an absorption coefficient α in water of 0.25 per meter. Such a radiation would produce at Pikes Peak, where the average barometer reading is 17.5 inches, an ionization I_0 given by

$$\tfrac{1}{2}I_0 = e^{.25\times 4.3} = e^{1.08}$$

Therefore,

$$I_0 = 2\times 2.95 = 5.9$$

and of these 5.9 ions 5.15 would have been found inside our lead screen 4.8 cm thick. Similarly of the 2 ions assumed at sea level to be due to the cosmic rays 1.75 would be found inside the lead screen. That is, radiation of the assumed characteristics would have caused by itself inside our lead screen an increase of $5.15 - 1.75 = 3.4$ in taking the screened electroscope to the top of Pikes Peak even if none of the large increase in radiation shown by the unshielded observations on the Peak got through the lead—a supposition well nigh certain to be contrary to fact, for gamma rays from ThD would pass through this lead to the extent of about one sixth of the value outside.

The observed increase inside the lead screen and outdoors on the peak was, however, but 2.23 ions, that indoors after the storm but 2.13 and that indoors before the storm 2.9, a mean of 2.4 in place of the required minimum value of 3.4. In other words, penetrating cosmic rays of such characteristics as were assumed above cannot exist, since these rays alone, without the aid of any local radiation such as almost certainly exists, would produce on Pikes Peak a 40 percent greater increase in ionization inside the lead shield than we found. *The net result of the Pikes Peak work is, then, to establish quite definitely* (1) *the existence of a considerable increase in soft radiation in ascending from Pasadena to the Peak*; (2) *the non-existence of a radiation of cosmic origin of such constants as are supposed above.*

If cosmic rays exist at all they must be less intense at the surface than above assumed, or else they must be more penetrating than any one had as yet suggested.

Norman Bridge Laboratory of Physics,
California Institute of Technology,
March 1, 1926.

[3] Kolhörster, Sitz. Ber. D. Preuss. Akad. **34,** 366 (1923).

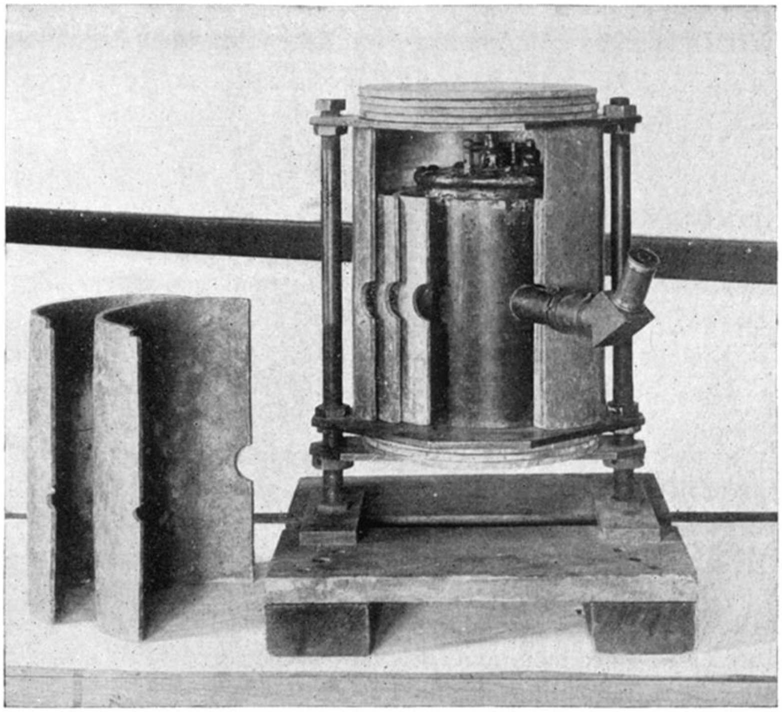

Fig. 3