Cosmic-Ray Measurements with a Small Ionization Chamber

I. Variation with Altitude and Latitude of the Total Ionization for Various Shields[1]

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Ionization data have been obtained with a small ionization chamber (230 cc volume) at three corresponding altitudes (76, 51, and 45 cm Hg) in northern and equatorial latitudes, for shielding thicknesses up to 19.4 cm Pb. It is found that within limits of error the latitude ionization ratios, northern: equatorial, are independent of shield at each elevation studied. The values of the latitude ratios are: 1.16 at 76 cm Hg, 1.27 at 51 cm Hg, and 1.30 at 45 cm Hg. An analysis of the lead absorption curves has been made in terms of a penetrating ionizing radiation and a softer secondary radiation. By comparing the ionization data with counter data on the absorption of vertical rays and on showers, available at two altitudes (76 and 51 cm Hg), an estimate has been made of the individual contributions of the penetrating and secondary rays to the measured ionizations. The analysis shows that the ionization due to secondaries associated with the soft component is to be identified with the shower radiation. The contribution of secondaries is important, even under thick shields. For 19.4 cm Pb it amounts to 50 percent of the total ionization at 51 cm Hg and to 20 percent at 76 cm Hg. The curves of intensity of secondary rays *vs.* thickness of lead indicate a second maximum for thick shields.

1. INTRODUCTION

THE existence of a latitude effect in the cosmic radiation has been well established, though the magnitudes of the effect found by different investigators are somewhat conflicting. At sea level Clay[2] finds with an unshielded vessel a maximum increase of 17 percent between 0° and 45° north magnetic latitude. Millikan and Neher[3] find increases from 8 to 12 percent depending on longitude, for 11 cm lead shield and for no shield, and Compton[4] gives the value 14 percent for 6 cm lead shield. The latitude effect increases rapidly with altitude. Compton[4] finds a 33 percent effect at 4300 m between 0° and 50° north magnetic latitude with both a shielded (6 cm Pb) and an unshielded chamber. Bowen, Millikan, Korff and Neher[5] find a 36 percent effect at 8800 m. Clay[2] reports a 30 percent effect at 5000 m between 18° south and 53° north, and at 15,000 m a latitude ratio of 8 to 1 for the ionization in Holland relative to that in Java. The magnitude of this last ratio is doubtful in view of Millikan's later findings which give a ratio of 2 to 1 between San Antonio, Texas, and Madras, India at about this same elevation.

It is of importance to know whether the radiation changes in quality, as well as intensity, with altitude and latitude. Schindler[6] has obtained a set of transition curves between various media at sea level. Clay and Alphen[7] state that altitude curves based on data from shielded and unshielded chambers are the same in form in equatorial latitudes, but differ in northern latitudes. They note, however, that the shielded curves are the same for both latitudes. Clay's measurements under water and lead[8] indicate the radiation in equatorial regions to be the more penetrating. We have obtained absorption curves in lead at three comparable altitudes up to 4300 m in northern and equatorial latitudes. Our data show that the variation with altitude at both latitudes is a function of the shielding, but that at a given altitude the curves at the two latitudes are similar.

[1] J. C. Street and R. T. Young, Jr., Phys. Rev. **46**, 823 (1934).
[2] J. Clay, Physica **1**, 363 (1934).
[3] R. A. Millikan and H. V. Neher, Phys. Rev. **50**, 15 (1936).
[4] A. H. Compton, Phys. Rev. **43**, 87 (1933).
[5] I. S. Bowen, R. A. Millikan, S. A. Korff and H. V. Neher, Phys. Rev. **50**, 579 (1936).
[6] H. Schindler, Zeits. f. Physik **72**, 625 (1931).
[7] J. Clay and P. M. V. Alphen, Physica **2**, 183 (1935).
[8] J. Clay, Physica **2**, 299 (1935).

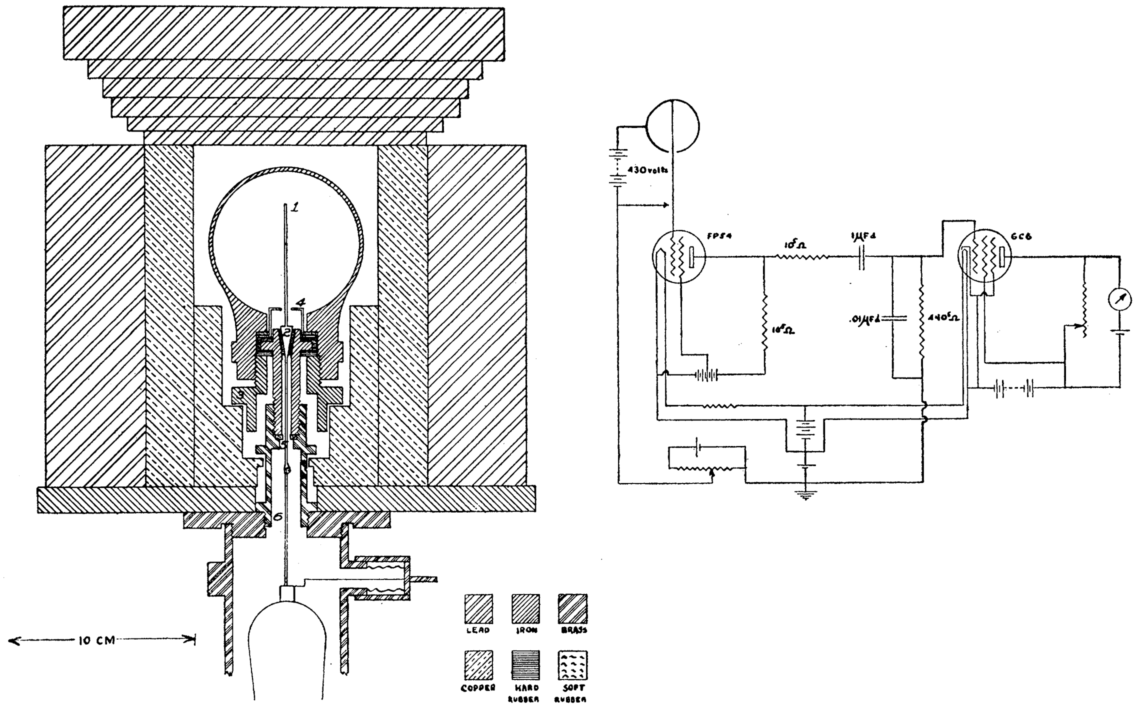

FIG. 1. Ionization chamber and recording circuit.

2. THE EQUIPMENT AND ITS OPERATION

Due to the fact that we wished to measure small bursts along with the total ionization (see II[9]) the volume of the chamber used was small, 230 cc. The design of the chamber and arrangement of shields is shown in Fig. 1. The collecting electrode, 1, passes through a conical plug, 2, to the grid of an FP 54 electrometer tube. The plug is insulated from the outer sphere by a hard rubber sleeve. This sleeve also holds the pressure (200 lb.) and behaved very satisfactorily, particularly when sealed with glyptol. The sphere is insulated from its support by flat hard rubber washers, which, together with a lead washer, likewise hold the pressure. Some trouble was experienced with the rubber flowing away from its supporting surfaces. However, if the large nut, 3, were tightened up at intervals throughout a period of a few days, the flow stopped and the chamber held its pressure. The guard ring, 4, in the shape of a brass hat, shields the collecting electrode from the insulating surfaces. If this electrode is not properly shielded, there is produced a spurious voltage on the inner electrode when the electric field is reversed, due to polarization effects in the dielectric, and a considerable length of time is required before equilibrium is established.

The amplifying system of Fig. 1 was designed to record both small bursts and ionization with the same apparatus. By means of the capacity coupling only sharp changes in potential of the collecting electrode are recorded. The electrometer tube is enclosed in a vacuum, the chamber support at 5 being sealed by a soft rubber washer and stopcock grease, and the threads at 6 by Apiezon putty. The output of the FP 54 is coupled by a 0.1 meg. resistor and a 1 μf condenser to the grid of a 6-C-6 pentode amplifier. The grid of the 6-C-6 is connected to ground by a 4 megohm resistance. The 0.1 meg. resistor and 0.01 μf condenser around this high resistance serve to filter out any high frequency pick-up. Variations of the plate current of the 6-C-6 were recorded by a galvanometer, with the steady plate current balanced out by a suitable battery in the galvanometer line. This circuit provided a convenient means of shifting the zero position of

[9] R. T. Young, Jr., Phys. Rev. 52, 559 (1937).

the galvanometer. By adjusting the plate, screen, and grid voltages, advantage was taken of the characteristics of the 6-C-6 to obtain a fairly drift-free circuit. The galvanometer deflections were recorded photographically on sensitive paper mounted on a revolving drum.

The grid of the FP 54 was periodically grounded by a clock-driven key mechanism and the net ionization charge accumulated on the collecting electrode during the given interval was recorded as a sharp jump on the photographic trace (see Fig. 1, II). To eliminate the effect of the grid current, runs were made with the sweeping field first in one direction and then in the other. Since the ionization current reverses in direction, while the grid current maintains the same direction, the latter can be averaged out.

The chamber was filled with commercially pure argon at 200 lb. pressure and operated at 430 volts. The side and bottom shields which were used to cut down local radioactivity are equivalent to 6 cm lead. This is sufficient to place the effects of the cosmic radiation incident from the side beyond the transition region. The top shields consist of flat lead plates of areas such that the same solid angle, i.e., that of a 41° cone, is subtended at the center of the sphere for all thicknesses. At each station values of the total ionization were obtained with upper shields up to 20 cm. Corrections for local radioactivity were made by methods similar to those described by Compton,[4] using values of the ionization obtained with and without side shielding. The voltage sensitivity of the FP 54 and amplifier were checked by means of the potentiometer arrangement shown in Fig. 1. For the most sensitive adjustment this amounted to 2 mm deflection on the trace per millivolt. The chamber sensitivity, i.e. the voltage change induced on the collecting electrode by a known amount of radiation, was determined at intervals by using a standard radium source.

TABLE I. *Elevations, barometric pressures and latitudes of stations.*

Station	Elevation	Barometric Pressure	Geomagnetic Latitude
Cambridge, Mass.	Sea level	76 cm Hg	53° N
Echo Lake, Colo.	3250 m	51.1	49
Mt. Evans, Colo.	4350 m	44.7	49
Lima, Peru	Sea level	76	1° S
Huancayo, Peru	3340 m	51.3	1
Cerro de Pasco, Peru	4360 m	45.4	1

The value of 2.48 ions per cc per sec. in air at S.T.P.[10] was taken as standard at Cambridge. With the use of this figure to set the value of a measured deflection for no upper shield (corrected for radioactivity), a reduction factor was obtained which enabled us to express all readings in ions per cc per sec. This procedure is justified only if the residual ionization due to radioactive contamination of the chamber is low. We were unable to check this by obtaining readings completely shielded from the cosmic radiation, but since the increase of measured ionization with altitude agrees with that of other observers, we conclude that the chamber contamination was not sufficient to distort our results.

3. Ionization Data

The various stations at which lead absorption data were obtained are listed in Table I.

Because of the fact that a mercury barometer was not carried with the expeditions and since our Aeronoid barometers did not behave satisfactorily in recording barometric differences between different elevations, the barometric pressures for some of the stations are uncertain by 0.1 or 0.2 cm Hg. Curves of barometric pressure against elevation for equatorial and northern latitudes were drawn from values given in Glazebrook's *Dictionary of Applied Physics* (Vol. III, p. 181, Table IX). Barometer readings were available at the Department of Terrestial Magnetism's observatory at Huancayo, and the value for Cerro de Pasco was fixed by subtracting from the Huancayo value the difference given by the curve. The barometric pressure given by Compton[4] was taken as standard for Mt. Evans, and the Echo Lake pressure obtained as above. Corrections were made for fluctuations of barometric pressure at a given station.

The total measured ionizations (corrected for local radioactivity) are given in Table II.

The trace deflections from which the ionization data were obtained were estimated to tenths of a millimeter, which corresponds to about $\frac{3}{4}$ of a percent for the smallest ionization rates. A study of the deviations of individual deflections shows

[10] R. A. Millikan, Phys. Rev. **39**, 397 (1932).

TABLE II. *Total measured ionizations in ions per cc per sec. in air at S.T.P.*

Northern Latitudes			
THICKNESS OF LEAD ABOVE CHAMBER IN CM	CAMBRIDGE	ECHO LAKE	MT. EVANS
0.00 no side shields	4.67	10.72	18.25
0.00 with side shields	2.48	7.30	11.31
0.64	2.48	7.92	12.21
1.27	2.43	7.34	11.61
3.18	2.05		8.45
6.66	1.84	4.32	6.06
9.2	1.79		
11.7	1.75		5.20
14.3	1.74		
19.4	1.70	3.74	4.90
Equatorial Latitudes			
THICKNESS OF LEAD ABOVE CHAMBERS IN CM	LIMA	HUANCAYO	CERRO DE PASCO
0.00 no side shields	4.41	7.22	11.83
0.00 with side shields	2.14	5.64	8.73
0.64		5.96	9.08
1.27		5.71	8.61
3.18		4.53	6.44
6.66	1.59	3.45	4.55
9.2		3.09	4.07
14.3		2.97	3.80
19.4		2.94	3.74

that the probable error of a single interval is about what one would expect from a consideration of the number of rays passing through the chamber. Taking the data as a whole, one can state the probable error of a measured ionization value at a given station to be within 2 percent. There may be, however, unsuspected systematic errors between values for different stations. The corrections for local radioactivity are only approximate, but since they amount to only 3 percent of the difference between the no-shield and side-shield readings, errors in estimation of the correction cannot affect the ionization values by more than 1 percent. Since the radioactive corrections refer only to ground radiations, contamination of the air above the chamber may lead to slightly greater inaccuracies in the values for no upper shields.

All measurements were made under light roofs. At the North American stations the apparatus was under canvas. At Lima the covering was one-half inch wood, Huancayo one inch wood, and at Cerro de Pasco one inch wood and one-half inch plaster. The stations were chosen to give as level a horizon as possible.

On the basis of Johnson's angular distribution data[11] an estimate was made of the fractional part, F, of the ionization due to radiation which does not pass through the cone subtended by the top shields. If $j(\theta)$ is the number of rays per unit solid angle per sq. cm perpendicular to the radiation, then:

$$F = 1 - \frac{\int_0^{\theta_1} j(\theta) \sin\theta d\theta}{\int_0^{\pi/2} j(\theta) \sin\theta d\theta},$$

where the upper limit, θ_1, is the angle subtended by the upper shield. The integrals were evaluated graphically, allowance being made for the shielding of the horizon. Measurements of the distribution of cosmic rays with varying zenith angle show their angular distribution to be, within limits of experimental error, the same at different latitudes.[11, 12] The factor F was evaluated for Lima and Cerro de Pasco, and the value for Huancayo obtained by interpolation. These same factors were applied to the northern data. The total ionization values for 6.66 cm shield (condition for approximate symmetry of shielding) at a given station were multiplied by the corresponding factor, and the result subtracted from all measured ionizations at that station. The quantities subtracted were: Cambridge, 0.77; Echo Lake, 1.71; Mt. Evans, 2.26; Lima, 0.67;

TABLE III. *Ionizations due to radiation passing through top shields.*

ALTITUDE: CM HG.	76		51		45	
GEOMAG. LAT.	53 N	1 S	49 N	1 S	49 N	1 S
THICKNESS LEAD ABOVE CHAMBER CM	IONIZATION IN IONS PER CC PER SEC. IN AIR AT S.T.P.					
0.00	1.71	1.47	5.64	4.40	8.82	7.12
0.64	1.71		6.26	4.72	9.69	7.47
1.27	1.66		5.68	4.46	9.10	6.99
3.18	1.28			3.24	6.04	4.75
6.66	1.07	.92	2.63	2.13	3.70	2.82
9.2	1.02			1.77		2.33
11.7	.98				2.86	
14.3	.97			1.64		2.04
19.4	.93		2.05	1.61	2.58	1.98

[11] T. H. Johnson, Phys. Rev. **45**, 584 (1934).
[12] W. Kolhörster and L. Janossy, Zeits. f. Physik **93**, 111 (1934).

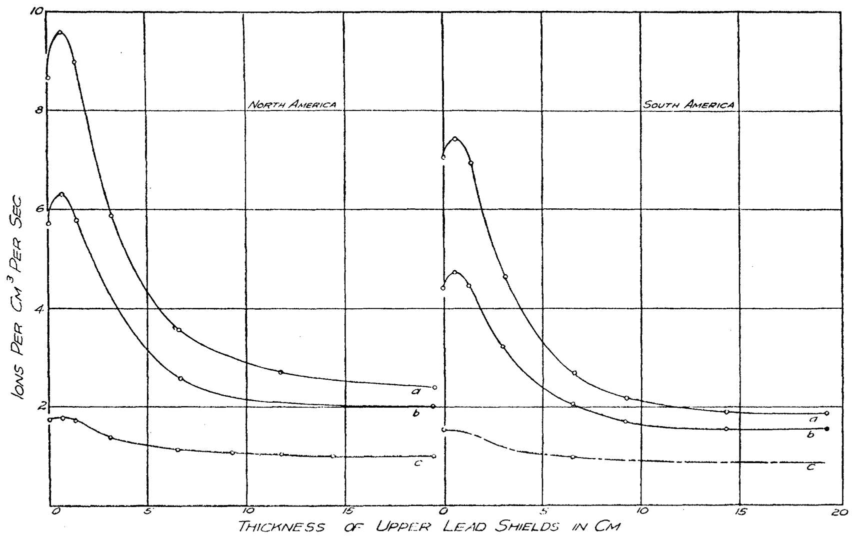

FIG. 2. Absorption curves of cosmic rays in lead. North America: *a*, 45 cm Hg; *b*, 51 cm Hg; *c*, 76 cm Hg. South America: *a*, 45 cm Hg; *b*, 51 cm Hg; *c*, 76 cm Hg.

Huancayo, 1.37; and Cerro de Pasco, 1.80 ions per cc per sec. The resultant ionizations obtained are those arising from the radiation passing through the top shields, and enable one to evaluate the absorption in the upper shields alone. The data thus obtained for corresponding northern and equatorial stations were reduced to the common barometric pressures: 45, 51, and 76 cm Hg, and are listed in Table III.

The curves of Fig. 2 are plotted from the data of Table III. These are essentially air-lead transition curves. Their initial portions may be affected to some extent by radioactive contamination of the air. This would tend to mask the initial rise and may be the explanation for the failure of the Cambridge curve to show any increase for the smaller shielding thicknesses, which Schindler[6] found to amount to 0.5 percent.

TABLE IV. *Latitude ratios.*

ALTITUDE: CM HG	76	51	45
THICKNESS LEAD ABOVE CHAMBER CM	LATITUDE RATIO	LATITUDE RATIO	LATITUDE RATIO
0.00	1.16	1.28	1.24
0.64		1.33	1.29
1.28		1.27	1.30
3.18			1.27
6.66	1.16	1.24	1.31
19.4		1.27	1.30
Average all Thicknesses	1.16	1.27	1.30

Also, the material above the chamber at Cerro de Pasco may have influenced the initial portions of that curve.

Two types of comparison may be made: (1) variation with latitude and, (2) variation with altitude.

4. LATITUDE EFFECT

In Table IV are recorded latitude effects, as calculated from the values of Table III, in the form of the latitude ratios:

$$I_{\text{northern}}/I_{\text{equatorial}}.$$

Examination of the table leads us to the conclusion that the latitude ratios are independent of the shielding, although the total ionization is reduced by 45 percent, 67 percent and 74 percent at 76, 51, and 45 cm Hg, respectively, when the shield is increased from 0.64 to 19.4 cm Pb. At each of the higher altitudes one or two of the values show a greater deviation from the average than one would expect from statistical considerations. However, the corresponding values at different altitudes for a particular shield do not support an interpretation that these deviations represent any significant trend. The average latitude ratios are in quite good agreement with those found by Compton[4] at the same elevations.

Transition curves represent ionization arising from two factors: (a) ionizing rays incident from the air which penetrate the shield and (b) secondaries produced in the shielding material. Since the relative contributions of these two factors change markedly with shield (see Section 5) whereas the latitude ratios for the total ionization remain constant, we must conclude that the latitude variation is the same for both. The simplest assumption to make is that they have a common primary origin. The alternative hypothesis that these factors arise from two independent primary components is not ruled out, however, if we assume the same field sensitivety for both.

There is one feature of the above data for which we have no adequate explanation, namely: the latitude ratios decrease from 1.30 to 1.16 as the thickness of the atmosphere increases from 45 to 76 cm Hg, whereas at a given altitude the latitude ratio is independent of thickness of lead up to 20 cm.

5. Variation with Altitude

Several attempts have heretofore been made to analyze transition curves. Johnson[13] has analyzed Schindler's curves in terms of a non-ionizing primary radiation coming into equilibrium with its secondaries in passing from one medium to another, and has evaluated the absorption and production coefficients from Schindler's data. Counter experiments by Rossi[14, 15] and cloud chamber experiments by Street, Woodward and Stevenson,[16] and by Auger and Ehrenfest[17] show however that the assumption of a non-ionizing penetrating radiation does not apply, and one must take account of the ionization produced directly by penetrating particles. Woodward[18] has carried out counter experiments on showers up to 10 cm Pb, and on penetrating rays (using 4 counters in line) up to 91 cm Pb at Cambridge and at Echo Lake. Utilizing his data we can make an analysis of our curves and assign values independently to the contributions of the penetrating and secondary radiations. We assume the measured ionization to be due to:

a. Penetrating ionizing rays, whose absorption in lead and variation with altitude is given by measurements with counters in line.

[13] T. H. Johnson, Phys. Rev. **41**, 545 (1932).

[14] B. Rossi, Zeits. f. Physik **82**, 151 (1933).

[15] B. Rossi, Internat. Conf. Physics, London, Oct. 1934.

[16] J. C. Street, R. H. Woodward and E. C. Stevenson, Phys. Rev. **47**, 891 (1935).

[17] P. Auger and Ehrenfest, Comptes rendus **199**, 1609 (1934).

[18] R. H. Woodward, Phys. Rev. **49**, 711 (1936).

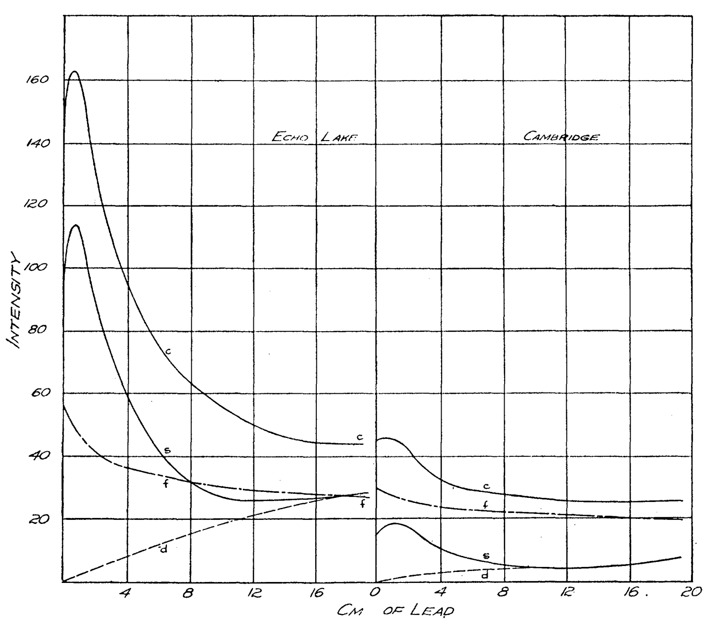

Fig. 3. (left) Curves of absorption of penetrating and secondary rays. c, total ionization; p, penetrating rays; s, secondary rays; d, penetrating component in secondary radiation.

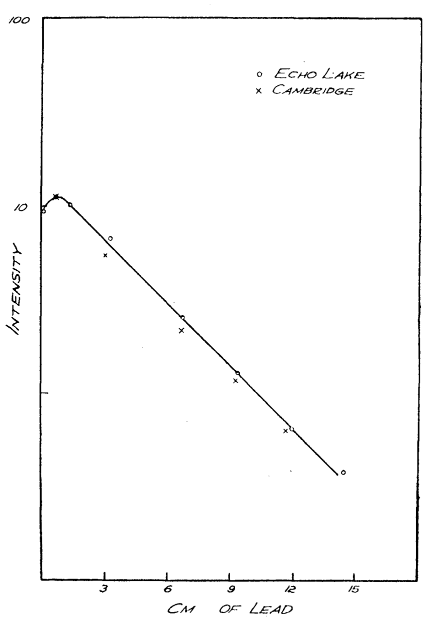

Fig. 4. (right) First peak for secondary rays.

b. Secondary rays, whose production and absorption are given by counter measurements on showers.

Let I_p and I_p' be the intensity of the penetrating rays at sea level and at Echo Lake, respectively, as determined by Woodward's counter arrangement; I_s and I_s' the intensity of secondary rays at sea level and Echo Lake in the same units as I_p and I_p'; J and J' the measured ionizations at sea level and Echo Lake. We can write:

$$J=K(I_p+I_s) \quad \text{and} \quad J'=K(I_p'+I_s').$$

From the counter data on the penetrating rays we obtain $I_p'/I_p=1.39$ at 19.4 cm Pb, and from the data on showers we take $I_s'/I_s=5.0$ for all thicknesses of lead.[19] Using the ratio $J'/J=2.2$ obtained from the ionization chamber measurements for 19.4 cm Pb we can solve the above equations for I_s and I_s' and find $I_s=5.5$ and $I_s'=28$ on the same arbitrary scale as I_p and I_p'. The values of I_p and I_p' for the same lead thickness are 19.2 and 26.7. The contribution of secondary rays is thus a considerable fraction of the total observed ionization under thick shields; roughly, 50 percent at 51 cm Hg and 20 percent at 76 cm Hg. Kulenkampff[20] finds by an entirely independent method that the contribution of secondary rays at sea level and for 30 cm Fe amounts to 17 percent.

In Fig. 3 we have plotted the counter data for the penetrating rays as the dashed curves, *p*, on the above arbitrary scale of intensity. The upper full curves, *c*, are the ionization curves of Fig. 2 reduced by the factor K, and adjusted so that at 19.4 cm Pb they lie 5.5 and 28 units, respectively, above the counter curves at sea level and Echo Lake. Subtracting the curves for the penetrating rays from the ionization curves we obtain the lower full curves, *s*, the values of which are proportional to the ionization produced by the secondary rays.

At zero lead the curves representing the measured ionization lie 95 and 17 units, on the scale chosen, above the counter curves for the penetrating rays at Echo Lake and sea level, respectively. These values are proportional to the ionization due to soft rays from air (and to some extent to those produced in the walls (1 mm steel) of the chamber itself) which will not be recorded by 4 counters in line (112 cm between end counters), due to absorption in the counter walls and to scattering, but will register in an ionization chamber.[21] The curves, *s*, rise from 10 cm on. This means that at greater lead thicknesses the ionization curves are flatter than the counter curves. Curves of a similar form would be obtained if we subtracted the values of the counter curves from those of the ionization curves irrespective of the scales used, but the above method gives the magnitude of the contribution of secondary rays relative to the penetrating rays. Too great significance cannot be attached to the numerical values of the relations between the penetrating and secondary rays, due to lack of exact counter data on showers at sufficiently great thicknesses of lead, but we believe the method of analysis used is of value for the interpretation of ionization chamber data.

The second rise in the curves, *s*, of Fig. 3 indicates the existence of a more penetrating component in the secondary producing radiation. Ackemann,[22] Hummel,[23] and Kulenkampff[20] have noted the appearance of a second peak in counter curves which represent secondary rays. This has been verified by Woodward.[18] We suggest that the rise in our curves is due to the same phenomenon. Making a reasonable estimate of the course of the ionization responsible for this second peak, as shown by the dotted curves, *d*

[19] Woodward states that the altitude ratio for showers between Echo Lake and Cambridge is 5.0 within limits of probable error for all lead thicknesses up to 10 cm (the extent of his measurements). Closer scrutiny of his data indicates that this ratio falls off somewhat with increasing lead; e.g. at 9.85 cm the ratio is 4.5. The behavior of small bursts described in II, Reference 9, indicates a similar decrease of the ratio, but in neither case are the data sufficiently precise to warrant a more refined analysis.

[20] H. Kulenkampff, Physik. Zeits. **35**, 785 (1935).

[21] Street and Woodward (J. C. Street and R. H. Woodward, Phys. Rev. **46**, 1029 (1934)) have discussed this point in connection with their determination of the specific ionization of cosmic rays by comparing the number of rays recorded by a counter set with the volume ionization produced in an ionization chamber. Using the above values for the relation between penetrating and secondary rays at zero lead we find that Street and Woodward's value of 100 ions per cm in air at S.T.P. would be reduced to 71, which is in the range of values found by others (W. F. G. Swann, Phys. Rev. **44**, 961 (1933); R. D. Evans and H. V. Neher, Phys. Rev. **45**, 144 (1934)). Since in the counter arrangement of Street and Woodward the effect of nonrecording of soft secondaries would be less pronounced than in the present case, this figure merely indicates that the relations we find between the penetrating and secondary rays are reasonable.

[22] M. Ackemann, Naturwiss. **22**, 169 (1934).

[23] J. N. Hummel, Naturwiss. **22**, 170 (1934).

of Fig. 3, and subtracting the values of this curve from those for the secondary rays, we obtain curves which should represent the ionization due to the softer secondary component. These curves for Echo Lake and sea level have been reduced to the same scale and plotted logarithmically in Fig. 4. The high altitude and sea level curves are similar in form, and after their initial rise, fall off linearly with a "decrease coefficient" of 0.3 cm^{-1} Pb. Woodward finds the coefficient 0.33 cm^{-1} Pb for the first peak of his shower curves. This indicates that the results of our analysis are in agreement with the assumption that the ionization arising from the transition effect is attributable to the radiation responsible for showers.

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Cosmic-Ray Measurements with a Small Ionization Chamber

II. Comparison of Small Bursts at Different Altitudes and Their Variations with Thickness of Shield*

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Measurements of bursts produced in a small ionization chamber (230 cc volume) have been carried out at several stations. A comparison is made between frequencies of occurrence of various sized bursts at Cambridge, Mass. (bar. 76), Echo Lake, Colo. (bar. 51.1), Mt. Evans, Colo. (bar. 44.7), and Cerro de Pasco, Peru (bar. 45.4). The altitude ratios for burst groups comprising 10–19 rays, 20–29, and 30 and greater, are: Echo Lake to Cambridge, 4.9, 8.0 and 8.8; Mt. Evans to Cambridge, 7.3, 14.3 and 20.0. The data for the smallest burst groups are in agreement with counter measurements on showers, while the ratios for the largest bursts agree with the ionization chamber data of others on large bursts. The maxima of the burst production absorption curves shift to greater lead thicknesses with increasing burst size.

1. Discussion of Apparatus

We have described in I[1] equipment which is suitable for the measurement of both total ionization and small bursts. The total ionization is determined from measurements of periodic jumps of a photographic trace when the grounding key is closed. While the key is open (see Fig. 1, I) the trace would be a straight line corresponding to the zero position of the galvanometer if the ionization were perfectly steady. However, if the radiation fluctuates within a period comparable to the time constant of the circuit, the trace will fluctuate. Instantaneous bursts of ionization will be recorded as sharp jumps. Fig. 1 is a reprint of a section of one of our records (6.66 cm Pb, Mt. Evans). The time scale is indicated by the large periodic jumps which correspond to the grounding of the collecting electrode every 70 seconds. Arrow 1 indicates a burst of 10 rays (the lower limit of

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[1] R. T. Young, Jr., and J. C. Street, Phys. Rev. **50**, 552 (1937).