error based on internal consistency differs from unity by 0.10. For 37 particles the calculated deviation from unity of this ratio is 0.12. The mean value of the mass of the mesotron in electron mass units deduced from this consistent set of 37 observations is 215 ± 4.

The existence of six observations that are not consistent with the other observations may indicate that the probable errors assigned to the individual observations are too small, or that the mass of the mesotron as observed at sea level is not unique. The existence of a small percentage of the π-mesotrons[14] in the normal, or μ mesotron spectrum would not be resolved in a series of observations with probable errors as large as indicated here.

The existence of mesotrons with lighter and heavier masses has been suggested by the observations of Hughes,[2] LePrince-Ringuet,[5] and Alichanian, Alichanow, and Weissenberg.[6] Adequate evidence for the existence of these particle will require the accumulation of more data. The chance of mistaking a normal mesotron for such a particle can be appreciably reduced by using thinner absorbing plates to reduce the error in range and by careful design and control of the cloud chamber to reduce turbulence.

[14] Lattes, Occhialini, and Powell, Nature **160**, 453, 486 (1947).

ACKNOWLEDGMENTS

One of us (J.G.R.) takes this opportunity to acknowledge the assistance of a Westinghouse Fellowship in Physics. We are indebted to Professor R. T. Birge for his interest in the statistical interpretation of the data, and to Mr. R. R. Brown, who built most of the control circuits.

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The Properties of Cosmic Radiation in the Lower Atmosphere*

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Experiments performed previously with apparatus carried to very high altitudes by free balloons have been conducted in the lower portion of the atmosphere. Two different instruments were operated in a B-29 airplane, and at Mt. Evans, Colorado. Absorption curves in lead, up to a thickness of 18 cm, were obtained at 14,260 feet, 25,000 feet, and 30,000 feet. Intensity *vs.* altitude curves for the lower regions of the atmosphere may now be combined with those for very high altitudes without an arbitrary normalization. A direct comparison has been made between the present measurements and those of others regarding the relative change of intensity between sea level and Mt. Evans, and the absorption in lead at Mt. Evans. Factors for the conversion of all of the data to absolute intensities have been determined utilizing a γ-ray howitzer method for measuring the effective length of a G-M counter. Satisfactory agreement is noted between values of the absolute intensity previously measured by others at sea level and at Mt. Evans, and those reported herewith. The absolute intensity of cosmic-ray particles near the "top of the atmosphere" at geomagnetic latitude 52°N is given as 10.1 ± 0.20 particles/min./cm^2/unit solid angle. Consideration is given to the considerable error which may be introduced in the comparison of measurements of the "total" intensity at very high altitudes obtained with different G-M counters.

I. INTRODUCTION

THE results of a series of investigations of the cosmic radiation in the upper regions of the atmosphere have been described recently.[1] Owing to a combination of the smaller intensity present at lower altitudes, and the relative briefness of the time interval during which free-balloon flights remain in regions of high atmospheric pressure (a consequence of the exponential variation of pressure as a function of altitude, and accentuated by the particular ballooning techniques employed here), data obtained at altitudes corresponding to pressures exceeding approximately 200 mm of Hg were not in general regarded as statistically significant.

The purpose of the present series of experiments was threefold:

(1) To obtain data at lower altitudes with the same apparatus utilized in the free-balloon ascents, thereby providing complete intensity *vs.* altitude curves, as well as cosmic-ray absorption curves for lead from sea level to the "top of the atmosphere;"

(2) To permit comparison of certain of the numerous measurements at various low altitudes (4350 meters—sea level) previously reported by others with those which would be yielded by the aforementioned apparatus. Comparison at more than one point furnishes a less arbitrary normalization than has usually been assumed.[2]

(3) To provide experimental evidence regarding the validity of comparison of data obtained with different geometrical arrangements, and specifically, to furnish at several altitudes a direct and precise standardization between two particular counter trains of different dimensions utilized in the balloon flight program.

* Assisted by the Joint Program of the ONR and AEC. Field trips were sponsored by the National Geographic Society.

[1] M. A. Pomerantz, Phys. Rev. **75**, 69 (1949).

[2] This matter has been discussed in reference 1.

TABLE I. Data pertaining to the influence of latitude variations upon the present measurements. It should be emphasized that the maximum percentages listed refer to the extreme termini and should not be construed as representing the expected fluctuations of the composite data listed in Table II.

Altitude—feet	Thickness of interposed absorber—cm of Pb	Maximum departure from intensity at average latitude (− South) (+ North)
25,000	0.0	±1%
	9.0	±1%
	18.0	±1.2%
30,000	0.0	−3%+5%
	9.0	−4%+8%
	18.0	−3%+5%

The above ends were realized by operating the two instruments concerned in a B-29 aircraft during a series of flights sponsored recently by the U. S. Air Force and the National Geographic Society. Opportunity for taking the same sets to Mt. Evans, Colorado, during the summer of 1948 was also afforded by the N.G.S. The first apparatus, designated as *A*, has already been described in reference 1. The second, *B*, also embodied a quadruple coincidence counter train with provision for interposing up to 18 cm of absorber. Each tray of *B* consisted of 3 G-M counters, identical with those of *A*, connected in parallel and overlapped to present an uninterrupted horizontal plane. Complete dimensions of both *A* and *B* are given later (Section III).

The instruments were shock-mounted in the rear pressurized cabin of the B-29. The solid absorber overhead amounted to 0.5 g/cm² of Al. Both day and night missions were flown at isobaric levels of 282 and 226 mm of Hg, corresponding to approximately 25,000 feet and 30,000 feet, respectively.

The average geomagnetic latitude weighted with respect to the time actually spent in the various regions was 43.6° N for flights at both 25,000 feet and 30,000 feet. Cyclical and mixed alternation of absorber thicknesses was provided for, so that any small influence of the latitude effect was smoothed out, as was shown by the agreement of different runs within their statistical uncertainties. Measurements obtained simultaneously by Swann, Morris, and Seymour[3] concerning the knee of the latitude effect provide pertinent information regarding the maximum departures of the intensity from that at the average latitude. The values listed in Table I are only approximate, and represent conservative upper limits.

At the summit of Mt. Evans (geomagnetic latitude 49° N, altitude 14,260 feet, average atmospheric pressure 453 mm of Hg) the equipment was installed in the building of the Inter-University High Altitude Laboratory, under a light wooden roof.

In Swarthmore (geomagnetic latitude 52° N, altitude 296 feet, average atmospheric pressure 756 mm of Hg) the data were obtained in a thin wooden shelter on the roof of the laboratory.

TABLE II. Summary of data obtained at several altitudes with two different instruments.

Altitude—feet	Atmospheric pressure—mm of Hg	Thickness of interposed absorber—g/cm² of Pb	Total number of quadruple coincidences	Total time—minutes	Counting rate—counts per minute
		Apparatus A			
		0.0	14346	15648	0.917±0.007
		11.8	3759	4865	0.773±0.012
		23.6	5792	7593	0.763±0.010
		35.4	4598	6403	0.720±0.010
296	756	47.2	4591	6426	0.714±0.010
		59.0	2896	4044	0.716±0.013
		70.8	3734	5416	0.689±0.011
		85.0	2074	3087	0.672±0.014
10,700	515	0.0	874	365	2.39±0.08
		70.8	711	514	1.38±0.05
		0.0	3560	1090	3.27±0.054
		11.8	6470	2763	2.34±0.029
		23.6	5893	2759	2.14±0.027
14,260	453	35.4	2521	1324	1.90±0.037
		47.2	4608	2499	1.84±0.027
		59.0	2463	1413	1.74±0.035
		70.8	3820	2222	1.72±0.028
		85.0	2690	1645	1.64±0.032
		12.9C	3757	1455	2.58±0.042
		0.0	1832	182	10.07±0.23
		11.8	1565	241	6.49±0.16
		23.6	1342	243	5.52±0.15
25,000	282	35.4	1501	308	4.87±0.12
		51.9	427	100	4.27±0.20
		70.8	1863	465	4.01±0.09
		85.0	1555	393	3.96±0.10
		0.0	1010	70	14.43±0.45
		11.8	1683	168	10.02±0.24
		23.6	297	40	7.43±0.43
30,000	226	35.4	1018	153	6.65±0.20
		70.8	1524	274	5.56±0.14
		85.0	677	131	5.16±0.20
		Apparatus B			
		0.0	10569	6969	1.51±0.015
		20.8	6022	4290	1.40±0.018
		41.0	6000	4465	1.34±0.017
		61.5	6214	4733	1.32±0.017
296	756	81.2	8646	6939	1.24±0.013
		109.4	5964	4994	1.19±0.015
		137.0	5529	4582	1.21±0.016
		157.0	7566	6592	1.15±0.013
		205.0	11801	10603	1.11±0.010
		0.0	7479	1392	5.37±0.062
		20.8	5336	1318	4.05±0.056
		41.0	5201	1410	3.09±0.051
		61.5	8089	2550	3.17±0.035
14,260	453	81.2	6252	2106	2.97±0.037
		109.4	4255	1532	2.78±0.043
		137.0	3479	1253	2.78±0.047
		157.0	3911	1468	2.66±0.042
		205.0	3368	1400	2.41±0.041
		32.1C	3961	1071	3.70±0.059
		26.9 C+32.0 Pb	3689	1106	3.34±0.055
		0.0	2612	142	18.39±0.36
		61.5	4100	512	8.01±0.12
25,000	282	109.4	2460	359	6.85±0.14
		157.0	2442	424	5.76±0.16
		205.0	2377	459	5.18±0.11
		0.0	1964	75	26.19±0.60
		61.5	1198	104	11.52±0.33
30,000	226	109.4	2238	230	9.73±0.20
		157.0	2408	293	8.42±0.17
		205.0	2411	335	7.20±0.14

[3] Swann, Morris, and Seymour, Phys. Rev. **75**, 1317 (1949).

II. RESULTS

Table II contains a complete summary of the various measurements. The uncertainties indicated are statistical standard deviations. In all instances, data obtained under similar conditions were consistent from day to day, or from flight to flight. Frequent checks indicated the constancy of the sensitivity of the equipment.

A. Variation of Intensity with Absorber Thickness

Figure 1 shows the lead absorption curves for cosmic-ray particles at the several altitudes, plotted on the basis of the data in Table II, and incorporating the results from both instruments. Points are also included for the determination of the relative stopping powers of carbon and lead (Section C below).

The data obtained with Apparatus B were reduced to the same scale as that of Apparatus A on the basis of the single factor 1.90 calculated in Section III, *B* on the basis of geometrical considerations. Following the practice adopted in reference 1, absorber thicknesses when expressed in g/cm^2 represent the average path determined from calculations of E. E. Witmer and the author.[4] The harmony between the points obtained with the two instruments as exemplified by the curves in Fig. 1 verify the correctness of the factor 1.90 referred to above.

The results of Hall[5] have also been reduced to a common scale and are plotted in Fig. 1. The normalization was made at 1.5 cm of Pb, and a slight departure at zero interposed absorber thickness is probably attributable to the differences in the thicknesses of counter walls. From the agreement with the present measurements it is evident that the integral and differential distributions-in-range labelled "Hall" in reference 1 (Figs. 3 and 4) may be compared directly with the corresponding curves based upon the results of the free-balloon

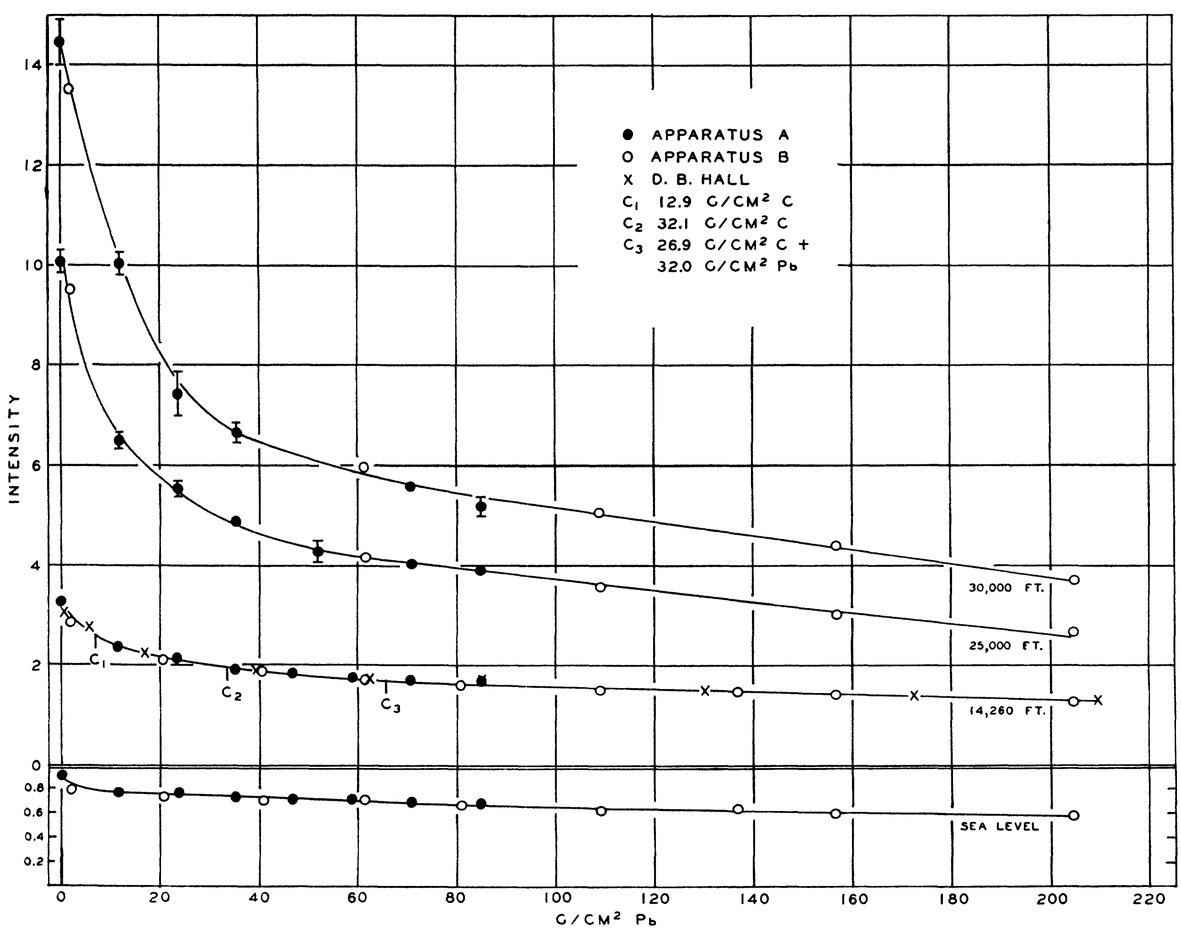

FIG. 1. Cosmic-ray absorption curves at several altitudes. The values of intensity correspond to counts per minute for Apparatus A, and counts per minute/1.90 for Apparatus B.

[4] E. E. Witmer and M. A. Pomerantz, J. Frank. Inst. **246**, 293 (1948).
[5] D. B. Hall, Phys. Rev. **66**, 321 (1944).

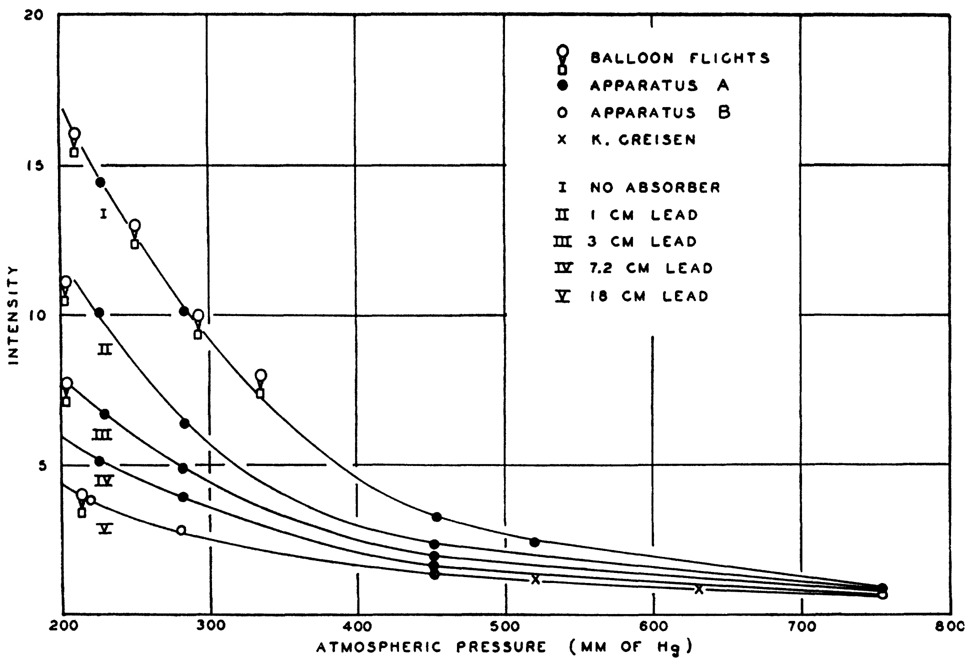

FIG. 2. Intensity *vs.* altitude curves obtained with different thicknesses of interposed absorber. The V large circles represent the balloon-flight data.

flights. Furthermore, the conclusion regarding the increase in the absorption coefficient between 4 and 6 cm of Pb from 0.003 cm^2/g at Mt. Evans to 0.008–0.006 cm^2/g at 200 mm–50 mm has received additional validation.

B. Variation of Intensity with Altitude

Figure 2 contains *intensity vs. altitude* curves for several different thicknesses of interposed absorber obtained from the B-29 flights and the Mt. Evans data. Similar curves could, of course, be plotted for any thickness up to 18 cm of Pb. In each instance, the points obtained in the free-balloon flights (Fig. 1, reference 1) are plotted in the figure. Since all the data were obtained with the same experimental arrangements, no normalization is required. The data have been plotted without regard to latitude changes which have a negligible influence upon the present considerations.

Experiments at very high altitudes are still in progress for interposed absorber thicknesses exceeding 7.5 cm. The balloon-flight data at the lower altitudes agree with the airplane data well within the rather large statistical uncertainties of the former.

A direct comparison may be made between the present results and those previously obtained by other investigators on Mt. Evans. Values of the ratio of the intensity of the penetrating component near sea level to that on Mt. Evans are summarized in Table III. Here again, the agreement is satisfactory.

On the basis of the present results, the analysis of the relative intensities of the non-electronic and electronic components undertaken in reference 1 for very high altitudes may be extended through the region in which only a rough interpolation was indicated previously. The results are presented in Fig. 3.

C. Relative Stopping Powers of Carbon and Lead

Values at Mt. Evans of the relative stopping powers of carbon and lead (S_C/S_{Pb}) are obtained by locating on the curve of Fig. 1 (14,260′) points with ordinates corresponding to the counting rates with a fixed amount of carbon (or carbon plus lead). The abscissa then indicates the amount of lead which produces equal absorption. The data are given in Table IV. The value with 12.9 g/cm^2 is comparable with those stated in reference 1 for higher altitudes.

The increase with the interposition of 32.1 g/cm^2 indicates that the lead becomes less effective per unit superficial mass compared with carbon as the minimum range required for penetration is increased. Differential comparison reveals that the net relative absorption is already approaching that expected for mesotrons alone, for cosmic rays having a residual range of somewhat less than 1 cm of Pb after passing through the absorber, and an initial range of 3 cm.

This is consistent with the observations of Hall[5] regarding the relative intensities of electrons and mesotrons at this location.

TABLE III. Ratio $N(0, t, h)/N(0, t, 4350)$ of the intensity of the penetrating component in the vertical direction near sea level to the intensity at Mt. Evans.

Reference	Location	Altitude, h—meters	Average atmospheric pressure —mm of Hg	Absorber thickness, t—g/cm² of Pb	$\frac{N(0, t, h)}{N(0, t, 4350 \text{ m})}$
Rossi, Hillberry, and Hoag[a]	Chicago	180	743	145	0.444±0.004
Greisen[b]	Ithaca	259	740	167	0.437±0.007
Author	Swarthmore	90	756	157	0.433±0.009

[a] Rossi, Hillberry, and Hoag, Phys. Rev. **57**, 461 (1940).
[b] K. Greisen, Phys. Rev. **61**, 212 (1942).

D. Effects of Showers and Scattering

The arguments upon which the negligibility of the effects introduced by side showers and scattering are based, have been discussed in reference 1, Section IV. Additional evidence bearing upon the latter is of some interest; to this end, the counting rates corresponding to various positions of a given absorber within the coincidence counter train were observed at each of the altitudes. Comparisons were also made between rates with the absorber slightly wider than the counter (1 cm) and those with greater width (4.5 cm). In all instances the observed rate was independent of the geometrical arrangement, within the statistical uncertainties of the data.

III. REDUCTION OF DATA TO ABSOLUTE INTENSITIES

A. Determination of Effective Dimensions of the Counter Train

In order to compute the absolute intensities from the observed counting rates it is necessary to ascertain the effective dimensions of the G-M counters. It has been demonstrated by Street and Woodward,[6] and, for certain self-quenching counters by Greisen and Nereson,[7] that the effective diameter of a counter coincides very closely with the inside diameter of the cathode. However, owing to end effects, the active length of a tube without guard rings is somewhat less than either the length of the cylinder or the length of the fine anode wire. The customary procedure for determining the end-correction involves inclusion of the counter under test as a member of a coincidence train, and recording of the coincidence rate as this counter is displaced along its own axis perpendicular to the plane defined by the central wires of the other counters. Although unquestionably reliable, this

[6] J. C. Street and R. H. Woodward, Phys. Rev. **46**, 1029 (1934).
[7] K. Greisen and N. Nereson, Phys. Rev. **62**, 316 (1942).

TABLE IV. Experimental values of S_C/S_{Pb} at Mt. Evans.

Carbon thickness —g/cm²	Equivalent lead thickness— g/cm²	Range—g/cm² Initial	Range—g/cm² Residual	S_C/S_{Pb}
12.9	7.0	12.9 C	c.w.[a]	0.54
32.1	33.5	32.1 C	c.w.	1.04
19.2	26.5	32.1 C	12.9 C +c.w.	1.38
26.9	33.5	26.9 C +32.0 Pb	32.0 Pb +c.w.	1.25

[a] c.w. = counter walls = 1.8 g/cm² Cu + 2.6 g/cm² glass (mean thickness required for penetration).

method has the disadvantage of requiring inordinately long runs in some instances, particularly in the case of counters of small diameter such as have been utilized in the present experiments. This would preclude rapid determinations of the effects of operating voltage, filling mixture, or even changes from counter to counter.

An alternative method was therefore attempted, and, despite factors which were of course not unanticipated, this simple scheme provides satisfactory results. The arrangement is shown in Fig. 4. A γ-ray howitzer irradiates the counter through a narrow slit, and the counting rate is observed to

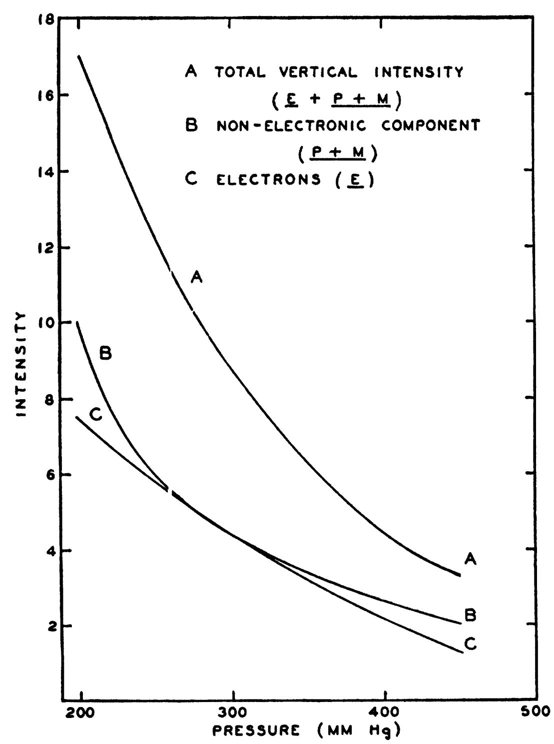

FIG 3. Variation with altitude of total vertical intensity $(E+P+M)$, heavy component intensity $(P+M)$, and electron intensity (E) for the lower portion of the atmosphere. The assumptions upon which the determination of these points are based have been discussed in reference 1, Section V. The above curves replace the broken lines (representing rough estimates) in Fig. 5 of that reference.

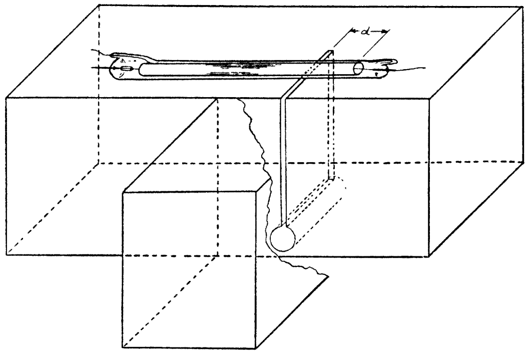

FIG. 4. Arrangement used in the determination of the effective length of a G-M counter. The radium source is inserted in the hole at the base of the slit in the pile composed of lead blocks. The length of the counter cathode is 20 cm.

depend upon the distance between the slit and the end of the counter.

Under these conditions, discharges of the G-M counter are produced by Compton electrons scattered out of the cylinder. The angular distribution of the Compton electrons is such that, for the energies present in the beam, the intensity falls to half value within roughly 15°. The preponderance in the forward direction renders this method feasible, as may be seen from the results plotted in Fig. 5. To a sufficient degree of approximation, the theoretical curve is easily calculated from an integration over the counter for each value of the abscissa x, utilizing the aforementioned distribution.[8]

Measurements were made with various geometrical arrangements, all of which gave equivalent conclusions. The final results do not depend critically upon the vertical distance of the counter above the lead, or upon the thickness of the shield.[9]

The background rate applicable to each value of x has been subtracted from the observed rate to obtain the relative counting rates of Fig. 5. This correction was obtained by plotting counting-rate as a function of x with the counter oriented parallel to the position indicated in Fig. 4, but off the slit.

Finally, it is necessary to ascertain the effect of any intrinsic inefficiency of the G-M counters introduced either by the dead-time or by the probability of the passage of a charged particle without the occurrence of at least one ionizing event. The combined contribution of both is negligible in these experiments.

A standard test of each of the counters used here consists of exposure to a graduated set of calibrated radium sources of identical form under conditions such that the individual counting rates exceed those of a single counter at any point in the atmosphere. The criterion for acceptance is that the recorded rates are proportional to the intensities. Additional tests have revealed that the dead-time of these counters is less than 10^{-4} sec.

B. Calculations

The quantity $N(O, h, t)$ represents the number of particles passing through a vertical cosmic-ray coincidence train in unit time. Here, the zenith angle of the principal axis of the train is zero, h is the altitude of the station of observation, and t the thickness of interposed absorber. If $I(\theta)$ is the number of particles arriving from a given direction θ, and passing through a unit area of the bottom tray within unit solid angle per second,

$$dN = I(\theta)d\omega dA_1 \cos\theta, \qquad (1)$$

where dA_1 is an element of area in the lower counter.

For a dependence of cosmic-ray intensity upon zenith angle given by

$$I(\theta) = I(O) \cos^p\theta, \qquad (2)$$

this immediately leads to an integral of the form:

$$N(O, h, t) = \int\int \frac{I(O, h, t) \cos^{p+2}\theta dA_1 dA_2}{\lambda^2}, \qquad (3)$$

where λ is the distance between the element of area dA_2 in the upper tray and dA_1.

The final result of the integration for a $\cos^2\theta$ distribution ($p=2$), including terms taking into account the extension of the solid angle beyond the ends of the rectangular area (due to the cylindrical shape of the counters[6]), is:

$$N(O, h, t) = I(O, h, t)\frac{w^2}{4}\left\{3\frac{l}{L}\tan^{-1}\frac{l}{L} + \frac{l^2}{L^2+l^2} + \frac{\pi w}{2L}\left[1 - \left(\frac{L^2}{L^2+l^2}\right)^2\right]\right\}, \qquad (4)$$

where l is the active length of the counter, w the tray width (counter diameter), L the perpendicular distance between the axes of the extreme counters.

The small correction to the width because of the cylindrical form of the counters amounts only to 0.6 percent of the factor thus calculated.

Inasmuch as the value of p at higher altitudes is somewhat smaller than 2, the normalization of measurements at very high altitudes with respect to other determinations of $I(O, h, t)$ low in the atmosphere is not justified, in some instances.

[8] This may be deduced either from theory, or from various experimental results, e.g., D. Skobelzyn, Nature **X**, 411 (1929).

[9] Presumably the optimum set of conditions may be predicted by maximizing the function which represents the ratio of collimated beam intensity (signal $= I_S$) to background intensity (noise $= I_N$) as follows:

$$f(S) = I_S/I_N = (A/S^2)/(I_0 e^{-\mu S}),$$

where μ = absorption coefficient in Pb for γ-ray energies present in beam, and S = depth of slit. For $f'(S) = 0$, $S = 2/\mu$.

As a matter of fact, recent experiments[10] have indicated that the nature of the distribution at the "top of the atmosphere" is isotropic. In this case by integration of Eq. (3) with $p=0$, and the addition of the end-correction term we arrive at the final relationship:

$$N(O,h,t)=I(O,h,t)w^2\left\{\frac{l}{L}\tan^{-1}\frac{l}{L}+\frac{\pi w}{4L}\left[1-\frac{L^2}{L^2+l^2}\right]\right\}. \quad (5)$$

As an intermediate possibility, we may consider $p=1$ ($\cos\theta$ distribution). In this case we obtain in a similar manner:

$$N(O,h,t)=I(O,h,t)\frac{2w^2}{3}\left\{\frac{2(L^2+l^2)^{\frac{1}{2}}}{L}-1-\frac{L}{(L^2+l^2)^{\frac{1}{2}}}+\frac{\pi w}{4L}\left[1-\left(\frac{L^2}{L^2+l^2}\right)^{\frac{3}{2}}\right]\right\}. \quad (6)$$

The dimensions of both instruments, together with the final values of the ratio $\varphi=N(O,h,t)/I(O,h,t)$ applicable to $\cos^2\theta$, $\cos\theta$, and isotropic distributions are listed in Table V. The resulting values of $I(O,h,t)$ on the basis of the present experiments, as well as several reported by other investigators for low altitudes, are given in Table VI. According to Sands,[11] there does not appear to be a significant departure from $p=2$ for the total intensity at 30,000 feet.

The factors (φ_A) listed in Table V may be divided into any of the various counting rates at very high altitudes reported in reference 1 to obtain $I(O,h,t)$. The stated value of the absolute intensity near the "top of the atmosphere" has been based upon all available data from the free-balloon flights at altitudes exceeding 90,000 feet. This embraces 9 flights with vertical telescopes, and includes data not contained in reference 1. Recent measurements in inclined directions have not been incorporated in this average.

Experiments now in progress will provide a complete determination of the zenith angle distribution law throughout the atmosphere for several values of t. Tentatively, one may assume that the $\cos\theta$ distribution is roughly applicable in the tropopause. This is in accord with the results of experiments performed during the National Geographic Society stratosphere flights.[12]

For various reasons it is not possible to compare

TABLE V. Geometrical factors for reduction of counting rates to absolute intensities.

Instrument	Effective length, l cm	Effective width, w cm	Separation, L cm	$\varphi=\frac{N(O,h,t)}{I(O,h,t)}$ $p=2$	$p=1$	$p=0$
A	19.4	0.9	11.5	1.23	1.29	1.45
B	19.4	2.3	26.6	2.33	2.50	2.52
φ_B/φ_A				1.90	1.94	1.74

the value of the absolute intensity near the "top of the atmosphere" directly with that recently published by Gangnes, Jenkins, and Van Allen.[13] However, their data obtained with coincidence telescopes in rockets do not appear to be inconsistent with the commencement of the constant intensity plateau at the altitudes attained in free-balloon ascents. Although the absolute intensities reported by the former are somewhat lower, the latitude effect alone may be sufficient to account for this, as has already been demonstrated.[14] Furthermore, an appreciable number of events which were rejected as involving multiples in the rocket experiments undoubtedly represent part of the genuine primary beam.

It should be mentioned that (in accordance with the warning in reference 1) the change with altitude in the value of φ affects the comparison (Fig. 6, reference 1) between our results, for 6 cm of interposed Pb, and those obtained by Schein and Allen

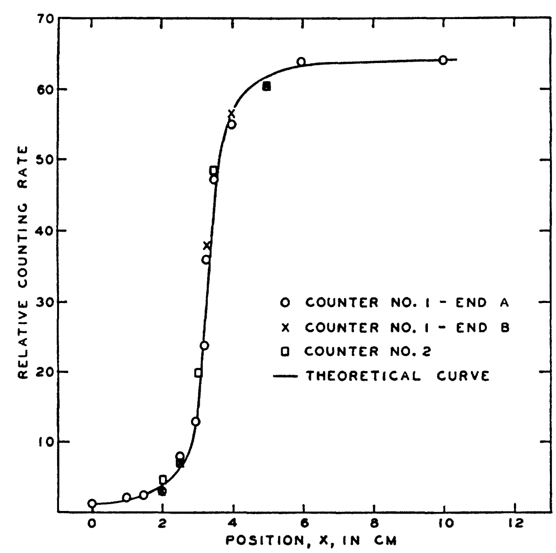

FIG. 5. Relative counting rate (after subtraction of background) as a function of the distance, x, between the slit and an arbitrary index on the counter. The theoretical curve (solid line) is calculated on the basis of an effective length, l, equal to 19.4 cm.

[10] M. A. Pomerantz, Phys. Rev. **75**, 1335 (1949).
[11] M. Sands, Phys. Rev. **73**, 1338 (1948).
[12] Swann, Locher, and Danforth, Nat. Geog. Soc. Cont. Tech. Papers, Stratosphere Series No. 2 (1936).
[13] Gangnes, Jenkins, and Van Allen, Phys. Rev. **75**, 57 (1949).
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TABLE VI. Absolute intensities in the vertical direction, $I(O, h, t)$—the number of particles per cm² per unit solid angle per minute.

$$\left(I(O,h,t)=\sum_{1}^{n}\int_{\epsilon(t)}^{\infty} i_n(O,h,\epsilon)d\epsilon,\right.$$

where the index n identifies the type of particle.)

Reference	Altitude, h—meters	Atmospheric pressure —mm of Hg	Absorber t—g/cm²	$I(O, h, t)$
Street and Woodward*	0	760	0.55[a]	0.80±0.028
Street and Woodward*	0	760	3.4[b]	0.74±0.026
Greisen**	259	740	1.7[c]	0.741±0.014
Greisen**	259	740	9.9[d]	0.623±0.004
Greisen**	259	740	167.0[e]	0.493±0.004
Greisen**	4350	453	1.7[c]	3.17±0.074
Greisen**	4350	453	9.9[d]	2.00±0.020
Greisen**	4350	453	167.0[e]	1.13±0.016
Author	90	756	4.4[f]	0.745±0.006
	90	756	157.0[g]	0.494±0.006
	4350	453	4.4[f]	2.66±0.044
	4350	453	157.0[g]	1.14±0.018
	25,000	282	4.4[f]	8.2±0.19
	25,000	282	157.0[g]	2.47±0.068
	30,000	226	4.4[f]	11.7±0.37
	30,000	226	157.0[g]	3.61±0.07
Reference 1	90,000	13	<89.0[g]	10.1±0.20***

* See reference 6.
** See reference b of Table III.
[a] Quoted minimum thickness between sensitive volumes of extreme counters, 0.32 g/cm² glass+0.23 g/cm² Cu.
[b] Quoted minimum thickness between sensitive volumes of extreme counters, 2.3 g/cm² glass+1.1 g/cm² Cu.
[c] Brass, minimum thickness between sensitive volumes of extreme counters.
[d] Minimum thickness between sensitive volumes at extreme counters, 8.2 g/cm² brass+1.4 g/cm² wood.
[e] Quoted value, includes counter walls, lead, and wood above and between counters.
[f] Mean thickness between sensitive volumes of extreme counters, 1.8 g/cm² Cu+2.6 g/cm² glass.
[g] Mean thickness of interposed absorber, not including counter walls (see note f).
*** This value represents an average of all available data obtained at altitudes exceeding 90,000 feet with vertical coincidence-counter trains. It is based upon the results of 9 flights having different amounts of interposed material. The indicated uncertainty is the statistical standard deviation.

with 18 cm of Pb. However, in the extreme case, the relative intensity of the latter would only be increased by about 15 percent near the "top of the atmosphere." This does not affect the general conclusions based on the difference which appreciably exceeds this amount.

IV. DISCUSSION

Although the above results are in good agreement with those of other investigators when an appreciable quantity of absorber is interposed in the counter train, the situation is quite different when only the counter walls determine the minimum range which must be penetrated for the registering of an event. The large absorption in small thicknesses of material is already strikingly evident in the data obtained by Greisen at the comparatively low altitude of 4350 meters (Table VI). Here the measured intensity increased by 58 percent when the interposed absorber was reduced by 8.2 g/cm². The absorption coefficient for small thicknesses becomes even greater at higher altitudes. A rather large difference between the relative total intensities computed from our data and those reported by Sands[11] on the basis of similar measurements, is doubtless attributable to this effect.

In the past, various methods for computing the effective thickness of the counter walls have been adopted, and the stated values are frequently not strictly comparable. It is desirable that the basis for the computation be explicitly stated, and it is therefore proposed that, following the custom which seems to have become somewhat prevalent, the minimum amount of material between the sensitive volumes be stated. The argument for omitting the upper wall has been based upon the hypothesis that as many soft particles are produced as are absorbed therein.

This minimum thickness may be multiplied by a constant which takes into account the fact that the mean thickness traversed is greater because of the cylindrical shape, and because of the distribution of cosmic-ray intensity with zenith angle.[4] On this basis, the absorber in Sands[15] apparatus amounted to 3.8 g/cm² as compared with 4.4 g/cm² similarly calculated for our counters, the walls of which contained some material of lower atomic number. This is apparently sufficient to introduce a difference in the relative intensities varying from 15 percent on Mt. Evans to 32 percent at 30,000 feet.

This clearly demonstrates the error which may be introduced into attempts to compare measurements by different investigators of the so-called "total" intensity at high altitudes. Indeed, the disagreement has been quite marked.[16]

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[15] M. Sands (private communication).
[16] See, e.g., B. Rossi, Rev. Mod. Phys. 20, 537 (1948).