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The Rate of Production of Very Large Cosmic-Ray Bursts as a Function of Lead Shielding Thickness

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Experiments have been performed at Chicago with two Compton-Bennett cosmic-ray meters to determine the frequency of occurrence of very large bursts (120 to more than 1000 particles) as a function of lead shielding thickness. The thickness of lead for optimum burst rate was found on both meters to be in the neighborhood of 3 centimeters. This is larger than the optimum for showers and small bursts, a fact which is in qualitative agreement with the theory of Carlson and Oppenheimer. Quantitatively, the maximum determined experimentally is of the same order of magnitude as that predicted by the theory though lower.

DURING the past few years many experiments have been performed on the effect of shielding upon cosmic-ray showers and small bursts. Much less work has been done where very large bursts are involved. It has, therefore, seemed worth while to report here in brief some experiments carried out at intervals during the past two years upon very large cosmic-ray bursts. These results are in general agreement with the work on showers and small bursts and are principally of interest because the bursts measured are probably as large as any which have been thus systematically studied.

The measurements were made at Chicago with two type C cosmic-ray meters of the Carnegie Institution of Washington which have been described in detail elsewhere.[1] The meters were both placed in a shop building directly under the roof in such a position that no side wall was less than fifteen feet from the instrument and the roof was at no point closer than twenty feet. The roof was a thin one of slate supported by steel girders. The ionization chamber of each instrument consisted of a spherical chamber 35 cm in diameter, the walls of which were $\frac{1}{2}$ inch (1.25 cm) steel. These chambers were filled with argon at a pressure of approximately fifty atmospheres. The lower hemisphere of the ionization chamber was at all times submerged in lead shot: the upper was covered with a succession of hemispherical caps, each of $\frac{1}{8}$ in. (0.32 cm) thickness. For any given shielding thickness, the number of bursts occurring during a given interval of time was read from the recording tape and hence the average burst rate could be computed.

The results for meter No. 4 and meter No. 6 are given in Table I. The smallest burst which

[1] A. H. Compton, E. O. Wollan and R. D. Bennett, Rev. Sci. Inst. 5, 415 (1934).

could be definitely distinguished from a random fluctuation on the trace was arbitrarily taken as one giving a sharp displacement of 1 millimeter. This corresponds to the formation of 23×10^6 ion pairs within the chamber. Above this minimum, bursts were observed ranging in magnitude up to a few scattered ones giving over 400×10^6 ion pairs. In Table I, the number of bursts observed in each size range is indicated and below it in parenthesis the rate of occurrence in bursts per hour. The small number of bursts counted within each size range precludes any great accuracy for the distribution curve of the number of bursts with size of burst. This distribution is, however, in agreement with previous work[2, 3] on

TABLE I. *Summary of data.*

Thickness of Lead cm	Hours	Distribution of burst size in ion pairs produced					
		23–45 $\times10^6$	45–68 $\times10^6$	68–90 $\times10^6$	90–113 $\times10^6$	over 113×10^6	Total
		Meter No. 6					
0	422	21 (0.050)	14 (0.033)	1 (0.002)	1 (0.002)	0 (0.00)	36 (0.085)
0.95	210	15 (0.071)	10 (0.048)	4 (0.019)	1 (0.005)	0 (0.00)	30 (0.143)
1.90	165	21 (0.127)	11 (0.067)	1 (0.006)	1 (0.006)	3 (0.02)	37 (0.224)
2.5	216	30 (0.139)	14 (0.065)	3 (0.014)	4 (0.018)	3 (0.014)	54 (0.25)
2.9	219	32 (0.146)	14 (0.065)	7 (0.032)	5 (0.023)	6 (0.028)	64 (0.292)
3.2	240	28 (0.117)	23 (0.096)	2 (0.008)	3 (0.012)	3 (0.012)	59 (0.246)
3.8	66	7 (0.106)	4 (0.06)	1 (0.015)	1 (0.015)	3 (0.045)	16 (0.242)
10.7	752	70 (0.093)	27 (0.036)	7 (0.009)	2 (0.003)	3 (0.004)	109 (0.145)
		Meter No. 4					
0	314	3 (0.01)	2 (0.006)	4 (0.013)	1 (0.003)	0	10 (0.032)
0.95	381	14 (0.037)	9 (0.024)	4 (0.105)	3 (0.008)	4 (0.01)	34 (0.089)
1.90	364	21 (0.058)	10 (0.027)	2 (0.005)	2 (0.005)	3 (0.008)	38 (0.104)
2.9	488	60 (0.123)	28 (0.057)	12 (0.025)	4 (0.008)	5 (0.01)	109 (0.223)
3.8	504	41 (0.081)	18 (0.036)	8 (0.016)	2 (0.004)	4 (0.008)	73 (0.145)
10.7	290	18 (0.062)	13 (0.045)	3 (0.01)	3 (0.01)	3 (0.01)	40 (0.138)

[2] R. L. Doan, Phys. Rev. **49**, 107 (1935).
[3] D. Heyworth and Ralph D. Bennett, Phys. Rev. **50**, 589 (1936).

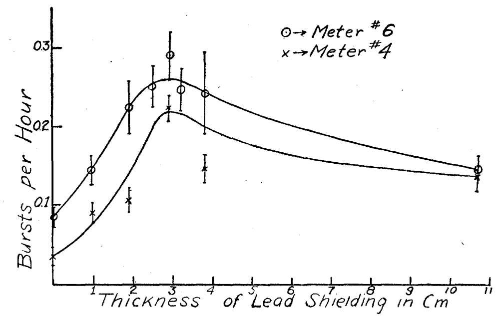

FIG. 1. Curve showing relation between burst rate and thickness of lead shielding for bursts of all sizes observed.

the same type meter. The total burst count and burst rate, including bursts of all sizes, are given in the last column. The burst rates for this column are plotted in Fig. 1 against the shielding thickness of lead. The statistical uncertainty, indicated by the length of the vertical lines through the points, is rather large. In addition, because of the scattered points, there is some uncertainty in the drawing of the curve for meter No. 4. Both curves are observed to have a maximum in the neighborhood of 3 cm of lead. The curve for meter No. 6, however, lies throughout somewhat above that for meter No. 4. The explanation for this is not apparent. The effect, however, has been observed before with two similar meters.[2]

If the number of ions produced by a particle per centimeter path in air at atmospheric pressure is taken as 60 ion pairs per centimeter,[4] then from the geometry of the system the ionization produced by each shower particle traversing the chamber is computed to be in the neighborhood of 100,000 ion pairs. This is at best only an approximation. Hence for our minimum burst size we have about 230 particles traversing the chamber. For the largest bursts observed the number of particles is of the order of 4000.

DISCUSSION

In comparing these results with the results obtained by others, we meet with the usual difficulty that the geometry of the systems used by various experimenters is quite different. In addition to this, the fact that the wall of our

[4] W. F. G. Swann, Phys. Rev. **44**, 961 (1933).

ionization chamber was quite thick (1.25 cm of iron) presents an added complication in the comparison. The effect of this wall thickness on the burst production observed might be twofold. First, we add an additional thickness of shielding material. This would probably amount to an equivalent thickness of only a few millimeters of lead, the exact value depending upon the form of the law[5] used to represent the relative burst frequency in iron and in lead. Second, an additional uncertainty would also be introduced by the possibility of lead-iron transition phenomena. These effects have been discussed by others[6] but the exact correction in the present experiments cannot be accurately evaluated. It might be pointed out that such phenomena may possibly be present as a disturbing factor, to a greater or less degree, in any experiments where the wall of the ionization chamber is of a different material from the shielding material. No attempt has been made to correct the data for either of these two effects.

The results of the present experiment are in good agreement with earlier[2,3] less quantitative experiments on the type C meter. The curve in Fig. 1 is also in agreement with the results of Carmichael[7] for bursts of comparable size (160–720 particles). Nie,[8] however, for about the same range of burst sizes finds an optimum shielding thickness of between 4 and 5 centimeters of lead. Finally, the present maximum at about 3 centimeters of lead is definitely larger than the maximum below 2 centimeters found by others[9,10] for showers of only two or three particles and of about 2 centimeters found for small bursts[11] consisting of 30 particles or less. This increase in the optimum thickness of shielding with the size of the burst has already been noted experimentally by the authors cited within the region of showers and small bursts, and is qualitatively in agreement with the multiplicative theory of showers of Carlson and Oppenheimer.[12] Because of the large uncertainties both in theory and experiment, it is impossible to make an exact quantitative comparison between the theoretical prediction and the present experimental value for the optimum lead thickness. Suffice it to say, that for a burst of 450 particles, about the mean size of the bursts observed above, a thickness in the neighborhood of 4 centimeters would be expected. This is of the same order of magnitude though larger than the present experimental result.

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[5] W. M. Nielsen and J. E. Morgan, Phys. Rev. **52**, 568 (1937).
[6] C. G. Montgomery, D. D. Montgomery, W. F. G. Swann, Phys. Rev. **47**, 512 (1935).
[7] H. Carmichael, Proc. Roy. Soc. **154**, 223 (1936).
[8] H. Nie, Zeits. f. Physik **99**, 453 (1936).
[9] D. K. Froman and J. C. Stearns, Phys. Rev. **52**, 382 (1937).
[10] M. A. Starr, Phys. Rev. **53**, 6 (1938).
[11] R. T. Young, Phys. Rev. **52**, 559 (1937).
[12] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 217 (1937).