Note on the Production of Showers in Various Materials

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Data are presented on the increased counting rate due to shower production by layers of equal atomic density for copper, tin and lead. The observed increases of counting rate in the case of these elements are found to vary as a power of the atomic number which is slightly although significantly greater than the second. These results appear qualitatively consistent with our previously reported observations in which the mass per unit area of the producing materials was kept constant for the various elements and for which a dependence on the atomic number of the second power was reported.

DURING the past few years, several papers have been published on the frequency of cosmic-ray shower and Stösse production in various materials.[1–5] Our own measurements[2] indicated the dependence on Z of the observed frequency of shower production to be approximately the second power. In that portion of our work the showers were produced in layers of material having the same mass per square centimeter for each element. The data were then weighted in such a way as to give the relative increases in counting rate per atom, assuming that the increase in each case varied linearly with the number of atoms. In the same paper, however, we also presented evidence showing that the increase in counting rate due to showers, as we observed them, was not a linear function of the thickness of the producing material above the counters for elements of high atomic number such as lead.[6] It is the purpose of the present note to put on record our measurements of shower production in various materials when the number of atoms in the producing layer is maintained equal for each element.

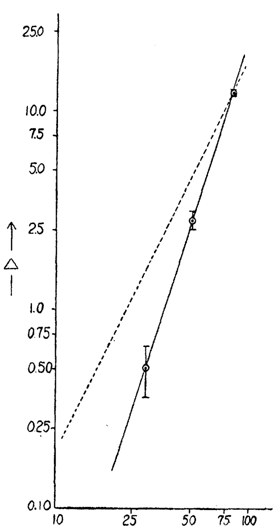

FIG. 1. Increase in counting rate, Δ, as a function of atomic number for layers of copper, tin and lead of equal atomic density.

The same general procedure and counter arrangement (Fig. 1 of reference 2) was followed. As in the previous work, the observations were extended over a considerable period of time in order to reduce the statistical error. The mass of each of the shower producing materials employed in the present experiment was so adjusted as to correspond, in terms of atoms per unit area, to a layer of lead 0.6 cm in thickness. The horizontal area of material above the counters was in all cases 22 cm×30 cm.

On the curve of Fig. 1 are plotted the respective differences, Δ, between the counting rates due to the background and to each producing material. The dotted line, which has a slope of 2, is included for comparison. These curves indicate that the departure of observed shower production from a simple Z^2 relation is greater than can be accounted for by probable errors. It is of some interest to point out that the observed variation of increased counting

[1] Alocco and Drigo, Ricerca Scient. **5**, 112 (1934).
[2] Morgan and Nielsen, Phys. Rev. **50**, 882 (1936).
[3] C. G. Montgomery and D. D. Montgomery, Phys. Rev. **50**, 490 (1936).
[4] Hu Chien Shan, Proc. Roy. Soc. **158A**, 581 (1937).
[5] J. C. Stearns and D. K. Froman, Contributed Paper No. 13, 215th Meeting American Physical Society.

[6] Since our original publication, Hu Chien Shan (reference 4) has also reported such curves which are concave upwards.

rate with atomic number is appreciably greater in the present data than in that previously reported. This result would appear to be associated with the above noted fact that the increase in counting rate due to showers from the heavier elements, as measured by our arrangement of counters, is not a linear function of the thickness of producing material. This follows because our earlier data were multiplied by the atomic weight to obtain the relative frequency of showers per unit atomic density. Such a procedure would only be accurate if the shower frequency *vs.* thickness curve were linear in each case.

The recent theoretical results of Carlson and Oppenheimer[7] and of Bhabha and Heitler[8] have indicated that the multiplication theory of showers is capable of accounting, in a rough way, for the showers due to the softer component of the general cosmic-radiation. It would appear that such a theory, if correctly applied, can account for a variation of shower production with a second or relatively small power of the atomic number. It is apparently not necessary to assume from such a dependence on atomic number that the showers have their origin in a single act. Any detailed analysis of results such as those herein reported would involve a number of complicating factors. An important one of these factors is the difference in angular spread of the showers from various materials, and its effect on the efficiency of the counting apparatus. Although such a complete analysis is impossible, it appears desirable to record these observations, the results of which are consistent with those of our previous data obtained under identical experimental conditions.

[7] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220 (1937).

[8] H. J. Bhabha and W. Heitler, Proc. Roy. Soc. **159A**, 432 (1937).

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On Fluctuation Phenomena in the Passage of High Energy Electrons through Lead

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It now seems reasonable on both theoretical and experimental grounds to suppose that the formulae of the present radiation theory are valid in the cosmic-ray energy range. The work of Carlson and Oppenheimer and of Bhabha and Heitler has shown that this assumption is capable of accounting for many of the observed features of cosmic-ray absorption and of shower production. These writers concern themselves principally with the mean behavior of a group of electrons and photons moving through matter. Since the fluctuations around this mean behavior are large and for some purposes very important, it is desirable to investigate their nature, even though this involves a loss of accuracy in dealing with other aspects of the situation. In this paper we consider two fluctuation problems: (1) The fluctuations in size of showers produced by single electrons or photons: In dealing with this problem we take the energetic relations into account only very roughly. (2) Fluctuations in energy loss of electrons: The possible production of secondaries is disregarded. The inadequacies in treatment have for both problems the consequence that the results are applicable only to thin layers of heavy substances. The first problem is discussed in Section II. The conclusion is that the distribution in shower sizes should be essentially of the type $P(n;\langle n\rangle) = (\langle n\rangle)^{-1}\{1-(\langle n\rangle)^{-1}\}^{n-1}$, where $\langle n\rangle$ is the mean number; but that under ordinary experimental conditions the number of very small showers should be rather greater than indicated by this law. The results account for two observed phenomena which might at first sight be taken as forming serious objections to the multiplicative hypothesis: First, the occasionally observed production of large showers ($\sim$20 or 30 particles) from small thicknesses ($\sim$1 cm) of lead; and second, the appearance which many of the larger showers present of having originated at a single point near the bottom of the lead. In Section III we deal with the second problem, with the purpose of providing a way to use energy loss measurements to provide a more detailed check on the theoretical formulae. A method is given for constructing energy loss distribution curves corresponding to any assumed form of the *Bremsstrahlung* spectrum. Also a solution is outlined for the problem of using accurate and detailed information on energy losses to compute an empirical spectrum curve.